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C++ NOTES

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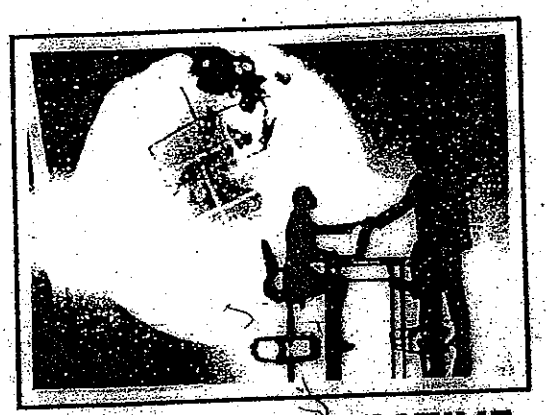

LEARNING INITIATIVE

C++ NOTES

Course DESD Batch AUG 2016

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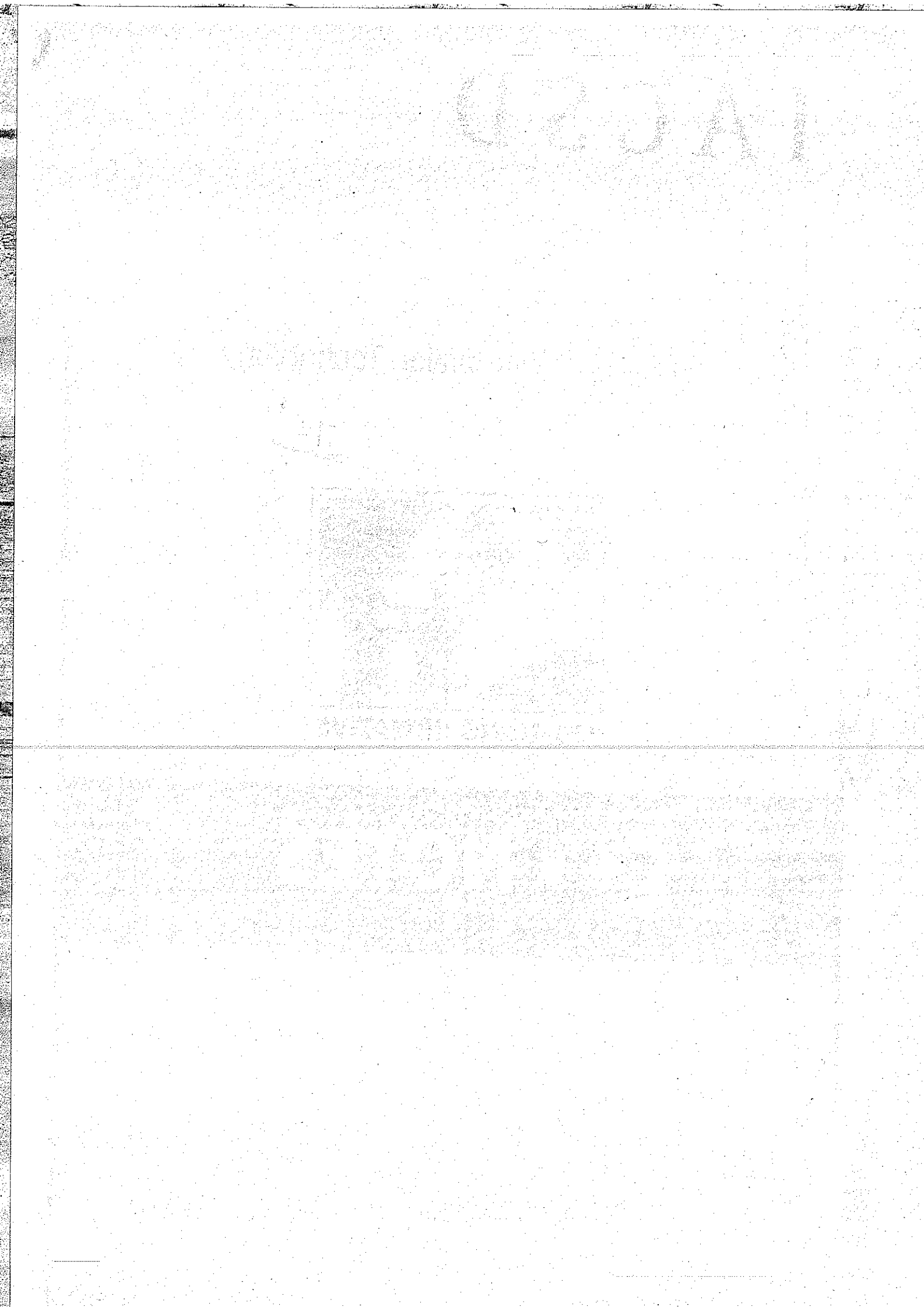


Language Basics:

Generally languages are classified as follows:

1. Procedure oriented programming languages.
   e.g. C, Pascal etc.
2. Object Oriented Programming languages.
   e.g. Simula, Smalltalk, C++, Java, C# etc.
3. Object Based Programming Languages.
   e.g. ada, modula-2, visual Basic
4. Logic Oriented Programming Languages.
5. Rule Oriented Programming Languages.
6. Constraint Oriented Programming Languages.

Advantages of object oriented programming:

1. Code Reusability

Objects created for object oriented programs can easily be reused in other programs.

2. Lower Cost Of Development

More effort is put into the object oriented analysis and design which lowers overall cost of development.

3. Improved Software Maintainability

Since design is modular, part of the system can be updated in case of issues without a need to make large scale changes.

4. Higher Quality Software

Faster development of software and lower cost of development allows more time and resources to be used in the verification of the software which tends to result in higher quality software.

Parts/Elements/Pillars of OOP model:

There are four major and three minor elements of object oriented programming model.

Major means a language without any one of these elements is not considered as object oriented.

Following are the major pillars of OOPs:

1. Abstraction
2. Encapsulation
3. Modularity
4. Hierarchy

Minor means, each of these elements is useful but not essential.

Following Are the minor pillars of OOP:

1. Typing
2. Concurrency
3. Persistence

Brief history of C++:

The C++ programming language has a history going back to 1979, when Bjarne Stroustrup was doing work for his Ph.D. thesis. One of the language Stroustrup had the opportunity to work with was a language called Simula, which as the name implies is a language primarily designed for simulations. The Simula 67 language is regarded as the first language to support the object-oriented programming paradigm. Stroustrup found that this paradigm was very useful for software development, however the Simula language was far too slow for practical use.

Shortly thereafter, he began work on "C with Classes", which as the name implies was meant to be a superset of the C language. His goal was to add object-oriented programming into the C language, which was and still is a language well-respected for its portability without sacrificing speed or low-level functionality.

The first C with Classes compiler was called Cfront. It was a program designed to translate C with Classes code to ordinary C. Cfront would later be abandoned in 1993 after it became difficult to integrate new features into it, namely C++ exceptions. Nonetheless, Cfront made a huge impact on the implementations of future compilers and on the Unix operating system.

In 1983, the name of the language was changed from C with Classes to C++.

Important

Data types:

Data type in any language describes three things:

1.How much memory is required to store the data.

2.Which kind of data that memory can hold.

3.Which operations we can perform on that data.

Basically there are only two types of data types but for our convenience we will classify it into three types

-Fundamental data types

1.void	unknown size	
2.bool	1 byte	[can contain either true or false value]

-in case of instantiation use of struct keyword is optional.

-we can write variable as well as function inside structure in c++.

-by default members of the structure are treated as a public.

-to create light weight object we should use structure.

Data member: Imp

-Variable declared inside class is called data member.

-Data member is also called field, property or attribute.

-If we create object then it gets single copy of the data member i.e. data member gets space inside object.

Member function: Imp

-Function implemented inside a class is called member function.

-Member function is also called method, operation,behavior or message.

-Member function do not get space inside object rather all the objects of same type share single copy of member function.

Class: Imp

-syntactically class is collection of data member and member function.

-In general 'Class is collection of such objects which represents common structure and common behavior'.

-Since object is always created by looking toward the, class is considered as a template/model/blueprint for an object.

-class is logical entity.

-class is a user defined data type. It is also called abstract data type.

Object: Imp

-Syntactically, object is variable of class.

-An entity which is having physical existence is called object.

-In object oriented way, we can define object as a instance of class.

-At the time of creation of object use of class keyword is optional.

① State
② behavior
③ Identity
④ Responsibility.

```
class Point pointInstance;//valid
Point  pointInstance;          //valid
```

Some important terminology

1. **Instantiation** - Process of creating object from a class is called instantiation.
2. **Concrete class** - If class allows us to create an object of a class then it is called concrete class.
3. **Concrete method** - Member function of a class which is having a body is called concrete method.

3.char	1 byte	[ASCII Compatible]
4.wchar_t	2 bytes	[Unicode Compatible]
5.int	4 bytes	
6.float	4 bytes	
7.double	8 bytes	

-Derived Datatypes

1.array
2.function
3.pointer
4.reference

-User Defined Data Types

1.Structure
2.Union
3.Class

Access Specifers in C++

There are three acess specifiers in c++

1.private:

If we declare elements of the class as private then we can access these members inside same class in which it is declared. We cannot access private members inside nonmember function. Generally data members should be declared as private.

2.protected:

If we declare elements of the class as protected then we can access these members inside same class in which it is declared as well as inside derived class. We cannot access protected members outside the class.

3.public:

If we declare elements of the class as public then we can access these members inside same class in which it is declared, inside derived class as well as inside non member function. Generally member function should be declared as public.

Structure in C++

-structure is collection of related elements which get continuous memory space.

4. **Abstract class** - If class do not allows us to create an object of a class then it is called abstract class.

5. **Abstract method** - Member function of a class which do not contain body is called concrete method.

6. **Message Passing** - Process of calling member function on object is called message passing.

consider the following example

```
Point pt1;
pt1.Point::printRecord( );//valid : Message passing
pt1.printRecord( );              //valid : Message passing
```

Characteristics of an Object:

1.State - The state of an object encompasses all of the properties of the object plus the current values of each of these properties. Values stored inside object is called state.

2.Behavior - Behavior is how an object acts and reacts, in terms of its state changes and message passing. Member functions of the class represent behavior of the object.

3.Identity - Identity is that property of an object which distinguishes it from all other objects.

An object is an entity that has state, behavior, and identity. The structure and behavior of similar objects are defined in their common class. The terms instance and object are interchangeable.

Empty class and object: Imp

A class which do not conain any member is called empty class.consider the following code.

```
class Empty
{
        //Empty implementation
};
```

According to Bjarne stroustrup, to differentiate object from a class, object must get space inside memory and it should be non zero. But compilers do optimization because there is no use of such memory. So *size of object of empty class is one byte.*

this pointer:

- this is a keyword in C++.
- It is implicit pointer available inside every non static member function of the class, which is used to store address of current object.
- this is constant pointer and its general type is as follows

  ClassName* const this
- this represent address of current object while (*this)represents current object itself.
- Data member and member function can communicate with each other with the help of this pointer so this is considered as connection / link between data member and member function.
- If any member function accepts parameters then this pointer is always pass as a first parameter implicitly.
- We cannot declare this as a function parameter explicitly.
- Use of this keyword is optional but we should use it.
- If name of data member and function parameter is same then it is mandatory to use this keyword before data member.
- Following function do not get this pointer:
  1. Global function
  2. Static member function
  3. Friend function.

Array of Objects:

```
Point arr[ 3 ];        //Here parameterless ctor will call three times
for( int index = 0; index < 3; ++ index )
      arr[ index ].printRecord();

Point arr[ 3 ] = { Point(10,20),Point(30,40),Point(50,60)};
                //Here parameterized constructor will call three times
for( int index = 0; index < 3; ++ index )
      arr[ index ].printRecord();
```

Namespace :

Namespace is logical term, which is used to control scope of global members. In other words to avoid name ambiguity or name clashing or name collision we should use namespace.

```
int num1 = 10;
int num1 = 20;      //error: 'num1' : redefinition; multiple initialization
```

```
int main( void )
{
        printf("Num1        :       %d\n",num1);
        return 0;
}
```

As shown in above code we cannot give same name to multiple members in same scope. Problem may occur, if name of elements refereed from different library and name of element declared in same program is same. To avoid this problem we should implement global members inside namespace. we can write above program as follows

```
namespace NA
{
        int num1 = 10;
}
namespace NB
{
        int num1 = 20;      //Now no error
}
int main( void )
{
        printf("Num1        :       %d\n",NA::num1);//Num1      :       10
        printf("Num1        :       %d\n",NB::num1);//Num1      :       20
        return 0;
}
```

As shown in above code, we should use namespace name and scope resolution operator to access elements of namespace.

We can implement namespace inside scope of another namespace. It is called nested namespace. First we will see nested namespace with different element names.

```
int num1 = 10;
namespace NA
{
        int num2 = 20;
        namespace NB
        {
                int num3 = 30;
```

```
        }
}
int main(void)
{
        printf("Num3    :    %d\n", NA::NB::num3);      //Num3    :    30
        printf("Num2    :    %d\n", NA::num2);          //Num2    :    20
        printf("Num1    :    %d\n", ::num1);            //Num1    :    10
        return 0;
}
```

Generally we use the statement that to access global variable or function we should use :: operator.

In namespace topic we have discussed that to access elements of namespace we should :: operator. Consider above code. Since num3 is member of NB namespace & NB namespace is member of NA namespace we have written NA::NB::num3. num2 is member of NA namespace, we have written NA::num2.Even though num1 is not a member of any namespace we can use :: operator with it. Meaning of this statement is that, if we declare or implement global members without namespace it is considered as member of unnamed or global namespace.

If we want to use any member of namespace frequently then instead of specifying namespace name every time we can use using directive. The using directive allows the names in a namespace to be used without the namespace name as an explicit qualifier. consider the following code.

```
int num1 = 10;
namespace NA
{
        int num2 = 20;
        namespace NB
        {
                int num3 = 30;
        }
}
int main(void)
{
        printf("Num1    :    %d\n", ::num1);            //Num1    :    10
        using namespace NA;
```

```
        printf("Num2    :    %d\n", num2);          //Num2    :    20
        printf("Num3    :    %d\n", NB::num3);      //Num3    :    30
        using namespace NB;
        printf("Num3    :    %d\n", num3);          //Num3    :    30
        return 0;
}
```

We can write "using namespace namespace_name" statement any number of times.

We can give same name to the outer namespace as well as inner namespace. In this case we cannot use 'using' directive to access namespace members.

```
namespace NA
{
        int num1 = 10;
        namespace NA
        {
                int num2 = 20;
        }
}



int main(void)
{
        printf("Num1    :    %d\n", NA::num1);          //Num1    :    10
        printf("Num2    :    %d\n", NA::NA::num2);      //Num2    :    20
        return 0;
}
```

We can give same namespace name to other namespace inside same scope.

```
namespace NA
{
        int num1 = 10;
}
namespace NA
{
        int num2 = 20;
}
int main(void)
```

```
{
    printf("Num1    :    %d\n", NA::num1);        //Num1    :    10
    printf("Num2    :    %d\n", NA::num2);        //Num2    :    20

    using namespace NA;
    printf("Num1    :    %d\n", num1);            //Num1    :    10
    printf("Num2    :    %d\n", num2);            //Num2    :    20
    return 0;
}
```

we should use using statement carefully otherwise we may get unexpected results. consider following code snippet.

```
namespace NA
{
    int num1 = 10;
}
int main(void)
{
    int num1 = 20;
    using namespace NA;
    printf("Num1    :    %d\n", num1);            //Num1    :    20
    printf("Num1    :    %d\n", num1);            //Num1    :    20

    printf("Num1    :    %d\n", NA::num1);        //Num1    :    20
    printf("Num1    :    %d\n", num1);            //Num1    :    20
    return 0;
}
```

If name of members of namespace is same and if we try to access it with the help of using directive then compiler produces ambiguity error. In this case we should use fully qualified name. consider following code.

```
namespace NA
{
    int num1 = 10;
    namespace NB
    {
        int num1 = 20;
        int num2 = 30;
```

```
    }
}
int main(void)
{
    using namespace NA;
    printf("Num1    :    %d\n",num1);          //Num1    :    10
    using namespace NB;
    //printf("Num1    :    %d\n", num1);       //ambiguity error
    printf("Num1    :    %d\n", NB::num1);     //Num1    :    20
    printf("Num1    :    %d\n", num2);         //Num2    :    30
    return 0;
}
```

We can declare using directive at local scope as well as file scope.

In following code snippet we have declared "using namespace namespace_name" statement at local scope.

```
namespace NA
{
    int num1 = 10;
}
void show_record(void)
{
    using namespace NA;
    printf("Num1    :    %d\n", num1);
}
void display_record(void)
{
    using namespace NA;
    printf("Num1    :    %d\n", num1);
}
int main(void)
{
    ::show_record();
    ::display_record();
```

```
    return 0;
}
```

If we want to access namespace elements at multiple location then we should declare "using namespace namespace_name" statement at file scope. Consider the following example.

```
namespace NA
{
    int num1 = 10;
}

using namespace NA;

void show_record(void)
{
    printf("Num1    :    %d\n", num1);
}


void display_record(void)
{
    printf("Num1    :    %d\n", num1);
}
int main(void)
{
    ::show_record();
    ::display_record();
    return 0;
}
```

unnamed or anonymous namespace -

In C/C++,if we declare any global element as static then we can access such element inside same file only. In C++ unnamed namespace or anonymous namespace is superior alternative given for global static member declarations.

```
namespace
{
    int num1;
```

```
}
int main(void)
{
        num1 = 10;
        printf("Num1        :       %d\n", num1);
        return 0;
}
```

Each unnamed namespace has an identifier, assigned and maintained by the program and represented here by unique

above code is implicitly interpreted as follows:

```
namespace unique
{
        int num1;
}
int main(void)
{
        unique::num1 = 10;
        printf("Num1        :       %d\n", unique::num1);
        return 0;
}
```

namespace Alias -

if name of the namespace is too lengthy then we can create alias for it. Consider the following syntax.

```
namespace namespace_name
{
        int num1;
}
namespace NA = namespace_name;
int main(void)
{
        printf("num1:       %d\n", NA::num1);
        return 0;
}
```

Points To Remember:

1. Namespace is logical term which is used to group or organize functionally equivalent or related code together.

2. In C++, We can achieve logical modularity with the help of namespace.

3. To access members of namespace we should use scope resolution(::)operator.

4. We can write any global variable, function, enum, structure, class as well as namespace inside namespace.

5. We cannot write namespace inside class i.e. A namespace definition must appear either at file scope or immediately within another namespace definition.

6. We cannot implement entry point function(main) inside namespace.

7. Inside same as well as different file we can give same name to the multiple namespace.

8. We cannot create instance of namespace.

9. Instead of declaring global element as static we should put them inside unnamed namespace.

Constructor:

Process of storing user defined value inside variable/object at the time of declaration/creation is called initialization.

e.g. int number = 123; //initialization

Constructor is member function of a class which is used to initialize the object.

```
namespace NPoint
{
        class Point
        {
        private:
                int xPosition;
                int yPosition;
        public:
                Point( void ) //constructor
                {
                        this->xPosition = 0;
                        this->yPosition = 0;
                }
        };
}
int main(void)
{
        NPoint::Point pointInstance;
                        //Here for pointInstance object constructor will
```

return 0;

}

Due to following reasons constructor is special member function

-its name is same class name.

-it do not have any return type (but we can write return statement inside constructor).

-it is not designed to call explicitly on object rather it gets call implicitly.

-in complete life cycle of an object, constructor gets call only once.

Types of Constructor:

C++ supports three kinds of constructor.

1. Parameterless constructor.
2. Parameterized constructor.
3. Default constructor.

* used to initialise data members of objects.

Most of us consider copy constructor is fourth type of constructor. But it is kind of parameterized constructor. We will discuss copy constructor separately.

Parameter less constructor: A constructor which do not take any parameter is called parameter less constructor. parameter less constructor is also called zero parameter constructor or user defined default constructor.

if we create an object without passing argument then parameter less constructor gets call.

Point pt1; Here for pt1 object parameterless constructor will call

Parameterized constructor: If constructor takes parameters then it is called parameterized constructor.

If we create an object by passing argument then parameterized constructor gets call.

Point pt1(10, 20); Here for pt1 object parameterized constructor which is taking 2 parameters will call

Point pt2(500); Here for pt2 object parameterized constructor which is taking 1 parameter will call

How many and which kind of constructor should be exist inside a class depends on instantiation.

Constructor calling sequence is depends on order of object declaration.

Default constructor: If class do not contain any kind of constructor then compiler provides one constructor for the class it is called default constructor.

Default constructor do not perform any operation on data member declared in our class. It look like as follows

```
Point( void )
{
    /*empty*/
};
```

Compiler generated default constructor do not take any parameter i.e. compiler never generate default parameterized constructor. If we want to create an object by passing argument then we cannot rely on default constructor. In this case we should define parameterized constructor inside a class.

We will see exact use of default constructor in virtual function topic.

Constructor is designed for initialization it doesn't mean we cannot call methods from it.

We cannot declare constructor as const, volatile, virtual or static. We can declare constructor as inline only. Inline function we will discuss later.

Aggregate type:

If type allows us to store multiple elements then it is called aggregate type and object is called aggregate object.

In C language, array, structure and union is called aggregate type. Aggregate type allows us to initialize object using initializer list. Consider the following code:

```
int arr[ ] = { 10, 20, 30 };
struct point pt1 = { 10, 20 };
```

class may be classified as aggregate type if it obeys following rule.

1. class should not contain user defined constructor.
2. Class should not contain private and protected members.
3. class should not be derived from any other class.
4. class should not contain virtual function.

Aggregate class is also called Plain Old Data struct(POD- struct).

Test your understanding:

```
class Point
{
private:
    int xPosition;
    int yPosition;
```

```
    public:
        Point( void );
        Point( int value );
        Point(int xPosition, int yPosition);
    };
```

In following cases which constructor will call?

1. `Point pt1;`

2. `Point pt2( 10 );`

3. `Point pt3( 20, 30 );`

4. `Point pt4( );`

5. `Point pt5 = 40 ;`

6. `Point pt6 = 50, 60;`

7. `Point pt7 = ( 50, 60 );`

8. `Point pt8 = { 70, 80 };`

9. `Point pt9( 90, 100 );`
   `Point pt10 = pt9;`

10. `Point* ptr;`

As per our requirement, we can use any access specifier for constructor. If we declare constructor as private or protected then we can create instance of class only inside member function. If we declare constructor as public then we can create instance of class inside member function as well as non member function.

Note: Generally we should public access specifier for constructor.

Constructors member initializer list:

c++ allows us to initialize data members of the class inside constructors body as well as constructors member initializer list. If we initialize data members inside constructors body

then it gets executed in the same order in which it is written inside constructor body. For example:

```
class Test
{
private:
        int x;
        int y;
        int z;
public:
        Test(void)
        {
                this->z = this->y;
                this->y = this->x;
                this->x = 10;
        }
};
int main(void)
{
        Test test;    //10,garbage value,garbage value
        return 0;
}
```

If we initialize data members inside constructors member initializer list then it gets executed according to the order of data member declaration.

For example:

```
class Test
{
private:
        int x;
        int y;
        int z;
public:
        Test(void) : z(y), x(10), y(x)     //ctor's member initializer list
        {       }
};
int main(void)
{
```

```
    Test test;    //10,10,10
    return 0; }
```

we cannot initialize array inside constructors member initializer list. It is limitation of constructors member initializer list.

we can use constructors member initializer list and constructor body together. In this case runtime environment executes constructors member initializer list first and then constructors body.

Note:Generally we should use constructor's member initializer to initialize data members. In case of modularity constructors member initializer list must appear in definition part only.

Default argument(s):

```
int sum(int num1, int num2)
{
    return num1 + num2;
}
int sum(int num1, int num2, int num3)
{
    return num1 + num2 + num3;
}
int sum(int num1, int num2, int num3, int num4 )
{
    return num1 + num2 + num3 + num4;
}
int main(void)
{
    int result = 0;
    result = sum(10, 20);
    result = sum(10, 20, 30);
    result = sum(10, 20, 30, 40);
    return 0;
}
```

if we consider above functions then its implementation is logically equivalent. Since all the functions having same name and same type of parameters then we can reuse its implementation by assigning some default values to the parameters. For example

```
int sum(int num1, int num2, int num3 = 0, int num4 = 0 )
{
        return num1 + num2 + num3 + num4;
}
int main(void)
{
        int result = 0;
        result = sum(10, 20);
        result = sum(10, 20, 30);
        result = sum(10, 20, 30, 40);
        return 0;
}
```

Default values assign to the parameters of function is called default argument and function parameter is called optional parameter. In above code 0 is default argument and num3 and num4 are the optional parameters. We cannot assign default arguments randomly. If we want to assign default argument to the parameter then it is necessary to assign default argument to all its right side parameters.

We can assign default arguments to parameters of any member function as well as non member function.

Note:In case of modularity, we must specify default arguments in declarations part only.

Constructor Chaining:

Process of calling constructor from another constructor is called constructor chaining. If we want to reuse implementation of existing constructor then we can use this feature. Since c++ support default argument, it do not support constructor chaining.

In C++ we cannot call constructor with pointer or object explicitly. But it is possible to call to constructor explicitly.

Constant:

l-value(Locator Value):

Expressions that refer to memory locations are called "l-value" expressions. An l-value represents a storage region's "locator" value, or a "left" value, implying that it can appear on the left of the equal sign (=). L-values are often identifiers.

In following example, x is an l-value because it persists beyond the expression that defines it.

```
int main()
{
  int x = 3 + 4;
```

```
    cout << x << endl;
}
```

r-value(Reference Value)

An rvalue is a temporary value that does not persist beyond the expression that uses it. All l-values are r-values but not all r-values are l-values.

In above example, the expression 3 + 4 is an r-value because it evaluates to a temporary value that does not persist beyond the expression that defines it.

Readonly Members:

Once initialized, if we don't want modify state of an object then we should declare variable/object as a constant. In C++ it is compulsory to initialize constant variable.

Note:Generally we should declare function parameter as a constant.

Constant Data Member:

if we dont want to modify state of the data member inside any member function of the class(including contructor) then we should declare data member as a constant.

Note:It is compulsory to initialize constant data member inside constructors member initializer list.

```
class Math
{
private:
        const double PI;     //constant data member
public:
        Math(void) : PI(3.14)
        {
                //this->PI = 3.142;         //Not allowed
        }
};
```

Constant Member function:

If we don't want to modify state on current object inside member function then we should declare member function as constant. We can declare only such function as a constant which get this pointer. Since global function do not get this pointer, we cannot declare global function as a constant.

Non constant member function always get this pointer of following type:

ClassName* const this;

Constant member function always get this pointer of following type:

const ClassName* const this;

As shown in above declaration,if we declare member function as constant then current object is considered as const object
inside that member function.

```
class Test
{
private:
	int number;
public:
	Test(void) : number(10)
	{	}
	//Test* const this = &testInstance;
	void increment()
	{
		this->number = this->number + 1;	//allowed
	}
	//const Test* const this = &testInstance;
	int getNumber(void)const
	{
		//this->number = this->number + 1; //Not allowed
		return this->number;
	}
};
int main(void)
{
	Test testInstance;
	return 0;
}
```

With the help of non constant object we can invoke constant as well as non constant member function.

mutable is a keyword in c++, which allows us to modify state of non constant data member inside constant member function.

```
class Test
```

```
{
private:
        const int num1;
        const int num2;
        mutable int count;
public:
        Test(const int num1 = 0, const int num2 = 0) : num1(num1), num2(num2)
        {
                this->count = 0;
        }
        void print(void)const
        {
                this->count = this->count + 1; //allowed
                cout << "Count    :      " << this->count << endl;
                cout << "Num1     :      " << this->num1 << endl;
                cout << "Num2     :      " << this->num2 << endl;
        }
};
int main(void)
{
        Test testInstance;
        testInstance.print();
        testInstance.print();
        return 0;
}
```

We can declare object of class as a constant. Using constant object we can call only constant member function.

const, volatile and mutable is called Access modifier.

Reference:

typdef is feature of C language which allows us to create alias for the existing data type.

e.g. typedef unsigned int size_t;
size_t size = sizeof(int);

Reference is feature of C++ which allows to create alias for existing object.

e.g. int num1 = 10;

```
int& num2 = num1;
```

In above code, num2 is reference variable where num1 is referent variable. Once initialized we cannot change referent of reference.

```
int num1 = 10;
int num2 = 20;
int& num3 = num1;        //num3 is reference variable for num1;
num3 = num2;             //Here we are not changing reference rather copy value from
```

num2 into num3;

Since references are implicitly considered as a constant pointer, it is compulsory to initialize references. Following code illustrate how references are implicitly const and pointer.

```
class Test
{
private:
    double& num3;
public:
    //It is compulsory to initialize references in ctors member initilaizer list
    Test(double& num2) : num3( num2 )
    {    }
};
int main(void)
{
    double num1 = 10;
    Test testInstance( num1 );
    size_t size = sizeof(testInstance);      // 4 bytes
    return 0;
}
```

Even though data member is a type of double, size of an object is 4 bytes, it means that references are implicitly treated as a pointer. References need to initialize inside ctors member initializer list it means that references are implicitly treated as const.

```
int num1 = 10;
int& num2 = num1;
```

Now we can treat above statement as follows:

```
int num1 = 10;
```

```
int& num2 = num1;       //int* const num2 = &num1;
```

i.e. References are automatically dereferenced constant pointer variables.

In following code i have used constant in combination with reference.

```
int num1 = 10;
int& num2 = num1;
const int& num3 = num1;
```

Here we can read as well as modify state of num1 via num2 but we cannot modify state via num3.

References are not designed to use independently rather it is designed to pass and return object from function by reference.

Note:Generally we should not return local variable by reference. In this case we should declare local variable as static.

Points To Remember:

1.Reference is derived data type.
2.Reference is used to create alias for the object.
3.We cannot change referent of the reference.
4.We cannot create reference to reference.
5.We cannot initialize reference to NULL.
6.We cannot create reference to constant.
7.We cannot create array of references.
8.We can create reference to pointer, array, function as well as object.
9.We can pass object to the function by value, by address and by reference.
10.With the help of reference we cannot save the memory rather we can minimize complexities of pointer.

Test your understanding:

How will you create reference to array?
What is the difference between pointer and reference?

Macro vs Inline Function:

Macro: A macro is short form of macro instruction.

It is a rule or pattern that specifies how a certain sequence of characters should be mapped to a replacement output sequence of characters according to a defined procedure. In short,

symbolic constant is also called macro. The mapping process that transforms a macro use into a specific sequence is known as macro expansion. Preprocessor is program which expands the macro.

Preprocessor performs two main task:

1.Expands the macro and

2.Removes the comments which included in .c file

There are two types of macros, object-like and function-like. Object-like macros do not take parameters; function-like macros do.

Consider the example of object like macro

```
#define     PI     3.142
```

Consider the example of function like macro

```
#define SQUARE( number )     number * number
int main(void)
{
      int number = 5;
      cout << SQUARE(number) << endl;
      return 0;
}
```

Several identifiers are predefined, and expand to produce special information.

__LINE__ A decimal constant containing the current source line number.

__FILE__ A string literal containing the name of the file being compiled.

__DATE__ A string literal containing the date of compilation, in the form "Mmmm dd yyyy"

__TIME__ A string literal containing the time of compilation, in the form "hh:mm:ss"

Inline Function: Imp

Giving call to the function is always overhead to the compiler because each time a function is called, a significant amount of overhead is generated by the calling and return mechanism. Typically, arguments are pushed onto the stack and various registers are saved when a function is called, and then restored when the function returns. The trouble is that these instructions take time.

An inline function is one for which the compiler copies the code from the function definition directly into the code of the calling function rather than creating a separate set of instructions in memory. Instead of transferring control to and from the function code segment, a modified

copy of the function body may be substituted directly for the function call. In this way, the performance overhead of a function call is avoided.

To declare function as inline we should use inline keyword.

```
inline int max( int num1, int num2 )
{
        return num1 > num2 ? num1 : num2;
}
```

If we implement member function inside structure/class then it is by default treated as inline.If we define functions globaly then we must specify inline keyword explicitly. Consider the following code.

```
class Point
{
private:
        int xPosition;
        int yPosition;
public:
        inline Point();
        inline void printRecord();
};
inline Point::Point()
{
        this->xPosition = 0;
        this->yPosition = 0;
}
inline void Point::printRecord()
{
        cout << "X Position      :       " << this->xPosition << endl;
        cout << "Y Position      :       " << this->yPosition << endl;
}
int main(void)
{
        Point pt1;
        pt1.printRecord();
        return 0;
}
```

We can declare constructor as inline only.

The inline specifier is only a suggestion/request to the compiler that an inline expansion can be performed; the compiler is free to ignore the suggestion.

In following condition, function cannot be classified as inline
1.If function contains a code which leads to larger executables.
2.If we implement function using recursion.
3.If we implement function using loop.

Note:If we declare function as inline then we cannot divide class declaration and definition in multiple files.
Test your understanding:
Why inline functions are hazardous?

string class:

C as well as C++ programming language supports strings but string is not a fundamental data type in it.Standard Template Library contains class 'basic_string' which allows us to handle the string. string is typedef of basic_string.

```
typedef basic_string string;
```

'basic_string' class is declared in string(#include<string>)header file. Lets see how to use it.

```
string name;
cout<<"Enter your name :      ";
cin>>name;
cout<<"Name      :      "<<name<<endl;
```

Now no need to declare character array. In MS Visual Studio size of object os string class is ____bytes.

Exception Handling:

'An exception is an event, which occurs during the execution of a program, that disrupts the normal flow of the program's instructions'.

To create an application, most of the times we take help of operating system resources. Following are some the resources we use frequently:

1. Memory
2. File
3. Socket etc.

Since these resources are very limited we should use it carefully. To manage these resources efficiently, we should use exception handling. In C++ we can handle exceptions with the help of following keywords:

1.try
2.throw
3.catch

if we want to inspect group of statements for exception then we should put such statement inside try block or try handler. If we want to use try block then it is necessary to provide at least one catch block.

Exceptions may be generated implicitly by the C++ runtime or programmer can generate it explicitly with the help of throw keyword. throw is jump statement. We can use throw statement inside try as well as catch block.

To handle exception thrown from try block we should use catch block or catch handler. Single try block may have multiple catch block but it must have at least one catch block.

```
void accept_record(int& number)
{
        cout << "Enter number   :       ";
        cin >> number;
}
void print_result(const int& result)
{
        cout << "Result     :       " << result << endl;
}
int main(void)
{
```

```
try
{
        int num1;
        ::accept_record(num1);

        int num2;
        ::accept_record(num2);

        if (num2 == 0)
                throw string("Divide By Zero Exception");
        int result = num1 / num2;
        cout << "Result    :        " << result << endl;
}
catch ( string ex )
{
        cout << ex << endl;
}
return 0;
}
```

We can write try catch block inside another try as well as catch block. Outer catch block can handle exception which are unhand-led by the inner catch block but catch block of inner try cannot handle exception which are unhand-led by outer catch block.

If we do not handle thrown exception then C++ runtime implicitly gives call to 'std::terminate' function which implicitly gives call to the 'std::abort' function which stops execution of program abnormally.In this case we should write such a catch block which can handle all kind of exception thrown by user. A catch block which can handle all types of exception is called generic catch block.

```
catch( ... )
{
        /* Inside generic catch block*/
}
```

If we want to use generic as well as specific catch handler together then generic catch handler must be the last handler.

In C++, we can throw exception from outside try block via function. Consider the following example:

```
void accept_record(int& number)
```

```
{
        cout << "Enter number   :       ";
        cin >> number;
}
int calculate(int num1, int num2)
{
        if (num2 == 0)
                throw string("Divide By Zero Exception");
        return num1 / num2;
}
void print_result(const int& result)
{
        cout << "Result    :       " << result << endl;
}
int main(void)
{
        try
        {
                try
                {
                        int num1;
                        ::accept_record(num1);
                        int num2;
                        ::accept_record(num2);
                        int result = ::calculate(num1, num2);
                        ::print_result(result);
                }
                catch (string ex)
                {
                        cout << ex << endl;
                }
        }
        catch (...)
        {
                cout << "Exception" << endl;
        }
```

```
    return 0;
}
```

In case of modularity, We can intimate to the user to handle specific exceptions with the help of exception specification list. Consider the following code

```
int calculate(int num1, int num2) throw ( string )
{
    if (num2 == 0)
        throw string("Divide By Zero Exception");
    return num1 / num2;
}
```

throw followed by type of exception is called exception specification list.

Note:We can write exception specification list inside declaration as well definition but ideally we should write it in declaration part only.

If we forget to specify type of exception in exception specification list then catch block do not handle such exception rather C++ runtime implicitly gives call to the std::unexpected function which gives call to the std:: terminate function. This feature do notify works in Microsoft Visual Studio. To test this feature we should write code in unix/linux.

If information required to handle the exception is incomplete at given place then we can rethrow the exception to its outer catch using throw keyword.

```
    try
    {
        try
        {
            int num1;
            ::accept_record(num1);
            int num2;
            ::accept_record(num2);
            int result = ::calculate(num1, num2);
            ::print_result(result);
        }
        catch (string ex)
        {
            throw;      //rethrow
        }
    }
```

```
        catch (string ex)
        {
                cout << ex << endl;
        }
        catch (...)
        {
                cout << "Exception" << endl;
        }
```

Sometimes we need to handle the exception by throwing different type of exception. It is called exception chaining. Consider the following example:

```
class LinkedList
{
        Node* head;
public:
        bool empty(void)
        {
                //TODO
        }
        void deleteFirst(void)throw( string )
        {
                if (this->empty())
                        throw string("List is empty");
                else
                        //TODO
        }
};
class Stack
{
private:
        LinkedList collection;
public:
        void pop(void)throw( string )
        {
                try
                {
                        collection.deleteFirst();
```

```
}
}
}
```



```
        }
        catch (string e)
        {
            throw string("Stack is full");      //Exception chaining
        }
    }
};
```

Stack Unwinding:

In the C++ exception mechanism, control moves from the throw statement to the first catch statement that can handle the thrown type. When the catch statement is reached, all of the automatic variables that are in scope between the throw and catch statements are destroyed in a process that is known as stack unwinding.

In stack unwinding, execution proceeds as follows:

1.Control reaches the try statement by normal sequential execution. The guarded section in the try block is executed.

2.If no exception is thrown during execution of the guarded section, the catch clauses that follow the try block are not executed. Execution continues at the statement after the last catch clause that follows the associated try block.

3.If a matching handler is still not found, or if an exception occurs during the unwinding process but before the handler gets control, the predefined run-time function terminate is called. If an exception occurs after the exception is thrown but before the unwind begins, terminate is called.

4.If a matching catch handler is found the process of unwinding stack begins. This involves the destruction of all automatic objects that were fully constructed—but not yet destructed—between the beginning of the try block that is associated with the catch handler and the throw site of the exception. Destruction occurs in reverse order of construction. The catch handler is executed and the program resumes execution after the last handler—that is, at the first statement or construct that is not a catch handler.

Types of Function:

An operation denotes a service that a class offers to its clients. Client typically performs five kinds of operations on an object.These functions allows us to write loosely coupled class.

1. Selector: an operation that accesses the state of an object but does not alter the state. Selector function is also called inspector function.

```
int getReal( void )const
{
        return this->_real;
}
```

Generally we should declare inspector function as a constant.

2.Modifier: an operation that alters the state of an object. Modifier function is also called mutator function.

```
void setReal( const int real )
{
    this->_real = real;
}
```

3. Iterator: an operation that permits all parts of an object to be accessed in some well-defined order.

4. Constructor: an operation that initializes an object.

5. Destructor: an operation that deinitializes an object.

Header Guard:

In case of repeated inclusion of headers, if we want to replace contents of header only once then we should use header guard.Header guard is also called #include guard or macro guard. Header guards are implemented by using three preprocessor directives in a header file. Two are placed at the beginning of the file, before any pertinent code. The last is placed at the end of the file.

```
#ifndef unique_symbol
#define unique_symbol


#endif
```

The symbol used is not crucial, but it must be unique. It is traditional to use all capital letters for the symbol. Only letters, numbers and the underscore character can be used in the symbols. No other punctuation is allowed. A very common symbol is to use the name of the header file, converting the .h suffix to a _H.

Consider the Complex.h header file with header guard as follows:

```
#ifndef     COMPLEX_H
#define     COMPLEX_H

    class Complex
    {
    private:
            int real;
            int imag;
    public:
            int getReal()const;
            void setReal( const int real );
            ...
            ...
    };

#endif
```

Modular approach:

If we want to divide code into multiple files then class declaration should appear in header file and member function definition should appear in source file. We should define all global functions in Main.cpp file.

To define functions globally, we should use following format:

```
ReturnType ClassName::MemberFunctionName( ... )
```

Points To Remember:

1.We must specify default arguments only in declaration part only(.h file).

2.Constructors member initializer list must be appear in definition part only(.cpp).

3.const keyword must be appear in declaration as well as definition part(.h & .cpp).

4.static keyword must be appear in declaration part only(.h file).

5.Global definition for static data member must be appear in source file(.cpp).

6.Friend keyword must be appear in declaration part only.(.h)

7.virtual keyword must be appear in declaration part only(.h file).

8.We should not define pure virtual function inside source file.

9.Exception specification list can be appeared in declaration as well as definition. But it must appear in declaration.

10.User defined header files should be included using double quotes(#include"Complex.h").

11.In case of multiple files,we should use following sequence of header files.

i.all C language standard header files.

ii.all C++ language standard header files.

iii.all user defined header files.

Modularity:

-Process of dividing complex system into modules which can be compiled separately, but which have connections with other modules is called modularity.

-It is major pillar of oops.

-Modularity helps to minimize module dependancy.

-In C++, we can achieve logical modularity with the help of namespace and physical modularity with the help of multiple files.

Abstraction: "selective Ignorance"

-Process of getting essential characteristics of an object is called abstraction.

-An abstraction focuses on the outside view of an object.

-Abstraction focuses on the essential characteristics of some object,relative to the perspective of the viewer.

kinds of abstractions include the following:

Entity abstraction =>An object that represents a useful model of a problem domain or solution domain entity

Action abstraction =>An object that provides a generalized set of operations, all of which perform the same kind of function.

Virtual machine abstraction => An object that groups operations that are all used by some superior level of control, or

operations that all use some junior-level set of operations

Coincidental abstraction => An object that packages a set of operations that have no relation to each other

Encapsulation:

-Abstraction and encapsulation are complementary concepts: Abstraction focuses on the observable behavior of an object, whereas encapsulation focuses on the implementation that gives rise to this behavior.

-Encapsulation is the process of compartmentalizing the elements of an abstraction that constitute its structure and behavior or binding of data and code together is called encapsulation. Encapsulation means binding & hiding data.

-Encapsulation hides the details of the implementation of an object.

Information Hiding :

It is the process of hiding all the secrets of an object that do not contribute to its essential characteristics. Generally we can hide data/information with the help of private or protected access specifier.

Data Security.

Process of giving control access to the members of class is called data security. To achieve data security first encapsulate variable and function inside a class and then the help of access specifiers give access to the data members using getter and setter method.

```
class Account
{
private:
        float balance;
public:
        void withdraw( float amount )
        {
                if( amount >= 100 )
                        this->_balance = this->balance - amount;
                else
                        throw Exception("Invalid amount");
        }
}
```

Function Overloading:

If implementation of function is logically equivalent then we should give same name to the function. If we want to give same name to the function then we must obey following rules:

1.number of parameters pass to the function must be different.

```
void sum( int num1, int num2 ){       }
void sum( int num1, int num2, int num3 ){   }       //allowed
```

2.If number of parameters are same then type of at least one parameter must be different.

```
void sum( int num1, int num2 ){       }
void sum( int num1, double num2 ){   }       //allowed
```

3.If number of parameters are same then order of type of parameter must be different.

```
void sum( int num1, float num2 ){    }
void sum( float num1, int num2 ){    }    //allowed
```

4.On the basis of return type we cannot give same name to the function. i.e. return type is not considered.

```
void sum( int num1, int num2 ){      }
int sum( int num1, int num2 ){ }     //Not allowed
```

Process of writing such functions which is having same name but different signature is called function overloading.Functions which are taking part into function overloading are called overloded function. In case of overloading functions must be exist inside same scope. Except main function and destructor, we can overload any global function as well as member function.

Since ANSI has not defined any strict specification on return type, catching values from the function are optional. so return type is not considered at the time of overloading.

Test Your Understanding

1:What will be the output of following program?

```
void print(int number)
{
    cout << "int :       " << number << endl;
}
void print(double number)
{
    cout << "double   :      " << number << endl;
}
1.  print( 10 );

2.  print( 10.5 );

3.  print( 10.5f );
```

2.What will be the output of following program?

```
void print(int number)
{
```

```
        cout << "int :       " << number << endl;
}
void print(float number)
{
        cout << "float       :       " << number << endl;
}
1.      print( 10 );

2.      print( 10.5 );

3.      print( 10.5f );
```

3.What will be the output of following program?

```
void print(int number)
{
        cout << "int :       " << number << endl;
}
void print(int& number)
{
        cout << "int&        :       " << number << endl;
}
1.      print( 10 );

2.      int number = 10;
        print( number );
```

4.What will be the output of following program?

```
void print(bool object)
{
        cout << "bool        :       " << object << endl;
}
void print(char object)
{
        cout << "char        :       " << object << endl;
}
```

1. print(true);

2. print('A');

3. print(65);

5.What will be the output of following program?

```
void print(int num1 = 0)
{
        cout << "int :       " << num1 << endl;
}
void print(int num1, int num2 = 0)
{
        cout << "int :       " << num1 << endl;
        cout << "int :       " << num2 << endl;
}
```

1. print(0, 10);

2. print(30);

3. print(10, 20);

4. print();

6.What will be the output of following program?

```
void print( char text[])
{
        cout << "char[]    :       " << text << endl;
}
void print(char* text)
{
        cout << "char*     :       " << text << endl;
}
```

1. print("Sandeep");

2. char name[] = "Sandeep";

```
print(name);
```

7.What will be the output of following program?

```
void print( const char* text)
{
        cout << "const char*      :      " << text << endl;
}
void print(char* const text)
{
        cout << "char* const      :      " << text << endl;
}
1.      print("Sandeep");

2.      char name1[] = "Sandeep";
        print(name1);

3.      const char name2[] = "Sandeep";
        print(name2);
```

8.What will be the output of following program?

```
class Test
{
public:
        void Print( void )
        {
                cout << "void print( void )" << endl;
        }
        void Print(void)const
        {
                cout << "void print( void )const" << endl;
        }
};
1.      Test t1;
        t1.Print();

2.      const Test t2;
```

```
t2.Print();
```

9.What will be the output of following program?

```
enum E
{
    eNumber = 10
};
void print(const int number)
{
    cout << "Number  :     " << number << endl;
}
void print(E number)
{
    cout << "Number  :     " << number << endl;
}
1.  print(10);

2.  const int number = 10;
    print(number);

3.  print(eNumber);
```

Name Mangling and Mangled Name:

C++ compiler generates encoded name by looking name of the function and type of argument pass to the function is called mangled name.

```
void sum( int num1, int num2 );                    //sum@@int,int

double sum( int num1, float num2, double num3);    //sum@@int,float,double
```

Since ANSI has not defined any specification on mangled name, compiler vendors are free to generate mangled name.It means that mangled name may vary from compiler vendor to compiler vendor.It you try to access any element without definition, compiler will return you mangled name.

Process or algorithm which decides how to generate mangled name is called name mangling. Generating mangled name is job of compiler.

If we want to access functions implemented in .c file into .cpp then it is necessary to declare functions as extern "C".

For functions declared as extern "C", compiler do not generate mangled name.

Dynamic Memory allocation:

C as well as C++ language allows us to reserve space for an object statically as well as dynamically. First we will see how to reserve space using C and then C++.

To allocate and deallocate space for an object dynamically we should use following functions. To use these functions we should use stdlib.h (cstdlib in C++) header file.

cstdlib

1. void* malloc(size_t size);

- The malloc() function allocates size bytes and returns a pointer to the allocated memory.
- The memory is not initialized.
- If size is 0, then malloc() returns either NULL, or a unique pointer value.

2.void* calloc(size_t nmemb, size_t size);

- The calloc() function allocates memory for an array of nmemb elements of size bytes each and returns a pointer to the allocated memory.
- The memory is set to zero.
- If nmemb or size is 0, then calloc() returns either NULL, or a unique pointer value.

3.void* realloc(void * ptr, size_t size);

- The realloc() function changes the size of the memory block pointed to by ptr to size bytes.
- The contents will be unchanged in the range from the start of the region up to the minimum of the old and new sizes.
- If the new size is larger than the old size, the added memory will not be initialized.
- If ptr is NULL, then the call is equivalent to malloc(size).
- if size is equal to zero, and ptr is not NULL, then the call is equivalent to free(ptr).
- If there is not enough available memory to expand the block to the given size, the original block is left unchanged, and NULL is returned.
- If the area pointed to was moved, a free(ptr) is done.

4.void free(void * ptr);

- The free() function deallocates the memory space pointed to by ptr, which must have been returned by a previous call to malloc(), calloc() or realloc().

- If ptr is NULL, no operation is performed.

Standard directory for visual studio(C:\Program Files (x86)\Microsoft Visual Studio 12.0\VC\include) contains new.h (and new also) header file. It contains declarations of following functions:

```
struct nothrow_t{  // Empty structure };

extern const nothrow_t nothrow;        // constant for placement new tag

void* operator new(size_t size) throw(bad_alloc);

void operator delete(void *) throw();

void* operator new[](size_t _Size)throw(bad_alloc);       // allocate array or throw exception

void  operator delete[](void *) throw();       // delete allocated array

void* operator new(size_t size, void *where) throw();

void* operator new(size_t _Size, const nothrow_t&) throw();

void*  operator new[](size_t _Size, const  nothrow_t&)throw(); //  allocate  array  or  return
null pointer
```

In C++, to allocate memory dynamically we should use new operator and to deallocate that memory we should use delete operator. new implicitly calls operator new and delete implicitly calls operator delete function which are declared in new.h header file. Lets see how to use new and delete operator.

1. Allocating and deallocating space dynamically for single integer varaible:

```
try
{
        int* ptr  = new int;
        //int* ptr = ( int* )::operator new( sizeof( int ) * 1 );
        ...
        ...
```

```
        delete ptr;          //::operator delete( ptr );
        ptr = NULL;
    }
    catch( bad_alloc ex )
    {
        cout<<ex.what()<<endl;
    }
```

2.Allocating and deallocating space dynamically for single dimensional array of integer:

```
    try
    {
        int* ptr = new int[ 3 ];
        //int* ptr = ( int* )::operator new[]( sizeof( int ) * 3 );
        ....
        ...
        delete[] ptr;              //::operator delete[]( ptr );
        ptr = NULL;
    }
    catch( bad_alloc ex )
    {
        cout<<ex.what()<<endl;
    }
```

3.Allocating and deallocating space dynamically for multidimensional array of integer:

```
    try
    {
        int** ptr = new int*[ 2 ];
    //int** ptr = ( int** )operator new[]( sizeof( int* ) * 2 );

    for( int index = 0; index < 2; ++ index )
        ptr[ index ] = new int[ 3 ];
    //ptr[ index ] = ( int* )::operator new[]( sizeof( int ) * 3 );
        .....
        .....
        for( int index = 0; index < 2; ++ index )
            delete[] ptr[ index ];          //::operator delete( ptr[ index ] );
```

```
        delete[] ptr;                   //::operator delete( ptr );
        ptr = NULL;
    }
    catch( bad_alloc ex )
    {
        cout<<ex.what()<<endl;
    }
```

If new operator fails to allocate memory then C++ runtime implicitly throws bad_alloc exception.

We can allocate and deallocate memory for an object of user defined data type. In this case new implicitly calls constructor and delete implicitly calls destructor.

```
1. Point* ptr = new Point;          //parameterless constructor will call
2. Point* ptr = new Point();        //parameterless constructor will call
//Recommended
3. Point* ptr = new Point( 10, 20 );    //parameterized constructor will call
4. delete ptr;                      //destructor will call
```

Main advantage of new operator over malloc function is that it allows us to reserve space for an object on allocated as well as un-allocated memory area. To reserve space on allocated space we should use following form of new operator. It is called placement new operator.

Consider the example;

```
    char buffer[ 30 ];
    int* ptr = new ( buffer ) int;
//int* ptr = ( int* )::operator new( sizeof( int ) * 1 , buffer );
    ....
    ....
    //delete ptr; //Not allowed
    ptr = NULL;
```

if we want to place an object at a particular location in memory then we can use placement new operator.

If malloc fails to allocate memory then it returns NULL. new operator may behave like this if we use nothrow object.

consider the following example:

1. Following code demonstrate bad_alloc exception.

```
    try
    {
```

```
        int size = 1000000000;
        int* ptr = new int[ size ];
    }
    catch (bad_alloc ex)
    {
        cout << ex.what();
    }
    //Output    :    bad allocation
```

2. Following code demonstrate use of nothrow.

```
    try
    {
        int size = 1000000000;
        int* ptr = new (nothrow)int[size]; //int* ptr = (int*)::operator new[](sizeof(int)* size, nothrow);
        if (ptr == NULL)
            cout << "NULL" << endl;
    }
    catch (bad_alloc ex)
    {
        cout << ex.what();
    }
    //Output    :    NULL
```

nothrow_t is an empty structure which is declared in new.h header file and nothrow is an instance of nothrow_t struct.

Wild pointer: Uninitialized pointer is called wild pointer.

```
    int* ptr;    //wild pointer
```

Dangling pointer : A pointer which stores address of released memory or pointer which points to the invalid memory location is called dangling pointer;

```
    int* ptr1 = new int();    //default value is 0
    int* ptr2 = ptr1;    //two pointers for same location
    *ptr2 = 10;
    cout << "Value    :    " << *ptr2 << endl;
    delete ptr2;
```

```
//Now ptr1 becomes dangling pointer
cout << "Value      :      " << *ptr2 << endl;
delete ptr1;  //Not allowed
```

To avoid dangling pointer we should deinitialize **all** pointers which are pointing to same location to NULL.

Memory leakage: If we reserve space in memory but no pointer is pointing to it then wastage of such memory is called memory leakage.

```
int* ptr = new int[3];
...
ptr = new int[5];   //this statement definitely loose 12 bytes.
```

To avoid memory leakage either we should use delete operator properly or we should use smart pointer.

Smart Pointer : If we treat an object as pointer then such object is called smart pointer. auto_ptr and unique_ptr are the predifined smart pointers. We will discuss smart pointer later. Consider the following example:

```
#include<iostream>
#include<memory>
using namespace std;
int main(void)
{
        auto_ptr<int> autoPointer(new int());

        *autoPointer = 10;

        cout << "Value      :      " << *autoPointer << endl;

        return 0;
}
```

Test your understanding:

1. int* ptr = new int( );
2. int* ptr = new int(3);
3. int* ptr = new int[3];

What is the difference between malloc and new?

Destructor:

A member function of class that has the same name as the class and is prepended with ~ operator is called destructor. It is used to do clean up after an object of a class is no longer in the scope of program segment. Consider the syntax for destructor:

```
~Point( void )      //destructor for the Point class
{

}
```

There are two situations in which a destructor is called. The first is when an object is destroyed under "normal" conditions, e.g., when it goes out of scope or is explicitly deleted. The second is when an object is destroyed by the exception-handling mechanism during the stack-unwinding part of exception propagation.

If we do not define destructor for the class then compiler provides one destructor for the class by default. It is called default destrucotr. Default destructor always does the job of deinitialiation only.

On exit from function or block, Objects created in that function are destroyed by the compiler automatically. But an object might have an accumulated resources (dynamic memory, disk blocks, network connections etc.)during its life time. These resources are stored in the objects data members and are manipulated by the member functions. When the object is destroyed, it is necessary that the resources held by the object are released because object is no longer accessible. Because compiler isn't aware of the resources held by the object, it is responsibility of object to release such resources. To help an object in doing so, on exit from function, destructor is called on all objects created statically. In other words, to release operating system resources held by the object we should write destructor inside class. Consider the following code snippet:

```
namespace NString
{
    class String
    {
    private:
        unsigned int length;
        char* buffer;
```

```
    public:
        String(unsigned int length = 0 )//ctor
        {
            //TODO
        }
        ~String(void)//dtor
        {
            if (this->buffer != NULL)
            {
                delete[] this->buffer;
                this->buffer = NULL;
            }
        }
    };
}
```

Points To Remember:

1.To Prevent resource leak we should use destructor.

2.Destructor calling sequence is exactly opposite of constructor calling sequence(in array too).

3.Since destructor do not take any parameter we cannot overload it.

4.We can declare destructor as inline and virtual only.

5.Even though destructor is designed to call implicitly, we can call it explicitly too.

6.if we try to create object using new then constructor gets call and if we try to delete that object using delete operator then destructor gets cail. Consider following example:

```
String* ptr = new String( );      //Here ctor will call implicitly
...
delete ptr;                       //Here dtor will call implicitly
```

If we create an instance with the help of placement new operator then we cannot deallocate memory of an object using delete operator. If we do not use delete operator then destructor will not be call. But to avoid resource leak we need to call destructor explicitly. Consider the following code.

```
char arr[30];
```

```
String* ptr = new ( arr )String();
....
....
ptr->~String();     //explicit call to dtor
ptr = NULL;
```

Array of Objects:

```
Point** ptr = new Point*[3];    //A
for (int index = 0; index < 3; ++index)
        ptr[index] = new Point();

.....
.....
for (int index = 0; index < 3; ++index)
        delete ptr[index];
delete[] ptr;
ptr = NULL;
```

Object Copy Semantics:

There are three different strategies for object coping.

1.Shallow Copy. (Also known as bitwise copy)

2.Deep Copy. (Also known as member-wise copy)

3.Lazy Copy.(Also known as Copy On Write(COW).)

The term shallow,deep & lazy copy originated in smalltalk and these terms are generally used to describe copy semantics

Shallow Copy:

At the time of copy operation, if we copy every member of source object into destination object as it is then such type of copy is shallow copy. Consider the following example:

1.
```
int num1 = 10;
int num2 = num1; //shallow copy.
```

2.
```
double num1 = 20.5;
double num2;
num2 = num1;            //shallow copy.
```

3. Point pt1(10, 20);
   Point pt2;
   pt2 = pt1; //shallow copy.

4. String str1("Sandeep");
   String str2 = str1; //shallow copy

Deep Copy:

If class data member holds operating system resource & if we want to create copy of the object then we need to rely on deep copy operation. Here i am going to consider memory for discussing deep copy.

If class contains at least one data member of pointer type, class contains user defined destructor which does job of deallocation and if we try to copy object into another object then instead of coping memory address from data member of source object into data member of destination object, we should allocate new memory for the data member of destination object and then we should copy contents from memory of source object into memory of destination object. Such type of copy is called deep copy.

Conditions to create deep copy.

1. Class should contain at least one data member of pointer type.
2. Class contains user defined destructor which does job of deallocation
3. We should create copy of object

Copy of the object gets created due to following reasons:

1. Initialization
2. Assignment
3. Passing object to the function by value.
4. Returning object function by value.

Steps to create deep copy:

1. Copy the size/length from data member of source object into data member of destination object.
2. Allocate new memory for the pointer data member of destination object.
3. Copy the contents from memory of source object into memory of destination object.

Where to create deep copy.:

1.In case of assignment we should create deep copy inside assignment operator function.[Operator Overloading]

2.In rest of the condition we should create deep copy inside copy constructor.

Copy Constructor:

A member function of class having same name as a class and which takes only one parameter of same type but as a reference is called copy constructor of the class. Copy constructor is a kind of parameterized constructor(Single Parameter Constructor).

General Syntax of copy constructor is as follows:

```
ClassName( const ClassName& other )
{
        //TODO:Copy operation
}
```

Initialization is the process of storing known value in a variable during its creation. Job of copy constructor is to initialize newly created object from existing object.

The copy constructor gets invoked in following conditions:

1.If we pass an object to the function by value.

```
class Point
{
private:
        int xPosition;
        int yPosition;
public:
        //Point* const this = & pt1;
        //Point pointInstance = pt2;
        void sum(Point pointInstance)   //Here for pointInstance, copy constructor will call
        {
                //TODO
        }
};
int main(void)
{
        Point pt1(10, 20);  //for pt1 parameterized ctor will call
```

String str2(str1);//Here for str2 copy constructor will call

4. If we throw and catch object of user defined type.

```
class Exception
{
private:
        int length;
        char* text;
};

int main(void)
{
        int num1 = 10;
        int num2 = 0;
        try
        {
                if (num2 == 0)
                        throw Exception("Divide By Zero Exception");
                int res = num1 / num2;
        }
        catch (Exception ex)      //Here for ex copy constructor will call
        {
                cout << "Exception" << endl;
        }
        return 0;
}
```

Note:It is however, not guaranteed that a copy constructor will be called in these because the C++ Standard allows the compiler to optimize the copy away in certain one example being the return value optimization

If class do not contain copy constructor then compiler provides one copy constructor class. Such copy constructor is called default copy constructor. Default behavior of copy constructor always creates shallow copy of an object. In case of initializatio

```
        Point pt2(30, 40);  //for pt2 parameterized ctor will call
        pt1.sum(pt2);
        return 0;
    }
```

2.If we return an object from function by value.

```
    class Point
    {
    private:
        int xPosition;
        int yPosition;
    public:
        //Point* const this = &pt1;
        //Point pointInstance = pt2;
        Point sum(Point pointInstance)
        {
            Point tempInstance;
                //TODO
            return tempInstance;
        }
    };
    int main(void)
    {
        Point pt1(10, 20);  //for pt1 parameterized ctor will call
        Point pt2(30, 40);  //for pt2 parameterized ctor will call
        Point pt3;          //for pt3 parameterless ctor will call
        pt3 = pt1.sum(pt2);//Here First Sum function & then for annonymous object
copy constructor will call
        return 0;
    }
```

3.If we initialize newly created object from existing object.

```
    String str1("Sandeep");
    String str2 = str1;  //Here for str2 copy constructor will call
```

or

```
    String str1("Sandeep");
```

object, if there is need to create deep copy then we should define user defined copy constructor inside a class.

```
class String
{
private:
        int length;
        char* buffer;
public:
        String( const String& other ) throw( bad_alloc )      //copy constructor with deep
copy
        {
                this->length = other.length;
                this->buffer = new char[ this->length + 1 ];
                strcpy( this->buffer, other.buffer );
        }
};
```

If we pass an object to the function by address or by reference then copy constructor do not call.

Lazy Copy:

String class which is declared above is fairly easy to understand and implement. What happens when objects of this class are used heavily as a function arguments and as a return values using the pass by value scheme? Since class uses deep copy semantics, if number of characters in the String object is not too small, significant time is spent in copying characters and in deleting the dynamically allocated memory. This also implies that object creation and destruction is expensive. The intention is that wherever character strings are needed,String object should be used. But if cost of creation, copying, assignment and destruction of these String objects is prohibitive, clients will refrain from using the class.

To optimize implementation,We could change implementation such that when a copy of a String object is made, both the copies share the characters in the original string without actually copying them. But when one of the copies try to modify the contents then it should get separate copy of characters without affecting other objects. This scheme of making a true copy of object when modification is attempted is called Copy-On-Write(COW) or Lazy Copy.

Concept of lazy copy or copy on write is based on reference counting mechanism. Reference counting is a technique that allows multiple objects with the same value to share a single representation of that value.

```
class String
{
private:
    struct StringValue
    {
        unsigned referenceCount;
        unsigned length;
        char* buffer;
    public:
        StringValue(void)
        {
            this->referenceCount = 1;
            this->length = 0;
            this->buffer = NULL;
        }
        StringValue(const char* string)throw(bad_alloc)
        {
            this->referenceCount = 1;
            this->length = strlen(string);
            this->buffer = new char[ this->length + 1 ];
            strcpy(this->buffer, string);
        }
        ~StringValue(void)
        {
            delete[] this->buffer;
            this->buffer = NULL;
        }
    };
private:
    StringValue* string;
public:
    String(void)
    {
        this->string = new StringValue();
    }
```

```
String( const char* str )
{
        this->string = new StringValue(str);
}
String(const String& other)//copy ctor
{
        //First increment the reference count
other.string->referenceCount=other.string->referenceCount + 1;
        //then share the resource
        this->string = other.string;
}
String& operator=(const String& other)
{
        if (this == &other)
                return *this;
        this->~String();
other.string->referenceCount=other.string->referenceCount + 1;
        this->string = other.string;
        return *this;
}
String& toLower(void)     //Copy-On-Write Strategy
{
        if (this->string->_referenceCount > 1)
        {
                char* str = this->string->_buffer;
                this->string->_referenceCount = this->string->_referenceCount - 1;
                this->string = new SStringValue(str);
        }
        char* str = this->string->_buffer;
        while (*str != '\0')
        {
                *str = tolower(*str);
                ++str;
        }
        *str = '\0';
        return *this;
```

```
    }
    ~String(void)
    {
this->string->referenceCount = this->string->referenceCount - 1;
        if (this->string->referenceCount == 0)
            delete this->string;
        this->string = NULL;
    }
};
int main(void)
{
    String str1("Sandeep Kulange");
    str1 = str1.toLower();
    return 0;}
```

Test Your Understanding:

1. Point pt1;
   Point* ptr = &pt1;

2. Point pt1;
   Point& pt2 = pt1;

3. Point pt1;
   Point pt2(pt1);

4. Point pt1;
   Point pt2 = pt1;

5. Point pt1,pt2;
   pt2 = pt1;

Static Members

"Scope" decides the area or region in which we can access the portion of the program. Following are the types of scope:

1.Statement Scope

2.Block Scope

3.Function Scope
4.Class Scope
5.Namespace Scope
6.File Scope

"Lifetime" is the period during execution of a program in which a variable or function exists. Storage classes govern the scope and lifetime of an object in C as well as C++.Following are the storage classes in C/C++.

1.auto
2.static
3.register
4.extern

Local variables are also called automatic variables becoz if we give call to the function then its memory gets managed automatically. Consider the following example:

```
void print(void)
{
        auto count = 0;
        ++count;
        cout << "Count     :       " << count << endl;
}
int main(void)
{
        ::print();     //1
        ::print();     //1
        ::print();     //1
        return 0;
}
```

If we want to persist value of the variable during function call then we should use static storage class. static variables are same as global variable but it is having limited scope. Consider the following example:

```
void print(void)
{
        static int count = 0;
        ++count;
        cout << "Count     :       " << count << endl;
```

```
}
int main(void)
{
        ::print();    //1
        ::print();    //2
        ::print();    //3
        return 0;
}
```

We can declare global function as a static. In this case we cannot access it outside the file. We can declare main function as static but compiler ignores it.

Non static data member is called instance variable and non static member function is called instance method. To access instance members(instance variable & method), inside member function we should use this pointer and inside non member function we should use object/instance of a class.

static data member is called class level variable and static member function is also called class level method. To access class level members(class level variable & method), inside member function as well as non member function we should use class name and scope resolution operator.

Static Data Member:

If we declare non static data member inside the class then every data member gets space inside object.

If we want to share value of any data member among all the objects of same type then we should declare data member as static. In other words all the objects of same type shares single copy of static data member. To declare data member as a static it is compulsory provide global definition for it. Because all the static variable/object gets space before starting execution of main.

Consider the following example:

```
namespace NTest
{
        class Test
        {
        private:
                static int count;
        };
```

```
        int Test::count = 0;//global definition
    }
```

If we forget to provide global definition then linker produces "unresovled external symbol" error.

Note:Generally we should declare constant data member as static.

```
    namespace NMath
    {
        class Math
        {
        private:
            static const float PI;
        };
        const float Math::PI = 3.142f;//global definition
    }
```

In c++, only static constant objects can be initialized at the time of declaration.

```
    namespace NMath
    {
        class Math
        {
        private:
            static const int count = 10;
            //Here type must be static const
        };
    }
```

Static Member Function:

To access non static data members we should define non static methods inside the class and to access static data members outside the class we should declare static method inside the class. Since static methods are designed to call using class name only, it do not get this pointer. Consider the following code:

```
    namespace NInstanceCount
    {
        class InstanceCount
        {
        private:
            static int instanceCount;
```

```
        public:
                instanceCount(void)
                {
InstanceCount::instanceCount = InstanceCount::instanceCount + 1;
                }
                static int getInstanceCount(void)
                {
                        return InstanceCount::instanceCount;
                }
        };
        int InstanceCount::instanceCount = 0;//global definition
}
int main(void)
{
        using namespace NInstanceCount;
        cout << "Instance Count :      " << InstanceCount::getInstanceCount() <<
endl; //0
        InstanceCount obj1, obj2, obj3;
        cout << "Instance Count :      " << InstanceCount::getInstanceCount() <<
endl; //3
        return 0;
}
```

Inside non static member function we can access both static as well as non static members.

```
namespace NTest
{
        class Test
        {
        private:
                int num1;
                static int num2;
        public:
                Test(void)
                {
                        this->num1 = 10;
                Test::num2 = 20;  //Now old value of num2 will be over written with 20.
                }
```

```
        void Print(void)
        {
            cout << "Num1    :    " << this->num1 << endl;
            cout << "Num2    :    " << Test::num2 << endl;      //Allowed
        }
    };
    int Test::num2;    //First it will be initialized to 0
}
```

Since static member function do not get this pointer we cannot access non static members inside static member function directly. To access non static members inside static member function we should create object of the class. Consider the following code.

```
namespace NTest
{
    class Test
    {
    private:
        int num1;
        int num2;
    private:
        Test(void)
        {
            this->num1 = 10;
            this->num2 = 20;
        }
    public:
        void print(void)
        {
            cout << "Num1    :    " << this->num1 << endl;
            cout << "Num2    :    " << this->num2 << endl;
        }
        static void invoke()
        {
            Test test;    //Instantiation
            test.print(); //Now it is allowed
        }
    };
```

```
}
int main(void)
{
        using namespace NTest;
        Test::invoke();
        return 0;
}
```

We cannot declare static member function as constant, volatile or virtual.

If we don't want to modify state of the current object inside member function then generally we declare member function as constant. Since static member functions are not designed to call using object we cannot declare static member function as constant.

Even though static members are designed to call using class name, it is possible to access static members using object name.

Note:Generally we should use classname and scope resolution operator to access static members.

Design Pattern And Its Classification:

Design patterns are not algorithms or components. The design patterns are language independent strategies for solving common object oriented design problems. Here is the classification of design patterns which is listed in book of GOF.

1. Creational Design Patterns
   - i.Abstract Factory
   - ii.Builder
   - iii.Factory Method
   - iv.Prototype
   - v.Singleton
2. Structural Design Patterns
   - i.Adapter
   - ii.Bridge
   - iii.Composite
   - iv.Decorator
   - v.Facade
   - vi.Flyweight
   - vii.Proxy
3. Behavioural Design Patterns
   - I.Chain of responsiblity
   - ii.Command

iii.Interpreter
iv.Iterator
v.Mediator
vi.Memento
vii.Observer
viii.State
ix.Strategy
X.Template method
xi.Visitor

Singleton class: A class which allows us to create only one instance of it and which provides global point of access to it is called singleton class.

```
namespace NSingleton
{
        class Singleton
        {
        private:
                static Singleton* ptrSingletonInstance;
        private:
                Singleton()
                {       }
        public:
                static Singleton* getInstance()
                {
                        if (Singleton::ptrSingletonInstance == NULL)
                                Singleton::ptrSingletonInstance = new Sing leton();
                        return Singleton::ptrSingletonInstance;
                }
        };
        Singleton* Singleton::ptrSingletonInstance = NULL;
}
```

Test Your Understanding:

1.Why static member function do not get this pointer?

2.Why we cannot declare static member function as a constant.

3.Observe the following code and decide wheather it is overloading or not?

```
class Test
{
public:
        void print();
        static void print();
};
```

Friend function and class:

If we want to access private members of the class inside non member function then we can use any one of the following:

1. Inspector/mutator function
2. Friend function/class
3. Pointer.

Already we have discussed how to use inspector and mutator function. We will discuss pointer part later.

Friend function:

A non member function of a class which is designed to access private and protected members of the class is called friend function.friend is a keyword in C++.

1. Including main function we can declare any global function as friend. But generally we should not declare main function as a friend. Consider the following code:

```
namespace NTest
{
        class Test
        {
        private:
                int num1;
                int num2;
        public:
                Test(void) : num1(10), num2(20)
                {       }
                friend void sum(void);
        };
        void sum(void)
        {
```

```
            Test test;
            int result = test.num1 + test.num2;
            cout << "Result    :       " << result << endl;
        }
    }
    int main(void)
    {
        NTest::sum();
        return 0; }
```

Friend declaration statement(friend void sum(void);)may appear in any region of the class(private, protected, public).

If we want to declare any function as a friend then class and function must be exist inside same namespace.

2. Member function of a class can be declared as friend function inside another class.

Note:It is trick. People generally preferred friend class.

```
class A
{
public:
    void sum(void);
    void sub(void);
};
class B
{
private:
    int num1;
    int num2;
public:
    B();
    friend void A::sum(void);
    friend void A::sub(void);
};
```

3. A Class can be declared as friend class of another class.

```
class A
```

```
{
public:
        void sum(void);
        void sub(void);
};
class B
{
private:
        int num1;
        int num2;
public:
        B();
        friend class A;
};
```

4. We cannot declare mutual friend functions but we can declare mutual friend classes.

```
class B;        //forward declaration
class A
{
private:
        int number;
public:
        void print();
        friend class B;
};
class B
{
private:
        int number;
public:
        void print();
        friend class A;
};
```

To access private or protected elements of the class inside another non member function or class, we declare function or class as a friend. With the help of friend function we cannot access members of function so we cannot declare mutual friend functions.

we can declare single function as a friend inside multiple classes.

```
class Complex
{
private:
        int real;
        int imag;
public:
        Complex(void) : real(10), imag(20)
        {       }
        friend void sum();
};
class Point
{
private:
        int xPosition;
        int yPosition;
public:
        Point(void) : xPosition(30), yPosition(40)
        {       }
        friend void sum();
};
void sum()
{
        //TODO
}
```

Linked list is a collection of items/elements where each item/element is called node. Node is an object which may consist of either two parts or three parts depending on type of linked list.

A pointer which stores address of first node is called head pointer. If value of head is NULL then linked list is considered as empty.

A pointer which stores address of next node is called tail pointer.

There are two types of linked list:

1. Singly linked list.
2. Doubly linked list.

Singly Linked List : In a linked list if node consist of two parts i.e.
1. Data
2. A pointer which stores address of next node(next)
Then such type of linked list is called singly linked list.

Doubly Linked List : In a linked list if node consist of three parts i.e.
1.A pointer which stores address of previous node(prev)
2.Data
3.A pointer which stores address of next node(next) then such type of linked list is called doubly linked list.
In a singly linked list, if next pointer of last node stores NULL value then it is called linear singly linked list.
In a singly linked list, if next pointer of last node stores address of first node then it is called circular singly linked list.
In a doubly linked list, if previous pointer of first node and next pointer of last node stores NULL value then it is called linear doubly linked list.
In a doubly linked list, if previous pointer of first node stores address of last node and next pointer of last node stores address of first node then it is called circular doubly linked list.
Process of visiting nodes in linked list is called traversing.Generally to traverse linked list or any collection we should use iterator. We will discuss iterator in operator overloading.

```
namespace NList
{
        class List;     //Forward declaration

class Node
        {
        private:
                int data;
                Node* next;
        public:
                Node(const int data = 0) : data(data), next(NULL)
                {       }
```

```
        friend class List;
    };
    class List
    {
    private:
        Node* head;
        Node* tail;
    public:
        List(void) :head(NULL), tail(NULL)
        {    }
        bool empty(void)const
        {
            return this->head == NULL;
        }
        void addFirst(const int data)throw( bad_alloc)
        {
            Node* newnode = new Node(data);
            if (this->empty())
                this->tail = newnode;
            else
                newnode->next = this->head;
            this->head = newnode;
        }
    };
}
int main(void)
{
    using namespace NList;
    List list;
    list.addFirst(10);
    list.addFirst(20);
    return 0;
}
```

Test your understanding:

Why friend function do not get this pointer?

Template:

C++ requires us to declare variables, functions, and most other kinds of entities using specific types. However, a lot of code looks the same for different types. Especially if we implement algorithms, such as quicksort, or if we implement a linked list or a binary tree for different types, the code looks the same despite the type used.

If language doesn't support a special feature for this, we only have bad alternatives:

1. we can implement the same behavior again and again for each type.
2. we can write general code using void*.
3. we can use special preprocessors.

Consider the following example:

```
void swap_object(int& object1, int& object2)
{
    int temp = object1;
    object1 = object2;
    object2 = temp;
}
void swap_object(string& object1, string& object2)
{
    string temp = object1;
    object1 = object2;
    object2 = temp;
}
```

In this case we can save programmers effort with the help of template. When we use a template, we can pass types as arguments. In other words "Parameterized type is also called template". we can write above code with the help of template.

```
template< typename Type >
void swap_object(Type& object1, Type& object2)
{
    Type temp = object1;
    object1 = object2;
    object2 = temp;
}
```

Now it is not a specific function it is generic function. More specific it is a Function template.
As shown in above code , template parameters must be announced with syntax of the following form:

template < comma-separated-list-of-parameters >

In our example, the list of parameters is typename Type. The keyword typename introduces a so-called type parameter. We can use any identifier as a parameter name, but using T is the convention.

```
int main( void )
{
        int num1 = 10;
        int num2 = 20;
        swap_object<int>( num1, num2 );     //Template argument list
        return 0;
}
```

At compile time Type will be replaced with int. Here swap_object<int>(...); indicated template argument list.
For historical reasons, you can also use class instead of typename to define a type parameter. The keyword
typename came relatively late in the evolution of the C++ language.
With the help of template we cannot save space or time rather we can save programmers effort only.
Not only function but also class can can be declared as template class.

```
template< class Type >
class Stack
{
private:
        int top;
        int size;
        Type* arr;
public:
        Stack( void );
        bool empty( void ) const;
```

```
    bool full( void ) const;
    void push( Type data );
    Type peek( void );
    void pop( void );
};
```

For class templates we can also define default values for template parameters. These values are called default template arguments.

```
template< class Type = int>
class Stack
{

};
int main(void)
{
    Stack<> s1;
    return 0;
}
```

Note:We cannot divide implementation of template class into multiple files. declaration and definition must be in same file.

Operator Overloading:

In C as well as C++ we can use operators with the objects of fundamental types only. In C we cannot use operators with the objects of user defined type directly(except sizeof).

In C++ if we want to use operators with objects then it is necessary to overload an operator. And to overload an operator it is necessary to define operator function. Now, we can define operator function as a member or non member function.

if we write pt3 = pt1 + pt2 then compiler can assume it like

```
pt3 = pt1.operator+( pt2 );
pt3 = operator+( pt1, pt2 );
```

operator is keyword in C++. If we want use + operator with objects then we should define logic of addition inside operator+() function. Now where to write definition of operator function is upto the programmer.

Consider the following code.

```
pt3 = pt1 + pt2;          //pt3 = pt1.operator+( pt2 );
```

in this case operator function will look like as follows

```
class Point
{
private:
        int xPosition;
        int yPosition;
public:
        //Point* const this = &pt1;
        //const Point& pointInstance = pt2;
        Point operator+( const CPoint& pointInstance )const
        {
                Point temp;
                temp.xPosition = this->xPosition + pointInstance.xPosition;
                temp.yPosition = this->yPosition + pointInstance.yPosition;
                return temp;
        }
};
```

And if we write

```
pt3 = pt1 + pt2;          //pt3 = operator+( pt1, pt2 );
```

in this case operator function will look like as follows

```
class Point
{
private:
        int xPosition;
        int yPosition;
public:
        //const Point& pt1 = pt1;
        //const Point& pt2 = pt2;
        friend Point operator+(const Point& pt1, const Point& pt2)
        {
                Point temp;
                temp.xPosition = pt1.xPosition + pt2.xPosition;
                temp.yPosition = pt1.yPosition + pt2.yPosition;
```

```
        return temp;
    }
};
```

With the help of operator overloading we cannot create new operator rather we can increase capability of the existing operators.

"Process of giving extension to the meaning of the operator is called operator overloading".

Limitations Of Operator Overloading:

1.We cannot overload following operators as a member or non member function.

a. Member selection operator. (.)
b. Pointer to member selection operator. (.*)
c. Conditional/Ternary operator. (? :)
d. Scope resolution operator. (::)
e. sizeof operator.
f. typeid operator.
g. static_cast operator.
h. dynamic_cast operator.
i. const_cast operator.
j. reinterprct_cast operator.

2.We cannot overload following operators as a non member function.

a. Assignment operator. (=)
b. Index/Subscript operator. ([])
c. Function call operator. (())
d. Dereferencing operator. (->)

3.We can change meaning of the operator with the help of operator overloading.

First we will discuss overloading by implementing operator function as a member of class.

If we want to overload binary operator using member function then operator function should take only one parameter.

If we want to overload unary operator using member function then operator function should not take any paramater.

Overloading Arithmetic Operator:

```
1.  pt3 = pt1 + pt2;        //pt3 = pt1.operator+( pt2 );
2.  pt4 = pt1 + pt2 + pt3;      //pt4 = pt1.operator+( pt2 ).operator+( pt3 );
3.  pt3 = pt1 - pt2;        //pt3 = pt1.operator-( pt2 );
4.  pt3 = pt1 * pt2;        //pt3 = pt1.operator*( pt2 );
5.  pt3 = pt1 / pt2;        //pt3 = pt1.operator/( pt2 );
6.  pt3 = pt1 % pt2;        //pt3 = pt1.operator%( pt2 );
7.  pt2 = pt1 + 5;          //pt2 = pt1.operator+( 5 );
8.  pt2 = 5 + pt1;          //Not allowed;
```

Overloading Relational Operator:

```
1.  bool result = pt1 == pt2;     //bool result = pt1.operator==( pt2 );
2.  bool result = pt1 != pt2;     //bool result = pt1.operator!=( pt2 );
3.  bool result = pt1 > pt2;      //bool result = pt1.operator>( pt2 );
4.  bool result = pt1 < pt2;      //bool result = pt1.operator<( pt2 );
5.  bool result = pt1 >= pt2;     //bool result = pt1.operator>=( pt2 );
6.  bool result = pt1 <= pt2;     //bool result = pt1.operator<=( pt2 );
```

Overloading Short Hand Operators:

```
1.  pt1 += pt2;         //pt1.operator+=( pt2 );
2.  pt1 -= pt2;         //pt1.operator-=( pt2 );
3.  pt1 *= pt2;         //pt1.operator*=( pt2 );
```

Overloading Unary Operators:

```
1.  pt2 = ++ pt1;           //pt2 = pt1.operator++( );
2.  pt2 = -- pt1;       //pt2 = pt1.operator--( );
3.  pt2 = pt1 ++;           //pt2 = pt1.operator++( 0 );
4.  pt2 = pt1 --;       //pt2 = pt1.operator--( 0 );
```

Now, we will discuss overloading by implementing operator function as a non member of class.

If we want to overload binary operator using non member function then operator function should take two parameters.

If we want to overload unary operator using non member function then operator function should take one parameter.

Overloading arithmetic operator:

1. pt3 = pt1 + pt2; //pt3 = operator+(pt1, pt2);
2. pt4 = pt1 + pt2 + pt3; //pt4 = operator+(operator+(pt1, pt2),pt3);
3. pt3 = pt1 - pt2; //pt3 = operator-(pt1, pt2);
4. pt2 = pt1 + 5; //pt2 = operator+(pt1, 5);
5. pt2 = 5 + pt1; //pt2 = operator+(5, pt1);

Overloading Relational Operator:

1. bool result = pt1 == pt2; //bool result = operator==(pt1, pt2);

Overloading Short Hand Operators:

1. pt1 += pt2; //operator+=(pt1, pt2);

Overloading Unary Operators:

1. pt2 = ++ pt1; //pt2 = operator++(pt1);
2. pt2 = -- pt1; //pt2 = operator--(pt1, 0);

There are two rules of thumb when implementing overloaded operators

1. Any operator that does not require an l-value is better implemented as non member function.
   a.Arithmetic operators
   b.Relational operators
2. Any operator that requires an l-value is better implemented as member function.
   a.Shorthand operators
   b.Increment and decrement operators
   c.Assignment,Index, Function call and dereferencing operator.

Overloading Insertion Operator (<<):

if we want to print state of an object on console then we should overload insertion operator.

```
cout<<pt1;          //operator<<( cout, pt1 );
cout<<pt1<<endl;//operator<<( cout, pt1 )<<endl;
cout<<pt1<<pt2;  //operator<<( operator<<( cout, pt1 ), pt2 )
```

If we pass object of ostream class by value then its copy constructor will call.But copy constructor of ostream class is private so it is necessary to pass and return object of ostream class by reference.

Overloading Extraction Operator(>>):

If we want to read state for an object from console then we should overload extraction operator.

```
cin>>pt1;          //operator>>( cin, pt1 );
cin>>pt1, pt2;     //operator>>( operator>>( cin, pt1 ), pt2 );
```

If we pass object of istream class by value then its copy constructor will call. But copy constructor of istream class is private so it is necessary to pass and return object of istream class by reference.

Overloading Assignment Operator:

If we initialize newly created object from existing object then copy constructor gets call.

```
Point pt2 = pt1;    //Here for pt2 object copy constructor will call.
```

If we assign existing object to another existing object then assignment operator gets call.

```
pt2 = pt1;          //Here assignment operator function gets call.
```

If we do not provide assignment operator function for the class then compiler provides one assignment operator function for that class by default. Such assignment operator function is called default assignment operator function.

Class contains following function by default:

1.default constructor
2.default destructor
3.default copy constructor
4.default assignment operator function.

Consider the assignment statement statement and its implicit call.

```
pt2 = pt1;          //pt2.operator=( pt1 );

pt3 = pt2 = pt1;    //pt3.operator=( pt2.operator=( pt1 ) );
```

We cannot overload assignment operator as non member function. Consider the following code:

```
class Point
{
private:
    ...
public:
```

```
        Point& operator=(const Point& other)
        {
                if (this == &other)
                        return *this;
                else
                {
                        this->xPosition = other.xPosition;
                        this->yPosition = other.yPosition;
                }
                return *this;
        }
};
```

In above program we have overloaded assignment operator and we have done shallow copy. If we want to do shallow copy then no need to overload assignment operator because default assignment operator do shallow copy. In case of assignment if we want to do deep copy or lazy copy then we should overload assignment operator.

Consider the following code:

```
class String
{
private:
        int length;
        char* buffer;
public:
        String& operator=(const String& other)
        {
                if (this == &other)
                        return *this;
                else
                {
                        this->~String();
                        this->length = other.length;
                        this->buffer = new char[this->length + 1];
                        strcpy(this->buffer, other.buffer);
                }
                return *this;
        }
```

```
};
```

Overloading Index/Subscript Operator:

We know that there are some disadvantages of language defined array:

1.We cannot decide size for an array at runtime.

2.The built in array type does not have any kind of subscript range checking.

3.We cannot copy arrays directly inside another array.

To avoid these limitations lets put array inside object and perform operations on object as array. Consider the following code.

```
class Array
{
private:
        int size;
        int* arr;
public:
        Array(const int size)
        {
                this->size = size;
                this->arr = new int[this->size];
        }
        int& operator[](const int index)
        {
                if (index >= 0 && index < this->_size)
                        return this->arr[index];
                throw Exception("Array index out of bounds");
        }
};
```

Now we can specify size for an array at runtime.

```
        int size = 5;
        Array a1( size );    //valid;
```

Note: When operator [] is on the left hand side of =, It must return an address(l-value) and when it is on the right side of =, it must return a value (r-value).

```
        int number = a1[ 2 ];           //int number = a1.operator[]( 2 );
```

In this case reference is act as value;

```
a1[ 2 ] = 300;                    //a1.operator[]( 2 ) = 300;
```

In this case reference is act as address.

In short, if we want to treat any object as a array then we should overload subscript or index operator. To overload index/subscript operator class should contain object of collection as a data member.

Overloading Function Call Operator:

If we treat any function as a object then it is called function object. To create function object it is necessary to overload function call operator.

```
class String
{
private:
        int length;
        char* buffer;
public:
        void operator()( const char* str )
        {
                this->~String();
                this->length = strlen(str);
                this->buffer = new char[this->length + 1];
                strcpy(this->buffer, str);
        }
};
int main(void)
{
        String str;
        str("Sandeep");     //here str is function object.
        return 0;
}
```

Overloading Dereferencing Operator:

if we want to use dot /member selection operator to access members of the class then left side oprand must be object.

e.g. pt1.print();

if we want to use arrow operator to access members of the class then left side oprand must be pointer of class.

e.g. ptr->print();

To avoid memory leakage we can use auto_ptr smart pointer. Lets write own version of auto_ptr class.

```
template< class Type >
class AutomaticPointer
{
private:
        Type* ptr;
public:
        AutomaticPointer(Type* ptr)
        {
                this->ptr = ptr;
        }
        Type* operator->(void)
        {
                return this->ptr;
        }
        ~AutomaticPointer(void)
        {
                delete ptr;
        }
};
int main(void)
{
        AutomaticPointer<Complex> autoPtr(new Complex());
        ptr->print();
        return 0;
}
```

In above code autoPtr is object which act as a pointer, so it is called smart pointer.

Nestsed class :

If we define class inside scope of another class then it is called nested class.

```
class List
{
private:
        class Node   //Nested class.
```

```
        {
            ....
        };
    private:
        Node* head;
};
```

Local class: If we define class inside scope of another function then it is called local class.

```
void f1( void )
{
    class SomeClass    //Local class.
    {
        ....
    };
}
```

Iterator is a smart pointer which is used to traverse the collection. It is a behavioral design pattern.

```
class List
{
private:
    class Iterator;        //Forward declaration
    class Node
    {
    private:
        int data;
        Node* next;
    public:
        friend class List;
        friend class Iterator;
    };
public:
    class Iterator
    {
    private:
        Node* ptrNode;
    public:
        Iterator(Node* ptrNode)
```

```
                {
                        this->ptrNode = ptrNode;
                }
                bool operator!=(Iterator& other)
                {
                        return this->ptrNode != other.ptrNode;
                }
                int operator*(void)
                {
                        return this->ptrNode->data;
                }
                void operator++(void)
                {
                        this->ptrNode = this->ptrNode->next;
                }
        };
private:
        Node* head;
        Node* tail;
public:
        Iterator begin(void)
        {
                return Iterator(this->_head);
        }
        Iterator end(void)
        {
                return Iterator(NULL);
        }
};
int main(void)
{
        List list;
        List::Iterator itrStart = list.begin();
        List::Iterator itrEnd = list.end();
        while (itrStart != itrEnd)
        {
```

```
            cout << *itrStart << endl;      //itrStart : smart pointer
            ++itrStart;
        }
        return 0;
    }
```

Conversion Function:

A member function of the class which is used to convert state of an object one type into another. In C++, there are three conversion functions:

1.Single parameter constructor.

```
int num1 = 10;
Point pt1 = num1;
```

In above statement, single parameter constructor is responsible for converting value of num1 into pt1 so single parameter constructor is also called conversion constructor.

2. Assignment Operator:

```
int num1 = 10;
Point pt1;
pt1 = num1;//pt1.operator=( Point( num1 ) );
```

In this case assignment operator is responsible for converting state of num1 into pt1 so it is called conversion function. To convert state of num1 into pt1, assignment takes help of anonymous object. If we want to keep control on anonymous object then we should declare single parameter constructor as explicit.

3. Type Conversion operator.

```
Point pt1( 10,20 );
int xPosition = pt1;//      int xPosition = pt1.operator int();
```

In this case type conversion operator (operator int( )) is responsible for converting state of pt1 into xPosition so it is called conversion function.

If "**has-a**" relationship exists between two types then we should declare object as data member.

e.g. Employee has a joinDate.

```
class Date
{
private:
    int day, month, year;
};//End of Date class
class Employee
{
private:
    string name;          //Composition
    int empid;
    float salary;
    Date joinDate;        //Composition
};//End of class Employee
```

If "**is-a**" relationship exists between two types then we should use inheritance. e.g Employee is a Person.

```
class Person                          //Parent class
{
private:
    string name;
    int age;
public:
    //TODO
};
class Employee : public Person  //Child class
{
private:
    int empid;
    float salary;
public:
    //TODO
};
```

Is-a hierarchy is also called as "**kind-of** " hierarchy.

"Journey from generalization to specialization is called as inheritance".

Inheritance is one of the most powerful concepts in object oriented software development. If the concept is clearly understood then it can be used very effectively in number of design scenarios.

```
class Person                                    //Parent / Base class
{
private:
    string name;
    int age;
public:
    Person( void ) : name(""),age(0)
    {   }
    Person( string name, int age ) : name(name),age(age)
    {   }
    void printRecord( void )
    {
        cout<<"Name :   "<<this->name<<endl;
        cout<<"Age  :   "<<this->age<<endl;
    }
};
```

Inheritance is one of the fundamental tool for code reusability. Lets consider the simple code for inheritance.

```
class Employee : public Person  //Derived / Child class
{
private:
    int empid;
    float salary;
public:
    Employee( void ) : empid( 0 ), salary( 0.0f )
    {   }
    Employee( string name, int age, int empid, float salary ) : Person( name, age ),//Ctor Base init list
            empid( empid ), salary( salary )    //Ctor member initializer list
    {   }
    void printRecord( void )
    {
        Person::printRecord();  //Call to Base class function
        cout<<"Empid    :   "<<this->empid<<endl;
        cout<<"Salary   :   "<<this->salary<<endl;
    }
};
```

In C++, parent class is called as Base class and Child class is called as Derived class. According to this concept, class Person is Base class and class Employee class is Derived class.

In inheritance, all static and non static data memebrs of base class inherits into the derived class.

If data member in base class is static then we can access it using base class name as well as derived classname but it do not get space inside object. Consider the following code:

```
class Base
{
protected:
    static int number;
public:
    void showRecord( void )
    {
        cout<<"Num1 :   "<<Base::number<<endl;
    }
};
int Base::number = 10;  //Global definition
class Derived : public Base
{
public:
    void displayRecord( void )
    {
        cout<<"Num1 :   "<<Derived::number<<endl;
    }
};
```

If data member in base class is non static then it inherits into the derived class and it gets space in derived class object.

Size of derived class object = size of all non static data members declared in base class + size of all non static data members declared in derived class.

Data members of base class inherits into the derived class hence it affects on the size of object but members of derived class do not inherit into the base class hence it do not affects on size of object.

"If we use inheritance then data members inherits into the derived class."

If we want to access data members of base in derived class and If name of base class data member and derived class data member is same then we should use class name and scope resolution operator

If name of base class data members and derived class data mebers are different then to access data members of base we can use either class name or this pointer. In general to access members of base class we should use class name. Consider the following code:

```
class Base
{
protected:
    int num1;
};
class Derived : public Base
{
private:
    int num1;
public:
    Derived( void )
    {
        Base::num1 = 10;
        this->num1 = 20;
    }
    void printRecord( void )
    {
        cout<<"Num1 :   "<<Base::num1<<endl;
        cout<<"Num1 :   "<<this->num1<<endl;
    }
};
```

Now lets consider the member function. Except few function all static and non static member function of base class inherits itnto the derived class.

Following function do not inherit into the derived class: – Imp

1. Constructor
2. Destructor
3. Copy constructor
4. Assignnment operator
5. Friend function

If we declare static member function in base class and if we want to access it in non member function then we can access it using base class as well as derived class name and scope resolution operator.

In general static data member and member function of base class inherits into the derived class.

Non static member function of base class inherits into the derived class hence using derived class object we can access non static member function of base class as well as derived class.

In general non static data member and member function of base class inherits into the derived class.

Consider the following code:

```
class Base
{
public:
    void showRecord( void )
    {   }
};
class Derived : public Base
{
public:
    void displayRecord( void )
    {   }
};
int main()
{
    Derived derived;

    derived.showRecord();    //Base::showRecord

    derived.displayRecord();    //Derived::displayRecord
    return 0;
}
```

If name of base class member function and derived class member function is same then derived class member function hides the implementation of base class member function which is inherited in derived class hence priority is always given to derived class member function. ***It is called as method hiding or shadowing.***

In this case, to access member function of base inside derived class, we should class name and scope resolution operator.

"In general, to access members of base class inside member function of derived class, we should use class name and scope resolution operator."

Applications of scope resolution operator[::]

1. To access members of namespace
2. To define member function globaly
3. To access static members
4. To access members of base class in derived class.

Consider the following code:

```
class Base
{
public:
    void printRecord( void )
    {   }
};
class Derived : public Base
{
public:
    void printRecord( void )
    {
        Base::printRecord();    //call to base class member function
        //TODO : print members of derived class.
    }
};
int main()
{
    Derived derived;

    derived.printRecord();
    return 0;
}
```

if we want to access printRecord member function of base class and derived class in non member function then we should use following syntax.

```
int main()
{
    Derived derived;

    derived.Base::printRecord();     //Call to Base class function

    derived.Derived::printRecord(); //Call to Derived class function

    return 0;
}
```

Already we have seen constructor calling sequence is depends on order of objects and destructor calling sequence is excatly opposite of constructor calling sequence.

```
class Base
{
private:
    int num1;
    int num2;
public:
    Base( void ) : num1( 0 ), num2( 0 ) //ctors member initializer list
    {   }
    Base( int num1, int num2 ) : num1( num1 ), num2( num2 ) //ctors member initializer list
    {   }
};
class Derived : public Base
{
private:
    int num3;
public:
    Derived( void ) : num3( 0 )//ctors member initializer list
    {   }
    Derived( int num1, int num2, int num3 ) :
        Base(num1, num2 ),//ctors base initializer list
        num3( num3 )//ctors member initializer list
    {   }
};
```

If we create object of derived class then first base class constructor gets called and then derived class constructor gets called. Destructor calling sequence is exactly opposite i.e. first derived class destructor gets called and then base class destructor gets called.

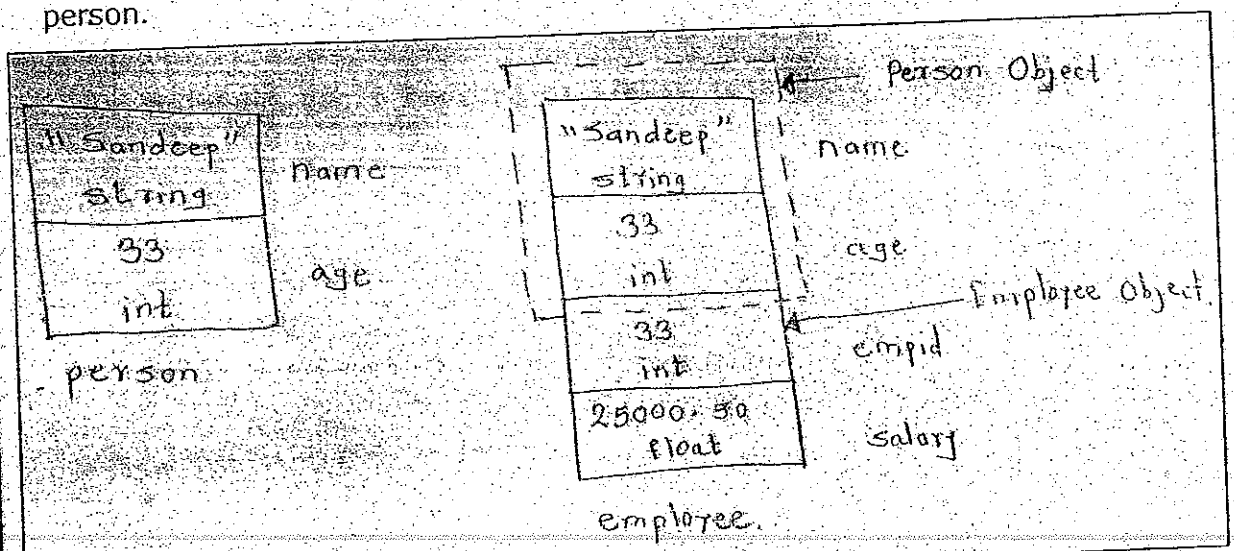
By default, from any derived class constructor(parameter less or parameterized), base class's parameter less constructor gets called. If we want to call any constructor of base class from derived class then we should use constructors base initializer list. Consider the following code:

Constructors base initializer list indicates explicit call to the constructor. As shown in above code we can use member initializer list and base initializer list together.

Constructor's member initializer list – It is used to initialize data members of same class.

Constructor's base initializer list – It is used to initialize data members of base class.

In inheritance, members of base class inherits into the derived class and hence every derived class object can be considered as base class object. e.g. Every employee is person.

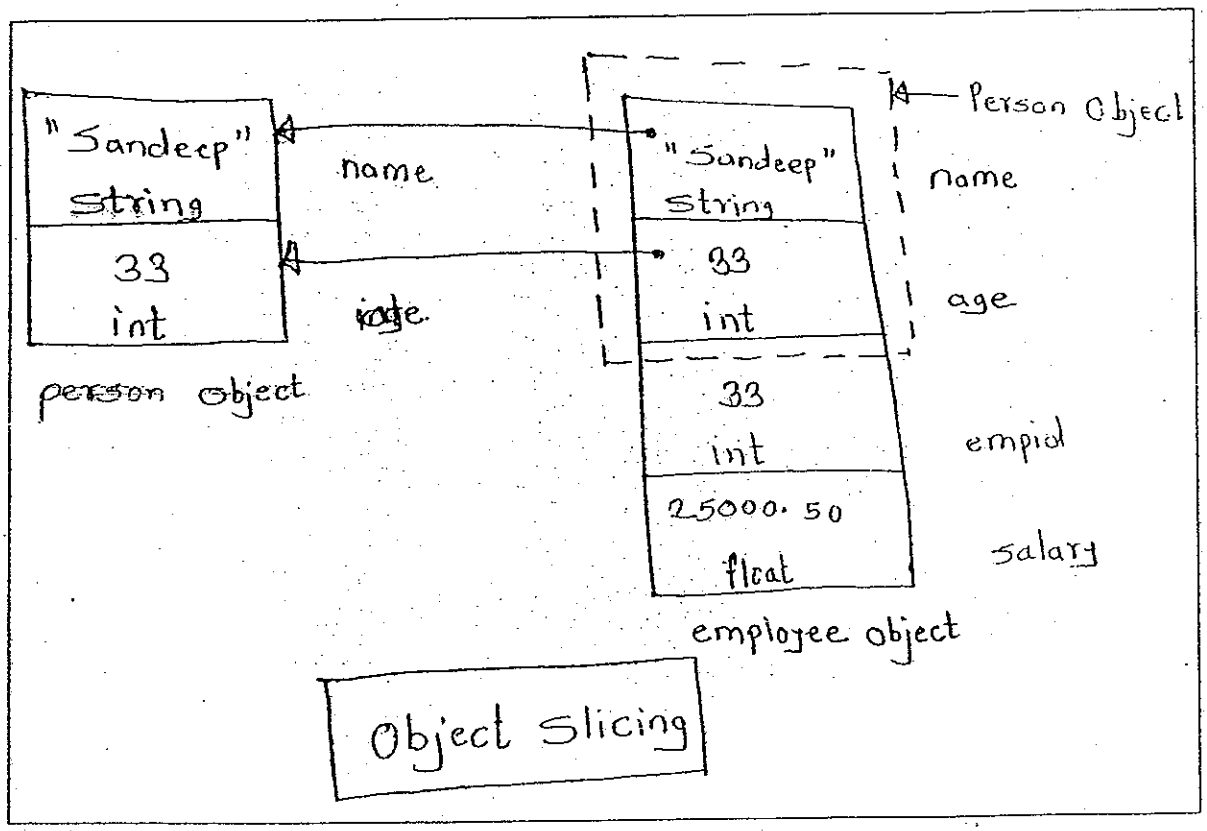


Without changing implementation of existing class, if we want extend meaning of the class then we should use inheritance. In other words, if implementation of existing class is partially complete and without modifying its implementation if we want to make it complete then we should create its derived class i.e. we should use inheritance.

In inheritance, members of base class inherits into the derived class hence every derived class object can be considered as base class object. Since every derived class object can be treated as base class object, we can assign derived class object to the base class object

```
Person p1("Sandeep",33);
Person p2 = p1;                    //OK

Employee emp1("Sandeep Kulange",33,33,25000.50f);
Employee emp2 = emp1;              //OK

Employee employee("Sandeep Kulange",33,33,25000.50f);
Person person = employee;          // Object Slicing
```

Object Slicing

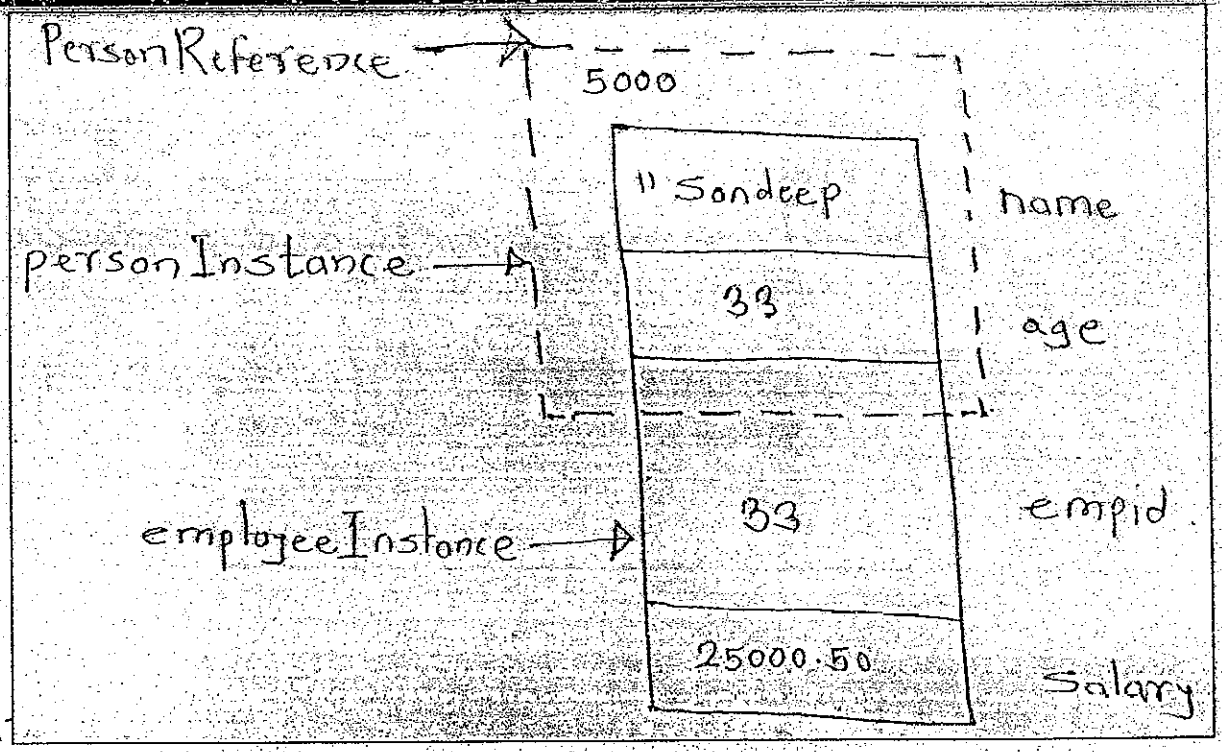


If we try to assign derived class object to the base class object, then compiler copies only values of base class members from derived object into base class object. Such process is called **object slicing**.

By declaring base class as a abstract, we can avoid object slicing.

Let us see object slicing in case of reference.

```
Employee employeeInstance("Sandeep",33,33,25000.50f);
Person&personReference= employeeInstance;
```



as shown in above code, personReference is an alias for the person instance exist inside employeeInstance. It is a form of object slicing.

Friend function do not inherit into the derived class.Lets see, how object slicing help us to overload insertion and extraction operator in inheritance.

```
class Person
{
private:
    string name;
    int age;
public:
    Person( void ) : name( " " ), age( 0 )
    {   }
    friend istream& operator>>( istream& cin, Person& other )
    {
        cout<<"Name      :       ";
        cin>>other.name;
        cout<<"Age       :       ";
        cin>>other.age;
        return cin;
    }
    friend ostream& operator<<( ostream& cout, const Person& other )
    {
        cout<<other.name<<"     "<<other.age<<" ";
        return cout;
    }
};
```

```
class Employee : public Person
{
private:
    int empid;
    float salary;
public:
    Employee( void ) : empid( 0 ), salary( 0 )
    {   }
    friend istream& operator>>( istream& cin, Employee& other )
    {
        Person& personRef = (Person&)( other );
        cin>>personRef;          //operator>>( cin, personRef );
        cout<<"Empid    :        ";
        cin>>other.empid;
        cout<<"Salary   :        ";
        cin>>other.salary;
        return cin;
    }
    friend ostream& operator<<( ostream& cout, const Employee& other )
    {
        const Person& personRef = (Person&)( other );
        cout<<personRef;         //operator<<( cout, personRef );
        cout<<other.empid<<"     "<<other.salary<<"       ";
        return cout;
    }
};
```

Consider the following code:

```
class Employee : public Person
```

We can read above statement using two ways.

1. class Person is inherited into class Employee or
2. class Employee is derived from class Person.[**Recommended**]

Direct & indirect base class and derived class :

```
class Person
{       };
class Employee : public Person
{       };
class Manager : public Employee
{       };
```

as shown in above code, class Employee is **direct** and class Person is **indirect** base class of class Manager.

Class Employee is **direct** and class Manager is **indirect** derived class of class Person.

Mode of Inheritance:

If we use private public and protected keywords to extend the class then it is called as mode of inheritance.

```
class Employee : public Person
```

Here mode of inheritance is public.

C++ supports three types of mode:

1. private mode of inheritance.[**Default mode of inheritance**]
2. protected mode of inheritance
3. public mode of inheritance

Public mode of inheritance :if "is-a" hierarchy or relationship exists between two types then we should use public mode of inheritance. e.g. rectangle is-a shape or circle is-a shape.

```
class Shape
{       };
class Rectangle : public Shape
{       };
class Circle : public Shape
{       };
```

Public mode of inheritance

	Same class	Derived class	Indirect derived class	Non-member function
Private	A	NA	NA	NA
Protected	A	A	A	NA
Public	A	A	A	A

Note : A – Accessible NA – Not Accessible

Private mode of inheritance: If "has-a" hierarchy / relationship is exist between two types then either we should use composition or private mode of inheritance.

It is default mode of inheritance in C++. Consider the following code.

```
class Date
{
    //TODO
};
class Employee : Date        //Here Default mode is private
{
    //TODO
};
```

Private mode of inheritance				
	Same class	**Derived class**	**Indirect derived class**	**Non member function**
Private	A	NA	NA	NA
Protected	A	A	NA	NA
Public	A	A	NA	A using Base Object
				NA using Derived Object

Note : *In case of has-a relationship, generally we should use composition.*

Protected mode of inheritance: It is rarely used. It is only used when you want to polymorphism to work only within the derived class but not for others. In case of public inheritance, an object of derived class can be used in place of object of base class by any client. With protected mode of inheritance, the conversion from derived to base will be allowed only within the methods of derived class.

Protected mode of inheritance

	Same class	Derived class	Indirect derived class	Non member function
Private	A	NA	NA	NA
Protected	A	A	A	NA
Public	A	A	A	A using Base Object
				NA using Derived Object

Any kind of mode, we can access private members inside declared class only. If we want to access private members in derived class then either we should use member function or we should declared derived class as a friend inside base classs.

Suppose B and C are derived from class A. We want to access members of class A in class B but not in C. Consider the following code :

```
class A
{
private:
    int num1;
public:
    A( void ) : num1( 10 )
    {   }
    friend class B;
};
class B : public A
{
private:
    int num2;
public:
    B( void ) : num2( 20 )
    {   }
    void print( void )
    {
        cout<<this->num1<<"     "<<this->num2<<endl;
    }
};
```

```
class C : public A
{
private:
    int num3;
public:
    C( void ) : num3( 30 )
    {   }
    void print( void )
    {
        cout<<this->num1<<"     "<<this->num3<<endl;     //Error
    }
};
```

class B is declared as friend in class A but Class C is not declared as friend in class A. Hence members of A are accessible in class B but not in class C

Types of inheritance

Inheritance can be classified as either ***implementation inheritance*** and***interface inheritance.*** Under these catogories following are the types of inheritance.[We will discuss implementation and interface inheritance later.]

1. Single inheritance
2. Multiple inheritance
3. Hierarchical inheritance
4. Multilevel inheritance.

Let us discuss each type in detail.

1. Single Inheritance :

e.g.class B is derived from class A.

Syntax :

```
class A                              //Base class
{     };
class Derived : public Base          //Derived class
{     };
```

If single base class is having single derived class then such inheritance is called single inheritance.

2. Multiple Inheritance :

e.g. class D is derived from class A,B and C.

Syntax:

```
class A{      };
class B{      };
class C{      }
class D : public A,publicB,public C
{     };
```

If multiple Base classes are having single derived class then such inheritance is called multiple inheritance.

3. Hierarchical inheritance :

e.g.class B, C and D are derived from class A.

Syntax :

```
class A
{      };
class B : public A
{      };
class C: public A
{      };
class D: public A
{      };
```

If single base class is having multiple derived classes then such inheritance is called hierarchical inheritance.

4. Multilevel inheritance :

e.g. class B is derived from class A, class C is derived from class B and class D is derived from class C.

Syntax :

```
class A{      };
class B : public A
{      };
class C : public B
{      };
class D : public C
```

If single inheritance is having number of levels then it is called multilevel inheritance.

Hybrid inheritance: In C++ we can combine any two or more than two types of inheritance.

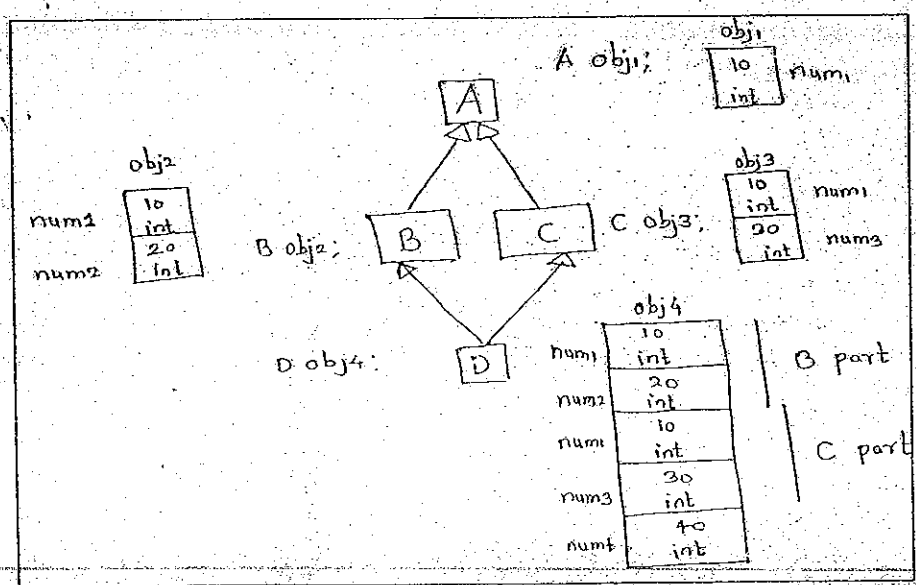
e.g. class istream&ostream are derived from class ios and class iostream is derived from class istream and ostream.

Syntax:

```
classios{     };
classistream : public ios
{     };
classostream : public ios
{     };
classiostream : public istream, public ostream
{     };
```

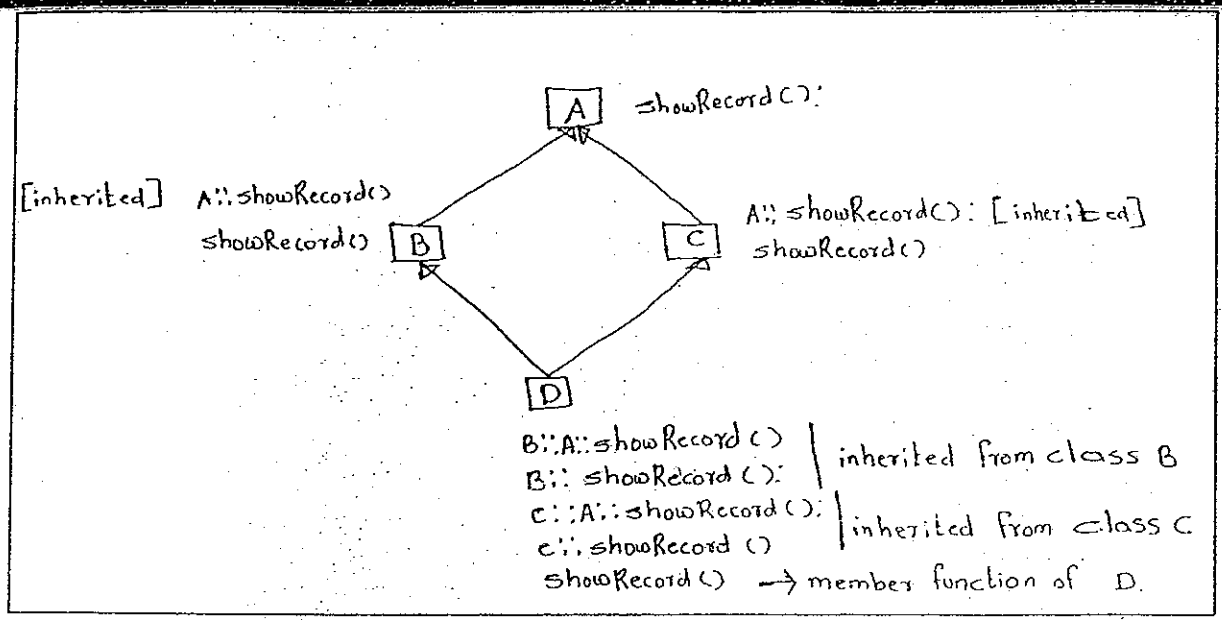
Combination of any two or more than two types of inheritance is called hybrid inheritance.

Diamond problem : suppose class B & C are derived from class A and class D is derived from class B & C. It is hybrid inheritance[Lets say it is diamond inheritance].



numz, num2,num3 and num4 are data members of class A, B, C and D respectivly.

ShowRecord() is member function declared in A,B,C as well as D class.



If we create instance of D class then constructor and destructor calling sequence is as follows:

Ctor calling sequence is : A --> B -->A -->C---> D

Dtor calling sequence is : D --> C -->A -->B---> A

i.e. constructor and destructor of class A will be call muliple times.

Lets list out the problems faced with diamond inheritace

1. datamemebrs of indirect base class inherits into the indirect derived class multiple times, hence it affects on size of object.
2. Member functions of indirect base class inherits into the indirect derived class multiple times,hence using instance of indirect derived class, if we try to access it then compiler generates ambiguity error.
3. Constructor and destructor of indirect derived class gets called multiple times.

All such problems created by hybrid inheritance is called diamond problem.

Solution of diamond problem

To overcome diamond problem we should declare base class[**class A**] as a virtual.

i.e.

```
class A
{       };

class B : virtual public A
{       };

class C : virtual public A
{       };

class D : public B, public C
{       };
```

as shown in above code, we should derive class B and class C from class A virtually. type of inheritance is called virtual inheritance.

```
class B : virtual public A      //Virtual inheritance


class C : virtual public A      //Virtual inheritance
```

If we declare base class [**A**]as virtual then members of A will be inherited into class C.if we derived class D from B and C then memebrs of A will not inherit from class B rather only non inherited members of B and C will be inherited into D. Then what members of class A?

. Members of class A will be inherited into class D directcly.

Runtime Polymorphism

```
class Base
{
private:
    int num1;
    int num2;
public:
    Base( void ) : num1( 10 ), num2( 20 )
    {       }
    Base( int num1, int num2 ) : num1( num1 ), num2( num2 )
    {       }
    void showRecord( void )
    {
        cout<<"Num1 :       "<<this->num1<<endl;
        cout<<"Num2 :       "<<this->num2<<endl;
    }
    void printRecord( void )
    {
        this->showRecord();
    }
};
```

```
class Derived : public Base
{
private:
    int num3;
public:
    Derived( void ) : num3( 30 )
    {       }
    Derived( int num1, int num2, int num3 ) : Base( num1, num2 ), num3( num3 )
    {       }
    void printRecord( void )
    {
        Base::showRecord();
        cout<<"Num3 :       "<<this->num3<<endl;
    }
    void displayRecord( void )
    {
        this->printRecord();
    }
};
```

Lets revise all the concepts using above program.

```
1. Base* ptr = new Base();

ptr->showRecord();

ptr->printRecord();

ptr->Derived::printRecord();

ptr->displayRecord();

delete ptr.
```

```
3.Derived derived( 500,600,700);
 Base base;
 base = derived;
 base.printRecord();

  ptr->displayRecord();
  delete ptr


4.Base base( 500, 600 );
  Derived derived;
  derived = base;
  derived.printRecord();

5.Derived* ptrDerived = new Derived( );
 ptrDerived->printRecord();
 Base* ptrBase = ( Base* )ptrDerived;
 ptrBase->printRecord();


6.Base* ptrBase = new Derived( );
 ptrBase->printRecord();
```

```
7.Derived derivedInstance( 500,600, 700);
  Derived& derivedReference = derivedInstance;
  Base& baseReference = ( Base& )derivedReference;
  baseReference.printRecord();

8.Base* ptrBase = new Derived( );
  ptrBase->printRecord();
  Derived* ptrDerived = ( Derived* ) ptrBase;
  ptrDerived->printRecord();
```

Virtual function

If we want to write geeric program or maintainable program then we should use upcasting. In case of upcasting , function gets called depending on type of pointer.If we want to call function depending on type of object rather than type of pointer then we should declare function in base class as a virtual.

In case of upcasting, if we want to call function of derived class then we should declare function in base class as virtual.

What is virtual function?

A member function of a class, which gets called depending on type of object rather than type of pointer is called virtual function.

In other words, member function of derived class which is designed to call using reference or pointer of base class is called virtual function.

According to the definition of virtual function, it is designed to call using either pointer or reference of base class only. Virtual functions are not designed to call using object.

Virtual member functions are designed to call using base class pointer or reference only. Static member functions are designed to call using class name only. Since static member functions are not designed to call using pointer or reference, we can not declare static member function as virtual.

If class contains at least one virtual function then such class is considered as polymorphic class. If signature of base class and derived class member function is same and if function in base class is virtual then derived class function is by default considered as virtual, hence it is optional to use virtual keyword with member function in derived class. In short, if base class is polymorphic then every derived class is considered as polymorphic.

```
class Product
{
private:
    string name;
    float price;
public:
    virtual void acceptRecord( void )   {       }
    virtual void printRecord( void )    {       }
};
class Book : public Product
{
private:
    int pageCount;
public:
    void acceptRecord( void )   {       }
    void printRecord( void )    {       }
};
class Tape : public Product
{
private:
    int playTime;
public:
    void acceptRecord( void )   {       }
    void printRecord( void )    {       }
};
```

Process of re-implementing virtual function of base class inside derived class with same signature is called function overriding. For function overriding signature of base class and derived class function must be same and function in base class must be virtual.

Constructor and destructor do not inherit into the derived class, hence we can not override it. Since, static member function can not be declared as virtual, we can not override it in derived class.

If we give call to the virtual function using pointer or reference then it is considered as late binding.

If we give call to the non-virtual function using pointer or reference then it is considered as early binding.

If we give call to any virtual or non-virtual function using object then it is considered as early binding.

Consider the following program.

```
int menu_list( void )
{
    int choice;
    cout<<"0.Exit"<<endl;
    cout<<"1.Book"<<endl;
    cout<<"2.Tape"<<endl;
    cout<<"Enter choice      :        ";
    cin>>choice;
    return choice;
}
```

```
int main( void )
{
    int choice;
    while(( choice = menu_list( ) ) != 0 )
    {
        Product* ptrProduct = NULL;
        switch( choice )
        {
        case 1:
            ptrProduct = new Book();
            break;
        case 2:
            ptrProduct = new Tape();
            break;
        }
        if( ptrProduct != NULL )
        {
            ptrProduct->acceptRecord();
            ptrProduct->printRecord();
        }
    }       return 0;
}
```

Early binding and late binding:

Consider the following program and decide whether it is early binding or late binding.

```
class Base
{
public:
    virtual void F1( void ){    }
    virtual void F2( void ){    }
    virtual void F3( void ){    }
    void F4( void ){    }
    void F5( void ){    }
};
class Derived : public Base
{
public:
    virtual void F1( void ){    }
    void F2( void ){    }
    void F4( void ){    }
    virtual void F5( void ){    }
    virtual void F6( void ){    }
};
```

1. Basebase;

Base.F1();

base.F2();

base.F3();

base.F4();

base.F5();

base.F6();

2.Base* ptrBase = newBase();

ptrBase->F1();

ptrBase->F2();

ptrBase->F3();

ptrBase->F4();

ptrBase->F5();

ptrBase->F6();

3.Base* ptrBase = **new**Derived();

ptrBase->F1();

ptrBase->F2();

ptrBase->F3();

ptrBase->F4();

ptrBase->F5();

ptrBase->F6();

4.Derived* ptrDerived = **new**Derived();

ptrDerived->F1();

ptrDerived->F2();

ptrDerived->F3();

ptrDerived->F4();

ptrDerived->F5();

ptrDerived->F6();

Algorithm to decide early binding and late binding

```
//Check Data Type of caller[ Base class or Derived class]
if( function is not exist in called Data type )
{
        Compiler error : Function is not a member of caller data type
}
else    //if Function is exist
{
        //Check Type of caller[ Object, poinyter or reference ]
        if( caller is object )
                Early binding : Caller type [ if not exist then inherited ] function will call.
        else    //If caller is pointer or reference
        {
                //Check type of function[ virtual or non virtual ]
                if( function is non virtual )
                        Early binding : Caller type [ if not exist then inherited ] function will call.
                else
                        Late binding : Object type [ if not exist then inherited ] function will call.
        }

}
```

Virtual function pointer and table

If class contains virtual function(s) then compiler implicitly creates a table which stores address of virtual function(s) declared inside the class. Such table is called virtual function table or vf-table or v-table.

In short, a table which stores address of virtual function declared inside class is called v-table.

To store address of virtual function table, compiler adds one hidden pointer as data member inside class. It is called virtual function pointer or vf-pointer or v-ptr.

In short, a pointer which stores address of v-table is called virtual function pointer.

If class contains virtual function then v-ptr gets added inside the class and hence size of the object gets increased.

V-table and v-ptr inherits into the derived class.In C++, if we create object of a class then constructor gets called. i.e constructor is not designed to call depending on type of pointer.

Virtual functions are designed to call using pointers. Since constructors are not desigend to call using pointer, we cannot declare constructor as virtual.

Initializing v-ptr, i.e storing address of v-table into v-ptr is a job of constructor. i.e virtual functions can execute their body after calling constructor. Hence we cannot declare constructor as a virtual.

We cannot declare constructor as virtual but we can declare destructor as a virtual.

In case of upcasting, to call derived class destructor first, it is necessary to declare destructor in base class as a virtual.

Consider the following code:

```
class Base
{
    int* ptr1;
public:
    Base( void ) : ptr1( new int[ 3 ] )
    {   }
    virtual ~Base( void )
    {
        delete this->ptr1;
    }
};
class Derived : public Base
{
    int* ptr2;
public:
    Derived( void ) : ptr2( new int[ 5 ] )
    {   }
    ~Derived( void )
    {
        delete this->ptr2;
    }
};
```

Only in case of inheritance, we need to declare function in base class as a virtual. In C++, every class is not designed for inheritance, hence function or destructor is not virtual by default.

Difference between function overloading and overriding.

Function Overloading	**Function Overriding**
Compile time polymorphism is achieved using function overloading.	Run time polymorphism is achieved using function overriding.
In this case function signature should not be same	In this case function signature must be same.
No keyword is required.	Function in base class must be virtual.
Return type is not considered.	Return type is considered
Implementation is based on mangled name.	Implementation is based on v-table.
It doesn't affect on size of object.	It affects on size of object.
Fuctions must be exist in same scope	Functions must be exist in base and derived class.

RTTI

RTTI and**advanced type casting** operators are features of advanced C++, but now it is considered as part of standard C++.

Header File Name : typeinfo

```
namespace std
{
      class type_info
      {
      protected:
          const char *__name;
      private:
              type_info(const type_info& other);     //Copy Constructor
              type_info& operator=(const type_info& other);
      public:
              const char* name() const; // Returns string
              bool operator==(const type_info& other) const;
              bool operator!=(const type_info& other) const;
              virtual ~type_info();
       };//End of type_info class

}//end of namespace
```

As shown in above code **type_info** is *class* which is declared in **std***namespace* and std namespace is declared in **typeinfo** *header file*.

If copy constructor or assignment operator function is private then we cannot create copy of the object inside non member function.

If we want to find out name of type of object at runtime, then we should use **typeid** operator.

typeid operator returns reference of type_info object which is constant object.

As shown in type_info class, copy constructor and assignment operator function of type_info class is private, hence we can not create copy of type_info class object in our program. To avoid copy operation we should use reference. Consider the following code.

```
#include<typeinfo>  //For type_info
#include<string>
using namespace std;

int main( void )
{
    int number = 10;

    const type_info& typeReference = typeid( number );

    string typeName = typeReference.name(); //int

    return 0;
}
```

As shown in above code, **name( )** is a non static method of type_info class, which returns name of type of object.

"This process of getting type of object object at runtime is called **RTTI**".

RTTI is not designed for simple types, It is designed for polymorphic type.

If we want to use name() method only once then we can use following way:

```
int number = 10;

cout<<"Type :   "<<typeid(number).name()<<endl;
```

RTTI is not designed to find out typename of simple objects, it is designed to work with polymorphic types.

In case of upcasting, if we want to find out information about true type of object, then we should use RTTI.

Consider following code:

```
class Base  //Non Polymorphic
{
public:
    void printRecord( void )
    {   }
};//End of Base class

class Derived : public Base
{
public:
    void printRecord( void )
    {   }
};//End of Derived class
```

Let us use RTTI with Base class pointer and object

```
Base* ptrBase = new Base( );

//On Linux
cout<< typeid( ptrBase ).name()<<endl;  //P4Base
//On Windows
cout<< typeid( ptrBase ).name()<<endl;  //class Base*

//On Linux
cout<< typeid( *ptrBase ).name()<<endl; //4Base
//On Windows
cout<< typeid( *ptrBase ).name()<<endl; //class Base
```

Let us use the RTTI with Derived class pointer and object.

```
Derived* ptrDerived = new Derived( );

//On Linux
cout<< typeid( ptrDerived ).name()<<endl;   //P7Derived
//On Windows
cout<< typeid( ptrDerived ).name()<<endl;   //class Derived*

//On Linux
cout<< typeid( *ptrDerived ).name()<<endl;  //7Derived
//On Windows
cout<< typeid( *ptrDerived ).name()<<endl;  //class Derived
```

Let us use the RTTI with upcasting

```
Base* ptrBase = new Derived( ); //Upcasting

//On Linux
cout<< typeid( ptrBase ).name()<<endl;  //P4Base
//On Windows
cout<< typeid( ptrBase ).name()<<endl;  //class Base*

//On Linux
cout<< typeid( *ptrBase ).name()<<endl; //4Base
//On Windows
cout<< typeid( *ptrBase ).name()<<endl; //class Base
```

If you observe above code carefully then you will realize that type of object is Derived but it is showing Base.

In case of upcasting if we want to find out true type of object then base class must be polymorphic i.e. we should declare at least one function as virtual or pure virtual.

Let's declare base class as a polymorphic.

```
class Base  //Polymorphic
{
public:
    virtual void printRecord( void )
    {   }
    virtual ~Base( void )
    {   }
};//End of Base class

class Derived : public Base
{
public:
    void printRecord( void )
    {   }
};//End of Derived class
```

If base class is polymorphic then all its derived classes are considered as polymorphic. Now let's use RTTI with upcasting.

```
Base* ptrBase = new Derived( ); //Upcasting

//On Linux
cout<< typeid( ptrBase ).name()<<endl;  //P4Base
//On Windows
cout<< typeid( ptrBase ).name()<<endl;  //class Base*

//On Linux
cout<< typeid( *ptrBase ).name()<<endl; //7Derived
//On Windows
cout<< typeid( *ptrBase ).name()<<endl; //class Derived
```

Using NULL pointer, If we try to find out true type of object then C++ runtime throws **bad_typeid** exception. Let us see following code:

```
try
{
    Base* ptrBase = NULL;

    cout<< typeid( ptrBase ).name()<<endl;  //P4Base

    cout<< typeid( *ptrBase ).name()<<endl; //throws exception
}
catch (bad_typeid& e)
{
    cout<<e.what()<<endl;   //std::bad_typeid
}
```

1. **reinterpret_cast :**

   It is used to convert pointer of any type into pointer of any other type. In other words, if you want to do type conversion between incompatible types then we should use reinterpret_cast operator.

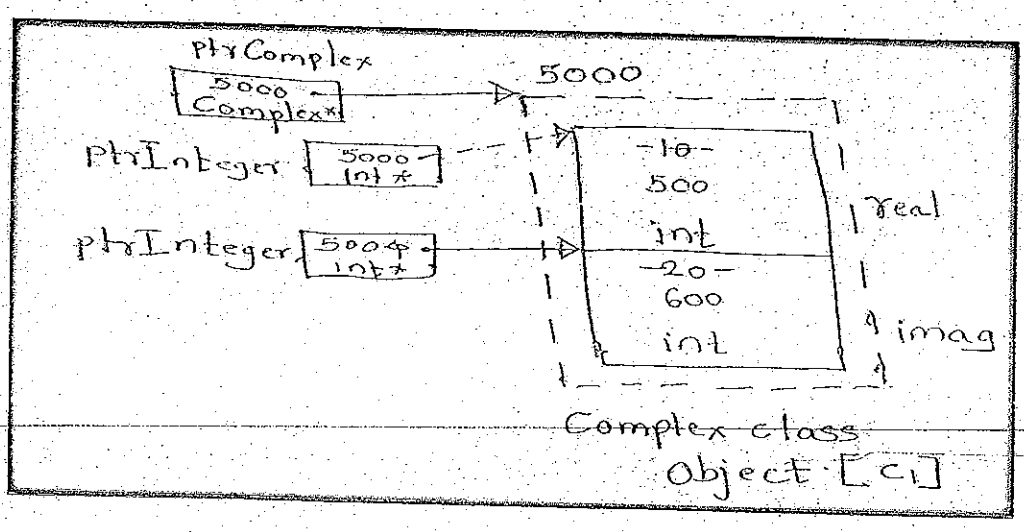
```
Syntax -- reinterpret_cast< type-id >( expression )
```

In C++, if we want to access state of private datamembers outside the class then we can use any one of the following feature:

i. Member function
ii. Friend function
iii. Pointer

Let's see how to use pointer to access state of private members outside the class.

```
Complex c1;
cout<<c1;   //10, 20

Complex* ptrComplex = &c1;
//int* ptrInteger = (int*)ptrComplex;   //Old C Style
int* ptrInteger = reinterpret_cast<int*>( ptrComplex );

*ptrInteger = 500;
ptrInteger = ptrInteger + 1;
*ptrInteger = 600;

cout<<c1;   //500, 600
```



Consider another example:

```
ofstream out;
out.open("Employee.data", ios::out | ios::binary );
if( out.is_open())
{
    Employee emp("Sandeep Kulange",33,25000.50f);
    out.write(reinterpret_cast<const char*>( &emp ) , sizeof( Employee ) );
}
else
    cerr<<"File io error"<<endl;
```

In above code we are trying to convert Employee pointer into character pointer(string).

2. **const_cast** :

If we want to convert pointer to constant object into pointer to non-constant object or reference to constant object into reference to non-constant object then we should use const_cast operator.

```
Syntax -- const_cast< type-id >( expression )
```

Lets revise some points

- Using non constant, object we can access constant as well as non constant memebr function of the class.
- Using constant object, we can access only constant member functions of the class.
- If type of this pointer is (**ClassName* const this**) then inside member function we can modify state of the current object.
- If type of this pointer is (**const ClassName* const this**) then inside member function we can not modify state of the current object.
- If we declare member function as const then it gets this pointer (**const ClassName* const this**) like this.
- Inside non constant member function we can access constant as well as non constant member functions of the class
- Inside constant member function we can access only constant member functions of the class.

Casting Operator

If we want to access non constant member function inside constant member function then we should use following technique:

```
class Test
{
public:
        void showRecord( /* Test* const this */ )
        {
                cout<<"Inside showRecord"<<endl;
        }
        void printRecord( /* const Test* const this */ )const
        {
                //this ->showRecord();   //Not Allowed
                //Test* const ptr = (Test* const)this;  //Old C Style
                Test* const ptr = const_cast<Test* const>(this);        //New Way
                ptr->showRecord();
        }
};
int main()
{
        const Test t;
        t.printRecord();
        return 0;
}
```

static_cast :

If we want to do type conversion between compatible types then we should use static_cast operator.

Consider the following code:

```
double num1 = 10.5;

//int num2 = ( int )num1;    //Old C Style

int num2 = static_cast<int>( num1 );     //New Way

cout<<"Num2 :    "<<num2<<endl;  //10
```

```
class Base
{
private:
    int num1;
    int num2;
public:
    void setNum1(int num1)
    {
        this->num1 = num1;
    }
    void setNum2(int num2)
    {
        this->num2 = num2;
    }
    void printRecord( void )
    {
        cout<<"Num1 :   "<<this->num1<<endl;
        cout<<"Num2 :   "<<this->num2<<endl;
    }
};
```

It is mainly designed to do downcasting.

"In case of non polymorphic type, if we want to do downcasting then we should use static_cast operator."

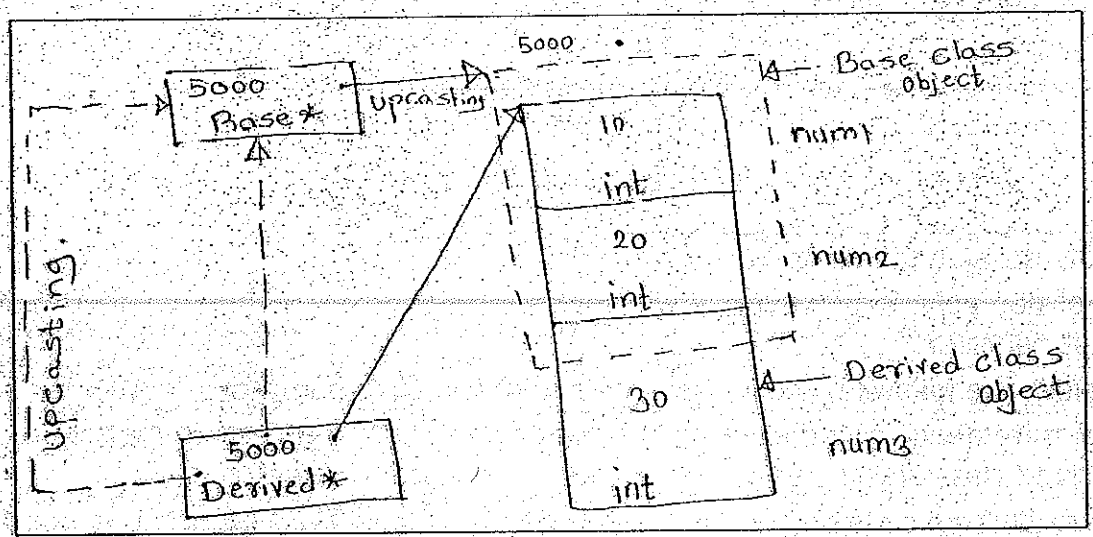
Lets consider the following code to understand static_cast operator.

In case of Inheritance, members of base class inherits into the derived class hence every derived class object can be considered as base class object.

Since every derived class object can be considered as base class object, it is possible to store address of derived class object into base class pointer.

```
class  Derived : public Base
{
private:
    int num3;
public:
    void setNum3( int num3 )
    {
        this->num3 = num3;
    }
    void printRecord( void )
    {
        Base::printRecord();
        cout<<"Num3 :   "<<this->num3<<endl;
    }
};
```

```
Derived* ptrDerived = new Derived();
ptrDerived->setNum3(30);

//Base* ptrBase = ( Base* ) ptrDerived; //Upcasting
Base* ptrBase = ptrDerived; //Explicit typecasting is optional

ptrBase->setNum1(10);
ptrBase->setNum2(20);

ptrDerived->printRecord();
```



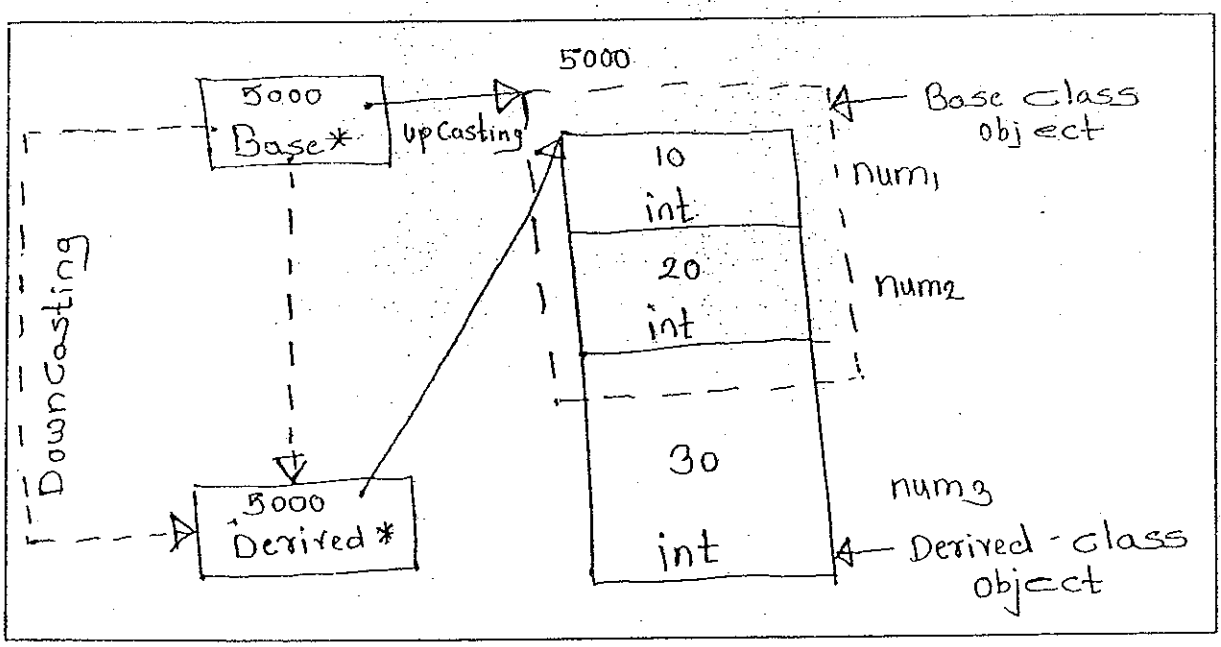
As shown in above diagram, process of converting pointer of derived class into pointer of base class is called as **upcasting**.

If we convert reference of derived class object into reference of base class then also it is called as **upcasting**.

```
Derived derivedInstance;

Derived& derivedReference = derivedInstance;

Base& baseReference = derivedReference; //Upcasting using reference
```

In case upcasting, using base class pointer or reference we can access only members of base class. In this case if we want to access data members or member function of derived class which is not exist in base class then we should do downcasting.

```
Base* ptrBase = new Derived();

ptrBase->setNum1(10);
ptrBase->setNum2(20);

Derived* ptrDerived = static_cast<Derived*>( ptrBase ); //Downcasting

ptrDerived->setNum3(30);

ptrDerived->printRecord();
```



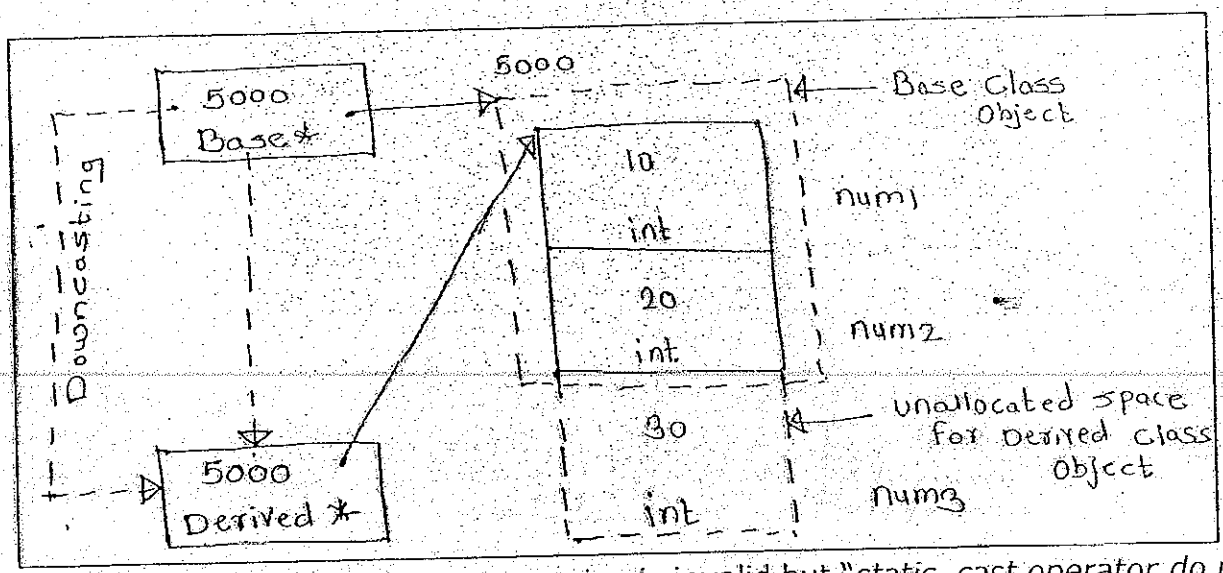
Since base class is non polymorphic we have used static_cast operator.

Since members of derived class do not inherit into the base class, every base class object can not be considered as derived class object.

e.g. Every rectangle is a shape but every shape is not a rectangle.

If base class object can not be considered as derived class object then it is not possible to store address of base class object into derived class pointer.

```
Base* ptrBase = new Base();

ptrBase->setNum1(10);
ptrBase->setNum2(20);

Derived* ptrDerived = static_cast<Derived*>( ptrBase ); //Downcasting

ptrDerived->setNum3(30);

ptrDerived->printRecord();
```



According to the concept, above conversion is invalid but "*static_cast operator do not check wheather type conversion is valid or not. It only checks inheritance relationship between source and destination type*".

Points to remember:

- To do type conversion between numeric types we should use static_cast operator.
- In case of non polymorphic type, to do downcasting, we should use static_cast operator.
- static_cast operator checks inheritance relationship at compile time.
- It do not check wheather type conversion is valid or not.

3. **dynamic_cast** :

Casting Operator

During type conversion if we want to check both i.e. inheritance relationship and type

```
class Base  //Now Base class is polymorphic class
{
private:
    int num1;
    int num2;
public:
    void setNum1(int num1)
    {
        this->num1 = num1;
    }
    void setNum2(int num2)
    {
        this->num2 = num2;
    }
    virtual void printRecord( void )
    {
        cout<<"Num1 :    "<<this->num1<<endl;
        cout<<"Num2 :    "<<this->num2<<endl;
    }
};
```

conversion is valid or not then we should use dynamic_cast operator.

To use dynamic_cast operator base class must be polymorphic i.e. base must contain at least on virtual function.In other words, "*in case of polymorphic type, if we want to*

```
class  Derived : public Base
{
private:
    int num3;
public:
    void setNum3( int num3 )
    {
        this->num3 = num3;
    }
    void printRecord( void )
    {
        Base::printRecord();
        cout<<"Num3 :    "<<this->num3<<endl;
    }
};
```

do downcasting then we should use dynamic_cast operator".

```
Base* ptrBase = new Base();

ptrBase->setNum1(10);
ptrBase->setNum2(20);

Derived* ptrDerived = dynamic_cast<Derived*>( ptrBase ); //Downcasting
if( ptrDerived != NULL )
{
    ptrDerived->setNum3(30);
    ptrDerived->printRecord();
}
else
    cout<<"NULL Pointer"<<endl;
//Output : NULL Pointer
```

```
try
{
    Base baseInstance;
    Base& baseReference = baseInstance;
    Derived& derivedReference = dynamic_cast<Derived&>(baseReference);//throws bad_alloc
    derivedReference.printRecord();
}
catch (exception& ex)
{
    cout<<ex.what()<<endl;
}
//Output : std::bad_cast
```

In case of pointer if dynamic_cast operator fail to do type conversion then it returns **NULL**.

Every base class object cannot be considered as derived class object therefore we cannot store address of base class object into derived class pointer. Hence in above code dynamic_cast operator returns NULL.

As shown in above code, in case of reference, If dynamic_cast operator fail to do type conversion then it throws **bad_cast** exception.

We should always remember that, in case of only upcasting there might be chances to do downcasting. In rest of the condition downcasting may fail.

dynamic_cast operator implicitlu use RTTI(typeid) to verify type conversion.

In following code, now there is no harm. After downcasting derived class pointer can store address of derived class object only.

```
Base* ptrBase = new Derived();  //Upcasting.

ptrBase->setNum1(10);
ptrBase->setNum2(20);

Derived* ptrDerived = dynamic_cast<Derived*>( ptrBase ); //Downcasting
if( ptrDerived != NULL )
{
    ptrDerived->setNum3(30);
    ptrBase->printRecord(); //late binding
}

else
    cout<<"NULL Pointer"<<endl;
//Output : 10, 20, 30
```

Points to remember:

- In case of polymorphic type, to do downcasting, we should use dynamic_cast operator.
- dynamic_cast operator checks inheritance relationship at run time.
- During type conversion, it checks wheather conversion is valid or not.
- In case of pointer if dynamic_cast operator fail to do type conversion then it returns NULL.
- In case of reference if dynamic_cast operator fail to do type conversion then it throws bad_cast exception.

Abstract Class

If implementation of base class is partially complete and without changing its implementation, if we want to add new functionality in it then we should create its derived class.

If implementation of base class member function is partially complete then we should declare function in base class as virtual and to provide complete implementation we should override it in derived class. Consider the following example.

```
class Object
{
public:
    virtual string toString()
    {
        string typeName = typeid( *this ).name();
        return typeName;
    }
    virtual ~Object( void ){    }
};
class Complex : public Object
{
private:
    int real, imag;
public:
    Complex( void ) : real( 10 ), imag ( 20 )
    {    }
    virtual string toString()    //Overriding method here
    {
        char text[ 50 ];
        sprintf(text,"[Real = %d , Imag = %d]",this->real,this->imag);
        return string(text);
    }
};
```

As shown in above code, if we do not override toString member function in derived class then it will return fully qualified name of the class. We want to return state of Complex class object in string format hence it is necessary to override toString in Complex class.

If implementation of base class member function is logically totally unknown/incomplete in base class then we can declare such member function as pure virtual and to provide complete implementation we should override it in derived class.

Abstract Class

```
class Shape
{
protected:
    float area;
public:
    Shape( void ) : area( 0 )
    {   }

    virtual void calculateArea( void ) = 0; //Pure virtual function

    float getArea( void )
    {
        return this->area;
    }
    virtual ~Shape( void ){ }
};
```

"If we equate any virtual function to zero then it is called as pure virtual function".

We cannot equate any function to zero. To equate function to zero, it must be virtual.

We cannot provide body for the pure virtual function.

According to OOPs concept a member function of class which is having body is called *concrete method* and a function which is having body is called *abstract method.*

In C++ abstract keyword is not given. Pure virtual function can be called as abstract method.

"If class contains at least one pure virtual function then such class is called as abstract class".

Since abstract class contains incomplete implementation, *we can not create object of abstarct class.*

We cannot instantiate abstract class but we can create either pointer or reference of abstract class.

If we declare function in base class as virtual then overriding it in derived class is optional but if we declare function in base class as pure virtual then it is mandatory to override it in derived class.

Abstract Class

If we do not override pure virtual function in derived class then derived class will be considered as abstract class.If we want to instantiate derived class then it is compulsory to override pure virtual function in derived class. Lets Consider the two derived classes Shape.

```
class Rectangle : public Shape
{
private:
    float length;
    float breadth;
public:
    Rectangle( void ) : length( 0 ), breadth( 0 )
    {   }

    void setBreadth(float breadth)
    {
        this->breadth = breadth;
    }

    void setLength(float length)
    {
        this->length = length;
    }

    void calculateArea( void )  //Overriding pure virtual function of Base class
    {
        this->area = this->length * this->breadth;
    }
};
```

In accept_record function we will create object of Rectangle and then we will set value for length and breadth. To calculate the area, we can call calculateArea() function in main or at the end of accept_record function.

We have declared getArea() function in base class, it will inherited in derived class and can be used to get area from rectangle object.

```
class Math  //utility class
{
public:
    static const float PI;
public:
    static float power( float base, int index )
    {
        float result = 1;
        for( int count = 1; count <= index;  ++ count   )
            result = result * base;
        return result;
    }
};
```

Math is utility class written to calculate area of circle.

Now lets implement class Circle to calculate its area:

```
class Circle : public Shape
{
private:
    float radius;
public:
    Circle( void ) : radius( 0 )
    {   }

    void setRadius(float radius)
    {
        this->radius = radius;
    }

    void calculateArea( void )  //Overriding pure virtual function of Base class
    {
        this->area = Math::PI * Math::power(this->radius, 2 );
    }
};
```

In accept_record function we will create object of Circle and then we will set value for radius. To calculate the area, we can call calculateArea() function in main or at the end of accept_record function.

Inherited function getArea() will be used to get area from the circle object.

Abstract Class

By defining pure virtual function in base class we can maintain same method design / signature in all the derived classes which will be helpful to maintainable code.

Let's complete the above program and discuss how to achieve runtime polymorphism in C++.

Polymorphism is an ability of any object to use same interface to perform different operation or behavior. We should use polymorphism to write maintainable code.

To write maintainable code we should use upcasting. In case of upcasting we can call only those function of derived class which are overrided from base class. If we want force all the derived classes to keep same function signature then we should declare all the functions in base class as pure virtual[abstract].

To minimize the complexity we will take help of factory class/ method. A class which hides object creation process from end user is called factory class. It is a creational design pattern.

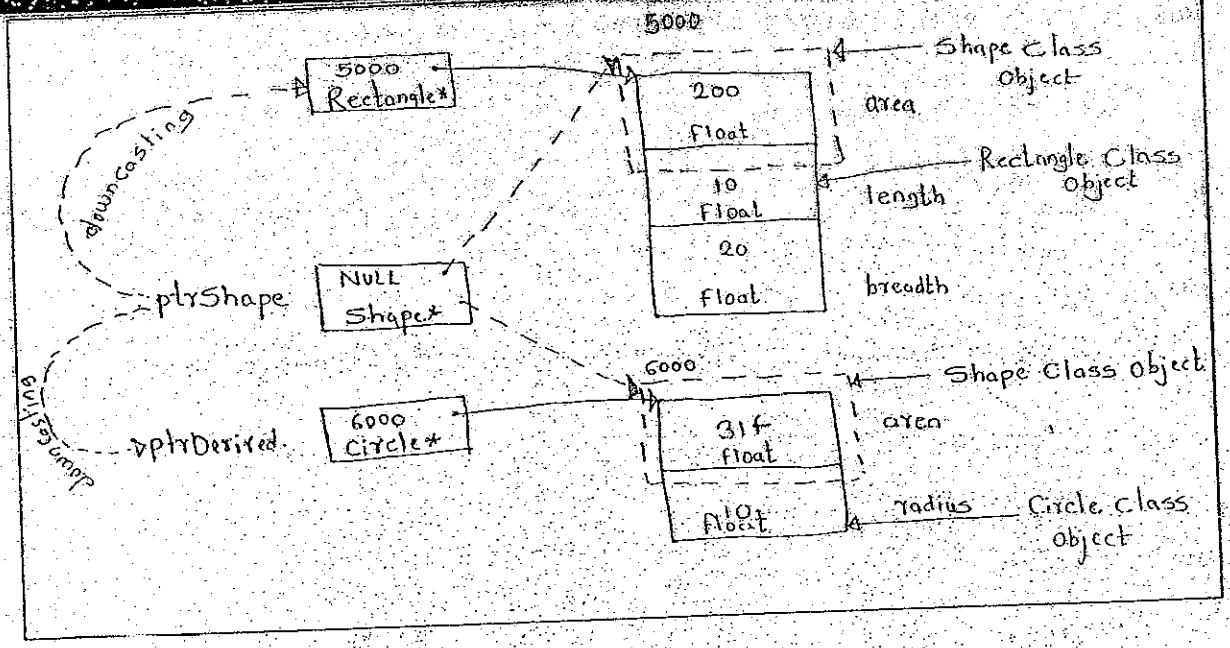
```
enum ShapeType
{
    EXIT, RECTANGLE,CIRCLE
};

class ShapeFactory
{
public:
    static Shape* getInstance( ShapeType shapeType )
    {
        switch( shapeType )
        {
        case RECTANGLE:
            return new Rectangle();
            break;
        case CIRCLE:
            return new Circle();
            break;
        }
        return NULL;
    }
};
```

Let's implement main function so that it will make picture more clear.

```
void accept_record( Shape* ptrShape )
{
        //TODO
}
void print_record( Shape* ptrShape )
{
        //TODO
}
ShapeType menu_list( void )
{
        int choice;
        cout<<"0.Exit"<<endl;
        cout<<"1.Rectangle"<<endl;
        cout<<"2.Circle"<<endl;
        cout<<"Enter choice      :       ";
        cin>>choice;
        return ShapeType( choice );
}
int main()
{
        ShapeType choice;
        while( ( choice = ::menu_list()) != EXIT)
        {
                Shape* ptrShape = ShapeFactory::getInstance(choice);
                if( ptrShape != NULL )
                {
                        ::accept_record(ptrShape);
                        ::print_record(ptrShape);
                        delete ptrShape;
                }
        }
        return 0;
}
```

According to the code written in main function, ptrShape (Base class pointer) can store address of any one of the derived class object(Rectangle/Circle) one at a time.

Code written in main function will work for any object which is derived from Shape class. Before discussing implementation of accept_record and print_record function let's see pictorial view.



Lets Consider Rectangle object. Area is depends on value of length and breadth. To set length and breadth we should use setLength and setBreadth function.

Using base class pointer we can not access undeclared member function of base class which is a member function of derived class.Hence to access setter functions of Rectangle class we need to do downcasting. For the Circle object also we should do same thing.

```
void accept_record( Shape* ptrShape )
{
    if( dynamic_cast<Rectangle*>(ptrShape) != NULL )
    {
        Rectangle* ptrRectangle = dynamic_cast<Rectangle*>(ptrShape);
        ptrRectangle->setLength(10);
        ptrRectangle->setBreadth(20);
    }
    else
    {
        Circle* ptrCircle = dynamic_cast<Circle*>(ptrShape );
        ptrCircle->setRadius(10);
    }
    ptrShape->calculateArea();  //Runtime polymorphism
}

void print_record( Shape* ptrShape )
{
    string typeName = typeid(*ptrShape).name();
    cout<<"Area of instance of "<<typeName<<" is "<<ptrShape->getArea()<<endl;
}
```

In accept_record function, first dynamic_cast operator is used to check, is it storing address of Rectangle or Circle class object and then it is used to do downcasting.

Using dynamic_cast operator, apart from type conversion, we can find out at runtime whether base class pointer is storing address of which derived class object.

ptrShape->calculateArea(); Function call will be resolve at runtime. If ptrShape stores address of Rectangle object then above function call will calculate area of rectangle and if it stores address of Circle class object then it will calculate area of circle. Depending on type of object behaviour of calculateArea() will be decided at runtime.

"At runtime, *an ability of objects of different types to use same interface to perform different operation is called runtime polymorphism*".

If class contains all pure virtual function then such class is called is called as pure abstract class. Pure abstract class is also called as interface.

```
class LinkedList
{
public:
    virtual void addFirst( int data ) = 0;
    virtual void addLast( int data ) = 0;
    virtual void removeFirst( void ) = 0;
    virtual void removeLast( void ) = 0;
    virtual void clear( void ) = 0;
};
```

In above code, LinkedList is considered as pure abstract class or interface.

Interface inheritance:

At the time of inheritance, if base type and derived type is interface then it is called as interface inheritance. Consider the following code.

Abstract Class

```
class LinkedList
{
private:
    Node* head;
    Node* tail;
public:
    LinkedList( void ) : head( NULL ),tail(NULL)
    {  }
```

```
void addLast( int data )
{
    Node* newnode = new IntegerNode(data);
    if( head == NULL )
        head = newnode;
    else
        tail->next = newnode;
    tail = newnode;
}
void addLast(string data )
{
    Node* newnode = new StringNode(data);
    if( head == NULL )
        head = newnode;
    else
        tail->next = newnode;
    tail = newnode;
}
```

```
void printList( void )
{
    if( head != NULL )
    {
        Node* trav = head;
        while( trav != NULL )
        {
            if( dynamic_cast<IntegerNode*>(trav) != NULL )
            {
                IntegerNode* node =  dynamic_cast<IntegerNode*>(trav);
                cout<<node->data<<" ";
            }
            else
            {
                StringNode* node =  dynamic_cast<StringNode*>(trav);
                cout<<node->data<<" ";
            }
            trav = trav->next;
        }
        cout<<endl;
    }
}
LinkedList( void ) {   /*    */ }
```