Advanced C++ Topics

- Inheritance
- Virtual methods and late binding
- Friend classes and methods
- Class templates
- Overloaded operators
- Iterators

Inheritance Revisited

- Inheritance is useful to
  - explicitly represent relationships among program components
  - reuse as much design and implementation effort as possible
  - avoid parallel implementations that are error prone since they are hard to keep synchronized
- Class hierarchies represent *shared* and *distinct* relationships between classes
  - derived (sub) class inherits base (super) class properties
    - all member data and functions except constructors and destructors

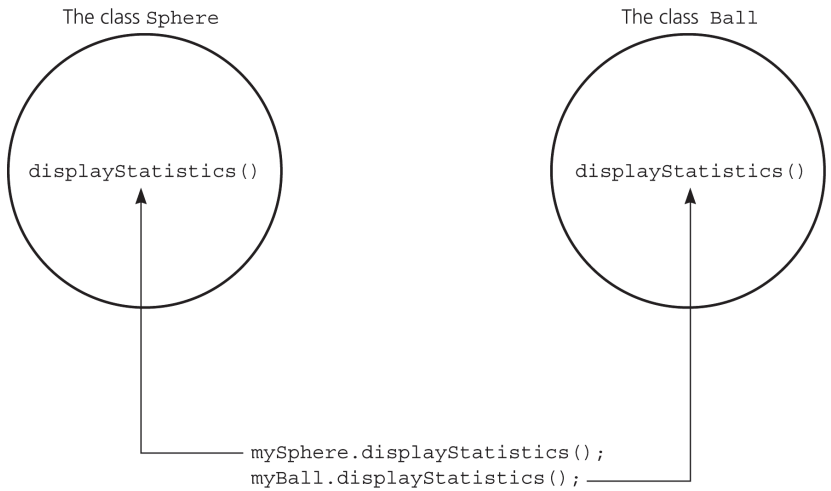
Inheritance – Basic Concepts

- Superclass or base class
  - a class from which another class is derived
- Subclass, derived class, or descendant class
  - a class that inherits all members of another class
  - can add new members to those it inherits
  - can redefine an inherited method of its base class, if the two methods have the same parameter declarations

Inheritance – Basic Concepts

- The base class's public methods can be called by
  - An instance of the base class
  - An instance of the derived class
  - The derived class's methods
- A derived class inherits all of the base class's members (except constructors and destructor)
  - An instance of a derived class has all the behaviors of its base class (can call the base class's public methods)
  - A derived class cannot access the base class's private data and methods directly by name

Inheritance Revisited



Inheritance – Syntax

- class derivedClass: *access-modifier* baseClass
- access modifier describes access semantics of base class components inherited by derived class
- Public methods can be used by any code
  - client, class member functions, derived classes
- Private members
  - class member functions and *friends*
- Protected
  - class members, friends, derived classes

Kinds of Inheritance

- Apply most restrictive access based on base access type and inheritance access modifier
- Public inheritance
  - Public/Protected → Public/Protected derived members
- Protected inheritance
  - Public/Protected → Protected derived members
- Private Inheritance
  - Public/Protected → Private derived members
- Private base class members remain private under all inheritance types

Inheritance Hierarchy – Example

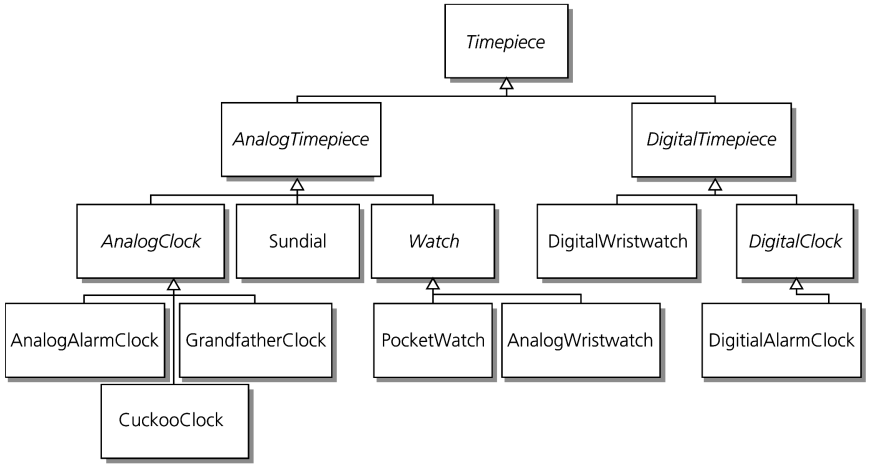
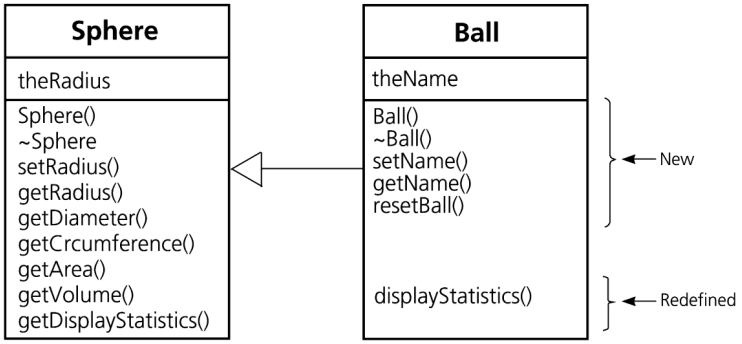


Figure 8-1 Inheritance: Relationships among timepieces

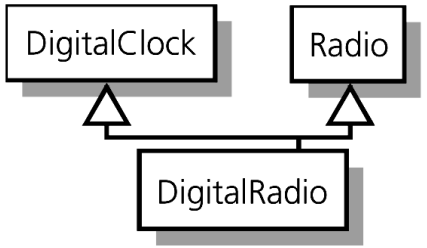
Inheritance – Example

- *Sphere* serves as a base class for *Ball*
  - some routines inherited, some new, and some are redefined (e.g. display Statistics())



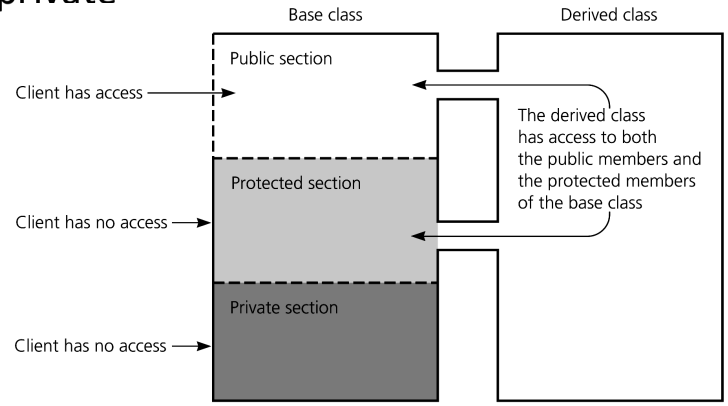
Multiple Inheritance

- Multiple inheritance
  - a derived class can have more than one base class
  - we will not study this kind of inheritance



Inheritance Revisited

- In general, a class's data members should be private



Is-a Relationships

- Public inheritance should imply an *is-a* relationship
- Object type compatibility
  - you can use an instance of a derived class anywhere you can use an instance of the base class (but not the other way around)
- Example
  - A *ball* is a *sphere*
  - Given the following function declaration:

    void displayDiameter(Sphere thing);

    The following statements are valid:

    Ball myBall(5.0, "Volleyball");

    displayDiameter(myBall);

see C8-Sphere.cpp, C8-Ball.cpp

Sphere/Ball Example

- Ball class (derived from Sphere)
  - both constructors call base class constructors to handle private radius data
  - getName() is a new method
  - setName() gives access to Ball data
  - resetBall() uses both Sphere and Ball access routines as the data is private in both classes
    - Ball could access name directly

Sphere/Ball Example – 2

- Ball class
  - displayStatistics() redefines the name in the derived class as a local method
    - to display Ball's unique data element "theName"
    - uses full class::member scope resolution syntax to call Sphere's displayStatistics()
  - instance of Ball has two data members
    - theName and theRadius (inherited)
    - since Sphere::theRadius is defined private (rather than protected or public) it can only be accessed through the public (get/set)Radius() methods

Has-a Relationships

- If the relationship between two classes is not is-a, do not use public inheritance
- Has-a relationship (also called *containment*)
  - a class has an object as a data member
  - cannot be implemented using inheritance
- Example: A has-a relationship between a pen and a ball

```
class Pen {
  ...
private:
  Ball point;  };
```


As-a Relationships

- Uses private inheritance
  - Example: Implement a stack as a list

    class Stack: private List
    - stack can manipulate the items on the stack by using List's methods
    - the underlying list is hidden from the clients and descendants of the stack
- Private inheritance is useful when
  - a class needs access to the protected members of another class, or
  - if methods in a class need to be redefined

As-a relationship – Private Inheritance

- All public, protected and private elements of the base class are *private* in the derived class.
- Client code reference to a public base class routine through the derived class instance is illegal.
- Derived class completely wraps base class elements.
- Derived class is implemented using or is implemented in terms of the base class.

see C8-StackL.cpp, C8-List.cpp

Stack as-a List Example

- A stack is *not* a type a list since it has unique semantics
- Stack semantics *can* be implemented in terms on List semantics
- Private inheritance strongly conceals any list related semantics from the clients
  - only exposes push()/pop()
  - cannot access insert()/remove()
- Contrast with the Stack *has-a* List implementation from Chapter 4
  - just as good; both work

Inheritance & Class Relationships

- Public inheritance
  - extend or specialize an existing class
  - most common
  - *is-a* relationship between base/derived classes
- Protected inheritance
  - not very useful; not often used
- Private inheritance
  - to implement one class in terms of another
  - *as-a* relationship

Class Relationships

- IS-A: derived class is special kind of base class
  - public inheritance used to implement in C++
- AS-A: derived class implemented in terms of base class
  - private inheritance can be used in C++
- HAS-A: object A includes instance of object B as part of its implementation
  - encapsulation is just as good as inheritance

Virtual Functions

- Derived class sometimes need to modify or completely replace actions of a base class method
  - derived class is said to override the inherited method
- Base class must give permission for redefinition
  - by declaring the method as virtual
- Redefinition is permitted but not required
- Redefined methods must have exactly the same signature as the inherited base class methods
- Derived functions do not need to use the virtual keyword
- Friend and constructor functions cannot be virtual, but destructors can be

Virtual Functions – 2

- Base class Animal gives permission to override *breathe()* and *move()*
- Derived class Fish over-rides both, but denies permission to further override *breathe()*
- WalkingCatFish over-rides *move()* but uses inherited *breathe()*

```
class Animal {
public:
   ...
   virtual void breathe( ); // uses a nose
   virtual void move(); // uses feet
   ...
};
class Fish: public Animal {
public:
   ...
   void breathe( ); // uses gills
   virtual void move(); // uses fins
   ...
}
class WalkingCatFish: public Fish {
   void move(); // uses fins as feet
}
```


Function Overriding Example

```
class baseClass{
public:
   virtual void print(){
      cout << "BaseClass";
   }
};

 class firstClass :
            public baseClass{
 public:
    void print(){
       cout << "firstClass";
    }
 };
```

```
class secondClass :
          public baseClass{
};
 class thirdClass :
           public baseClass{
 public:
    void print(){
       cout << "thirdClass";
    }
 };
 class fourthClass :
           public thirdClass{
 };
```

see C8-staticBinding.cpp

Name Binding Time

- Binding time can be *compile-time* or *run-time*
  - controls what methods are called in some cases
- see C8-staticBinding2.cpp
- Direct access using *b* and *d* instance variable obviously compile time
- But what if they point to a different type object??
  - bp1 is legal (but bogus)
  - dp2 illegal type conversion

Virtual Methods and Late Binding

- Methods declared as virtual are tracked at runtime by a *virtual method table* (VMT)
  - methods not declared as virtual can be *redefined*
  - methods declared as virtual are *overridden*
- Use of non-virtual methods is determined at compile-time and references to the function are compiled-in
  - lower overhead reference method
- Use of virtual methods is determined at runtime by consulting the VMT of the object accessed
  - pointer to calling object (this) given to every method call
  - higher overhead, but avoids some undesirable behaviors

see C8-bindingTime.cpp

Virtual Methods and Late Binding

- Late, or dynamic, binding
  - the appropriate version of a polymorphic method is decided at execution time
  - a polymorphic method has multiple meanings and overrides a method of the superclass
  - the outcome of an operation depends upon the objects on which it acts
- Defining class methods as virtual preserves flexibility at the cost of slightly higher VMT overhead.

Virtual Methods and Late Binding

- In general, define a class's methods virtual, unless you do not want derived class to override them.
- Any class that contains a virtual method is called a *polymorphic* class
  - and is extensible, i.e., can add capabilities to a derived class without access to the ancestor's source code
- Constructors cannot be virtual
- Destructors can and should be virtual
- A virtual method's return type cannot be overridden

Abstract Base Class

- Classes may declare a virtual function prototype without providing an implementation for it
  - used as a placeholder for an API element, which derived classes are obligated to implement
- Method functions declared but not defined in a class are pure virtual

  virtual type func_name(param_list) = 0;
- A base class containing a pure virtual function is called an *abstract base class*
- No instances of an abstract class can exist since at least one method lacks an implementation.

Friend Methods/Classes

- Perfect adherence to object encapsulation is not always convenient or clear
  - access to private, and protected, members of a class by collaborating classes can simplify implementation
  - *friend* definition is a mechanism for granting other exceptions
- Functions and classes can be *friends* of a class
- Friend functions can access *private* and *protected*
- Friend functions of a class are not class members
- Friends of base class are not friends of derived classes

Friend Methods/Classes

- *Friend* functions permit input and output routines to have access to private and protected class data
  - general input/output routines can be friends of objects they are creating and initializing
- Useful when one class (A) contains an instance of another class (B) because A HAS-A B as part of its implementation
  - remember implementing stacks and queues using different mappings onto the List ADT operations

Friends – Example

- 'write' can access private variables in 'Base'
  - cannot access private variables in Derived

```
class Base{
public:
    friend void write(Base& b);
private:
    double bvalue;
};
void write(Base& b){
    cout << b.bvalue << endl;
}
```

```
class Derieved:public Base{
public:
private:
    double dval;
};
int main(){
    Base b; Derived d;
    write(b); write(d);
}
```

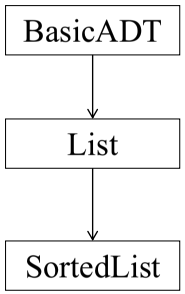

Friend Methods/Classes

- A class `List` can be a friend of the class `ListNode`
  - `List` can access `ListNode`'s private and protected members)

```
class ListNode
{
private:
… // define constructors and data
  // members item and *next
  friend class List;
};
```

ADTs List and Sorted List Revisited

- Section 8.4 in Carrano provides a good discussion of applying these new concepts to familiar examples
  - abstract Base Class (BasicADT)
  - pure Virtual Functions
  - virtual Functions
- Three level class hierarchy



Class Templates

- Way to describe commonality among different solution components.
  - Situation: same basic structure with different data components
  - lists, stacks, queues, trees, etc.
  - same data structures, different data
- Parameterized class definition
  - data types are the parameters

```
template <typename T>
class NewClass
{
 public:
   NewClass();
   NewClass(T initialData);

   void setData(T newData);
   T getData();

 private:
   T theData;
};
```


Class Templates – 2

- Declarations and methods must specify the type parameters in creating an instance

```
int main() {
    NewClass<int> first;
    NewClass<double> second(4.8);

    first.setData(5);
    cout << second.getData() << endl;
}
```

```
template <typename T>
NewClass<T>::NewClass()
{ }
template <typename T>
NewClass<T>::NewClass
    (T initialData): theData(initialData)
{ }
```

```
template <typename T>
void NewClass<T>::setData(T newData){
   theData = newData;
}
template <typename T>
T NewClass<T>::getData() {
   return theData;
}
```

see C8-templareEx1.cpp

Class Templates – 3

- Precede class definition template with
  template <typename T>
- Precede each method template with
  template <typename T>

see C8-ListT.cpp

C8-ListT.h/.cpp

- Data Type parameter <T> takes the place of
  typedef <listitemtypespec> ListItemType;
- Default constructor for the list node cannot initialize the data element
  - abstract definition of <T> has no information about what the type will be (it can be any type)
  - but copy constructor can
- Note the inclusion of the implementation source file at the end of the header file.
- Templat List class supports client code creating two standard lists holding double and char data

see C8-ListTClient.cpp

Class Templates – 4

- Abstract nature of the class description can lead to problems with apparently "standard" operations
- Everything the class does must be valid for every possible *type specified for T*
- For example, specified type should overload the "<<" operator to support output
- Class template specification must thoroughly document all such operations and other assumptions made by the class implementation
  - must be satisfied by all classes provided as T

Class Templates – 5

- Compiler must know the class specified for T before it can compile the template instance
- Class template header and source files are defined as normal
  - but the implementation file is not compiled separately ahead of time
  - implementation file #included at the end of the header file
- All client code using the template thus includes it, making the definition available to compiler when it compiles instances for specific T

Overloaded Operators

- Overloaded operator has more than one meaning
- Overload common operators for classes to enable a particular operator to work correctly on instances of a class
- Example: a list
  - Define the equality operator for a list
    virtual bool operator == (const List& rhs) const
  - Overload the assignment operator to get a deep copy of a list
    virtual List& operator = (const List& rhs);

Overloading Operators -- Guidelines

- Can overload any operator except: ., .*, ::, ?, :, sizeof
- Cannot define new operators by overloading symbols that are not already operators in C++
- Cannot change the standard precedence of a C++ operator or the number of its operands
- At least one operand of an overloaded operator must be an instance of a class
- Cannot change the number of arguments for an overloaded method
- A typical class should overload the assignment, equality, and relational operators (= == != < <= > >=)

Iterators

- An iterator is an object that traverses a collection of like objects
- Common iterator operations

Operation	Description
*	Return the item that the iterator currently references
++	Move the iterator to the next item in the list
--	Move the iterator to the previous item in the list
==	Compare two iterators for equality
!=	Compare two iterators for inequality

Iterators

- A header file for the class `ListIterator`

```
// List and ListIterator are friend classes of ListNode
#include "ListNode.h"
class ListIterator
{
public:
    ListIterator(const List *aList, ListNode *nodePtr);
    const ListItemType & operator*();
    ListIterator operator++();
    bool operator==(const ListIterator& rhs) const;
    bool operator!=(const ListIterator& rhs) const;
    friend class List;
private:
    const List *container //ADT associated with iterator
    ListNode   *cur;      //current location in collection
};
```


Summary

- Inheritance
- Virtual methods and late binding
- Friend classes and methods
- Class templates
- Overloaded operators
- Iterators
- All these are ways to express desired semantics in C++ to specify algorithmic solution to a problem.