Lesson 10 - Chapter 11 Object-Oriented Programming: Inheritance

C++ How to Program, 9/e

OBJECTIVES

In this chapter you'll learn:

- What inheritance is and how it promotes software reuse.
- The notions of base classes and derived classes and the relationships between them.
- The `protected` member access specifier.
- The use of constructors and destructors in inheritance hierarchies.
- The order in which constructors and destructors are called in inheritance hierarchies.
- The differences between `public`, `protected` and `private` inheritance.
- To use inheritance to customize existing software.

11.1 Introduction

- Inheritance is a form of software reuse in which you create a class that absorbs an existing class's data and behaviors and enhances them with new capabilities.
- You can designate that the new class should inherit the members of an existing class.
- This existing class is called the base class, and the new class is referred to as the derived class.
- A derived class represents a *more specialized* group of objects.
- C++ offers `public`, `protected` and `private` inheritance.
- *With `public` inheritance, every object of a derived class is also an object of that derived class's base class.*
- However, base-class objects are not objects of their derived classes.

11.1 Introduction (cont.)

- With object-oriented programming, you focus on the commonalities among objects in the system rather than on the special cases.
- We distinguish between the *is-a* relationship and the *has-a* relationship.
- The *is-a* relationship represents inheritance.
- In an *is-a* relationship, an object of a derived class also can be treated as an object of its base class.
- By contrast, the *has-a* relationship represents composition.

11.2 Base Classes and Derived Classes

- Figure 11.1 lists several simple examples of base classes and derived classes.
  - Base classes tend to be *more general* and derived classes tend to be *more specific*.
- Because every derived-class object *is an* object of its base class, and one base class can have *many* derived classes, the set of objects represented by a base class typically is *larger* than the set of objects represented by any of its derived classes.
- Inheritance relationships form class hierarchies.

11.2 Base Classes and Derived Classes (cont.)

- A base class exists in a hierarchical relationship with its derived classes.
- Although classes can exist independently, once they're employed in inheritance relationships, they become affiliated with other classes.
- A class becomes either a base class—supplying members to other classes, a derived class—inheriting its members from other classes, or *both*.

Base class	Derived classes
Student	GraduateStudent, UndergraduateStudent
Shape	Circle, Triangle, Rectangle, Sphere, Cube
Loan	CarLoan, HomeImprovementLoan, MortgageLoan
Employee	Faculty, Staff
Account	CheckingAccount, SavingsAccount

Fig. 11.1 | Inheritance examples.

11.2 Base Classes and Derived Classes (cont.)

CommunityMember Class Hierarchy

- Let's develop a simple inheritance hierarchy with five levels (represented by the UML class diagram in Fig. 11.2).
- A university community has thousands of `CommunityMember`s.
- `Employee`s are either `Faculty` or `Staff`.
- `Faculty` are either `Administrator`s or `Teacher`s.
- Some `Administrator`s, however, are also `Teacher`s.
- We've used *multiple inheritance* to form class `AdministratorTeacher`.

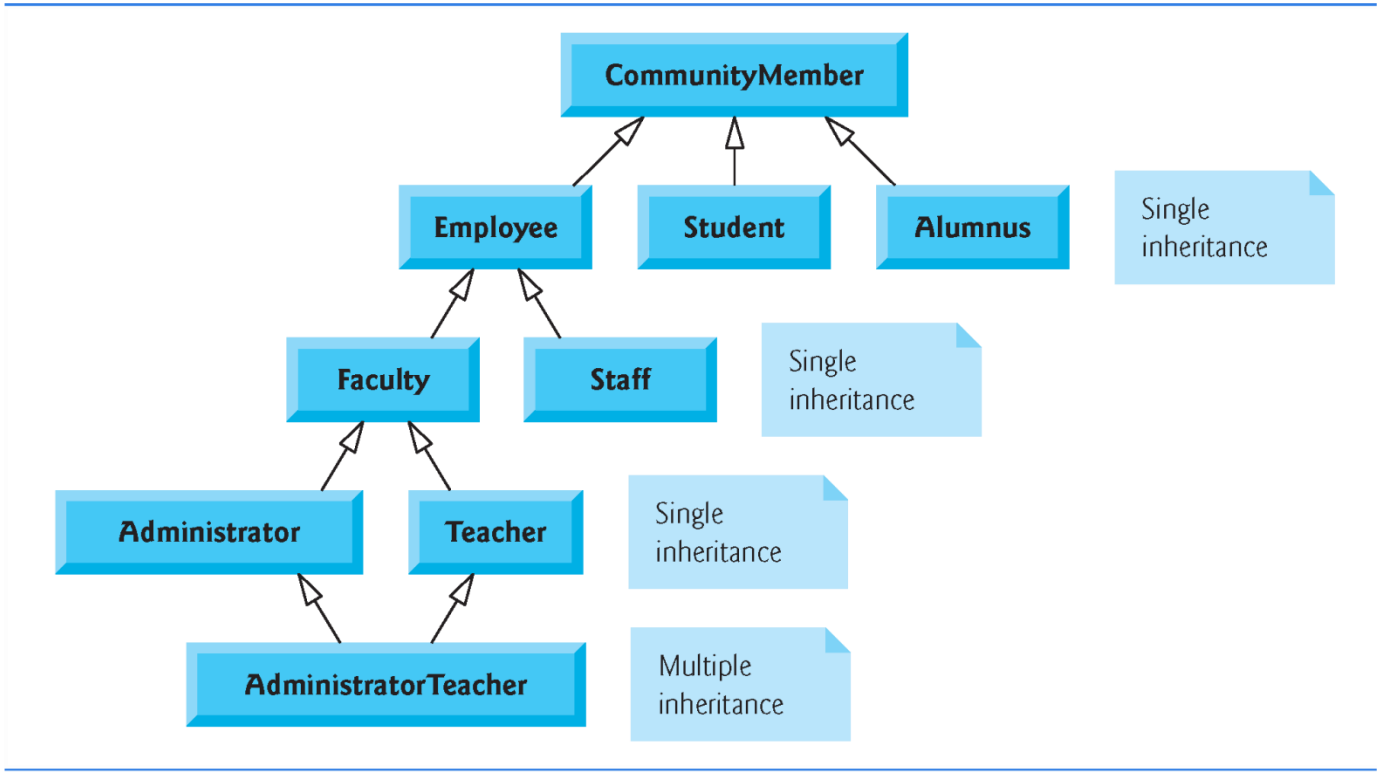
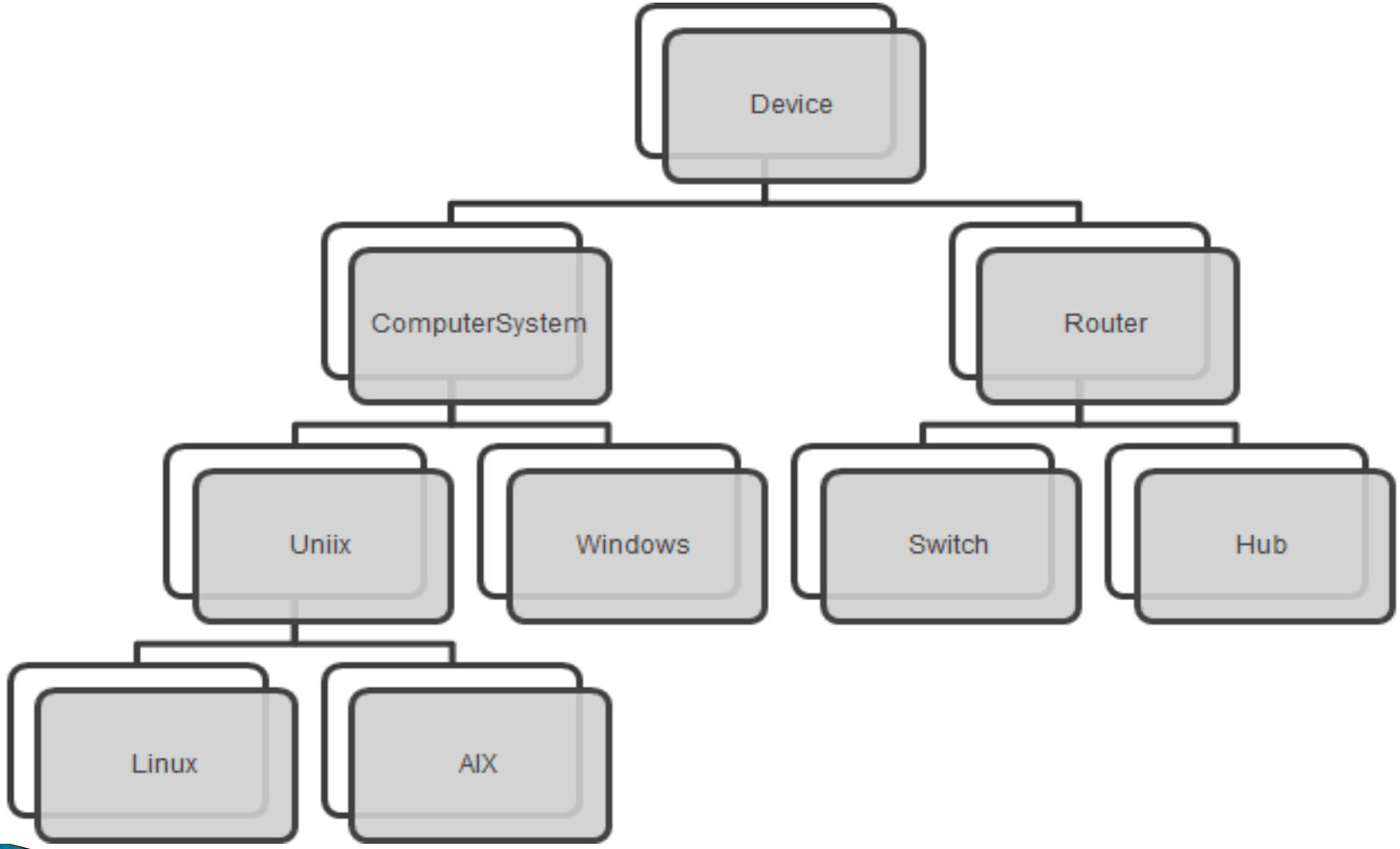


Fig. 11.2 | Inheritance hierarchy for university `CommunityMembers`.

Computer System Inheritance



11.2 Base Classes and Derived Classes (cont.)

- With single inheritance, a class is derived from *one* base class.
- With multiple inheritance, a derived class inherits simultaneously from *two or more* (possibly unrelated) base classes.
  - We discuss multiple inheritance in Chapter 23, Other Topics.

11.2 Base Classes and Derived Classes (cont.)

- Each arrow in the hierarchy (Fig. 11.2) represents an *is-a relationship*.
  - As we follow the arrows in this class hierarchy, we can state "an `Employee` *is a* `CommunityMember`" and "a `Teacher` *is a* `Faculty` member."
  - `CommunityMember` is the direct base class of `Employee`, `Student` and `Alumnus`.
  - `CommunityMember` is an indirect base class of all the other classes in the diagram.
- Starting from the bottom of the diagram, you can follow the arrows and apply the *is-a* relationship to the topmost base class.
  - An `AdministratorTeacher` *is an* `Administrator`, *is a* `Faculty` member, *is an* `Employee` and *is a* `CommunityMember`.

11.2 Base Classes and Derived Classes (cont.)

Shape Class Hierarchy

- Consider the `Shape` inheritance hierarchy in Fig. 11.3.
- Begins with base class `Shape`.
- Classes `TwoDimensionalShape` and `ThreeDimensionalShape` derive from base class `Shape`—`Shape`s are either `TwoDimensionalShape`s or `Three-DimensionalShape`s.
- The third level of this hierarchy contains some more specific types of `TwoDimensionalShape`s and `ThreeDimensionalShape`s.
- As in Fig. 11.2, we can follow the arrows from the bottom of the diagram to the topmost base class in this class hierarchy to identify several *is-a* relationships.

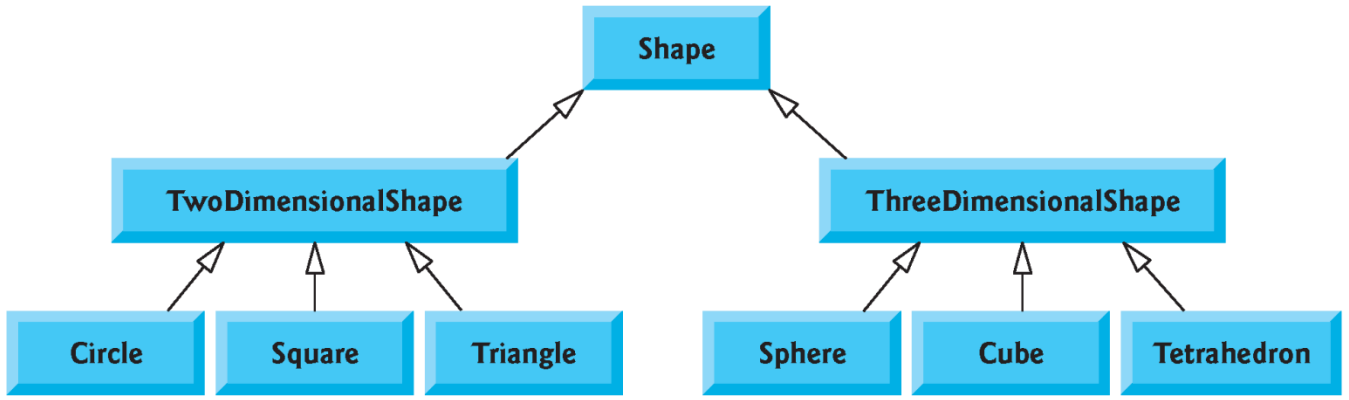


Fig. 11.3 | Inheritance hierarchy for Shapes.

11.3 Relationship between Base and Derived Classes

- In this section, we use an inheritance hierarchy containing types of employees in a company's payroll application to discuss the relationship between a base class and a derived class.
- Commission employees (who will be represented as objects of a base class) are paid a percentage of their sales, while base-salaried commission employees (who will be represented as objects of a derived class) receive a base salary plus a percentage of their sales.

11.3.1 Creating and Using a `CommissionEmployee` Class

- `CommissionEmployee`'s class definition (Figs. 11.4–11.5).
- `CommissionEmployee`'s `public` services include a constructor and member functions `earnings` and `print`.
- Also includes `public` *get* and *set* functions that manipulate the class's data members `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate`.
  - These data members are `private`, so objects of other classes cannot directly access this data.
  - Declaring data members as `private` and providing non-`private` *get* and *set* functions to manipulate and validate the data members helps enforce good software engineering.

```
1  // Fig. 11.4: CommissionEmployee.h
2  // CommissionEmployee class definition represents a commission employee.
3  #ifndef COMMISSION_H
4  #define COMMISSION_H
5
6  #include <string> // C++ standard string class
7
8  class CommissionEmployee
9  {
10 public:
11    CommissionEmployee( const std::string &, const std::string &,
12       const std::string &, double = 0.0, double = 0.0 );
13
14    void setFirstName( const std::string & ); // set first name
15    std::string getFirstName() const; // return first name
16
17    void setLastName( const std::string & ); // set last name
18    std::string getLastName() const; // return last name
19
20    void setSocialSecurityNumber( const std::string & ); // set SSN
21    std::string getSocialSecurityNumber() const; // return SSN
22
23    void setGrossSales( double ); // set gross sales amount
24    double getGrossSales() const; // return gross sales amount
```

Fig. 11.4 | CommissionEmployee class header. (Part 1 of 2.)

```
25
26      void setCommissionRate( double ); // set commission rate (percentage)
27      double getCommissionRate() const; // return commission rate
28
29      double earnings() const; // calculate earnings
30      void print() const; // print CommissionEmployee object
31   private:
32      std::string firstName;
33      std::string lastName;
34      std::string socialSecurityNumber;
35      double grossSales; // gross weekly sales
36      double commissionRate; // commission percentage
37   }; // end class CommissionEmployee
38
39   #endif
```

Fig. 11.4 | CommissionEmployee class header. (Part 2 of 2.)

```
1  // Fig. 11.5: CommissionEmployee.cpp
2  // Class CommissionEmployee member-function definitions.
3  #include <iostream>
4  #include <stdexcept>
5  #include "CommissionEmployee.h" // CommissionEmployee class definition
6  using namespace std;
7
8  // constructor
9  CommissionEmployee::CommissionEmployee(
10    const string &first, const string &last, const string &ssn,
11    double sales, double rate )
12 {
13    firstName = first; // should validate
14    lastName = last; // should validate
15    socialSecurityNumber = ssn; // should validate
16    setGrossSales( sales ); // validate and store gross sales
17    setCommissionRate( rate ); // validate and store commission rate
18 } // end CommissionEmployee constructor
19
```

Fig. 11.5 | Implementation file for `CommissionEmployee` class that represents an employee who is paid a percentage of gross sales. (Part 1 of 5.)

```
20  // set first name
21  void CommissionEmployee::setFirstName( const string &first )
22  {
23     firstName = first; // should validate
24  } // end function setFirstName
25
26  // return first name
27  string CommissionEmployee::getFirstName() const
28  {
29     return firstName;
30  } // end function getFirstName
31
32  // set last name
33  void CommissionEmployee::setLastName( const string &last )
34  {
35     lastName = last; // should validate
36  } // end function setLastName
37
```

Fig. 11.5 | Implementation file for `CommissionEmployee` class that represents an employee who is paid a percentage of gross sales. (Part 2 of 5.)

```
38   // return last name
39   string CommissionEmployee::getLastName() const
40   {
41      return lastName;
42   } // end function getLastName
43
44   // set social security number
45   void CommissionEmployee::setSocialSecurityNumber( const string &ssn )
46   {
47      socialSecurityNumber = ssn; // should validate
48   } // end function setSocialSecurityNumber
49
50   // return social security number
51   string CommissionEmployee::getSocialSecurityNumber() const
52   {
53      return socialSecurityNumber;
54   } // end function getSocialSecurityNumber
55
```

Fig. 11.5 | Implementation file for `CommissionEmployee` class that represents an employee who is paid a percentage of gross sales. (Part 3 of 5.)

```
56  // set gross sales amount
57  void CommissionEmployee::setGrossSales( double sales )
58  {
59     if ( sales >= 0.0 )
60        grossSales = sales;
61     else
62        throw invalid_argument( "Gross sales must be >= 0.0" );
63  } // end function setGrossSales
64
65  // return gross sales amount
66  double CommissionEmployee::getGrossSales() const
67  {
68     return grossSales;
69  } // end function getGrossSales
70
71  // set commission rate
72  void CommissionEmployee::setCommissionRate( double rate )
73  {
74     if ( rate > 0.0 && rate < 1.0 )
75        commissionRate = rate;
76     else
77        throw invalid_argument( "Commission rate must be > 0.0 and < 1.0" );
78  } // end function setCommissionRate
```

Fig. 11.5 | Implementation file for `CommissionEmployee` class that represents an employee who is paid a percentage of gross sales. (Part 4 of 5.)

```
79
80  // return commission rate
81  double CommissionEmployee::getCommissionRate() const
82  {
83     return commissionRate;
84  } // end function getCommissionRate
85
86  // calculate earnings
87  double CommissionEmployee::earnings() const
88  {
89     return commissionRate * grossSales;
90  } // end function earnings
91
92  // print CommissionEmployee object
93  void CommissionEmployee::print() const
94  {
95     cout << "commission employee: " << firstName << ' ' << lastName
96        << "\nsocial security number: " << socialSecurityNumber
97        << "\ngross sales: " << grossSales
98        << "\ncommission rate: " << commissionRate;
99  } // end function print
```

Fig. 11.5 | Implementation file for `CommissionEmployee` class that represents an employee who is paid a percentage of gross sales. (Part 5 of 5.)

11.3.1 Creating and Using a `CommissionEmployee` Class (cont.)

`CommissionEmployee` Constructor

- The `CommissionEmployee` constructor definition *purposely does not use member-initializer syntax* in the first several examples of this section, so that we can demonstrate how `private` and `protected` specifiers affect member access in derived classes.
  - Later in this section, we'll return to using member-initializer lists in the constructors.

11.3.1 Creating and Using a CommissionEmployee Class (cont.)

CommissionEmployee* Member Functions *earnings* and *print

- Member function `earnings` calculates a `CommissionEmployee`'s earnings.
- Member function `print` displays the values of a `CommissionEmployee` object's data members.

Testing Class CommissionEmployee

- Figure 11.6 tests class `CommissionEmployee`.

```
1  // Fig. 11.6: fig11_06.cpp
2  // CommissionEmployee class test program.
3  #include <iostream>
4  #include <iomanip>
5  #include "CommissionEmployee.h" // CommissionEmployee class definition
6  using namespace std;
7
8  int main()
9  {
10    // instantiate a CommissionEmployee object
11    CommissionEmployee employee(
12       "Sue", "Jones", "222-22-2222", 10000, .06 );
13
14    // set floating-point output formatting
15    cout << fixed << setprecision( 2 );
16
17    // get commission employee data
18    cout << "Employee information obtained by get functions: \n"
19       << "\nFirst name is " << employee.getFirstName()
20       << "\nLast name is " << employee.getLastName()
21       << "\nSocial security number is "
22       << employee.getSocialSecurityNumber()
23       << "\nGross sales is " << employee.getGrossSales()
24       << "\nCommission rate is " << employee.getCommissionRate() << endl;
```

Fig. 11.6 | CommissionEmployee class test program. (Part 1 of 3.)

```
25
26      employee.setGrossSales( 8000 ); // set gross sales
27      employee.setCommissionRate( .1 ); // set commission rate
28
29      cout << "\nUpdated employee information output by print function: \n"
30         << endl;
31      employee.print(); // display the new employee information
32
33      // display the employee's earnings
34      cout << "\n\nEmployee's earnings: $" << employee.earnings() << endl;
35   } // end main
```

Fig. 11.6 | CommissionEmployee class test program. (Part 2 of 3.)

```
Employee information obtained by get functions:

First name is Sue
Last name is Jones
Social security number is 222-22-2222
Gross sales is 10000.00
Commission rate is 0.06

Updated employee information output by print function:

commission employee: Sue Jones
social security number: 222-22-2222
gross sales: 8000.00
commission rate: 0.10

Employee's earnings: $800.00
```

Fig. 11.6 | `CommissionEmployee` class test program. (Part 3 of 3.)

11.3.2 Creating a `BasePlusCommissionEmployee` Class Without Using Inheritance

- We now discuss the second part of our introduction to inheritance by creating and testing (a completely new and independent) class `BasePlusCommissionEmployee` (Figs. 11.7–11.8), which contains a first name, last name, social security number, gross sales amount, commission rate *and* base salary.

```
1  // Fig. 11.7: BasePlusCommissionEmployee.h
2  // BasePlusCommissionEmployee class definition represents an employee
3  // that receives a base salary in addition to commission.
4  #ifndef BASEPLUS_H
5  #define BASEPLUS_H
6
7  #include <string> // C++ standard string class
8
9  class BasePlusCommissionEmployee
10 {
11 public:
12    BasePlusCommissionEmployee( const std::string &, const std::string &,
13       const std::string &, double = 0.0, double = 0.0, double = 0.0 );
14
15    void setFirstName( const std::string & ); // set first name
16    std::string getFirstName() const; // return first name
17
18    void setLastName( const std::string & ); // set last name
19    std::string getLastName() const; // return last name
20
21    void setSocialSecurityNumber( const std::string & ); // set SSN
22    std::string getSocialSecurityNumber() const; // return SSN
23
```

Fig. 11.7 | BasePlusCommissionEmployee class header. (Part 1 of 2.)

```
24      void setGrossSales( double ); // set gross sales amount
25      double getGrossSales() const; // return gross sales amount
26
27      void setCommissionRate( double ); // set commission rate
28      double getCommissionRate() const; // return commission rate
29
30      void setBaseSalary( double ); // set base salary
31      double getBaseSalary() const; // return base salary
32
33      double earnings() const; // calculate earnings
34      void print() const; // print BasePlusCommissionEmployee object
35  private:
36      std::string firstName;
37      std::string lastName;
38      std::string socialSecurityNumber;
39      double grossSales; // gross weekly sales
40      double commissionRate; // commission percentage
41      double baseSalary; // base salary
42  }; // end class BasePlusCommissionEmployee
43
44  #endif
```

Fig. 11.7 | BasePlusCommissionEmployee class header. (Part 2 of 2.)

```
1  // Fig. 11.8: BasePlusCommissionEmployee.cpp
2  // Class BasePlusCommissionEmployee member-function definitions.
3  #include <iostream>
4  #include <stdexcept>
5  #include "BasePlusCommissionEmployee.h"
6  using namespace std;
7
8  // constructor
9  BasePlusCommissionEmployee::BasePlusCommissionEmployee(
10    const string &first, const string &last, const string &ssn,
11    double sales, double rate, double salary )
12 {
13    firstName = first; // should validate
14    lastName = last; // should validate
15    socialSecurityNumber = ssn; // should validate
16    setGrossSales( sales ); // validate and store gross sales
17    setCommissionRate( rate ); // validate and store commission rate
18    setBaseSalary( salary ); // validate and store base salary
19 } // end BasePlusCommissionEmployee constructor
20
```

Fig. 11.8 | BasePlusCommissionEmployee class represents an employee who receives a base salary in addition to a commission. (Part 1 of 6.)

```
21   // set first name
22   void BasePlusCommissionEmployee::setFirstName( const string &first )
23   {
24      firstName = first; // should validate
25   } // end function setFirstName
26
27   // return first name
28   string BasePlusCommissionEmployee::getFirstName() const
29   {
30      return firstName;
31   } // end function getFirstName
32
33   // set last name
34   void BasePlusCommissionEmployee::setLastName( const string &last )
35   {
36      lastName = last; // should validate
37   } // end function setLastName
38
```

Fig. 11.8 | `BasePlusCommissionEmployee` class represents an employee who receives a base salary in addition to a commission. (Part 2 of 6.)

```
39  // return last name
40  string BasePlusCommissionEmployee::getLastName() const
41  {
42     return lastName;
43  } // end function getLastName
44
45  // set social security number
46  void BasePlusCommissionEmployee::setSocialSecurityNumber(
47     const string &ssn )
48  {
49     socialSecurityNumber = ssn; // should validate
50  } // end function setSocialSecurityNumber
51
52  // return social security number
53  string BasePlusCommissionEmployee::getSocialSecurityNumber() const
54  {
55     return socialSecurityNumber;
56  } // end function getSocialSecurityNumber
57
```

Fig. 11.8 | `BasePlusCommissionEmployee` class represents an employee who receives a base salary in addition to a commission. (Part 3 of 6.)

```
58  // set gross sales amount
59  void BasePlusCommissionEmployee::setGrossSales( double sales )
60  {
61     if ( sales >= 0.0 )
62        grossSales = sales;
63     else
64        throw invalid_argument( "Gross sales must be >= 0.0" );
65  } // end function setGrossSales
66
67  // return gross sales amount
68  double BasePlusCommissionEmployee::getGrossSales() const
69  {
70     return grossSales;
71  } // end function getGrossSales
72
73  // set commission rate
74  void BasePlusCommissionEmployee::setCommissionRate( double rate )
75  {
76     if ( rate > 0.0 && rate < 1.0 )
77        commissionRate = rate;
78     else
79        throw invalid_argument( "Commission rate must be > 0.0 and < 1.0" );
80  } // end function setCommissionRate
```

Fig. 11.8 | `BasePlusCommissionEmployee` class represents an employee who receives a base salary in addition to a commission. (Part 4 of 6.)

```
81
82  // return commission rate
83  double BasePlusCommissionEmployee::getCommissionRate() const
84  {
85     return commissionRate;
86  } // end function getCommissionRate
87
88  // set base salary
89  void BasePlusCommissionEmployee::setBaseSalary( double salary )
90  {
91     if ( salary >= 0.0 )
92        baseSalary = salary;
93     else
94        throw invalid_argument( "Salary must be >= 0.0" );
95  } // end function setBaseSalary
96
97  // return base salary
98  double BasePlusCommissionEmployee::getBaseSalary() const
99  {
100    return baseSalary;
101 } // end function getBaseSalary
102
```

Fig. 11.8 | `BasePlusCommissionEmployee` class represents an employee who receives a base salary in addition to a commission. (Part 5 of 6.)

```
103 // calculate earnings
104 double BasePlusCommissionEmployee::earnings() const
105 {
106    return baseSalary + ( commissionRate * grossSales );
107 } // end function earnings
108
109 // print BasePlusCommissionEmployee object
110 void BasePlusCommissionEmployee::print() const
111 {
112    cout << "base-salaried commission employee: " << firstName << ' '
113       << lastName << "\nsocial security number: " << socialSecurityNumber
114       << "\ngross sales: " << grossSales
115       << "\ncommission rate: " << commissionRate
116       << "\nbase salary: " << baseSalary;
117 } // end function print
```

Fig. 11.8 | `BasePlusCommissionEmployee` class represents an employee who receives a base salary in addition to a commission. (Part 6 of 6.)

11.3.2 Creating a `BasePlusCommissionEmployee` Class Without Using Inheritance (cont.)

Defining Class `BasePlusCommissionEmployee`

- The `BasePlusCommissionEmployee` header (Fig. 11.7) specifies class `BasePlusCommissionEmployee`'s `public` services, which include the `BasePlusCommissionEmployee` constructor and member functions `earnings` and `print`.
- Lines 15–31 declare `public` *get* and *set* functions for the class's `private` data members `firstName`, `lastName`, `socialSecurityNumber`, `grossSales`, `commissionRate` *and* `baseSalary`.

11.3.2 Creating a `BasePlusCommissionEmployee` Class Without Using Inheritance (cont.)

- Note the similarity between this class and class `Commission-Employee` (Figs. 11.4–11.5)—in this example, we won't yet exploit that similarity.
- Class `BasePlusCommissionEmployee`'s `earnings` member function computes the earnings of a base-salaried commission employee.

Testing Class `BasePlusCommissionEmployee`

- Figure 11.9 tests class `BasePlusCommissionEmployee`.

```
1  // Fig. 11.9: fig11_09.cpp
2  // BasePlusCommissionEmployee class test program.
3  #include <iostream>
4  #include <iomanip>
5  #include "BasePlusCommissionEmployee.h"
6  using namespace std;
7
8  int main()
9  {
10    // instantiate BasePlusCommissionEmployee object
11    BasePlusCommissionEmployee
12       employee( "Bob", "Lewis", "333-33-3333", 5000, .04, 300 );
13
14    // set floating-point output formatting
15    cout << fixed << setprecision( 2 );
16
17    // get commission employee data
18    cout << "Employee information obtained by get functions: \n"
19       << "\nFirst name is " << employee.getFirstName()
20       << "\nLast name is " << employee.getLastName()
21       << "\nSocial security number is "
22       << employee.getSocialSecurityNumber()
23       << "\nGross sales is " << employee.getGrossSales()
24       << "\nCommission rate is " << employee.getCommissionRate()
25       << "\nBase salary is " << employee.getBaseSalary() << endl;
```

Fig. 11.9 | BasePlusCommissionEmployee class test program. (Part 1 of 3.)

```
26
27      employee.setBaseSalary( 1000 ); // set base salary
28
29      cout << "\nUpdated employee information output by print function: \n"
30         << endl;
31      employee.print(); // display the new employee information
32
33      // display the employee's earnings
34      cout << "\n\nEmployee's earnings: $" << employee.earnings() << endl;
35   } // end main
```

Fig. 11.9 | BasePlusCommissionEmployee class test program. (Part 2 of 3.)

```
Employee information obtained by get functions:

First name is Bob
Last name is Lewis
Social security number is 333-33-3333
Gross sales is 5000.00
Commission rate is 0.04
Base salary is 300.00

Updated employee information output by print function:

base-salaried commission employee: Bob Lewis
social security number: 333-33-3333
gross sales: 5000.00
commission rate: 0.04
base salary: 1000.00

Employee's earnings: $1200.00
```

Fig. 11.9 | BasePlusCommissionEmployee class test program. (Part 3 of 3.)

11.3.2 Creating a `BasePlusCommissionEmployee` Class Without Using Inheritance (cont.)

Exploring the Similarities Between Class `BasePlusCommissionEmployee` and Class `CommissionEmployee`

- Most of the code for class `BasePlusCommissionEmployee` (Figs. 11.7–11.8) is similar, if not identical, to the code for class `CommissionEmployee` (Figs. 11.4–11.5).
- In class `BasePlusCommissionEmployee`, `private` data members `firstName` and `lastName` and member functions `setFirstName`, `getFirstName`, `setLastName` and `getLastName` are identical to those of class `CommissionEmployee`.
- Both classes contain `private` data members `socialSecurityNumber`, `commissionRate` and `grossSales`, as well as *get* and *set* functions to manipulate these members.

11.3.2 Creating a `BasePlusCommissionEmployee` Class Without Using Inheritance (cont.)

- The `BasePlusCommissionEmployee` constructor is *almost* identical to that of class `CommissionEmployee`, except that `BasePlusCommissionEmployee`'s constructor also sets the `baseSalary`.
- The other additions to class `BasePlusCommissionEmployee` are `private` data member `baseSalary` *and* member functions `setBaseSalary` and `getBaseSalary`.
- Class `BasePlusCommissionEmployee`'s `print` member function is *nearly identical* to that of class `CommissionEmployee`, except that `BasePlusCommissionEmployee`'s `print` also outputs the value of data member `baseSalary`.

11.3.2 Creating a `BasePlusCommissionEmployee` Class Without Using Inheritance (cont.)

- We literally *copied* code from class `CommissionEmployee` and *pasted* it into class `BasePlusCommissionEmployee`, then modified class `BasePlusCommissionEmployee` to include a base salary and member functions that manipulate the base salary.
- This *copy-and-paste approach* is error prone and time consuming.
- Worse yet, it can spread many physical copies of the same code throughout a system, creating a code-maintenance nightmare.

Software Engineering Observation 11.1

Copying and pasting code from one class to another can spread many physical copies of the same code and can spread errors throughout a system, creating a code-maintenance nightmare. To avoid duplicating code (and possibly errors), use inheritance, rather than the "copy-and-paste" approach, in situations where you want one class to "absorb" the data members and member functions of another class.

Software Engineering Observation 11.2

With inheritance, the common data members and member functions of all the classes in the hierarchy are declared in a base class. When changes are required for these common features, you need to make the changes only in the base class—derived classes then inherit the changes. Without inheritance, changes would need to be made to all the source code files that contain a copy of the code in question.

11.3.3 Creating a CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy

- Now we create and test a new `BasePlusCommissionEmployee` class (Figs. 11.10–11.11) that derives from class `CommissionEmployee` (Figs. 11.4–11.5).
- In this example, a `BasePlusCommissionEmployee` object *is a* `CommissionEmployee` (because inheritance passes on the capabilities of class `CommissionEmployee`), but class `BasePlusCommissionEmployee` also has data member `baseSalary` (Fig. 11.10, line 22).
- The colon (`:`) in line 10 of the class definition indicates inheritance.
- Keyword `public` indicates the *type of inheritance*.
- As a derived class (formed with `public` inheritance), `BasePlusCommissionEmployee` inherits all the members of class `CommissionEmployee`, except for the constructor—each class provides its own constructors that are specific to the class.

11.3.3 Creating a CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy (cont.)

- Destructors, too, are not inherited
- Thus, the `public` services of `BasePlusCommissionEmployee` include its constructor and the `public` member functions inherited from class *`CommissionEmployee`—although we cannot see these inherited member functions* in `BasePlusCommissionEmployee`'s source code, they're nevertheless a part of derived class `BasePlusCommissionEmployee`.
- The derived class's `public` services also include member functions `setBaseSalary`, `getBaseSalary`, `earnings` and `print`.

```
1  // Fig. 11.10: BasePlusCommissionEmployee.h
2  // BasePlusCommissionEmployee class derived from class
3  // CommissionEmployee.
4  #ifndef BASEPLUS_H
5  #define BASEPLUS_H
6
7  #include <string> // C++ standard string class
8  #include "CommissionEmployee.h" // CommissionEmployee class declaration
9
10 class BasePlusCommissionEmployee : public CommissionEmployee
11 {
12 public:
13    BasePlusCommissionEmployee( const std::string &, const std::string &,
14       const std::string &, double = 0.0, double = 0.0, double = 0.0 );
15
16    void setBaseSalary( double ); // set base salary
17    double getBaseSalary() const; // return base salary
18
```

Fig. 11.10 | BasePlusCommissionEmployee class definition indicating inheritance relationship with class CommissionEmployee. (Part 1 of 2.)

```
19      double earnings() const; // calculate earnings
20      void print() const; // print BasePlusCommissionEmployee object
21   private:
22      double baseSalary; // base salary
23   }; // end class BasePlusCommissionEmployee
24
25   #endif
```

Fig. 11.10 | `BasePlusCommissionEmployee` class definition indicating inheritance relationship with class `CommissionEmployee`. (Part 2 of 2.)

```
1  // Fig. 11.11: BasePlusCommissionEmployee.cpp
2  // Class BasePlusCommissionEmployee member-function definitions.
3  #include <iostream>
4  #include <stdexcept>
5  #include "BasePlusCommissionEmployee.h"
6  using namespace std;
7
8  // constructor
9  BasePlusCommissionEmployee::BasePlusCommissionEmployee(
10    const string &first, const string &last, const string &ssn,
11    double sales, double rate, double salary )
12    // explicitly call base-class constructor
13    : CommissionEmployee( first, last, ssn, sales, rate )
14 {
15    setBaseSalary( salary ); // validate and store base salary
16 } // end BasePlusCommissionEmployee constructor
17
```

Fig. 11.11 | BasePlusCommissionEmployee implementation file: `private` base-class data cannot be accessed from derived class. (Part 1 of 4.)

```
18  // set base salary
19  void BasePlusCommissionEmployee::setBaseSalary( double salary )
20  {
21     if ( salary >= 0.0 )
22        baseSalary = salary;
23     else
24        throw invalid_argument( "Salary must be >= 0.0" );
25  } // end function setBaseSalary
26
27  // return base salary
28  double BasePlusCommissionEmployee::getBaseSalary() const
29  {
30     return baseSalary;
31  } // end function getBaseSalary
32
33  // calculate earnings
34  double BasePlusCommissionEmployee::earnings() const
35  {
36     // derived class cannot access the base class's private data
37     return baseSalary + ( commissionRate * grossSales );
38  } // end function earnings
39
```

Fig. 11.11 | BasePlusCommissionEmployee implementation file: `private` base-class data cannot be accessed from derived class. (Part 2 of 4.)

```
40  // print BasePlusCommissionEmployee object
41  void BasePlusCommissionEmployee::print() const
42  {
43     // derived class cannot access the base class's private data
44     cout << "base-salaried commission employee: " << firstName << ' '
45        << lastName << "\nsocial security number: " << socialSecurityNumber
46        << "\ngross sales: " << grossSales
47        << "\ncommission rate: " << commissionRate
48        << "\nbase salary: " << baseSalary;
49  } // end function print
```

Fig. 11.11 | `BasePlusCommissionEmployee` implementation file: `private` base-class data cannot be accessed from derived class. (Part 3 of 4.)

Compilation Errors from the LLVM Compiler in Xcode 4.5

```
BasePlusCommissionEmployee.cpp:37:26:
   'commissionRate' is a private member of 'CommissionEmployee'
BasePlusCommissionEmployee.cpp:37:43:
   'grossSales' is a private member of 'CommissionEmployee'
BasePlusCommissionEmployee.cpp:44:53:
   'firstName' is a private member of 'CommissionEmployee'
BasePlusCommissionEmployee.cpp:45:10:
   'lastName' is a private member of 'CommissionEmployee'
BasePlusCommissionEmployee.cpp:45:54:
   'socialSecurityNumber' is a private member of 'CommissionEmployee'
BasePlusCommissionEmployee.cpp:46:31:
   'grossSales' is a private member of 'CommissionEmployee'
BasePlusCommissionEmployee.cpp:47:35:
   'commissionRate' is a private member of 'CommissionEmployee'
```

Fig. 11.11 | `BasePlusCommissionEmployee` implementation file: `private` base-class data cannot be accessed from derived class. (Part 4 of 4.)

11.3.3 Creating a `CommissionEmployee`–`BasePlusCommissionEmployee` Inheritance Hierarchy (cont.)

- Figure 11.11 shows `BasePlusCommissionEmployee`'s member-function implementations.
- The constructor introduces base-class initializer syntax, which uses a member initializer to pass arguments to the base-class constructor.
- C++ requires that a derived-class constructor call its base-class constructor to initialize the base-class data members that are inherited into the derived class.
- If `BasePlusCommissionEmployee`'s constructor did not invoke class `CommissionEmployee`'s constructor *explicitly*, C++ would attempt to invoke class `CommissionEmployee`'s default constructor—but the class does not have such a constructor, so the compiler would issue an error.

Common Programming Error 11.1

When a derived-class constructor calls a base-class constructor, the arguments passed to the base-class constructor must be consistent with the number and types of parameters specified in one of the base-class constructors; otherwise, a compilation error occurs.

Performance Tip 11.1

In a derived-class constructor, invoking base-class constructors and initializing member objects explicitly in the member initializer list prevents duplicate initialization in which a default constructor is called, then data members are modified again in the derived-class constructor's body.

11.3.3 Creating a CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy (cont.)

Compilation Errors from Accessing Base-Class `private` Members

- The compiler generates errors for line 37 of Fig. 11.11 because base class `CommissionEmployee`'s data members `commissionRate` and `grossSales` are `private`—derived class `BasePlusCommissionEmployee`'s member functions are *not* allowed to access base class `CommissionEmployee`'s `private` data.
- We used red text in Fig. 11.11 to indicate erroneous code.
- The compiler issues additional errors in lines 44–47 of `BasePlus-Commission-Employee`'s `print` member function for the same reason.
- C++ rigidly enforces restrictions on accessing `private` data members, so that *even a derived class (which is intimately related to its base class) cannot access the base class's `private` data.*

11.3.3 Creating a `CommissionEmployee`–`BasePlusCommissionEmployee` Inheritance Hierarchy (cont.)

Preventing the Errors in `BasePlusCommissionEmployee`

- We purposely included the erroneous code in Fig. 11.11 to emphasize that a derived class's member functions cannot access its base class's `private` data.
- The errors in `BasePlusCommissionEmployee` could have been prevented by using the *get* member functions inherited from class `CommissionEmployee`.

11.3.3 Creating a CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy (cont.)

- For example, line 37 could have invoked `getCommissionRate` and `getGrossSales` to access `CommissionEmployee`'s `private` data members `commissionRate` and `grossSales`, respectively.
- Similarly, lines 44–47 could have used appropriate *get* member functions to retrieve the values of the base class's data members.

11.3.3 Creating a CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy (cont.)

Including the Base-Class Header in the Derived-Class Header with #include

- We `#include` the base class's header in the derived class's header (line 8 of Fig. 11.10).
- This is necessary for three reasons.
  - The derived class uses the base class's name in line 10, so we must tell the compiler that the base class exists.
  - The compiler uses a class definition to determine the size of an object of that class. A client program that creates an object of a class `#include`s the class definition to enable the compiler to reserve the proper amount of memory for the object.
  - The compiler must determine whether the derived class uses the base class's inherited members properly.

11.3.3 Creating a CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy (cont.)

Linking Process in an Inheritance Hierarchy

- In Section 3.7, we discussed the linking process for creating an executable `GradeBook` application.
- The linking process is similar for a program that uses classes in an inheritance hierarchy.
- The process requires the object code for all classes used in the program and the object code for the direct and indirect base classes of any derived classes used by the program.
- The code is also linked with the object code for any C++ Standard Library classes used in the classes or the client code.

11.3.4 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using protected Data

- In this section, we introduce the access specifier `protected`.
- To enable class `BasePlusCommissionEmployee` to *directly access* `CommissionEmployee` data members `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate`, we can declare those members as `protected` in the base class.
- A base class's `protected` members can be accessed within the body of that base class, by members and `friend`s of that base class, and by members and `friend`s of any classes derived from that base class.

11.3.4 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using protected Data (cont.)

Defining Base Class CommissionEmployee with protected Data

- Class `CommissionEmployee` (Fig. 11.12) now declares data members `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate` as `protected` (lines 31–36) rather than `private`.
- The member-function implementations are identical to those in Fig. 11.5.

```
1  // Fig. 11.12: CommissionEmployee.h
2  // CommissionEmployee class definition with protected data.
3  #ifndef COMMISSION_H
4  #define COMMISSION_H
5
6  #include <string> // C++ standard string class
7
8  class CommissionEmployee
9  {
10 public:
11    CommissionEmployee( const std::string &, const std::string &,
12       const std::string &, double = 0.0, double = 0.0 );
13
14    void setFirstName( const std::string & ); // set first name
15    std::string getFirstName() const; // return first name
16
17    void setLastName( const std::string & ); // set last name
18    std::string getLastName() const; // return last name
19
20    void setSocialSecurityNumber( const std::string & ); // set SSN
21    std::string getSocialSecurityNumber() const; // return SSN
22
```

Fig. 11.12 | `CommissionEmployee` class definition that declares `protected` data to allow access by derived classes. (Part 1 of 2.)

```
23      void setGrossSales( double ); // set gross sales amount
24      double getGrossSales() const; // return gross sales amount
25
26      void setCommissionRate( double ); // set commission rate
27      double getCommissionRate() const; // return commission rate
28
29      double earnings() const; // calculate earnings
30      void print() const; // print CommissionEmployee object
31   protected:
32      std::string firstName;
33      std::string lastName;
34      std::string socialSecurityNumber;
35      double grossSales; // gross weekly sales
36      double commissionRate; // commission percentage
37   }; // end class CommissionEmployee
38
39   #endif
```

Fig. 11.12 | `CommissionEmployee` class definition that declares `protected` data to allow access by derived classes. (Part 2 of 2.)

11.3.4 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using protected Data (cont.)

- `BasePlusCommissionEmployee` inherits from class `CommissionEmployee` in Fig. 11.12.
- Objects of class `BasePlusCommissionEmployee` can access inherited data members that are declared `protected` in class `CommissionEmployee` (i.e., data members `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate`).
- As a result, the compiler does *not* generate errors when compiling the `BasePlusCommissionEmployee` `earnings` and `print` member-function definitions in Fig. 11.11 (lines 34–38 and 41–49, respectively).
- Objects of a derived class also can access `protected` members in any of that derived class's *indirect* base classes.

11.3.4 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using protected Data (cont.)

Testing the Modified BasePlusCommissionEmployee Class

- To test the updated class hierarchy, we reused the test program from Fig. 11.9.
- As shown in Fig. 11.13, the output is identical to that of Fig. 11.9.
- The code for class `BasePlusCommissionEmployee`, which is 74 lines, is considerably shorter than the code for the noninherited version of the class, which is 161 lines, because the inherited version absorbs part of its functionality from `CommissionEmployee`, whereas the noninherited version does not absorb any functionality.
- Also, there is now only *one* copy of the `CommissionEmployee` functionality declared and defined in class `CommissionEmployee`.
  - Makes the source code easier to maintain, modify and debug.

```
Employee information obtained by get functions:

First name is Bob
Last name is Lewis
Social security number is 333-33-3333
Gross sales is 5000.00
Commission rate is 0.04
Base salary is 300.00

Updated employee information output by print function:

base-salaried commission employee: Bob Lewis
social security number: 333-33-3333
gross sales: 5000.00
commission rate: 0.04
base salary: 1000.00

Employee's earnings: $1200.00
```

Fig. 11.13 | `protected` base-class data can be accessed from derived class.

11.3.4 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using protected Data (cont.)

Notes on Using `protected` Data

- Inheriting `protected` data members slightly increases performance, because we can directly access the members without incurring the overhead of calls to *set* or *get* member functions.

Software Engineering Observation 11.3

In most cases, it's better to use `private` data members to encourage proper software engineering, and leave code optimization issues to the compiler. Your code will be easier to maintain, modify and debug.

11.3.4 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using protected Data (cont.)

- Using `protected` data members creates two serious problems.
  - The derived-class object does not have to use a member function to set the value of the base class's `protected` data member.
  - Derived-class member functions are more likely to be written so that they depend on the base-class implementation. Derived classes should depend only on the base-class services (i.e., non-`private` member functions) and not on the base-class implementation.
- With `protected` data members in the base class, if the base-class implementation changes, we may need to modify all derived classes of that base class.
- Such software is said to be fragile or brittle, because a small change in the base class can "break" derived-class implementation.

Software Engineering Observation 11.4

It's appropriate to use the `protected` access specifier when a base class should provide a service (i.e., a non-`private` member function) only to its derived classes and `friend`s.

Software Engineering Observation 11.5

Declaring base-class data members `private` (as opposed to declaring them `protected`) enables you to change the base-class implementation without having to change derived-class implementations.

11.3.5 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using private Data

- We now reexamine our hierarchy once more, this time using the best software engineering practices.
- Class `CommissionEmployee` now declares data members `firstName`, `lastName`, `socialSecurityNumber`, `grossSales` and `commissionRate` as `private` (as shown previously in lines 31–36 of Fig. 11.4).

11.3.5 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using private Data (cont.)

Changes to Class CommissionEmployee's Member Function Definitions

- In the `CommissionEmployee` constructor implementation (Fig. 11.14, lines 9–16), we use member initializers (line 12) to set the values of members `firstName`, `lastName` and `socialSecurityNumber`.
- We show how derived-class `BasePlusCommissionEmployee` (Fig. 11.15) can invoke non-`private` base-class member functions (`setFirstName`, `getFirstName`, `setLastName`, `getLastName`, `setSocialSecurityNumber` and `getSocialSecurityNumber`) to manipulate these data members.

```
1  // Fig. 11.14: CommissionEmployee.cpp
2  // Class CommissionEmployee member-function definitions.
3  #include <iostream>
4  #include <stdexcept>
5  #include "CommissionEmployee.h" // CommissionEmployee class definition
6  using namespace std;
7
8  // constructor
9  CommissionEmployee::CommissionEmployee(
10    const string &first, const string &last, const string &ssn,
11    double sales, double rate )
12    : firstName( first ), lastName( last ), socialSecurityNumber( ssn )
13 {
14    setGrossSales( sales ); // validate and store gross sales
15    setCommissionRate( rate ); // validate and store commission rate
16 } // end CommissionEmployee constructor
17
```

Fig. 11.14 | `CommissionEmployee` class implementation file: `CommissionEmployee` class uses member functions to manipulate its `private` data. (Part 1 of 6.)

```
18  // set first name
19  void CommissionEmployee::setFirstName( const string &first )
20  {
21     firstName = first; // should validate
22  } // end function setFirstName
23
24  // return first name
25  string CommissionEmployee::getFirstName() const
26  {
27     return firstName;
28  } // end function getFirstName
29
30  // set last name
31  void CommissionEmployee::setLastName( const string &last )
32  {
33     lastName = last; // should validate
34  } // end function setLastName
35
```

Fig. 11.14 | `CommissionEmployee` class implementation file: `CommissionEmployee` class uses member functions to manipulate its `private` data. (Part 2 of 6.)

```
36  // return last name
37  string CommissionEmployee::getLastName() const
38  {
39     return lastName;
40  } // end function getLastName
41
42  // set social security number
43  void CommissionEmployee::setSocialSecurityNumber( const string &ssn )
44  {
45     socialSecurityNumber = ssn; // should validate
46  } // end function setSocialSecurityNumber
47
48  // return social security number
49  string CommissionEmployee::getSocialSecurityNumber() const
50  {
51     return socialSecurityNumber;
52  } // end function getSocialSecurityNumber
53
```

Fig. 11.14 | `CommissionEmployee` class implementation file: `CommissionEmployee` class uses member functions to manipulate its `private` data. (Part 3 of 6.)

```
54  // set gross sales amount
55  void CommissionEmployee::setGrossSales( double sales )
56  {
57     if ( sales >= 0.0 )
58        grossSales = sales;
59     else
60        throw invalid_argument( "Gross sales must be >= 0.0" );
61  } // end function setGrossSales
62
63  // return gross sales amount
64  double CommissionEmployee::getGrossSales() const
65  {
66     return grossSales;
67  } // end function getGrossSales
68
```

Fig. 11.14 | `CommissionEmployee` class implementation file: `CommissionEmployee` class uses member functions to manipulate its `private` data. (Part 4 of 6.)

```
69  // set commission rate
70  void CommissionEmployee::setCommissionRate( double rate )
71  {
72     if ( rate > 0.0 && rate < 1.0 )
73        commissionRate = rate;
74     else
75        throw invalid_argument( "Commission rate must be > 0.0 and < 1.0" );
76  } // end function setCommissionRate
77
78  // return commission rate
79  double CommissionEmployee::getCommissionRate() const
80  {
81     return commissionRate;
82  } // end function getCommissionRate
83
84  // calculate earnings
85  double CommissionEmployee::earnings() const
86  {
87     return getCommissionRate() * getGrossSales();
88  } // end function earnings
89
```

Fig. 11.14 | `CommissionEmployee` class implementation file: `CommissionEmployee` class uses member functions to manipulate its `private` data. (Part 5 of 6.)

```
90  // print CommissionEmployee object
91  void CommissionEmployee::print() const
92  {
93     cout << "commission employee: "
94        << getFirstName() << ' ' << getLastName()
95        << "\nsocial security number: " << getSocialSecurityNumber()
96        << "\ngross sales: " << getGrossSales()
97        << "\ncommission rate: " << getCommissionRate();
98  } // end function print
```

Fig. 11.14 | `CommissionEmployee` class implementation file: `CommissionEmployee` class uses member functions to manipulate its `private` data. (Part 6 of 6.)

Performance Tip 11.2

Using a member function to access a data member's value can be slightly slower than accessing the data directly. However, today's optimizing compilers are carefully designed to perform many optimizations implicitly (such as inlining `set` and `get` member-function calls). You should write code that adheres to proper software engineering principles, and leave optimization to the compiler. A good rule is, "Do not second-guess the compiler."

11.3.5 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using private Data (cont.)

Changes to Class BasePlusCommissionEmployee's Member Function Definitions

- Class `BasePlusCommissionEmployee` has several changes to its member-function implementations (Fig. 11.15) that distinguish it from the previous version of the class (Figs. 11.10–11.11).
- Member functions `earnings` (Fig. 11.15, lines 34–37) and `print` (lines 40–48) each invoke `getBaseSalary` to obtain the base salary value.

```
1  // Fig. 11.15: BasePlusCommissionEmployee.cpp
2  // Class BasePlusCommissionEmployee member-function definitions.
3  #include <iostream>
4  #include <stdexcept>
5  #include "BasePlusCommissionEmployee.h"
6  using namespace std;
7
8  // constructor
9  BasePlusCommissionEmployee::BasePlusCommissionEmployee(
10    const string &first, const string &last, const string &ssn,
11    double sales, double rate, double salary )
12    // explicitly call base-class constructor
13    : CommissionEmployee( first, last, ssn, sales, rate )
14 {
15    setBaseSalary( salary ); // validate and store base salary
16 } // end BasePlusCommissionEmployee constructor
17
```

Fig. 11.15 | `BasePlusCommissionEmployee` class that inherits from class `CommissionEmployee` but cannot directly access the class's `private` data. (Part 1 of 3.)

```
18  // set base salary
19  void BasePlusCommissionEmployee::setBaseSalary( double salary )
20  {
21     if ( salary >= 0.0 )
22        baseSalary = salary;
23     else
24        throw invalid_argument( "Salary must be >= 0.0" );
25  } // end function setBaseSalary
26
27  // return base salary
28  double BasePlusCommissionEmployee::getBaseSalary() const
29  {
30     return baseSalary;
31  } // end function getBaseSalary
32
33  // calculate earnings
34  double BasePlusCommissionEmployee::earnings() const
35  {
36     return getBaseSalary() + CommissionEmployee::earnings();
37  } // end function earnings
38
```

Fig. 11.15 | `BasePlusCommissionEmployee` class that inherits from class `CommissionEmployee` but cannot directly access the class's `private` data. (Part 2 of 3.)

```
39  // print BasePlusCommissionEmployee object
40  void BasePlusCommissionEmployee::print() const
41  {
42     cout << "base-salaried ";
43
44     // invoke CommissionEmployee's print function
45     CommissionEmployee::print();
46
47     cout << "\nbase salary: " << getBaseSalary();
48  } // end function print
```

Fig. 11.15 | `BasePlusCommissionEmployee` class that inherits from class `CommissionEmployee` but cannot directly access the class's `private` data. (Part 3 of 3.)

11.3.5 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using private Data (cont.)

BasePlusCommissionEmployee* Member Function *earnings

- Class `BasePlusCommissionEmployee`'s `earnings` function (Fig. 11.15, lines 34–37) redefines class `CommissionEmployee`'s `earnings` member function (Fig. 11.14, lines 85–88) to calculate the earnings of a base-salaried commission employee. It also calls `CommissionEmployee`'s `earnings` function.
  - Note the syntax used to invoke a redefined base-class member function from a derived class—place the base-class name and the binary scope resolution operator (`::`) before the base-class member-function name.
  - Good software engineering practice: If an object's member function performs the actions needed by another object, we should call that member function rather than duplicating its code body.

Common Programming Error 11.2

When a base-class member function is redefined in a derived class, the derived-class version often calls the base-class version to do additional work. Failure to use the `::` operator prefixed with the name of the base class when referencing the base class's member function causes infinite recursion, because the derived-class member function would then call itself.

11.3.5 CommissionEmployee–BasePlusCommissionEmployee Inheritance Hierarchy Using private Data (cont.)

BasePlusCommissionEmployee* Member Function *print

- `BasePlusCommissionEmployee`'s `print` function (Fig. 11.15, lines 40–48) redefines class `CommissionEmployee`'s `print` function (Fig. 11.14, lines 91–98) to output the appropriate base-salaried commission employee information.
- By using inheritance and by calling member functions that hide the data and ensure consistency, we've efficiently and effectively constructed a well-engineered class.

11.4 Constructors and Destructors in Derived Classes

- Instantiating a derived-class object begins a *chain* of constructor calls in which the derived-class constructor, before performing its own tasks, invokes its direct base class's constructor either explicitly (via a base-class member initializer) or implicitly (calling the base class's default constructor).
- If the base class is derived from another class, the base-class constructor is required to invoke the constructor of the next class up in the hierarchy, and so on.
- The last constructor called in this chain is the constructor of the class at the base of the hierarchy, whose body actually finishes executing *first*.
- The most derived-class constructor's body finishes executing *last*.
- Each base-class constructor initializes the base-class data members that the derived-class object inherits.

Software Engineering Observation 11.6

When a program creates a derived-class object, the derived-class constructor immediately calls the base-class constructor, the base-class constructor's body executes, then the derived class's member initializers execute and finally the derived-class constructor's body executes. This process cascades up the hierarchy if it contains more than two levels.

11.4 Constructors and Destructors in Derived Classes (cont.)

- When a derived-class object is destroyed, the program calls that object's destructor.
- This begins a chain (or cascade) of destructor calls in which the derived-class destructor and the destructors of the direct and indirect base classes and the classes' members execute in *reverse* of the order in which the constructors executed.
- When a derived-class object's destructor is called, the destructor performs its task, then invokes the destructor of the next base class up the hierarchy.
- This process repeats until the destructor of the final base class at the top of the hierarchy is called.
- Then the object is removed from memory.

Software Engineering Observation 11.7

Suppose that we create an object of a derived class where both the base class and the derived class contain (via composition) objects of other classes. When an object of that derived class is created, first the constructors for the base class's member objects execute, then the base-class constructor body executes, then the constructors for the derived class's member objects execute, then the derived class's constructor body executes. Destructors for derived-class objects are called in the reverse of the order in which their corresponding constructors are called.

11.4 Constructors and Destructors in Derived Classes (cont.)

- Base-class constructors, destructors and overloaded assignment operators (Chapter 10) are *not* inherited by derived classes.
- Derived-class constructors, destructors and overloaded assignment operators, however, can call base-class versions.

11.4 Constructors and Destructors in Derived Classes (cont.)

C++11: Inheriting Base Class Constructors

- Sometimes a derived class's constructors simply mimic the base class's constructors.
- A frequently requested convenience feature for C++11 was the ability to *inherit* a base class's constructors.
- You can now do this by explicitly including a using declaration of the form

```
using BaseClass::BaseClass;
```

- *anywhere* in the derived-class definition.
- In the preceding declaration, `BaseClass` is the base class's name.

11.4 Constructors and Destructors in Derived Classes (cont.)

- When you inherit constructors:
  - By default, each inherited constructor has the *same* access level (`public`, `protected` or `private`) as its corresponding base-class constructor.
  - The default, copy and move constructors are *not* inherited.
  - If a constructor is *deleted* in the base class by placing `= delete` in its prototype, the corresponding constructor in the derived class is *also* deleted.
  - If the derived class does not explicitly define constructors, the compiler generates a default constructor in the derived class—*even* if it inherits other constructors from its base class.
  - If a constructor that you *explicitly* define in a derived class has the *same* parameter list as a base-class constructor, then the base-class constructor is *not* inherited.
  - A base-class constructor's default arguments are *not* inherited. Instead, the compiler generates overloaded constructors in the derived class.

11.5 `public`, `protected` and `private` Inheritance

- When deriving a class from a base class, the base class may be inherited through `public`, `protected` or `private` inheritance.
- Use of `protected` and `private` inheritance is rare.
- Figure 11.16 summarizes for each type of inheritance the accessibility of base-class members in a derived class.
- The first column contains the base-class access specifiers.
- A base class's `private` members are *never* accessible directly from a derived class, but can be accessed through calls to the `public` and `protected` members of the base class.

Base-class member-access specifier	Type of inheritance		
	`public` inheritance	`protected` inheritance	`private` inheritance
`public`	`public` in derived class. Can be accessed directly by member functions, `friend` functions and nonmember functions.	`protected` in derived class. Can be accessed directly by member functions and `friend` functions.	`private` in derived class. Can be accessed directly by member functions and `friend` functions.
`protected`	`protected` in derived class. Can be accessed directly by member functions and `friend` functions.	`protected` in derived class. Can be accessed directly by member functions and `friend` functions.	`private` in derived class. Can be accessed directly by member functions and `friend` functions.
`private`	Hidden in derived class. Can be accessed by member functions and `friend` functions through `public` or `protected` member functions of the base class.	Hidden in derived class. Can be accessed by member functions and `friend` functions through `public` or `protected` member functions of the base class.	Hidden in derived class. Can be accessed by member functions and `friend` functions through `public` or `protected` member functions of the base class.

11.6 Software Engineering with Inheritance

- When we use inheritance to create a new class from an existing one, the new class inherits the data members and member functions of the existing class, as described in Fig. 11.16.
- We can customize the new class to meet our needs by including additional members and by redefining base-class members.
- The derived-class programmer does this in C++ without accessing the base class's source code.
- The derived class must be able to link to the base class's object code.

11.6 Software Engineering with Inheritance (cont.)

- When we use inheritance to create a new class from an existing one, the new class inherits the data members and member functions of the existing class.
- We can customize the new class to meet our needs by redefining base-class members and by including additional members.
- The derived-class programmer does this in C++ without accessing the base class's source code (the derived class must be able to link to the base class's object code).

11.7 Software Engineering with Inheritance (cont.)

- Software developers can develop proprietary classes for sale or license.
- Users then can derive new classes from these library classes rapidly and without accessing the proprietary source code.
- The software developers need to supply the headers along with the object code
- The availability of substantial and useful class libraries delivers the maximum benefits of software reuse through inheritance.

Software Engineering Observation 11.8

At the design stage in an object-oriented system, the designer often determines that certain classes are closely related. The designer should "factor out" common attributes and behaviors and place these in a base class, then use inheritance to form derived classes.

Software Engineering Observation 11.9

Creating a derived class does not affect its base class's source code. Inheritance preserves the integrity of the base class.