8

Inheritance: Extending Classes

Key Concepts

- Reusability
- Inheritance
- Single inheritance
- Multiple inheritance
- Multilevel inheritance
- Hybrid inheritance
- Hierarchical inheritance
- Defining a derived class
- Inheritiing private members
- Virtual base class
- Direct base class
- Indirect base class
- Abstract class
- Defining derived class constructors
- Nesting of classes

8.1 Introduction

Reusability is yet another important feature of OOP. It is always nice if we could reuse something that already exists rather than trying to create the same all over again. It would not only save time and money but also reduce frustration and increase reliability. For instance, the reuse of a class that has already been tested, debugged and used many times can save us the effort of developing and testing the same again.

Fortunately, C++ strongly supports the concept of *reusability*. The C++ classes can be reused in several ways. Once a class has been written and tested, it can be adapted by other programmers to suit their requirements. This is basically done by creating new classes, reusing the properties of the existing ones. The mechanism of deriving a new class from an old one is called *inheritance (or derivation)*. The old class is referred to as the *base class* and the new one is called the *derived class or subclass*.

The derived class inherits some or all of the traits from the base class. A class can also inherit properties from more than one class or from more than one level. A derived class with only one base class, is called *single inheritance* and one with several base classes is called *multiple inheritance*. On the other hand, the traits of one class may be inherited by more than one class. This process is known as *hierarchical inheritance*. The mechanism of deriving a class from another 'derived class' is known as *multilevel inheritance*. Figure 8.1 shows various forms of inheritance that could be used for writing extensible programs. The direction of arrow indicates the direction of inheritance. (Some authors show the arrow in opposite direction meaning "inherited from".)

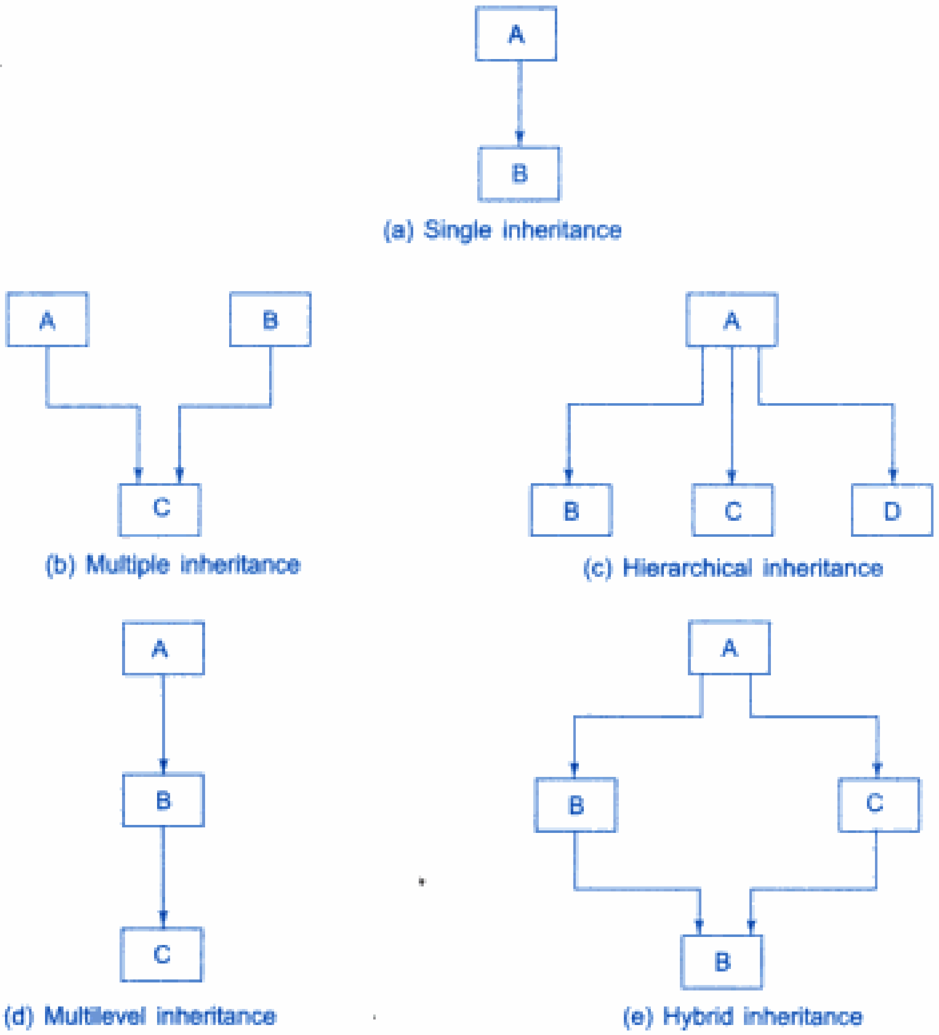


Fig. 8.1 ⇔ Forms of inheritance

8.2 Defining Derived Classes

A derived class can be defined by specifying its relationship with the base class in addition to its own details. The general form of defining a derived class is:

```
class derived-class-name  : visibility-mode base-class-name
{
        .....//
        .....//   members of derived class
        .....//
};
```

The colon indicates that the *derived-class-name* is derived from the *base-class-name*. The *visibility-mode* is optional and, if present, may be either **private** or **public**. The default visibility-mode is **private**. Visibility mode specifies whether the features of the base class are *privately derived or publicly derived.*

Examples:

```
class ABC: private XYZ        // private derivation
{
       members of ABC
};

class ABC: public XYZ         // public derivation
{
       members of ABC
};

class ABC: XYZ                // private derivation by default
{
       members of ABC
};
```

When a base class is *privately inherited* by a derived class, 'public members' of the base class become 'private members' of the derived class and therefore the public members of the base class can only be accessed by the member functions of the derived class. They are inaccessible to the objects of the derived class. Remember, a public member of a class can be accessed by its own objects using the *dot operator*. The result is that no member of the base class is accessible to the objects of the derived class.

On the other hand, when the base class is *publicly inherited*, 'public members' of the base class become 'public members' of the derived class and therefore they are accessible to the objects of the derived class. In *both the cases, the private members are not inherited* and therefore, the private members of a base class will never become the members of its derived class.

In inheritance, some of the base class data elements and member functions are 'inherited' into the derived class. We can add our own data and member functions and thus extend the functionality of the base class. Inheritance, when used to modify and extend the capabilities of the existing classes, becomes a very powerful tool for incremental program development.

8.3 Single Inheritance

Let us consider a simple example to illustrate inheritance. Program 8.1 shows a base class B and a derived class D. The class B contains one private data member, one public data member, and three public member functions. The class D contains one private data member and two public member functions.

SINGLE INHERITANCE : PUBLIC

```
#include <iostream>

using namespace std;

class B
{
        int a;                    // private; not inheritable
    public:
        int b;                    // public; ready for inheritance
        void get_ab();
        int  get_a(void);
        void show_a(void);
};

class D : public B                // public derivation
{
         int c;
    public:
         void mul(void);
         void display(void);
};
//-------------------------------------------------------
void B :: get_ab(void)
{
         a = 5; b = 10;
}
int B :: get_a()
{
         return a;
}
void B :: show_a()
{
```

(Contd)

```
        cout << "a = " << a << "\n";
}
void D :: mul()
{
        c = b * get_a();
}
void D :: display()
{
        cout << "a = " << get_a() << "\n";
        cout << "b = " << b << "\n";
        cout << "c = " << c << "\n\n";
}
//----------------------------------------------------------
int main()
{
        D d;

        d.get_ab();
        d.mul();
        d.show_a();
        d.display();

        d.b = 20;
        d.mul();
        d.display();

        return 0;
}
```

PROGRAM 8.1

Given below is the output of Program 8.1:

```
a = 5
a = 5
b = 10
c = 50

a = 5
b = 20
c = 100
```

The class **D** is a public derivation of the base class **B**. Therefore, **D** inherits all the **public** members of **B** and retains their visibility. Thus a **public** member of the base class **B** is also a public member of the derived class **D**. The **private** members of **B** cannot be inherited by **D**. The class **D**, in effect, will have more members than what it contains at the time of declaration as shown in Fig. 8.2.

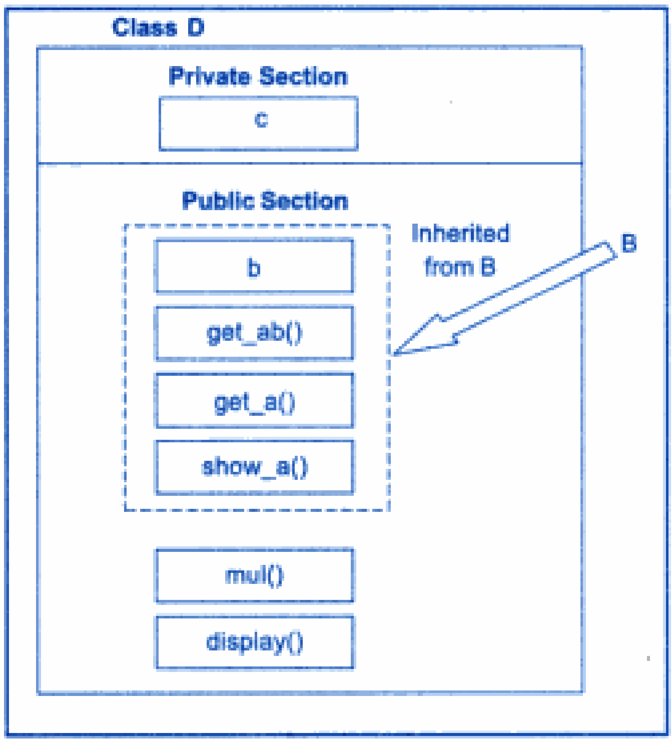


Fig. 8.2 ⇔ *Adding more members to a class (by public derivation)*

The program illustrates that the objects of class **D** have access to all the public members of **B**. Let us have a look at the functions **show_a()** and **mul()**:

```
void show_a()
{
      cout << "a = " << a << "\n";
}

void mul()
{
      c = b * get_a();          // c = b * a
}
```

Although the data member **a** is private in **B** and cannot be inherited, objects of **D** are able to access it through an inherited member function of **B**.

Let us now consider the case of private derivation.

```
class B
{
        int a;
   public:
        int b;
        void get_ab();
void get_a();
        void show_a();
};

class D : private B             // private derivation
{
         int c;
    public:
         void mul();
         void display();
};
```

The membership of the derived class **D** is shown in Fig. 8.3. In **private** derivation, the **public** members of the base class become **private** members of the derived class. Therefore, the objects of **D** can not have direct access to the public member functions of **B**.

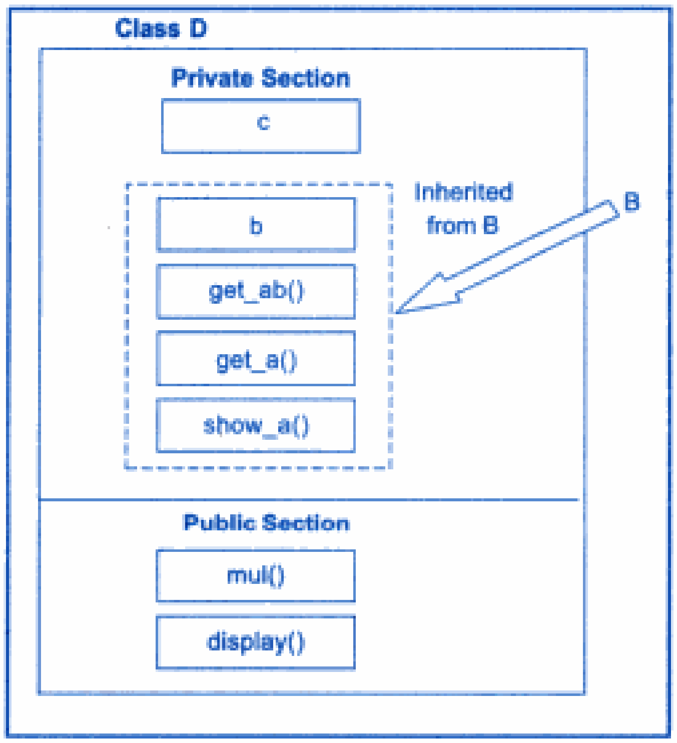


Fig. 8.3 ⇔ *Adding more members to a class (by private derivation)*

The statements such as

```
d.get_ab();       // get_ab() is private
d.get_a();        // so also get_a()
d.show_a();       // and show_a()
```

will not work. However, these functions can be used inside **mul()** and **display()** like the normal functions as shown below:

```
void mul()
{
     get_ab();
     c = b * get_a();
}

void display()
{
     show_a();           // outputs value of 'a'
     cout << "b = " << b << "\n"
          << "c = " << c << "\n\n";
}
```

Program 8.2 incorporates these modifications for private derivation. Please compare this with Program 8.1.

SINGLE INHERITANCE : PRIVATE

```
#include <iostream>

using namespace std;

class B
{
       int a;           // private; not inheritable
     public:
       int b;           // public; ready for inheritance
       void get_ab();
       int  get_a(void);
       void show_a(void);
};

class D : private B              // private derivation
{
      int c;
```

(Contd)

```
    public:
        void mul(void);
        void display(void);
};

//-----------------------------------------------------------

void B :: get_ab(void)
{
     cout << "Enter values for a and b:";
     cin >> a >> b;
}

int B :: get_a()
{
     return a;
}

void B :: show_a()
{
      cout << "a = " << a << "\n";
}

void D :: mul()
{
      get_ab();
      c = b * get_a();         // 'a' cannot be used directly
}

void D :: display()
{
      show_a();                // outputs value of 'a'

      cout << "b = " << b << "\n"
           << "c = " << c << "\n\n";
}

//-----------------------------------------------------------

int main()
{
     D d;

     // d.get_ab();  WON'T WORK
     d.mul();
     // d.show_a();  WON'T WORK
     d.display();
```

(Contd)

```
        // d.b = 20;       WON'T WORK; b has become private
        d.mul();
        d.display();

        return 0;
   }
```

PROGRAM 8.2

The output of Program 8.2 would be:

```
Enter values for a and b:5 10
a = 5
b = 10
c = 50
Enter values for a and b:12 20
a = 12
b = 20
c = 240
```

Suppose a base class and a derived class define a function of the same name. What will happen when a derived class object invokes the function?. In such cases, the derived class function supersedes the base class definition. The base class function. will be called only if the derived class does not redefine the function.

8.4 Making a Private Member Inheritable

We have just seen how to increase the capabilities of an existing class without modifying it. We have also seen that a private member of a base class cannot be inherited and therefore it is not available for the derived class directly. What do we do if the **private** data needs to be inherited by a derived class? This can be accomplished by modifying the visibility limit of the **private** member by making it **public**. This would make it accessible to all the other functions of the program, thus taking away the advantage of data hiding.

C++ provides a third *visibility modifier*, **protected**, which serve a limited purpose in inheritance. A member declared as **protected** is accessible by the member functions within its class and any class *immediately* derived from it. It *cannot* be accessed by the functions outside these two classes. A class can now use all the three visibility modes as illustrated below:

```
class alpha
{
  private:                 // optional
     .....                 // visible to member functions
```

```
        .....              // within its class
    protected:
        .....              // visible to member functions
        .....              // of its own and derived class
    public:
        .....              // visible to all functions
        .....              // in the program
  };
```

When a **protected** member is inherited in **public** mode, it becomes **protected** in the derived class too and therefore is accessible by the member functions of the derived class. It is also ready for further inheritance. A **protected** member, inherited in the **private** mode derivation, becomes **private** in the derived class. Although it is available to the member functions of the derived class, it is not available for further inheritance (since **private** members cannot be inherited). Figure 8.4 is the pictorial representation for the two levels of derivation.

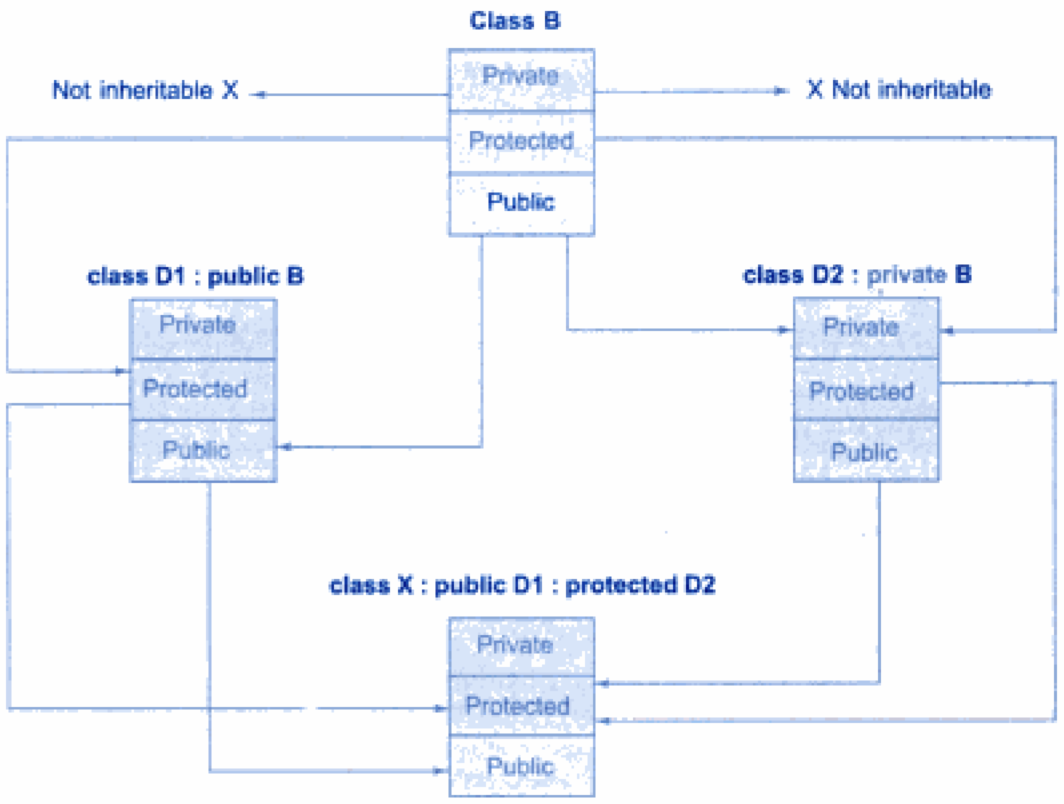


Fig. 8.4 ⇔ *Effect of inheritance on the visibility of members*

The keywords **private**, **protected**, and **public** may appear in any order and any number of times in the declaration of a class. For example,

```
class beta
{
  protected:
      .....
  public:
      .....
  private:
      .....
  public:
      .....
};
```

is a valid class definition.

However, the normal practice is to use them as follows:

```
class beta
{
     .....                        // private by default
     .....
  protected:
     .....
  public:
     .....
}
```

It is also possible to inherit a base class in **protected** mode (known as *protected derivation*). In protected derivation, both the **public** and **protected** members of the base class become **protected** members of the derived class. Table 8.1 summarizes how the visibility of base class members undergoes modifications in all the three types of derivation.

Now let us review the access control to the **private** and **protected** members of a class. What are the various functions that can have access to these members? They could be:

1. A function that is a friend of the class.
2. A member function of a class that is a friend of the class.
3. A member function of a derived class.

While the friend functions and the member functions of a friend class can have direct access to both the **private** and **protected** data, the member functions of a derived class can directly access only the **protected** data. However, they can access the **private** data through the member functions of the base class. Figure 8.5 illustrates how the access control mechanism works in various situations. A simplified view of access control to the members of a class is shown in Fig. 8.6.

Table 8.1 *Visibility of inherited members*

Base class visibility		***Derived class visibility***		
		Public derivation	***Private derivation***	***Protected derivation***
Private	⟶	Not inherited	Not inherited	Not inherited
Protected	⟶	Protected	Private	Protected
Public	⟶	Public	Private	Protected

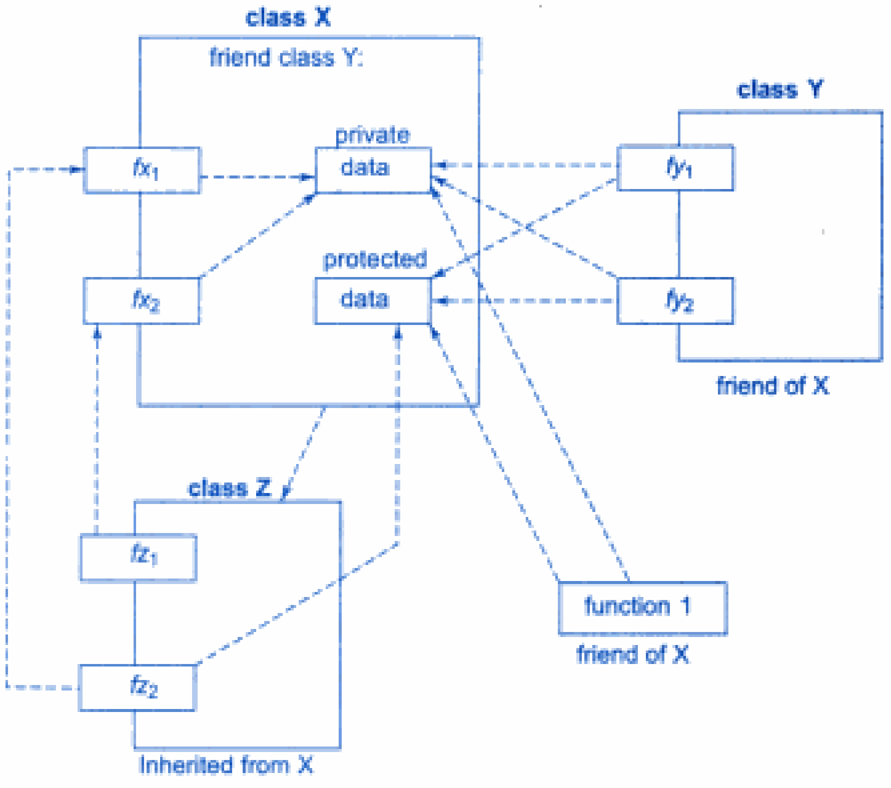


Fig. 8.5 ⇔ *Access mechanism in classes*

8.5 Multilevel Inheritance

It is not uncommon that a class is derived from another derived class as shown in Fig. 8.7. The class **A** serves as a base class for the derived class **B**, which in turn serves as a base class for the derived class **C**. The class **B** is known as *intermediate* base class since it provides a link for the inheritance between **A** and **C**. The chain **ABC** is known as *inheritance path*.

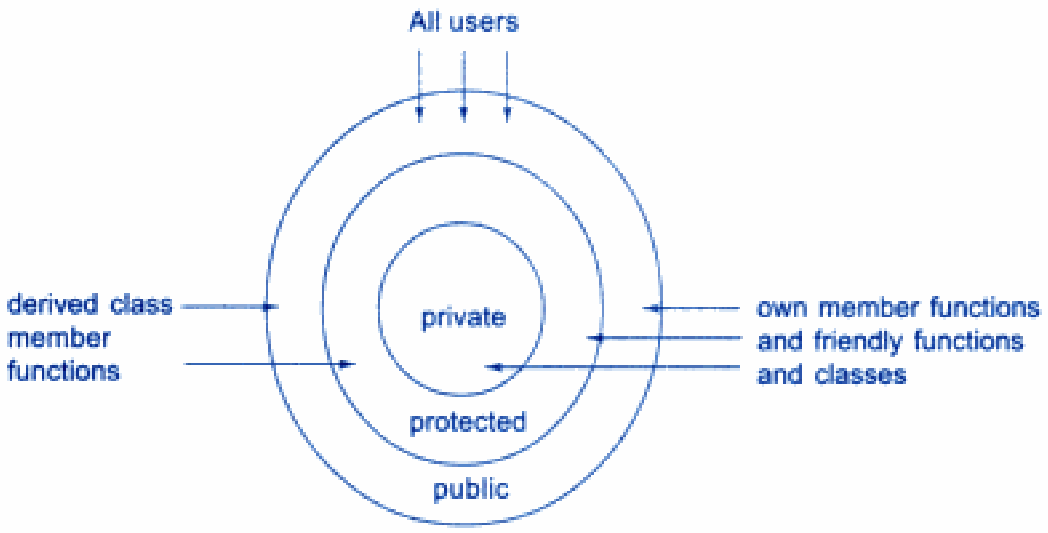

All users
derived class member functions
private
protected
public
own member functions and friendly functions and classes

Fig. 8.6 ⇔ *A simple view of access control to the members of a class*

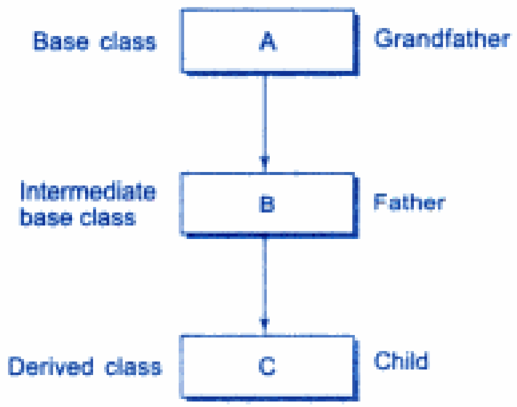


Fig. 8.7 ⇔ *Multilevel inheritance*

A derived class with multilevel inheritance is declared as follows:

```
class A{.....};                // Base class
class B: public A {.....};     // B derived from A
class C: public B {.....};     // C derived from B
```

This process can be extended to any number of levels.

Let us consider a simple example. Assume that the test results of a batch of students are stored in three different classes. Class **student** stores the roll-number, class **test** stores the marks obtained in two subjects and class **result** contains the **total** marks obtained in the test. The class **result** can inherit the details of the marks obtained in the test and the roll-number of students through multilevel inheritance. Example:

```
class student
{
      protected:
      int roll_number;
   public:
      void get_number(int);
      void put_number(void);
};
void student :: get_number(int a)
{
    roll_number = a;
}
void student :: put_number()
{
       cout << "Roll Number: " << roll_number << "\n";
}

class test : public student          // First level derivation
{
  protected:
     float sub1;
     float sub2;
  public:
     void get_marks(float, float);
     void put_marks(void);
};
void test :: get_marks(float x, float y)
{
     sub1 = x;
     sub2 = y;
}
void test :: put_marks()
{
     cout << "Marks in SUB1 = " << sub1 << "\n";
     cout << "Marks in SUB2 = " << sub2 << "\n";
}
class result : public test           // Second level derivation
{
     float total;              // private by default
  public:
     void display(void);
};
```

The class **result**, after inheritance from 'grandfather' through 'father', would contain the following members:

```
private:
    float total;               // own member
protected:
    int roll_number;           // inherited from  student via test
    float sub1;                // inherited from test
    float sub2;                // inherited from test
public:
   void get_number(int);              // from student via test
   void put_number(void);             // from student via test
   void get_marks(float, float);      // from test
   void put_marks(void);              // from test
   void display(void);                // own member
```

The inherited functions **put_number()** and **put_marks()** can be used in the definition of **display()** function:

```
void result :: display(void)
{
      total = sub1 + sub2;
      put_number();
      put_marks();
      cout << "Total = " << total << "\n";
}
```

Here is a simple **main()** program:

```
int main()
{
      result student1;                // student1 created
      student1.get_number(111);
      student1.get_marks(75.0, 59.5);
      student1.display();

   return 0;
}
```

This will display the result of **student1**. The complete program is shown in Program 8.3.

MULTILEVEL INHERITANCE

```
#include <iostream>

using namespace std;

class student
```

(Contd)

```
{
  protected:
        int roll_number;
  public: .
        void get_number(int);
        void put_number(void);
};

void student :: get_number(int a)
{
        roll_number = a;
}

void student :: put_number()
{
        cout << "Roll Number: " << roll_number << "\n";
}

class test : public student               // First level derivation
{
  protected:
     float sub1;
     float sub2;
  public:
        void get_marks(float, float);
        void put_marks(void);
};

void test :: get_marks(float x, float y)
{
     sub1 = x;
     sub2 = y;
}

void test :: put_marks()
{
        cout << "Marks in SUB1 = " << sub1 << "\n";
        cout << "Marks in SUB2 = " << sub2 << "\n";
}

class result : public test        // Second level derivation
{
      float total;                // private by default
  public:
      void display(void);
};

void result :: display(void)
{
```

(Contd)

```
                total = sub1 + sub2;
                put_number();
                put_marks();
                cout << "Total = " << total << "\n";
        }

        int main()
        {
                result student1;        // student1 created

                student1.get_number(111);
                student1.get_marks(75.0, 59.5);

                student1.display();

            return 0;
        }
```

PROGRAM 8.3

Program 8.3 displays the following output:

```
Roll Number: 111
Marks in SUB1 = 75
Marks in SUB2 = 59.5
Total = 134.5
```

8.6 Multiple Inheritance

A class can inherit the attributes of two or more classes as shown in Fig. 8.8. This is known as *multiple inheritance*. Multiple inheritance allows us to combine the features of several existing classes as a starting point for defining new classes. It is like a child inheriting the physical features of one parent and the intelligence of another.

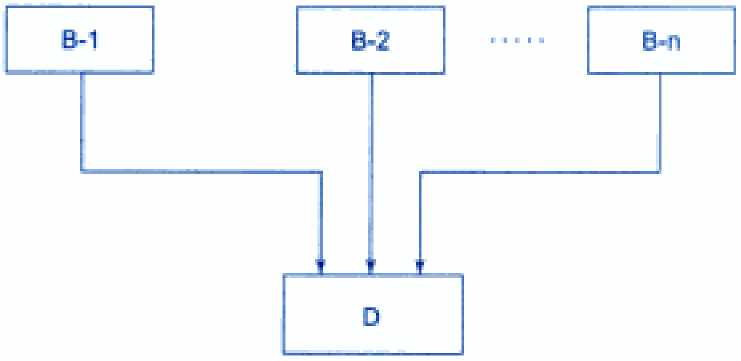


Fig. 8.8 ⇔ *Multiple inheritance*

The syntax of a derived class with multiple base classes is as follows:

```
class D: visibility B-1, visibility B-2 ...
{
        .....
        .....(Body of D)
        .....
};
```

where, *visibility* may be either **public** or **private**. The base classes are separated by commas.

Example:

```
class P : public M, public N
{
  public:
      void display(void);
};
```

Classes M and N have been specified as follows:

```
class M
{
  protected:
        int m;
  public:
        void get_m(int);
};
void M :: get_m(int x)
{
        m = x;
}
class N
{
  protected:
        int n;
  public:
        void get_n(int);
};
void N :: get_n(int y)
   {
        n = y;
    }
```

The derived class **P**, as declared above, would, in effect, contain all the members of **M** and **N** in addition to its own members as shown below:

```
class P
{
  protected:
      int m;                              // from M
      int n;                              // from N
  public:
      void get_m(int);                    // from M
      void get_n(int);                    // from N
      void display(void);                 // own member
};
```

The member function display() can be defined as follows:

```
void P :: display(void)
{
      cout << "m = " << m << "\n";
      cout << "n = " << n << "\n";
      cout << "m*n =" << m*n << "\n";
};
```

The main() function which provides the user-interface may be written as follows:

```
main()
{
      P p;
      p.get_m(10);
      p.get_n(20);
      p.display();
}
```

Program 8.4 shows the entire code illustrating how all the three classes are implemented in multiple inheritance mode.

MULTIPLE INHERITANCE

```
#include <iostream>

using namespace std;

class M
{
  protected:
         int m;
  public:
         void get_m(int);
};

class N
{
  protected:
      int n;
  public:
      void get_n(int);
};

class P : public M, public N
{
  public:
      void display(void);
};

void M :: get_m(int x)
{
      m = x;
}

void N :: get_n(int y)
{
      n = y;
}

void P :: display(void)
{
      cout << "m = " << m << "\n";
      cout << "n = " << n << "\n";
      cout << "m*n = " << m*n << "\n";
}

int main()
{
```

(Contd)

```
            P p;

            p.get_m(10);
            p.get_n(20);
            p.display();

            return 0;
    }
```

PROGRAM 8.4

The output of Program 8.4 would be:

```
m = 10
n = 20
m*n = 200
```

Ambiguity Resolution in Inheritance

Occasionally, we may face a problem in using the multiple inheritance, when a function with the same name appears in more than one base class. Consider the following two classes.

```
class M
{
  public:
      void display(void)
      {
            cout << "Class M\n";
      }
};

class N
{
  public:
      void display(void)
      {
             cout << "Class N\n";
      }
};
```

Which **display()** function is used by the derived class when we inherit these two classes? We can solve this problem by defining a named instance within the derived class, using the class resolution operator with the function as shown below:

```
class P : public M, public N
```

```
    {
      public:
          void display(void)        // overrides display() of M and N
          {
                 M :: display();
          }
    };
```

We can now use the derived class as follows:

```
      int main()
      {
              P p;
              p.display();
      }
```

Ambiguity may also arise in single inheritance applications. For instance, consider the following situation:

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

In this case, the function in the derived class overrides the inherited function and, therefore, a simple call to **display()** by **B** type object will invoke function defined in **B** only. However, we may invoke the function defined in **A** by using the scope resolution operator to specify the class.

Example:

```
    int main()
    {
        B b;                      // derived class object
        b.display();              // invokes display() in B
        b.A::display();           // invokes display() in A
        b.B::display();           // invokes display() in B

         return 0;
    }
```

This will produce the following output:

```
    B
    A
    B
```

8.7 Hierarchical Inheritance

We have discussed so far how inheritance can be used to modify a class when it did not satisfy the requirements of a particular problem on hand. Additional members are added through inheritance to extend the capabilities of a class. Another interesting application of inheritance is to use it as a support to the hierarchical design of a program. Many programming problems can be cast into a hierarchy where certain features of one level are shared by many others below that level.

As an example, Fig. 8.9 shows a hierarchical classification of students in a university. Another example could be the classification of accounts in a commercial bank as shown in Fig. 8.10. All the students have certain things in common and, similarly, all the accounts possess certain common features.

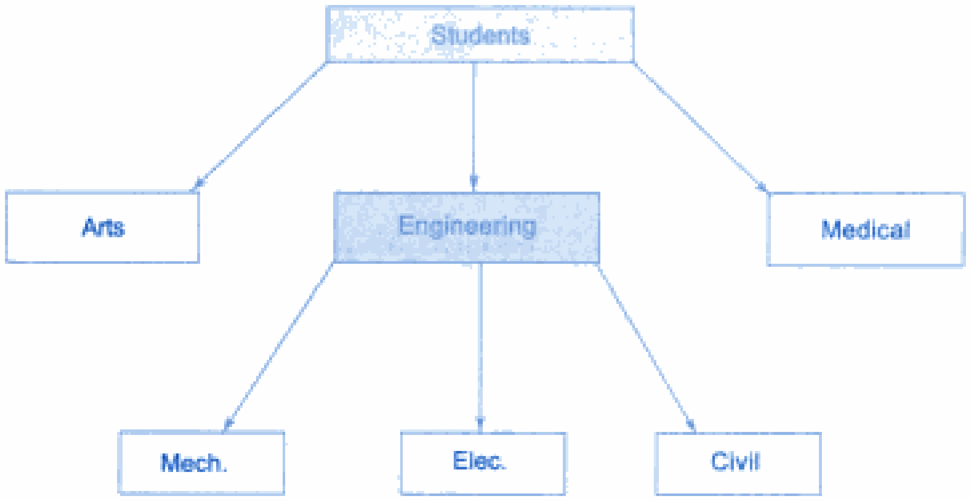


Fig. 8.9 ⇔ *Hierarchical classification of students*

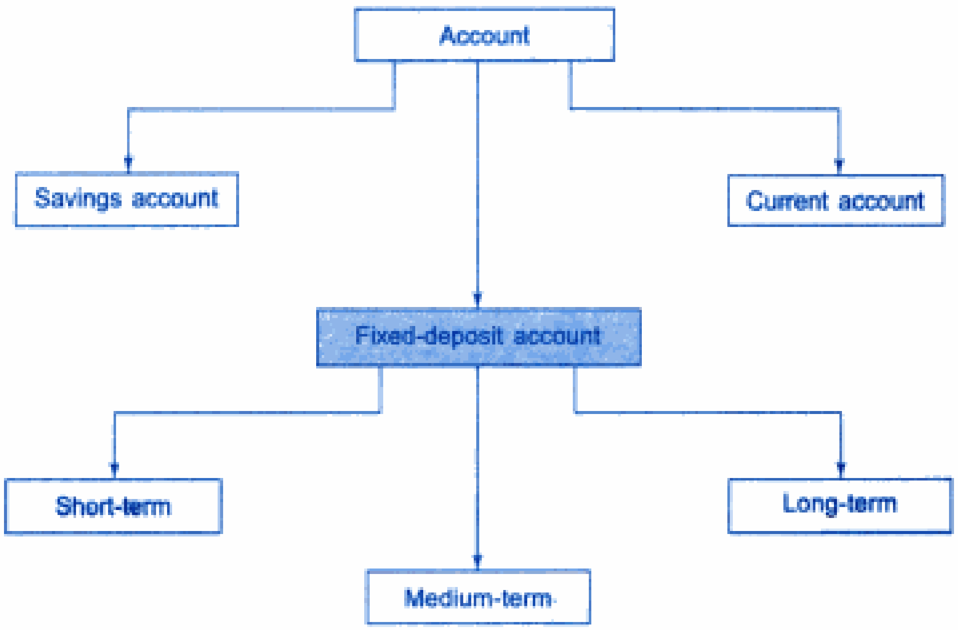


Fig. 8.10 ⇔ *Classification of bank accounts*

In C++, such problems can be easily converted into class hierarchies. The base class will include all the features that are common to the subclasses. A *subclass* can be constructed by inheriting the properties of the base class. A subclass can serve as a base class for the lower level classes and so on.

8.8 Hybrid Inheritance

There could be situations where we need to apply two or more types of inheritance to design a program. For instance, consider the case of processing the student results discussed in Sec. 8.5. Assume that we have to give weightage for sports before finalising the results. The weightage for sports is stored in a separate class called **sports**. The new inheritance relationship between the various classes would be as shown in Fig. 8.11.

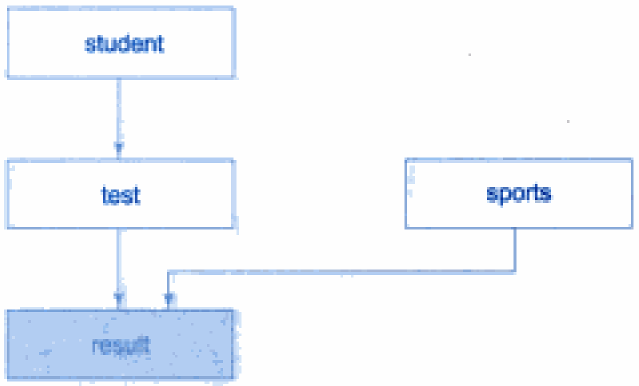


Fig. 8.11 ⇔ *Multilevel, multiple inheritance*

The **sports** class might look like:

```
class sports
{
  protected:
      float  score;
  public:
      void get_score(float);
       void put_score(void);
};
```

The result will have both the multilevel and multiple inheritances and its declaration would be as follows:

```
class result : public test, public sports
{
       .....
       .....
};
```

Where test itself is a derived class from student. That is

```
class test : public student
{
      .....
      .....
};
```

Program 8.5 illustrates the implementation of both multilevel and multiple inheritance.

HYBRID INHERITANCE

```
#include <iostream>

using namespace std;

class student
{
  protected:
      int  roll_number;
  public:
      void get_number(int a)
      {
          roll_number = a;
```

(Contd)

```
        }
        void put_number(void)
        {
              cout << "Roll No: " << roll_number << "\n";
        }
};

class test : public student
{
  protected:
        float part1, part2;
  public:
        void get_marks(float x, float y)
        {
              part1 = x;  part2 = y;
        }
        void put_marks(void)
        {
              cout << "Marks obtained: " << "\n"
                   << "Part1 = " << part1 << "\n"
                   << "Part2 = " << part2 << "\n";
        }
};

class sports
{
   protected:
         float score;
   public:
         void get_score(float s)
         {
              score = s;
         }
         void put_score(void)
         {
              cout << "Sports wt: " << score << "\n\n";
         }
};

class result : public test, public sports
{
         float total;
  public:
         void display(void);
```

(Contd)

```
};

void result :: display(void)
{
        total = part1 + part2 + score;

        put_number();
        put_marks();
        put_score();

        cout << "Total Score: " << total << "\n";
}

int main()
{
        result student_1;
        student_1.get_number(1234);
        student_1.get_marks(27.5, 33.0);
        student_1.get_score(6.0);
        student_1.display();

        return 0;
}
```

PROGRAM 8.5

Here is the output of Program 8.5:

```
Roll No: 1234
Marks obtained:
Part1 = 27.5
Part2 = 33
Sports wt: 6

Total Score: 66.5
```

8.9 Virtual Base Classes

We have just discussed a situation which would require the use of both the multiple and multilevel inheritance. Consider a situation where all the three kinds of inheritance, namely, multilevel, multiple and hierarchical inheritance, are involved. This is illustrated in Fig. 8.12. The 'child' has two *direct base classes* 'parent1' and 'parent2' which themselves have a common base class 'grandparent'. The 'child' inherits the traits of 'grandparent' via two separate paths. It can also inherit directly as shown by the broken line. The 'grandparent' is sometimes referred to as *indirect base class*.

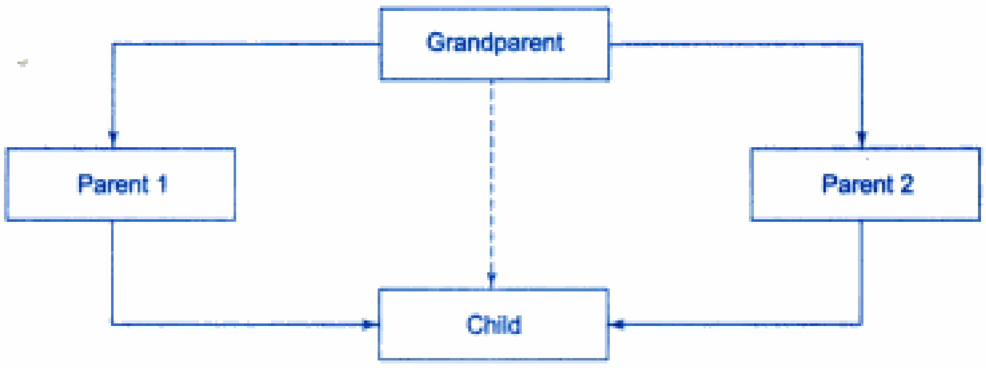


Fig. 8.12 ⇔ *Multipath inheritance*

Inheritance by the 'child' as shown in Fig. 8.12 might pose some problems. All the public and protected members of 'grandparent' are inherited into 'child' twice, first via 'parent1' and again via 'parent2'. This means, 'child' would have *duplicate* sets of the members inherited from 'grandparent'. This introduces ambiguity and should be avoided.

The duplication of inherited members due to these multiple paths can be avoided by making the common base class (ancestor class) as *virtual base class* while declaring the direct or intermediate base classes as shown below:

```
class A                          // grandparent
{
        .....
        .....
};
class B1 : virtual public A       // parent1
{
        .....
        .....
};
class B2 : public virtual A       // parent2
{
        .....
        .....
};
class C : public B1, public B2   // child
{
        .....              // only one copy of A
        .....              // will be inherited
};
```

When a class is made a **virtual** base class, C++ takes necessary care to see that only one copy of that class is inherited, regardless of how many inheritance paths exist between the virtual base class and a derived class.

note

The keywords **virtual** and **public** may be used in either order.

For example, consider again the student results processing system discussed in Sec. 8.8. Assume that the class **sports** derives the **roll_number** from the class **student**. Then, the inheritance relationship will be as shown in Fig. 8.13.

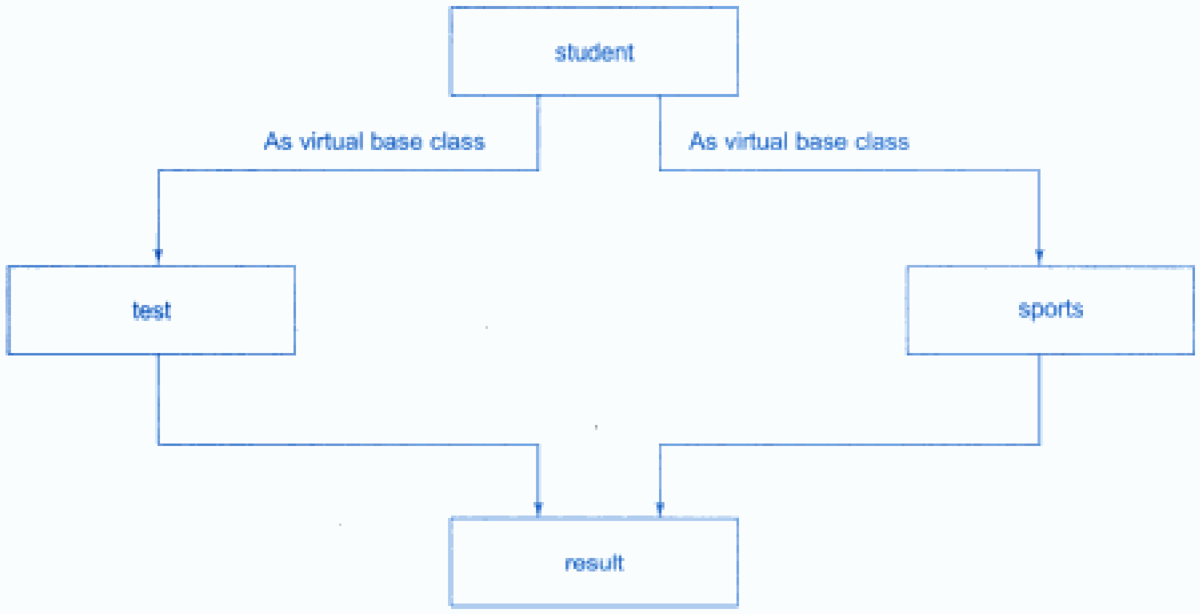


Fig. 8.13 ⇔ *Virtual base class*

A program to implement the concept of virtual base class is illustrated in Program 8.6.

VIRTUAL BASE CLASS

```
#include <iostream>

using namespace std;

class student
{
   protected:
     int roll_number;
   public:
     void get_number(int a)
     {
```

(Contd)

```
            roll_number = a;
        }
        void put_number(void)
        {
            cout << "Roll No: " << roll_number << "\n";
        }
};

class test : virtual public student
{
    protected:
      float part1, part2;
    public:
      void get_marks(float x, float y)
      {
            part1 = x;  part2 = y;
      }
      void put_marks(void)
      {
            cout << "Marks obtained: " << "\n"
                 << "Part1 = " << part1 << "\n"
                 << "Part2 = " << part2 << "\n";
      }
};

class sports : public virtual student
{
    protected:
      float score;
    public:
      void get_score(float s)
    {
            score = s;
    }
    void put_score(void)
    {
            cout << "Sports wt: " << score << "\n\n";
    }
};

class result : public test, public sports
{
      float total;
    public:
            void display(void);
};
```

(Contd)

```
void result :: display(void)
{
         total = part1 + part2 + score;

         put_number();
         put_marks();
         put_score();

         cout << "Total Score: " << total << "\n";
}

int main()
{
         result student_1;
         student_1.get_number(678);
         student_1.get_marks(30.5, 25.5);
         student_1.get_score(7.0);
         student_1.display();

         return 0;
}
```

PROGRAM 8.6

The output of Program 8.6 would be

```
Roll No: 678
Marks obtained:
Part1 = 30.5
Part2 = 25.5
Sport wt: 7

Total Score: 63
```

8.10 Abstract Classes

An *abstract class* is one that is not used to create objects. An abstract class is designed only to act as a base class (to be inherited by other classes). It is a design concept in program development and provides a base upon which other classes may be built. In the previous example, the **student** class is an abstract class since it was not used to create any objects.

8.11 Constructors in Derived Classes

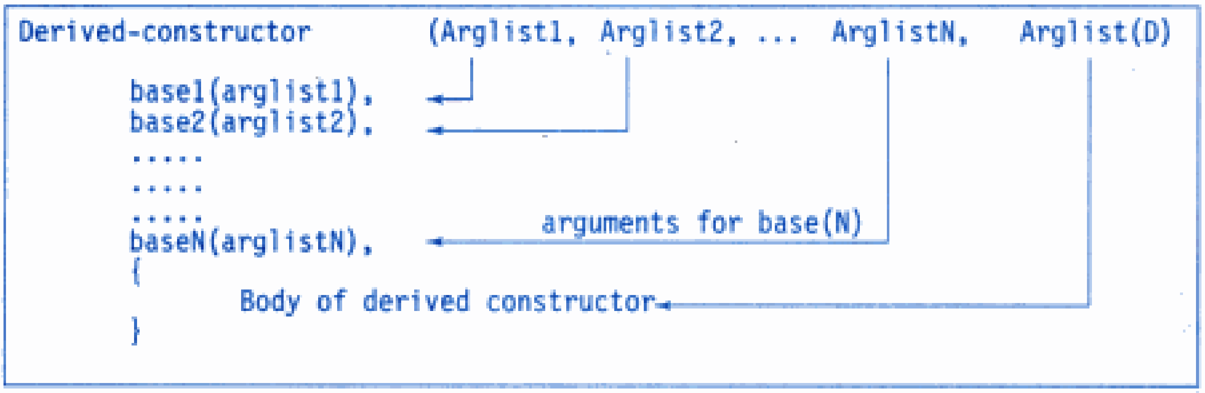
As we know, the constructors play an important role in initializing objects. We did not use them earlier in the derived classes for the sake of simplicity. One important thing to note here is that, as long as no base class constructor takes any arguments, the derived class need not have a constructor function. However, if any base class contains a constructor with one or more arguments, then it is *mandatory* for the derived class to have a constructor and pass the arguments to the base class constructors. Remember, while applying inheritance we usually create objects using the derived class. Thus, it makes sense for the derived class to pass arguments to the base class constructor. When both the derived and base classes contain constructors, the base constructor is executed first and then the constructor in the derived class is executed.

In case of multiple inheritance, the base classes are constructed *in the order in which they appear in the declaration of the derived class.* Similarly, in a multilevel inheritance, the constructors will be executed *in the order of inheritance.*

Since the derived class takes the responsibility of supplying initial values to its base classes, we supply the initial values that are required by all the classes together, when a derived class object is declared. How are they passed to the base class constructors so that they can do their job? C++ supports a special argument passing mechanism for such situations.

The constructor of the derived class receives the entire list of values as its arguments and passes them on to the base constructors in the order in which they are declared in the derived class. The base constructors are called and executed before executing the statements in the body of the derived constructor.

The general form of defining a derived constructor is:



```
Derived-constructor      (Arglist1, Arglist2, ... ArglistN,   Arglist(D)

        base1(arglist1),
        base2(arglist2),
        .....
        .....
        .....                    arguments for base(N)
        baseN(arglistN),
        {
                Body of derived constructor
        }
```

The header line of *derived-constructor* function contains two parts separated by a colon(:). The first part provides the declaration of the arguments that are passed to the *derived-constructor* and the second part lists the function calls to the base constructors.

base1(arglist1), base2(arglist2) ... are function calls to base constructors **base1(), base2(),** ... and therefore *arglist1, arglist2,* ... etc. represent the actual parameters that are passed to the base constructors. *Arglist1* through *ArglistN* are the argument declarations for base constructors *base1* through *baseN*. *ArglistD* provides the parameters that are necessary to initialize the members of the derived class.

Example:

```
D(int a1, int a2, float b1, float b2, int d1):
A(a1, a2),        /* call to constructor A */
B(b1, b2)        /* call to constructor B */
{
     d = d1;     // executes its own body
}
```

A(a1, a2) invokes the base constructor **A()** and B(b1, b2) invokes another base constructor **B()**. The constructor **D()** supplies the values for these four arguments. In addition, it has one argument of its own. The constructor **D()** has a total of five arguments. **D()** may be invoked as follows:

```
.....
D objD(5, 12, 2.5, 7.54, 30);
.....
```

These values are assigned to various parameters by the constructor **D()** as follows:

5	⟶	a1
12	⟶	a2
2.5	⟶	b1
7.54	⟶	b2
30	⟶	d1

The constructors for virtual base classes are invoked before any non-virtual base classes. If there are multiple virtual base classes, they are invoked in the order in which they are declared. Any non-virtual bases are then constructed before the derived class constructor is executed. See Table 8.2.

Table 8.2 *Execution of base class constructors*

Method of inheritance	***Order of execution***

Class B: public A
{
};
	A( ) ; base constructor
	B( ) ; derived constructor

class A : public B, public C
{
};
	B( ) ; base(first)
	C( ) ; base(second)
	A( ) ; derived

class A : public B, virtual public C
{
};
	C( ) ; virtual base
	B( ) ; ordinary base
	A( ) ; derived

Program 8.7 illustrates how constructors are implemented when the classes are inherited.

CONSTRUCTORS IN DERIVED CLASS

```
#include <iostream>

using namespace std;

class alpha
{
     int x;
   public:
     alpha(int i)
     {
          x = i;
          cout << "alpha initialized \n";
     }
     void show_x(void)
     { cout << "x = " << x << "\n"; }
};

class beta
{
     float y;
   public:
     beta(float j)
     {
          y = j;
          cout << "beta initialized \n";
     }
     void show_y(void)
     { cout << "y = " << y << "\n"; }
};

class gamma: public beta, public alpha
{
     int m, n;
   public:
     gamma(int a, float b, int c, int d):
          alpha(a), beta(b)
     {
          m = c;
          n = d;
          cout << "gamma initialized \n";
     }
```

(Contd)

```
        void show_mn(void)
        {
            cout << "m = " << m << "\n"
                 << "n = " << n << "\n";
        }
};

int main()
{
        gamma g(5, 10.75, 20, 30);
        cout << "\n";
        g.show_x();
        g.show_y();
        g.show_mn();

        return 0;
}
```

PROGRAM 8.7

The output of Program 8.7 would be:

```
beta initialized
alpha initialized
gamma initialized

x = 5
y = 10.75
m = 20
n = 30
```

note

beta is initialized first, although it appears second in the derived constructor. This is because it has been declared first in the derived class header line. Also, note that **alpha(a)** and **beta(b)** are function calls. Therefore, the parameters should not include types.

C++ supports another method of initializing the class objects. This method uses what is known as initialization list in the constructor function. This takes the following form:

```
constructor (arglist) : intialization-section
{
        assignment-section
}
```

The *assignment-section* is nothing but the body of the constructor function and is used to assign initial values to its data members. The part immediately following the colon is known as the *initialization section*. We can use this section to provide initial values to the base constructors and also to initialize its own class members. This means that we can use either of the sections to initialize the data members of the constructors class. The initialization section basically contains a list of initializations separated by commas. This list is known as *initialization list*. Consider a simple example:

```
class XYZ
{
        int a;
        int b;
   public:
        XYZ(int i, int j) : a(i), b(2 * j) { }
};

main()
{
        XYZ x(2, 3);
}
```

This program will initialize **a** to 2 and **b** to 6. Note how the data members are initialized, just by using the variable name followed by the initialization value enclosed in the parenthesis (like a function call). Any of the parameters of the argument list may be used as the initialization value and the items in the list may be in any order. For example, the constructor **XYZ** may also be written as:

```
XYZ(int i, int j) : b(i), a(i + j) { }
```

In this case, **a** will be initialized to 5 and **b** to 2. Remember, the data members are initialized in the order of declaration, independent of the order in the initialization list. This enables us to have statements such as

```
XYZ(int i, int j) : a(i), b(a * j) { }
```

Here **a** is initialized to 2 and **b** to 6. Remember, **a** which has been declared first is initialized first and then its value is used to initialize **b**. However, the following will not work:

```
XYZ(int i, int j) : b(i), a(b * j) { }
```

because the value of **b** is not available to **a** which is to be initialized first.

The following statements are also valid:

```
XYZ(int i, int j) : a(i) {b = j;}
XYZ(int i, int j) { a = i; b = j;}
```

We can omit either section, if it is not needed. Program 8.8 illustrates the use of initialization lists in the base and derived constructors.

INITIALIZATION LIST IN CONSTRUCTORS

```
#include <iostream>

using namespace std;

class alpha
{
     int x;
   public:
     alpha(int i)
     {
          x = i;
          cout << "\n alpha constructed";
     }

     void show_alpha(void)
     {
          cout << " x = " << x << "\n";
     }
};

class beta
{
     float p, q;
   public:
     beta(float a, float b): p(a), q(b+p)
     {
          cout << "\n beta constructed";
     }
     void show_beta(void)
     {
          cout << " p = " << p << "\n";
          cout << " q = " << q << "\n";
     }
};
class gamma : public beta, public alpha
{
     int u,v;
   public:
```

(Contd)

```
        gamma(int a, int b, float c):
        alpha(a*2), beta(c,c), u(a)
        { v = b; cout << "\n gamma constructed"; }

        void show_gamma(void)
        {
        cout << " u = " << u << "\n";
        cout << " v = " << v << "\n";
        }
};

int main()
{
        gamma g(2, 4, 2.5);

        cout << "\n\n Display member values " << "\n\n";

        g.show_alpha();
        g.show_beta();
        g.show_gamma();

        return 0;
};
```

PROGRAM 8.8

The output of Program 8.8 would be:

```
beta constructed
alpha constructed
gamma constructed

Display member values

x = 4
p = 2.5
q = 5
u = 2
v = 4
```

note

The argument list of the derived constructor **gamma** contains only three parameters **a**, **b** and **c** which are used to initialize the five data members contained in all the three classes.

8.12 Member Classes: Nesting of Classes

Inheritance is the mechanism of deriving certain properties of one class into another. We have seen in detail how this is implemented using the concept of derived classes. C++ supports yet another way of inheriting properties of one class into another. This approach takes a view that an object can be a collection of many other objects. That is, a class can contain objects of other classes as its members as shown below:

```
class alpha {....};
class beta {....};
class gamma
{
        alpha a;                // a is an object of alpha class
        beta b;                 // b is an object of beta class
        .....
};
```

All objects of **gamma** class will contain the objects **a** and **b**. This kind of relationship is called *containership* or *nesting*. Creation of an object that contains another object is very different than the creation of an independent object. An independent object is created by its constructor when it is declared with arguments. On the other hand, a nested object is created in two stages. First, the member objects are created using their respective constructors and then the other 'ordinary' members are created. This means, constructors of all the member objects should be called before its own constructor body is executed. This is accomplished using an initialization list in the constructor of the nested class.

Example:

```
class gamma
{
      .....
      alpha a;          // a is object of alpha
      beta b;           // b is object of beta
  public:
      gamma(arglist): a(arglist1), b(arglist2)
      {
                 // constructor body
      }
};
```

arglist is the list of arguments that is to be supplied when a **gamma** object is defined. These parameters are used for initializing the members of **gamma**. *arglist1* is the argument list for the constructor of **a** and *arglist2* is the argument list for the constructor of **b**. *arglist1* and *arglist2* may or may not use the arguments from *arglist*. Remember, **a**(*arglist1*) and **b**(*arglist2*) are function calls and therefore the arguments do not contain the data types. They are simply variables or constants.

Example:

```
gamma(int x, int y, float z) : a(x), b(x,z)
{
        Assignment section(for ordinary other members)
}
```

We can use as many member objects as are required in a class. For each member object we add a constructor call in the initializer list. The constructors of the member objects are called in the order in which they are declared in the nested class.

SUMMARY

⇔ The mechanism of deriving a new class from an old class is called inheritance. Inheritance provides the concept of reusability. The C++ classes can be reused using inheritance.

⇔ The derived class inherits some or all of the properties of the base class.

⇔ A derived class with only one base class is called single inheritance.

⇔ A class can inherit properties from more than one class which is known as multiple inheritance.

⇔ A class can be derived from another derived class which is known as multilevel inheritance.

⇔ When the properties of one class are inherited by more than one class, it is called hierarchical inheritance.

⇔ A private member of a class cannot be inherited either in public mode or in private mode.

⇔ A protected member inherited in public mode becomes protected, whereas inherited in private mode becomes private in the derived class.

⇔ A public member inherited in public mode becomes public, whereas inherited in private mode becomes private in the derived class.

⇔ The friend functions and the member functions of a friend class can directly access the private and protected data.

⇔ The member functions of a derived class can directly access only the protected and public data. However, they can access the private data through the member functions of the base class.

⇔ Multipath inheritance may lead to duplication of inherited members from a 'grandparent' base class. This may be avoided by making the common base class a virtual base class.

⇔ In multiple inheritance, the base classes are constructed in the order in which they appear in the declaration of the derived class.

⇔ In multilevel inheritance, the constructors are executed in the order of inheritance.

⇔ A class can contain objects of other classes. This is known as containership or nesting.

Key Terms

- abstract class
- access control
- access mechanism
- ancestor class
- assignment section
- base class
- base constructor
- child class
- common base class
- containership
- derivation
- derived class
- derived constructor
- direct base class
- dot operator
- duplicate members
- father class
- **friend**
- grandfather class
- grandparent class
- hierarchical inheritance
- hybrid inheritance
- indirect base class
- inheritance
- inheritance path
- initialization list
- initialization section
- intermediate base
- member classes
- multilevel inheritance
- multiple inheritance
- nesting
- **private**
- private derivation
- private members
- privately derived
- **protected**
- protected members
- **public**
- public derivation
- public members
- publicly derived
- reusability
- single inheritance
- subclass
- virtual base class
- visibility mode
- visibility modifier

Review Questions

8.1 *What does inheritance mean in C++?*

8.2 *What are the different forms of inheritance? Give an example for each.*

8.3 *Describe the syntax of the single inheritance in C++.*

8.4 *We know that a private member of a base class is not inheritable. Is it anyway possible for the objects of a derived class to access the private members of the base class? If yes, how? Remember, the base class cannot be modified.*

8.5 *How do the properties of the following two derived classes differ?*

(a) *class D1: private B{/ /...};*

(b) *class D2: public B{/ /...};*

8.6 *When do we use the protected visibility specifier to a class member?*

8.7 *Describe the syntax of multiple inheritance. When do we use such an inheritance?*

8.8 *What are the implications of the following two definitions?*

(a) *class A: public B, public C{/ /....};*

(b) *class A: public C, public B{/ /....};*

8.9 *What is a virtual base class?*

8.10 *When do we make a class virtual?*

8.11 *What is an abstract class?*

8.12 *In what order are the class constructors called when a derived class object is created?*

8.13 *Class D is derived from class B. The class D does not contain any data members of its own. Does the class D require constructors? If yes, why?*

8.14 *What is containership? How does it differ from inheritance?*

8.15 *Describe how an object of a class that contains objects of other classes created?*

8.16 *State whether the following statements are TRUE or FALSE:*

(a) *Inheritance helps in making a general class into a more specific class.*

(b) *Inheritance aids data hiding.*

(c) *One of the advantages of inheritance is that it provides a conceptual framework.*

(d) *Inheritance facilitates the creation of class libraries.*

(e) *Defining a derived class requires some changes in the base class.*

(f) *A base class is never used to create objects.*

(g) *It is legal to have an object of one class as a member of another class.*

(h) *We can prevent the inheritance of all members of the base class by making base class virtual in the definition of the derived class.*

Debugging Exercises

8.1 Identify the error in the following program.

```
#include <iostream.h>
```

```
class Student {
      char* name;
      int rollNumber;
private:
      Student() {
            name = "AlanKay";
            rollNumber = 1025;
      }
      void setNumber(int no) {
            rollNumber = no;
      }
      int getRollNumber() {
            return rollNumber;
      }
};

class AnualTest: Student {
      int mark1, mark2;
public:
      AnualTest(int m1, int m2)
            :mark1(m1), mark2(m2) {
      }
      int getRollNumber() {
            return Student::getRollNumber();
      }
};

void main()
{
      AnualTest test1(92, 85);
      cout << test1.getRollNumber();
}
```

8.2 Identify the error in the following program.

```
#include <iostream.h>
class A
{
public:
      A()
      {
```

```
                        cout << "A";
                }
        };
        class B: public A
        {
        public:
                B()
                {
                        cout << "B";
                }
        };
        class C: public B
        {
        public:
                C()
                {
                        cout << "C";
                }
        };
        class D
        {
        public:
                D()
                {
                        cout << "D";
                }
        };
        class E: public C, public D
        {
        public:
                E()
                {
                        cout << "D";
                }
        };
        class F: B, virtual E
        {
        public:
                F()
        {
                cout << "F";
        }
};
void main()
{
        F f;
}
```

8.3 Identify the error in the following program.

```
#include <iostream.h>
class A
{
        int i;
};

class AB: virtual A
{
        int j;
};
class AC: A, ABAC
{
        int k;
};
class ABAC: AB, AC
{
        int l;
};
void main()
{
        ABAC abac;
        cout << "sizeof ABAC:" << sizeof(abac);
}
```

8.4 Find errors in the following program. State reasons.

```
// Program test
#include <iostream.h>

class X
```

```
{
        private:
           int x1;
        protected:
           int x2;
        public:
           int x3;
};

class Y: public X
{
        public:
           void f()
           {
                 int y1,y2,y3;
                 y1 = x1;
                 y2 = x2;
                 y3 = x3;
           }
};

class Z: X
{
        public:
           void f()
        *  {
                 int z1,z2,z3;
                 z1 = x1;
                 z2 = x2;
                 z3 = x3;
           }
};
main()
{
              int m,n,p;
              Y y;
              m = y.x1;
              n = y.x2;
              p = y.x3;
              Z z;
              m = z.x1;
              n = z.x2;
              p = z.x3;
}
```

8.5 Debug the following program.

```
// Test program
#include <iostream.h>

class B1
{
        int b1;
  public:
        void display();
        {
                  cout << b1 <<"\n";
        }
};

class B2
{
        int b2;
  public:
        void display();
        {
                  cout << b2 <<"\n";
        }
};
class D: public B1, public B2
{
        // nothing here
};
main()
{
        D d;
        d.display()
        d.B1::display();
        d.B2::display();
}
```

Programming Exercises

8.1 *Assume that a bank maintains two kinds of accounts for customers, one called as savings account and the other as current account. The savings account provides compound interest and withdrawal facilities but no cheque book facility. The current account provides cheque book facility but no interest. Current account holders should also maintain a minimum balance and if the balance falls below this level, a service charge is imposed.*

Create a class ***account*** *that stores customer name, account number and type of account. From this derive the classes* ***cur_acct*** *and* ***sav_acct*** *to make them more specific to their requirements. Include necessary member functions in order to achieve the following tasks:*

(a) *Accept deposit from a customer and update the balance.*

(b) *Display the balance.*

(c) *Compute and deposit interest.*

(d) *Permit withdrawal and update the balance.*

(e) *Check for the minimum balance, impose penalty, necessary, and update the balance.*

Do not use any constructors. Use member functions to initialize the class members.

8.2 *Modify the program of Exercise 8.1 to include constructors for all the three classes.*

8.3 *An educational institution wishes to maintain a database of its employees. The database is divided into a number of classes whose hierarchical relationships are shown in Fig. 8.14. The figure also shows the minimum information required for each class. Specify all the classes and define functions to create the database and retrieve individual information as and when required.*

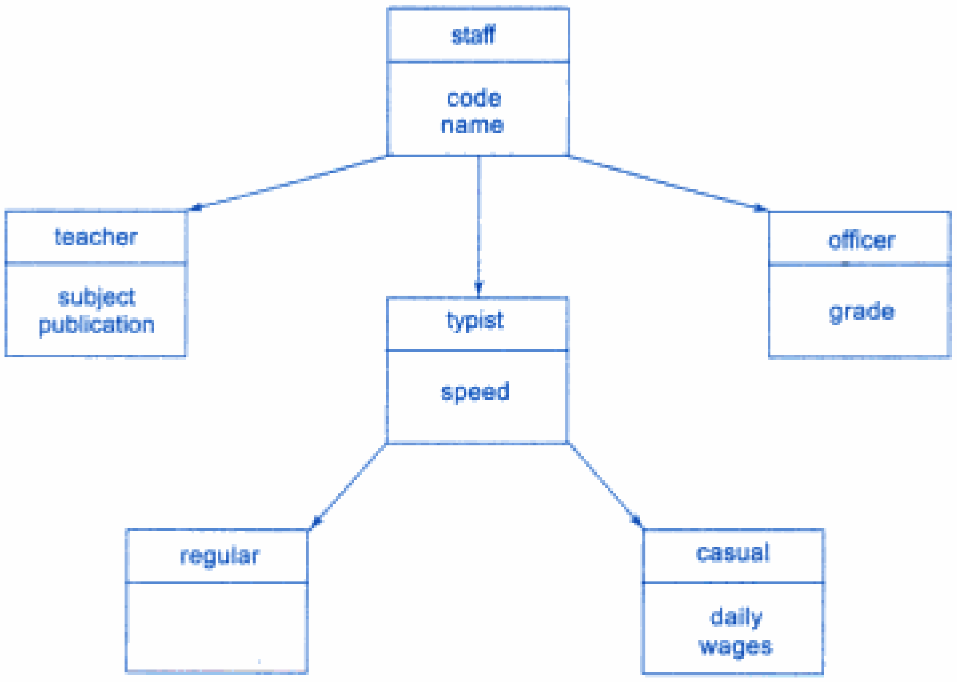


Fig. 8.14 ⇔ Class relationships (for Exercise 8.19)

8.4 *The database created in Exercise 8.3 does not include educational information of the staff. It has been decided to add this information to teachers and officers (and not for typists) which will help the management in decision making with regard to training, promotion, etc. Add another data class called* ***education*** *that holds* *two pieces of educational information, namely, highest qualification in general education and highest professional qualification. This class should be inherited by the classes **teacher** and **officer**. Modify the program of Exercise 8.19 to incorporate these additions.*

8.5 *Consider a class network of Fig. 8.15. The class **master** derives information from both account and admin classes which in turn derive information from the class **person**. Define all the four classes and write a program to create, update and display the information contained in **master** objects.*

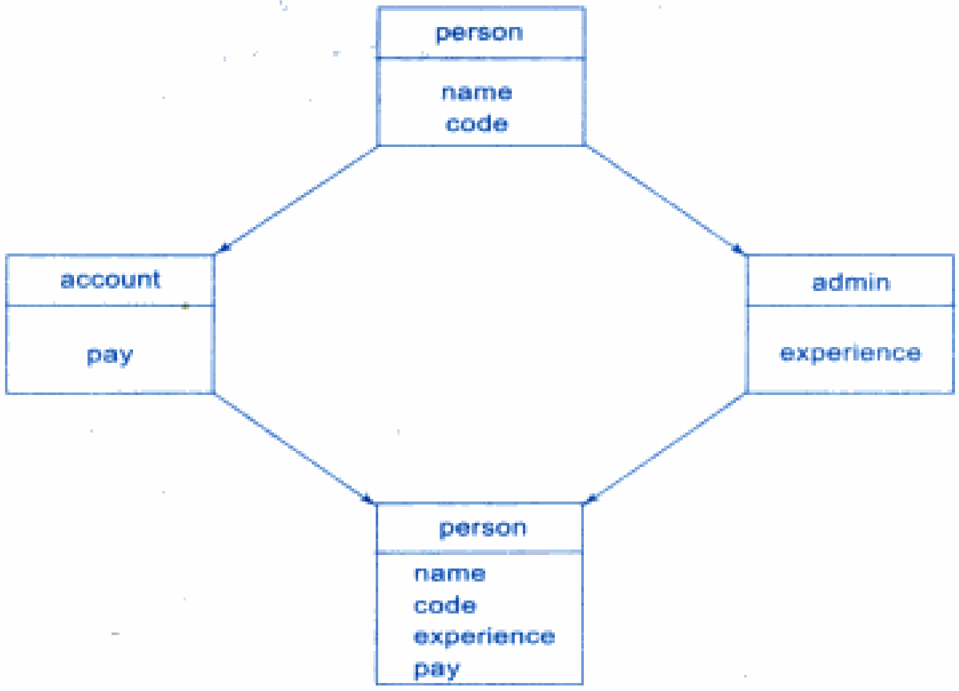


Fig. 8.15 ⇔ *Multipath inheritance (for Exercise 8.21)*

8.6 *In Exercise 8.3, the classes **teacher**, **officer**, and **typist** are derived from the class **staff**. As we know, we can use container classes in place of inheritance in some situations. Redesign the program of Exercise 8.3 such that the classes **teacher**, **officer**, and **typist** contain the objects of **staff**.*

8.7 *We have learned that OOP is well suited for designing simulation programs. Using the techniques and tricks learned so far, design a program that would simulate a simple real-world system familiar to you.*

9

Pointers, Virtual Functions and Polymorphism

Key Concepts

- Polymorphism
- Pointers
- Pointers to objects
- this pointer
- Pointers to derived classes
- Virtual functions
- Pure virtual function

9.1 Introduction

Polymorphism is one of the crucial features of OOP. It simply means 'one name, multiple forms'. We have already seen how the concept of *polymorphism* is implemented using the overloaded functions and operators. The overloaded member functions are 'selected' for invoking by matching arguments, both type and number. This information is known to the compiler at the compile time and, therefore, compiler is able to select the appropriate function for a particular call at the compile time itself. This is called *early binding* or *static binding* or *static linking*. Also known as *compile time polymorphism*, early binding simply means that an object is bound to its function call at compile time.

Now let us consider a situation where the function name and prototype is the same in both the base and derived classes. For example, consider the following class definitions:

```
class A
{
  int x;
 public:
        void show() {....}          // show() in base class
    };
    class B: public A
    {
            int y;
        public:
            void show() {....}      // show() in derived class
    };
```

How do we use the member function **show()** to print the values of objects of both the classes **A** and **B**?. Since the prototype of **show()** is the same in both the places, the function is not overloaded and therefore static binding does not apply. We have seen earlier that, in such situations, we may use the class resolution operator to specify the class while invoking the functions with the derived class objects.

It would be nice if the appropriate member function could be selected while the program is running. This is known as *run time polymorphism*. How could it happen? C++ supports a mechanism known as *virtual function* to achieve run time polymorphism. Please refer Fig. 9.1.

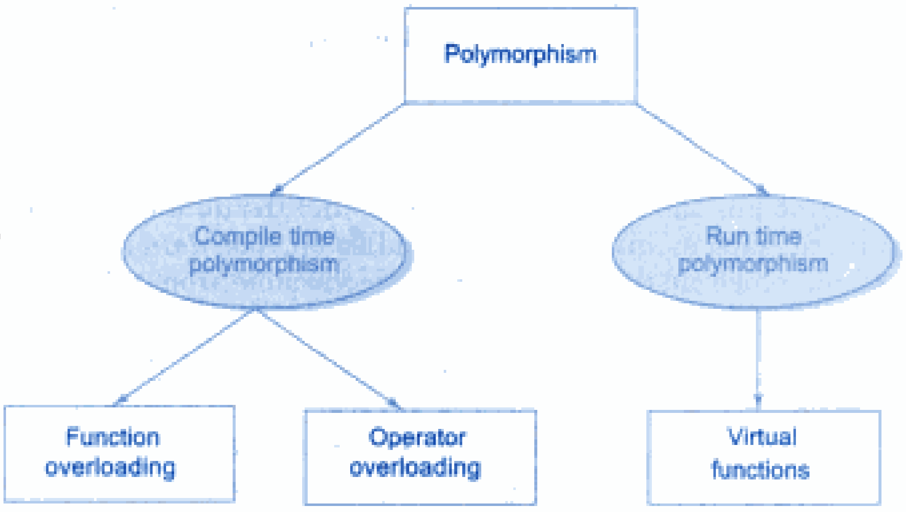


Fig. 9.1 ⇔ *Achieving polymorphism*

At run time, when it is known what class objects are under consideration, the appropriate version of the function is invoked. Since the function is linked with a particular class much later after the compilation, this process is termed as *late binding*. It is also known as *dynamic binding* because the selection of the appropriate function is done dynamically at run time.

Dynamic binding is one of the powerful features of C++. This requires the use of pointers to objects. We shall discuss in detail how the object pointers and virtual functions are used to implement dynamic binding.

9.2 Pointers

Pointers is one of the key aspects of C++ language similar to that of C. As we know, pointers offer a unique approach to handle data in C and C++. We have seen some of the applications of pointers in Chapters 3 and 5. In this section, we shall discuss the rudiments of pointers and the special usage of them in C++.

We know that a pointer is a derived data type that refers to another data variable by storing the variable's memory address rather than data. A pointer variable defines where to get the value of a specific data variable instead of defining actual data.

Like C, a pointer variable can also refer to (or point to) another pointer in C++. However, it often points to a data variable. Pointers provide an alternative approach to access other data objects.

Declaring and Initializing Pointers

As discussed in Chapter 3, we can declare a pointer variable similar to other variables in C++. Like C, the declaration is based on the data type of the variable it points to. The declaration of a pointer variable takes the following form:

```
data-type *pointer-variable;
```

Here, *pointer-variable* is the name of the pointer, and the *data-type* refers to one of the valid C++ data types, such as int, char, float, and so on. The *data-type* is followed by an asterisk (*) symbol, which distinguishes a pointer variable from other variables to the compiler.

note

We can locate asterisk (*) immediately before the pointer variable, or between the data type and the pointer variable, or immediately after the data type. It does not cause any effect in the execution process.

As we know, a pointer variable can point to any type of data available in C++. However, it is necessary to understand that a pointer is able to point to only one data type at the specific time. Let us declare a pointer variable, which points to an integer variable, as follows:

```
int *ptr;
```

Here, **ptr** is a pointer variable and points to an integer data type. The pointer variable, ptr, should contain the memory location of any integer variable. In the same manner, we can declare pointer variables for other data types also.

Like other programming languages, a variable must be initialized before using it in a C++ program. We can initialize a pointer variable as follows:

```
int *ptr, a; // declaration
ptr=&a; // initialization
```

The pointer variable, **ptr**, contains the address of the variable **a**. Like C, we use the 'address of' operator or reference operator i.e. '&' to retrieve the address of a variable. The second statement assigns the address of the variable **a** to the pointer **ptr.**

We can also declare a pointer variable to point to another pointer, similar to that of C. That is, a pointer variable contains address of another pointer. Program 9.1 explains how to refer to a pointer's address by using a pointer in a C++ program.

EXAMPLE OF USING POINTERS

```
#include <iostream.h>
#include <conio.h>
void main()
{
int a, *ptr1, **ptr2;
clrscr();
ptr1 = &a;
ptr2=&ptr1;
cout << "The address of a : " << ptr1 << "\n";
cout << "The address of ptr1 : " << ptr2;
cout << "\n\n";
cout << "After incrementing the address values:\n\n";
ptr1+=2;
cout << "The address of a : " << ptr1 << "\n";
ptr2+=2;
cout << "The address of ptr1 : " << ptr2 << "\n";
}
```

PROGRAM 9.1

The memory location is always addressed by the operating system. The output may vary depends on the system. Output of Program 9.1 would look like:

```
The address of a :      0x8fb6fff4
The address of ptrl:    0x8fb6fff2
After incrementing the address values:
The address of a :      0x8fb6fff8
The address of a :      0x8fb6fff6
```

We can also use *void pointers*, known as generic pointers, which refer to variables of any data type. Before using void pointers, we must type cast the variables to the specific data types that they point to.

note

The pointers, which are not initialized in a program, are called Null pointers. Pointers of any data type can be assigned with one value i.e., '0' called null address.

Manipulation of Pointers

As discussed earlier, we can manipulate a pointer with the indirection operator, i.e. '*', which is also known as dereference operator. With this operator, we can indirectly access the data variable content. It takes the following general form:

```
*pointer_variable
```

As we know, dereferencing a pointer allows us to get the content of the memory location that the pointer points to. After assigning address of the variable to a pointer, we may want to change the content of the variable. Using the dereference operator, we can change the contents of the memory location.

Let us consider an example that illustrates how to dereference a pointer variable. The value associated with the memory address is divided by 2 using the dereference operator. The division affects only the memory contents and not the memory address itself. Program 9.2 illustrates the use of dereference operator in C++.

MANIPULATION OF POINTERS

```
#include <iostream.h>
#include <conio.h>
void main()
```

(Contd)

```
{
int a=10, *ptr;
ptr = &a;
clrscr();
cout << "The value of a is : " << a;
cout << "\n\n";
*ptr=(*ptr)/2;
cout << "The value of a is : " << (*ptr);
cout << "\n\n";
}
```

PROGRAM 9.2

Output of Program 9.2:

```
The value of a is : 10
The value of a is : 5
```

caution

Before dereferencing a pointer, it is essential to assign a value to the pointer. If we attempt to dereference an uninitialized pointer, it will cause runtime error by referring to any other location in memory.

Pointer Expressions and Pointer Arithmetic

As discussed in Chapter 3, there are a substantial number of arithmetic operations that can be performed with pointers. C++ allows pointers to perform the following arithmetic operations:

- A pointer can be incremented (++) (or) decremented (– –)
- Any integer can be added to or subtracted from a pointer
- One pointer can be subtracted from another

Example:

```
int a[6];
int *aptr;
aptr=&a[0];
```

Obviously, the pointer variable, **aptr**, refers to the base address of the variable **a**. We can increment the pointer variable, shown as follows:

```
aptr++ (or) ++aptr
```

This statement moves the pointer to the next memory address. Similarly, we can decrement the pointer variable, as follows:

```
aptr-- (or) --aptr
```

This statement moves the pointer to the previous memory address. Also, if two pointer variables point to the same array can be subtracted from each other.

We cannot perform pointer arithmetic on variables which are not stored in contiguous memory locations. Program 9.3 illustrates the arithmetic operations that we can perform with pointers.

ARITHMETIC OPERATIONS ON POINTERS

```
#include<iostream.h>
#include<conio.h>
void main()
{
        int num[]={56,75,22,18,90};
        int *ptr;
        int i;
        clrscr();
        cout << "The array values are:\n";
        for(i=0;i<5;i++)
                    cout<< num[i]<<"\n";
        /* Initializing the base address of str to ptr */
        ptr = num;
        /* Printing the value in the array */
        cout << "\nValue of ptr    : "<< *ptr;
        cout << "\n";
        ptr++;
        cout<<"\nValue of ptr++    : "<<*ptr;
        cout << "\n";
        ptr--;
        cout<<"\nValue of ptr--    : "<<*ptr;
        cout << "\n";
        ptr=ptr+2;
```

(Contd)

```
        cout<<"\nValue of ptr+2   : "<<*ptr;
        cout << "\n";
        ptr=ptr-1;
        cout <<"\nValue of ptr-1: "<< *ptr;
        cout << "\n";
        ptr+=3;
        cout<<"\nValue of ptr+=3: "<<*ptr;
        ptr-=2;
        cout << "\n";
        cout<<"\nValue of ptr-=2: "<<*ptr;
        cout << " \n";
        getch();
}
```

PROGRAM 9.3

Output of Program 9.3:

```
The array values are:
56
75
22
18
90
Value of ptr     :  56
Value of ptr++   :  75
Value of ptr--   :  56
Value of ptr+2   :  22
Value of ptr-1   :  75
Value of ptr+=3  :  90
Value of ptr-=2  :  22
```

Using Pointers with Arrays and Strings

Pointer is one of the efficient tools to access elements of an array. Pointers are useful to allocate arrays dynamically, i.e. we can decide the array size at run time. To achieve this, we use the functions, namely **malloc()** and **calloc()**, which we already discussed in Chapter 3. Accessing an array with pointers is simpler than accessing the array index.

In general, there are some differences between pointers and arrays; arrays refer to a block of memory space, whereas pointers do not refer to any section of memory. The memory addresses of arrays cannot be changed, whereas the content of the pointer variables, such as the memory addresses that it refer to, can be changed.

Even though there are subtle differences between pointers and arrays, they have a strong relationship between them.

note

There is no error checking of array bounds in C++. Suppose we declare an array of size 25. The compiler issues no warnings if we attempt to access 26th location. It is the programmer's task to check the array limits.

We can declare the pointers to arrays as follows:

```
int *nptr;
nptr=number[0];
```

Or

```
nptr=number;
```

Here, **nptr** points to the first element of the integer array, number[0]. Also, consider the following example:

```
float *fptr;
fptr=price[0];
```

Or

```
fptr=price;
```

Here, **fptr** points to the first element of the array of float, price[0]. Let us consider an example of using pointers to access an array of numbers and sum up the even numbers of the array. Initially, we accept the count as an input to know the number of inputs from the user. We use pointer variable, ptr to access each element of the array. The inputs are checked to identify the even numbers. Then the even numbers are added, and stored in the variable, sum. If there is no even number in the array, the output will be 0. Program 9.4 illustrates how to access the array contents using pointers.

POINTERS WITH ARRAYS

```
#include <iostream.h>
void main()
{
          int numbers[50], *ptr;
          int n,i;
          cout << "\nEnter the count\n";
          cin >> n;
```

(Contd)

```
          cout << "\nEnter the numbers one by one\n";
          for(i=0;i<n;i++)
          cin >> numbers[i];
          /* Assigning the base address of numbers to ptr and initializing
          the sum to 0*/
          ptr = numbers;
          int sum=0;
          /* Check out for even inputs and sum up them*/
          for(i=0;i<n;i++)
      {
          if (*ptr%2==0)
               sum=sum+*ptr;
          ptr++;
      }

      cout << "\n\nSum of even numbers: " << sum;
   }
```

PROGRAM 9.4

Output of Program 9.4:

```
Enter the count
5
Enter the numbers one by one
10
16
23
45
34
Sum of even numbers:    60
```

Arrays of Pointers

Similar to other variables, we can create an array of pointers in C++. The array of pointers represents a collection of addresses. By declaring array of pointers, we can save a substantial amount of memory space.

An array of pointers point to an array of data items. Each element of the pointer array points to an item of the data array. Data items can be accessed either directly or by dereferencing the elements of pointer array. We can reorganize the pointer elements without affecting the data items.

We can declare an array of pointers as follows:

```
int *inarray[10];
```

This statement declares an array of 10 pointers, each of which points to an integer. The address of the first pointer is inarray[0], and the second pointer is inarray[1], and the final pointer points to inarray[9]. Before initializing, they point to some unknown values in the memory space. We can use the pointer variable to refer to some specific values. Program 9.5 explains the implementation of array of pointers.

ARRAYS OF POINTERS

```
#include <iostream.h>
#include <conio.h>
#include <string.h>
#include <ctype.h>
void main()
{
      int i=0;
      char *ptr[10] = {
              "books",
              "television",
              "computer",
              "sports"
              };
      char str[25];
      clrscr();
      cout << "\n\n\n\nEnter your favorite leisure pursuit: " ;
      cin >> str;
      for(i=0; i<4; i++)
      {
              if(!strcmp(str, *ptr[i]))
              {
              cout << "\n\nYour favorite pursuit " << " is available here"
              << endl;
              break;
              }
```

(Contd)

```
    }
    if(i==4)
        cout << "\n\nYour favorite " << " not available here" << endl;
   getch();
}
```

PROGRAM 9.5

Output of Program 9.5:

```
Enter your favorite leisure pursuit: books
Your favorite pursuit is available here
```

Pointers and Strings

We have seen the usage of pointers with one dimensional array elements. However, pointers are also efficient to access two dimensional and multi-dimensional arrays in C++. There is a definite relationship between arrays and pointers. C++ also allows us to handle the special kind of arrays, i.e. strings with pointers.

We know that a string is one dimensional array of characters, which start with the index 0 and ends with the null character '\0' in C++. A pointer variable can access a string by referring to its first character. As we know, there are two ways to assign a value to a string. We can use the character array or variable of type char *. Let us consider the following string declarations:

```
char num[]="one";
const char *numptr= "one";
```

The first declaration creates an array of four characters, which contains the characters, 'o','n','e','\0', whereas the second declaration generates a pointer variable, which points to the first character, i.e. 'o' of the string. There is numerous string handling functions available in C++. All of these functions are available in the header file <cstring>.

Program 9.6 shows how to reverse a string using pointers and arrays.

ACCESSING STRINGS USING POINTERS AND ARRAYS

```
#include <iostream.h>
#include <string.h>
void main()
```

(Contd)

```
{
    char str[] = "Test";
    int len = strlen(str);
    for(int i=0; i<len; i++)
    {
            cout << str[i] << i[str] << *(str+i) << *(i+str);
    }
    cout << endl;
    //String reverse
    int lenM = len / 2;
    len--;
    for(i=0; i<lenM; i++)
    {
            str[i]     = str[i] + str[len-i];
            str[len-i] = str[i] - str[len-i];
            str[i]     = str[i] - str[len-i];
    }
    cout << " The string reversed : "  << str;
    }
```

PROGRAM 9.6

Output of Program 9.6:

```
TTTTeeeesssstttt
The string reversed : tseT
```

Pointers to Functions

Even though pointers to functions (or function pointers) are introduced in C, they are widely used in C++ for dynamic binding, and event-based applications. The concept of pointer to function acts as a base for pointers to members, which we have discussed in Chapter 5.

The pointer to function is known as callback function. We can use these function pointers to refer to a function. Using function pointers, we can allow a C++ program to select a function dynamically at run time. We can also pass a function as an argument to another function. Here, the function is passed as a pointer. The function pointers cannot be dereferenced. C++ also allows us to compare two function pointers.

C++ provides two types of function pointers; function pointers that point to static member functions and function pointers that point to non-static member functions. These two function pointers are incompatible with each other. The function pointers that point to the non-static member function requires hidden argument.

Like other variables, we can declare a function pointer in C++. It takes the following form:

```
data_type(*function_name)();
```

As we know, the data_type is any valid data types used in C++. The function_name is the name of a function, which must be preceded by an asterisk (*). The function_name is any valid name of the function.

Example:

```
int (*num_function(int x));
```

Remember that declaring a pointer only creates a pointer. It does not create actual function. For this, we must define the task, which is to be performed by the function. The function must have the same return type and arguments. Program 9.7 explains how to declare and define function pointers in C++.

POINTERS TO FUNCTIONS

```
#include <iostream.h>
typedef void (*FunPtr)(int, int);
void Add(int i, int j)
{
     cout << i << " + " << j << " = " << i + j;
}
void Subtract(int i, int j)
{
     cout << i << " - " << j << " = " << i - j;
}
void main()
{
     FunPtr ptr;
     ptr = &Add;
     ptr(1,2);
     cout << endl;
     ptr = &Subtract;
     ptr(3,2);
}
```

PROGRAM 9.7

Output of Program 9.7:

```
1 + 2 = 3
3 - 2 = 1
```

9.3 Pointers to Objects

We have already seen how to use pointers to access the class members. As stated earlier, a pointer can point to an object created by a class. Consider the following statement:

```
item x;
```

where **item** is a class and x is an object defined to be of type item. Similarly we can define a pointer **it_ptr** of type **item** as follows:

```
item *it_ptr;
```

Object pointers are useful in creating objects at run time. We can also use an object pointer to access the public members of an object. Consider a class **item** defined as follows:

```
class item
{
      int code;
      float price;
   public:

      void getdata(int a, float b)
      {
         code = a;
         price = b;
      }

      void show(void)
      {
          cout << "Code : " << code << "\n";
                << "Price: " << price << "\n\n";
      }
};
```

Let us declare an **item** variable **x** and a pointer **ptr** to **x** as follows:

```
item x;
item *ptr = &x;
```

The pointer **ptr** is initialized with the address of **x**.

We can refer to the member functions of **item** in two ways, one by using the *dot operator* and *the object*, and another by using the *arrow operator* and the *object pointer*. The statements

```
x.getdata(100,75.50);
x.show();
```

are equivalent to

```
ptr->getdata(100, 75.50);
ptr->show();
```

Since ***ptr** is an alias of **x**, we can also use the following method:

```
(*ptr).show();
```

The parentheses are necessary because the dot operator has higher precedence than the *indirection operator* *.

We can also create the objects using pointers and **new** operator as follows:

```
item *ptr = new item;
```

This statement allocates enough memory for the data members in the object structure and assigns the address of the memory space to **ptr**. Then **ptr** can be used to refer to the members as shown below:

```
ptr -> show();
```

If a class has a constructor with arguments and does not include an empty constructor, then we must supply the arguments when the object is created.

We can also create an array of objects using pointers. For example, the statement

```
item *ptr = new item[10];      // array of 10 objects
```

creates memory space for an array of 10 objects of **item**. Remember, in such cases, if the class contains constructors, it must also contain an empty constructor.

Program 9.8 illustrates the use of pointers to objects.

POINTERS TO OBJECTS

```
#include <iostream>

using namespace std;

class item
{
        int code;
        float price;
    public:
        void getdata(int a, float b)
        {
                code = a;
                price = b;
        }

        void show(void)
        {
                cout << "Code : " << code << "\n";
                cout << "Price: " << price << "\n";
        }
};

const int size = 2;

int main()
{
        item *p = new item [size];
        item *d = p;
        int x, i;
        float y;

        for(i=0; i<size; i++)
        {
                cout << "Input code and price for item" << i+1;
                cin >> x >> y;
                p->getdata(x,y);
                p++;
        }

        for(i=0; i<size; i++)
        {
                cout << "Item:" << i+1 << "\n";
```

(Contd)

```
                d->show();
                d++;
            }

            return 0;
        }
```

PROGRAM 9.8

The output of Program 9.8 will be:

```
Input code and price for item1 40 500
Input code and price for item2 50 600
Item:1
Code : 40
Price: 500
Item:2
Code : 50
Price: 600
```

In Program 9.8 we created space dynamically for two objects of equal size. But this may not be the case always. For example, the objects of a class that contain character strings would not be of the same size. In such cases, we can define an array of pointers to objects that can be used to access the individual objects. This is illustrated in Program 9.9.

ARRAY OF POINTERS TO OBJECTS

```
    #include <iostream>
    #include <cstring>

    using namespace std;

    class city
    {
      protected:
            char *name;
            int len;
      public:
            city()

            {
                    len = 0;
                    name = new char[len+1];
```

(Contd)

```
        }
        void getname(void)
        {
                char *s;
                s = new char[30];

                cout << "Enter city name:";
                cin >> s;
                len = strlen(s);
                name = new char[len + 1];
                strcpy(name, s);
        }
        void printname(void)
        {
                cout << name << "\n";
        }
};

int main()
{
        city *cptr[10];                 // array of 10 pointers to cities

        int n = 1;
        int option;

        do
        {
                cptr[n] = new city;   // create new city
                cptr[n]->getname();
                n++;
                cout << "Do you want to enter one more name?\n";
                cout << "(Enter 1 for yes 0 for no):";
                cin >> option;
        }
        while(option);

        cout << "\n\n";
        for(int i=1; i<=n; i++)
        {
                cptr[i]->printname();
        }

        return 0;
}
```

PROGRAM 9.9

The output of Program 9.9 would be:

```
Enter city name:Hyderabad
Do you want to enter one more name?
(Enter 1 for yes 0 for no);1
Enter city name:Secunderabad
Do you want to enter one more name?
(Enter 1 for yes 0 for no);1
Enter city name:Malkajgiri
Do you want to enter one more name?
(Enter 1 for yes 0 for no);0

Hyderabad
Secunderabad
Malkajgiri
```

9.4 this Pointer

C++ uses a unique keyword called **this** to represent an object that invokes a member function. **this** is a pointer that points to the object for which *this* function was called. For example, the function call **A.max()** will set the pointer **this** to the address of the object **A**. The starting address is the same as the address of the first variable in the class structure.

This unique pointer is automatically passed to a member function when it is called. The pointer **this** acts as an *implicit* argument to all the member functions. Consider the following simple example:

```
class ABC
{
      int a;
      .....
      .....
};
```

The private variable 'a' can be used directly inside a member function, like

```
a = 123;
```

We can also use the following statement to do the same job:

```
this->a = 123;
```

Since C++ permits the use of shorthand form **a = 123**, we have not been using the pointer **this** explicitly so far. However, we have been implicitly using the pointer **this** when overloading the operators using member function.

Recall that, when a binary operator is overloaded using a member function, we pass only one argument to the function. The other argument is implicitly passed using the pointer **this**. One important application of the pointer **this** is to return the object it points to. For example, the statement

```
return *this;
```

inside a member function will return the object that invoked the function. This statement assumes importance when we want to compare two or more objects inside a member function and return the *invoking object* as a result. Example:

```
person & person :: greater(person & x)
{
        if x.age > age
            return x;                    // argument object
        else
             return *this;             // invoking object
}
```

Suppose we invoke this function by the call

```
max = A.greater(B);
```

The function will return the object **B** (argument object) if the age of the person **B** is greater than that of **A**, otherwise, it will return the object **A** (invoking object) using the pointer **this**. Remember, the dereference operator * produces the contents at the address contained in the pointer. A complete program to illustrate the use of **this** is given in Program 9.10.

this POINTER

```
#include <iostream>
#include <cstring>

using namespace std;

class person
{
        char name[20];
        float age;
  public:
        person(char *s, float a)
        {
```

(Contd)

```
                        strcpy(name, s);
                        age = a;
                }
                person & person :: greater(person & x)

                {
                        if(x.age >= age)
                                return x;
                        else
                                return *this;
                }

                void display(void)
                {
                        cout << "Name: " << name << "\n"
                             << "Age:  " << age << "\n";
                }
        };

        int main()
        {
                person P1("John", 37.50),
                        P2("Ahmed", 29.0),
                        P3("Hebber", 40.25);

                person P = P1.greater(P3);          // P3.greater(P1)
                cout << "Elder person is: \n";
                P.display();

                P = P1.greater(P2);                 // P2.greater(P1)
                cout << "Elder person is: \n";
                P.display();

                return 0;
        }
```

PROGRAM 9.10

The output of Program 9.10 would be:

```
Elder person is:
Name: Hebber
Age:  40.25
Elder person is:
Name: John
Age:  37.5
```

9.5 Pointers to Derived Classes

We can use pointers not only to the base objects but also to the objects of derived classes. Pointers to objects of a base class are type-compatible with pointers to objects of a derived class. Therefore, a single pointer variable can be made to point to objects belonging to different classes. For example, if **B** is a base class and **D** is a derived class from **B**, then a pointer declared as a pointer to **B** can also be a pointer to **D**. Consider the following declarations:

```
B *cptr;          // pointer to class B type variable
B  b;             // base object
D  d;             // derived object
cptr = &b;        // cptr points to object b
```

We can make **cptr** to point to the object **d** as follows:

```
cptr = &d;        // cptr points to object d
```

This is perfectly valid with C++ because **d** is an object derived from the class **B**.

However, there is a problem in using **cptr** to access the public members of the derived class **D**. Using **cptr**, we can access only those members which are inherited from **B** and not the members that originally belong to **D**. In case a member of **D** has the same name as one of the members of **B**, then any reference to that member by **cptr** will always access the base class member.

Although C++ permits a base pointer to point to any object derived from that base, the pointer cannot be directly used to access all the members of the derived class. We may have to use another pointer *declared* as pointer to the derived type.

Program 9.11 illustrates how pointers to a derived object are used.

POINTERS TO DERIVED OBJECTS

```
#include <iostream>

using namespace std;

class BC
{
  public:
      int b;
      void show()
      { cout << "b = " << b << "\n";}
};
```

(Contd)

```
class DC : public BC

{
  public:
      int d;
      void show()
      { cout << "b = " << b << "\n"
             << "d = " << d << "\n";
      }
};

int main()
{
      BC *bptr;                  // base pointer
      BC base;
      bptr = &base;              // base address

      bptr->b = 100;             // access BC via base pointer
      cout << "bptr points to base object \n";
      bptr -> show();
      // derived class
      DC derived;
      bptr = &derived;           // address of derived object
      bptr -> b = 200;           // access DC via base pointer

      /* bptr -> d = 300;*/      // won't work
      cout << "bptr now points to derived object \n";
      bptr -> show();            // bptr now points to derived object

      /* accessing d using a pointer of type derived class DC */

      DC *dptr;                  // derived type pointer
      dptr = &derived;
      dptr->d = 300;

      cout << "dptr is derived type pointer\n";
      dptr -> show();

      cout << "using ((DC *)bptr)\n";
      ((DC *)bptr) -> d = 400;
      ((DC *)bptr) -> show();

      return 0;
}
```

PROGRAM 9.11

Program 9.11 produces the following output:

```
bptr points base object
b = 100
bptr now points to derived object
b = 200
dptr is derived type pointer
b = 200
d = 300
using ((DC *)bptr)
b = 200
d = 400
```

note

We have used the statement

```
bptr -> show();
```

two times. First, when **bptr** points to the base object, and second when **bptr** is made to point to the derived object. But, both the times, it executed **BC::show()** function and displayed the content of the base object. However, the statements

```
dptr -> show();
((DC *) bptr) -> show();       // cast bptr to DC type
```

display the contents of the **derived** object. This shows that, although a base pointer can be made to point to any number of derived objects, it cannot directly access the members defined by a derived class.

9.6 Virtual Functions

As mentioned earlier, polymorphism refers to the property by which objects belonging to different classes are able to respond to the same message, but in different forms. An essential requirement of polymorphism is therefore the ability to refer to objects without any regard to their classes. This necessitates the use of a single pointer variable to refer to the objects of different classes. Here, we use the pointer to base class to refer to all the derived objects. But, we just discovered that a base pointer, even when it is made to contain the address of a derived class, always executes the function in the base class. The compiler simply ignores the contents of the pointer and chooses the member function that matches the type of the pointer. How do we then achieve polymorphism?. It is achieved using what is known as 'virtual' functions.

When we use the same function name in both the base and derived classes, the function in base class is declared as *virtual* using the keyword **virtual** preceding its normal declaration. When a function is made **virtual, C++** determines which function to use at run time based on the type of object pointed to by the base pointer, rather than the type of the pointer. Thus, by making the base pointer to point to different objects, we can execute different versions of the **virtual** function. Program 9.12 illustrates this point.

VIRTUAL FUNCTIONS

```
#include <iostream>

using namespace std;

class Base
{
  public:
       void display() {cout << "\n Display base ";}
       virtual void show() {cout << "\n show base";}
};
class Derived : public Base
{
  public:
       void display() {cout << "\n Display derived";}
       void show() {cout << "\n show derived";}
};

int main()
{
       Base B;
       Derived D;
       Base *bptr;

       cout << "\n bptr points to Base \n";
       bptr = &B;
       bptr -> display();   // calls Base version
       bptr -> show();      // calls Base version

       cout << "\n\n bptr points to Derived\n";
       bptr = &D;
       bptr -> display();   // calls Base version
       bptr -> show();      // calls Derived version

       return 0;
}
```

PROGRAM 9.12

The output of Program 9.12 would be:

```
bptr points to Base

Display base
Show base

bptr points to Derived

Display base
Show derived
```

note

When **bptr** is made to point to the object **D**, the statement

```
bptr -> display();
```

calls only the function associated with the **Base** (i.e. **Base :: display( )**), whereas the statement

```
bptr -> show();
```

calls the **Derived** version of **show()**. This is because the function **display()** has not been made **virtual** in the **Base** class.

One important point to remember is that, we must access **virtual** functions through the use of a pointer declared as a pointer to the base class. Why can't we use the object name (with the dot operator) the same way as any other member function to call the virtual functions?. We can, but remember, run time polymorphism is achieved only when a virtual function is accessed through a pointer to the base class.

Let us take an example where **virtual** functions are implemented in practice. Consider a book shop which sells both books and video-tapes. We can create a class known as **media** that stores the title and price of a publication. We can then create two derived classes, one for storing the number of pages in a book and another for storing the playing time of a tape. Figure 9.2 shows the class hierarchy for the book shop.

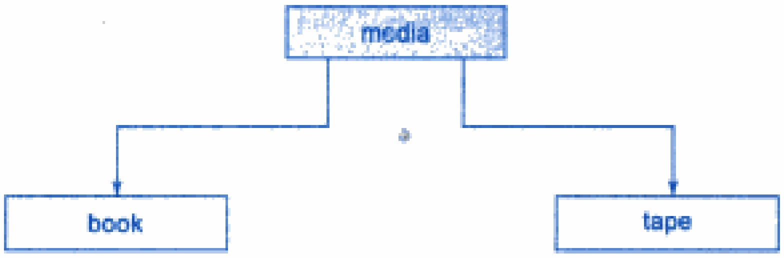


Fig. 9.2 ⇔ *The class hierarchy for the book shop*

The classes are implemented in Program 9.13. A function **display()** is used in all the classes to display the class contents. Notice that the function **display()** has been declared virtual in media, the base class.

In the **main** program we create a heterogeneous list of pointers of type **media** as shown below:

```
media *list[2] = { &book1, &tape1};
```

The base pointers **list[0]** and **list[1]** are initialized with the addresses of objects **book1** and **tape1** respectively.

RUNTIME POLYMORPHISM

```
#include <iostream>
#include <cstring>

using namespace std;

class media
{
  protected:
        char  title[50];
        float price;
  public:
        media(char *s, float a)
        {
              strcpy(title, s);
              price = a;
        }
        virtual void display() { }  // empty virtual function
};

class book: public media
{
        int pages;
  public:
        book(char *s, float a, int p):media(s,a)
        {
              pages = p;
        }
        void display();
};
```

(Contd)

```
class tape :public media
{
        float time;
  public:
        tape(char * s, float a, float t):media(s, a)
        {
                time = t;
        }
        void display();
};

void book :: display()
{
        cout << "\n Title: " << title;
        cout << "\n Pages: " << pages;
        cout << "\n Price: " << price;
}
void tape :: display()
{
        cout << "\n Title: " << title;
        cout << "\n play time: " << time << "mins";
        cout << "\n price: " << price;
}

int main()
{
        char * title = new char[30];
        float price, time;
        int pages;

        // Book details
        cout << "\n ENTER BOOK DETAILS\n";
        cout << " Title:"; cin >> title;
        cout << " Price: "; cin >> price;
        cout << " Pages: "; cin >> pages;

        book book1(title, price, pages);

        // Tape details
        cout << "\n ENTER TAPE DETAILS\n";
        cout << " Title: "; cin >> title;
        cout << " Price: "; cin >> price;
        cout << " Play time (mins): "; cin >> time;
```

(Contd)

```
          tape tape1(title, price, time);

          media* list[2];
          list[0] = &book1;
          list[1] = &tape1;

          cout << "\n MEDIA DETAILS";

          cout << "\n ......BOOK......";
          list[0] -> display();// display book details

          cout << "\n ......TAPE......";
          list[1] -> display();// display tape details

          result 0;
    }
```

PROGRAM 9.13

The output of Program 9.13 would be:

```
ENTER BOOK DETAILS
Title:Programming_in_ANSI_C
Price: 88
Pages: 400

ENTER TAPE DETAILS
Title: Computing_Concepts
Price: 90
Play time (mins): 55

MEDIA DETAILS
......BOOK......
Title:Programming_in_ANSI_C
Pages: 400
Price: 88

.....TAPE......
Title: Computing_Concepts
Play time: 55mins
Price: 90
```

Rules for Virtual Functions

When virtual functions are created for implementing late binding, we should observe some basic rules that satisfy the compiler requirements:

1. The virtual functions must be members of some class.
2. They cannot be static members.
3. They are accessed by using object pointers.
4. A virtual function can be a friend of another class.
5. A virtual function in a base class must be defined, even though it may not be used.
6. The prototypes of the base class version of a virtual function and all the derived class versions must be identical. If two functions with the same name have different prototypes, C++ considers them as overloaded functions, and the virtual function mechanism is ignored.
7. We cannot have virtual constructors, but we can have virtual destructors.
8. While a base pointer can point to any type of the derived object, the reverse is not true. That is to say, we cannot use a pointer to a derived class to access an object of the base type.
9. When a base pointer points to a derived class, incrementing or decrementing it will not make it to point to the next object of the derived class. It is incremented or decremented only relative to its base type. Therefore, we should not use this method to move the pointer to the next object.
10. If a virtual function is defined in the base class, it need not be necessarily redefined in the derived class. In such cases, calls will invoke the base function.

9.7 Pure Virtual Functions

It is normal practice to declare a function virtual inside the base class and redefine it in the derived classes. The function inside the base class is seldom used for performing any task. It only serves as a *placeholder*. For example, we have not defined any object of class media and therefore the function display() in the base class has been defined 'empty'. Such functions are called "do-nothing" functions.

A "do-nothing" function may be defined as follows:

```
virtual void display() = 0;
```

Such functions are called *pure virtual* functions. A pure virtual function is a function declared in a base class that has no definition relative to the base class. In such cases, the compiler requires each derived class to either define the function or redeclare it as a pure virtual function. Remember that a class containing pure virtual functions cannot be used to declare any objects of its own. As stated earlier, such classes are called *abstract base classes*. The main objective of an abstract base class is to provide some traits to the derived classes and to create a base pointer required for achieving run time polymorphism.

SUMMARY

⇔ Polymorphism simply means one name having multiple forms.

⇔ There are two types of polymorphism, namely, compile time polymorphism and run time polymorphism.

⇔ Functions and operators overloading are examples of compile time polymorphism. The overloaded member functions are selected for invoking by matching arguments, both type and number. The compiler knows this information at the compile time and, therefore, compiler is able to select the appropriate function for a particular call at the compile time itself. This is called early or static binding or static linking. It means that an object is bound to its function call at compile time.

⇔ In run time polymorphism, an appropriate member function is selected while the program is running. C++ supports run time polymorphism with the help of virtual functions. It is called late or dynamic binding because the appropriate function is selected dynamically at run time. Dynamic binding requires use of pointers to objects and is one of the powerful features of C++.

⇔ Object pointers are useful in creating objects at run time. It can be used to access the public members of an object, along with an arrow operator.

⇔ A **this** pointer refers to an object that currently invokes a member function. For example, the function call **a.show()** will set the pointer 'this' to the address of the object 'a'.

⇔ Pointers to objects of a base class type are compatible with pointers to objects of a derived class. Therefore, we can use a single pointer variable to point to objects of base class as well as derived classes.

⇔ When a function is made virtual, C++ determines which function to use at run time based on the type of object pointed to by the base pointer, rather than the type of the pointer. By making the base pointer to point to different objects, we can execute different versions of the virtual function.

⇔ Run time polymorphism is achieved only when a virtual function is accessed through a pointer to the base class. It cannot be achieved using object name along with the dot operator to access virtual function.

⇔ We can have virtual destructors but not virtual constructors.

⇔ If a virtual function is defined in the base class, it need not be necessarily redefined in the derived class. In such cases, the respective calls will invoke the base class function.

⇔ A virtual function, equated to zero is called a pure virtual function. It is a function declared in a base class that has no definition relative to the base class. A class containing such pure function is called an abstract class.

Key Terms

- Abstract base classes
- 'address of' operator
- argument object
- arrays of pointers
- arrow operator
- base address
- base object
- base pointer
- call back function
- class hierarchy
- compile time
- compile time polymorphism
- dereference operator
- Derived object
- do-nothing function
- dot operator
- dynamic binding
- early binding
- function overloading
- function pointer
- Implicit argument
- indirection operator
- invoking object
- late binding
- **new** operator
- Null pointers
- object pointer
- operator overloading
- placeholder
- pointers
- pointer arithmetic
- pointers to functions
- polymorphism
- pure virtual function
- run time
- run time polymorphism
- static binding
- static linking
- **this** pointer
- virtual constructors
- virtual destructors
- virtual function
- void pointers

Review Questions

9.1 *What does polymorphism mean in C++ language?*

9.2 *How is polymorphism achieved at (a) compile time, and (b) run time?*

9.3 *Discuss the different ways by which we can access public member functions of an object.*

9.4 *Explain, with an example, how you would create space for an array of objects using pointers.*

9.5 *What does **this** pointer point to?*

9.6 *What are the applications of **this** pointer?*

9.7 *What is a virtual function?*

9.8 *Why do we need virtual functions?*

9.9 *When do we make a virtual function "pure"? What are the implications of making a function a pure virtual function?*

9.10 *State which of the following statements are TRUE or FALSE.*

(a) *Virtual functions are used to create pointers to base classes.*

(b) *Virtual functions allow us to use the same function call to invoke member functions of objects of different classes.*

(c) *A pointer to a base class cannot be made to point to objects of derived class.*

(d) ***this** pointer points to the object that is currently used to invoke a function.*

(e) ***this** pointer can be used like any other pointer to access the members of the object it points to.*

(f) ***this** pointer can be made to point to any object by assigning the address of the object.*

(g) *Pure virtual functions force the programmer to redefine the virtual function inside the derived classes.*

Debugging Exercises

9.1 Identify the error in the following program.

```
#include <iostream.h>
class Info
{
     char *name;
     int number;
public:
     void getInfo()
     {
          cout << "Info::getInfo ";
          getName();
     }

     void getName()
     {
          cout << "Info::getName ";
     }
};
```

```
class Name: public Info
{
    char *name;
public:
    void getName()
    {
          cout << "Name::getName ";
    }
};

void main()
{
    Info *p;
    Name n;
    p = n;
    p->getInfo();
}
/*
```

9.2 Identify the error in the following program.

```
#include <iostream.h>
class Person
{
    int age;
public:
    Person()
    {
    }
    Person(int age)
    {
          this.age = age;
    }
    Person& operator < (Person &p)
    {
          return age < p.age ? p: *this;
    }
    int getAge()
    {
          return age;
```

```
        }
};
Void main ()
{
        Person P1 (15);
        Person P2 (11);
        Person P3;
        //if p1 is less than p2
        p3 = p1 < p2; p1. lessthan(p2)
        cout << p3.getAge();
}
/*
```

9.3 Identify the error in the following program.

```
#include "iostream.h"

class Human
{
public:
        Human()
        {
        }

        virtual -Human()
        {
                cout << "Human::-Human";
        }
};

class Student: public Human
{
public:
        Student()
        {
        }
        ~Student()
        {
                cout << "Student::-Student()";
        }
};

void main()
{
     Human *H = new Student();
     delete H;
}
```

9.4 Correct the errors in the following program.

```
class test
{
   private:
        int m;
   public:
        void getdata()
        {
             cout <<"Enter number:";
             cin >> m;
        }
        void display()
        {
             cout << m;
        }
};

main()
{
        test T;
        T->getdata();
        T->display();

        test *p;
        p = new test;
        p.getdata();
        (*p).display();
}
```

9.5 Debug and run the following program. What will be the output?

```
#include <iostream.h>
class A
{
  protected:
```

```
            int a,b;
        public:
            A(int x = 0, int y)
            {
              a = x;
              b = y;
            }
            virtual void print();
    };
    class B: public A
    {
      private:
         float p,q;
      public:
         B(int m, int n, float u, float v)
          {
              p = u;
              q = v;
          }
          B() {p = q = 0;}
          void input(float u, float v);
          virtual void print(float);
    };
    void A::print(void)
    {
         cout << A values: << a <<""<< b <<"\n";
    }
    void B::print(float)
    {
         cout <<B values:<< u <<""<< v <<"\n";
    }
    void B::input(float x, float y)
    {
          p = x;
          q = y;
     }
    main()
    {
          A a1(10,20), *ptr;
          B b1;
          b1.input(7.5,3.142);
          ptr = &a1;
          ptr->print();

          ptr = &b1;
          ptr->print();
        }
```

Programming Exercises

9.1 *Create a base class called* **shape**. *Use this class to store two* **double** *type values that could be used to compute the area of figures. Derive two specific classes called* **triangle** *and* **rectangle** *from the base* **shape**. *Add to the base class, a member function* **get_data()** *to initialize base class data members and another member function* **display_area()** *to compute and display the area of figures. Make* **display_area()** *as a virtual function and redefine this function in the derived classes to suit their requirements.*

Using these three classes, design a program that will accept dimensions of a triangle or a rectangle interactively, and display the area.

Remember the two values given as input will be treated as lengths of two sides in the case of rectangles, and as base and height in the case of triangles, and used as follows:

```
Area of rectangle = x * y
Area of triangle = 1/2 * x * y
```

9.2 *Extend the above program to display the area of circles. This requires addition of a new derived class 'circle' that computes the area of a circle. Remember, for a circle we need only one value, its radius, but the get_data() function in the base class requires two values to be passed. (Hint: Make the second argument of get_data() function as a default one with zero value.)*

9.3 *Run the above program with the following modifications:*

(a) *Remove the definition of* **display_area()** *from one of the derived classes.*

(b) *In addition to the above change, declare the* **display_area()** *as* **virtual** *in the base class* **shape**.

Comment on the output in each case.

10 Managing Console I/O Operations

Key Concepts

- Streams
- Stream classes
- Unformatted output
- Character-oriented input/output
- Line-oriented input/output
- Formatted output
- Formatting functions
- Formatting flags
- Manipulators
- User-defined manipulators

10.1 Introduction

Every program takes some data as input and generates processed data as output following the familiar input-process-output cycle. It is, therefore, essential to know how to provide the input data and how to present the results in a desired form. We have, in the earlier chapters, used **cin** and **cout** with the operators >> and << for the input and output operations. But we have not so far discussed as to how to control the way the output is printed. C++ supports a rich set of I/O functions and operations to do this. Since these functions use the advanced features of C++ (such as classes, derived classes and virtual functions), we need to know a lot about them before really implementing the C++ I/O operations.

Remember, C++ supports all of C's rich set of I/O functions. We can use any of them in the C++ programs. But we restrained from using them due to two reasons. First, I/O methods in C++ support the concepts of OOP and secondly, I/O methods in C cannot handle the user-defined data types such as class objects.

C++ uses the concept of *stream* and *stream classes* to implement its I/O operations with the console and disk files. We will discuss in this chapter, how stream classes support the console- oriented input-output operations. File-oriented I/O operations will be discussed in the next chapter.

10.2 C++ Streams

The I/O system in C++ is designed to work with a wide variety of devices including terminals, disks, and tape drives. Although each device is very different, the I/O system supplies an interface to the programmer that is independent of the actual device being accessed. This interface is known as *stream*.

A stream is a sequence of bytes. It acts either as a *source* from which the input data can be obtained or as a *destination* to which the output data can be sent. The source stream that provides data to the program is called the *input stream* and the destination stream that receives output from the program is called the *output stream*. In other words, a program *extracts* the bytes from an input stream and *inserts* bytes into an output stream as illustrated in Fig. 10.1.

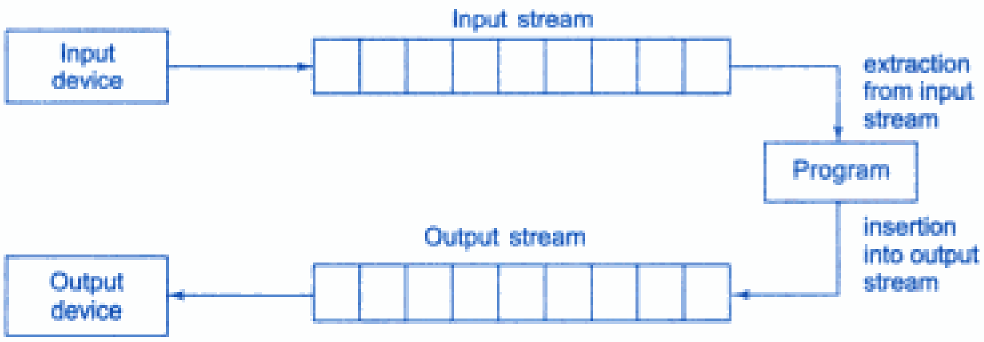


Fig. 10.1 ⇔ *Data streams*

The data in the input stream can come from the keyboard or any other storage device. Similarly, the data in the output stream can go to the screen or any other storage device. As mentioned earlier, a stream acts as an interface between the program and the input/output device. Therefore, a C++ program handles data (input or output) independent of the devices used.

C++ contains several pre-defined streams that are automatically opened when a program begins its execution. These include cin and cout which have been used very often in our earlier programs. We know that cin represents the input stream connected to the standard input device (usually the keyboard) and cout represents the output stream connected to the standard output device (usually the screen). Note that the keyboard and the screen are default options. We can redirect streams to other devices or files, if necessary.

10.3 C++ Stream Classes

The C++ I/O system contains a hierarchy of classes that are used to define various streams to deal with both the console and disk files. These classes are called *stream classes*. Figure 10.2 shows the hierarchy of the stream classes used for input and output operations with the console unit. These classes are declared in the header file *iostream*. This file should be included in all the programs that communicate with the console unit.

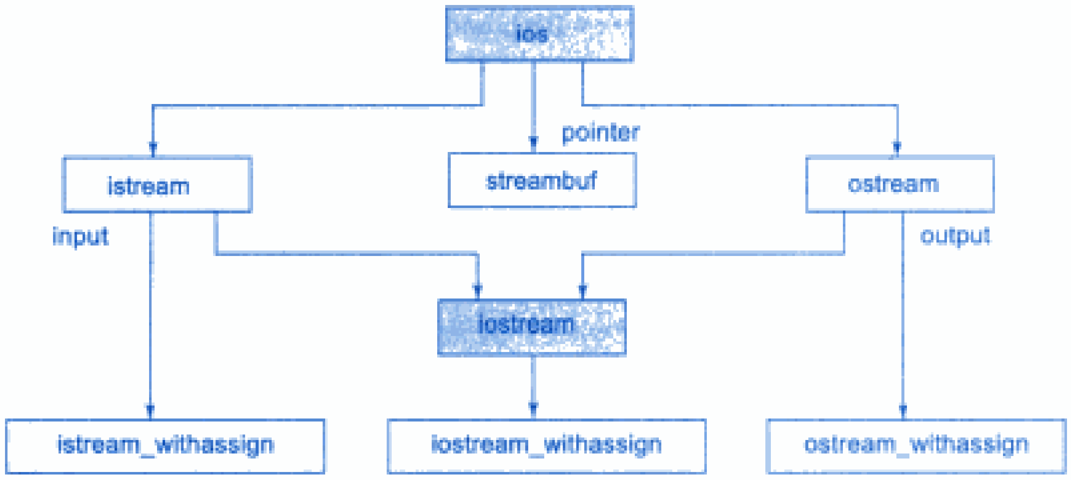


Fig. 10.2 ⇔ *Stream classes for console I/O operations*

As seen in the Fig. 10.2, **ios** is the base class for **istream** (input stream) and **ostream** (output stream) which are, in turn, base classes for **iostream** (input/output stream). The class **ios** is declared as the virtual base class so that only one copy of its members are inherited by the **iostream**.

The class **ios** provides the basic support for formatted and unformatted I/O operations. The class **istream** provides the facilities for formatted and unformatted input while the class **ostream** (through inheritance) provides the facilities for formatted output. The class **iostream** provides the facilities for handling both input and output streams. Three classes, namely, **istream_withassign, ostream_withassign**, and **iostream_withassign** add assignment operators to these classes. Table 10.1 gives the details of these classes.

10.4 Unformatted I/O Operations

Overloaded Operators >> and <<

We have used the objects **cin** and **cout** (pre-defined in the *iostream* file) for the input and output of data of various types. This has been made possible by overloading the operators >> and << to recognize all the basic C++ types. The >> operator is overloaded in the

Table 10.1 *Stream classes for console operations*

Class name	***Contents***
ios (General input/output stream class)	▪ Contains basic facilities that are used by all other input and output classes ▪ Also contains a pointer to a buffer object (**streambuf** object) ▪ Declares constants and functions that are necessary for handling formatted input and output operations
istream (input stream)	▪ Inherits the properties of **ios** ▪ Declares input functions such as **get(), getline()** and **read()** ▪ Contains overloaded extraction operator >>
ostream (output stream)	▪ Inherits the properties of ios ▪ Declares output functions **put()** and **write()** ▪ Contains overloaded insertion operator <<
iostream (input/output stream)	▪ Inherits the properties of **ios istream** and **ostream** through multiple inheritance and thus contains all the input and output functions
streambuf	▪ Provides an interface to physical devices through buffers ▪ Acts as a base for **filebuf** class used ios files

istream class and << is overloaded in the **ostream** class. The following is the general format for reading data from the keyboard:

```
cin >> variable1 >> variable2 >> .... >> variableN
```

variable1, *variable2*, ... are valid C++ variable names that have been declared already. This statement will cause the computer to stop the execution and look for input data from the keyboard. The input data for this statement would be:

```
data1 data2 ...... dataN
```

The input data are separated by white spaces and should match the type of variable in the **cin** list. Spaces, newlines and tabs will be skipped.

The operator >> reads the data character by character and assigns it to the indicated location. The reading for a variable will be terminated at the encounter of a white space or a character that does not match the destination type. For example, consider the following code:

```
int code;
cin >> code;
```

Suppose the following data is given as input:

```
4258D
```

The operator will read the characters upto 8 and the value 4258 is assigned to **code.** The character D remains in the input stream and will be input to the next **cin** statement. The general form for displaying data on the screen is:

```
cout << item1 << item2 << .... << itemN
```

The items *item1* through *itemN* may be variables or constants of any basic type. We have used such statements in a number of examples illustrated in previous chapters.

put() and get() Functions

The classes **istream** and **ostream** define two member functions **get**() and **put**() respectively to handle the single character input/output operations. There are two types of **get**() functions. We can use both **get(char *)** and **get(void)** prototypes to fetch a character including the blank space, tab and the newline character. The **get(char *)** version assigns the input character to its argument and the **get(void)** version returns the input character.

Since these functions are members of the input/output stream classes, we must invoke them using an appropriate object.

Example:

```
char c;
cin.get(c);              // get a character from keyboard
                         // and assign it to c
while(c != '\n')
{
        cout << c;       // display the character on screen
        cin.get(c);      // get another character
}
```

This code reads and displays a line of text (terminated by a newline character). Remember, the operator >> can also be used to read a character but it will skip the white spaces and newline character. The above **while** loop will not work properly if the statement

```
cin >> c;
```

is used in place of

```
cin.get(c);
```

note

Try using both of them and compare the results.

The **get(void)** version is used as follows:

```
.....
char c;
c = cin.get();   // cin.get(c); replaced
.....
.....
```

The value returned by the function **get**() is assigned to the variable **c**.

The function **put**(), a member of **ostream** class, can be used to output a line of text, character by character. For example,

```
cout.put('x');
```

displays the character **x** and

```
cout.put(ch);
```

displays the value of variable **ch.**

The variable **ch** must contain a character value. We can also use a number as an argument to the function **put**(). For example,

```
cout.put(68);
```

displays the character D. This statement will convert the **int** value 68 to a **char** value and display the character whose ASCII value is 68.

The following segment of a program reads a line of text from the keyboard and displays it on the screen.

```
char c;
cin.get(c);              // read a character

while(c != '\n')
{
       cout.put(c);     // display the character on screen
       cin.get(c);
}
```

Program 10.1 illustrates the use of these two character handling functions.

CHARACTER I/O WITH get() AND put()

```
#include <iostream>

using namespace std;

int main()
{
   int count = 0;
   char c;

   cout << "INPUT TEXT\n";

   cin.get(c);

   while(c != '\n')
   {
         cout.put(c);
         count++;
         cin.get(c);
   }
   cout << "\nNumber of characters = " << count << "\n";

   return 0;
}
```

PROGRAM 10.1

```
Input
     Object Oriented Programming
Output
     Object Oriented Programming
     Number of characters = 27
```

note

When we type a line of input, the text is sent to the program as soon as we press the RETURN key. The program then reads one character at a time using the statement **cin.get(c);** and displays it using the statement **cout.put(c);**. The process is terminated when the newline character is encountered.

getline() and write() Functions

We can read and display a line of text more efficiently using the line-oriented input/output functions **getline**() and **write**(). The **getline**() function reads a whole line of text that ends with a newline character (transmitted by the RETURN key). This function can be invoked by using the object **cin** as follows:

```
cin.getline (line, size);
```

This function call invokes the function **getline()** which reads character input into the variable line. The reading is terminated as soon as either the newline character '\n' is encountered or size-1 characters are read (whichever occurs first). The newline character is read but not saved. Instead, it is replaced by the null character. For example, consider the following code:

```
char  name[20];
cin.getline(name, 20);
```

Assume that we have given the following input through the keyboard:

```
Bjarne Stroustrup <press RETURN>
```

This input will be read correctly and assigned to the character array **name**. Let us suppose the input is as follows:

```
Object Oriented Programming  <press RETURN >
```

In this case, the input will be terminated after reading the following 19 characters:

```
Object Oriented Pro
```

Remember, the two blank spaces contained in the string are also taken into account.

We can also read strings using the operator >> as follows:

```
cin >> name;
```

But remember **cin** can read strings that do not contain white spaces. This means that **cin** can read just one word and not a series of words such as "Bjarne Stroustrup". But it can read the following string correctly:

```
Bjarne_Stroustrup
```

After reading the string, **cin** automatically adds the terminating null character to the character array.

Program 10.2 demonstrates the use of >> and **getline()** for reading the strings.

READING STRINGS WITH getline()

```
#include <iostream>

using namespace std;
```

(Contd)

```
int main()
{
    int size = 20;
    char city[20];

    cout << "Enter city name: \n";
    cin  >> city;
    cout << "City name:" << city << "\n\n";

    cout << "Enter city name again: \n";
    cin.getline(city, size);
    cout << "City name now: " << city << "\n\n";

    cout << "Enter another city name: \n";
    cin.getline(city, size);
    cout << "New city name: " << city << "\n\n";

    return 0;
}
```

PROGRAM 10.2

The output of Program 10.2 would be:

```
First run
     Enter city name:
     Delhi
     City name: Delhi

     Enter city name again:
     City name now:
     Enter another city name:
     Chennai
     New city name: Chennai

Second run
     Enter city name:
     New Delhi
     City name: New

     Enter city name again:
     City name now: Delhi

     Enter another city name:
     Greater Bombay
     New city name: Greater Bombay
```

note

During first run, the newline character '\n' at the end of "Delhi" which is waiting in the input queue is read by the **getline()** that follows immediately and therefore it does not wait for any response to the prompt 'Enter city name again:'. The character '\n' is read as an empty line. During the second run, the word "Delhi" (that was not read by cin) is read by the function **getline()** and, therefore, here again it does not wait for any input to the prompt 'Enter city name again:'. Note that the line of text "Greater Bombay" is correctly read by the second **cin.getline(city,size);** statement.

The **write()** function displays an entire line and has the following form:

```
cout.write (line, size)
```

The first argument line represents the name of the string to be displayed and the second argument size indicates the number of characters to display. Note that it does not stop displaying the characters automatically when the null character is encountered. If the size is greater than the length of line, then it displays beyond the bounds of line. Program 10.3 illustrates how **write()** method displays a string.

DISPLAYING STRINGS WITH write()

```
#include <iostream>
#include <string>

using namespace std;

int main()
{
    char * string1 = "C++ ";
    char * string2 = "Programming";
    int m = strlen(string1);
    int n = strlen(string2);

    for(int i=1; i<n; i++)
    {
        cout.write(string2,i);
        cout << "\n";
    }

    for(i=n; i>0; i--)
    {
        cout.write(string2,i);
        cout << "\n";
    }
```

(Contd)

```
    // concatenating strings
    cout.write(string1,m).write(string2,n);

    cout << "\n";

    // crossing the boundary
    cout.write(string1,10);

    return 0;
}
```

PROGRAM 10.3

Look at the output of Program 10.3:

```
P
Pr
Pro
Prog
Progr
Progra
Program
Programm
Programmi
Programmin
Programming
Programmin
Programmi
Programm
Program
Progra
Progr
Prog
Pro
Pr
P
C++ Programming
C++ Progr
```

The last line of the output indicates that the statement

```
cout.write(string1, 10);
```

displays more characters than what is contained in **string1.**

It is possible to concatenate two strings using the **write**() function. The statement

```
cout.write(string1, m).write(string2, n);
```

is equivalent to the following two statements:

```
    cout.write(string1, m);
    cout.write(string2, n);
```

10.5 Formatted Console I/O Operations

C++ supports a number of features that could be used for formatting the output. These features include:

- **ios** class functions and flags.
- Manipulators.
- User-defined output functions.

The **ios** class contains a large number of member functions that would help us to format the output in a number of ways. The most important ones among them are listed in Table 10.2.

Table 10.2 ios *format functions*

Function	***Task***
Width ()	To specify the required field size for displaying an output value
precision ()	To specify the number of digits to be displayed after the decimal point of a float value
fill()	To specify a character that is used to fill the unused portion of a field
setf()	To specify format flags that can control the form of output display (such as left-justification and right-justification)
unsetf()	To clear the flags specified

Manipulators are special functions that can be included in the I/O statements to alter the format parameters of a stream. Table 10.3 shows some important manipulator functions that are frequently used. To access these manipulators, the file iomanip should be included in the program.

Table 10.3 *Manipulators*

Manipulators	***Equivalent ios function***
setw()	**width()**
setprecision()	**precision()**
setfill()	**fill()**
setiosflags()	**setf()**
resetiosflags()	**unsetf()**

In addition to these functions supported by the C++ library, we can create our own manipulator functions to provide any special output formats. The following sections will provide details of how to use the pre-defined formatting functions and how to create new ones.

Defining Field Width: width()

We can use the **width()** function to define the width of a field necessary for the output of an item. Since, it is a member function, we have to use an object to invoke it, as shown below:

```
cout.width(w);
```

where *w* is the field width (number of columns). The output will be printed in a field of *w* characters wide at the right end of the field. The **width**() function can specify the field width for only one item (the item that follows immediately). After printing one item (as per the specifications) it will revert back to the default. For example, the statements

```
cout.width(5);
cout << 543  <<  12 << "\n";
```

will produce the following output:

```
  54312
```

The value 543 is printed right-justified in the first five columns. The specification width(5) does not retain the setting for printing the number 12. This can be improved as follows:

```
cout.width(5);
cout << 543;
cout.width(5);
cout << 12  << "\n";
```

This produces the following output:

```
  543   12
```

Remember that the field width should be specified for each item separately. C++ never truncates the values and therefore, if the specified field width is smaller than the size of the value to be printed, C++ expands the field to fit the value. Program 10.4 demonstrates how the function **width**() works.

SPECIFYING FIELD SIZE WITH width()

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

int main()
{
    int items[4] = {10,8,12,15};
    int cost[4] = {75,100,60,99};

    cout.width(5);
    cout <<  "ITEMS";
    cout.width(8);
    cout << "COST";

    cout.width(15);
    cout << "TOTAL VALUE"  << "\n";

    int sum = 0;

    for(int i=0; i<4; i++)
    {
          cout.width(5);
          cout << items[i];

          cout.width(8);
          cout << cost[i];

          int value = items[i] * cost[i];
          cout.width(15);
          cout << value << "\n";
          sum = sum + value;
    }
     cout << "\n Grand Total = ";

    cout.width(2);
    cout << sum << "\n";

    return 0;
}
```

PROGRAM 10.4

The output of Program 10.4 would be:

```
ITEMS         COST   TOTAL VALUE

   10           75          750
    8          100          800
   12           60          720
   15           99         1485

Grand Total = 3755
```

note

A field of width two has been used for printing the value of sum and the result is not truncated. A good gesture of C++ !

Setting Precision: precision()

By default, the floating numbers are printed with six digits after the decimal point. However, we can specify the number of digits to be displayed after the decimal point while printing the floating-point numbers. This can be done by using the **precision()** member function as follows:

```
cout.precision(d);
```

where d is the number of digits to the right of the decimal point. For example, the statements

```
cout.precision(3);
cout << sqrt(2) << "\n";
cout << 3.14159 << "\n";
cout << 2.50032 << "\n";
```

will produce the following output:

```
1.141  (truncated)
3.142  (rounded to the nearest cent)
2.5    (no trailing zeros)
```

Not that, unlike the function **width()**, **precision()** retains the setting in effect until it is reset. That is why we have declared only one statement for the precision setting which is used by all the three outputs.

We can set different values to different precision as follows:

```
cout.precision(3);
```

```
    cout << sqrt(2)  << "\n";
    cout.precision(5);          // Reset the precision
    cout << 3.14159  << "\n";
```

We can also combine the field specification with the precision setting. Example:

```
cout.precision(2);
cout.width(5);
cout << 1.2345;
```

The first two statements instruct: "print two digits after the decimal point in a field of five character width". Thus, the output will be:

	1		2	3

Program 10.5 shows how the functions **width()** and **precision()** are jointly used to control the output format.

PRECISION SETTING WITH precision()

```
#include <iostream>
#include <cmath>

using namespace std;

int main()
{
        cout << "Precision set to 3 digits \n\n";
        cout.precision(3);

        cout.width(10);
        cout << "VALUE";
        cout.width(15);
        cout << "SQRT_OF_VALUE" << "\n";

        for(int n=1; n<=5; n++)
        {
                cout.width(8);
                cout << n;
                cout.width(13);
                cout << sqrt(n)  << "\n";
        }
```

(Contd)

```
        cout << "\n Precision set to 5 digits \n\n";
        cout.precision(5);              // precision parameter changed
        cout << " sqrt(10) = " << sqrt(10) << "\n\n";

        cout.precision(0);              // precision set to default
        cout << " sqrt(10) = " << sqrt(10) << " (default setting)\n";

        return 0;
}
```

PROGRAM 10.5

Here is the output of Program 10.5

```
Precision set to 3 digits
       VALUE    SQRT_OF_VALUE
         1             1
         2          1.41
         3          1.73
         4             2
         5          2.24

Precision set to 5 digits

sqrt(10) = 3.1623

sqrt(10) = 3.162278 (default setting)
```

note

Observe the following from the output:

1. The output is rounded to the nearest cent (i.e., 1.6666 will be 1.67 for two digit precision but 1.3333 will be 1.33).
2. Trailing zeros are truncated.
3. Precision setting stays in effect until it is reset.
4. Default precision is 6 digits.

Filling and Padding: fill()

We have been printing the values using much larger field widths than required by the values. The unused positions of the field are filled with white spaces, by default. However, we can use the fill() function to fill the unused positions by any desired character. It is used in the following form:

```
cout.fill (ch);
```

Where *ch* represents the character which is used for filling the unused positions. Example:

```
cout.fill('*');
cout.width(10);
cout << 5250  << "\n";
```

The output would be:

*	*	*	*	*	*	5	2	5	0

Financial institutions and banks use this kind of padding while printing cheques so that no one can change the amount easily. Like **precision()**, **fill()** stays in effect till we change it. See Program 10.6 and its output.

PADDING WITH fill()

```
#include <iostream>

using namespace std;

int main( )
{       cout.fill('<');

        cout.precision(3);
        for(int n=1; n<=6; n++)
        {
            cout.width(5);
            cout << n;
            cout.width(10);
            cout << 1.0 / float(n) << "\n";
            if (n == 3)
               cout.fill ('>');
        }
        cout << "\nPadding changed \n\n";
        cout.fill ('#');    // fill( ) reset
        cout.width (15);
        cout << 12.345678   << "\n";

        return 0;
}
```

PROGRAM 10.6

The output of Program 10.6 would be:

```
<<<<1<<<<<<<<<1
<<<<2<<<<<<<0.5
<<<<3<<<<<0.333
>>>>4>>>>>>0.25
>>>>5>>>>>>>0.2
>>>>6>>>>>0.167

Padding changed

#########12.346
```

Formatting Flags, Bit-fields and setf()

We have seen that when the function **width()** is used, the value (whether text or number) is printed right-justified in the field width created. But, it is a usual practice to print the text left-justified. How do we get a value printed left-justified? Or, how do we get a floating-point number printed in the scientific notation?

The **setf()**, a member function of the **ios** class, can provide answers to these and many other formatting questions. The **setf()** (*setf* stands for set flags) function can be used as follows:

```
cout.setf(arg1,arg2)
```

The *arg1* is one of the formatting *flags* defined in the class **ios**. The formatting flag specifies the format action required for the output. Another **ios** constant, *arg2*, known as bit *field* specifies the group to which the formatting flag belongs.

Table 10.4 shows the bit fields, flags and their format actions. There are three bit fields and each has a group of format flags which are mutually exclusive. Examples:

```
cout.setf(ios::left, ios::adjustfield);
cout.setf(ios::scientific, ios::floatfield);
```

Note that the first argument should be one of the group members of the second argument.

Consider the following segment of code:

```
cout.fill('*');
cout.setf(ios::left, ios::adjustfield);
cout.width(15);
cout << "TABLE 1" <<  "\n";
```

Table 10.4 *Flags and bit fields for setf() function*

Format required	*Flag (arg1)*	*Bit-field (arg2)*
Left-justified output	ios :: left	ios :: adjustfield
Right-justified output	ios :: right	ios :: adjustfield
Padding after sign or base Indicator (like +##20)	ios :: internal	ios :: adjustfield
Scientific notation	ios :: scientific	ios :: floatfield
Fixed point notation	ios :: fixed	ios :: floatfield
Decimal base	ios :: dec	ios :: basefield
Octal base	ios :: oct	ios :: basefield
Hexadecimal base	ios :: hex	ios :: basefield

This will produce the following output:

```
TABLE 1********
```

The statements

```
cout.fill ('*');
cout.precision(3);
cout.setf(ios::internal, ios::adjustfield);
cout.setf(ios::scientific, ios::floatfield);
cout.width(15);

cout << -12.34567  << "\n";
```

will produce the following output:

```
-*****1.235e+01
```

note

The sign is left-justified and the value is right left- justified. The space between them is padded with stars. The value is printed accurate to three decimal places in the scientific notation.

Displaying Trailing Zeros and Plus Sign

If we print the numbers 10.75, 25.00 and 15.50 using a field width of, say, eight positions, with two digits precision, then the output will be as follows:

```
   10.75
      25
    15.5
```

Note that the trailing zeros in the second and third items have been truncated.

Certain situations, such as a list of prices of items or the salary statement of employees, require trailing zeros to be shown. The above output would look better if they are printed as follows:

```
10.75
25.00
15.50
```

The **setf()** can be used with the flag **ios::showpoint** as a single argument to achieve this form of output. For example,

```
cout.setf(ios::showpoint);          // display trailing zeros
```

would cause cout to display trailing zeros and trailing decimal point. Under default precision, the value 3.25 will be displayed as 3.250000. Remember, the default precision assumes a precision of six digits.

Similarly, a plus sign can be printed before a positive number using the following statement:

```
cout.setf(ios::showpos);        // show +sign
```

For example, the statements

```
cout.setf(ios::showpoint);
cout.setf(ios::showpos);
cout.precision(3);
cout.setf(ios::fixed, ios::floatfield);
cout.setf(ios::internal, ios::adjustfield);
cout.width(10);
cout << 275.5 << "\n";
```

will produce the following output:

```
+  275.500
```

The flags such as **showpoint** and **showpos** do not have any bit fields and therefore are used as single arguments in **setf()**. This is possible because the **setf()** has been declared as an overloaded function in the class **ios**. Table 10.5 lists the flags that do not possess a named bit field. These flags are not mutually exclusive and therefore can be set or cleared independently.

Table 10.5 *Flags that do not have bit fields*

Flag	*Meaning*
ios :: showbase	Use base indicator on output
ios :: showpos	Print + before positive numbers
ios :: showpoint	Show trailing decimal point and zeroes
ios :: uppercase	Use uppercase letters for hex output
ios :: skipus	Skip white space on input
ios :: unitbuf	Flush all streams after insertion
ios :: stdio	Flush **stdout** and **stderr** after insertion

Program 10.7 demonstrates the setting of various formatting flags using the overloaded **setf()** function.

FORMATTING WITH FLAGS IN setf()

```
#include <iostream>
#include <cmath>

using namespace std;

int main()
{
        cout.fill('*');
        cout.setf(ios::left, ios::adjustfield);
        cout.width(10);
        cout << "VALUE";

        cout.setf(ios::right, ios::adjustfield);
        cout.width(15);
        cout << "SQRT OF VALUE" << "\n";

        cout.fill('.');
        cout.precision(4);
        cout.setf(ios::showpoint);
        cout.setf(ios::showpos);
        cout.setf(ios::fixed, ios::floatfield);

        for(int n=1; n<=10; n++)
        {
                cout.setf(ios::internal, ios::adjustfield);
                cout.width(5);
                cout << n;

                cout.setf(ios::right, ios::adjustfield);
                cout.width(20);
                cout << sqrt(n)  << "\n";
        }
```

(Contd)

```
        // floatfield changed
        cout.setf(ios::scientific, ios::floatfield);
        cout << "\nSQRT(100) = " << sqrt(100) << "\n";

        return 0;
}
```

PROGRAM 10.7

The output of Program 10.7 would be:

```
VALUE*********SQRT OF VALUE
+...1...............+1.0000
+...2...............+1.4142
+...3...............+1.7321
+...4...............+2.0000
+...5...............+2.2361
+...6...............+2.4495
+...7...............+2.6458
+...8...............+2.8284
+...9...............+3.0000
+..10...............+3.1623

SQRT(100) = +1.0000e+001
```

note

1. The flags set by **setf()** remain effective until they are reset or unset.
2. A format flag can be reset any number of times in a program.
3. We can apply more than one format controls jointly on an output value.
4. The setf() sets the specified flags and leaves others unchanged.

10.6 Managing Output with Manipulators

The header file *iomanip* provides a set of functions called *manipulators* which can be used to manipulate the output formats. They provide the same features as that of the **ios** member functions and flags. Some manipulators are more convenient to use than their counterparts in the class **ios**. For example, two or more manipulators can be used as a chain in one statement as shown below:

```
cout << manip1 << manip2 << manip3 << item;
cout << manip1 << item1  << manip2 << item2;
```

This kind of concatenation is useful when we want to display several columns of output.

The most commonly used manipulators are shown in Table 10.6. The table also gives their meaning and equivalents. To access these manipulators, we must include the file *iomanip* in the program.

Table 10.6 *Manipulators and their meanings*

Manipulator	***Meaning***	***Equivalent***
setw (int *w*)	Set the field width to w.	width( )
setprecision(int *d*)	Set the floating point precision to *d*.	precision( )
setfill(int *c*)	Set the fill character to c.	fill( )
setiosflags(long *f*)	Set the format flag *f*.	setf( )
resetiosflags(long *f*)	Clear the flag specified by *f*.	unsetf( )
endl	Insert new line and flush stream.	"\n"

Some examples of manipulators are given below:

```
cout << setw(10) << 12345;
```

This statement prints the value 12345 right-justified in a field width of 10 characters. The output can be made left-justified by modifying the statement as follows:

```
cout << setw(10) << setiosflags(ios::left) << 12345;
```

One statement can be used to format output for two or more values. For example, the statement

```
cout   << setw(5)  << setprecision(2) << 1.2345
       << setw(10) << setprecision(4) << sqrt(2)
       << setw(15) << setiosflags(ios::scientific) << sqrt(3);
       << endl;
```

will print all the three values in one line with the field sizes of 5, 10, and 15 respectively. Note that each output is controlled by different sets of format specifications.

We can jointly use the manipulators and the **ios** functions in a program. The following segment of code is valid:

```
cout.setf(ios::showpoint);
cout.setf(ios::showpos);
cout << setprecision(4);
cout << setiosflags(ios::scientific);
cout << setw(10) << 123.45678;
```

note

There is a major difference in the way the manipulators are implemented as compared to the **ios** member functions. The **ios** member function return the previous format state which can be used later, if necessary. But the manipulator does not return the previous format state. In case, we need to save the old format states, we must use the **ios** member functions rather than the manipulators. Example:

```
cout.precision(2);              // previous state
int p = cout.precision(4);     // current state;
```

When these statements are executed, **p** will hold the value of 2 (previous state) and the new format state will be 4. We can restore the previous format state as follows:

```
cout.precision(p);             // p = 2
```

Program 10.8 illustrates the formatting of the output values using both manipulators and **ios** functions.

FORMATTING WITH MANIPULATORS

```
#include <iostream>
#include <iomanip>

using namespace std;

int main()
{
        cout.setf(ios::showpoint);

        cout << setw(5)  <<  "n"
             << setw(15) << "Inverse_of_n"
             << setw(15) << "Sum_of_terms\n\n";

        double term, sum = 0;

        for(int n=1; n<=10; n++)
        {
                term = 1.0 / float(n);
                sum  = sum + term;

                cout << setw(5) << n
                     << setw(14) << setprecision(4)
```

(Contd)

Hidden page

The statement

```
cout << 36 << unit;
```

will produce the following output

```
36 inches
```

We can also create manipulators that could represent a sequence of operations. Example:

```
ostream & show(ostream & output)
{
        output.setf(ios::showpoint);
        output.setf(ios::showpos);
        output << setw(10);
        return output;
}
```

This function defines a manipulator called **show** that turns on the flags **showpoint** and **showpos** declared in the class **ios** and sets the field width to 10.

Program 10.9 illustrates the creation and use of the user-defined manipulators. The program creates two manipulators called **currency** and **form** which are used in the **main** program.

USER-DEFINED MANIPULATORS

```
#include <iostream>
#include <iomanip>

using namespace std;

// user-defined manipulators

ostream & currency(ostream & output)
{
        output << "Rs";
        return output;
}

ostream & form(ostream & output)
{
        output.setf(ios::showpos);
        output.setf(ios::showpoint);
```

(Contd)

```
        output.fill('*');
        output.precision(2);
        output << setiosflags(ios::fixed)
               << setw(10);
        return output;
}

int main()
{
        cout << currency << form << 7864.5;

        return 0;
}
```

PROGRAM 10.9

The output of Program 10.9 would be:

```
Rs**+7864.50
```

Note that **form** represents a complex set of format functions and manipulators.

SUMMARY

⇔ In C++, the I/O system is designed to work with different I/O devices. This I/O system supplies an interface called 'stream' to the programmer, which is independent of the actual device being used.

⇔ A stream is a sequence of bytes and serves as a source or destination for an I/O data.

⇔ The source stream that provides data to the program is called the *input stream* and the destination stream that receives output from the program is called the *output stream*.

⇔ The C++ I/O system contains a hierarchy of stream classes used for input and output operations. These classes are declared in the header file **'iostream'**.

⇔ **cin** represents the input stream connected to the standard input device and **cout** represents the output stream connected to the standard output device.

⇔ The **istream** and **ostream** classes define two member functions **get()** and **put()** to handle the single character I/O operations.

⇔ The >> operator is overloaded in the **istream** class as an extraction operator and the << operator is overloaded in the **ostream** class as an insertion operator.

⇔ We can read and write a line of text more efficiently using the line oriented I/O functions **getline()** and **write()** respectively.

⇔ The **ios** class contains the member functions such as **width()**, **precision()**, **fill()**, **setf()**, **unsetf()** to format the output.

⇔ The header file **'iomanip'** provides a set of manipulator functions to manipulate output formats. They provide the same features as that of **ios** class functions.

⇔ We can also design our own manipulators for certain special purposes.

Key Terms

- adjustfield
- basefield
- bit-fields
- console I/O operations
- decimal base
- destination stream
- field width
- **fill()**
- filling
- fixed point notation
- flags
- floatfield
- formatted console I/O
- formatting flags
- formatting functions
- **get()**
- **getline()**
- hexadecimal base
- input stream
- internal
- **ios**
- iomanip
- iostream
- istream
- left-justified
- manipulator
- octal base
- ostream
- output stream
- padding
- **precision()**
- **put()**
- **resetiosflags()**
- right-justified
- scientific notation
- **setf()**
- **setfill()**
- **setiosflags()**
- **setprecision()**
- setting precision
- **setw()**
- showbase
- showpoint
- showpos
- skipus
- source stream
- standard input device
- standard output device
- stream classes
- streambuf
- streams
- unitbuf
- **unsetf()**
- **width()**
- **write()**

Review Questions

10.1 *What is a stream?*

10.2 *Describe briefly the features of I/O system supported by C++.*

10.3 *How do the I/O facilities in C++ differ from that in C?*

10.4 *Why are the words such as **cin** and **cout** not considered as keywords?*

10.5 *How is **cout** able to display various types of data without any special instructions?*

10.6 *Why is it necessary to include the file iostream in all our programs?*

10.7 *Discuss the various forms of **get()** function supported by the input stream. How are they used?*

10.8 *How do the following two statements differ in operation?*

```
cin >> c;
cin.get(c);
```

10.9 *Both **cin** and **getline()** function can be used for reading a string. Comment.*

10.10 *Discuss the implications of size parameter in the following statement:*

```
cout.write(line, size);
```

10.11 *What does the following statement do?*

```
cout.write(s1,m).write(s2,n);
```

10.12 *What role does the **iomanip** file play?*

10.13 *What is the role of **file()** function? When do we use this function?*

10.14 *Discuss the syntax of **set()** function.*

10.15 *What is the basic difference between manipulators and **ios** member functions in implementation? Give examples.*

10.16 *State whether the following statements are TRUE or FALSE.*

(a) *A C++ stream is a file.*

(b) *C++ never truncates data.*

(c) *The main advantage of **width()** function is that we can use one width specification for more than one items.*

(d) *The **get(void)** function provides a single-character input that does not skip over the white spaces.*

(e) *The header file **iomanip** can be used in place of iostream.*

(f) *We cannot use both the C I/O functions and C++ I/O functions in the same program.*

(g) *A programmer can define a manipulator that could represent a set of format functions.*

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10.2 Will the statement cout.setf(ios::right) work or not?

```
#include <iostream.h>
void main()
{
        cout.width(5);
        cout << "99" << endl;

        cout.setf(ios::left);
        cout.width(5);
        cout << "99" << endl;

        cout.setf(ios::right);
        cout << "99" << endl;
}
```

10.3 State errors, if any, in the following statements.

(a) `cout << (void*) amount;`
(b) `cout << put("John");`
(c) `cout << width();`
(d) `int p = cout.width(10);`
(e) `cout.width(10).precision(3);`
(f) `cout.setf(ios::scientific,ios::left);`
(g) `ch = cin.get();`
(h) `cin.get().get();`
(i) `cin.get(c).get();`
(j) `cout << setw(5) << setprecision(2);`
(k) `cout << resetiosflags(ios::left |ios::showpos);`

Programming Exercises

10.1 *Write a program to read a list containing item name, item code, and cost interactively and produce a three column output as shown below.*

```
NAME            CODE         COST
---------------------------------
Turbo C++       1001       250.95
C Primer         905        95.70
.....            ...        .....
.....            ...        .....
.....            ...        .....
---------------------------------
```

Note that the name and code are left-justified and the cost is right-justified with a precision of two digits. Trailing zeros are shown.

10.2 *Modify the above program to fill the unused spaces with hyphens.*

10.3 *Write a program which reads a text from the keyboard and displays the following information on the screen in two columns:*

(a) *Number of lines*

(b) *Number of words*

(c) *Number of characters*

Strings should be left-justified and numbers should be right-justified in a suitable field width.