Inheritance

Chapter 15
& additional topics

Overview

- Inheritance Introduction
- Three different kinds of inheritance
- Changing an inherited member function
- More Inheritance Details
- Polymorphism

Motivating Example: Employee Classes

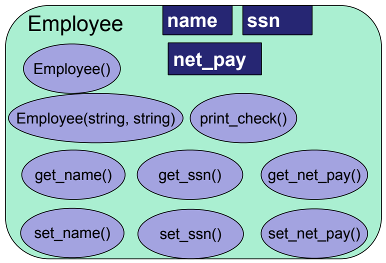
- Design a record-keeping program with records for salaried and hourly employees
  - Salaried and hourly employees belong to a class of people who share the property "employee"
  - Salaried employee
    - A subset of employees with a fixed wage
  - Hourly employees
    - Another subset of employees earn hourly wages
- All employees have a name and SSN
  - Functions to manipulate name and SSN are the same for hourly and salaried employees

---

- First define a class called `Employee` for all kinds of employees
- The `Employee` class will be used later to define classes for hourly and salaried employees

employee.h

```
class Employee
{
public:
    Employee( );
    Employee(string the_name, string the_ssn);
    string get_name( ) const;
    string get_ssn( ) const;
    double get_net_pay( ) const;
    void set_name(string new_name);
    void set_ssn(string new_ssn);
    void set_net_pay(double new_net_pay);
    void print_check( ) const;
private:
    string name;
    string ssn;
    double net_pay;
};
```



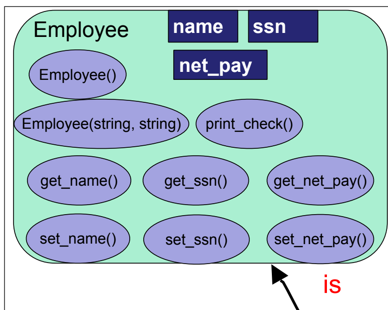
see book Display 15.3

hourlyemployee.h

```
class HourlyEmployee : public Employee
{
public:
    HourlyEmployee( );
    HourlyEmployee(string the_name, string the_ssn,
                   double the_wage_rate, double the_hours);
    void set_rate(double new_wage_rate);
    double get_rate( ) const;
    void set_hours(double hours_worked);
    double get_hours( ) const;

    void print_check( ) ;
private:
    double wage_rate;
    double hours;
};
```

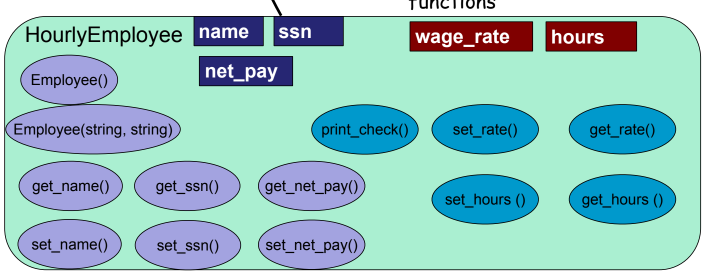
- `HourlyEmployee` is derived from Class `Employee`
- `HourlyEmployee` inherits all member functions and member variables of `Employee`
  - `NOT SHOWN explicitly in HourlyEmployee's defn`
- The class definition begins `class HourlyEmployee : public Employee`
  - note that `:public Employee` shows that `HourlyEmployee` is derived from class `Employee`
- `HourlyEmployee` declares additional member



- Inheritance:

a new class, called a derived class, is created from another class (i.e., the base class)

- A derived class automatically has all the member variables and functions of the base class
- A derived class can have additional member variables and/or member functions



A derived class automatically **has** all the member variables and functions of the base class.

But, the derived class might not have the same access rights as the base class when accessing those inherited members! (To be discussed soon…)

Inherited Members

- A derived class inherits all the members (data members, functions) of the parent class
- The derived class should **not** re-declare or re-define a member function inherited from the parent **unless** …
  - The derived class wants to use the inherited member function for doing something different
- The derived class can add member variables & member functions

Display 15.3

```
class HourlyEmployee : public Employee
{
public:
    HourlyEmployee( );
    HourlyEmployee(string the_name, string the_ssn,
                   double the_wage_rate, double the_hours);
    void set_rate(double new_wage_rate);
    double get_rate( ) const;
    void set_hours(double hours_worked);
    double get_hours( ) const;

    void print_check( ) ;
private:
    double wage_rate;
    double hours;
};
```

hourlyemployee.h

Only list the declaration of an inherited member function if you want to change the defn of the function.

Why re-define print_check() ?

A practical concern here…

- `print_check` will have different definitions to print different checks for each type of employee
  - An `Employee` object lacks sufficient information to print a check
  - Each derived class will have sufficient information to print a check

DImplementation for the Base Class `Employee` (*part 1 of 2*)

```
//This is the file: employee.cpp.
//This is the implementation for the class Employee.
//The interface for the class Employee is in the header file employee.h.
#include <string>
#include <cstdlib>
#include <iostream>
#include "employee.h"
using namespace std;

namespace employeessavitch
{
    Employee::Employee( ) : name("No name yet"), ssn("No number yet"), net_pay(0)
    {
        //deliberately empty
    }

    Employee::Employee(string the_name, string the_number)
       : name(the_name), ssn(the_number), net_pay(0)
    {
        //deliberately empty
    }

    string Employee::get_name( ) const
    {
        return name;
    }

    string Employee::get_ssn( ) const
    {
        return ssn;
    }
```

employee.cpp

Implementation for the Base Class Employee (*part 2 of 2*)

```
    double Employee::get_net_pay( ) const
    {
        return net_pay;
    }

   void Employee::set_name(string new_name)
    {
        name = new_name;
    }

    void Employee::set_ssn(string new_ssn)
    {
        ssn = new_ssn;
    }

    void Employee::set_net_pay (double new_net_pay)
    {
        net_pay = new_net_pay;
    }

    void Employee::print_check( ) const
    {
        cout << "\nERROR: print_check FUNCTION CALLED FOR AN \n"
             << "UNDIFFERENTIATED EMPLOYEE. Aborting the program.\n"
             << "Check with the author of the program about this bug.\n";
        exit(1);
    }

}//employeessavitch
```

employee.cpp

Implementing a Derived Class

- Any member function added in the derived class are defined in the implementation file for the derived class
  - Definitions are not given for inherited functions that are not to be changed
- The `HourlyEmployee` class is implemented in `HourlyEmployee.cpp`

Textbook Display 15.5

Implementation for the Derived Class HourlyEmployee (*part 1 of 2*)

```
//This is the file: hourlyemployee.cpp
//This is the implementation for the class HourlyEmployee.
//The interface for the class HourlyEmployee is in
//the header file hourlyemployee.h.
#include <string>
#include <iostream>
#include "hourlyemployee.h"
using namespace std;

namespace employeessavitch
{
    HourlyEmployee::HourlyEmployee( ) : Employee( ), wage_rate(0), hours(0)
    {
        //deliberately empty
    }

    HourlyEmployee::HourlyEmployee(string the_name, string the_number,
                                   double the_wage_rate, double the_hours)
    : Employee(the_name, the_number), wage_rate(the_wage_rate), hours(the_hours)
    {
        //deliberately empty
    }

    void HourlyEmployee::set_rate(double new_wage_rate)
    {
        wage_rate = new_wage_rate;
    }

    double HourlyEmployee::get_rate( ) const
    {
        return wage_rate;
    }
```

Display 15.5 (1/2)

Implementation for the Derived Class HourlyEmployee (*part 2 of 2*)

Display 15.5 (2/2)

```
    void HourlyEmployee::set_hours(double hours_worked)
    {
        hours = hours_worked;
    }

    double HourlyEmployee::get_hours( ) const
    {
        return hours;
    }


    void HourlyEmployee::print_check( )
    {
        set_net_pay(hours * wage_rate);

        cout << "\n________________________________________________\n";
        cout << "Pay to the order of " << get_name( ) << endl;
        cout << "The sum of " << get_net_pay( ) << " Dollars\n";
        cout << "_________________________________________________\n";
        cout << "Check Stub: NOT NEGOTIABLE\n";
        cout << "Employee Number: " << get_ssn( ) << endl;
        cout << "Hourly Employee. \nHours worked: " << hours
             << " Rate: " << wage_rate << " Pay: " << get_net_pay( ) << endl;
        cout << "_________________________________________________\n";
    }

}//employeessavitch
```

We have chosen to set `net_pay` as part of the `print_check` function since that is when it is used, but in any event, this is an accounting question, not a programming question.
But note that C++ allows us to drop the `const` in the function `print_check` when we redefine it in a derived class.

Class SalariedEmployee

salariedemployee.h

```
class SalariedEmployee : public Employee
{
public:
    SalariedEmployee( );
    SalariedEmployee (string the_name,
                      string the_ssn,
                      double the_weekly_salary);
    double get_salary( ) const;
    void set_salary(double new_salary);
    void print_check( );
private:
    double salary;//weekly
};
```

- The class `SalariedEmployee` is also derived from `Employee`
  - Function `print_check` is redefined to have a meaning specific to salaried employees
  - `SalariedEmployee` adds a member variable `salary`

salariedemployee.cpp

Display 15.6 (1/2)

Implementation for the Derived Class `SalariedEmployee` **(*part 1 of 2*)**

```
//This is the file salariedemployee.cpp.
//This is the implementation for the class SalariedEmployee.
//The interface for the class SalariedEmployee is in
//the header file salariedemployee.h.
#include <iostream>
#include <string>
#include "salariedemployee.h"
using namespace std;

namespace employeessavitch
{
    SalariedEmployee::SalariedEmployee( ) : Employee( ), salary(0)
    {
        //deliberately empty
    }

    SalariedEmployee::SalariedEmployee(string the_name, string the_number,
                                       double the_weekly_salary)
                     : Employee(the_name, the_number), salary(the_weekly_salary)
    {
        //deliberately empty
    }

    double SalariedEmployee::get_salary( ) const
    {
        return salary;
    }

    void SalariedEmployee::set_salary(double new_salary)
    {
        salary = new_salary;
    }
```

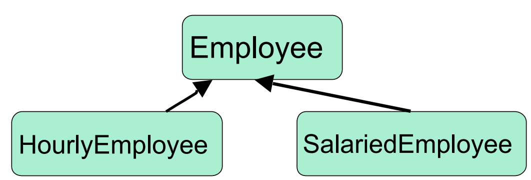
Display 15.6 (2/2)

Implementation for the Derived Class `SalariedEmployee` **(*part 2 of 2*)**

```
    void SalariedEmployee::print_check( )
    {
        set_net_pay(salary);
        cout << "\n__________________________________________________\n";
        cout << "Pay to the order of " << get_name( ) << endl;
        cout << "The sum of " << get_net_pay( ) << " Dollars\n";
        cout << "_________________________________________________\n";
        cout << "Check Stub NOT NEGOTIABLE \n";
        cout << "Employee Number: " << get_ssn( ) << endl;
        cout << "Salaried Employee. Regular Pay: "
             << salary << endl;
        cout << "_________________________________________________\n";
    }
}//employeessavitch
```

Parent and Child Classes

- Recall that a child class automatically has all the members of the parent class
- The parent class is an ancestor of the child class
- The child class is a descendent of the parent class
- The parent class (Employee) contains all the code common to the child classes
  - You do not have to re-write the code for each child



Parent and Child Classes (cont'd)

- An hourly employee **is** an employee
  - An object of type `HourlyEmployee` can be used wherever an object of type `Employee` can be used
    - An object of a class type can be used wherever any of its ancestors can be used
  - An ancestor cannot be used in a place where one of its descendents is expected

```
void  fun1(Employee x);
void  fun2(HourlyEmployee y);
int main()
{
  Employee a;
  HourlyEmployee b;
  fun1(a); //correct
  fun1(b); //correct
  fun2(a); //incorrect
  fun2(b); //correct
}
```

public inheritance is an **is-a** relationship

Derived Class's Constructors

- A base class's constructor is **not** inherited in a derived class
  - base class constructor can be invoked by the constructor of the derived class
  - constructor of a derived class begins by invoking constructor of base class in the initialization section:

```
HourlyEmployee::HourlyEmployee : Employee( ), wage_rate(
  0), hours(0)
  { //no code needed }
```

Call a constructor for Employee

Default Initialization

- If a derived class constructor does not invoke a base class constructor explicitly, base class's **no-paremeter constructor** will be used automatically
- If class B is derived from class A and class C is derived from class B
  - When a object of class C is created
    - The base class A's constructor is the first invoked
    - Class B's constructor is invoked next
    - C's constructor completes execution

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Private is Private

- A member variable (or function) that is private in parent class is **not directly accessible by member functions in** the child class
- This code is illegal as `net_pay` is a private member of `Employee`!

```
void HourlyEmployee::print_check( )
{
    net_pay = hours * wage_rage;
}
```

- The parent class member functions must be used to access the private members of the parent

protected Qualifier

- `protected` members of a class appear to be private outside the class, but are directly accessible within a derived classes
- If member variables name, `net_pay`, is listed as protected (not private) in `Employee` class, this code becomes legal:

```
HourlyEmployee::print_check( )
{
    net_pay = hours * wage_rage;
```

access_specifiers_demo.cpp

Using protected or not?

- Using `protected` members of a class is a convenience to facilitate writing code of derived classes.
- Protected members are not necessary
  - Derived classes can use public methods of their ancestor classes to access private members
- Many programming authorities consider it bad style to use protected member variables

Three different ways for classes to inherit from other classes: public, private, and protected.

```
// Inherit from Base publicly
class D1: public Base
{ };
// Inherit from Base privately
class D2: private Base
{ };
// Inherit from Base protectedly
class D3: protected Base
{ };
class D4: Base // Defaults to private inheritance
{ };
```

If you do not choose an inheritance type, C++ defaults to private inheritance (just like members default to private access if you do not specify otherwise).

Public inheritance

// Inherit from Base publicly
class D1: **public** Base
{ };

- All inherited members keep their original access specifications.

public inheritance			
Base class access specifier	*Derived class access specifier (implicitly given)*	*Directly accessible in member functions of derived class?*	*Directly accessible in any other code?*
public	*public*	*yes*	*yes*
private	*private*	*no*	*no*
protected	*protected*	*yes*	*no*

Private inheritance

class D2: **private** Base // Inherit from Base privately
{ };

- All inherited members are private in derived class:
  - private members stay private, and protected and public members become private.

private inheritance			
Base class access specifier	*Derived class access specifier (implicitly given)*	*Directly accessible in member functions of derived class?*	*Directly accessible in any other code?*
public	*private*	*yes*	*no*
private	*private*	*no*	*no*
protected	*private*	*yes*	*no*

Protected inheritance

class D3: **protected** Base// Inherit from Base protectedly
{ };

- Rarely used. public and protected members become protected, and private members stay private.

protected inheritance			
Base class access specifier	*Derived class access specifier (implicitly given)*	*Directly accessible in member functions of derived class?*	*Directly accessible in any other code?*
public	*protected*	*yes*	*no*
private	*private*	*no*	*no*
protected	*protected*	*yes*	*no*

- Member functions of a derived classes have access to its inherited members based ONLY on access specifiers of its immediate parent, not affected by inheritance method used!

Base class access specifier for members	Derived class access specifier (implicitly given for inherited members)	Directly accessible in member functions of derived class?	Directly accessible in any other code?
public inheritance			
public	*public*	*yes*	*yes*
private	*private*	*no*	*no*
protected	*protected*	*yes*	*no*
private inheritance			
public	***private***	***yes***	***no***
private	***private***	***no***	***no***
protected	***private***	***yes***	***no***
protected inheritance			
public	***protected***	***yes***	***no***
private	***private***	***no***	***no***
protected	***protected***	***yes***	***no***

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Redefinition of Member Functions

- When defining a derived class, list the inherited functions that you wish to change for the derived class
  - The function is declared in the class definition
  - `HourlyEmployee` and `SalariedEmployee` each have their own definitions of `print_check`
- Next page demonstrates the use of the derived classes defined in `HourlyEmployee.h` and `SalariedEmployee.h`.

Functions defined in Employee class
set_name()
set_ssn()
print_check()
Functions defined in HourlyEmployee class
set_rate()
set_hours()
print_check()

```
int main( )
{
    HourlyEmployee joe;
    joe.set_name("Mighty Joe");
    joe.set_ssn("123-45-6789");
    joe.set_rate(20.50);
    joe.set_hours(40);
    cout << "Check for " << joe.get_name( )
         << " for " << joe.get_hours( ) << " hours.\n";
    joe.print_check( );
    cout << endl;

    SalariedEmployee
      boss("Mr. Big Shot", "987-65-4321", 10500.50);
    cout << "Check for " << boss.get_name( ) << endl;
    boss.print_check( );

    return 0;
}
```

Redefining vs. Overloading

- A function redefined in a derived class has parameters as that in base class
  - its prototype (return value, function name, and parameters) must be identical to that in base class.
- An overloaded function has a different number and/or type of parameters than that in base class
  - derived class has two functions with same name as that in base class: one is overloading, one is redefining.

```
void set_name(string first_name, string last_name);// overloading
void set_name(string new_name); //redefine
```

Access to a Redefined Base Function

- When a function of a base class is redefined in a derived class, base class function can still be used
  - To specify that you want to use the base class version of the redefined function:

```
int main()
{
   HourlyEmployee sally_h;
   sally_h.Employee::print_check( );
}
```

A side note: function signatures

- An overloaded function has multiple signatures
  - A function signature is the function's name with the sequence of types in the parameter list, not including any const or '&'
  - Compiler uses function signature to decide which version of overloaded function to be called
- Some compilers allow overloading based on including const or not including const

Change access specifier for an inherited member

- When re-define a function in a derived class,
  - it does not inherit access specifier from parent class
  - can specify its own access specifier
- In derived class, one can:
  - hide an inherited member: public in base class => private
  - expose an inherited member: protected in base class => public
- In derived class, **one cannot:**
  - **change from private to protected or public**
    - because derived classes do not have access to private members of the base class.

Hide functionality of an inherited member function

Two ways to do this:

- Give it a new access specifier private when re-defining it in derived class.
- Or, simply list it in private section:

```
class Circle : public Shape()
{
private:
        Shape::display; //display() is a function defined as
public in Shape, it's now a private member of Circle
```

without even re-defining it.

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- Some special functions are not inherited by a derived class. They include
  - The assignment operator
  - Copy constructors
  - Destructors

The Assignment Operator

- In implementing an assignment operator (`operator=`) in a derived class
  - It is normal to use the assignment operator from the base class in the definition of the derived class's assignment operator
  - Recall that the assignment operator is written as a member function of a class

The Operator = Implementation

- This code segment shows how to begin the implementation of the = operator for a derived class:

```
Derived& Derived::operator= (const Derived& rhs)
 {
     Base::operator=(rhs);
/*
Base is the name of the parent class
This line handles the assignment of the inherited member variables by calling the base class assignment operator
The remaining code would assign the member variables introduced in the derived class
*/
```

Operator = and Derived Classes

- If a base class has a defined assignment `operator =` but the derived class does not, then
  - When assigning an object of the derived class to another object of the derived class, C++ will use a default operator that will have nothing to do with the base class assignment operator!

Copy Constructors and Derived Classes

- If a copy constructor is not defined in a derived class, C++ will generate a default copy constructor
  - This copy constructor copies only the contents of member variables and will not work with pointers and dynamic variables
  - The base class copy constructor will not be used (even if it is defined)

The Copy Constructor

- Implementation of the derived class copy constructor is much like that of the assignment operator:

```
Derived::Derived(const Derived& object)
         :Base(object), <other initializing>
{…}
```

  - Invoking the base class copy constructor sets up the inherited member variables
    - Since object is of type `Derived` it is also of type `Base`

Destructors and Derived Classes

- A destructor is not inherited by a derived class
- The derived class should define its own destructor

Destructors in Derived Classes

- If base class has a programmer-defined destructor, then defining the destructor for the derived class is relatively easy
  - When the destructor for a derived class is called, the destructor for the base class is automatically called
  - The derived class destructor only need to release memory for the dynamic variables added in the derived class

Destruction Sequence

- If class B is derived from class A

and class C is derived from class B…

  - When an object of class C goes out of scope
    - The destructor of class C is called
    - Then the destructor of class B
    - Then the destructor of class A
  - Notice that destructors are called in the reverse order of constructor calls

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Polymorphism

- **Polymorphism** refers to the ability to associate multiple definitions with one function declaration using a mechanism called **late binding**
- Polymorphism is a key component of the philosophy of object oriented programming

Binding & Early binding

- **Binding**

The process to convert identifiers (such as variable and function names) into machine language addresses.

- **Early binding** (or static binding)

An C++ compiler directly associates an identifier name (such as a function or variable name) with a machine address during compilation process.

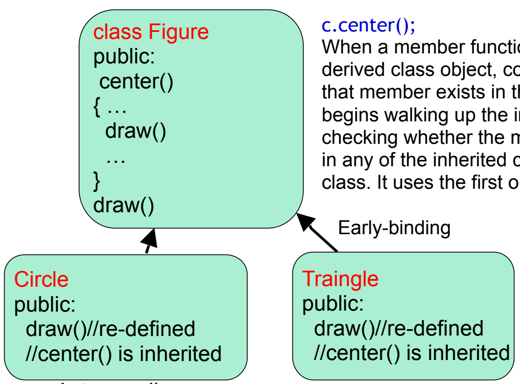
Note that all functions have a unique machine address.

When the compiler encounters a function call, it replaces the function call with an instruction that tells the CPU to jump to the address of the function.

- **Late binding** (or dynamic binding)
  - To be discussed very soon…

A motivating example

- Imagine a graphics program with several types of figures
- Each figure may be an object of a different class, such as a `circle, oval, rectangle,` etc.
- Each is a descendant of a class `Figure`
- Each has a function `draw( )` implemented with code specific to each shape
- Class `Figure` has functions common to all figures



c.center();
When a member function is called with a derived class object, compiler first looks to see if that member exists in the derived class. If not, it begins walking up the inheritance chain and checking whether the member has been defined in any of the inherited classes or the top base class. It uses the first one it finds.

```
int man()
{
  Circle c;
  c.draw(); //which draw() is called?
  c.center(); //which draw() is called inside center()?
}
```

Look at : figure_demo.cpp

A Problem

- Class `Figure` has a function `center that`
  - moves a figure to center of the screen by erasing the figure and redrawing it in the center of the screen
- Function `center` is inherited by each of the derived classes
  - Function `center` SHOULD use each derived object's `draw` function to draw the figure
  - But, `Figure` class does not know about its derived classes, so how can it know how to invoke a derived object's `draw` function?

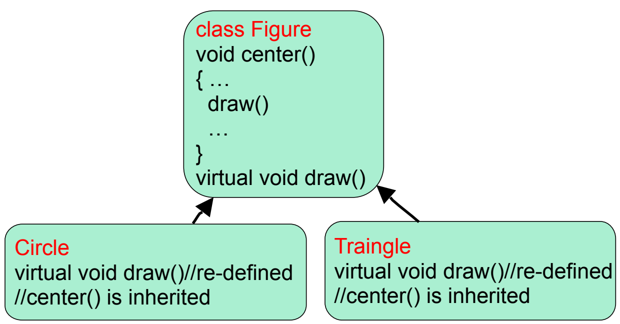
Virtual Functions to the rescue

- Making a function virtual tells compiler that ...
  - When defining base class, the programmer doesn't know how it should be implemented
  - wait until the function of an object is called in a program at running time. Only at that time, the implementation of the function is clear, i.e., it is given by the class type of the object.
    - if it's object of rectangle, draw a rectangle; if it's ...
- This is called late binding
  - in contrast to early binding (compile-time binding)

How to use virtual functions?

- Add keyword virtual to a function's declaration in base class
  - virtual is not added to the function definition
- Define the function differently in a derived class
  - This is the intention of introducing virtual function
- virtual is not needed for the function declaration in the derived class, but is often included
- Note that, virtual functions require considerable overhead so excessive use reduces program efficiency

figure_demo_virtual.cpp



Look at : figure_demo_virtual.cpp

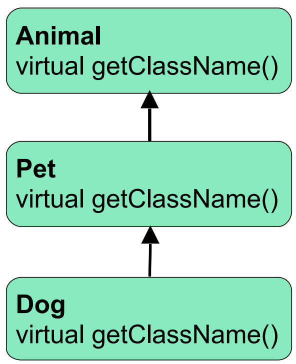
```
int main()
{
  Circle c;
  c.draw() //which draw() is called?
  c.center() //which draw() is called inside center()?
}
```

More benefits of virtual functions

- Code that works for a base class will also work for all of its derived class if virtual functions are used.
  - Examples: PrintPayChecks (Employee* all[], int len)
- Write a newly derived class that will automatically (without modification) work with existing code that works for the base class.

More than two classes in a chain of inheritance hierarchy

inheritance hierarchy




```
Dog d ;
Animal &animal_ref = d;
cout <<
animal_ref.GetClassName();
```

C++ will check every inherited class between Animal and Dog (including Animal and Dog) and use the most-derived version of the function that it finds.

Pure virtual function

- Consider this situation:

We have a function that we want to put in the base class, but we know that only the derived classes know what the function should do.

Then, make the function pure virtual

Pure virtual function

- If a class has a pure virtual function, then the class cannot be instantiated, and the derived classes of the class have to define these function before they can be instantiated.
  - This ensures the derived classes NOT forget to redefine those pure virtual functions (which is what the base class hopes)

Revisit Employee class

- print_check() function should be a pure virtual function in the defn of Employee class.
  - the original implementation in Employee class's print_check() prints out an error msg is not a good design, as it leaves the problem checking to the run time, not compile time.

Design suggestions

- Simple virtual function
  - Inheriting it implies → inherit both interface and a default implementation.
  - In your derive class, you need to support this function, but if you don't want to write your own, you can fall back on the default version in base class.
  - **Danger**: if a derived class might not want to use the default implementation from the base class, but forget to define its own, then it will use the inherited one (which is not what it wants!)

Another Example of Virtual Functions

- As another example, let's design a record-keeping program for an **auto parts store**
- We want to introduce a bill function, and we want a versatile program, but we do not know all the possible types of sales we might have to account for
  - Later we may add **mail-order** and **discount** sales
  - Functions to compute bills will have to be added later when we know what type of sales to add
  - To accommodate the future possibilities, we will make the bill function a virtual function

The Sale Class

- All sales will be derived from the base class `Sale`
- The `bill` function of the `Sale` class is virtual
- The `Sale` class interface and implementation are shown in

Display 15.8 Display 15.9

Interface for the Base Class Sale

```
//This is the header file sale.h.
//This is the interface for the class Sale.
//Sale is a class for simple sales.
#ifndef SALE_H
#define SALE_H

#include <iostream>
using namespace std;

namespace salesavitch
{

    class Sale
    {
    public:
        Sale();
        Sale(double the_price);
        virtual double bill() const;
        double savings(const Sale& other) const;
        //Returns the savings if you buy other instead of the calling object.
    protected:
        double price;
    };

    bool operator < (const Sale& first, const Sale& second);
    //Compares two sales to see which is larger.

}//salesavitch

#endif // SALE_H
```

Display 15.8

Sale, DiscountSale

The Derived Class DiscountSale

```
//This is the interface for the class DiscountSale.
#ifndef DISCOUNTSALE_H
#define DISCOUNTSALE_H
#include "sale.h"

namespace salesavitch
{
    class DiscountSale : public Sale
    {
    public:
        DiscountSale();
        DiscountSale(double the_price, double the_discount);
        //Discount is expressed as a percent of the price.
        virtual double bill() const;
    protected:
        double discount;
    };
}//salesavitch
#endif //DISCOUNTSALE_H
```

This is the file discountsale.h.

The keyword virtual is not required here, but it is good style to include it.

```
//This is the implementation for the class DiscountSale.
#include "discountsale.h"

namespace salesavitch
{
    DiscountSale::DiscountSale() : Sale(), discount(0)
    {}

    DiscountSale::DiscountSale(double the_price, double the_discount)
              : Sale(the_price), discount(the_discount)
    {}

    double DiscountSale::bill() const
    {
        double fraction = discount/100;
        return (1 - fraction)*price;
    }
}//salesavitch
```

This is the file discountsale.cpp.

DiscountSale::bill

- Class `DiscountSale` has its own version of virtual function `bill`
  - Even though class `Sale` is already compiled, `Sale::savings( )` and `Sale::operator< can` still use function `bill` from the `DiscountSale` class
  - The keyword `virtual` tells C++ to wait until `bill` is used in a program to get the implementation of `bill` from the calling object

Display 15.9

Implementation of the Base Class Sale

```
//This is the implementation file: sale.cpp
//This is the implementation for the class Sale.
//The interface for the class Sale is in
//the header file sale.h.
#include "sale.h"

namespace salesavitch
{

    Sale::Sale() : price(0)
    {}

    Sale::Sale(double the_price) : price(the_price)
    {}

    double Sale::bill() const
    {
        return price;
    }

    double Sale::savings(const Sale& other) const
    {
        return ( bill() - other.bill() );
    }

    bool operator < (const Sale& first, const Sale& second)
    {
        return (first.bill() < second.bill());
    }

}//salesavitch
```

- Because function `bill` is virtual in class `Sale`, function `savings` and `operator<`, defined only in the base class, can in turn use a version of `bill` found in a derived class
  - When a `DiscountSale` object calls its `savings` function, **defined only in the base class**, function `savings` calls function `bill`
  - Because `bill` is a virtual function in class `Sale`, C++ uses the version of `bill` defined in the object that called `savings`

Implementation of the Base Class Sale

Sale
virtual bill()
savings()

DiscountSale
virtual bill()
//no re-defined savings()


```
//This is the implementation file: sale.cpp
//This is the implementation for the class Sale.
//The interface for the class Sale is in
//the header file sale.h.
#include "sale.h"

namespace salesavitch
{

    Sale::Sale() : price(0)
    {}

    Sale::Sale(double the_price) : price(the_price)
    {}

    double Sale::bill() const
    {
        return price;
    }

    double Sale::savings(const Sale& other) const
    {
        return ( bill() - other.bill() );
    }

    bool operator < (const Sale& first, const Sale& second)
    {
        return (first.bill() < second.bill());
    }

}//salesavitch
```


Q:
Since bill() is a virtual function, what will happen in the following code?

If bill() is not a virtual function, what will happen in the following code?

```
Sale simple(10.00);
DiscountSale d1(11.0, 10);
DiscountSale d2(11.0, 10);
if (d1 < simple)
{
  cout << “Saving is $” <<
simple.savings(d1);
}
if (d1 < d2)
{
  cout << “Saving is $” <<
d2.savings(d1);
}
```

Use of a Virtual Function

Display 15.11

```
//Demonstrates the performance of the virtual function bill.
#include <iostream>
#include "sale.h" //Not really needed, but safe due to ifndef.
#include "discountsale.h"
using namespace std;
using namespace salesavitch;

int main()
{
    Sale simple(10.00);//One item at $10.00.
    DiscountSale discount(11.00, 10);//One item at $11.00 with a 10% discount.

    cout.setf(ios::fixed);
    cout.setf(ios::showpoint);
    cout.precision(2);

    if (discount < simple)
    {
        cout << "Discounted item is cheaper.\n";
        cout << "Savings is $" << simple.savings(discount) << endl;
    }
    else
        cout << "Discounted item is not cheaper.\n";

    return 0;
}
```

Sample Dialogue

```
Discounted item is cheaper.
Savings is $0.10
```

A potential slicing problem
if we do not use virtual functions.

Preliminary: C++'s Type Checking

- C++ carefully checks for type mismatches in the use of values and variables
  - This is referred to as strong type checking
  - Generally, the type of a value assigned to a variable must match the type of the variable
    - E.g., double a = "Hello"; //incorrect.
  - Recall that some automatic type casting occurs
    - E.g., int a = 20.34; //correct
- **Strong type checking interferes with the concepts of inheritance**

Type Checking and Inheritance

- Consider

```
class Pet
{
public:
    virtual void print();
    string name;
}
```

Pet
print()
name

```
class Dog : public Pet
{
public:
    virtual void print();
    string breed;
}
```

Dog
print() //overridden
name
breed

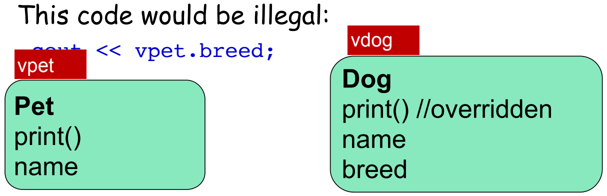
Slicing problem: A Sliced Dog is a Pet

- C++ allows the following assignments:

```
vdog.name = "Tiny";
vdog.breed = "Great Dane";
vpet = vdog;
```

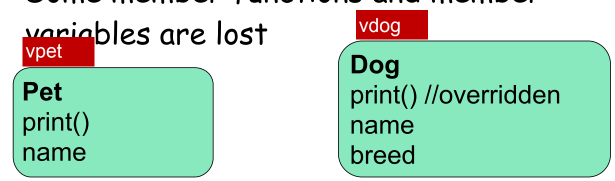
- However, vpet will lose breed member of vdog since an object of class Pet has no breed member
  - This code would be illegal:

```
cout << vpet.breed;
```



The Slicing Problem

- It is **legal** to **assign** a derived class object into a base class **variable (not a reference)**, however...
  - This slices off data in derived class that is not also part of base class
  - Some member functions and member variables are lost



Extended Type Compatibility

- It is possible in C++ to avoid slicing problem
  - Using pointers to dynamic variables and virtual functions, we can still access added members of derived class object.

Dynamic Variables and Derived Classes

- Example:

Pet *ppet; **Dog *pdog;** **pdog = new Dog;** **pdog->name = "Tiny";** **pdog->breed = "Great Dane";** **ppet = pdog;**	**void Dog::print( )** **{** **cout << "name: "** **<< name << endl;** **cout << "breed: "** **<< breed << endl;** **}**

`ppet->print( );` is legal and produces:

```
name:  Tiny
breed:  Great Dane
```

Display 15.12 (1-2)

Display 15.12 (1/2)

More Inheritance with Virtual Functions (*part 1 of 2*)

```
//Program to illustrate use of a virtual function
//to defeat the slicing problem.

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

class Pet
{
public:
    virtual void print();
    string name;
};

class Dog : public Pet
{
public:
    virtual void print();//keyword virtual not needed, but put
                         //here for clarity. (It is also good style!)
    string breed;
};

int main()
{
    Dog vdog;
    Pet vpet;

    vdog.name = "Tiny";
    vdog.breed = "Great Dane";
    vpet = vdog;

    //vpet.breed; is illegal since class Pet has no member named breed

    Dog *pdog;
    pdog = new Dog;
```

Display 15.12 (2/2)

More Inheritance with Virtual Functions (*part 2 of 2*)

```
    pdog->name = "Tiny";
    pdog->breed = "Great Dane";

    Pet *ppet;
    ppet = pdog;
    ppet->print(); // These two print the same output:
    pdog->print(); // name: Tiny breed: Great Dane

    //The following, which accesses member variables directly
    //rather than via virtual functions, would produce an error:
    //cout << "name: " << ppet->name << "  breed: "
    //     << ppet->breed << endl;
    //generates an error message: 'class Pet' has no member
    //named 'breed' .
    //See Pitfall section "Not Using Virtual Member Functions"
    //for more discussion on this.

    return 0;
}

void Dog::print()
{
    cout << "name: " << name << endl;
    cout << "breed: " << breed << endl;
}

void Pet::print()
{
    cout << "name: " << endl;//Note no breed mentioned
}
```

Sample Dialogue

```
name: Tiny
breed: Great Dane
name: Tiny
breed: Great Dane
```

Use Virtual Functions

- The previous example:

  `ppet->print( );`

  worked because print was declared as a virtual function
- The following code would still produce an error:

```
cout << "name: " << ppet->name
     << "breed: " << ppet->breed;
//name, breed are public member
//but we still cannot use a base class
//pointer to DIRECTLY access them
//but we can use virtual functions to access them
```

Why?

- `ppet->breed` is still illegal because `ppet` is a pointer to a `Pet` object that has no breed member
  - breed is just a data member, not a virtual function!
- Function `print( )` was declared virtual by class `Pet`
  - When computer sees `ppet->print( )`, it checks the virtual table for classes `Pet` and `Dog` and finds that **`ppet` points to an object of type `Dog`**
  - Because `ppet` points to a `Dog` object, code for `Dog::print( )` is used

Remember Two Rules

- If the domain type of the **pointer** `p_ancestor` is a base class for the domain type of **pointer** `p_descendant`,
  the following assignment of pointers is allowed

```
p_ancestor = p_descendant;
```

and we can use `p_ancestor` and virtual functions to access those data members added only by the derived class (i.e., **no data members will be inaccessible)**

- Although all the fields of the `p_descendant` are there, virtual functions are required to access them
  - You can NOT directly access an inherited member (even though it is public)

A side note on reference (1/3)

- A reference has to be initialized at the time when declared (except as a function parameter)

Use references

```
int x=10;
int& y = x;
//when & is used in between a type and a variable name,
// & specifies the name immediately after it as a reference.
// Similarly, double fun1(int & y)
cout << &x <<endl;
//& is an operator to get the address of variable x.
//Here, & does not specify x as a reference
cout << &y <<endl;
```

- A reference **cannot** be redirected to refer to something else.

A side note on reference (2/3)

Call-by-Reference Parameters ***(part 1 of 2)***

```
//Program to demonstrate call-by-reference parameters.
#include <iostream>

void get_numbers(int& input1, int& input2);
//Reads two integers from the keyboard.

void swap_values(int& variable1, int& variable2);
//Interchanges the values of variable1 and variable2.

void show_results(int output1, int output2);
//Shows the values of variable1 and variable2, in that order.

int main()
{
    int first_num, second_num;

    get_numbers(first_num, second_num);
    swap_values(first_num, second_num);
    show_results(first_num, second_num);
    return 0;
}

//Uses iostream:
void get_numbers(int& input1, int& input2)
{
    using namespace std;
    cout << "Enter two integers: ";
    cin >> input1
        >> input2;
}

void swap_values(int& variable1, int& variable2)
{
    int temp;

    temp = variable1;
    variable1 = variable2;
    variable2 = temp;
}
```

Use reference as function parameters

Recall this example (from the textbook)

A side note on reference (3/3): Variable name, reference, pointer

C++

- reference to a variable (or object) ---- another name for a variable, and it will never be changed to be a reference to a different variable
- pointer to a variable (or object) ---- can be modified to point to different variables
  - imagine it as an erasable address tag

Java

- reference to a variable---- can be modified to refer to different variables
  - imagine it as an erasable name tag, or a named hat that can be given to different persons to wear

Design suggestions

- Pure virtual function
  - Inheriting it implies → inherit interface only
  - In your derived class (that can be instantiated), you must define it, but the base class has not idea how you are going to implement it.
  - The danger mentioned for the simple virtual function does not exist.

Design suggestions

- Regular non-virutal function
  - Don't redefine an inherited non-virtual function (even though allowed by C++). Make sure the "is-a" relationship always true for public inheritance.

```
class B
{ public:
    void fun1();
}
class D: public B
{public: void fun1(//different
implementation);}
//inconsistent, confusing behavior.
//same object D, but different fun1() is
called,
// when D is pointed to by different ptr types
// (also true if references used)
D d;
B *pB=&d;
pB ->fun1();// B::fun1() is called!!
D *pD=&d;
pD ->fun1();//D::fun1() is called!!
```

Interface Class

- An **interface class** is a class that …
  - has no members variables,
  - all of the functions are pure virtual!
- The class is only an interface definition, no actual implementation.
- Why use interface?
  - When you want to define the functionality that derived classes must implement, but leave the details of how the derived class implements that functionality entirely up to the derived class.