UCLA PIC 10 B

Problem Solving using C++ Programming

- **Instructor**: **Ivo Dinov**, Asst. Prof. in Mathematics, Neurology, Statistics
- **Teaching Assistant:** Suzanne Nezzar, Mathematics

University of California, Los Angeles, Summer 2001

http://www.math.ucla.edu/~dinov/10b.1.011/

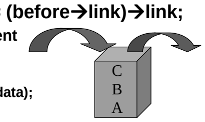
1

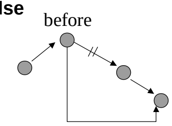
Review, Tuesday, July 31, 2001
PIC 10 B

- Linked-lists:

```
struct Node
{       int data;
        Node *link;
};
```

```
void head_insert(NodePtr& head, int the_number);
NodePtr search(NodePtr head, int target);
void insert(NodePtr after_me, int the_number);
void remove(NodePtr before);
// If before→link ==NULL, do nothing, else
// before→link = (before→link)→link;
// Ptr to next element
Template<class T>
class Stack
{  void push(T the_data);
   T pop( );
```





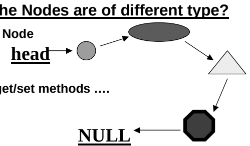
2

Review, Tuesday, July 31, 2001
PIC 10 B

- Two questions arose from the Linked-List chapter:

1. Can we have a linked-list where the Nodes are of different type?

```
template<class T_data, class T_link>  struct Node
{      Node();
       Node(T_data data, T_link * _link);
       // a number of data and link interface get/set methods ....
   private:     T_data data;
                T_link * link;
}
```



2. Do we need a public interface method getTop() in the Stack class example?

```
Stack::Stack(const Stack& a_stack)   // copy constructor
{  if (a_stack.getTop() == NULL)
        EQ.
Stack::Stack(const Stack& a_stack)   // copy constructor
{  if (a_stack.top() == NULL)        // since inside the scope of Stack class
```

3

Chapter 15
Inheritance

4

15 Inheritance

- Inheritance
  - Derived Classes
  - Constructor Base Initializer List
  - Constructors in Derived Classes
  - The *protected* Qualifier
  - Redefinition of Member Functions
  - Redefining Versus Overloading
- Polymorphism
  - Late Binding
  - Virtual Functions in C++
  - Virtual Functions and Extended Type Compatibility

5

15 Inheritance

- Object oriented programming (OOP) is a popular and powerful programming technique.
- OOP provides the abstraction technique called inheritance.
- There are several definitions of an Object Oriented Language. Most definitions disagree in some detail.
- All agree that inheritance is necessary.
- Inheritance provides:
  - A very general form of a class/type can be defined *and compiled.*
  - Later, another version of the class that can use (*inherit)* the already <u>defined features of the first class</u>, that can add new features not present in the first class, and can redefine (in at least two senses) features from the first class.

6

15.1 Inheritance Basics

- The process of inheritance allows the programmer to create a new class -- called the derived (sub-) class -- from another -- called the base (super-) class.
- The derived class automatically has all the member variables and functions present in the base class.
- The derived class can define additional member functions, variables, or both.
- class D is derived from class B means that class D has all the features of class B and some extra, added features as well.
- Sometimes D is called the child class and B the parent class.
- Recall that `class ifstream` is derived from `class istream` by adding extra features such as `open` and `close`.

7

Inheritance: Point, Circle, Cylinder

- We now consider the capstone exercise for Inheritance topic. We consider a point, circle, cylinder hierarchy. First, we develop and use class Point. Then we present an example in which we derive class Circle from class Point. Finally, we present an example in which we derive class Cylinder from class Circle .

8

Inheritance: Point, Circle, Cylinder

```
        //Definition of class Point actually Point2D
#ifndef POINT2_H
#define POINT2_H
#include <iostream>
using std::ostream;
class Point {
   friend ostream &operator<<(ostream &,const Point &);
   public:
        Point(int =0,int =0 );          //default constructor
        void setPoint(int,int );        //set coordinates
        int getX()  {return x;}         //get x coordinate
        int getY()  {return y;}         //get y coordinate
   protected:                    //accessible to derived classes
        int x,y;                 //coordinates of the point
};
#endif
```

Inheritance: Point, Circle, Cylinder

```
//      Member functions for class Point
#include "point2.h“

//      Constructor for class Point
Point::Point(int a,int b )   {    setPoint(a, b);    }
//      Set the x and y coordinates
void Point::setPoint(int a, int b)
{       x =a;           y =b; }
//      Output the Point
ostream &operator<<(ostream &output, const Point &p)
{       output <<'['<<p.x <<","<<p.y <<']';
        return output;     //       enables cascading
}
```

Inheritance: Point, Circle, Cylinder

```
                //Definition of class Circle
#ifndef CIRCLE2_H
#define CIRCLE2_H
#include <iostream>    //      using std::ostream;
#include "point2.h"
class Circle :public Point {            // NOTE class-extension
{   friend ostream &operator<<(ostream &,const Circle &);
    public:              //default constructor
        Circle(double r =0.0,int x =0,int y =0 );
        void setRadius(double );      //set radius
        double getRadius();           //return radius
        double area();                //calculate area
    protected:                  //accessible to derived classes
        double radius;          //radius of the Circle
};
#endif
```

Inheritance: Point, Circle, Cylinder

```
      // Member function definitions for class Circle

using std::ios;
using std::setiosflags;
using std::setprecision;
#include "circle2.h"

//   Constructor for Circle calls constructor for Point
//   with a member initializer and initializes radius
Circle::Circle(double r,int a,int b ) : Point(a,b )
              //call base-class constructor
{       setRadius(r);               }
```

Inheritance: Point, Circle, Cylinder

```
        //Set radius
void Circle::setRadius(double r )
{   radius =(r >=0 ?r :0 );      }
        //Get radius
double Circle::getRadius()   {        return radius;          }

   //Calculate area of Circle
double Circle::area()  {        return 3.14159 *radius *radius;     }
   //Output a circle in the form:
   //Center =[x,y ];Radius =#.##

ostream &operator<<(ostream &output,const Circle &c )
{    output <<"Center ="<< static_cast<Point >(c ) <<
        "; Radius =“ <<setiosflags(ios::fixed |ios::showpoint )
         <<setprecision(2 ) << c.radius;
   return output;                //enables cascaded calls
}
```

Inheritance: Point, Circle, Cylinder

```
        //Definition of class Cylinder
#ifndef CYLINDR2_H
#define CYLINDR2_H
#include <iostream>              // using std::ostream;
#include "circle2.h"
class Cylinder : public Circle {
   friend ostream &operator<<(ostream &,const Cylinder &);
   public:    //default constructor
        Cylinder(double h =0.0,double r =0.0, int x =0,int y =0 );
        void setHeight(double );              //set height
        double getHeight()const;              //return height
        double area();                   //calculate and return area
        double volume();                 //calculate and return volume
   protected:
        double height;                   //height of the Cylinder
};
#endif
```

Inheritance: Point, Circle, Cylinder

   //<u>Member and friend function definitions for class Cylinder</u>.

```
#include "cylindr2.h“

//Cylinder constructor calls Circle constructor
Cylinder::Cylinder(double h,double r,int x, int y):Circle(r,x,y )
{   setHeight(h );      }   //call base-class constructor

//Set height of Cylinder
void Cylinder::setHeight(double h )
{height =(h >=0 ?h :0 );}
//Get height of Cylinder
double Cylinder::getHeight()        {        return height;          }

//Calculate area of Cylinder (i.e.,surface area)
double Cylinder::area()
{        return (2 *Circle::area() + 2 *3.14159 *radius *height);    }
```

Inheritance: Point, Circle, Cylinder

//<u>Member and friend function definitions for class Cylinder</u>.

```
//Calculate volume of Cylinder
double Cylinder::volume()
{  return Circle::area()*height;       }

//Output Cylinder dimensions
ostream &operator<<(ostream &output, const Cylinder &c )
{       output << static_cast<Circle >(c)
              << "; Height =“ << c.height;
        return output;              //enables cascaded calls
}
```

Inheritance: Point, Circle, Cylinder

```
                   //Driver for class Cylinder
#include <iostream>
using std::cout;
using std::endl;
#include "point2.h"
#include "circle2.h"
#include "cylindr2.h"

int main()
{       Cylinder cyl(5.7, 2.5, 12, 23 );
        //use get functions to display the Cylinder
        cout  << "X coordinate is “ << cyl.getX()
              << "\nY coordinate is “ << cyl.getY()
              << "\nRadius is “ << cyl.getRadius()
              << "\nHeight is “ << cyl.getHeight()  <<  endl;
```

Inheritance: Point, Circle, Cylinder

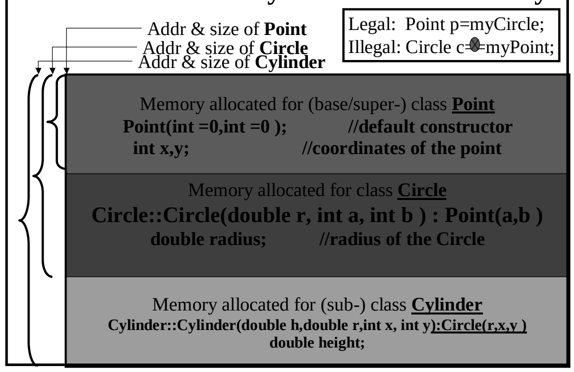
```
           //Driver for class Cylinder
//use set functions to change the Cylinder's attributes
cyl.setHeight(10 );  cyl.setRadius(4.25 );   cyl.setPoint(2,2 );

cout <<"The new location,radius,and height of cyl are:\n"<<cyl <<endl;
cout  << "The area of cyl is:\n“  << cyl.area() << endl;

//display the Cylinder as a Point
Point &pRef =cyl;              //    pRef   "thinks“   it is a Point
cout <<"\nCylinder printed as a Point is:"<<pRef <<"\n \n";

//display the Cylinder as a Circle
Circle &circleRef =cyl;       //   circleRef  “thinks” it is a Circle
cout <<"Cylinder printed as a Circle is:\n"<<circleRef
        <<"\nArea:"<<circleRef.area()<<endl;
return 0;
}        // end of main()
```

Inheritance: Point, Circle, Cylinder

//Output of main() driver

X coordinate is 12
Y coordinate is 23
Radius is 2.5
Height is 5.7
The new location, radius, and height of cyl are:
Center =[2,2];Radius =4.25;Height =10.00
The area of cyl is:
380.53
Cylinder printed as a Point is:[2,2]
Cylinder printed as a Circle is:
Center =[2,2];Radius =4.25
Area:56.74

Point → Circle → Cylinder Class hierarchy



Inheritance

So far, we have discussed single inheritance in which each class is derived from exactly one base class.

A class may be derived from more than one base class; such derivation is called *multiple inheritance* .

Multiple inheritance means that a derived class inherits the members of several base classes. This powerful capability encourages interesting forms of software reuse, but can cause a variety of ambiguity problems.

Go to polymorphism, sec. 15.2, slide 52.

Sub- Classes (1 of 6)

- There is a hierarchy for classifying employees.
- We may think of employees in terms of:
- A general class of employee, of which there is
  - A subset of employees that are paid an hourly wage
  - A subset of employees that are paid a fixed wage

  (Employee subsets such as administrative, permanent, temporary, part-time, or a catch-all "other" may be added.)
- A notion of general employee may not be *essential* to the program but it can be useful in thinking about the program.
- All kinds of employees have names, employee numbers, and perhaps member functions that are the same.

Sub- Classes (2 of 6)

- These can be put into the base class so each of these is inherited by other classes derived from the general employee class.
- We define an undifferentiated class Employee (Display 15.1) to enable definition of derived classes for different kinds of employees.
- The reason for an (undifferentiated) base class Employee is to encapsulate the common behavior and data for all employees so we can derive classes for different employees from this.
- Each derived class inherits all member functions of the base class Employee: `print_check, get_name, change_name, give_raise,` and so on.
- Each derived class (re)defines the functions `print_check` and give_raise in a way that is meaningful for an employee of that class.

Sub- Classes (3 of 6)

- It makes little sense to call the base class Employee `print_check` function, so it is implemented to display an error message and stop the program.
- A class that is derived from class Employee will automatically have the data members of the class Employee: (`name, ssn, net_pay`).
- Notice there is the keyword `protected` where you may be accustomed to seeing `private`.
- A `protected` member is the same as `private` to any function that is except a member function of a class derived from the base class (or a class that is derived from a class derived from the base class, that is by any chain of derivations).

Sub- Classes (4 of 6)

- A sub-class inherits all data members and all function members of the super-class. The `public` members of the base class are accessible to any function. The `protected` members are directly accessible by any function that is a member of any class derived directly or indirectly by an inheritance chain from the super-class, regardless of length.
- Interface files for classes derived from class Employee are given in Display 15.3 (`HourlyEmployee`) and in Display 15.4 (`SalariedEmployee`).
- Because these classes are related, we have placed them in one namespace.

25

Display 15.1 Interface for the Base Class Employee (1 of 2)

```
//This is primarily intended to be used as a base class to derive
//classes for different kinds of employees.
#ifndef EMPLOYEE_H
#define EMPLOYEE_H
#include <string>
using namespace std;
namespace savitchemployees
{   class Employee
   { public:
      Employee( );
      Employee(string new_name, string new_ssn);
      string get_name( );
      string get_ssn( );
      void change_name(string new_name);
      void change_ssn(string new_ssn);
      void print_check( );
      void give_raise(double amount);
```

Display 15.1 Interface for the Base Class Employee (2 of 2)

```
   protected:
      string name;
      string ssn;
      double net_pay;
   };

} //   savitchemployees

#endif //EMPLOYEE_H
```

27

Display 15.2 Implementation for the Base Class Employee (1 of 3)

```
#include <iostream>
#include <string>
#include <cstdlib>
#include "employee.h"
using namespace std;

namespace savitchemployees
{   Employee::Employee( ) // default is to fetch data from keyboard
   {   cout << "Enter employee name, followed by return.:\n";
      getline(cin, name);
      cout << endl << "Enter employee social security number,"
           << " followed by return.:\n";
      getline(cin, ssn);
      cin.ignore(10000, '\n');
      cout << endl;
   }
```

8

Display 15.2 Implementation for the Base Class Employee (2 of 3)

```
Employee::Employee(string new_name, string new_number) :
          name(new_name), ssn(new_number) //initializer list
{
   //deliberately empty
}
string Employee::get_name( )
{    return name;    }
string Employee::get_ssn( )
{      return ssn;   }
 void Employee::change_name(string new_name)
{    name = new_name;    }
```

Display 15.2 Implementation for the Base Class Employee (3 of 3)

```
void Employee::change_ssn (string new_ssn)
 {    ssn = new_ssn;  }
 void Employee::print_check( )
 {  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);
 }
 void Employee::give_raise(double amount)
 {  cout << "\nERROR: give_raise FUNCTION CALLED FOR AN \n"
         << "UNDIFFERENTIATED EMPLOYEE. Aborting the program.\n"
         << "Check with the author of the program about this bug.\n";
    exit(1);
 }
}//savitchemployees
```

Sub- Classes (5 of 6)

- Interface files for classes derived from class Employee are given in Display 15.3 (`HourlyEmployee`) and in Display 15.4 (`SalariedEmployee`).
- These classes are related so they are placed in one namespace.
- Syntax for inheritance:
  class HourlyEmployee : *public* Employee
  { ... };
- The definition of a sub-class begins in the usual way: with the keyword *class*, followed by the name of the class.
- Then there is a colon separator, followed by an access specifier *public*, then the name of the super-class, Employee.
- This is called public inheritance. There is private and protected inheritance as well, but we will not deal with that in this course.

31

Display 15.3 Interface for the Derived Class HourlyEmployee (1 of 2)

```
#ifndef HOURLYEMPLOYEE_H
#define HOURLYEMPLOYEE_H
#include <string>
#include "employee.h"
using namespace std;

namespace savitchemployees
{
  class HourlyEmployee : public Employee
  { public:
    HourlyEmployee( );
    HourlyEmployee(string new_name, string new_ssn,
                   double new_wage_rate, double new_hours);
    void set_rate(double new_wage_rate);
    double get_rate( );
    void set_hours(double hours_worked);
    double get_hours( );
    void give_raise(double amount);
    void print_check( );
```

32

Display 15.3 Interface for the Derived Class HourlyEmployee (2 of 2)

```
   private:
    double wage_rate;
    double hours;
  };

}  //    savitchemployees

#endif //HOURLYMPLOYEE_H
```

33

Display 15.4 Interface for Sub-Class SalariedEmployee (1 of 2)

```
#ifndef SALARIEDEMPLOYEE_H
#define SALARIEDMPLOYEE_H
#include <string>
#include "employee.h"
using namespace std;


namespace savitchemployees
{
  class SalariedEmployee : public Employee
  { public:
    SalariedEmployee( );
    SalariedEmployee (string new_name,  string new_ssn,
                      double new_weekly_salary);
    double get_salary( );
    void change_salary(double new_salary);
    void print_check( );
    void give_raise(double amount);
```

34

Display 15.4 Interface for Derived Class SalariedEmployee (2 of 2)

```
  private:
     double salary;//weekly
  };

}  //    savitchemployees

#endif //SALARIEDEMPLOYEE_H
```

35

Sub-Classes (6 of 6)

- The definition of class HourlyEmployee does not mention member variables name and net_pay, nor is there any need to do so. These variables along with the super-class's member functions are automatically supplied by inheritance.
- When a sub-class is defined, all prototypes of *new* member functions must be given. For example, in class HourlyEmployee the prototype for the replacement for print_check must be given.
- You do *not* give the prototypes of *inherited* member functions that are *not* being replaced when a derived class is defined.

36

Sub-Classes (7 of 7)

Inherited Members

A derived class automatically has all the functions and member variables of the base class. These members from the base class are said to be inherited. These inherited member functions and inherited member variables are not mentioned in the definition of the derived class, but they are automatically member of the derived class. (As we will see, you do mention an inherited member function in the definition of the derived class if you want to change the definition of the inherited member function.)

37

An Object of a Sub-Class is also an Object of the Super-Class

In everyday experience an hourly employee is an employee. In C++ the same sort of thing holds. Since HourlyEmployee is a derived class of class Employee, every object of the class HourlyEmployee can be used any place a class Employee can be used. In particular, you can use an argument of type HourlyEmployee when a function requires an argument of type Employee. You can assign an object of class HourlyEmployee to a variable of type Employee. (But be warned: You cannot assign a plain old Employee object to a variable of type HourlyEmployee. After all, an Employee object is not necessarily an HourlyEmployee.) Of course, the same remarks apply to any base class and its derived class. You can use an object of a derived class any place that an object of its base class is allowed.

This relationship between a derived class and its base class is often referred to as the "Is-A" relationship. An HourlyEmployee *is an* Employee.

38

Constructor Base Initialization List (1 of 3)

- When we use inheritance, the inherited members must be initialized as well as new variables defined in the derived class.
- When defining a constructor you can initialize member variables in a base initialization list.
- The base initialization list is part of the heading of the constructor definition.

```
class Rational
{ public:
    Rational( );
    Rational(int t, int b);
    Rational(int w);
    // other members
  private:
    int top;
    int bottom;
};
```

39

Constructor Base Initialization List (2 of 3)

- The base initialization list AS part of the heading of the constructor definition.

```
Rational::Rational( ): top(0), bottom(0)
{ /* empty body */ }
Rational::Rational(int t, int b): top(t), bottom(b)
{ /* empty body */ }
Rational::Rational(int w): top(w), bottom(1)
{ /* empty body */ }
```

- These examples illustrate the rule: The initialization goes in the constructor implementation header following a colon that in turn follows the parenthesis that closes the parameter list, and before the opening brace of the function block.
- The initialization list is a comma separated list of initializers.
- The initializers consist of the name of the member variable with its initializing value enclosed in parentheses.

40

Constructor Base Initialization List (3 of 3)

- These examples recall an alternate initialization we discussed briefly in Chapter 2 for simple variables:

  int x(2); is a variant of int x = 2;

- There need not be an initialization section, but when we define a derived class constructor, most of the time we must invoke a base class constructor to initialize the inherited variables.
- Use of initializer lists in constructor is a good practice, and will help you in some obscure cases where you *must* use initializer lists. (See the footnote on page 849 of the text.)
- There are times when the logic necessary to confirm that a constructor's argument is legal will be difficult or impossible to squeeze into the parentheses of in an initializer. Place such logic in the body of the constructor.

41

Constructors in Derived Classes (1 of 2)

- A constructor for a derived class uses the constructor for the base class to initialize the inherited data members.
- A derived class constructor calls the base class constructor first. The call is placed in the implementation.
- An example of a constructor for a derived class is illustrated in Display 15.5.
- The syntax for invoking a base class constructor is:

```
HourlyEmployee::HourlyEmployee() : Employee()
{
  //code for the default HourlyEmployee initialization.
}
```

- The portion, `: Employee()`, is the initialization section for the default constructor call to initialize the inherited data members.
- Always include a call to the super-class constructor in the initialization section of sub-class constructor.

42

Review, Thursday, Aug. 02, 2001
PIC 10 B

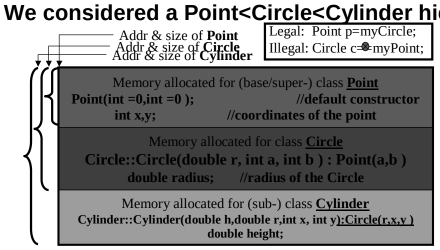
- We considered a Point<Circle<Cylinder hierarchy.

```
ostream &operator<<(ostream &output, const Circle &c )
{    output <<"Center ="<< static_cast<Point >(c ) <<
        "; Radius =“ <<setiosflags(ios::fixed |ios::showpoint )
         <<setprecision(2 ) << c.radius;
        return output;                    //enables cascaded calls
}
class Cylinder : public Circle {
        public:    //default constructor
                Cylinder(double h =0.0,double r =0.0, int x =0,int y =0 );
                void setHeight(double );                //set height
                double getHeight()const;                //return height
                double area();                  //calculate and return area
                double volume();                //calculate and return volume
        protected:
                double height;                  //height of the Cylinder
};
```

43

Review, Thursday, Aug. 02, 2001
PIC 10 B

- We considered a Point<Circle<Cylinder hierarchy.



- Employee and HourlyEmployee/SalariedEmployee class organization

44

Review, Thursday, Aug. 02, 2001
PIC 10 B

You can assign an object of class HourlyEmployee to a variable of type Employee. But you cannot assign a plain Employee object to a variable of type HourlyEmployee.
HourlyEmployee is an Employee
but is Employee not an HourlyEmployee.)

- base initialization list.
  Rational::Rational(int t, int b): top(t), bottom(b)
  { /* empty body */ }
- Heterogeneous Linked Lists: See online class notes for examples.

45

Constructors in Derived Classes (2 of 2)

- This is the parameterized constructor for HourlyEmployee constructor.

```
HourlyEmployee::
HourlyEmployee(string new_name, string new_number,
               double new_wage_rate, double new_hours)
    : Employee(new_name, new_number),
      wage_rate(new_wage_rate), hours(new_hours)
{
    // deliberately empty.
 }
```

- Notice that all the work of the constructor is done in the initializer list, so the body is empty.
- It is good practice to comment a deliberately empty block.

46

Display 15.5 Implementations for the Derived Class HourlyEmployee (1 of 3)

```
#include <iostream>
#include <string>
#include "hourlyemployee.h"
using namespace std;

namespace savitchemployees
{   HourlyEmployee::HourlyEmployee( ) : Employee( )
   {  cout << "Enter HourlyEmployee wage rate, followed by return.:\n";
      cin >> wage_rate;
      cout << "Enter number of hours worked, followed by return:\n";
      cin >> hours;
   }

   HourlyEmployee::HourlyEmployee(string new_name, string new_number,
        double new_wage_rate, double new_hours) : Employee(new_name,
          new_number), wage_rate(new_wage_rate), hours(new_hours)
   {
          //        deliberately empty
   }
```

47

Display 15.5 Implementations for the Derived Class HourlyEmployee (2 of 3)

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

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

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

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

48

Display 15.5 Implementations for the Derived Class HourlyEmployee (3 of 3)

```
void HourlyEmployee::give_raise( double amount)
{   wage_rate = wage_rate + amount;   }
void HourlyEmployee::print_check( )
{  net_pay = hours * wage_rate;
   cout << "\n_____________________________________________\n";
   cout << "Pay to the order of " << name << endl;
   cout << "The sum of        " << net_pay << " Dollars\n";
   cout << "_____________________________________________\n";
   cout << "Check Stub: NOT NEGOTIABLE\n";
   cout << "Employee Number: " << ssn << endl;
   cout << "Hourly Employee. \nHours worked: " << hours
        << " Rate: " << wage_rate << " Pay: " << net_pay << endl;
   cout << "_____________________________________________\n";
 }
}  //    savitchemployees
```

49

The `protected` Qualifier

- We used the keyword `protected` where you might expect to see `private`.
- A `protected` member is the same as `private` to any function that is except a member function of a class derived from the base class (or a class that is derived from a class derived from the base class, that is by any chain of derivations).
- The meaning of the `protected` qualifier is illustrated in the definition of the function `print_check` of the derived class `HourlyEmployee` in Display 15.5.
- The inherited member variables `net_pay`, `name` and `ssn` are marked `protected` in the base class, these variables can be accessed by name in the definition of member functions of all derived classes.
- If the inherited members had been marked `private` in the base class definition, direct use of these variables in the derived class would be illegal.

50

Redefinition of Member Functions (1 of 2)

- In HourlyEmployee we gave prototypes for the *new* member functions `set_rate`, `get_rate`, `set_hours`, and `get_hours`.
- We gave prototypes for some but not all member functions inherited from class Employee.
- The inherited member functions whose prototypes were not given have the same definition in the derived class HourlyEmployee as they do in the base class Employee.
- The only prototypes from the base class that are included in the derived class are the functions whose definitions are to be changed in the derived class definition.
- The class HourlyEmloyee gave new definitions for `print_check` and `give_raise`, definitions that are different from the base class definitions.
- We say that the functions, `print_check` and `give_raise` are redefined (like overloading, but not quite) in the sub-class.

51

Redefinition of Member Functions (2 of 2)

- We can derive another class for company officers from SalariedEmployee, which itself is a class derived from Employee.
- A class that does nothing more than add a title is possible.
- The only changes needed are
  - a change in constructor to add set the new information
  - redefinition of change_name to insert a title.
- All other member functions are inherited unchanged from the base class SalariedEmployee, and its base class, Employee.

52

Redefining an Inherited Function

A derived class inherits all of the member function (and data members as well) that belong to the base class. However, if a derived class requires a different implementation for an inherited member function, the function may be redefined in the derived class. When a member function is redefined, you must list its prototype in the definition of the derived class, even though the prototype is the same as in the base class. If you do not wish to redefine a member function that is inherited from the base class, then it is listed in the definition of the derived class.

Display 15.7 Using Derived Classes

```
#include <iostream>
#include "hourlyemployee.h"
#include "salariedemployee.h"
using namespace std;
using namespace savitchemployees;

int main( )
{  cout << "Data for hourly employee \n";
   HourlyEmployee h;
   cout  << "Check for " << h.get_name( )
         << " for " << h.get_hours( ) << " hours.\n";
   h.print_check( );
   SalariedEmployee doc("Doc Adams", "345-12-3456", 1234.45);
   cout << "Check for " << doc.get_name( ) << endl;
   doc.print_check( );
   return 0;
}
```

54

Redefining versus Overloading (1 of 2)

- Do not confuse **redefinition** with **overloading**.
- When you redefine a function, the new function given in the derived class has the exact same number and types of parameters.
- By contrast, suppose that in the derived class, there is a (new) function with the same name, but a different number of parameters or a different sequence of parameter types (or both).
- Then the derived class will have access to both functions.
- This is an example of **overloading**.
- Overloading is defined on page 158, in Chapter 3.
- If this prototype had been added to class HourlyEmployee:
  void change_name(string first_name, string last_name);
- The class HourlyEmployee would have this function *and* the inherited function as well:
  void change_name(string new_name);

55

Redefining versus Overloading (2 of 2)

- By contrast, both the base class Employee and the derived class HourlyEmployee have the prototype
  void print_check( );
- The derived class HourlyEmployee has *only* the one function named print _check, namely the one provided in the implementation of HourlyEmployee.
- print_check has been **redefined**.

Signature

A function's signature is the function's name with the sequence of types in the parameter list, including things like the *const* keyword. When you redefine a function, the function in the base class and the redefined function in the derived class have the same signature. If a function has the same name in a derive class as in the base class, but has a different signature, that is overloading not redefinition.

56

15.2 Polymorphism

- The term polymorphism is made up of "poly", meaning many; "morph", meaning form; and "ism", an action suffix. The most general meaning of the term is "having many forms".
- In the most general sense in programming, the word refers to the association of multiple meanings with one function name.
- Polymorphism is also used in a more restrictive sense.
- When used in this more restrictive sense, overloading refers to the ability to associate multiple meanings with one function name by means of the mechanism of *late binding.*
- Remember, in C++, the *name of a function* is more than just the function identifier. In C++, the name of a function is the function's *identifier* together with the *sequence of types in the parameter list*.
- Polymorphism is more than conventional function identifier overloading.

57

Late Binding (1 of 4)

- A virtual function is a function that, in some sense, may be used prior to definition.
- Consider a graphics program that has several kinds of figures: rectangles, circle, ovals, etc.
- There is a base class Figure.
- Each figure might be an object of a different class, derived from class Figure:
  - A rectangle class has width, breadth and center point.
  - An oval class has a large width, a short width and center point.
  - A circle class has a radius and center point.
- Each of these classes needs a draw member function, and each implemented differently.
- What does this have to do with "virtual functions" and use before definition?

58

Late Binding (2 of 4)

- The class Figure may have functions that apply to all figures.
- Suppose Figure has a member function Figure::center that moves a figure to the center of the screen by two steps:
  - erasing the existing figure,
  - redrawing the figure at the center of the screen
- The Figure::center member function uses the draw function to to redraw the figure at the center.
- Suppose the class Figure is already written. In some later time we add a class for a new kind of figure, perhaps Triangle.
- Triangle is a derived class of base class Figure.
- The member function center is inherited by each derived class from base class Figure, and should perform correctly for all Triangle class objects.
- We have some trouble here. Why?

59

Late Binding (3 of 4)

- There is trouble here. Why?
- The inherited function center (unless something special is done) will use the definition of draw in class Figure, and that version of draw won't work for Triangle figures.
- We want the inherited function draw to use Triangle::draw, not Figure::draw.
- However, class Triangle and Triangle::draw were not written at the time Figure was written.
- If the function draw is declared virtual (abstract) function in class Figure, then things work correctly. How?
- By declaring a member function virtual in a super-class, we are telling the compiler to wait until this function is used in a program to decide what implementation to use.
- This is called late binding or dynamic binding.

60

Late Binding (4 of 4)

- Technically:
  - Late or dynamic binding is carried out with a table, called the virtual table, that is hidden from the programmer.
  - If you have a virtual function for which there is no implementation, you may get an error message that mentions a virtual table.
  - When a derived class needs a virtual base class function, the system decides at run time which of several available functions to use.
  - We will show how the system makes these decisions later.

61

Virtual Functions in C++ (1 of 5)

- In an automobile parts store point of sales program:
- We cannot account for all possible types of sales but
- We want to make the program versatile enough to be sure it is possible to account for all possibilities in the future.
- Initially, there are only retail sales of single parts.
- Later we include support for
  - volume discount,
  - mail order sales that include shipping costs
- This version must report the sum of gross sales daily.
- Additional features intended for the future:
  - the largest and smallest sales, and
  - average
- The additional features these can be computed from individual sales.

62

Display 15.8 Interface for Base Class Sale

```
#ifndef SALE_H
#define SALE_H
#include <iostream>
using namespace std;
namespace savitchsale
{
  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.
}   //    savitchsale
#endif // SALE_H
```

63

Display 15.9 Implementation of the Base Class Sale

```
#include "sale.h"

namespace savitchsale
{   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( ));    }
}//savitchsale
```

Virtual Functions in C++ (2 of 5)

- Only a stub, bill(), for comparing sales will be provided to allow delay of implementation until types of sales are known.
- To enable this, the sales computation function will be virtual.
- Display 15.8 contains the interface and Display 15.9 contains the implementation for the base class `Sale`.
- In 15.8, the keyword virtual is used with the prototype of the function `bill`.
- In 15.9, both the member function savings and the overloaded operator < use the function `bill`.
- The function `bill` is declared to be virtual, <u>we can define derived classes of the class `Sale` each of which defines its own versions of the function `bill`.</u>
- The version of `bill` in the derived classes will use the version of `savings`, and overloaded `operator<` that correspond to the object of the derived class.

65

Virtual Functions in C++ (3 of 5)

- Display 15.10 shows a derived class <u>`DiscountSale`</u>.
- The `class DiscountSale` requires a new definition for the function `bill`.
- The function `savings` and `operator<` will use the *new* version of `bill` given with `DiscountSale`.
- Note that the new version of the function `bill` <u>had not been written</u> at the time the functions `savings` and `operator<` were written.
- How can these functions know to use the `DiscountSale` version of `bill`?
- In C++ you assume that it happens automatically.
- When you define a function to be virtual, you are telling the C++ environment to create the necessary machinery so it can wait until the program is being run to decide how to get the correct implementation.

66

Virtual Functions in C++ (4 of 5)

- Display 15.11 contains a sample program illustrating how the virtual function `bill` and the functions that use `bill` work in a complete program.
- Some useful technical details:

1. If a function will have a different definition in a derived class than in the base class, and you want it to be a `virtual` function, you place the `virtual` keyword in front of the function prototype in the base class.
2. The property of being `virtual` is inherited. That means if the base class declares a function to be `virtual`, then a function with the same signature in a derived class will automatically be `virtual`. (It is a good practice to use the `virtual` keyword on function the derived class that are already virtual, though this is not required.)
3. The `virtual` keyword is used in the prototype (in the class) but not in the function definition.
4. You do not get a `virtual` function and you do not get the benefits of a `virtual` function unless you use the keyword `virtual`.

67

Display 15.10 The Derived Class DiscountSale (1 of 2)

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

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

Display 15.10 The Derived Class DiscountSale (2 of 2)

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

namespace savitchsale
{   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;
    }
}   //    savitchsale
```

Display 15.11 Use of a Virtual Function

```
#include <iostream>
#include "sale.h"                    //Not really needed, but safe due to ifndef.
#include "discountsale.h"
using namespace std;
using namespace savitchsale;
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)           // compares 2 obj's of type Sale
    {   cout << "Discounted item is cheaper.\n";
        cout << "Savings is $" << simple.savings(discount) << endl;
    }
    else    cout << "Discounted item is not cheaper.\n";
    return 0;
}
```

70

Virtual Functions in C++ (5 of 5)

- Some languages make all functions `virtual` .
- Why doesn't C++ do that?
- There is a small but significant cost in the use of virtual functions.
- A C++ design rule says

"If you don't use a feature, you don't pay for that feature."

- C++ provides both late binding (at a cost) with `virtual` functions and early binding (at no cost) for functions that are not.
- Rule: Use `virtual` functions only when you need them.

71

Overriding

When a function definition is changed in a derived class, programmers often say the function definition is overridden. In C++ literature a distinction is made between the terms ***redefined*** and ***overridden***. Both terms refer to changing the definition of the function in a derived class. If the function is a virtual function then this is called *overriding*. If the function is not a virtual function then it is called a *redefinition*.

This may seem silly -- a distinction without a difference, but these *are* treated differently by the compiler: One case, virtual functions and overriding, involves significant overhead while the other, redefinition, does not.

72

Polymorphism

The term polymorphism is made up of "poly", meaning many; "morph", meaning form; and "ism", an action suffix. The most general meaning of the term is "having many forms". In the most general sense in programming, the word refers to the association of multiple meanings with one function name.

Polymorphism is also used in a more restrictive sense. When used in this more restrictive sense, overloading refers to the <u>ability to associate multiple meanings with one function name by means of the mechanism of *late binding*</u>.

Remember, in C++, the *name of a function* is more than just the function identifier. In C++, the name of a function is the function's *identifier* together with the *sequence of types in the parameter list*.

Polymorphism is more than conventional function identifier overloading.

When we use polymorphism in the more restricted sense, polymorphism, late binding, and virtual functions all really are the same topic.

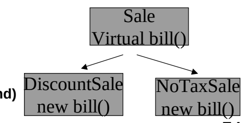
73

Review, Monday, Aug. 06, 2001
PIC 10 B

- Redefining (same function signature) vs. Overloading (diff. Signature) functions
- Polymorphism - <u>association of multiple meanings with one function name</u>.

- By declaring a member function virtual in a super-class, we are telling the compiler to place it in a virtual-table & <u>wait</u> until this function is used in a program to decide what implementation to use.

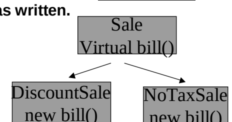
```
class Sale
{ ....
  virtual double bill( ) const;
   ....
};
bool operator < (Sale &first, Sale &second)
{   return (first.bill( ) < second.bill( ));   }
```



74

Review, Monday, Aug. 06, 2001
PIC 10 B

- Note that the new version of the function `bill()` <u>had not been written</u> at the time the `operator<` was written.
- <u>Some useful technical details</u>:



1. The `virtual` keyword in front of the function prototype in the base class.
2. The property of being `virtual` is inherited. That means if the base class declares a function to be `virtual`, then a function with the same signature in a derived class will <u>automatically</u> be `virtual`.
3. The `virtual` keyword is used in the prototype (in the class) <u>but not</u> in the function definition.
4. You do not get a `virtual` function and you do not get the benefits of a `virtual` function unless you use the keyword `virtual`.
5. There is a cost in the use of virtual functions. So, use `virtual` functions only when you need them.

75

Virtual Functions and Extended Type Compatibility (1 of 5)

- Further consequences of declaring a class member function to be virtual and one example of use of some of these features follows:
- C++ is ***strongly typed*** but relaxes this by providing <u>automatic casts</u>, called coercion, enabling assignment of a value of one type to variable of another type, such as `int` to `double`.
- On the other hand, you cannot assign a `double` to any of the integer types (`int`, `char`, `short`, `long`).
- However, <u>strong typing prevents assignments between base and derived class objects</u>.

76

Virtual Functions and Extended Type Compatibility (2 of 5)

- Consider the declarations:

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

class Dog : public Pet
{ public:
   virtual void print( ); // virtual not needed, but
                 // provides  clarity and is good style
    string breed;
};
Dog vdog;
Pet vpet;
```

77

Virtual Functions and Extended Type Compatibility (3 of 5)

- We concentrate on data members name and breed.
- Note that this is an example. In a real example, the data would be private or protected, and functions would be provided to manipulate them.
- Anything that is a `Dog` is also a `Pet`. Thus these assignments should be reasonable and legal.

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

- This is legal, but there are problems. <u>The breed field is lost</u>. The variable `vpet` has type Pet, and only members of `Pet` are available to the object `vpet`, regardless of what was assigned to it. This is the "slicing problem". Here is an attempted access and an error message:

```
cout << vpet.breed;
       //Error: class Pet has no member named breed.
```

78

Virtual Functions and Extended Type Compatibility (4 of 5)

- It is arguable that this is reasonable, that vpet should be an ordinary Pet object though it was set from a Dog of type Pet.
- Interesting discussion -- but little assistance with programming.
- The dog is named Tiny, it is a Great Dane, and we would like for it to retain its breed even if we treat it as a Pet along the way.
- C++ provides a mechanism to treat Dog as a Pet without slicing away the derived class attributes of breed and the member function associated with class Dog. Consider the declarations:

```
Pet *ppet;
Dog *pdog;
```

- Using pointers and dynamic variables we can treat Tiny as a Pet yet keep the breed:

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

79

Virtual Functions and Extended Type Compatibility (5 of 5)

- We can still access the `breed` data member of the node pointed to by `ppet`, but not directly:
- Suppose `Dog::print( );`
- is defined:

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

The statement

```
ppet→print();            // (*ppet).print();
```

will cause the following to be printed:

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

by virtue of the fact that `print()` is a `virtual` member of `Pet` and `Dog`.

80

Bottom line: The Slicing Problem

- It is legal to assign a derived class object to a base class variable, because such an assignment slices off data belonging exclusively to the derived class object.
- Any data members in the derived class but not in the base class will be lost in the assignment and any member functions that are not defined in the base class are similarly unavailable to the resulting base class object.
- If we make the assignments
  - Dog vdog;
  - Pet vpet;
  - vdog.name = "Tiny";
  - vdog.breed = "Great Dane";
  - vpet = vdog;

  then vpet cannot be a calling object for a member function introduced in Dog, and the data member Dog::breed is lost.
- Why? The base class doesn't know about derived class extensions made in the inheritance process.

81

Pitfall: Not Using `virtual` Member Functions(1 of 3)

- To get the benefit of extended type compatibility discussed in above, you must use `virtual` member functions.
- Example: If we have not used `virtual` member functions in Display 15.7, and suppose in place of

```
ppet→print( );
```

  we had used

```
cout  << "name: " << ppet → name
      << " breed: " << ppet → breed << endl;
```

- This would have precipitated an error message to the effect that there is no member variable breed for an object of class Pet.
- The type of the variable `ppet` pointer to class Pet, thus the expression `*ppet` has type class Pet, which has no member variable `breed`.

82

Pitfall: Not Using `virtual` Member Functions(2 of 3)

- The function, `print( )` was declared `virtual` in class Pet, so when the system sees the call

```
ppet→print( );
```

  it looks in the `virtual` table for classes Pet and Dog, sees that ppet points to an object of type Dog, and calls the function

```
Dog::print( )
```

  instead of

```
Pet::print( )
```

83

Pitfall: Not Using `virtual` Member Functions(3 of 3)

- Object oriented programming with dynamic variables is very different way of viewing programming. This can be bewildering.
- These rules will help:

> 1. If the domain type of a pointer p_ancestor is a base class for the domain type of the pointer p_descendant, then the following assignment of pointers is allowed:
>
> ```
> p_ancestor = p_descendant; // POINTER assignment!!!
> ```
>
> Moreover, none of the data members or member functions of the dynamic variable being pointed to by p_descendant will be lost.
>
> 2. Although all the extra fields of the dynamic variable are there, you will need virtual member functions to access them.

84

Pitfall: Attempting to Compile Class Definitions without the Definitions for Every Virtual Member Function (1 of 2)

- We have advocated developing incrementally. This means code a little and test a little, then code a little more then test some more. Usually, you can ignore implementations of member functions you do not call.
- This is definitely not the case for virtual member functions.
- An attempt to compile a program with a class that has even one virtual function that does not have an implementation, results in some very hard-to-understand error messages, even if you do not call the undefined member functions!
- An error message that one compiler gives is
  "undefined reference to Class_Name virtual table."
- Such an error message results even if there is no derived class and there is only one virtual member, but that member is not defined.

85

Pitfall: Attempting to Compile Class Definitions without the Definitions for Every Virtual Member Function (2 of 2)

- It gets worse: For the functions declared virtual, there will be further error messages complaining about an undefined reference to a default constructor, even if these constructors are already defined.
- The moral is clear: You should implement all virtual functions prior to compiling, even if it is just a dummy, as in

```
class A
{  public:
     // constructors
       virtual void foo( );
     // the rest of the class members
};
void A::foo( )
{ // dummy implementation to prevent hard to understand
  // error messages.
}
```

86

Summary

- Inheritance provides a tool for code reuse by deriving one class from another, adding features to the derived.
- Derived class object inherit all the members of the base class, and may add members.
- Late binding means that the decision of which version of a member function is appropriate is decided at runtime. Virtual functions are what C++ uses to achieve late binding.
- A *protected* member in the base class is directly available to a publicly derived class's member functions.

87