Chapter: 13

Polymorphism, Exceptions, RTTI, Operator cast

Virtual functions, Generic function & class, Exception, RTTI, Casting Operators

13.1 Pointers To Derived Classes

A *pointer* declared as a ***pointer to a base*** class can also be used to ***point to any class derived from that base***. For example, assume two classes called ***base*** and ***derived***, where ***derived inherits base***. Then the following statements are correct:

```
base *p;                    /* base class pointer */

base base_ob ;                    /* object of type base */
derived derived_ob ;              /* object of type derived */

p = &base_ob ;              /* p points to base object : Normally p can.*/
p = &derived_ob ;           /* p points to derived object : Advanced pointing by p */
```

- A ***base pointer*** can point to an object of **any class derived from that base** without generating a ***type mismatch error***.
  - By a ***base pointer*** we can access only those members of the derived object that were inherited from the base. Because the base pointer has ***knowledge only of the base*** class, nothing about the ***members added by the derived*** class.
  - ***The reverse is not true:*** A ***pointer of the derived type cannot*** be used to ***access*** an ***object of the base*** class. (A ***type cast*** can be used to ***overcome this restriction***, but its use is not recommended practice.)
  - NOTE ***(Be careful):*** ***Pointer arithmetic is relative to the data type*** the pointer is declared as pointing to. Thus, if you point a ***base pointer*** to a ***derived object*** and then ***increment*** that pointer, it will ***not be pointing*** to the ***next derived object***. It will be ***pointing to*** (what it thinks is) the ***next base object***. Be careful about this.
- ***Example 1:*** Following illustrates how a base class pointer can be used to access a derived class:

```
class base{          int x;
      public:        void setx(int i){ x=i; }
                     int getx(){ return x; }        };

class derived : public base { int y;
      public :       void sety(int i){ y=i; }
                     int gety(){ return y; }        };

int main(){          base *p;          /* pointer to base type */
                     base b_ob ;       /* object of base */
                     derived d_ob ;    /* object of derived */
```

```
p = &b_ob ;              /* p access base  : point to base object */
p-> setx(10) ;           /* access base object */
cout << " Base object x: " << p-> getx () << '\n';

p = &d_ob ;              /* p access derived : point to derived object */
p-> setx(99) ;           /* access derived object */

d_ob.sety(88) ;          /* can't use p to set y, so do it directly */
cout << " Derived object x: " << p-> getx() << '\n';
cout << " Derived object y: " << d_ob.gety() << '\n';
      return 0; }
```

  - There is no value in using a base class pointer in the way shown in this example.

13.2 Virtual Functions (VF)

A ***virtual function*** is a *member function* that is declared ***within a base*** and ***redefined by a derived***. To create a ***virtual function***, ***precede the function's declaration*** with the keyword ***virtual***. When a ***VF*** is redefined by a derived, the keyword ***virtual*** is not needed. A class that contains a ***VF*** is referred to as a ***polymorphic class***.

- When a class containing a ***VF*** is ***inherited***, the derived *redefines the VF* relative to the derived. ***VF*** implements the ***"one interface, multiple methods"*** philosophy that underlies ***polymorphism***.
  - The ***VF*** within the base class defines the ***form*** of the ***interface*** to that function.
  - Each redefinition of the ***VF*** by a *derived* implements its operation as it *relates specifically to that* ***derived***. I.e. the *redefinition creates a* ***specific method***.
- A ***VF*** can be called just like any other *member function*. But interesting thing happens when a virtual function is ***called through a pointer*** - creates the ***run-time polymorphism***.
  - When a base pointer points to a *derived object that contains a VF* and that ***VF*** is called *through that pointer*, it is ***the type of that pointed object*** that determines which version of the ***VF*** will be executed at the time when the call occurs. And, this determination is made at ***run time***. This process is the way that ***run-time polymorphism is achieved***.
  - Therefore, if two or more different classes are derived from a base class that contains a ***VF***, then when ***different objects are pointed to by a base pointer, different versions of the virtual function are executed***.
- ***Example 1:*** Following uses a ***VF***. Here the ***type of the object being pointed to*** determines which version of an ***overridden virtual function*** will be executed when accessed via a ***base class pointer***, and that this decision is made at ***run time***.

```
class base{
      public: int i;
              base(int x) { i = x; }
              virtual void func() { cout<< " Using base version of func(): ";
              cout << i << '\n'; }
             };
```

```
class derived1 : public base {
public : derived1(int x) : base(x){} /* passing argument to base constructor and uses same definition. Using base's constructor */
void func(){cout<< " Using derived1's version of func (): ";
            cout << i*i << '\n'; }
                        };
```

```
class derived2 : public base {
public : derived2(int x) : base(x){} /* passing argument to base constructor and uses same definition. Using base's constructor */
void func(){cout << " Using derived2 's version of func (): ";
            cout << i+i << '\n'; }
                        };
```

```
int main(){   base *p;
              base ob (10) ;
              derived1 d_ob1 (10) ;
              derived2 d_ob2 (10) ;
      p = &ob;      p -> func();  /* use base 's func() */
      p = &d_ob1 ;  p -> func();  /* use derived1's func() */
      p = &d_ob2 ;  p -> func();  /* use derived2 's func() */
return 0; }
```

This program displays the following output:

Using base version of func( ): 10
Using derived1's version of func( ): 100
Using derived2's version of func( ): 20

☞ Above program creates three classes.
- ❖ The ***base*** class defines the virtual function **func()**.
- ❖ "***base***" is then inherited by both ***derived1*** and ***derived2***. Each of these classes overrides ***func()*** with its individual implementation.

☞ Inside ***main()***, the ***base pointer p*** is declared along with objects of type ***base***, ***derived1***, and ***derived2***.

i. First, ***p*** is assigned the address of ***ob*** (***base type*** object). When ***func()*** is called by using ***p***, the ***base version*** of ***func()*** is used.

ii. Next, ***p*** is assigned the address of ***d_ob1***. In this time ***derived1*** version (the ***overridden*** version) of ***func()*** is executed when ***func()*** is called using ***p***. (the ***type of the object pointed to*** determines which ***VF*** will be called)

iii. Finally, ***p*** is assigned the address of ***d_ob2*** and ***func()*** is called again by using ***p***. This time, it is the ***overridden*** version of ***func()*** defined inside ***derived2*** is executed.

❒ Virtual functions are ***hierarchical in order of inheritance***. Further, ***when a derived class does not override a virtual function, the function defined within its base class is used***. For example consider the previous example with the modified "***derived2***"

```
class derived2 : public base
{ public :
       derived2 (int x) : base(x){}
       /* derived2 does not override func( ) */
};
```

```
int main() {. . . . .
       p = &d_ob2 ;
       p -> func();
       /* use base's func( ) */
return 0;
}
```

This program displays the following output:

Using base version of func( ): 10
Using derived1's version of func( ): 100
Using base version of func( ): 10

☞ In this version, ***derived2*** does not override ***func()***. When ***p*** is assigned ***d_ob2*** and ***func()*** is called, ***base***'s version is used because it is ***next up in the class hierarchy***. In general, ***when a derived class does not override a VF, the base class's version is used***.

❒ A ***VF*** can respond to ***random events that occur at run time***. Consider ***Example 1***, following modified ***main()*** selects between ***d_ob1*** and ***d_ob2*** based upon the value returned by the ***standard random number generator rand()***.

☞ Remember that the version of ***func()*** executed is resolved at ***run time***. (Which is impossible at ***compile time***.)

```
int main(){   base *p;
              derived1 d_ob1 (10);
              derived2 d_ob2 (10);
              int i,j;
              for(i=0; i<10; i++){ j = rand();
                                   if((j%2) ) p = &d_ob1 ;       /* if odd use d_ob1 */
                                   else p = &d_ob2 ;             /* if even use d_ob2 */
                                 p -> func(); }            /* call appropriate function */
              return 0; }
```

NOTE

[1] ***Redefinition*** of a ***VF*** inside a derived class and ***function overloading*** are different process (although they look similar).

- ➢ An ***overloaded function must differ in type and/or number of parameters***, while ***a redefined VF must have precisely the same type and number of parameters and the same return type***. *(changing either the number or type of parameters of **redefined VF** destroys its virtual nature and makes it an "overloaded function")*
- ➢ Virtual functions must be class members. This is not the case for overloaded functions.
- ➢ ***Destructor*** functions can be virtual, ***constructors*** cannot.
- ➢ Because of the difference between ***overloaded functions*** and ***redefined VF***, the term ***"overriding"*** is used to describe ***VF redefinition***.

13.3 Abstract class and Pure Virtual function (PVF)

Sometimes when a ***VF*** is declared in the ***base*** class there is no meaningful operation for it to perform. Because often ***a base simply supplies a core set of member functions and variables*** to which the ***derived class supplies the remainder***. In this case we use ***pure virtual functions (PVF)***.

- A **PVF** has ***no definition*** relative to the ***base*** class. ***Only the function's prototype*** is included. To make a **PVF**, use this general form:

  virtual type func_name(parameter_list =0;

  - The key part of this declaration is the setting of the ***function equal to 0***. This tells the compiler that ***no body exists for this function relative to the base class***.
  - When a ***virtual function*** is made ***pure***, it ***forces any derived class to override*** it. If a derived class does not, a ***compile-time error*** results.

- ***Abstract class:*** When a class contains at least one **PVF**, it is referred to as an ***abstract class***. It is an ***incomplete type***, and ***no objects of that class can be created***. Thus, abstract classes exist only to be ***inherited***. They are neither intended nor able to stand alone.
  - You can still create a ***pointer*** to an abstract class, since it is through the use of ***base class pointers*** that ***run-time polymorphism*** is achieved.
  - It is also permissible to have a ***reference*** to an abstract class.

- When a **VF** is inherited, so is its ***virtual nature***. I.e. when a ***derived*** inherits a **VF** from a ***base*** and then ***that derived*** is used as a ***base*** for yet another derived, the **VF** can be ***overridden by the final derived*** class (as well as the first derived). For example, if **base B** contains a **VF** called **f()**, and **D1** inherits **B** and **D2** inherits **D1**, both **D1** and **D2** can override **f()** relative to their respective classes.

- ***Example 1:*** This program creates a **base** called ***area*** that holds two dimensions of a figure. It also declares a ***VF*** called ***getarea()*** that, when overridden by derived classes, returns the area of the ***type of figure defined by the derived***.

```
class area{  double dim1 , dim2 ;       /* dimensions of figure */
        public :     void setarea(double d1, double d2){ dim1 = d1; dim2 = d2;}
                     void getdim(double &d1 , double &d2) { d1 = dim1 ; d2 = dim2 ; }
                virtual double getarea(){  cout << "You must override this function \n";
                                           return 0.0; }
        };
```

```
class rectangle : public area {
      public :
            double getarea(){double d1, d2;
                             getdim(d1, d2);
                             return d1*d2;  }
                           };
```

```
class triangle : public area {
      public :
            double getarea() { double d1, d2;
                               getdim(d1, d2);
                               return 0.5*d1*d2;}
                             };
```

```
int main(){  area *p;
             rectangle r;
             triangle t;
                   r.setarea(3.3, 4.5) ;
                   t.setarea(4.0, 5.0) ;
                   p = &r; cout << " Rectangle has area : " << p-> getarea() << '\n';
                   p = &t; cout << " Triangle has area : " << p-> getarea() << '\n';
             return 0; }
```

  - In this case, the declaration of ***getarea()*** inside the base determines the nature of the interface. The actual implementation is left to the ***classes that inherit it***. In this example, the area of a ***triangle*** and a ***rectangle*** are computed.
  - Here the definition of getarea() inside area is just a placeholder and performs no real function. Because area is not linked to any specific type of figure, there is no meaningful definition that can be given to getarea() inside area.
    - ***getarea()*** must be overridden by a derived class in order to be useful.

```
class area{ . . . . . same as previous . . . . .
                virtual double getarea() = 0;    /* pure virtual function */      };
```

- ***Example 2:*** Following program illustrates how a function's ***virtual nature*** is preserved when it is ***inherited***.

```
class base {
public : virtual void func(){
cout << " Base version of func ( )\n"; }
       };
```

```
class derived1 : public base {
public : void func(){
cout <<"derived1's version of func()\n"; }
 };
```

```
class derived2 : public derived1{
        /* derived2 inherits derived1 */
public : void func(){
cout << "derived2's version of func()\n";
} };
```

```
int main() { base *p;
             base ob;
             derived1 d_ob1 ;
             derived2 d_ob2 ;
                   p = &ob;     p -> func();        /* use base's func() */
                   p = &d_ob1 ; p -> func();        /* use derived1's func() */
                   p = &d_ob2 ; p -> func();        /* use derived2's func() */
             return 0; }
```

  - The ***VF func()*** is first inherited by ***derived1***, which overrides it relative to itself. Next, ***derived2*** inherits ***derived1***. In ***derived2***, ***func()*** is again overridden.
    - Since ***VF***s are hierarchical, if ***derived2*** did not override ***func()***, when ***d_ob2*** was accessed, ***derived1***'s ***func()*** would have been used.
    - If neither ***derived1*** nor ***derived2*** had overridden ***func()***, ***base's func()*** would have been used.

13.4 Polymorphism: Early binding & Late binding

Polymorphism: Polymorphism is the process by which a **common interface** is applied to two or more similar (but technically different) situations, thus implementing the ***"one interface, multiple methods"*** philosophy. In polymorphism a single, well-defined interface is used to access a number of ***different but related*** actions, and artificial complexity is removed.

❒ There are two terms that are often linked to ***OOP in general*** and to ***C++*** specifically. They are ***early binding*** and ***late binding***.

☞ ***Early binding:*** Early binding essentially refers to those events that can be known at ***compile time***. Specifically, it refers to those function calls that can be ***resolved during compilation***. Early bound entities include:

[1] "***Normal***" functions, ***[2]*** ***Overloaded*** functions, ***[3]*** ***Non-virtual*** member ***[4]*** ***Friend*** functions.

➲ When these types of functions are compiled, ***all address information*** necessary to call them is known at ***compile time***.

➲ Calls to ***functions bound at compile time*** are the ***fastest types of function calls***. Main disadvantage is **lack of flexibility**.

☞ ***Late binding:*** Late binding refers to events that must occur at ***run time***. A ***late bound function call*** is one in which the address of the function to be called is **not known until the program runs**.

⇨ In C++, a ***virtual function is a late bound object***. When a **VF** is accessed via a ***base class pointer***, the program must determine at ***run time*** what ***type of object*** is being pointed to and then select which ***version*** of the ***overridden function*** to **execute**.

⇨ **Advantage**: Flexibility at run time. **Disadvantage**: is that there Slower than ***early binding***.

❒ ***Example 1:*** Here is a program that illustrates "***one interface, multiple methods***." It defines an **abstract *list* class** for integer values.

☞ The interface to the ***list*** is defined by the PVFs ***`store()`*** and ***`retrieve()`***. To ***store a value***, call ***`store()`***. To ***retrieve a value***, call ***`retrieve()`***.

☞ The **base *list*** does not define any ***default methods*** for these actions. Instead, each **derived** defines exactly ***what type of list*** will be maintained.

➢ In the program, two types of lists are implemented: a ***queue*** and a ***stack***. Although the two lists operate completely differently, each is accessed using the ***same interface***.

```
#include<iostream >
#include<cstdlib >
using namespace std;
class list{  public:      list *head ;        /* pointer to start of list */
                          list *tail ;        /* pointer to end of list */
                          list *next ;        /* pointer to next item */
                          int num ;                 /* value to be stored */
                          list(){ head = tail = next = NULL ; }
                    virtual void store(int i) = 0;          /* PVF */
                    virtual int retrieve() = 0;             /* PVF */
      };
```

```
            /* Create a queue - type list.*/

class queue : public list {
                    public : void store(int i);
                             int retrieve();
                          };

void queue :: store(int i){ list *item;
      item = new queue ;
      if(!item ){   cout << "Allocation error.\n";
                    exit(1); }
      item -> num = i;
                /* put on end of list */
      if(tail) tail -> next = item ;
      tail = item ;
      item -> next = NULL ;
      if(!head) head = tail ;  }

int queue :: retrieve(){   int i;
                           list *p;
      if(!head){    cout << "List empty.\n ";
                    return 0; }
              /* remove from start of list */
      i = head -> num;
      p = head ;
      head = head -> next ;
      delete p;
      return i; }
```

```
            /* Create a stack - type list.*/

class stack : public list {
                    public : void store(int i);
                             int retrieve();
                          };

void stack :: store(int i){ list *item ;
      item = new stack ;
      if(!item){    cout << "Allocation error.\n";
                    exit(1); }
      item -> num = i;
      /* put on front of list for stack - like operation */
      if(head) item -> next = head ;
      head = item ;
      if(!tail) tail = head ; }

int stack :: retrieve(){   int i;
                           list *p;
      if(!head){    cout << "List empty.\n";
                    return 0; }
              /* remove from start of list */
      i = head -> num;
      p = head ;
      head = head -> next ;
      delete p;
      return i; }
```

```
int main() {  list *p;
                /* demonstrate queue */
              queue q_ob ;
              p = &q_ob;   /* point to queue */
                    p-> store(1);
                    p-> store(2);
                    p-> store(3);
              cout << "Queue : ";
                    cout << p-> retrieve();
                    cout << p-> retrieve();
                    cout << p-> retrieve();
                    cout << '\n';
                /* demonstrate stack */
              stack s_ob;
              p = &s_ob;   /* point to stack */
                    p-> store(1);
                    p-> store(2);
                    p-> store(3);
              cout << "Stack : ";
                    cout << p-> retrieve();
                    cout << p-> retrieve();
                    cout << p-> retrieve();
                    cout << '\n';
              return 0;}
```

❒ ***Example 2:*** To see why ***run-time polymorphism*** is so powerful, try using this ***main()*** instead of previous example:

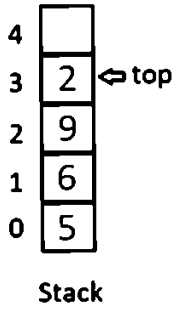
- ☞ This ***main()*** illustrates how random events that occur at run time can be easily handled by using ***VFs*** and ***run-time polymorphism***.
- ☞ The program executes a ***for*** loop running from ***0*** to ***9***. Each iteration through the loop, you are asked to choose into which type of list- ***stack*** or the ***queue***-you want to put a value. According to your answer, the base ***pointer p*** is set to point to the correct object and the current value of ***i*** is stored.
- ☞ Once the loop is finished, another loop begins that prompts you to indicate you to indicate from which list to remove a value. Once again, it is your response that determines which list is selected.

```
int main(){   list *p;
              queue q_ob ;
              stack s_ob ;
              char ch;
              int i;
       for(i=0; i <10; i++) {
              cout << "Stack or Queue ? (S/Q): ";
              cin >> ch;
              ch = tolower(ch);
              if(ch == 'q') p = &q_ob ;
              else p = &s_ob ;
              p -> store(i);      }
cout << "Enter T to terminate \n";
for(;;){  cout << "Remove from Stack or Queue ? (S/Q): ";
           cin >> ch;
           ch = tolower(ch);
              if(ch == 't') break ;
              if(ch == 'q') p = &q_ob ;
              else p = &s_ob ;
           cout << p-> retrieve() << '\n';   }
           cout << '\n';
return 0;}
```

Difference between ***Stack*** and ***Queue*** Data Structures :

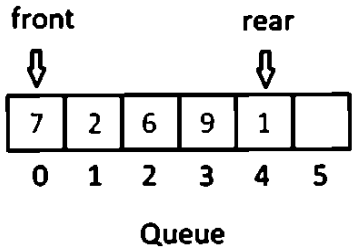
Stack: A stack is a *linear data structure* in which elements can be *inserted* and *deleted* only from ***one side of the list***, called the ***top***.

- A ***stack*** follows the ***LIFO (Last In First Out)*** principle, i.e., the *element inserted at the last is the first element to come out.*
- The *insertion of an element* into stack is called ***push*** operation, and *deletion of an element* from the stack is called ***pop*** operation.
- In stack we always keep track of the last element present in the list with a *pointer* called ***top***.



Queue: A queue is a *linear data structure* in which elements can be *inserted only from one side* of the list called ***rear***, and the elements can be *deleted only from the other side* called the ***front***.

- The ***queue*** follows the ***FIFO (First In First Out)*** principle, i.e. the *element inserted at first in the list, is the first element to be removed from the list.*
- The *insertion of an element* in a queue is called an ***enqueue*** operation and the *deletion of an element* is called a ***dequeue*** operation.
- In queue we always maintain two pointers, one pointing to the element which was ***inserted at the first and still present in the list*** with the ***front pointer*** and the second pointer pointing to ***the element inserted at the last*** with the ***rear pointer***.



13. 5 Generic-Functions & Generic-Classes (GnF & GnC)

Generic functions and classes (reusable code): We create *generic functions* & *classes* using ***templates***. In a *generic function or class*, the ***type of data*** that operated upon is *specified as a parameter*. This allows you to use one function or class with ***several different types of data*** without *specific explicit-code* for each different ***data type***.

- A ***GnF*** defines a **general set of operations** that will be applied to ***various types of data***. A ***GnF*** has the type of data that ***it will operate upon*** passed to it ***as a parameter***.
  - A ***GnF*** is the **data-independent-code** which defines the *nature of the algorithm*. The compiler automatically generates the correct code for the type of data during function execution. By a ***Gnf*** the function can ***automatically overload itself***.
  - It helps a lot because *many algorithms are logically the same* no matter what type of data is being operated upon. For example, the ***Quicksort*** algorithm is applicable for both ***integers*** and ***floats***. It is just that the *type of the data* being sorted is different.
- ***template:*** A ***GnF*** is created using the keyword ***template***. In C++ the keyword ***template*** is used to create a ***template (or framework)*** that describes what a function will do, leaving it to the *compiler* to fill in the details as needed. The general form of a template is :

```
template <class Ttype> ret_type func_name(parameter list){ /* body of function */ }
```

  - Here ***Ttype*** is a *placeholder name* for a ***data type*** used by the function. It can be used within the function definition. The compiler will automatically replace this placeholder with an actual ***data type*** during function execution.
  - ***Class*** is used to specify a ***generic type*** in a **template declaration**. It is traditional; you can also use the keyword ***typename***.
  - ***Template function:*** A ***generic function / GnF*** (that is, a function definition preceded by a ***template statement***) is also called a ***template function***.
  - ***Generated function:*** When the compiler creates a specific version of this function, it is said to have created a ***generated function***.
  - ***Instantiating a function:*** The act of generating a function is referred to as ***instantiating*** it. Put differently, a *generated function* is a specific instance of a *template function*.
- ***Generic-Classes (GnC):*** When you define ***GnC*** you create a ***class that defines all algorithms*** used by that class, but the actual type of the data being manipulated will be specified as a parameter when objects of that class are created.
  - ***GnC*** are useful when a class contains **generalizable logic** (i.e when data types varies). By using a ***GnC***, you can create a class that will maintain a *queue*, a *linked list*, and so on for any type of data.
  - The ***compiler*** will *automatically generate* the correct ***type of object*** based upon the ***type*** you specify when the object is created.
  - Member functions of a ***GnC*** are, themselves, automatically ***GnF***. They need not be explicitly specified as such using ***template***.
- The general form of a ***GnC*** declaration is:

```
template <class Ttype > class class_name { . . .
                                           . . . };
```

  - Here ***Ttype*** is the ***placeholder type name*** that will be specified when a class is instantiated.
  - If necessary, you can define **more than one generic data type** by using a *comma-separated list*.
- Once you have created a ***GnC***, you create a specific instance of that class by using the following general form:

```
class_name <type> ob;
```

  - Here ***type*** is the ***type name*** of the data that the class will be operating upon.
  - ***One point to remember(?):*** in the case of ***GnC*** we create the object of that generic class using

```
class_name<type> obj_name ;
```

    instead of ordinary ***" class_name obj_name ;"***. And we can ***access/define*** any *function/member* of that generic class "***outside***" of it by using:

```
template <class Ttype > class_name<type> :: member(parametr){}
```

    Here the key point is that ***" class_name<type>"*** considered the class name instead of ordinary ***" class_name"*** to define an object of its type or accessing any member outside of it.
- When you create a ***GnF***, you are, in essence, allowing the ***compiler*** to generate as many **different versions of that function** as necessary *to handle the various ways that your program calls that function.*
- ***Example 1:*** The following program creates a ***GnF / Function template*** that swaps the values of the two variables it is called with. (Because the general process of exchanging two values is independent of the type of the variables)

```
template<class X> void swapargs(X &a, X &b){    X temp;
                                                temp = a;
                                                a = b;
                                                b= temp ;  }
int main( ){      int i=10 , j =20;
                  float x=10 , y =23.3;
                  cout << " Original i, j: " << i << ' ' << j << endl ;
                  cout << " Original x, y: " << x << ' ' << y << endl ;

                  swapargs(i, j);          /* swap integers */
                  swapargs(x, y);          /* swap floats */
                  cout << " Swapped i, j: " << i << ' ' << j << endl ;
                  cout << " Swapped x, y: " << x << ' ' << y << endl ;
                  return 0; }
```

  - The keyword ***template*** is used to define a generic function. The line:

```
template<class X> void swapargs(X &a, X &b)
```

    tells the ***compiler*** two things: that **a template is being created** and that **a generic definition is beginning**.
    - ✓ Here ***X*** is a ***generic type*** that is used as a **placeholder**.
    - ✓ After the template portion, function ***swapargs()*** is declared, using ***X*** as the ***data type of the values*** that will be swapped.
  - In ***main()***, the ***swapargs()*** function is called using two different types of data: ***integers*** and ***floats***. Because ***swapargs()*** is a generic function, the compiler automatically creates two versions of ***swapargs()***.

- one that will exchange ***integer*** values and
- one that will exchange ***floating-point*** values.

❒ The ***template portion*** of a ***GnF*** definition does not have to be on the same line as the ***function's name***. For example,

```
template <class X>
void swapargs(X &a, X &b) { X temp;  temp=a;  a=b;  b=temp;  }
```

☞ No other statements can occur between the ***template statement*** and the start of the ***GnF*** definition. For example, the following fragment will not compile:

```
template <class X>
int i;        /* this line causes error */
void swapargs (X &a, X &b) { X temp ; temp = a; a = b; b= temp ; }
```

❒ Instead of using the keyword ***class***, we can use the keyword ***typename*** to specify a ***generic type*** in a template definition. Eg:

```
template<typename X> void swapargs(X &a, X &b){ X temp; temp = a; a = b; b= temp; }
```

☞ The ***typename*** keyword can also be used to ***specify an unknown type*** within a template.

❒ To define **more than one generic data-type** with the template statement, use a ***comma-separated list***. For example:

```
template<class type1, class type2>
            void myfunc(type1 x, type2 y){ cout<< x <<' '<< y << endl; }

int main(){  myfunc(10 , "hi");
             myfunc (0.23 , 10L);
             return 0; }
```

☞ The placeholder types ***type1*** and ***type2*** are replaced by the ***compiler*** with the data types ***int*** and ***char **** and ***double*** and ***long***, respectively, when the ***compiler generates*** the ***specific instances (or specific object)*** of ***myfunc()***.

❒ ***GnF*** are similar to ***overloaded*** functions except that they are **more restrictive**.

- For ***overloaded function*** different actions can be performed within the body of each function.
- But a GnF must perform the same general action for all versions.

☞ For example, the following overloaded functions cannot be replaced by a ***Gnf*** because they do not do the same thing:

```
void outdata(int i){ cout << i; }
void outdata(double d){   cout << setprecision(10) << setfill ('#');
                          cout << d;
                          cout << setprecision(6) << setfill (' '); }
```

❒ ***Example 2*** (overloading ***GnF / template***): Generally a template function overloads ***itself*** as needed. But we can ***explicitly overload*** one, too. If you overload a ***GnF***, that **overloaded function (our version)** overrides (or "hides") the ***GnF*** relative to that **specific version**. For example, consider this version of ***Example 1***:

```
template <class X> void swapargs(X &a, X &b) { X temp ; temp = a; a = b; b= temp ; }
void swapargs (int a, int b) { cout << " this is inside swapargs (int ,int )\n"; }        /* This overrides the GnF swapargs().*/

int main( ){      int i=10, j =20;
                  float x=10, y =23.3;
                  cout << " Original i, j: " << i << ' ' << j << endl ;   cout << " Original x, y: " << x << ' ' << y << endl ;
                  swapargs(i, j);          /* calls overloaded swapargs(), because of matched int arguments  */
                  swapargs (x, y);         /* swap floats */
                  cout << " Swapped i, j: " << i << ' '<< j << endl ;   cout << " Swapped x, y: " << x << ' ' << y << endl ;
                  return 0; }
```

☞ When ***swapargs(i,j)*** is called, it invokes the ***explicitly overloaded version*** of ***swapargs()*** defined in the program (because of ***int*** values). Thus, the ***compiler*** does not generate this version of the ***generic swapargs()*** function because the ***GnF*** is ***overridden*** by the **explicit *overloading***.

☞ **Manual overloading** of a ***template***, as shown in this example, allows you to ***tailor a version*** of a ***GnF*** to accommodate a special situation.

- In general, if you need to have different versions of a function for different data types, you should use ***overloaded*** functions rather than ***templates***.

❒ ***Example 3:*** This program creates a very simple generic singly linked list class. It then demonstrates the class by creating a linked list that stores ***characters***.

```
template <class data_t > class list {   data_t data ;
                                        list *next ;
                                public :
                                        list ( data_t d);
                                void add(list *node){
                                                node -> next = this;
                                                next = 0; }
                                list *getnext(){ return next ; }
                                data_t getdata(){ return data ; }
                                };

        /* definition of member function 'list' */

template <class data_t > list <data_t >:: list ( data_t d) { data = d;
                                                             next = 0;}
```

```
int main(){         list<char>  start ('a');
                    list<char>  *p, * last ;
                    int i;
                        /* build a list */
        last = &start ;
        for (i=1; i <26; i++){  p = new list <char >( 'a' + i);
                                p->add ( last );
                                last = p;          }
/* follow the list */
        p = &start ;
        while(p) {  cout << p-> getdata();
                    p = p-> getnext();}
        return 0;}
```

☞ The actual data-type stored by the ***list*** is ***generic*** in the **class declaration**. Here ***objects*** and ***pointers*** are created inside ***main()*** that specify that the ***data-type*** of the ***list*** will be ***char***.

☞ ***Setting data type in object declaration of a generic class-type:*** The desired data type is passed inside the angle brackets in the following declaration:

```
list< char > start('a') ;
```

✓ By simply changing the data-type specified "**inside < >**" when ***list objects*** are created, you can change the type of data stored by the list. For example, you could create another object that stores ***integers*** by using:

```
list< int > int_start(1) ;
```

☞ Use list to store data types that you create: For example, if you want to store address information, use following ***structure***:

```
struct addr {char name[40];
             char street[40];
             char city[30];
             char state[3];
             char zip[12]; }
```

Then, to use ***list*** to generate objects that will store objects of type ***addr***, use: `list< addr > obj( structvar );`
(assuming that ***structvar*** contains a valid ***addr*** structure)

❒ A ***template class*** can have **more than one** ***generic data type***. Simply *declare all the data types required by the class* in a ***comma-separated list*** within the ***template specification***.

❒ ***Example 4:*** the following short example creates a class that uses two generic data types:

```
template <class Type_1 , class Type_2> class myclass{  Type1 i;
                                                       Type2 j;
        public : myclass( Type1 a, Type2 b) { i = a;  j = b; }
        void show() { cout << i << ' ' << j << '\n'; }
        };
```

```
int main(){     myclass< int, double > ob1 (10 , 0.23) ;
                myclass<char , char *> ob2('X', " This is a test ");
                  ob1.show();       /* show int , double */
                  ob2.show();       /* show char , char **/
          return 0; }
```

This program produces the following output:

```
10   0.23
X This is a test
```

☞ The program declares two types of objects. ***ob1*** uses ***integer*** and ***double*** data. ***ob2*** uses a ***character*** and a ***character pointer***.

☞ For both cases, the compiler automatically generates the appropriate data and functions for each object.

NOTE

[1] C++ provides a library that is built upon ***template classes***. This library is usually referred to as the ***Standard Template Library***, or ***STL*** for short.

[2] ***STL*** provides generic versions of the most *commonly used algorithms and data structures*.

13.6 EXCEPTION HANDLING

Exception handling (resilient code): ***Exception handling*** is the subsystem of C++ that allows us to handle errors that occur at ***run time*** in a *structured and controlled way*. By ***exception handling***, your program can *automatically* invoke an *error handling routine* when an error occurs.

❒ ***Exception handling*** is C++'s *built-in error handling mechanism*. Mostly used to manage and respond to ***run-time errors***. C++ exception handling is built upon three keywords: ***try***, ***catch***, and ***throw***.

- ➲ Generally the program statements that you want to monitor for exceptions are contained in a ***try block***.
- ➲ If an ***exception (i.e., an error) occurs*** within the ***try block***, it is thrown using ***throw***.
- ➲ The exception is caught, using ***catch***, and processed.

❒ ***General Form and*** `try-catch` ***blocks:*** The general form of try and catch are:

```
try{   /* try block */ }
catch(type1 arg){          /* catch block */   }
catch(type2 arg){          /* catch block */   }
catch(type3 arg){          /* catch block */   }
                              . . .
catch(typeN arg){          /* catch block */   }
```

☛ ***try***: The ***try block*** must contain the portion of your program that you want to *monitor for errors*. This can be a **few statements** within one function or **all-codes by enclosing the *main()* function within a *try block* *(which causes the entire program to be monitored).***

- ❍ Any statement that ***throws an exception*** must have been **executed from within** a ***try block***.
- ❍ A function **called from within** a ***try block*** can also ***throw an exception***.

☛ ***catch***: Any exception must be caught by a ***catch statement*** that immediately follows the ***try statement*** that throws the exception. Catch statement **processes the exception**.

- ❍ ***Any type of data*** can be caught by ***catch***. ***Class types*** are frequently used as exceptions.
- ❍ There can be **more than one** ***catch*** associated with a ***try***. The ***catch*** that is used is ***determined by*** the ***type*** of the ***exception***. I.e, if the ***data type*** specified by a ***catch matches the data type of the exception***, that ***catch*** is executed (and all others are bypassed).
- ❍ When an **exception** is caught, ***arg*** will receive its value. If you don't need access to the exception itself, specify only type in the catch clause-***arg is optional***.

❒ ***General form of the `throw`:*** The general form of the throw statement is: ***`throw exception ;`***

☛ ***`throw`*** must be executed either from within the ***try*** block proper or from any function that the code ***within the block calls*** (directly or indirectly).

☛ ***`exception`*** is the value thrown. If you throw an exception for which there is no applicable ***catch*** statement, an abnormal program termination might occur.

- In standard C++, throwing an unhandled exception causes the standard library function ***`terminate()`*** to be invoked. By default, ***`terminate()`*** calls ***`abort()`*** to stop your program.
- You can specify your own ***termination handler*** by referring to your compiler's library reference for details.

❒ ***Catch all exceptions with ellipsis "...":*** To *catch all exceptions* instead of just a certain type, use following form of catch:

```
catch(...){  /* process all exceptions */  }
```

Here the ellipsis matches any type of data. ***[". . ." called ellipsis. It indicates an intentional omission of a word/whole-line/text-section without altering original meaning.]***

◘ ***Appling restrictions to exceptions:***

➲ We can ***restrict*** the *type of exceptions* that a function can throw ***back*** to its ***caller***.

➲ We can ***control*** what *type of exceptions* a function can throw ***outside*** of ***itself***.

➲ We can also ***prevent*** a function from throwing any exceptions whatsoever.

☛ To apply these restrictions, you must add a ***throw clause*** to the function definition. The general form is:

```
ret_type func_name(arg_list)  throw(type_list){ /* exceptions */ }
```

⇨ Here only those data types contained in the *comma-separated* ***type-list*** may be thrown by the function.

☛ When a function attempts to throw a ***disallowed exception*** the standard library function ***`unexpected()`*** is called, this causes the ***`terminate()`*** function to be called, which causes **abnormal program termination**.

⇨ ***For own termination handler:*** need to refer to compiler's documentation for directions on how this can be accomplished.

⇨ If you don't want a function to be able to throw any exceptions, use an ***empty list***.

◘ ***Rethrowing exceptions:*** To ***rethrow*** an expression from within an exception handler: call ***`throw`***, by itself with no exception. This causes the current exception to be passed on to an outer ***`try/catch`*** sequence.

❒ ***Example 1: (Execution process of Exception Handling):*** Following shows the way C++ exception handling operates:

```
int main(){cout << " start \n";
            try{                                    /* start a try block */
                cout << " Inside try block \n";
                throw 10;                           /* throw an error */
                cout << " This will not execute ";  /* not execute, control transferred to "catch" due to "throw 10"*/
                }
            catch(int i){                           /* beginning catch block: catch an error */
                      cout << " Caught One ! Number is: ";
                      cout << i << "\n"; }
        cout << "end ";
        return 0; }
```

This program displays the OUTPUT:

```
start
Inside try block
Caught One! Number is: 10
end
```

☞ There is:
⇨ a ***`try`*** block containing three statements and
⇨ a ***`catch(int i)`*** statement that processes an **integer exception**.

☞ Within the ***`try`*** block, only two of the three statements will execute: the first ***`cout`*** statement and the ***`throw`***. Once an ***exception*** has been ***thrown***, *control passes to the* ***`catch`*** expression and the ***`try`*** block is ***terminated***. The ***`cout`*** statement following the ***`throw`*** will *never execute*.

▶ i.e. ***`catch`*** is not called, rather, ***program execution is transferred to it***. (The stack is automatically reset as needed to accomplish this.)

▶ After the ***`catch`*** statement executes, ***program control*** continues with the statements following the ***`catch`***.

☞ Often, however, a ***`catch block`*** *will end with* a call to ***`exit()`***, ***`abort()`***, or some other function that causes *program termination* because exception handling is frequently used ***to handle catastrophic errors***.

❒ The ***type of the exception*** must match the ***type specified in a `catch`*** statement. Considering ***Example 1***, following won't work.

```
catch(double i){        /* 'catch' is double type: won't work for an int exception */
          cout << " Caught One ! Number is: ";
          cout << i << "\n"; }
```

☞ This program produces the following output because the ***integer `exception`*** will not be caught by a ***double `catch`*** statement.

This program displays the OUTPUT:

```
start
Inside try block
Abnormal program termination
```

❒ ***Example 2:*** An ***exception*** can be **thrown** *from a statement that is outside* the ***`try block`*** as long as the *statement is within a function that is called from within the* ***`try block`***. For example, this is a valid program:

```
void Xtest(int test) {     cout << " Inside Xtest , test is: " << test << "\n";
                           if(test) throw test ; }
```

```
int main(){   cout << " start \n";
          try{     /* throwing by the function Xtest : calling function within try block */
              Xtest(0);
              Xtest(1);
              Xtest(2);}   /* it is also an exception but never thrown or executed */
          catch(int i{    cout << " Caught One ! Number is: ";
                          cout << i << "\n";     }
       cout << "end ";
       return 0; }
```

OUTPUT:
start
Inside try block
Inside Xtest, test is: 0
Inside Xtest, test is: 1
Caught One! Number is: 1
end

☞ ***Xtest(2)*** is also ***exception*** but never thrown because of control transferred to "***catch***" after throwing ***1*** as ***exception***.

❒ ***Example 3:*** [To avoid "***error skipping***" as ***Xtest(2)*** in ***Example 2***] A ***try block*** can be ***localized*** to a function. In this case, each time the function is entered, the **exception handling** relative to that function is ***reset***. For example:

```
       void Xhandler(int test){   try {  if( test )
                                          throw test ; }
                                  catch(int i){ cout << " Caught One ! Ex. #: " << i << '\n'; }
                                }
       int main(){   cout << " start \n";
                           Xhandler (1);
                           Xhandler (2);
                           Xhandler (0);
                           Xhandler (3);
                     cout << "end ";
                     return 0;}
```

OUTPUT:
start
Caught One! Ex. #: 1
Caught One! Ex. #: 2
Caught One! Ex. #: 3
end

☞ ***try block*** is not inside ***main()***, instead ***try-catch blocks*** containing function ***Xhandler()*** is called from ***main()***.

☞ As you can see, three exceptions are thrown. After each exception, the function returns. When the function is called again, the ***exception handling is reset***.

❒ ***Example 4:*** More than one catch associated with a try. ***Each catch must catch a different type of exception*** (two or more catch with same data-type returns error). For example, consider ***Example 3*** with the following ***Xhandler()*** [catches both integers and strings]:

```
       void Xhandler(int test){   try {  if(test)  throw test ;
                                          else throw "value is zero" }
                                  catch(int i){ cout << " Caught One ! Ex. #: " << i << '\n'; }
                                  catch(char *str){          /* *str is used to print ' value is zero ' */
                                                   cout << " Caught a string :";
                                                   cout << str << '\n';}
                                }
```

❒ In general, ***catch*** expressions are checked in the order in which they occur in a program. Only a matching statement is executed. All other ***catch blocks*** are ignored.

❒ ***Example 5:*** Following catches all exceptions [with ellipsis ***...***] using ***catch(...)***:

```
void Xhandler (int test ) {   try { if( test ==0) throw test ;     /* throw int */
                                    if( test ==1) throw 'a';       /* throw char */
                                    if( test ==2) throw 123.23;  /* throw double */
                                    }
                              catch (...){                  /* catch all exceptions */
                                          cout << " Caught One !\n";   }
                              }
int main(){ cout << " start \n";
                 Xhandler(0);
                 Xhandler(1);
                 Xhandler(2);
       cout << "end ";
       return 0; }
```

OUTPUT:
start
Caught One!
Caught One!
Caught One!
end

☞ All three ***throws*** were caught using the one ***catch*** statement.

❒ ***Example 6:*** Use ***catch(...)*** as the last catch of a ***cluster of catches*** [as last catch block for miscellaneous errors]. In this capacity it provides a useful default or ***"catch all"*** statement. For example, this slightly different version of the preceding program explicitly catches integer exceptions but relies upon ***catch(...)*** to catch all others:

```
void Xhandler (int test ) {   try { if( test ==0) throw test ;     /* throw int */
                                    if( test ==1) throw 'a';       /* throw char */
                                    if( test ==2) throw 123.23;  /* throw double */
                                    }
                              catch (int i){                /* catch an int exception */
                                          cout << " Caught" << i << '\n';   }
                              catch (...){                  /* all other  exceptions */
                                          cout << " Caught One !\n";   }
                              }
int main(){ cout << " start \n";
                 Xhandler(0);
                 Xhandler(1);
                 Xhandler(2);
       cout << "end ";
       return 0; }
```

OUTPUT:
start
Caught 0
Caught One!
Caught One!
end

☞ By catching all exceptions, you prevent an ***unhandled exception*** from causing an ***abnormal program termination***.

❒ ***Example 7:*** ***ret_type func_name(arg_list) throw(type_list){ /* exceptions */ }*** to restrict the types of exceptions that can be thrown from a function:

```
void Xhandler(int test ) throw(int, char, double) {
        if( test ==0) throw test ;      /* throw int */
        if( test ==1) throw 'a';        /* throw char */
        if( test ==2) throw 123.23;  /* throw double */   }
int main(){ cout<< "start \n";
                 try{ Xhandler(0);  }          /* 1 and 2 also  */
                 catch(int i) { cout << " Caught int \n";}
                 catch ( char c) { cout << " Caught char \n"; }
                 catch ( double d) { cout << " Caught double \n"; }
       cout << "end ";
       return 0; }
```

- In this program, the function ***Xhandler()*** can throw only ***integer***, ***character***, and ***double*** exceptions. If it attempts to throw any other type of exception, an abnormal program termination will occur. (That is, ***unexpected()*** will be called.) To see an example of this, remove ***int*** from the list and retry the program.
- A function can only be ***restricted*** in what types of exceptions it ***throws*** back to the ***try block*** that called it. That is, ***a try block within a function can thrown any type of exception so long as it is caught within that function***.
- The ***restriction*** applies only when ***throwing an exception out of the function***.

❒ ***Example 8:*** The following change to ***Xhandler()*** prevents it from throwing any exceptions:

```
void Xhandler(int test ) throw(){if( test ==0) throw test ;
                                 if( test ==0) throw 'a';
                                 if( test ==2) throw 123.23; }
```

- The above statements no longer work . Instead , they will cause an ***abnormal program termination*** .

❒ ***Example 9:*** The reason for ***rethrow*** an exception is to allow ***multiple handlers*** access to the exception. For example, perhaps one exception handler manages one ***aspect*** of an exception and a second handler ***copes*** with another.

- An ***exception*** can only be ***rethrown*** from within a ***catch block*** (or from any function called from within that block).
- When you ***rethrow*** an exception, it ***will not be recaught*** by the ***same catch statement***. It will propagate to an ***outer catch*** statement.
  - ▶ The following program illustrates ***rethrowing an exception***. It rethrows a ***char **** exception.

```
void Xhandler() {
        try { throw " hello "; }        /* throw  char *  */
        catch( const char *) {          /* catch  char *  */
                cout << " char * inside Xhandler \n";
                throw ;       /* rethrow char * */     }
              }
```

```
int main(){ cout << " start \n";
        try { Xhandler (); }
        catch ( const char *) {
            cout << "char * inside main \n"; }
    cout << "end ";
    return 0; }
```

OUTPUT:

```
start
char * inside Xhandler
char * inside main
end
```

13.7 Handling *exceptions* thrown by *new*

Behavior of new as specified by Standard C++: In early C++, ***new*** returned ***null*** on ***failure***. In later version ***new*** caused an ***exception*** on ***failure***. Finally, it was decided that a ***new failure*** will generate an ***exception*** by default, but that a ***null pointer*** could be returned instead, as an option.

◘ ***Allocation exceptions with new and xalloc or bad_alloc:*** In Standard C++, when an ***allocation request cannot be honored***, ***new*** throws a ***bad_alloc*** (***xalloc*** in older versions) exception. If you don't catch this exception, your program will be ***terminated***.

- It is good for short programs but in real applications you ***must catch this exception*** and process it in some ***rational manner***.
- To have access to this exception, you must include the ***header*** **<new>** in your program.

◘ ***Returning old fashioned null In Standard C++:*** It is also possible to have new return null instead of throwing an exception when an allocation failure occurs. This form of new is : ***p_var =new(nothrow) type ;***

  - ❖ Here ***p_var*** is a ***pointer variable*** of ***type***.

- The ***nothrow*** form of ***new*** works like the original version of ***new*** from years ago. Since it returns ***null*** on failure, it can be ***"dropped into"*** older code and ***avoid exception handling***. Useful when compiling older code with a modern C++ compiler.
- It is also valuable when you are ***replacing*** calls to ***malloc()*** with ***new***.

❒ ***Example 1:*** Here is an example of ***new*** that uses a ***try/catch block*** to monitor for an allocation failure.

```
#include <iostream>
#include <new>
using namespace std;
        int main(){ int *p;
                    try{ p = new int; }        /* allocate memory for int */
                    catch (bad_alloc xa){  cout << " Allocation failure .\n";
                                           return 1;  }
```

```
for(*p = 0; *p < 10; (*p)++)     cout << *p << " " ;
delete p; // free the memory
return 0; }
```

- Here if an allocation failure occurs, it is caught by the ***catch*** statement.

❒ ***Example 2:*** Since the previous program is unlikely to fail under any normal circumstance, the following program demonstrates ***new's*** exception-throwing capability by forcing on allocation failure. It does this by allocating memory until it is exhausted.

```
int main(){ double *p;
            do{ try{ p = new double[100000]; }          /* this will eventually run out of memory */
                catch( bad_alloc xa ){     cout << " Allocation failure .\n";
                                           return 1;}
                }while (p);
          return 0;}
```

❒ ***Example 3:*** Following shows the use of ***new(nothrow)*** alternative. It reworks the ***Example 2*** and forces an allocation failure.

```
int main(){ double *p;
            do{ p = new(nothrow) double[100000];          /* this will eventually run out of memory */
                if(p) cout << "Allocation ok \n";
                else cout << "Allocation error \n";
                }while (p);
          return 0;}
```

- When you use the ***nothrow*** approach, you must check the ***pointer returned by new*** after each allocation request.

▣ ***RTTI*** allows you to identify the type of an object during the execution of your program.

▣ The ***casting operators*** give you safer, more controlled ways to cast. As you will see, one of the casting operators, dynamic cast, relates directly to RTTI.

13.8 RTTI (run-time type identification)

- ***RTTI*** is not found in ***non-polymorphic*** languages such as ***C***. In such languages, there is no need for ***run-time type information*** because the type of each object is known at ***compile time*** (i.e., when the program is written).
- In ***polymorphic languages*** such as C++, there can be situations in which the type of an object is unknown at compile time because the precise nature of that object is not determined until the program is executed. For example: A ***base class pointer*** can be used to point to objects of the ***base class*** or to any object ***derived*** from that base. This determination must be made at ***run-time***, using ***RRTI***.
  - ⇨ C++ implements ***polymorphism*** through :
    - ✓ The use of ***class hierarchies***,
    - ✓ ***Virtual functions***, and
    - ✓ ***Base class pointers***.

■ To obtain an object's type, use ***typeid*** and must include the header **<typeinfo>**. The most common form of ***typeid*** is:

```
typeid(object)
```

- ☛ Here ***object*** is the object whose type you will be obtaining.
- ☛ ***typeid*** returns a reference to an object of type ***type_info*** that describes the type of object defined by object.
  - ➲ The ***type_info*** class defines these public members:
    - ✓ `bool operator==( const type_info &ob);`
    - ✓ `bool operator!=( const type_info &ob);`
    - ✓ `bool before( const type_info &ob);`
    - ✓ `const char*name();`
  - ➢ The overloaded **"=="** and **"!="** provide for the comparison of types.
  - ➢ The ***before()*** function returns ***true*** if the invoking object is before the object ***used as a parameter in collation order***. *(Internal use only. Its return value has nothing to do with inheritance or class hierarchies.)*
  - ➢ The ***name()*** function ***returns a pointer*** to the ***name of the type***.

■ ***The most important use of typeid is:*** its application through a **pointer of a polymorphic base**. Using ***typeid*** you can determine at ***run-time*** the ***type of the object*** that is being pointed to by a ***base pointer***.

- ☛ ***typeid*** will automatically return the ***type of the actual object being pointed to***, which can be a ***base object*** or a ***derived object*** from that ***base***. [NOTE: A ***base pointer*** can point to a ***base object*** or any ***derived object*** from that ***base***.]

■ The same applies to ***references***:
- ➲ When ***typeid*** is applied to a ***reference to an object*** of a ***polymorphic class***, it will return the ***type*** of the **object actually being referred to**, which can be of a ***derived type***.
- ➲ When ***typeid*** is applied to a ***non-polymorphic class***, the ***base type*** of the **pointer** or **reference** is obtained.

■ ***Another form of typeid:*** This form of ***typeid*** takes a ***type name*** as its **argument**: `typeid( type_name )`

- ☛ It is used to obtain a ***type_info object*** that describes the **specified type** so that it can be used in a ***type comparison statement***.

■ ***bad_typeid exception***: Because ***typeid*** is commonly applied to a ***dereferenced pointer*** (i.e., one to which the * operator has been applied), a special exception has been created to handle the situation in which the **pointer being dereferenced** is ***null***. In this case, ***typeid*** throws a ***bad_typeid*** exception.

❒ ***Example 1:*** The following program demonstrates typeid. It first obtains type information about one of C++'s built-in types, int. It then displays the types of objects pointed to by p, which is a pointer of type BaseClass.

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

class BaseClass {
        virtual void f(){ }     /* BaseClass polymorphic */
                        /* ... */ };

class Derived1 : public BaseClass{ /* ... */ };
class Derived2 : public BaseClass{ /* ... */ };

int main(){         int i;
                    BaseClass *p, baseob;
                    Derived1 ob1;
                    Derived2 ob2;

                    /* First, display type name of a built -in type. */
cout << " Typeid of i is " <<  typeid (i). name () << endl ;

                    /* Demonstrate typeid with polymorphic types. */
p = &baseob ;
 cout << "p is pointing to an object of type" << typeid(*p).name() << endl;
p = &ob1;
 cout <<"p is pointing to an object of type" << typeid(*p).name() << endl ;
p = &ob2;
 cout <<"p is pointing to an object of type" << typeid(*p).name() << endl ;
return 0;}
```

OUTPUT [may vary depending on compiler] :

```
Typeid of i is int
p is pointing to an object of type class BaseClass
p is pointing to an object of type class Derived1
p is pointing to an object of type class Derived2
```

☞ when ***typeid*** is applied to a ***base pointer of a polymorphic type***, the type of object pointed to will be determined at ***run time***, as the output produced by the program shows.

❒ ***Example 2 (When objects are passed to functions by reference):*** In the following program, the function ***WhatType()*** declares a ***reference parameter*** to objects of type ***BaseClass***. This means that ***WhatType()*** can be passed ***references to objects*** of type ***BaseClass*** or any class derived from ***BaseClass***. When the ***typeid*** operator is applied to this parameter, it returns the actual type of the object being passed.

```
class BaseClass {
        virtual void f(){ }     /* BaseClass polymorphic */
                        /* ... */ };
class Derived1 : public BaseClass{ /* ... */ };
class Derived2 : public BaseClass{ /* ... */ };

                /* Demonstrate typeid with a reference parameter.*/
void WhatType( BaseClass &ob){
        cout << "ob is referencing an object of type " << typeid(ob).name() << endl ; }
```

```
int main(){ BaseClass baseob ;
            Derived1 ob1;
            Derived2 ob2;

                WhatType( baseob );
                WhatType(ob1);
                WhatType(ob2);
        return 0;}
```

OUTPUT:

*ob is pointing to an object of type **class BaseClass***
*ob is pointing to an object of type **class Derived1***
*ob is pointing to an object of type **class Derived2***

❒ ***Example 3:*** Since the ***type_info*** object returned by ***typeid*** overloads the ***==*** and ***!=*** operators, this too is easy to know whether the type of ***one object matches that of another***. The following program demonstrates the use of these operators.

```
class X { virtual void f(){}  };
class Y { virtual void f(){}  };

int main(){     X x1, x2;
                Y y1;

                if(typeid(x1) == typeid(x2)) cout << "x1 and x2 are same types \n";
                else cout << "x1 and x2 are different types \n";

                if( typeid (x1) != typeid (y1)) cout << "x1 and y1 are different types \n";
                else cout << "x1 and y1 are same types \n";

        return 0;}
```

OUTPUT

x1 and x2 are same types
x1 and y1 are different types

❒ ***Example 4:*** The ***typeid*** operator can be applied to ***template classes***. For example, consider the following program. It creates a hierarchy of template classes that store a value.

☞ The ***VF get_val()*** returns a value that is defined by each class.

▶ ***Num*** for value of the number itself ▶ ***Square*** for square of the number ▶ ***Sqr_root*** for square root of the number.

☞ Objects derived from ***Num*** are generated by ***generator()*** function. The ***typeid*** determines the type of the generated object .

```
#include <iostream>
#include <typeinfo>
#include <cmath>
#include <cstdlib>
using namespace std;

template <class T> class Num{
        public :
                T x;
                Num (T i) { x = i; }
                virtual T get_val () { return x; }
        };
```

```
template <class T> class Square : public Num <T> {
        public :
                Square(T i) : Num <T>(i){ }
                T get_val(){ return (this -> x)*(this ->x);
                /* Edited: main book 'return x*x;' */    }
        };
```

```
template <class T> class Sqr_root : public Num <T> {
        public :
                Sqr_root(T i) : Num <T>(i){ }
                T get_val(){ return sqrt((double) this -> x);
                /* Edited: main book sqrt( (double) x);' */         }
        };
```

```
/* A Random selection factory for objects derived from Num : for run-time selection.*/
Num <double> *generator(){
                switch( rand() % 2){
                                        case 0: return new Square <double> ( rand() % 100) ;
                                        case 1: return new Sqr_root <double> ( rand() % 100) ; }
                return NULL ;  }
```

```
int main(){
        Num <double> ob1(10), *p1;
        Square <double> ob2(100.0) ;
        Sqr_root <double> ob3(999.2) ;
        int i;

        cout << typeid(ob1).name() << endl ;
        cout << typeid(ob2).name() << endl ;
        cout << typeid(ob3).name() << endl ;

        if( typeid(ob2) == typeid(Square <double>)) cout << "is Square <double>\n";

        p1 = &ob2 ;
        if( typeid(*p1) != typeid(ob1)) cout << " Value is: " << p1 -> get_val();
        cout << "\n\n";

        cout << "Now , generate some Objects .\n";
        for (i=0; i <10; i++){
                        p1 = generator();               /* get next object */
                        if(typeid(*p1) == typeid(Square <double>)) cout << "Square object :";
                        if(typeid (*p1) == typeid(Sqr_root <double>)) cout << "Sqr_root object:";
                        cout << "Value is:" << p1 -> get_val();
                        cout << endl ;
                        }
        return 0;}
```

OUTPUT :

```
class Num<double>
class Square<double>
class Sqr root<double>
is Square<double>
Value is: 10000
Now, generate some Objects.
Sqr root object: Value is: 8.18535
Square object: Value is: 0
Sqr root object: Value is: 4.89898
Square object: Value is: 3364
Square object: Value is: 4096
Sqr root object: Value is: 6.7082
Sqr root object: Value is: 5.19615
Sqr root object: Value is: 9.53939
Sqr root object: Value is: 6.48074
Sqr root object: Value is: 6
```

☞ The example shown in main book ***will not compile*** . ***Reason***: Consider a template class Derived with a template base class:

```
template <typename T> class Base { public: int d; };
template <typename T> class Derived : public Base<T>{  void f(){this->d = 0;}   };
```

- ***this*** has type ***Derived<T>***, a type which depends on ***T***. So ***this*** has a ***dependent type***. So ***this->d*** makes ***d*** a ***dependent name***. **Dependent names** are looked-up in the context of the **template definition** as *non-dependent* names and in the context of **instantiation**.
- Without ***this->***, the name ***d*** would only be ***looked-up as a non-dependent name, and not be found***.
- Another solution is to declare ***d*** in the ***template definition*** itself:

```
template <typename T> class Derived : public Base<T> {   using Base::d;
                                                         void f(){ d = 0; }  };
```

NOTE: ***RTTI*** is **not common** in every program. However, when you are working with ***polymorphic types***, it allows you to know what type of object is being operated upon in any given situation.

13.9 C++ casting operators

C++ has four new casting operators. They are: [1] ***dynamic_cast*** [2] ***const_cast*** [3] ***reinterpret_cast*** [4] ***static_cast***

13.9.1 dynamic_cast:

❒ The ***dynamic cast*** is related to ***RTTI***, it performs a ***run-time cast*** that verifies the ***validity of a cast***. Dynamic cast can be used to cast ***one type of pointer into another*** or ***one type of reference into another***. The **general form** of ***dynamic cast*** is:

dynamic_cast<target_type***>(expr)***

☞ Here ***target_type*** specifies the ***target type of the cast*** and ***expr*** is the ***expression being cast into the new type***.

☞ The ***target_type*** must be a ***pointer*** or ***reference*** type, and "***expr***" the expression being cast must ***evaluate*** to a ***pointer*** or ***reference***.

☞ If the ***cast is invalid*** during the execution of ***dynamic_cast***, the ***cast fails***.

❒ The purpose of **dynamic_cast** is to perform ***casts on polymorphic types***: For example, given the two ***polymorphic classes*** **B** and **D**, with **D** ***derived from*** **B**.

- ✓ A **dynamic_cast** can ***always cast*** a **D*** *pointer* into a **B*** *pointer*. Because a ***base pointer*** can always ***point to a derived***.
- ✓ But a **dynamic_cast** can cast a **B*** *pointer* into a **D*** *pointer* ***only if*** the ***object being pointed to*** actually is a **D** object.

☛ In general, ***dynamic_cast*** will succeed if the ***pointer*** (or ***reference***) being cast is a ***pointer*** (or ***reference***) to either an ***object of the target type*** or an ***object derived from the target type***. Otherwise, the cast will ***fail***.

- If the cast fails, ***dynamic_cast*** evaluates to ***null*** if the cast involves ***pointers***.
- If a ***dynamic_cast*** on ***reference types*** fails, a ***bad_cast*** ***exception*** is thrown.

❒ ***Example of Successful cast:*** Assume that ***Base*** is a polymorphic class and that ***Derived*** is derived from ***Base***.

```
Base *bp, b_ob;
Derived *dp, d_ob;
      bp = &d_ob ;              /* base pointer points to Derived object : ok */
      dp = dynamic_cast < Derived * >(bp);
if(dp) cout << " Cast OK ";
```

☛ Here the cast from the **base pointer** ***bp*** to the **derived pointer** ***dp*** works because ***bp*** is actually pointing to a **Derived object**. It displays "***Cast OK***".

❒ ***Example of Unsuccessful cast:*** In the next fragment, the ***cast fails*** because ***bp*** is ***pointing to a Base object*** and it is ***illegal to cast*** a ***base object*** into a ***derived object***. It displays "***Cast Fails***".

```
      bp = &b_ob ;              /* base pointer points to Base object : Wrong */
      dp = dynamic_cast < Derived *>(bp);
if (!dp) cout << " Cast Fails ";
```

NOTES:

The ***dynamic_cast*** operator can sometimes be used **instead** of ***typeid***. Consider the previous example. The following fragment will assign ***dp*** the ***address of the object pointed to*** by ***bp iff*** the ***object is really a Derived object***.

```
Base *bp;
Derived *dp;
      // ...
if( typeid(*bp) == typeid(Derived) ) dp  = (Derived *) bp;
```

- Here a ***C-style cast*** is used to perform the cast. It's safe because the ***if*** checks the ***legality of the cast*** using ***typeid*** before the cast actually occurs.
- The better way to accomplish this is to **replace** the ***typeid*** operators and ***if*** statement with this ***dynamic_cast***:

```
dp = dynamic_cast < Derived *> (bp);
```

  - After this statement executes **dp** will contain either a ***null*** or a ***pointer*** to an ***object of type Derived***. Because ***dynamic_cast*** succeeds only if the object being cast is either
    - already an object of the ***target type*** or
    - an object ***derived*** from the ***target type***,
  - Since ***dynamic_cast*** succeeds ***only if the cast is legal***, it can ***simplify*** the ***logic*** in certain situations.

13.9.2 const_cast, reinterpret_cast and static_cast

General forms of other three casting operators are:

```
const_cast< target_type > (expr)
reinterpret_cast< target_type > (expr)
static_cast< target_type > (expr)
```

➲ Here ***target_type*** specifies the ***target type*** of the ***cast*** and ***expr*** is the ***expression being cast*** into the ***new type***.

❒ ***const_cast:*** The ***const_cast*** operator is used to explicitly override const ***and/or volatile*** in a ***cast***. The most common use of ***const_cast*** is to remove ***const***-ness.

☛ The ***target_type*** must be the ***same as*** the ***source type*** except for the alteration of its ***const*** or ***volatile*** attributes.

❒ ***static_cast:*** The ***static_cast*** operator performs a ***non-polymorphic cast***. For example, it can be used to ***cast a base class pointer*** into a ***derived class pointer***.

☛ It can also be used for any ***standard conversion***. ☛ No ***run-time checks*** are performed.

❒ ***reinterpret_cast:*** The *reinterpret_cast* operator: ☛ Changes one ***pointer type*** into ***another*** (mainly different, ***pointer type***).

☛ It can also change a ***pointer*** into an ***integer*** and an ***integer*** into a ***pointer***.

▶ A ***reinterpret_cast*** should be used for casting ***inherently incompatible pointer types***.

NOTE: Only ***const_cast*** can cast away ***const***-ness. That is, neither ***dynamic_cast***, ***static_cast***, nor ***reinterpret_cast*** can alter the ***const***-ness of an object.

❒ ***Example 1:*** The following program demonstrates ***dynamic_cast***:

```
class Base{ public : virtual void f(){ cout << "Inside Base \n"; } };
class Derived : public Base{ public : void f() {
                                   cout << " Inside Derived \n"; } };

int main() {        Base *bp , b_ob ;
                    Derived *dp , d_ob ;

        dp = dynamic_cast < Derived *> (& d_ob );
if(dp) {  cout << " Cast from Derived * to Derived * OK .\n";    dp ->f(); }
else      cout << " Error \n";
          cout << endl ;

        bp = dynamic_cast < Base *> (& d_ob );
if(bp) {  cout << " Cast from Derived * to Base * OK .\n";   bp ->f(); }
else      cout << " Error \n";
          cout << endl ;

        bp = dynamic_cast < Base *> (& b_ob );
if(bp) { cout << " Cast from Base * to Base * OK .\n";   bp ->f();}
else      cout << " Error \n";
          cout << endl ;

                    /*following is not ok*/
        dp = dynamic_cast < Derived *> (& b_ob );
if(dp)    cout << " Error \n";
else      cout << " Cast from Base* to Derived* not OK .\n";
          cout << endl ;
```

```
bp = &d_ob ;      /* base pointer bp points to Derived object */
dp = dynamic_cast < Derived *> (bp);
if(dp){cout  << " Casting bp to a Derived * OK .\n"
             <<" because bp is really  pointing \n"
             <<"to a Derived object .\n";
       dp ->f();}
else  cout << " Error \n";
cout << endl ;

bp = &b_ob ;                    /* bp points to Base object */
dp = dynamic_cast < Derived *> (bp);          /* NOT OK:  */
if(dp) cout << " Error \n";
else { cout  << "Now casting bp to a Derived *\n"
             << "is not OK because bp is really \n"
             <<" pointing to a Base object .\n"; }
cout << endl ;

dp = &d_ob ;                    /* dp points to Derived object */
bp = dynamic_cast < Base *> (dp);
if(bp){   cout << " Casting dp to a Base * is OK .\n";
          bp ->f(); }
else cout << " Error \n";
return 0; }
```

OUTPUT:

```
Cast from Derived * to Derived * OK.
Inside Derived
Cast from Derived * to Base * OK.
Inside Derived
Cast from Base * to Base * OK.
Inside Base
Cast from Base * to Derived * not OK.
Casting bp to a Derived * OK.
because bp is really pointing
to a Derived object.
Inside Derived
Now casting bp to a Derived *
is not OK because bp is really
pointing to a Base object.
Casting dp to a Base * is OK.
Inside Derived
```

☛ Cast from ***base**** to ***derived**** means: derived pointer points to a base object via ***derived**** cast.

❒ ***Example 2:*** The following example illustrates how a ***dynamic_cast*** can be used to replace ***typeid***.

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

class Base { public : virtual void f() {} };
class Derived : public Base { public : void derivedOnly(){ cout << "Is a Derived Object \n";}  };
```

OUTPUT :

```
Cast from Base to Derived failed.
Is a Derived Object
Cast from Base to Derived failed.
Is a Derived Object
```

```
int main() {  Base *bp , b_ob ;
              Derived *dp , d_ob ;
                              /* use typeid */
        bp = & b_ob ;
        if( typeid (* bp) == typeid ( Derived )){dp = ( Derived *) bp;
                                                 dp -> derivedOnly( );}
        else cout << " Cast from Base to Derived failed .\n";

        bp = & d_ob ;
        if( typeid (* bp) == typeid ( Derived )){dp = ( Derived *) bp;
                                                 dp -> derivedOnly( );}
        else cout << "Error , cast should work !\n";
```

```
                    /* use dynamic_cast */
        bp = &b_ob ;
        dp = dynamic_cast < Derived *> (bp);
        if(dp) dp -> derivedOnly ();
        else cout << " Cast from Base to Derived failed .\n";

        bp = & d_ob ;
        dp = dynamic_cast < Derived *> (bp);
        if(dp) dp -> derivedOnly ();
        else cout << "Error , cast should work !\n";

return 0; }
```

☛ The use of ***dynamic_cast simplifies the logic*** required to **cast a base pointer into a derived pointer**.

❒ ***Example 3:*** The ***dynamic_cast*** operator can also be used with template classes. For example, the following program reworks the template class from ***Example 4*** in the preceding section so that it uses ***dynamic_cast*** to determine the type of object returned by the ***generator()*** function.

```
                    /* ..... same as Exampole 4,  section 13.8  RTTI */
int main() {  Num <double> ob1(10), *p1;
              Square <double> ob2(100.0), *p2;
              Sqr_root <double> ob3(999.2), *p3;
              int i;

              cout << " Generate some objects .\n";
              for(i=0; i <10; i++) {     p1 = generator();

                                         p2 = dynamic_cast < Square<double> * > (p1);
                                         if(p2) cout << " Square object : ";

                                         p3 = dynamic_cast < Sqr_root<double> * > (p1);
                                         if(p3) cout << " Sqr_root object : ";

                                         cout << "Value is:" << p1 -> get_val();
                                         cout << endl; }
              return 0; }
```

❒ ***Example 4:*** The following program demonstrates the use of ***reinterpret_cast***.

```
          int main() {  int i;
                        char *p = "  This is a string  ";

                        i = reinterpret_cast <int> (p);          /* cast pointer to integer */
                        cout << i;
                        return 0;}
```

☞ Here ***reinterpret_cast*** converts the pointer ***p*** into an ***integer***. This conversion represents a ***fundamental type change*** and is a good use of ***reinterpret_cast***.

❒ ***Example 5 :***The following program demonstrates const_cast.

```
void f( const int *p) {    int *v;
                           v = const_cast <int *> (p); /* cast away const - ness */
                           *v = 100;      /* now , modify object through v */    }
int main(){   int x = 99;
              cout << "x before call : " << x << endl ;
              f(&x);
              cout << "x after call : " << x << endl ;
              return 0; }
```

OUTPUT:
x before call: 99
x after call: 100

☞ As you can see, ***x*** was modified by ***f()*** even though the ***parameter*** to ***f()*** was specified as a ***const*** pointer.

☞ It must be stressed that the use of ***const_cast*** to ***cast way const-ness*** is a potentially ***dangerous*** feature. Use it with care.

❒ ***Example 6:*** The ***static_cast*** operator is essentially a substitute for the original cast operator. It simply performs a ***non-polymorphic*** cast. For example, the following casts a ***float*** into an ***int***.

```
                    int main() {  int i; float f;
                                  f = 199.22;
                                  i = static_cast <int> (f);
                                  cout << i;
                          return 0;}
```