Robotics Corner

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Object-Oriented Programming(OOP)

01 Classes and Objects

02 Advanced Class Features

03 Operator overloading

04 Inheritance

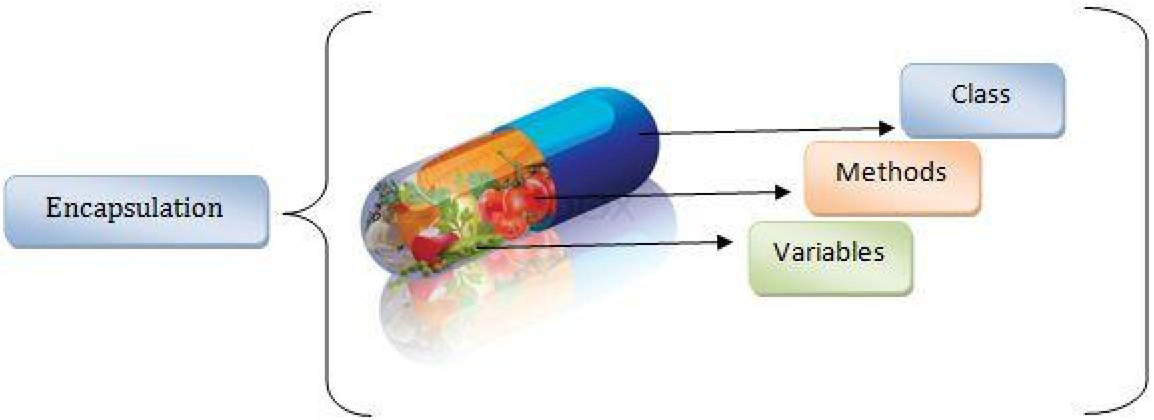
05 Object Relationships

Content

- Members of the class. Access levels. Encapsulation.
- Class: **interface + implementation**
- Constructors and **destructors**
- **`const`** member functions
- Constructor initializer
- Copy constructor
- Object's lifecycle

Encapsulation

- refers to the bundling of data, along with the methods that operate on that data, into a single unit.
- A *class* is a program-code-template that allows developers to create an object that has both variables (data) and behaviors (functions or methods).



OOP: Types of Classes Types of classes:

- **Polymorphic** Classes – *designed for extension*
  - `Shape, exception,` ...
- **Value** Classes – *designed for storing values*
  - `int, complex<double>, ...`
- **RAII** (**R**esource **A**cquisition **I**s **I**nitialization) Classes –
- (encapsulate a **resource** into a class → resource lifetime object lifetime)
  - `thread, unique_ptr, ...`

What type of resource?

Class = Type (Data + Operations)

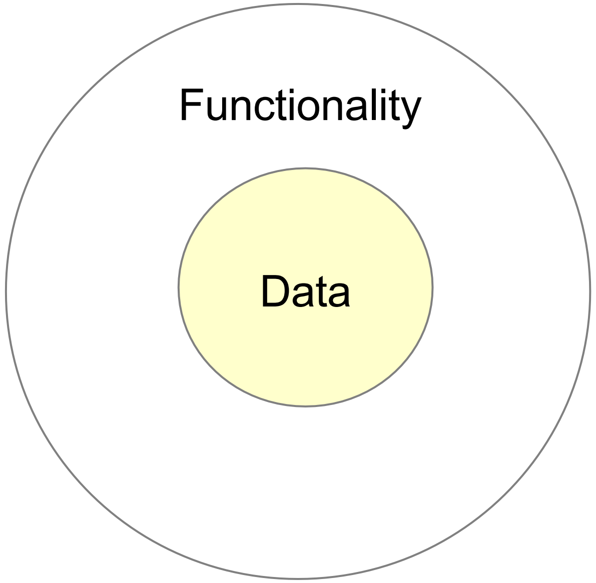
- Members of the class
- **Data:**
  - data members (properties, attributes)
- **Operations:**
  - methods (behaviors)
- Each member is associated with an **access level**:
  - `private` **-**
  - `public` **+**
  - `protected` **#**

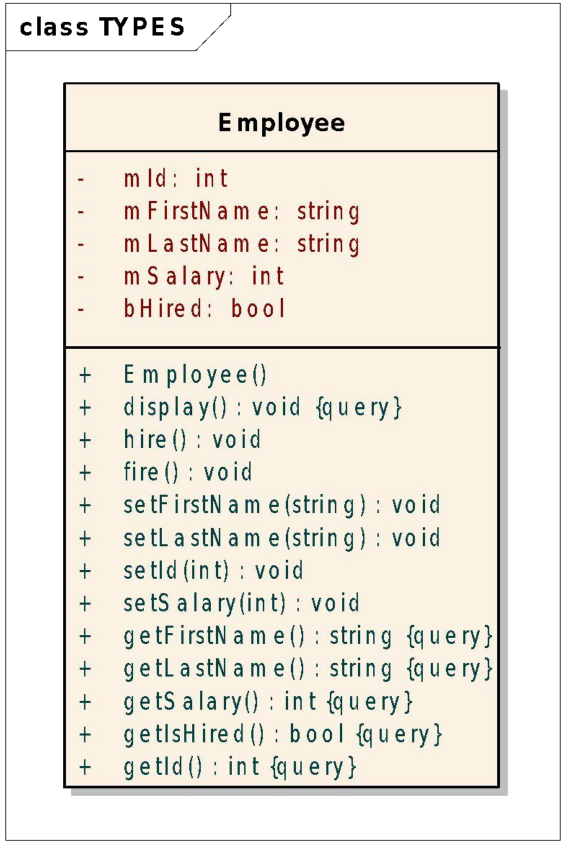
Object = Instance of a class

- An employee object: `Employee emp;`
  - **Properties** are the characteristics that describe an object.
    - *What makes this object different?*
      - `id, firstName, lastName, salary, hired`
  - **Behaviors** answer the question:
    - *What can we do to this object?*
      - `hire(), fire(), display(), get` and `set` data members

Encapsulation

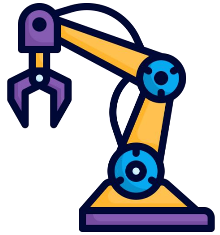
- an object encapsulates *data* and *functionality*.





Class creation

- class **declaration** - *interface*
  - `Employee.h`
- class **definition** – *implementation*
  - `Employee.cpp`



Employee.h

```
class
Employee
{ public:
    Employee();
    void display() const;
    void hire();
    void fire();
    // Getters and setters
    void setFirstName( string inFirstName );
    void setLastName ( string inLastName );
    void setId( int inId );
    void setSalary( int inSalary );
    string getFirstName() const;
    string getLastName() const;
    int getSalary() const;
    bool getIsHired() const;
     int getId() const;
private:
    int mId;
    string mFirstName;
    string mLastName;
    int mSalary;
    bool bHired;
};
```

Methods' declaration

Data members

The Constructor and the object's state

- The **state of an object** is defined by its data members.
- The **constructor** is responsible for the **initial state** of the object

```
Employee :: Employee() : mId(-1),
                         mFirstName(""),
                         mLastName(""),
                         mSalary(0),
                         bHired(false){
}
```

Members are initialized through the constructor initializer list

```
Employee :: Employee()
        { mId = -1;
        mFirstName="";
        mLastName="";
        mSalary =0;
        bHired = false;
}
```

Members are assigned

Only constructors can use this initializer-list syntax!!!

Constructors

- *responsibility:* data members initialization of a class object
- invoked automatically for each object
- have the *same name* as the class
- have *no return type*
- a class can have *multiple constructors* (function **overloading**)
- may not be declared as `const`
    - constructors can write to const objects

Member initialization (C++11)

```
class C{
    string s ("abc");
    double d = 0;
    char * p {nullptr};
    int y[4] {1,2,3,4};
public:
    C(){}
};
```

Compiler

```
class C{
    string s;
    double d;
    char * p;
    int y[5];
public:
    C():s("abc"),
    d(0.0),p(nullptr),
    y{1,2,3,4} {}
};
```

Defining a member function

- Employee.cpp
- A `const` **member function** cannot change the object's state, can be invoked on const objects

```
void
    Employee::hire()
    { bHired = true;
}

string Employee::getFirstName()
    const{ return mFirstName;
}
```

Defining a member function

```
void Employee::display() const {
     cou  << "Employee: " << getLastName() << ",
     t    << "
          << getFirstName() << endl;
     cou     "-------------------------" << endl;
     t
     cout << (bHired ? "Current Employee" :
                        "Former Employee") <<
                        endl;
     cout << "Employee ID: " << getId() << endl;
     cout << "Salary: " << getSalary() << endl;
     cout << endl;
}
```

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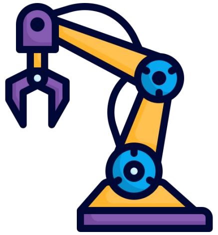
TestEmployee.cpp

- Using `const` member functions

```
void foo( const Employee& e){
   e.display();  // OK. display() is a const member function
   e.fire();     // ERROR. fire() is not a const member function
}

int main() {
    Employee emp;
    emp.setFirstName("Robert");
    emp.setLastName("Black");
    emp.setId(1);
    emp.setSalary(1000);
    emp.hire();
    emp.display();
    foo( emp );
    return 0;
}
```

Classes and Objects



Interface: **Employee.h**

```
#ifndef EMPLOYEE_H
#define EMPLOYEE_H

#include <string>
using namespace std;

class
Employee
{ public:
    Employee();
    //...
protected:
    int mId;
    string mFirstName;
    string mLastName;
    int mSalary;
    bool bHired;
};

#endif
```

Implementation: **Employee.cpp**

```
#include "Employee.h"


Employee::Employee() :
  mId(-1),
  mFirstName(""),
  mLastName(""),
  mSalary(0),
  bHired(false){
}

string Employee::getFirstName()
    const{ return mFirstName;
}
/
/ ...
```

Object life cycles:

- creation
- assignment
- destruction

Object creation:

```
int main() {
    Employee emp;
    emp.display();

    Employee *demp = new Employee();
    demp->display();
    // ..
    delete demp;
    return 0;
}
```

object's lifecycle

- all its *embedded objects* are also created

Object creation – constructors:

- *default constructor* (0-argument constructor)

```
Employee :: Employee() : mId(-1), mFirstName(""), mLastName(""),
mSalary(0), bHired(false){
}
```

```
Employee :: Employee() {
}
```

```
• Employee employees[ 10 ];
• vector<Employee>  emps(10);
```

- memory allocation
- constructor call on each allocated object

Object creation – constructors:

- *Compiler-generated default constructor*

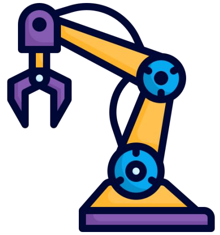
- if a class *does not specify* any constructors, the *compiler will generate* one that does not take any arguments

```
class
Value
{ public:
    void setValue( double inValue);
    double getValue() const;
private:
    double value;
};
```

Constructors: `default` and `delete` specifiers (C++ 11)

```
class X{
    int i = 4;
    int j {5};
public:
    X(int a) : i{a} {} // i = a, j = 5
    X() = default;       // i = 4, j = 5
};
```

Explicitly forcing the automatic generation of a **default** constructor by the compiler.



Constructors: `default` and `delete` specifiers (C++ 11)

```
class
X
{
public:
    X( double ){}
X;x2(3.14); //OK
X x1(10); //OK
```

int → double conversion

```
class
X
{
public:
    X( int )= delete;
    X( double );
};
X x1(10); //ERROR
X x2(3.14); //OK
```

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Best practice: *always provide default values for members!* C++ 11

```
struct Point{
    int x, y;
    Point ( int x = 0, int y = 0 ): x(x), y(y){}
};
class Foo{
    int i{};  double
    d {}; char c {};
    Point p {};
public:
    void print(){
        cout <<"i: "<<i<<endl; cout
        <<"d: "<<d<<endl; cout
        <<"c: "<<c<<endl;
        cout <<"p: "<<p.x<<", "<<p.y<<endl;
    }
};
```

```
int main() {
    Foo f;
    f.print();
    return 0;
}
```

OUTPUT:

```
i: 0
d: 0
c:
p: 0, 0
```

Constructor initializer

```
class
ConstRef
{ public:
    ConstRef( int& );
private:
    int mI;
    const int mCi;
    int& mRi;
};

ConstRef::ConstRef( int&
    inI ){ mI = inI;        //OK
    mCi = inI; //ERROR: cannot assign to a const
    mRi = inI; //ERROR: uninitialized reference member
}
```

```
ConstRef::ConstRef( int& inI ): mI( inI ), mCi( inI ), mRi( inI ){}
```

ctor initializer

Constructor initializer

- data types that must be initialized in a ctor-initializer
  - `const` data members
  - reference data members
  - object data members having no default constructor
  - superclasses without default constructor

A *non-default* Constructor

```
Employee :: Employee( int inId, string inFirstName,
                            string inLastName,
                            int inSalary, int inHired) :
            mId(inId), mFirstName(inFirstName),
            mLastName(inLastName), mSalary(inSalary),
            bHired(inHired){
}
```

Delegating Constructor (C++11)

```
class
  SomeType{ int
  number;

public:
  SomeType(int newNumber) : number(newNumber) {}
  SomeType() : SomeType(42) {}
};
```

Copy Constructor

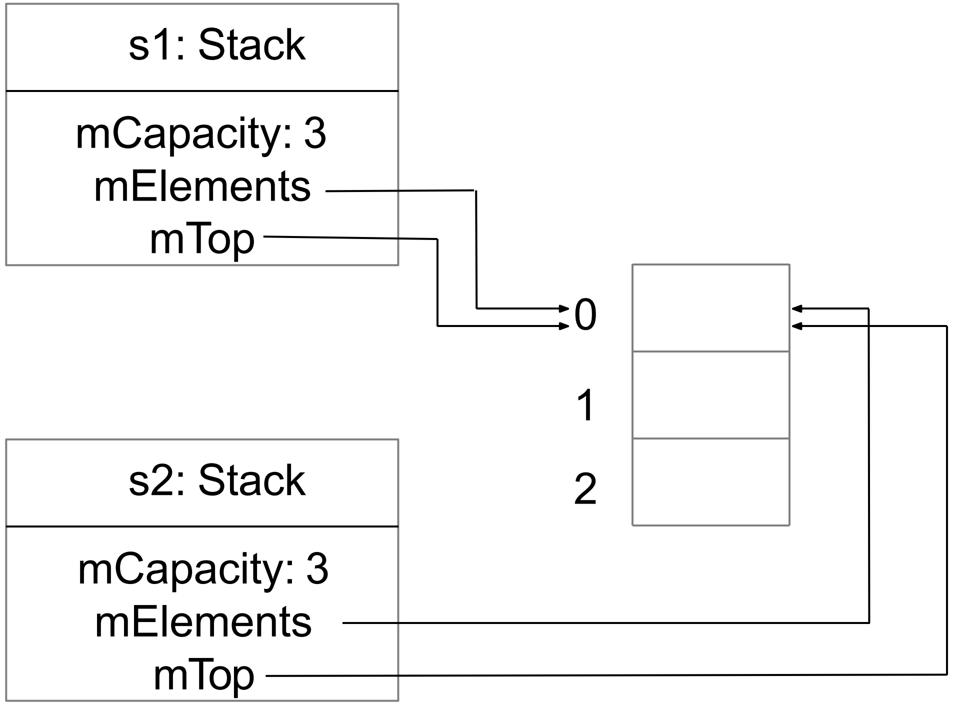
```
Employee emp1(1, "Robert", "Black", 4000, true);
```

- called in one of the following cases:
  - `Employee emp2( emp1 ); //copy-constructor called`
  - `Employee emp3 = emp2;   //copy-constructor called`
  - `void foo( Employee emp );//copy-constructor called`
- if you don't define a copy-constructor explicitly, the compiler creates one for you
  - this performs a **bitwise** copy

```cpp
//Stack.h

#ifndef STACK_H
#define  STACK_H

class Stack{
public:
     Stack( int inCapacity );
     void push( double inDouble );
     double top() const;
     void pop();
     bool isFull() const;
     bool isEmpty()const;

private:
     int mCapacity;
     double * mElements;
     double * mTop;
};
#endif   /* STACK_H */
```

```cpp
//Stack.cpp

#include  "Stack.h"

 Stack::Stack( int inCapacity ){
     mCapacity = inCapacity;
     mElements = new double [ mCapacity ];
     mTop = mElements;
 }

 void Stack::push( double
     inDouble ){ if( !isFull()){
         *mTop = inDouble;
         mTop++;
     }
 }
```

```
//TestStack.cpp
#include "Stack.h"

int main(){
      Stack s1(3);
     Stack s2 = s1;
     s1.push(1);
     s2.push(2);

     cout<<"s1: "<<s1.top()<<endl;
     cout<<"s2: "<<s2.top()<<endl;
}
```

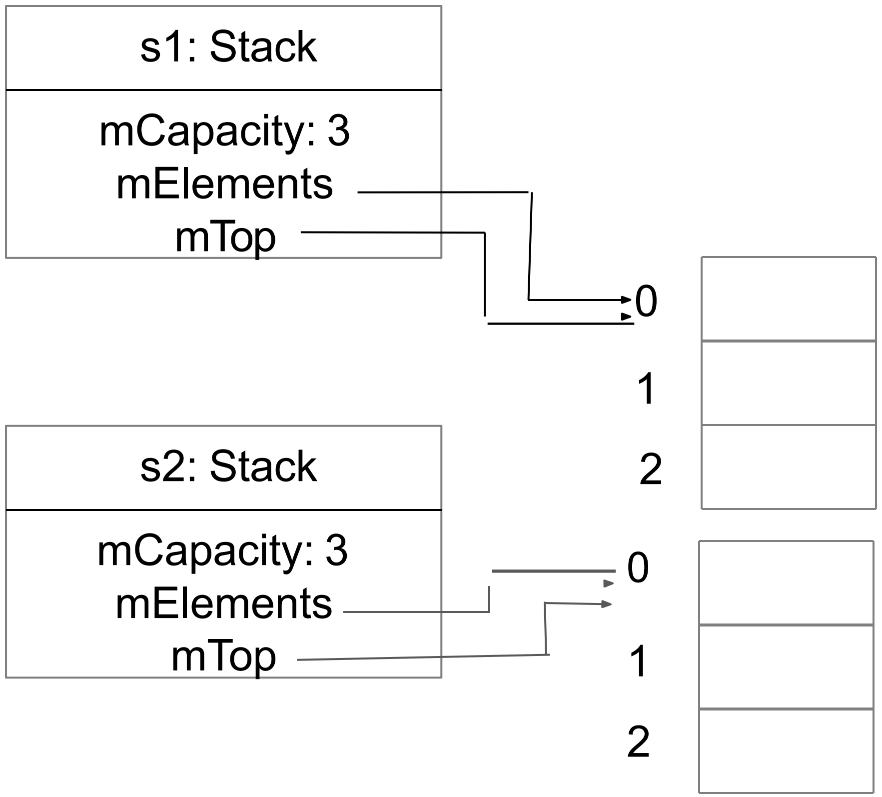


Copy constructor: `T ( const T&)`

```
//Stack.h

#ifndef STACK_H
#define  STACK_H

class Stack{
public:
    //Copy constructor
    Stack( const Stack& );
private:
    int mCapacity;
    double * mElements;
    double * mTop;
};
#endif    /* STACK_H */
```

```
//Stack.cpp

#include "Stack.h"

Stack::Stack( const Stack& s ){
    mCapacity = s.mCapacity;
    mElements = new double[ mCapacity ];
    int nr = s.mTop - s.mElements;
    for( int i=0; i<nr; ++i ){
        mElements[ i ] = s.mElements[ i ];
    }
    mTop = mElements + nr;
}
```

```
//TestStack.cpp
#include "Stack.h"

int main(){
     Stack s1(3);
    Stack s2 = s1;
    s1.push(1);
    s2.push(2);

    cout<<"s1: "<<s1.top()<<endl;
    cout<<"s2: "<<s2.top()<<endl;
}
```



Destructor

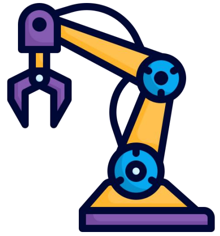
- when an object is destroyed:
  - the object's destructor is automatically invoked,
  - the memory used by the object is freed.
- each class has one destructor
- usually place to perform cleanup work for the object
- if you don't declare a destructor → the compiler will generate one, which destroys the object's member

Destructor

- Syntax: `T :: ~T();`

```
Stack::~Stack(){
    if( mElements !=
        nullptr ){  delete[]
        mElements;  mElements
        = nullptr;
    }
}
```

```
{    // block begin
     Stack s(10);            // s: constructor
    Stack* s1 = new Stack(5);// s1: constructor
    s.push(3);
     s1->push(10);
     delete s1;                // s1: destructor
     s.push(16);
}   // block end             //s: destructor
```



Default parameters

- if the user specifies the arguments → the defaults are ignored
- if the user omits the arguments → the defaults are used
- the default parameters are specified **only** in the ***method declaration*** (not in the definition)

```
//Stack.h
class
Stack
{ public:
    Stack( int inCapacity = 5 );
     ..
};
//Stack.cpp
Stack::Stack( int
     inCapacity ){ mCapacity =
     inCapacity;
     mElements = new double [ mCapacity ];
     mTop = mElements;
}
```

```
//TestStack.cpp

Stack s1( 3 );  //capacity: 3
Stack s2;       //capacity: 5
Stack s3( 10 ); //capacity: 10
```

The `this` pointer

- every method call passes a pointer to the object for which it is called as *hidden parameter* having the name `this`
- Usage:
  - for disambiguation

```
Stack::Stack( int mCapacity ){
      this → mCapacity = mCapacity;
      //..
}
```

Programming task [Prata]

```
class Queue
{
    enum {Q_SIZE = 10};
private:
    // private representation to be developed later
public:
    Queue(int qs = Q_SIZE); // create queue with a qs limit
    ~Queue();
    bool isempty() const;
    bool isfull()  const;
    int queuecount() const;
    bool enqueue(const Item &item); // add item to end
    bool dequeue(Item &item); // remove item from front
};
```

Programming task [Prata]

```
class Queue
{
private:
    // class scope definitions

    // Node is a nested structure definition local to this class
    struct Node { Item item; struct Node * next;};
    enum {Q_SIZE = 10};

    // private class members
    Node * front; // pointer to front of Queue
    Node * rear; // pointer to rear of Queue
    int items; // current number of items in Queue
    const int qsize; // maximum number of items in Queue

};
```

Content

- Inline functions
- Stack vs. Heap
- Array of objects vs. array of pointers
- Passing function arguments
- Static members
- Friend functions, friend classes
- Nested classes
- Move semantics (C++11)

`Inline` functions

- designed to speed up programs (like macros)
- the compiler replaces the function call with the function code (no function call!)
- advantage: *speed*
- disadvantage: *code bloat*
    - ex. 10 function calls → 10 * function's size

How to make a function `inline`?

- use the `inline` keyword either in function declaration or in function definition
- both member and standalone functions can be `inline`
- common practice:
  - place the implementation of the `inline` function into the header file
- only small functions are eligible as `inline`
- the compiler may completely ignore your request

`inline` function examples

```
inline double square(double
   a){ return a * a;
}

class
   Value{ int
   value;
public:
   inline int getValue()const{ return value; }

    inline void setValue( int
       value ){ this->value = value;
   }
};
```

- Stack vs. Heap
- Heap – Dynamic allocation

```
void draw(){
     Point * p = new Point();
     p->move(3,3);
     //...
     delete p;
}
```

- Stack – Automatic allocation

```
void draw(){
     Point p;
     p.move(6,6);
     //...
}
```

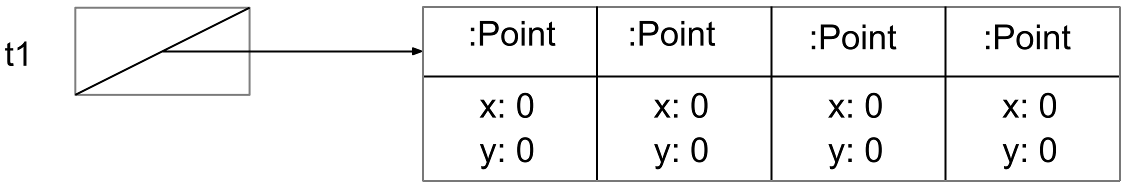
Array of objects

```
class Point{
     int x, y;
public:
     Point( int x=0, int y=0);
     //...
};
```

What is the difference between these two arrays?

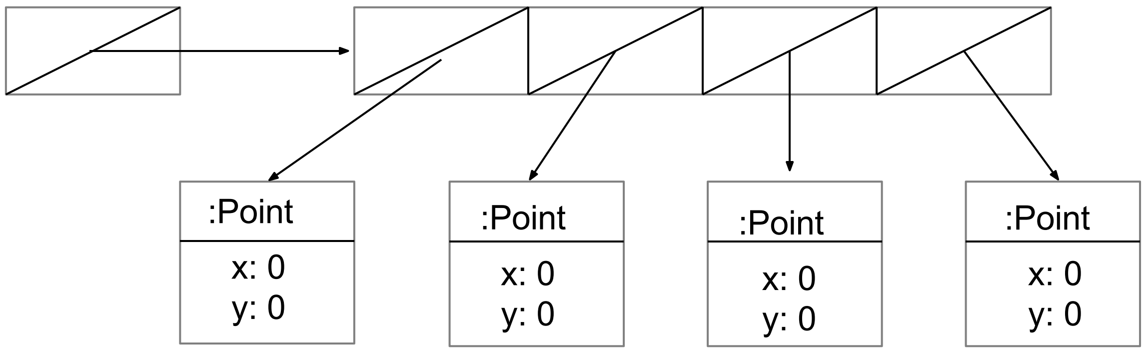
Point * t1 = new Point[4];

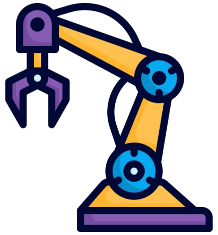
Point t1[4];



Array of pointers

```
Point ** t2 = new Point*[ 4 ];
for(int i=0; i<4; ++i ){
      t2[i] = new Point(0,0);
}
for( int i=0; i<4;
      ++i )
      {
      cout<<*t2[ i ]<<endl;
}
```





Static members:

- `static` methods
- `static` data

- Functions belonging to a *class scope* which don't access object's data can be `static`
- Static methods can't be `const` methods (they do not access object's state)
- They are not called on specific objects ⇒ they have no `this` pointer

- Static members

```
//Complex.h

class
Complex
{ public:
    Complex(int re=0, int im=0);
     static int getNumComplex();
     // ...
private:
    static int num_complex;
    double re, im;
};
```

instance counter

initializing static class member

```
//Complex.cpp

int Complex::num_complex = 0;

int
     Complex::getNumComplex()
     { return num_complex;
}

Complex::Complex(int re, int
     im){ this->re = re;
     this->im = im;
     ++num_complex;
}
```

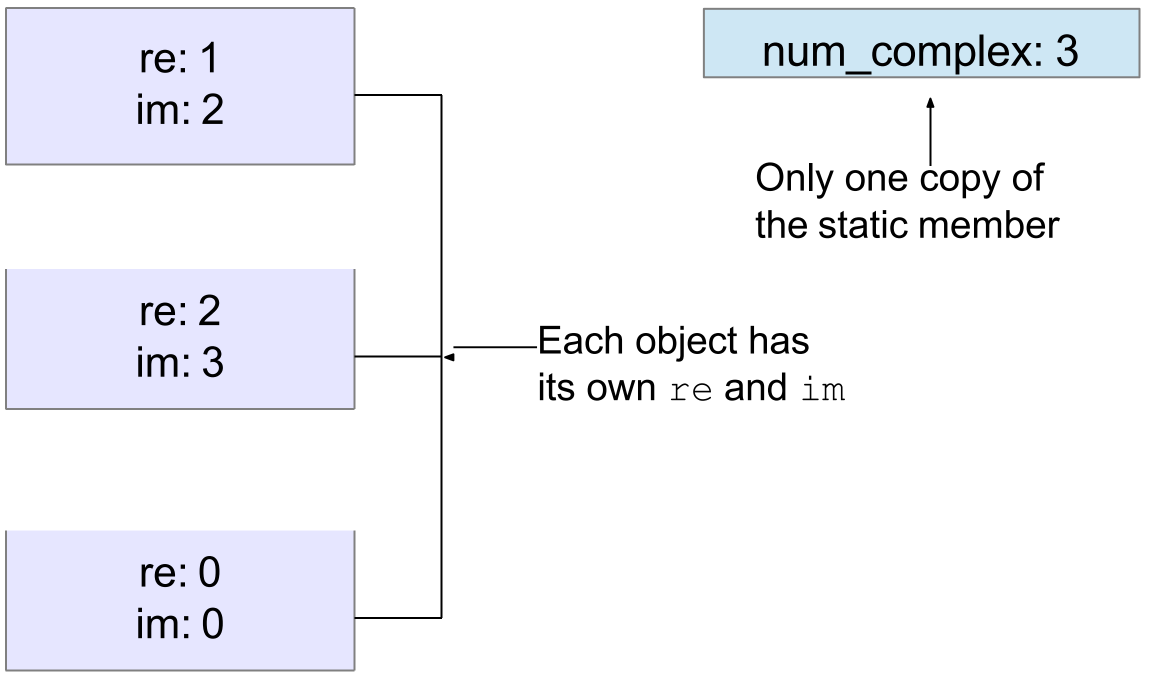
- Static method invocation

elegant

```
Complex z1(1,2), z2(2,3), z3;
cout<<"Number of complexs:"<<Complex::getNumComplex()<<endl;

 cout<<"Number of complexes: "<<z1.getNumComplex()<<endl;
```

non - elegant

Complex z1(1,2), z2(2,3), z3;



- Classes vs. Structs
  - default access specifier
    - class: `private`
    - struct: `public`
  - class: data + methods, can be used polymorphically
  - struct: mostly data + convenience methods

- Classes vs. structures

```
Class list{
private:
  struct node
  {
    node *next;
    int val;
    node( int val = 0, node * next = nullptr):val(val), next(next){}
  };
  node * mHead;
public:
  list ();
  ~list ();
  void insert (int a);
  void printAll()const;
};
```

- Passing function arguments
  - by value
    - the function works on a copy of the variable
  - by reference
    - the function works on the original variable, may modify it
  - by constant reference
    - the function works on the original variable, may not modify (verified by the compiler)

- Passing function arguments

passing primitive values

```
void f1(int x)   {x = x + 1;}
void f2(int& x) {x = x + 1;}
void f3(const int& x) {x = x + 1;}// !!!!
void f4(int *x) {*x = *x + 1;}

int main(){
     int y = 5;
     f1(y);
     f2(y);
     f3(y);
     f4(&y);
     return 0;
}
```

– Passing function arguments

```
void f1(Point p);
void f2(Point& p);
void f3(const Point& p);
void f4(Point *p);

int main(){
     Point p1(3,3);
     f1(p1);
     f2(p1);
     f3(p1);
     f4(&p1);
     return 0;
}
```

copy constructor will be used on the argument

only `const` methods of the class can be invoked on this argument

- `friend` functions, `friend` classes, `friend` member functions
  - friends are allowed to access private members of a class
  - Use it rarely
    - operator overloading

- friend vs. static functions

```
class
Test
{ private:
    int iValue;
    static int sValue;
public:
    Test( int in ):iValue( in ){}
    void print() const;
    static void print( const Test& what );
    friend void print( const Test& what );
};
```

- `friend` vs. `static` functions

```
int Test :: sValue = 0;

void Test::print()
    const{  cout<<"Member:
    "<<iValue<<endl;
}

void Test::print( const Test&
    what ){  cout<<"Static:
    "<<what.iValue<<endl;
}

void print( const Test&
    what ){  cout<<"Friend:
    "<<what.iValue<<endl;
}

int main() {
    Test test( 10 );
    test.print();
    Test::print( test );
    print( test );
}
```

- `friend` class vs. `friend` member function

```
class
List
{ private:
      ListElement * head;
public:
      bool find( int key );
      …
};
```

```
class
ListElement
{ private:
      int key;
      ListElement * next;
      friend class List;
      ...
};
```

```
Class
ListElement
{ private:
      int key;
      ListElement * next;
      friend class List::find( int key);
      ...
};
```

C++03

- Returning a reference to a `const` object

```
// version 1
vector<int> Max(const vector<int> & v1, const vector<int> & v2){
    if (v1.size() > v2.size())
        return v1;
    else
        return v2;
}

// version 2
const vector<int> & Max(const vector<int> & v1, const vector<int> &
    v2){ if (v1.size() > v2.size())
        return v1;
    else
        return v2;
}
```

Copy constructor invocation

More efficient

The reference should be to a non-local object

- Returning a reference to a `const` object

C++11

```
vector<int> selectOdd( const vector<int>&
   v){ vector<int> odds;
   for( int a: v ){
       if (a % 2 == 1 ){
           odds.push_back( a );
       }
   }
   return odds;
}

//...
vector<int> v(N);
for( int i=0; i<N;
    ++i)
    {  v.push_back( rand()%
    M);
}
vector<int> result = selectOdd( v );
```

EFFICIENT! MOVE constructor invocation

- Nested classes
  - the class declared within another class is called a *nested class*
  - usually helper classes are declared as nested

```
// Version 1

class Queue
{
 private:
     // class scope definitions
     // Node is a nested structure definition local to this class
     struct Node {Item item; struct Node * next;};
     ...
};
```

- Nested classes [Prata]

Node visibility!!!

```
// Version 2

class Queue
{
     // class scope definitions
     // Node is a nested class definition  local to this class
     class Node
     {
     public:
          Item item;
          Node * next;
          Node(const Item & i) : item(i), next(0) { }
     };
     //...
};
```

ROBOTICS CORNER

- Nested classes
  - a nested class **B** declared in a **private** section of a class **A**:
    - **B** is local to class **A** (only class A can use it)
  - a nested class **B** declared in a **protected** section of a class **A**:
    - **B** can be used both in **A** and in the derived classes of **A**
  - a nested class **B** declared in a **public** section of a class **A**:
    - **B** is available to the outside world (Usage: `A::B  b;`)

- Features of a *well-behaved* C++ class
  - implicit constructor
    - `T :: T(){ … }`
  - destructor
    - `T :: ~T(){ … }`
  - copy constructor
    - `T :: T( const T& ){ … }`
  - assignment operator (*see next module*)
    - `T& T :: operator=( const T& ){ … }`

– Constructor delegation (C++11)

```
// C++03
class A
{
    void init() { std::cout << "init()"; }
    void doSomethingElse() { std::cout << "doSomethingElse()\n"; }
public:
    A() { init(); }
    A(int a) { init(); doSomethingElse(); }
};
```

```
// C++11
class A
{
    void doSomethingElse() { std::cout << "doSomethingElse()\n"; }
public:
    A() { ... }
    A(int a) : A() { doSomethingElse(); }
};
```

- Lvalues:
  - Refer to objects accessible at more than one point in a source code
    - Named objects
    - Objects accessible via pointers/references
  - Lvalues may not be moved from
- Rvalues:
  - Refer to objects accessible at exactly one point in source code
    - Temporary objects (e.g. by value function return)
  - Rvalues may be moved from

- Lvalue

```
int  x;
x = 10;
```

Rvalue

- Move Semantics (C++11)

```
class string{
     char* data;
public:
    string( const char* );
    string( const string& );
    ~string();
};
```

```
string :: string(const char*
     p){ size_t size = strlen(p)
     + 1; data = new char[size];
     memcpy(data, p, size);
}
string :: string(const string&
     that){  size_t size =
     strlen(that.data) + 1; data = new
     char[size];
     memcpy(data, that.data, size);
}

string ::
     ~string()
     { delete[]
     data;
}
```

- Move Semantics (C++11): lvalue, rvalue

```
string a(x);                              // Line 1
string b(x + y);                          // Line 2
string c(function_returning_a_string()); // Line 3
```

- **lvalue**: real object having an address
  - **Line 1:** x
- **rvalue**: temporary object – no name
  - **Line 2:** x + y
  - **Line 3:** function_returning_a_string()

- Move Semantics (C++11): rvalue reference, move constructor

```
//string&& is an rvalue reference to a string
string :: string(string&&
    that){ data = that.data;
    that.data = nullptr;
}
```

- **Move constructor**
  - **Shallow copy** of the argument
  - **Ownership transfer** to the new object

- **Move** constructor – Stack class

```
Stack::Stack(Stack&& rhs){
    //move rhs to this
    this->mCapacity = rhs.mCapacity;
    this->mTop = rhs.mTop;
    this->mElements = rhs.mElements;

    //leave rhs in valid state
    rhs.mElements = nullptr;
    rhs.mCapacity = 0;
    rhs.mTop = 0;
}
```

- Copy constructor vs. move constructor
  - Copy constructor: **deep copy**
  - Move constructor: **shallow copy + ownership transfer**

```
// constructor
string s=”apple”;
// copy constructor: s is an lvalue
string s1 = s;
// move constructor: right side is an rvalue
string s2 = s + s1;
```

- Passing large objects

```
// C++98
// avoid expense copying

void makeBigVector(vector<int>& out){
 ...
}
vector<int> v;
makeBigVector( v );
```

```
// C++11
// move semantics

vector<int> makeBigVector(){
 …
}
auto v = makeBigVector();
```

- All STL classes have been extended to support **move semantics**
- The content of the temporary created vector is moved in v (not copied)

02 Advanced class features

```
class A{
     int value {10};
     static A instance;
public:
     static A& getInstance(){ return instance;}
     static A  getInstanceCopy(){ return instance;}
     int getValue() const { return value;}
     void setValue( int value ){ this->value = value;}
};
```

Reference to a static variable → **lvalue**

A temporary copy of instance → **rvalue**

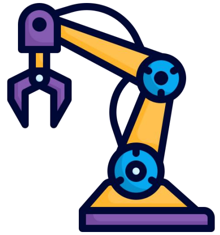
```
A A::instance;
int main(){
     A& v1 = A::getInstance();
     cout<<"v1: "<<v1.getValue()<<endl;
     v1.setValue(20);
     cout<<"v1: "<<v1.getValue()<<endl;
     A v2 = A::getInstanceCopy();
     cout<<"v2: "<<v2.getValue()<<endl;
     return 0;
}
```

Output?

http://geant4.web.cern.ch/geant4/collaboration/c++11_guidelines.pdf

Content

- Objectives
- Types of operators
- Operators
  - Arithmetic operators
  - Increment/decrement
  - Inserter/extractor operators
  - Assignment operator (copy and move)
  - Index operator
  - Relational and equality operators
  - Conversion operators



Objective

- To make the class usage easier, more intuitive
  - the ability to read an object using the `extractor` operator (>>)
    - `Employee e1; cin >> e;`
  - the ability to write an object using the `inserter` operator (<<)
    - `Employee e2; cout<<e<<endl;`
  - the ability to compare objects of a given class
    - `cout<< ((e1 < e2) ? "less" : "greater");`

Operator overloading: a service to the clients of the class

Limitations

- You cannot add new operator symbols. Only the existing operators can be redefined.
- Some operators cannot be overloaded:
  - `.` (member access in an object)
  - `::`(scope resolution operator)
  - `sizeof`
  - `?:`
- You cannot change the **arity** (the number of arguments) of the operator
- You cannot change the **precedence** or **associativity** of the operator

How to implement?

- write a function with the name `operator<symbol>`
- alternatives:
  - method of your class
  - global function (usually a friend of the class)

http://en.cppreference.com/w/cpp/language/operators

- There are 3 types of operators:
  - operators that must be methods (**member functions**)
    - they don't make sense outside of a class:
      - `operator=, operator(),operator[], operator->`
  - operators that must be **global functions**
    - the left-hand side of the operator is a variable of different type than your class: `operator<<, operator>>`
      - `cout << emp;`
        - `cout: ostream`
        - `emp: Employee`
  - operators that can be **either** methods or global functions
    - **Gregoire:** “Make every operator a method unless you must make it a global function.”

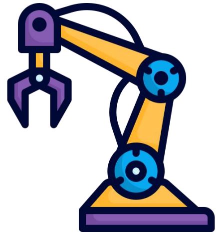
- Choosing argument types:
  - value vs. reference
    - Prefer passing-by-reference instead of passing-by-value.
  - `const` vs. non const
    - Prefer const unless you modify it.
- Choosing return types
  - you can specify any return type, however
    - follow the built-in types rule:
      - comparison always return `bool`
      - **arithmetic operators return an object representing the result of the arithmetic**

ROBOTICS CORNER

Operator overloading

```
#ifndef COMPLEX_H
#define COMPLEX_H

class
Complex
{ public:
    Complex(double, double );
    void setRe( double );
    void setIm( double im);
    double getRe() const;
    double getIm() const;
    void print() const;
private:
    double re, im;
};
#endif
```

03 Operator overloading



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

Complex::Complex(double re, double im):re( re),im(im) {} void

Complex::setRe( double re){this->re = re;}

void Complex::setIm( double im){ this->im = im;}

double Complex::getRe() const{ return this->re;}

double Complex::getIm() const{ return this->im;}

void Complex::print()const{    cout<<re<<"+"<<im<<"i";}
```

- Arithmetic operators (**member** or standalone func.)
  - unary minus
  - binary minus

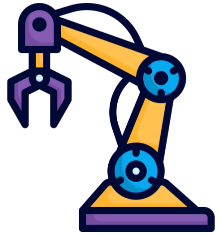
```
Complex Complex::operator-()
    const{  Complex temp(-this->re, -
    this->im); return temp;
}

Complex Complex::operator-( const Complex& z)
    const{ Complex temp(this->re - z.re, this->im-
    z.im);  return temp;
}
```

- Arithmetic operators (member or **standalone** func.)
  - unary minus
  - binary minus

```
Complex operator-( const Complex&
     z ){   Complex temp(-z.getRe(), -
     z.getIm()); return temp;
}

Complex operator-( const Complex& z1, const Complex&
     z2 ){   Complex temp(z1.getRe()-z2.getRe(), z1.getIm()-
     z2.getIm()); return temp;
}
```

Increment/Decrement operators

- postincrement:
  - `int i = 10; int j = i++; // j → 10`
- preincrement:
  - `int i = 10; int j = ++i; // j → 11`
- The C++ standard specifies that the prefix increment and decrement return an **lvalue** (left value).



- Increment/Decrement operators (member func.)

```
Complex& Complex::operator++(){              //prefix
      (this->re)++;
      (this->im)++;
      return *this;
}

Complex   Complex::operator++( int ){  //postfix
      Complex
      temp(*this);
      (this->re)++;
      (this-
      >im)++;
      return
      temp;
}
```

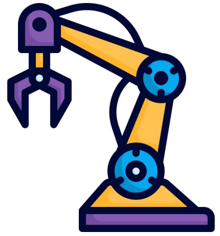
Which one is more efficient? Why?

- Inserter/Extractor operators (standalone func.)

```
//complex.h

class Complex
{ public:
    friend ostream& operator<<(
                     ostream& os, const Complex& c);
    friend istream& operator>>(
                     istream& is, Complex& c);
    //...
};
```

- Inserter/Extractor operators (standalone func.)

```
//complex.cpp

ostream& operator<<( ostream& os, const Complex&
      c){ os<<c.re<<"+"<<c.im<<"i";
      return os;
}

istream& operator>>( istream& is, Complex&
      c){ is>>c.re>>c.im;
      return is;
}
```



- Inserter/Extractor operators
- **Syntax:**

```
ostream& operator<<( ostream& os, const T& out)
istream& operator>>( istream& is, T& in)
```

- Remarks:
  - Streams are always *passed by reference*
  - **Q:** Why should inserter operator return an **ostream&**?
  - **Q:** Why should extractor operator return an **istream&**?

- Inserter/Extractor operators
- Usage:

```
Complex z1, z2;
cout<<"Read 2 complex number:";
//Extractor
cin>>z1>>z2;
//Inserter
cout<<"z1: "<<z1<<endl;
cout<<"z2: "<<z2<<endl;

cout<<"z1++: "<<(z1++)<<endl;
cout<<"++z2: "<<(++z2)<<endl;
```

- **Assignment operator (=)**
  - **Q:** When should be overloaded?
  - **A:** When bitwise copy is not satisfactory (e.g. if you have dynamically allocated memory ⇒
    - when we should implement the copy constructor and the destructor too).
    - Ex. our Stack class

- Assignment operator (member func.)
  - Copy assignment
  - Move assignment (since C++11)

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- **Copy** assignment operator (member func.)
  - **Syntax:** `X& operator=( const X& rhs);`
  - **Q:** Is the return type necessary?
    - Analyze the following example code

```
Complex z1(1,2), z2(2,3), z3(1,1);
z3 = z1;
z2 = z1 = z3;
```

- **Copy** assignment operator example

```
Stack& Stack::operator=(const Stack& rhs)
 { if (this != &rhs) {
   //delete lhs - left hand side
   delete [] this->mElements;
   this->mCapacity = 0;
    this_>melements = nullptr; // in case next line throws
   //copy rhs - right hand side
   this->mCapacity = rhs.mCapacity;
   this->mElements = new double[ mCapacity ];
   int nr = rhs.mTop - rhs.mElements;
   std::copy(rhs.mElements,rhs.mElements+nr,this->mElements);
   mTop = mElements + nr;
 }
 return *this;
}
```

- Copy assignment operator vs Copy constructor

```
Complex z1(1,2), z2(3,4); //Constructor
Complex z3 = z1; //Copy constructor
Complex z4(z2);   //Copy constructor
z1 = z2;          //Copy assignment operator
```

- **Move** assignment operator (member func.)
  - **Syntax:** `X& operator=( X&& rhs);`
  - When it is called?

```
Complex z1(1,2), z2(3,4); //Constructor
Complex z4(z2); //Copy constructor
z1 = z2;      //Copy assignment operator
Complex z3 = z1 + z2; //Move constructor
z3 = z1 + z1;//Move assignment
```

OOP: Operator overloading

- **Move** assignment operator example

```
Stack& Stack::operator=(Stack&& rhs){
    //delete lhs - left hand side
    delete [] this->mElements;
    //move rhs to this
    this->mCapacity = rhs.mCapacity;
    this->mTop = rhs.mTop;
    this->mElements = rhs.mElements;
    //leave rhs in valid state
    rhs.mElements = nullptr;
    rhs.mCapacity = 0;
    rhs.mTop = 0;
    //return permits s1 = s2 = create_stack(4);
    return *this;
}
```

- Features of a *well-behaved* C++ class (**2011**)
  - implicit constructor `T :: T();`
  - destructor `T :: ~T();`
  - copy constructor `T :: T( const T& );`
  - **move** constructor `T :: T( T&& );`
  - copy assignment operator
    - `T& T :: operator=( const T& );`
  - **move** assignment operator
    - `T& T :: operator=( T&& rhs );`

03 Operator overloading

- Subscript operator: needed for arrays (member func.)
- Suppose you want your own dynamically allocated C-style array ⇒ implement your own `CArray`

```
#ifndef CARRAY_H
#define   CARRAY_H
class
CArray{  public:
    CArray( int size = 10 );
    ~CArray();
    CArray( const CArray&) = delete;
    CArray& operator=( const Carray&) = delete;
    double& operator[]( int index );
    double  operator[]( int index ) const;
private:
    double * mElems;
    int mSize;
};
#endif    /* ARRAY_H */`
```

Provides read-only access

"If the value type is known to be a built-in type, the const variant should return by value."
http://en.cppreference.com/w/cpp/language/operators.

03 Operator overloading

- Implementation

```
CArray::CArray( int
size ){ if( size < 0 ){

     this->size = 10;

 }

 this->mSize = size;

 this->mElems = new double[ mSize ];

}


CArray::~CArray(){
     if( mElems !=
     nullptr ){ delete[] mElems;
     mElems = nullptr;

 }

}


double& CArray::operator[]( int
index ){ if( index <0 || index >= mSize ){

     throw out_of_range("");

 }

 return mElems[ index ];

}
```

```
double CArray::operator[](
                         int index )
     const{ if( index <0 || index >=
     mSize ){
          throw out_of_range("");
     }
     return mElems[ index ];
}
```

```
#include<stdexcept>
```

- const vs non-const [] operator

```
void printArray(const CArray& arr, size_t size)
    {  for (size_t i = 0; i < size; i++) {
        cout << arr[i] << "" ;
        // Calls the const operator[] because arr is
        // a const object.
    }
    cout << endl;
}
```

```
CArray myArray;
for (size_t i = 0; i < 10; i++)
   { myArray[i] = 100;
   // Calls the non-const operator[] because
   // myArray is a non-const object.
}
printArray(myArray, 10);
```

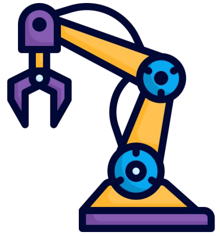
- Relational and equality operators
  - used for **search** and **sort**
  - the container must be able to compare the stored objects

```
bool operator ==( const Point& p1, const Point& p2){
    return p1.getX() == p2.getX() && p1.getY() == p2.getY();
}


bool operator <( const Point& p1, const Point& p2){
   return p1.distance(Point(0,0)) < p2.distance(Point(0,0));
}
```

```
set<Point> p;
```

```
vector<Point> v; //...
sort(v.begin(), v.end());
```

Operator overloading



- The function call operator ()
- Instances of classes overloading this operator behave as functions too (they are function objects = function + object)

```
#ifndef ADDVALUE_H
#define   ADDVALUE_H
class AddValue{
    int value;
public:
    AddValue( int inValue = 1);
    void operator()( int& what );
};
#endif    /* ADDVALUE_H */
```

```
#include "AddValue.h"

AddValue::AddValue( int
    inValue ){ this->value =
    inValue;
}

void AddValue::operator()( int&
    what ){ what += this->value;
}
```

03 Operator overloading

- The function call operator

```
AddValue func(2);
int array[]={1, 2, 3};
for( int& x : array ){
   func(x);
}
for( int x:
   array ){ cout
   <<x<<endl;
}
```

- Function call operator
  - frequently used for defining sorting criterion

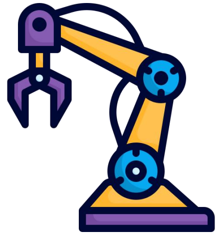
```
struct EmployeeCompare{
    bool operator()( const Employee& e1, const Employee&
        e2){ if( e1.getLastName() == e2.getLastName())
            return e1.getFirstName() < e2.getFirstName();
        else
            return e1.getLastName() < e2.getLastName();

    }
};
```

- Function call operator
  - sorted container

```
set<Employee, EmployeeCompare> s;

Employee e1; e1.setFirstName("Barbara");
e1.setLastName("Liskov");
Employee e2; e2.setFirstName("John");
e2.setLastName("Steinbeck");
Employee e3; e3.setFirstName("Andrew");
e3.setLastName("Foyle");
s.insert( e1 ); s.insert( e2 ); s.insert( e3 );

for( auto& emp :
    s)
    { emp.display();
}
```

- Sorting elements of a given *type*:
  - **A.** override operators: **<**, **==**
  - **B.** define a function object containing the comparison
- **Which one to use?**
  - **Q:** How many sorted criteria can be defined using method **A**?
  - **Q:** How many sorted criteria can be defined using method **B**?

Operator overloading

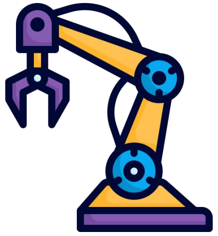


- Writing conversion operators

```
class
Complex
{ public:
  operator string() const;
  //
};

Complex::operator string()
    const{ stringstream ss;
    ss<<this->re<<"+"<<this->im<<"i";
    return ss.str();
}
```

```
//usage
 Complex z(1, 2);
 string a = z;
 cout<<a<<endl;
```

- After templates
  - Overloading operator *
  - Overloading operator →



- Find all possible errors or shortcommings!

```
class Array
{ public:
  Array (int n) : rep_(new int [n]) { }
  Array (Array& rhs) : rep_(rhs.rep_) { }
  ~Array () { delete rep_; }
  Array& operator = (Array rhs) { rep_= rhs.rep_;   }
  int& operator [] (int n) { return &rep_[n]; }
private:
  int * rep_;
}; // Array
```

Source: http://www.cs.helsinki.fi/u/vihavain/k13/gea/exer/exer_2.html

Solution required!

- It is given the following program!

```
#include <iostream>

int main(){
    std::cout<<"Hello\n";
    return 0;
}
```

Modify the program *without modifying the main function* so that the output of the program would be:

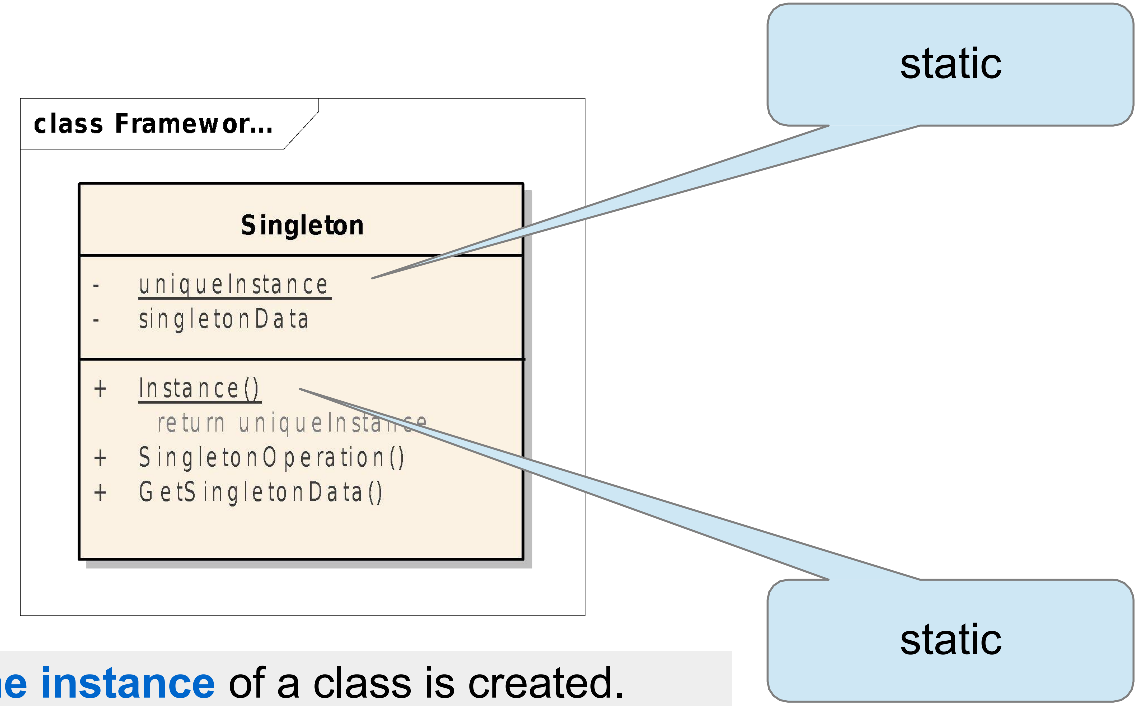
```
Start
Hello
Stop
```

Singleton Design Pattern

```
#include <string>
class
Logger{   public:
     static Logger* Instance();
     bool openLogFile(std::string logFile);
     void writeToLogFile();
     bool closeLogFile();
private:
     Logger(){};   // Private so that it can  not be called
     Logger(Logger const&){}; // copy constructor is private
     Logger& operator=(Logger const&){};// assignment operator is private
     static Logger* m_pInstance;
};
```

http://www.yolinux.com/TUTORIALS/C++Singleton.html

Singleton Design Pattern

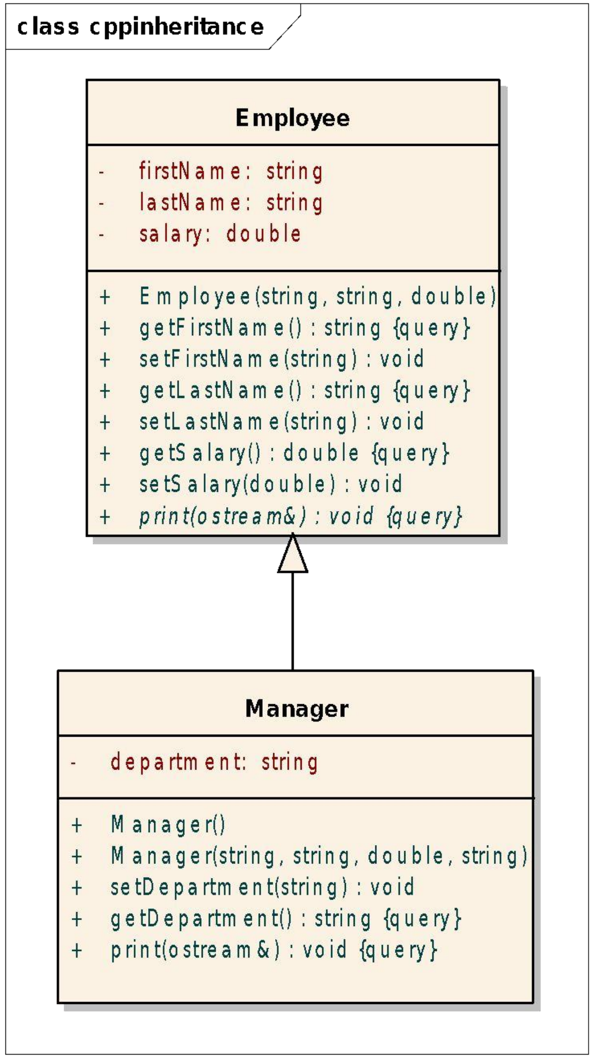


- Ensure that **only one instance** of a class is created.
- Provide a **global point of access** to the object.

- Inheritance
  - *is-a* relationship - public inheritance
  - protected access
  - virtual member function
  - early (static) binding vs. late (dynamic) binding
  - abstract base classes
  - pure virtual functions
  - virtual destructor

Inheritance

- `public` inheritance
  - *is-a* relationship
  - base class: Employee
  - derived class: Manager
- You can do with inheritance
  - *add data*
    - ex. `department`
  - *add functionality*
    - ex. `getDepartment()`, `setDepartment()`
  - *modify methods' behavior*
    - ex. `print()`



- `protected` access
  - base class's private members can not be accessed in a derived class
  - base class's protected members can be accessed in a derived class
  - base class's public members can be accessed from anywhere

- `public` inheritance

```
class
Employee
{ public:
    Employee(string firstName = "", string lastName = "",
             double salary = 0.0) : firstName(firstName),
                                    lastName(lastName),
                                    salary(salary) {
    }
    //...
};
```

```
class Manager:public
    Employee{ string
    department;
public:
    Manager();
    Manager( string firstName, string lastName, double salary,
             string department );
    //...
};
```

- Derived class's constructors

```
Manager::Manager(){
}
```

↑

Employee's constructor invocation → Default constructor can be invoked implicitly

– Derived class's constructors

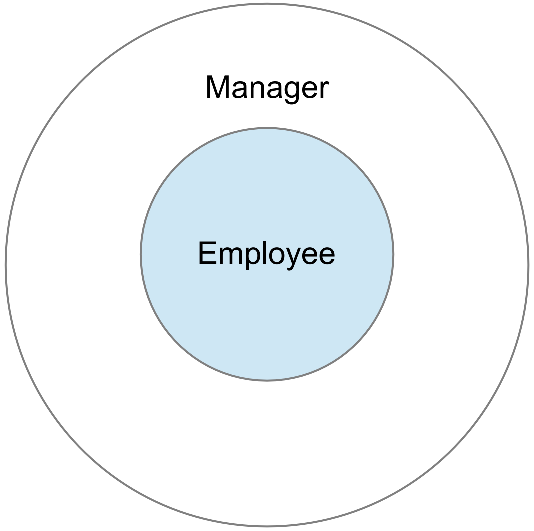
```
Manager::Manager(){
}
```

Employee's constructor invocation → Default constructor can be invoked implicitly

```
Manager::Manager(string firstName, string lastName, double salary,
                 string department):Employee(firstName, lastName, salary),
                                     artment(department){


}
```

base class's constructor invocation – *constructor initializer list*
arguments for the base class's constructor are specified in the definition of a derived class's constructor

- How are derived class's objects constructed?
  - *bottom up* order:
    - base class constructor invocation
    - member initialization
    - derived class's constructor block
  - destruction
    - in the opposite order



- Method overriding

```
class
Employee
{ public:
     virtual void print(ostream&) const;
};
```

```
class Manager:public
Employee{ public:

    virtual void print(ostream&) const;
};
```

- Method overriding

```
class Employee
{ public:
     virtual void print( ostream&) const;
};
```

```
void Employee::print(ostream& os ) const{
    os<<this->firstName<<" "<<this->lastName<<" "<<this->salary;
}
```

```
class Manager:public
Employee{ public:
    virtual void print(ostream&) const;
};
```

```
void Manager::print(ostream& os) const{
    Employee::print(os);
    os<<" "<<department;
}
```

- Method overriding - virtual functions
  - non virtual functions are bound statically
    - compile time
  - virtual functions are bound dynamically
    - run time

- Polymorphism

```
void printAll( const vector<Employee*>&
     emps ){   for( int i=0; i<emps.size();
     ++i){
          emps[i]-> print(cout);
          cout<<endl;
     }
}

int main(int argc, char** argv)
     { vector<Employee*> v;
     Employee e("John", "Smith", 1000);
     v.push_back(&e);
     Manager m("Sarah", "Parker", 2000, "Sales");
     v.push_back(&m);
     cout<<endl;
     printAll( v );
     return 0;
}
```

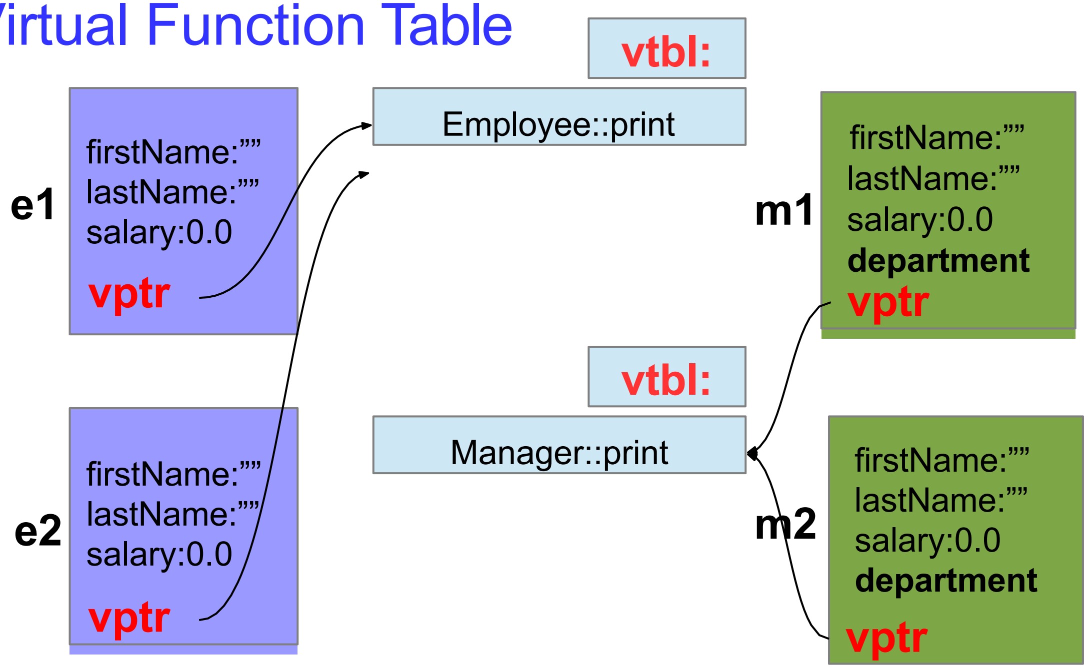
Output:

```
John Smith 1000
Sarah Parker 2000 Sales
```

- Polymorphism
  - a type with virtual functions is called a polymorphic type
  - polymorphic behavior **preconditions**:
    - the member function must be virtual
    - objects must be manipulated through
      - pointers or
      - references
    - `Employee :: print( os )` static binding – no polymorphism

– Polymorphism – Virtual Function Table

```
class
Employee
{ public:
 virtual void print(ostream&) const;
      //...
};

class Manager:public
 Employee{  virtual void
 print(ostream&) const;
      //...
};
Employee e1, e2;
Manager m1, m2;
```



Discussion!!!

```
Employee * pe;
pe = &e1; pe->print(); //???
pe = &m2; pe->print(); //???
```

Each class with virtual functions has its own virtual function table (vtbl).

dynamic_cast<>(pointer)

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

Base* basePointer = new Derived();
Derived* derivedPointer = nullptr;

//To find whether basePointer is pointing to Derived type of object

derivedPointer = dynamic_cast<Derived*>(basePointer);
if (derivedPointer != nullptr){
   cout << "basePointer is pointing to a Derived class object";
}else{
   cout << "basePointer is NOT pointing to a Derived class object";
}
```

Java:
instanceof

ROBOTICS CORNER

dynamic_cast<>(reference)

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

Derived derived;
Base& baseRef = derived;

// If the operand of a dynamic_cast to a reference isn't of the expected type,
//  a bad_cast exception is thrown.

try{
        Derived& derivedRef = dynamic_cast<Derived&>(baseRef);
} catch( bad_cast ){
        // ..
}
```

- Abstract classes
  - used for representing abstract concepts
  - used as a base class for other classes
  - no instances can be created

- Abstract classes – pure virtual functions

```
class Shape{ // abstract class
    public:
        virtual void rotate(int)  = 0;      // pure virtual function
        virtual void draw()  = 0;  // pure virtual function
        // ...
};
```

```
 Shape s; //???
```

- Abstract classes – pure virtual functions

```
class Shape{ // abstract class
    public:
        virtual void rotate(int)  = 0;      // pure virtual function
        virtual void draw()  = 0;  // pure virtual function
        // ...
};
```

```
 Shape s;  //Compiler error
```

- Abstract class → concrete class

```
class Point{ /* ... */ };
class Circle : public Shape {
    public:
        void rotate(int);          // override Shape::rotate
        void draw();               // override Shape::draw
        Circle(Point p, int r) ;
    private:
        Point center;
        int radius;
};
```

- Abstract class → abstract class

```
class Polygon : public Shape
{   public:
      // draw() and rotate() are not overridden

};
```

```
Polygon p;  //Compiler error
```

- Virtual destructor
  - Every class having at least one virtual function should have virtual destructor. Why?

```
class
X
{
public:
    // ...
    virtual ~X();
};
```

- Virtual destructor

```
void deleteAll( Employee ** emps, int
    size){ for( int i=0; i<size; ++i){
        delete emps[ i ];
    }
    delete [] emps;
}

 // main
 Employee ** t = new Employee *[ 10 ];
 for(int i=0; i<10; ++i){
    if( i % 2 == 0 )
        t[ i ] = new Employee();
    else
        t[ i ] = new Manager();
 }
 deleteAll( t, 10);
```

Which destructor is invoked?

05

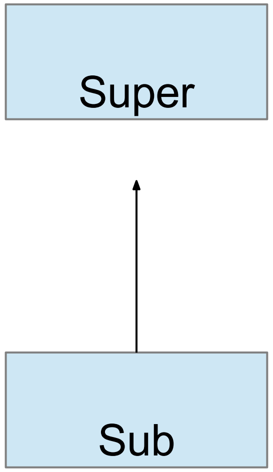
Object relationships

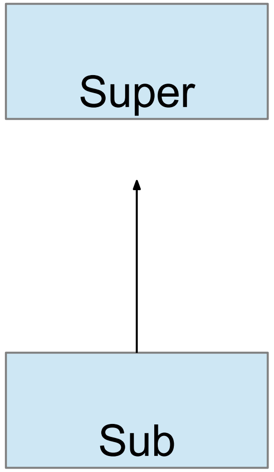
- The ***is-a*** relationship
  - Private inheritance
  - Multiple inheritance

- The ***has-a*** relationship
  - Association
    - Composition (strong containment)
    - Aggregation (weak containment)

- The *is-a* relationship – *Client's view (1)*
  - works in only *one direction:*
    - every **Sub** object **is** also **a Super** one
    - but **Super** object **is not a Sub**

```
void foo1( const Super& s );
void foo2( const Sub& s);
Super super;
Sub sub;

foo1(super); //OK
foo1(sub);   //OK
foo2(super); //NOT OK
foo2(sub);   //OK
```

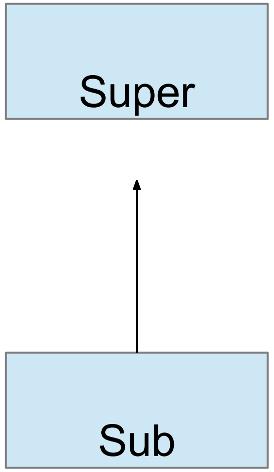




- The *is-a* relationship – *Client's view (2)*

```
class
Super
{ public:
   virtual void method1();
};
class Sub : public
Super{ public:
   virtual void method2();
};
```

```
Super * p= new Super();
p->method1(); //OK

p = new Sub();
p->method1(); //OK
p->method2(); //NOT OK
((Sub *)p)->method2();//OK
```



- The *is-a* relationship – *Sub-class's view*

  - the `Sub` class augments the `Super` class by **adding additional methods**
  - the `Sub` class **may override** the `Super` class **methods**
  - the subclass can use all the public and protected members of a superclass.

- The *is-a* relationship: *preventing inheritance* ***C++11***
  - `final` classes – cannot be extended

```
class Super final
{

};
```

- The *is-a* relationship: *a client's view of overridden methods(1)*
  - *polymorphism*

```
class
Super
{ public:
    virtual void method1();
};
class Sub : public
Super{ public:
    virtual void method1();
};
```

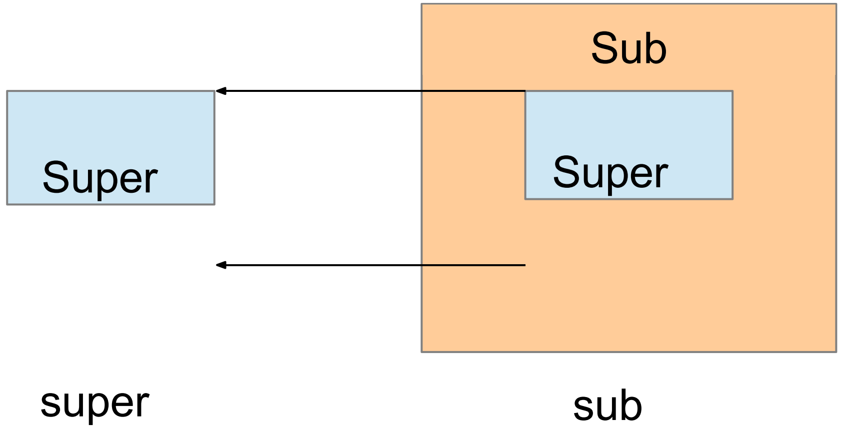
```
Super super;
super.method1(); //Super::method1()

Sub sub;
sub.method1();    //Sub::method1()

Super& ref =super;
ref.method1();    // Super::method1();

ref = sub;
ref.method1();    // Sub::method1();

Super* ptr =&super;
ptr->method1(); // Super::method1();

ptr = &sub;
ptr->method1();    // Sub::method1();
```

ROBOTICS CORNER

- The *is-a* relationship: *a client's view of overridden methods(2)*
  - object slicing

```
class
Super
{ public:
    virtual void method1();
};
class Sub : public
Super{ public:
    virtual void method1();
};
```

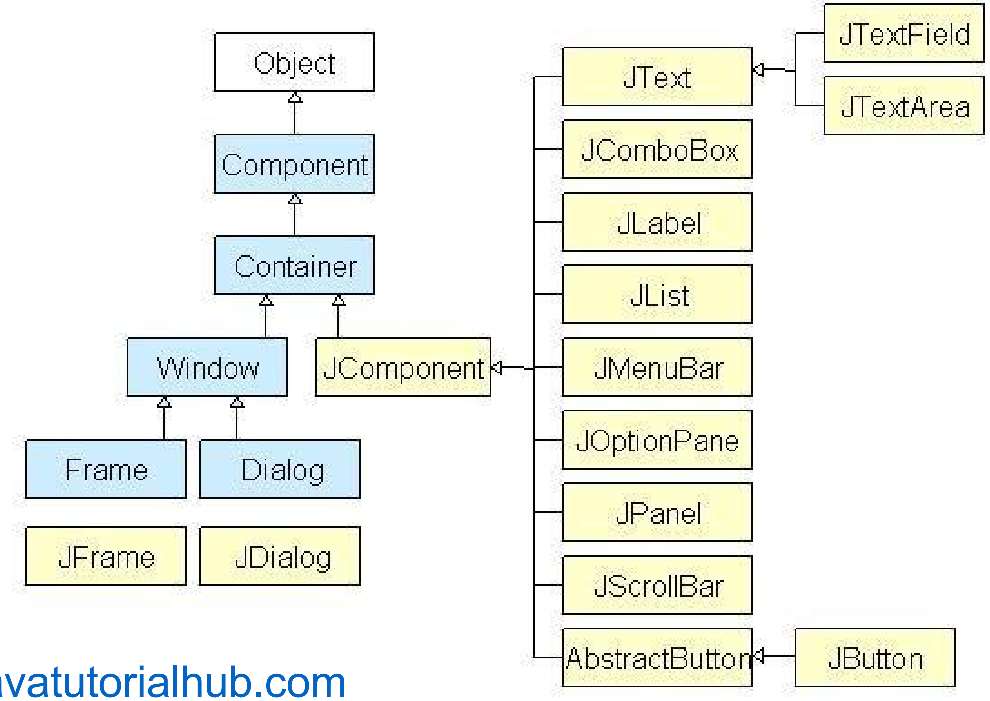
```
Sub sub;
Super super = sub;
super.method1(); // Super::method1();
```



- The *is-a* relationship: *preventing method overriding* ***C++11***

```
class
Super
{ public:
    virtual void method1() final;
};
class Sub : public
Super{ public:
    virtual void method1(); //ERROR
};
```

- Inheritance for polymorphism



www.javatutorialhub.com

- The *has-a* relationship

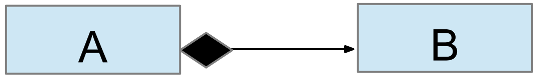
- Implementing the *has-a* relationship
  - An object **A** has an object **B**

```
class B;

class
A
{
privat
e:
    B b;
};
```

```
class B;

class
A
{
privat
e:
    B*  b;
};
```

```
class B;

class
A
{
privat
e:
    B&  b;
};
```

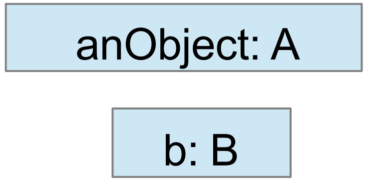
- Implementing the *has-a* relationship



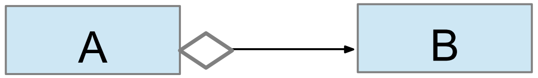
  - An object **A** has an object **B**
    - **strong containment (composition)**

```
class B;

class
A
{
private:
    B b;
};
```

```
A anObject;
```



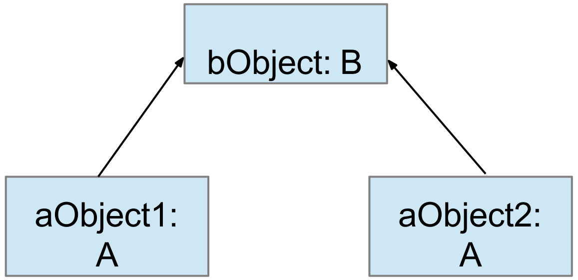
- Implementing the *has-a* relationship



  - An object **A** has an object **B**
    - **weak containment (aggregation)**

```
class B;

class
A
{
private:
    B& b;
public:
    A( const B& pb):b(pb){}
};
```

```
B bObject;
A aObject1(bObject);
A aObject2(bObject);
```



- Implementing the *has-a* relationship
  - An object **A** has an object **B**

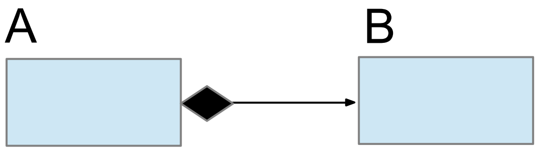
weak containment

```
class B;

class A{
private:
      B* b;
public:
      A( B* pb):b( pb ){}
};
```

strong containment

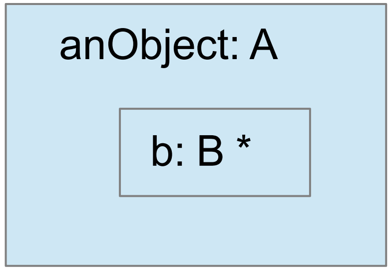
```
class B;

class A{
private:
      B* b;
public:
      A(){
            b = new B();
      }
      ~A(){
            delete b;
      }
};
```

- Implementing the *has-a* relationship
  - An object **A** has an object **B strong containment**



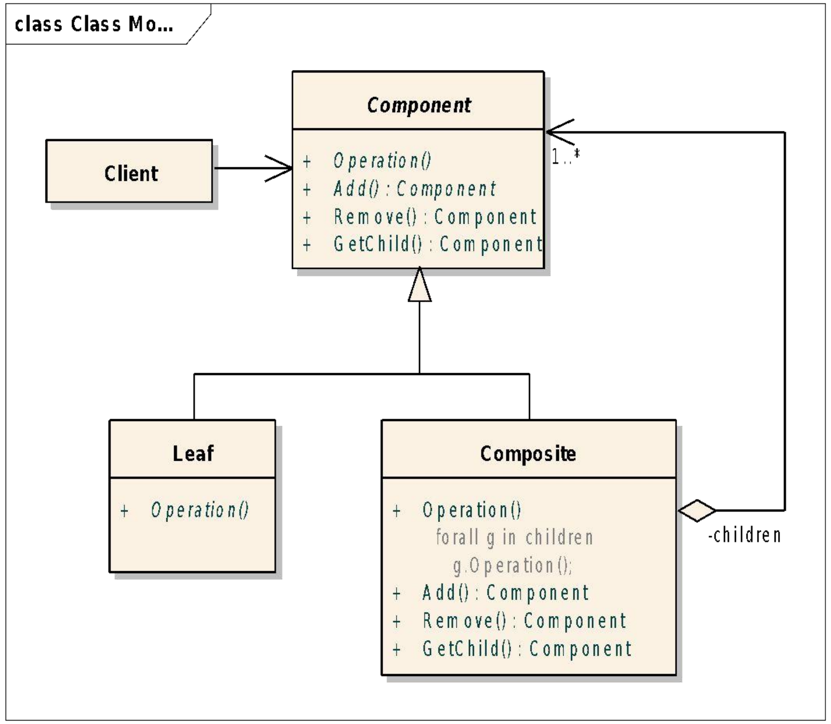

```
class B;

class A{ private:
     B* b; public:
     A(){
          b = new B();
     }
     ~A(){
          delete b;
     }
};
```

```
Usage:
     A aObject;
```



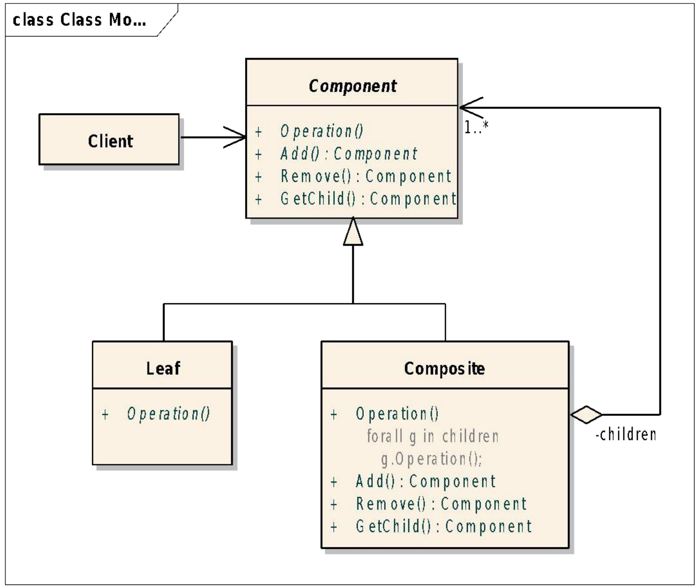
05 Object relationships

- Combining the *is-a* and the *has-a* relationships



05

Object relationships



- Compose objects into tree structures to represent **part-whole hierarchies.**
- Let clients treat **individual objects** and the **composition of objects uniformly.**

Composite Design Pattern

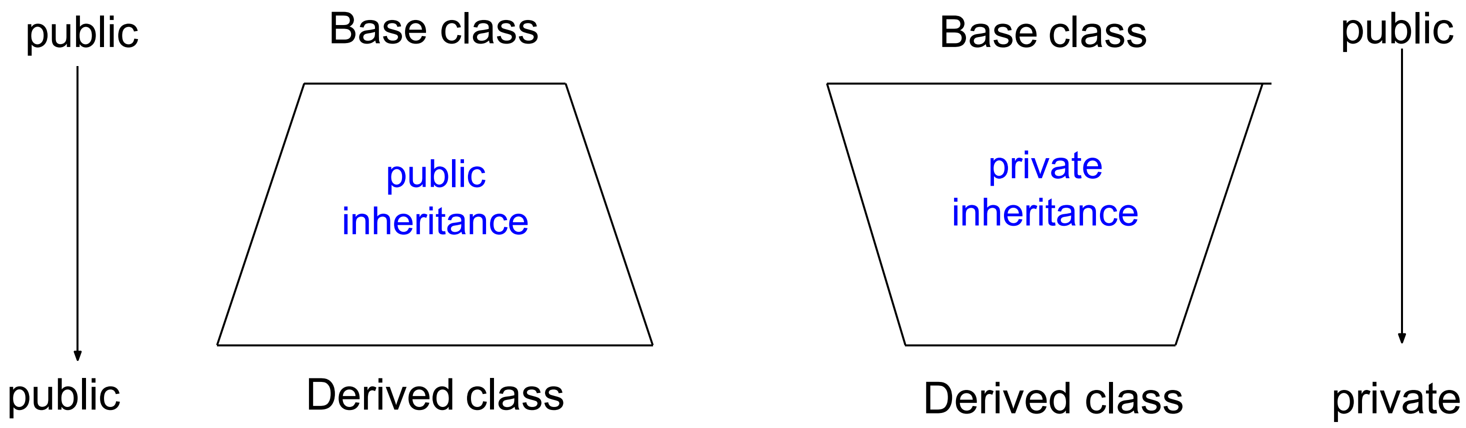
Examples:

- Menu – MenuItem: Menus that contain menu items, each of which could be a menu.
- Container – Element: Containers that contain Elements, each of which could be a Container.
- GUI Container – GUI component: GUI containers that contain GUI components, each of which could be a container

Source: http://www.oodesign.com/composite-pattern.html

Private Inheritance

– another possibility for *has-a* relationship



Derived class **inherits** the base class behavior

Derived class **hides** the base class behavior

Private Inheritance

```
template <typename T>
class MyStack : private vector<T>
{ public:
    void push(T elem) {
        this->push_back(elem);
    }
    bool isEmpty() {
        return this->empty();
    }
    void pop() {
        if (!this->empty())this->pop_back();
    }
    T top() {
        if (this->empty()) throw out_of_range("Stack is empty");
        else return this->back();
    }
};
```

Why is **public inheritance** in this case dangerous???

Non-public Inheritance

- it is very rare;
- use it cautiously;
- most programmers are not familiar with it;

What does it print?

```
class
Super
{ public:
    Super(){}
    virtual void someMethod(double d)
            const{ cout<<"Super"<<endl;
     }
};
class Sub : public
Super{ public:
    Sub(){}
    virtual void someMethod(double
            d){ cout<<"Sub"<<endl;
     }
};

Sub sub; Super super;
Super& ref = sub;ref.someMethod(1);
ref = super; ref.someMethod(1);
```

What does it print?

```
class
Super
{ public:
    Super(){}
    virtual void someMethod(double d)
    }        const{ cout<<"Super"<<endl;
};
class Sub : public Super{
public:
    Sub(){}
    virtual void someMethod(double
             d){ cout<<"Sub"<<endl;
    }
};

Sub sub; Super super;
Super& ref = sub;ref.someMethod(1);
ref = super; ref.someMethod(1);
```

creates a new method, instead of overriding the method

The override keyword

C++11

```
class
Super
{ public:
    Super(){}
    virtual void someMethod(double d)
            const{ cout<<"Super"<<endl;
     }
};
class Sub : public
Super{ public:
    Sub(){}
    virtual void someMethod(double d) const
            override{ cout<<"Sub"<<endl;
     }
};

Sub sub; Super super;
Super& ref = sub;ref.someMethod(1);
ref = super; ref.someMethod(1);
```

Thank You

Do you have any questions?

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