CPP

Modern C++
Object-Oriented Programming

"Combine old and newer features to get the best out of the language"

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Course Content

1. Introduction to C++

Object-Oriented Programming	**Generic Programming**
2. Classes and objects	7. Templates
3. Advanced class features	8. STL – Standard Template Library
4. Operator overloading	9. Function objects
5. Public inheritance	10. Advanced C++
6. Object relationships	11. I/O streams

C++ - Object-Oriented Programming

References

- Bjarne Stroustrup, Herb Sutter, C++ Core Guidelines, **2017.**
- M. **Gregoire**, *Professional C++*, 3rd edition, John Wiley & Sons, **2014**.
- S. **Lippman**, J. Lajoie, B. E. Moo, *C++ Primer*, 5th edition, Addison Wesley, , **2013**.
- S. **Prata**, *C++ Primer Plus*, 6th edition, Addison Wesley, **2012**.
- N. **Josuttis**, *The C++ standard library. a tutorial and reference.* Pearson Education. **2012.**
- A. **Williams**, C++ Concurrency in Action:Practical Multithreading. Greenwich, CT: Manning. **2012.**

Module 1

Introduction to C++

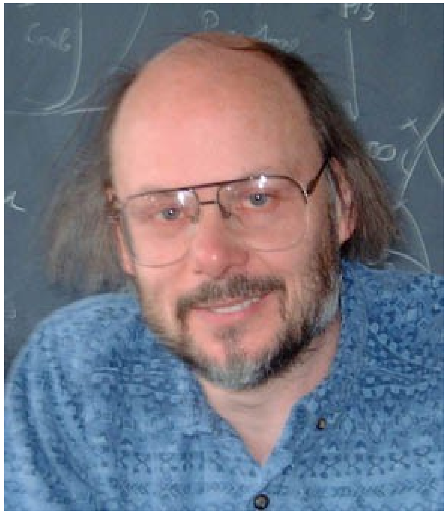
Introduction to C++

Content

- History and evolution
- Overview of the key features
  - New built-in types
  - Scope and namespaces
  - Enumerations
  - Dynamic memory: `new` and `delete`
  - Smart pointers: `unique_ptr, shared_ptr..`
  - Error handling with exceptions
  - References
  - The `const` modifier

Introduction to C++

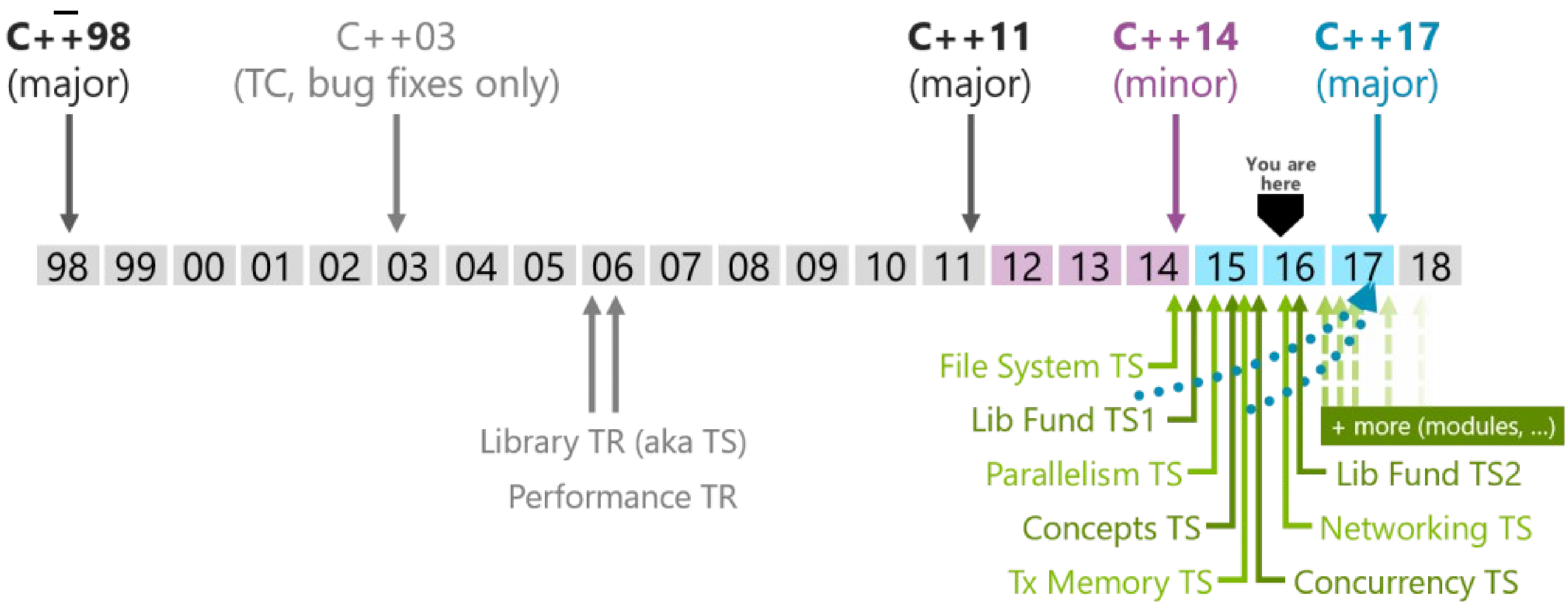
History and evolution



- Creator: Bjarne Stroustrup 1983
- Standards:
  - The first C++ standard
    - 1998 (C++98, major)
    - 2003 (C++03, minor)
  - The second C++ standard
    - 2011 (C++11, major) – significant improvements in language and library
    - 2014 (C++14, minor)

Introduction to C+

History and evolution



source: https://isocpp.org/std/status

Introduction to C++

Standard library

- C++ standard library = C standard library + STL (Standard Template Library)
- STL – designed by Alexander Stepanov, provides:
  - Containers: list, vector, set, map …
  - Iterators
  - Algorithms: search, sort, …

Introduction to C++

Philosophy

- Statically typed
- General purpose
- Efficient
- Supports multiple programming styles:
  - Procedural programming
  - Object-oriented programming
  - Generic programming

Introduction to C++

Portability

- Recompilation without making changes in the source code means portability.
- Hardware specific programs are usually not portable.

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Creating a program

- Use a text editor to write a program and save it in a file → *source code*
- Compile the source code (compiler is a program that translates the source code to machine language) → *object code*
- Link the object code with additional code (*libraries*) → *executable code*

Introduction to C++

Creating a program (using GNU C++ compiler, Unix)

- Source code: `hello.cpp`
- Compile: `g++ -c hello.cpp`
  - Output: `hello.o` (object code)
- Compile + Link: `g++ hello.cpp`
  - Output: `a.out` (executable code)
- C++ 2014: **`g++ hello.cpp -std=c++14`**

Introduction to C++

The first C++ program

One-line comment

Preprocessor directive

The main function

I/O streams

```
//hello.cpp

#include <iostream>
using namespace std;

int main(){
    cout<<"Hello"<<endl;
    return 0;
}
```

```
#include <iostream>

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

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Building a C++ program: 3 steps

- preprocessor (line starting with #)
- compiler
- linker

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Most common preprocessor directives

- `#include [file]`
  - the specified `file` is inserted into the code
- `#define [key] [value]`
  - every occurrence of the specified `key` is replaced with the specified `value`
- `#ifndef [key] … #endif`
  - code block is conditionally included

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Header files

- C++ header
  - `#include <iostream>`
- C header
  - `#include <cstdio>`
- User defined header
  - `#include "myheader.h"`

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Avoid multiple includes

```
//myheader.h

#ifndef MYHEADER_H
#define MYHEADER_H

// the contents

#endif
```

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The `main()` function

- `int main(){ … }`

or

- `int main( int argc, char* argv[] ){ … }`

Result status

The number
of arguments

The arguments

Introduction to C++

I/O Streams

- `cout`: standard output

```
cout<<"Hello, world!"<<endl;
```

End of line

- `cin`: standard input

```
int i; double d;
cin >> i >> d;
```

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Namespaces

- avoid naming conflicts

```
//my1.h
namespace myspace1{
   void foo();
}
```

```
//my2.h
namespace myspace2{
   void foo();
}
```

```
//my1.cpp
#include "my1.h"
namespace myspace1{
   void foo(){
       cout<<"myspace1::foo\n";
   }
}
```

myspace1::foo()

```
//my2.cpp
#include "my2.h"
namespace myspace2{
   void foo(){
       cout<<"myspace2::foo\n";
   }
}
```

myspace2::foo()

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Variables

- can be declared almost anywhere in your code

```
double d;   //uninitialized
int i = 10; //initialized
```

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Variable types

- `short, int, long` – range depends on compiler, but usually `2, 4, 4 bytes`
- `long long` (C++11) – range depends on compiler – usually `8 bytes`
- `float, double, long double`
- `bool`
- `char, char16_t`(C++11), `char32_t`(C++11), `wchar_t`
- `auto` (C++11) – the compiler decides the type automatically (`auto i=7;`)
- `decltype(expr)` (C++11)

```
int i=10;
decltype(i) j = 20; // j will be int
```

Introduction to C++

Variable types

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

int main(int argc, char** argv) {
    cout<<"short    : "<<sizeof( short)<<" bytes"<<endl;
    cout<<"int      : "<<sizeof( int ) <<" bytes"<<endl;
    cout<<"long     : "<<sizeof( long) <<" bytes"<<endl;
    cout<<"long long: "<<sizeof( long long)<<" bytes"<<endl;
    return 0;
}
```

Introduction to C++

- C++0x/C++11 Support in GCC
  - https://gcc.gnu.org/projects/cxx0x.html

- Online C++ compilers:
  - http://isocpp.org/blog/2013/01/online-c-compilers
  - http://www.tutorialspoint.com/compile_cpp11_online.php

Introduction to C++

C enumerations (*not type-safe*)

- always interpreted as integers →
  - you can compare enumeration values from completely different types

```
enum Fruit{ apple, strawberry, melon};

enum Vegetable{ tomato, cucumber, onion};

void foo(){
    if( tomato == apple){
        cout<<"Hurra"<<endl;
    }
}
```

Introduction to C++

C++ enumerations (*type-safe*)

```
enum class Mark {
    Undefined, Low, Medium, High
};

Mark myMark( int value ){
    switch( value ){
        case 1: case2: return Mark::Low;
        case 3: case4: return Mark::Medium;
        case 5: return Mark::High;
        default:
            return Mark::Undefined;
    }
}
```

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Range-based `for` loop

```
int elements[]={1,2,3,4,5};

for( auto& e: elements){
    cout<<e<<endl;
}
```

Introduction to C++

The `std::array`

- replacement for the standard C-style array
- cannot grow or shrink at run time

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

int main() {
    array<int, 5 > arr = {10, 20, 30, 40, 50};
    cout << "Array size = " << arr.size() << endl;
    for(int i=0; i<arr.size(); ++i){
        cout<<arr[ i ]<<endl;
    }
}
```

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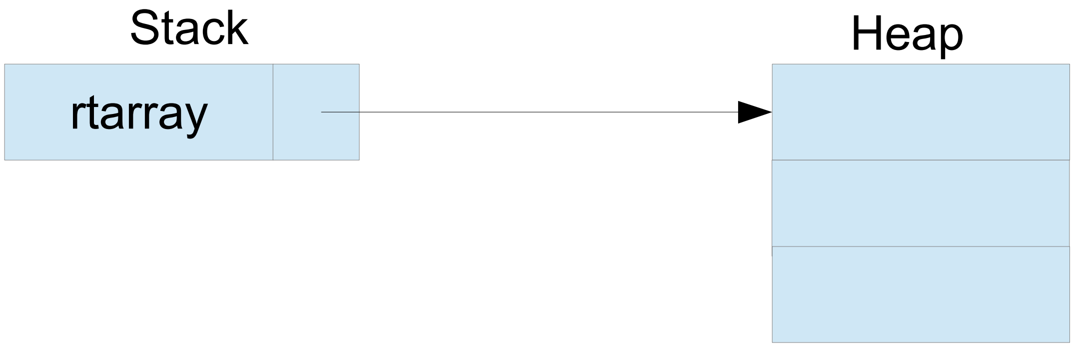
Pointers and dynamic memory

- compile time array

```
int ctarray[ 3 ]; //allocated on stack
```

- run time array

```
int * rtarray = new int[ 3 ]; //allocated on heap
```



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Dynamic memory management

- allocation

```
int * x = new int;
int * t = new int [ 3 ];
```

- deletion

```
delete x;
delete [] t;
```

Introduction to C++

Strings

- `C-style` strings:
  - array of characters
  - `'\0'` terminated
  - functions provided in `<cstring>`
- `C++ string`
  - described in `<string>`

```
string firstName = "John"; string lastName = "Smith";

string name = firstName+ " "+ lastName; cout<<name<<endl;
```

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References

- A reference defines an *alternative name (alias)* for an object.
- A reference *must be initialized.*
- Defining a reference = binding a reference to its initializer

```
int i = 10;

int &ri = i; //OK   ri refers to (is another name for) i

int &ri1;    //ERROR: a reference must be initialized
```

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Operations on references

- the operation is always performed on the referred object

```
int i = 10;

int &ri = i;

++ri;

cout<<i<<endl;  // outputs 11

++i;

cout<<ri<<endl; // outputs 12
```

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References as function parameters

- to permit *pass-by-reference:*
  - allow the function to modify the value of the parameter
  - avoid copies

```
void inc(int &value)
{
    value++;
}

usage:
int x = 10;
inc( x );
```

```
bool isShorter(const string &s1,
               const string &s2)
{
    return s1.size() < s2.size();
}
usage:
string str1 ="apple";
string str2 ="nut";
cout<<str1<<"<"<<str2<<": " <<
isShorter(str1, str2);
```

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Exceptions

- Exception = unexpected situation

- Exception handling = a mechanism for dealing with problems

  - *throwing* an exception – detecting an unexpected situation

  - *catching* an exception – taking appropriate action

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Exceptions

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

double divide( double m, double n){
    if( n == 0 ){
        throw std::exception();
    }else{
        return m/n;
    }
}

int main() {
    try{
        cout<<divide(1,0)<<endl;
    }catch( const exception& e){
        cout<<"Exception was caught!"<<endl;
    }
}
```

Introduction to C++

The `const` modifier

- Defining constants

```
const int N =10;
int t[ N ];
```

- Protecting a parameter

```
void sayHello( const string& who){
    cout<<"Hello, "+who<<endl;
    who = "new name";
}
```

Compiler error

Uniform initialization (C++ 11)

brace-init

```
int n{2};

string s{"alma"};

map<string,string> m {
                       {"England","London"},
                       {"Hungary","Budapest"},
                       {"Romania","Bucharest"}
                      };
struct Person{
   string name;
   int age;
};
Person p{"John Brown", 42};
```

Introduction to C++

Using the standard library

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

int main() {
    vector<string> fruits = {"apple","melon"};
    fruits.push_back("pear");
    fruits.push_back("nut");
    // Iterate over the elements in the vector and print them
    for (auto it = fruits.cbegin();
              it != fruits.cend(); ++it) {
        cout << *it << endl;
    }
    //Print the elements again using C++11 range-based for loop
    for (auto& str : fruits)
          cout << str << endl;
    return 0;
}
```

Introduction to C++

Programming task:

- Write a program that reads one-word strings from the standard input, stores them and finally prints them on the standard output
- Sort the container before printing
  - use the `sort` algorithm

```
#include <algorithm>
...
vector<string> fruits;
...
sort(fruits.begin(),fruits.end());
```

–

Module 2

Object-Oriented Programming

Classes and Objects

Object-Oriented Programming (OOP)

Content

- Classes and Objects
- Advanced Class Features
- Operator overloading
- Object Relationships
- Abstraction

OOP: Classes and Objects

Content

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

OOP: Types of Classes

Types of calsses:

- **Polymorphic** Classes:
  - `Shape, exception`, ...
- **Value** Classes:

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  - `int, complex<double>, ...`
- **RAAI** (**R**esource **A**cquisition **I**s **I**nitialization) Classes:

  (RAAI meaning: resource lifetime → object lifetime)
  - `thread, unique_ptr, ...`

OOP: Classes and objects

Class = Type (Data + Operations)

- Members of the class
- **Data:**
  - data members (properties)

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- **Operations:**
  - methods (behaviors)
- Each member is associated with an **access level**:
  - `private` **-**
  - `public` **+**
  - `protected` **#**

OOP: Classes and objects

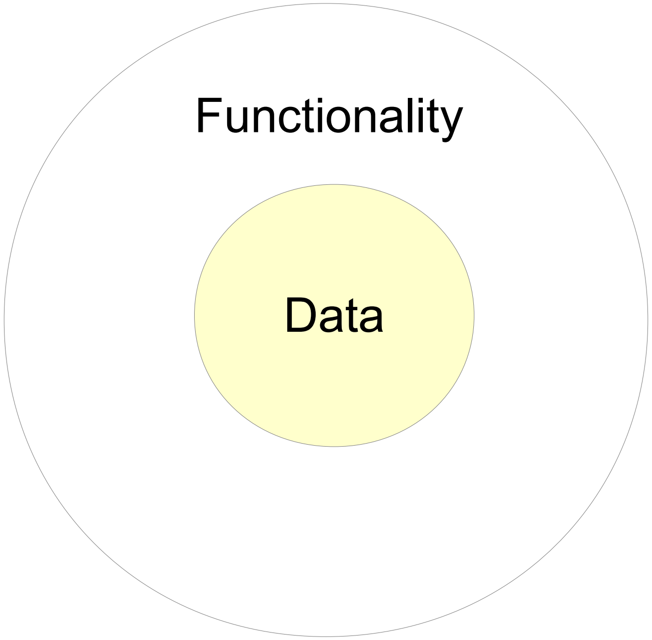
Object = Instance of a class

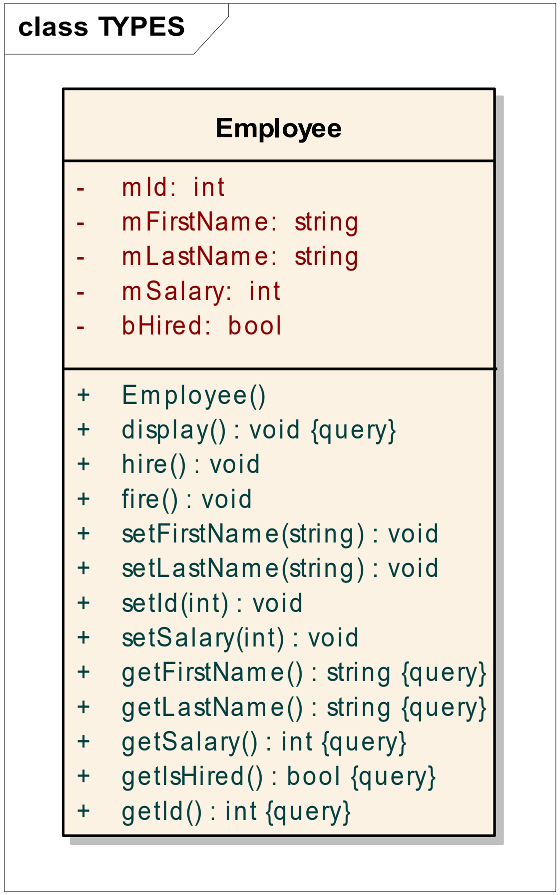
- An employee object: `Employee emp;`
  - **Properties** are the characteristics that describe an object.
    - *What makes this object different?*
      - `id, firstName, lastName, salary, hired`
  - **Behaviors** answer the question:
    - *What can we do to this object?*
      - `hire(), fire(), display(),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

OOP: Classes and objects

Encapsulation

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





OOP: Classes and objects

Class creation

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

OOP: Classes and objects

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

OOP: Classes and objects

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!!!

OOP: Classes and objects

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

OOP: Classes and objects

Member initialization (C++11)

```
class C
{
    string s ("abc");
    double d = 0;
    char * p {nullptr};
    int y[5] {1,2,3,4};
public:
    C();
};
```

```
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} {}
};
```

Compiler

OOP: Classes and objects

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;
}
```

OOP: Classes and objects

Defining a member function

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

OOP: Classes and objects

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;
}
```

OOP: Classes and objects

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;
}
```

OOP: 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;
}
/
/ ...
```

OOP: Classes and objects

Object life cycles:

- creation
- assignment
- destruction

OOP: Classes and objects

Object creation:

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

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

object's lifecycle

- when an object is created,
  - one of its *constructors* is executed,
  - all its *embedded objects* are also created

OOP: Classes and objects

Object creation – constructors:

- *default constructor* (0-argument constructor)

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

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

- when you need
  - `Employee employees[ 10 ];`
  - `vector<Employee>  emps;`

- memory allocation
- constructor call on each allocated object

OOP: Classes and objects

Object creation – constructors:

- *Compiler-generated default constructor*

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

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

OOP: Classes and objects

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.

OOP: Classes and objects

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

```
class X{
public:
    X( int x ){}
};

X x1(10); //OK
X x2(3.14); //OK
```

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

`double` → `int` conversion

Inhibiting the automatic generation of a **default** constructor by the compiler.

OOP: Classes and objects

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
```

OOP: Classes and objects

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

OOP: Classes and objects

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

OOP: Classes and objects

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){
}
```

OOP: Classes and objects

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

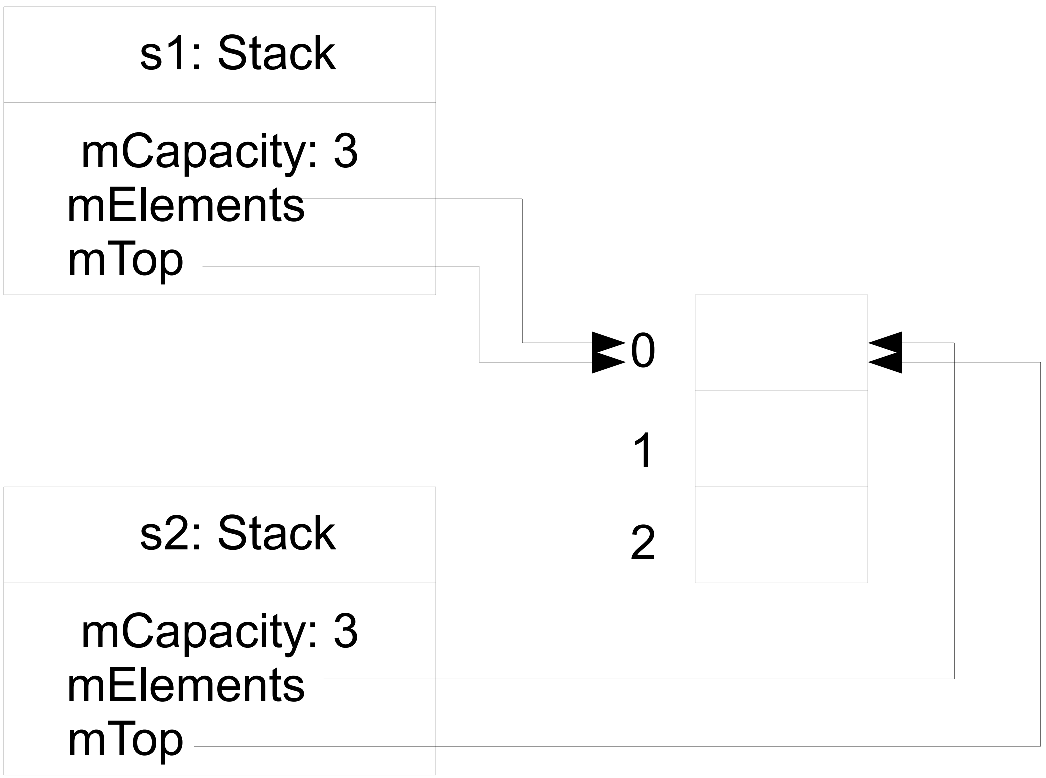
OOP: Classes and objects

```
//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 */
```

```
//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++;
     }
 }
```

OOP: Classes and objects

```
//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;
}
```



OOP: Classes and objects

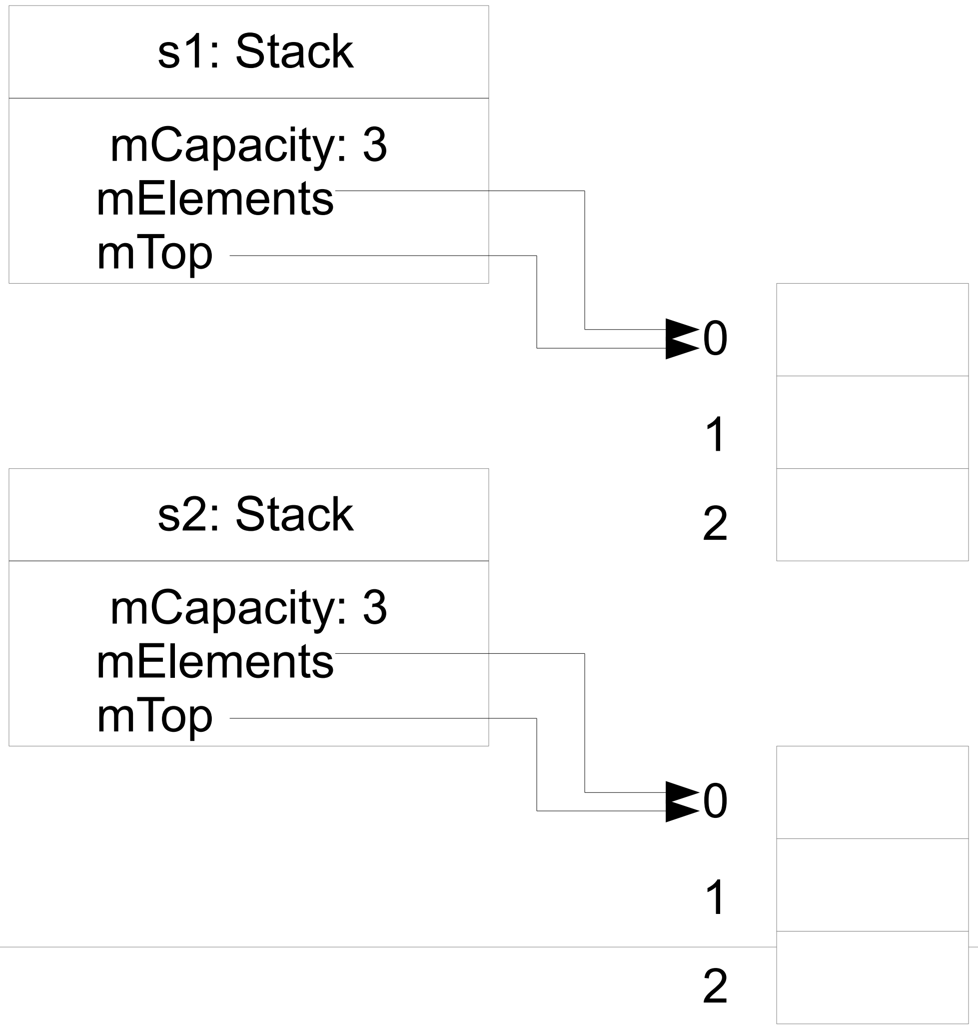
Copy constructor: `T ( const T&)`

```
//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;
 }
```

OOP: Classes and objects

```
//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;
}
```



OOP: Classes and objects

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

OOP: Classes and objects

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
```

OOP: Classes and objects

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
```

OOP: Classes and objects

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;
      //..
}
```

OOP: Classes and objects

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
};
```

OOP: Classes and objects

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

};
```

Module 3

Object-Oriented Programming

Advanced Class Features

OOP: Advanced class features

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)

OOP: Advanced class features

`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

OOP: Advanced class features

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

OOP: Advanced class features

`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;
   }
};
```

OOP: Advanced class features

- 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);
    //...
}
```

OOP: Advanced class features

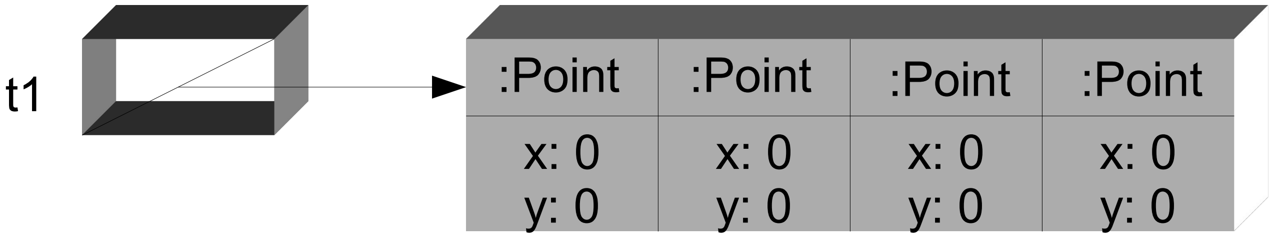
Array of objects

```
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];

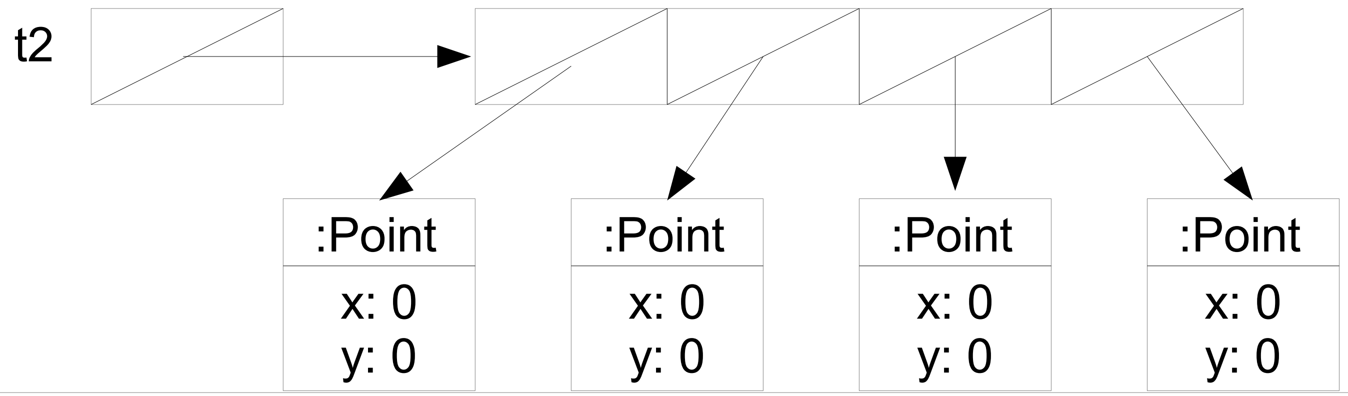
Point t1[4];



OOP: Advanced class features

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;
}
```



OOP: Advanced class features

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

OOP: Advanced class features

– Static members

initializing static class member

```
//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

```
//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;
}
```

OOP: Advanced class features

- Static method invocation

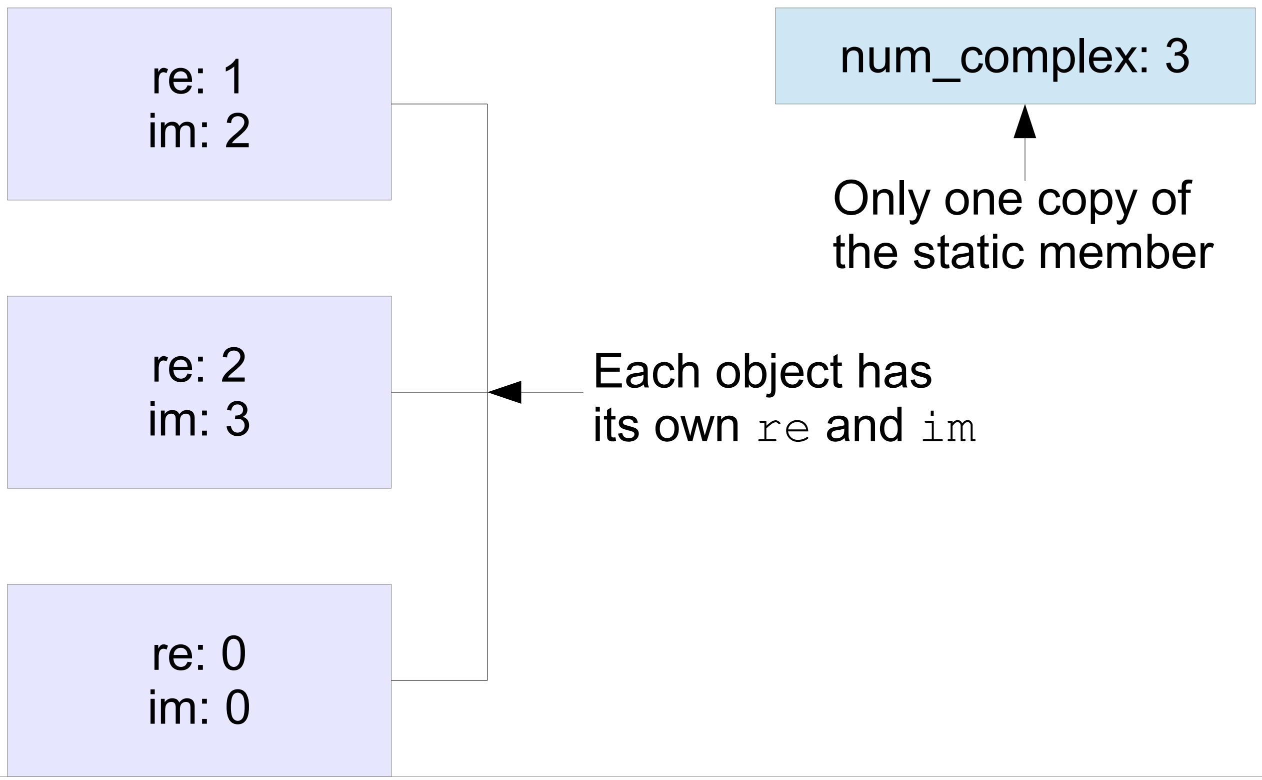
elegant

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

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

non - elegant

OOP: Advanced class features

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



OOP: Advanced class features

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

OOP: Advanced class features

– 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;
};
```

OOP: Advanced class features

- 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)

OOP: Advanced class features

- 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;
}
```

OOP: Advanced class features

– Passing function arguments

passing objects

```
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

OOP: Advanced class features

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

OOP: Advanced class features

- `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 );
};
```

OOP: Advanced class features

- `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 );
}
```

OOP: Advanced class features

- `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);
    ...
};
```

OOP: Advanced class features

- 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

OOP: Advanced class features

- 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;};
    ...
};
```

OOP: Advanced class features

– 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) { }
     };
     //...
};
```

OOP: Advanced class features

- 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 (`A :: B b;`)

OOP: Advanced class features

- 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 :: operator=( const T& ){ … }`

OOP: Advanced class features

– 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;
}
```

OOP: Advanced class features

- 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(); }
};
```

OOP: Advanced class features

– 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()`

OOP: Advanced class features

- 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

OOP: Advanced class features

- Lvalue

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

Rvalue

OOP: Advanced class features

– 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

OOP: Advanced class features

- 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;
```

OOP: Advanced class features

- 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)

OOP: Advanced class features

- Rvalues, lvalues, &&

```
class A {
public:
   static A  inst;

   static A& getInst() {return inst;}

   static A  getInstCopy(){return inst;}
};
```

Reference to a static variable → lvalue

A temporary copy of instance → rvalue

```
A&  inst1 = A :: getInst();  //1
A&& inst2 = A :: getInst();  //2
A::getInst() = A();          //3
A   inst4 = A :: getInstCopy();//4
A&  inst5 = A :: getInstCopy();//5
A&& inst6 = A :: getInstCopy();//6
```

1. ok - we've fetched a reference to the static instance variable
2. ERROR - can't assign a reference to an rvalue reference
3. getInst() is an lvalue reference, we assign a new value to it
4. ok - we've fetched a copy of the instance
5. ERROR- can't assign a reference to a temporary (an rvalue)
6. ok - we've assigned an rvalue reference to the temporary copy that was made of the instance

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

Module 4

Object-Oriented Programming

Operator overloading

OOP: Operator overloading

Content

- Objectives
- Types of operators
- Arithmetic operators
- Increment/decrement
- Inserter/extractor operators
- Assignment operator
- Index operator
- Relational and equality operators
- Conversion operators

OOP: Operator overloading

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

OOP: Operator overloading

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

OOP: Operator overloading

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

OOP: Operator overloading

- 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."

OOP: Operator overloading

- 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

OOP: Operator overloading

– The Complex class: `Complex.h, Complex.cpp`

```
#ifndef COMPLEX_H
#define COMPLEX_H

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

```
#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";}
```

OOP: Operator overloading

– 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;
}
```

OOP: Operator overloading

- 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;
}
```

OOP: Operator overloading

- 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).

OOP: Operator overloading

– 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?

OOP: Operator overloading

- 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);
    //...
};
```

```
//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;
}
```

OOP: Operator overloading

- 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&**?

OOP: Operator overloading

- 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;
```

OOP: Operator overloading

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

OOP: Operator overloading

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

OOP: Operator overloading

- **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;
```

OOP: Operator overloading

– **Copy** assignment operator example

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

OOP: Operator overloading

- 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
```

OOP: Operator overloading

- **Move** assignment operator (member func.)
  - **Syntax:** `X& operator=( X&& rhs) noexcept;`
  - 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) noexcept {
  if (this != &rhs) {
    //delete lhs - left hand side
    delete [] mElements;
    //move rhs to this
    mCapacity = rhs.mCapacity;
    mTop = rhs.mTop;
    Melements = rhs.mElements;
    //leave rhs in valid state
    mElements = nullptr;
    rhs.mCapacity = 0;
    rhs.mTop = 0;
  }
  return *this;
}
```

OOP: 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.

OOP: Operator overloading

– Implementation

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

OOP: Operator overloading

- `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);
```

OOP: Operator overloading

- Non-integral array indices: *associative array*
- `( Key, Value )`
- Ex: Key → string, Value → double
  - **Homework**

OOP: Operator overloading

- 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());
```

OOP: 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;
}
```

OOP: 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;
}
```

OOP: Operator overloading

- Function call operator
  - used frequently 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();

    }
};
```

OOP: Operator overloading

– 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();
}
```

OOP: Operator overloading

- 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**?

OOP: Operator overloading

- Writing conversion operators

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


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

//usage
Complex z(1, 2), z2;
string a = z;
cout<<a<<endl;
```

OOP: Operator overloading

- After templates
  - Overloading operator *
  - Overloading operator →

OOP: Review

- 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:

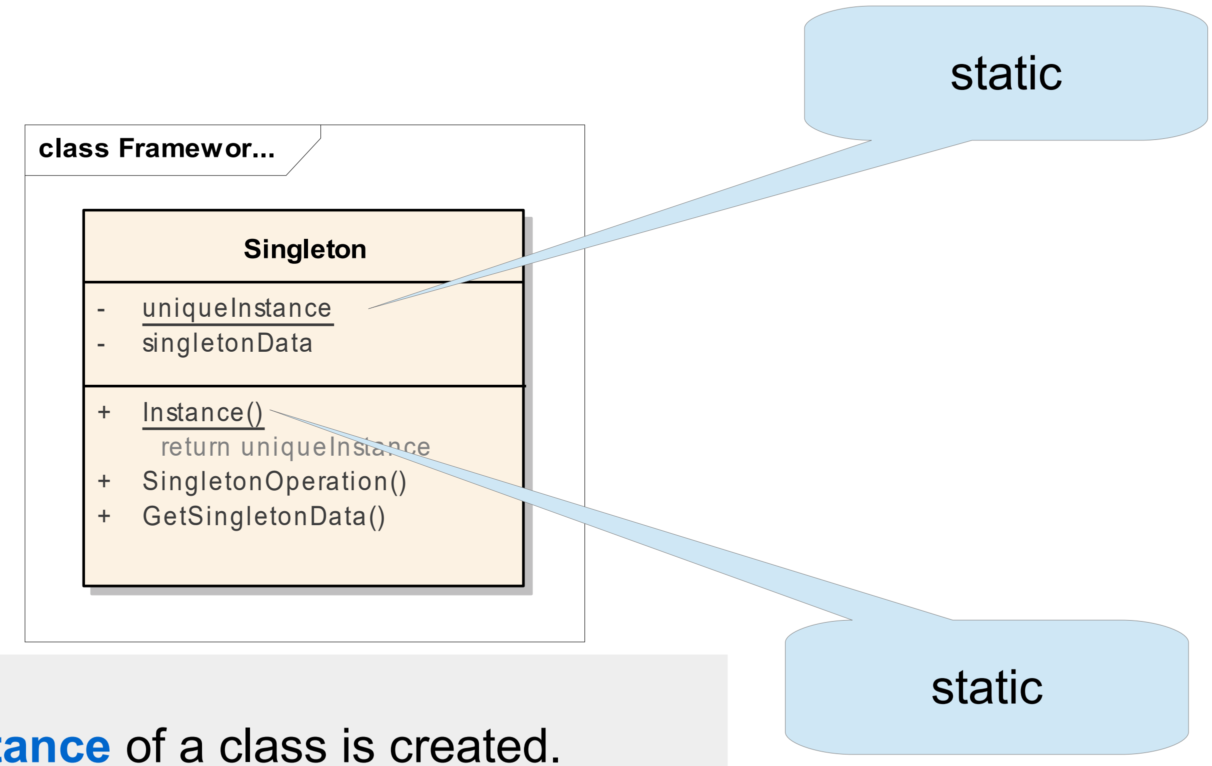
```
Start
Hello
Stop
```

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.

Module 5

Object-Oriented Programming

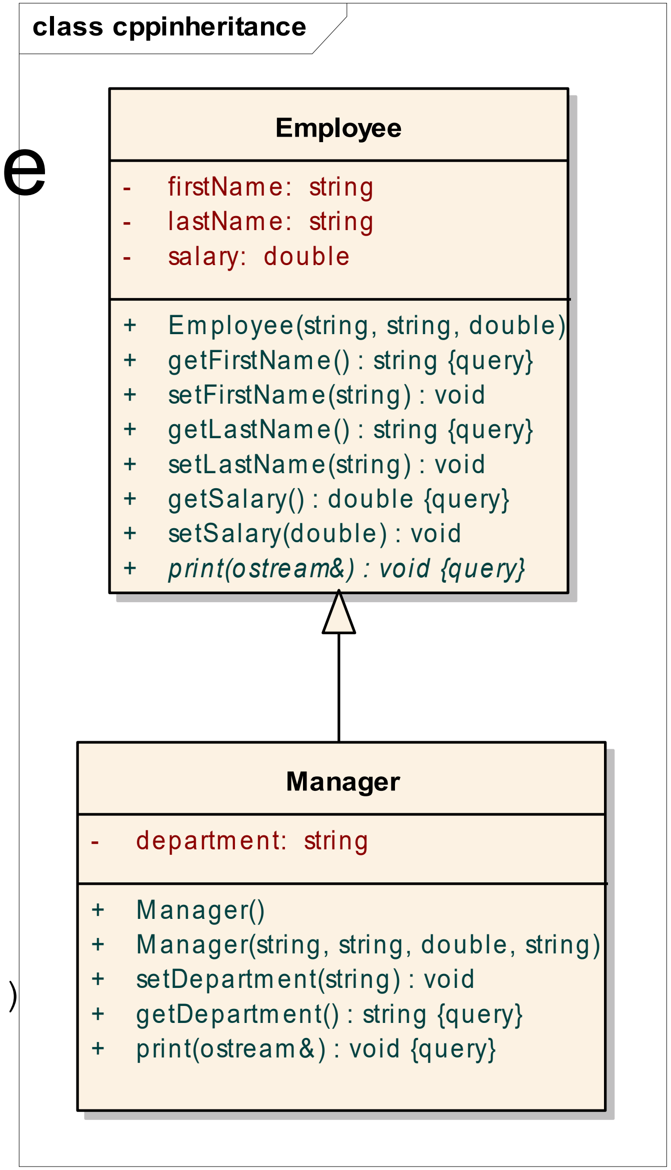
Public Inheritance

OOP: Inheritance

– 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

OOP: 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()`



OOP: Inheritance

- `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

OOP: Inheritance

- `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 );
    //...
};
```

OOP: Inheritance

– Derived class's constructors

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

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

OOP: Inheritance

- Derived class's constructors

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

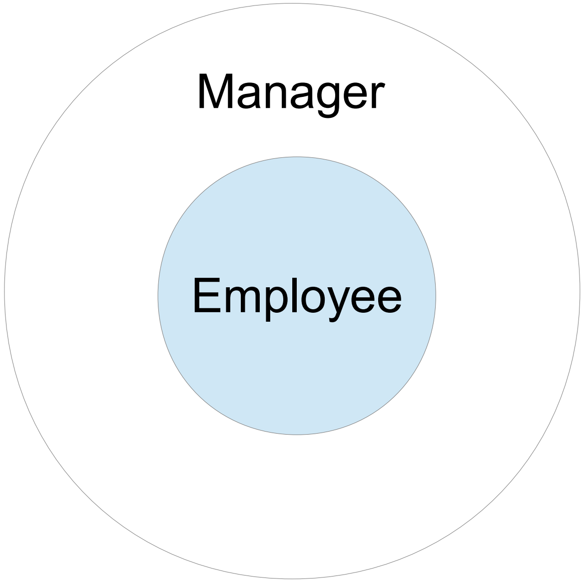
Employee's constructor invocation → Default constructor can be invoked implicitly

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

OOP: Inheritance

- 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



OOP: Inheritance

- Method overriding

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

```
class Manager:public Employee{
public:

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

OOP: Inheritance

– 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;
}
```

OOP: Inheritance

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

OOP: Inheritance

– 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
```

OOP: Inheritance

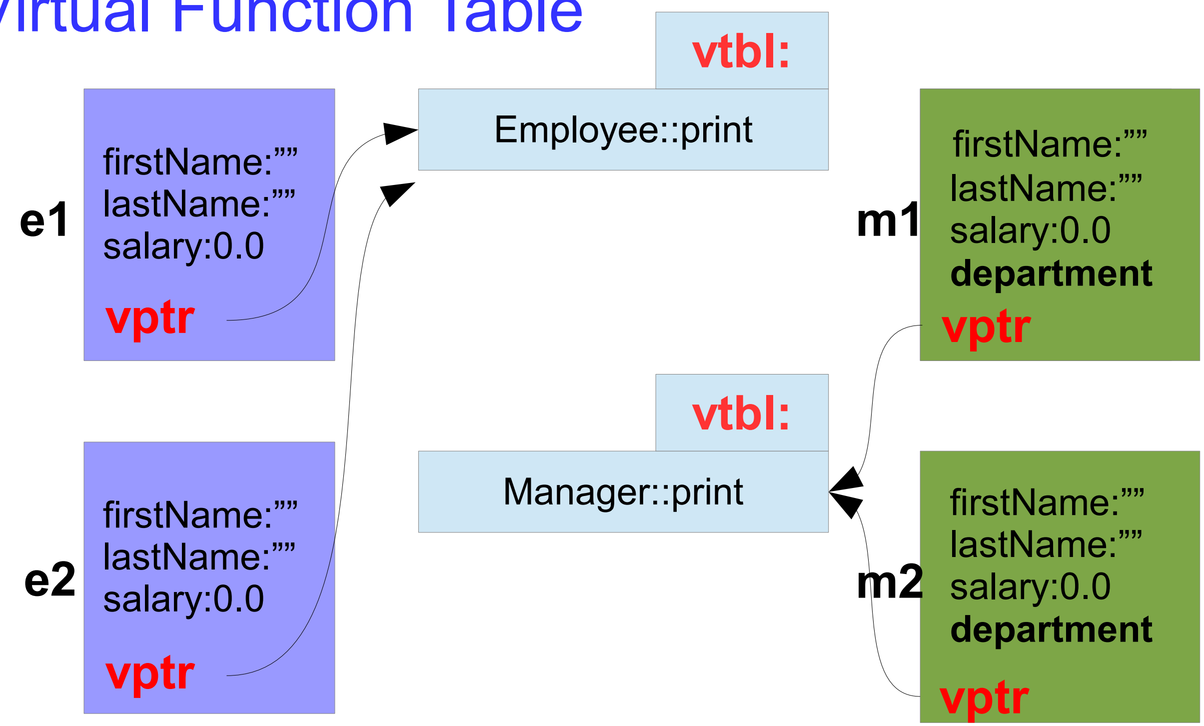
- Polymorphism
  - a type with virtual functions is called a polymorphic type
  - polymorphic behavior **preconditions**:
    - the member function must be virtual
    - objects must be manipulated through
      - pointers or
      - references

    - **`Employee :: print( os )`** static binding – no polymorphism

OOP: Inheritance

- 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).

RTTI – Run-Time Type Information

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

RTTI – Run-Time Type Information

`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 ){
       // ..
}
```

OOP: Inheritance

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

OOP: Inheritance

- 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; //???
```

OOP: Inheritance

– 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
```

OOP: Inheritance

- 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;
};
```

OOP: Inheritance

– Abstract class → abstract class

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

};
```

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

OOP: Inheritance

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

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

OOP: Inheritance

- 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?

Module 6

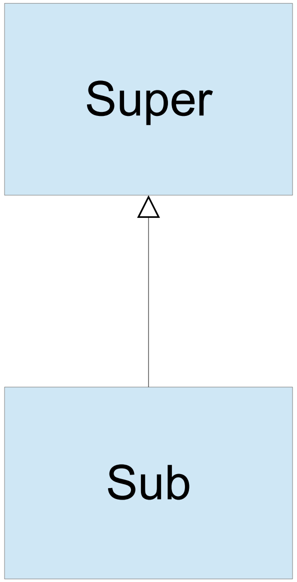
Object-Oriented Programming

Object relationships

OOP: Object relationships

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

OOP: Object relationships

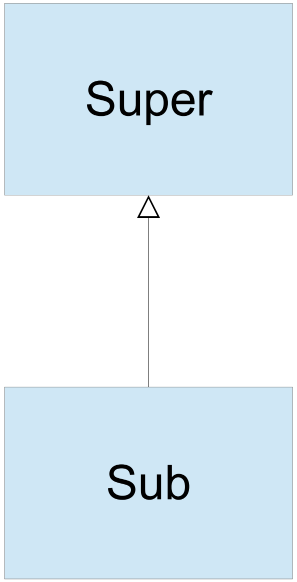


- The *is-a* relationship – *Client's view (1)*
  - works in only *one direction:*
    - every **Sub** object **is** also **a** **Super** one
    - but **Super** object **is not a** **Sub**

```
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
```

OOP: Object relationships

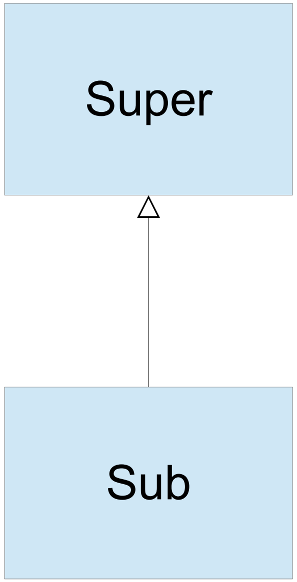
- The *is-a* relationship – *Client's view (2)*




```
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
```

OOP: Object relationships



- 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
  - the subclass can use all the public and protected members of a superclass.

OOP: Object relationships

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

```
class Super final
{

};
```

OOP: Object relationships

- 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();
};
```

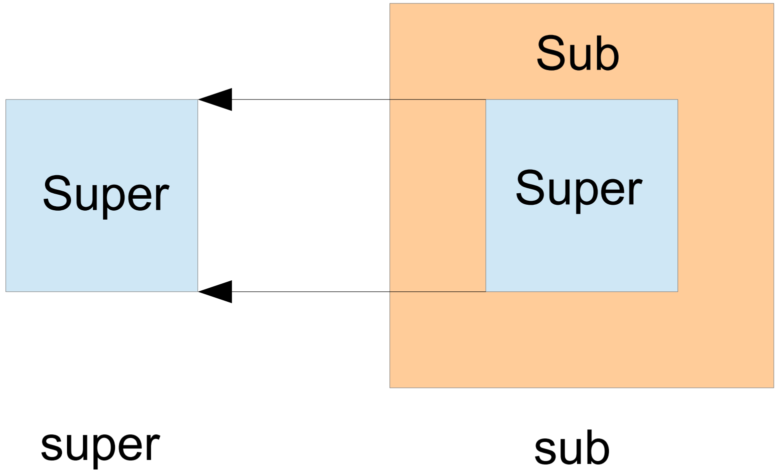
```
Super super;
super.method1(); //Super::method1()

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();
```

OOP: Object relationships

- 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();
```



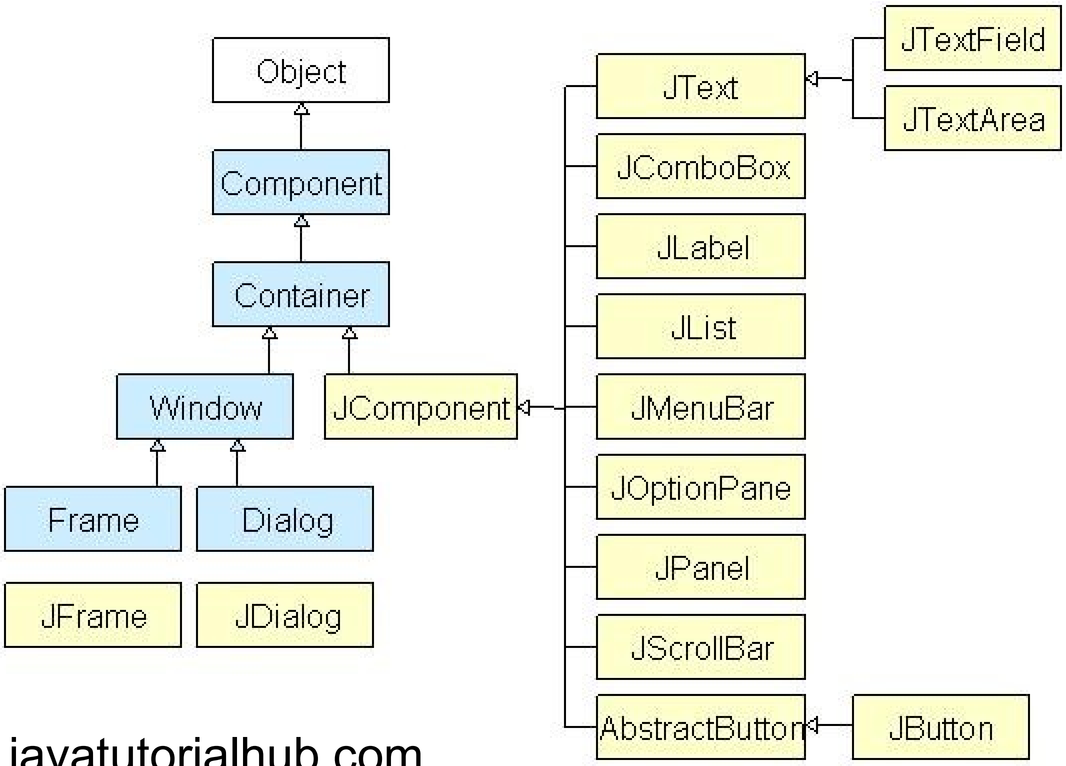
OOP: Object relationships

- 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
};
```

OOP: Object relationships

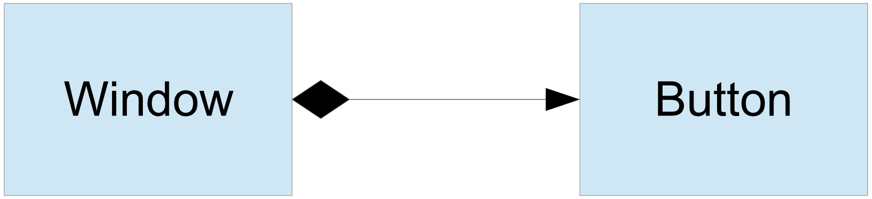
– Inheritance for polymorphism



www.javatutorialhub.com

OOP: Object relationships

- The *has-a* relationship



OOP: Object relationships

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

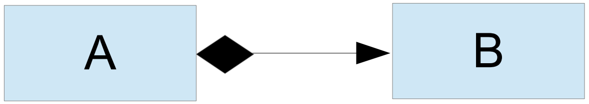
```
class B;

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

```
class B;

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

```
class B;

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

OOP: Object relationships

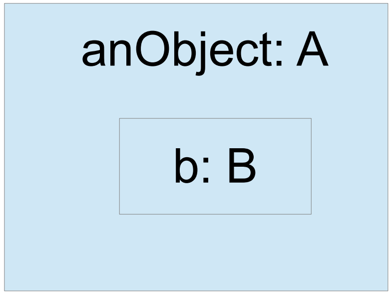
- Implementing the *has-a* relationship



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

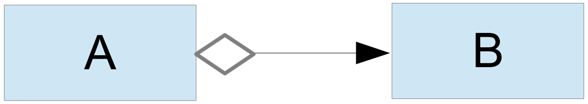
```
class B;

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

```
A anObject;
```



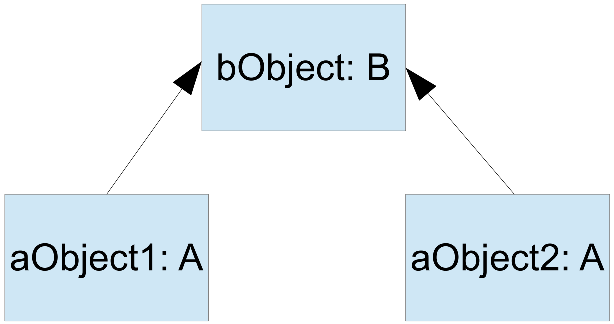
OOP: Object relationships

- 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);
```



OOP: Object relationships

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

weak containment

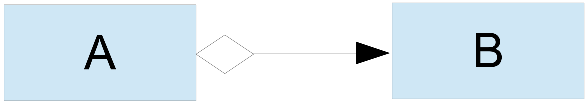
```
class B;

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;
    }
};
```

OOP: Object relationships

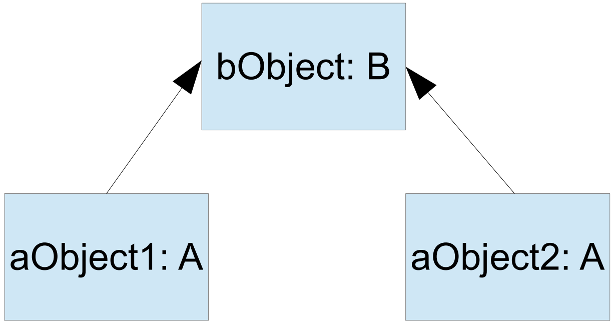
– Implementing the *has-a* relationship
  - An object **A** has an object **B**



weak containment

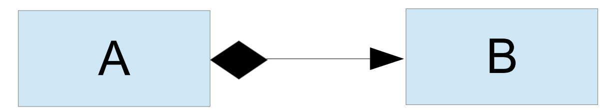
```
class B;

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

```
Usage:
    B bObject;
    A aObject1(&bObject);
    A aObject2(&bObject);
```



OOP: Object relationships

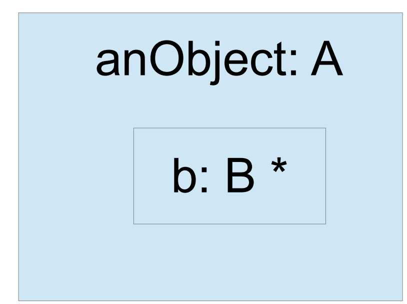
– Implementing the *has-a* relationship
  - An object **A** has an object **B**



strong containment

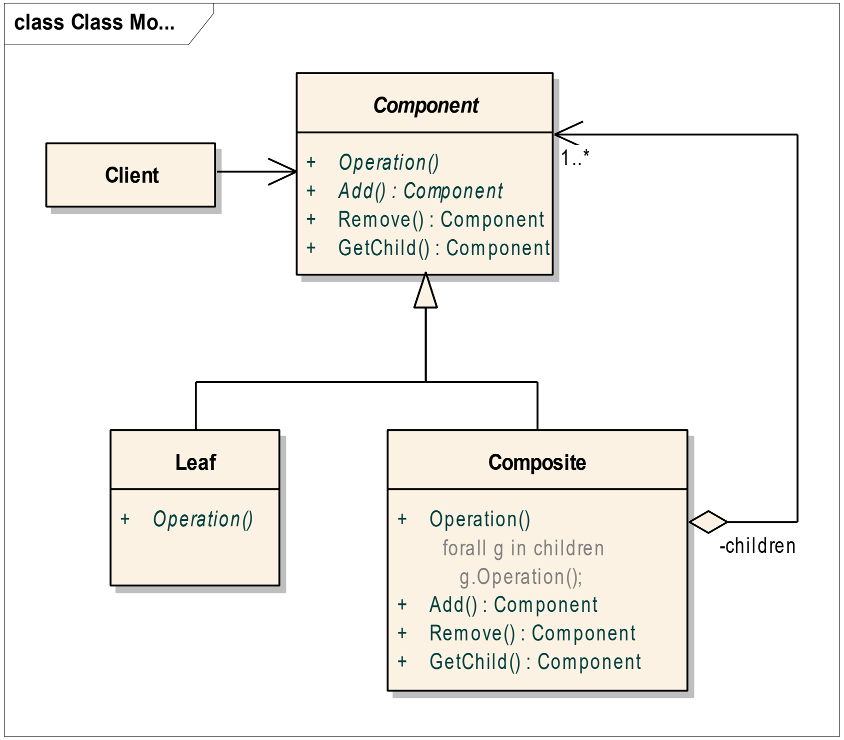
```
class B;

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

```
Usage:
    A aObject;
```

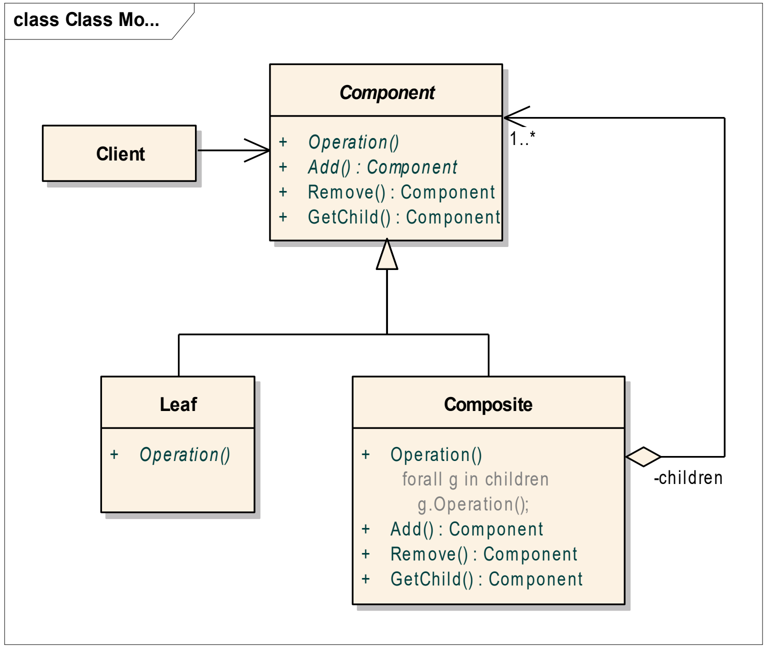


OOP: Object relationships

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



Composite Design Pattern



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

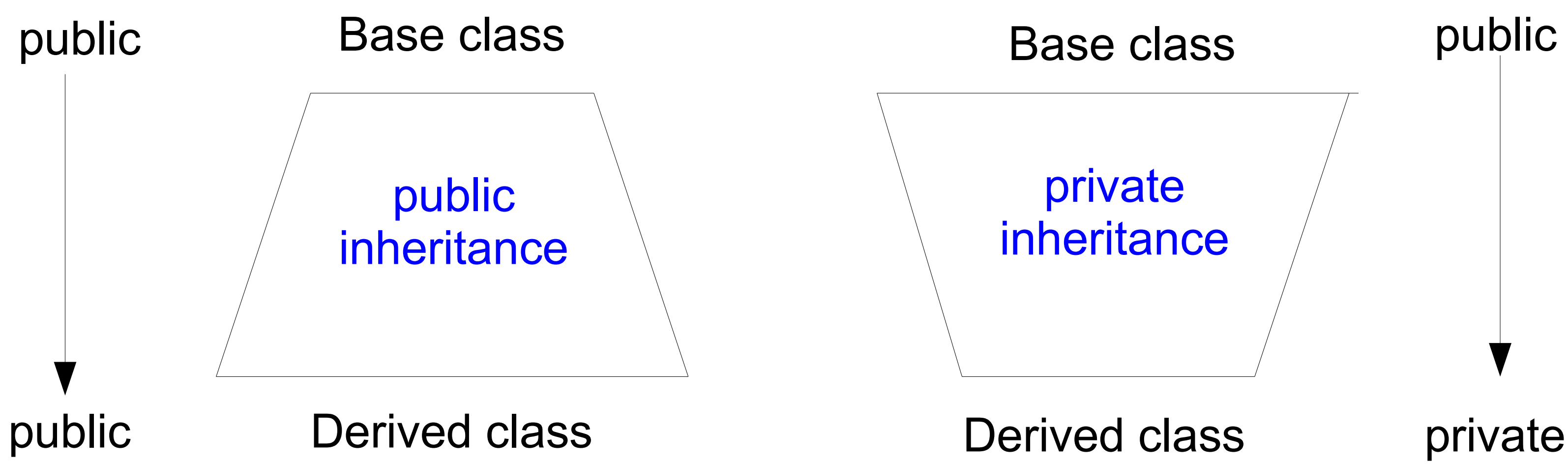
Composite Design Pattern

- 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);
```

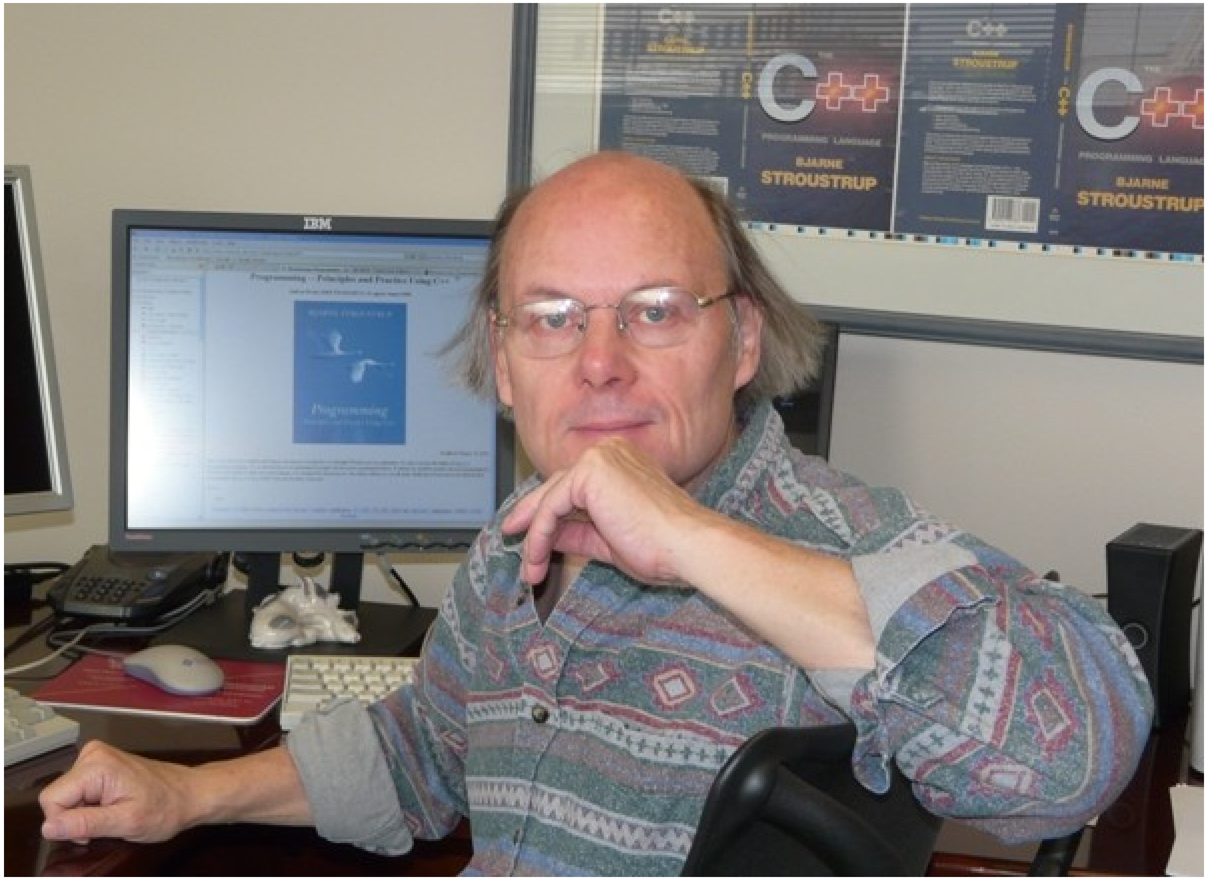
Module 7

Generic Programming: Templates

Outline

- Templates
  - Class template
  - Function template
  - Template metaprogramming

Templates



http://www.stroustrup.com/

Templates

- Allow generic programming
  - to write code that can work with all kind of objects
  - **template programmer's obligation:** specify the *requirements of the classes* that define these objects
  - **template user's obligation:** supplying those operators and methods that the template programmer requires

Function Template

Template parameter

– Allows writing **function families**

```
template<typename T>
const T max(const T& x, const T& y) {
   return x < y ? y : x;
}
```

```
template<class T>
const T max(const T& x, const T& y) {
   return x < y ? y : x;
}
```

- What are the requirements regarding the type T?

Function Template

```
template<class T>
const T max(const T& x, const T& y) {
   return x < y ? y : x;
}
```

- Requirements regarding the type T:
  - less operator (<)
  - copy constructor

Function Template

```
template<class T>
const T max(const T& x, const T& y) {
   return x < y ? y : x;
}
```

- Usage:
  - `cout<<max(2, 3)<<endl; // max: T → int`
  - `string a(“alma”); string b(“korte”);`
    `cout<<max(a, b)<<endl; // max: T → string`
  - `Person p1(“John”,”Kennedy”),p2(“Abraham”, “Lincoln”);`
    `cout<<max(p1,p2)<<endl;// max: T-> Person`

Function Template

```
template<class T>
void swap(T& x, T& y) {
  const T tmp = x;
  x = y;
  y = tmp;
}
```

- Requirements regarding the type T:
  - copy constructor
  - assignment operator

Function Template

- Allows writing **function families**
  - **polymorphism:** *compile time*
- How the compiler processes templates?
  - `cout<<max(2, 3)<<endl; //` **`max: T → int`**
  - `cout<<max(2.5, 3.6)<<endl; //` **`max: T → double`**
  -
- How many max functions?

Warning: Code bloat!

Function Template

- What does it do? [Gregoire]

```
static const size_t MAGIC = (size_t)(-1);
template <typename T>
size_t Foo(T& value, T* arr, size_t size)
{
   for (size_t i = 0; i < size; i++) {
      if (arr[i] == value) {
         return i;
      }
   }
   return MAGIC;
}
```

Class Template

- Allow writing **class families**

```
template<typename T>
class Array {
   T* elements;
   int size;
public:
   explicit Array(const int size);
   ...
};
```

Class Template

– Template class's method definition

```
template<typename T>
class Array {
   T* elements;
   int size;
public:
   explicit Array(const int size);
   ...
};
template<typename T>
Array<T>::Array(const int size):size(size),
                         elements(new T[size]){
}
```

Class Template

– Template parameters
  - type template parameters
  - non-type template parameters

```
template<typename T>
class Array {
   T* elements;
   int size;
public:
   Array(const int size);
   ...
};
```

```
template<class T, int MAX=100>
class Stack{
      T elements[ MAX ];
public:
      ...
};
```

Class Template

– Distributing Template Code between Files

- Normal class:
  - Person.h → interface
  - Person.cpp → implementation
- Template class:
  - interface + implementation go in the same file e. g. `Array.h`
    - it can be a .h file → usage: `#include "Array.h"`
    - it can be a .cpp file → usage: `#include "Array.cpp"`

Class Template+ Function Template

```
template<class T1, class T2>
struct pair {
        typedef T1 first_type;
        typedef T2 second_type;
        T1 first;
        T2 second;
        pair();
        pair(const T1& x, const T2& y);
        ...
};
```

```
#include <utility>
```

```
template< class T1, class T2>
pair<T1, T2> make_pair(const T1& x, const T2& y)
{
   return pair<T1, T2>(x, y);
}
```

Advanced Template

- *template template* parameter

```
template<typename T, typename Container>
class Stack{
    Container elements;
public:
    void push( const T& e ){
        elements.push_back( e );
    }
    ...
};
```

Usage:

```
Stack<int, vector<int> > v1;
Stack<int, deque<int>  > v2;
```

Advanced Template

- *template template* parameter

```
template<typename T, typename Container=vector<T> >
class Stack{
    Container elements;
public:
    void push( const T& e ){
        elements.push_back( e );
    }
    ...
};
```

Advanced Template

- *What does it do?*

```
template < typename Container >
void foo( const Container& c, const char * str="")
{
   typename Container::const_iterator it;
   cout<<str;
   for(it = c.begin();it != c.end(); ++it)
      cout<<*it<<' ';
   cout<<endl;
}
```

Advanced Template

- *What does it do?*

```
template < typename Container >
void foo( const Container& c, const char * str="")
{
    typename Container::const_iterator it;
    cout<<str;
    for(auto& a: c ){
        cout<< a <<' ';
    }
    cout<<endl;
}
```

Examples

Implement the following template functions!

```
template <typename T>
bool linsearch( T* first, T* last, T what);

template <typename T>
bool binarysearch( T* first, T* last, T what);
```

More Advanced Template

- Template Metaprogramming

```
template<unsigned int N> struct Fact{
static const unsigned long int
  value = N * Fact<N-1>::value;
};
template<> struct Fact<0>{
   static const unsigned long int value = 1;
};
// Fact<8> is computed at compile time:
const unsigned long int fact_8 = Fact<8>::value;
int main()
{
  cout << fact_8 << endl;
  return 0;
}
```

Module 8

STL – Standard Template Library

Alexander Stepanov

https://www.sgi.com/tech/stl/drdobbs-interview.html

Outline

- Containers
- Algorithms
- Iterators

STL – General View

- library of *reusable components*
- a support for C++ development
- based on *generic programming*

STL – General View

- **Containers** – Template Class
  - generalized data structures (you can use them for any type)
- **Algorithms** – Template Function
  - generalized algorithms (you can use them for almost any data structure)
- **Iterators** – Glue between Containers and Algorithms
  - specifies a position into a container (generalized pointer)
  - permits traversal of the container

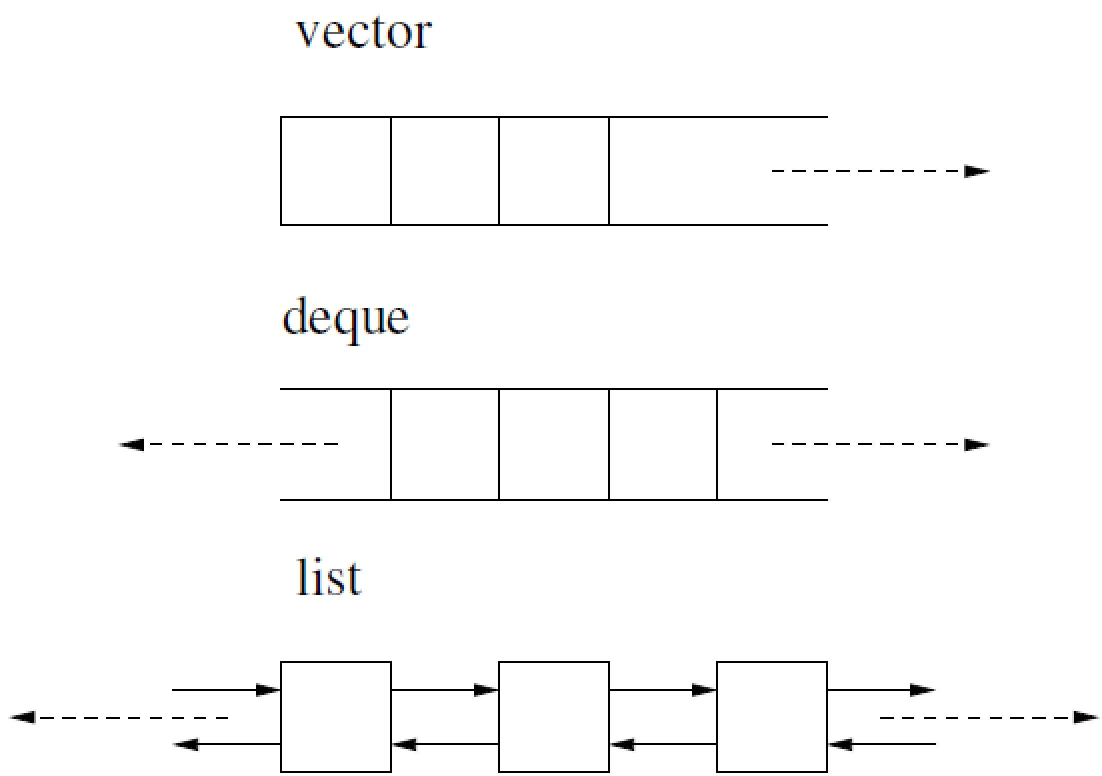
Basic STL Containers

- **Sequence containers**
  - linear arrangement
    - **`vector, deque, list`** — **`<vector> <deque> <list>`**
    - **`stack, queue, priority_queue`** — **`<stack> <queue>`**

Container adapters

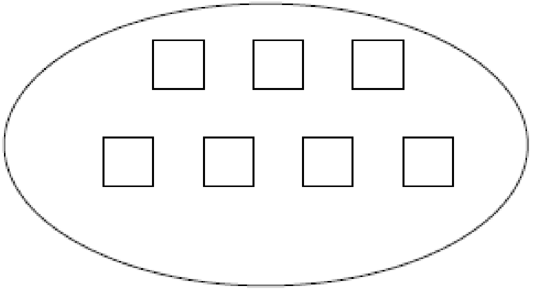
- **Associative containers**
  - provide fast retrieval of data based on keys
    - **`set, multiset, map, multimap`** — **`<set> <map>`**

Sequence Containers

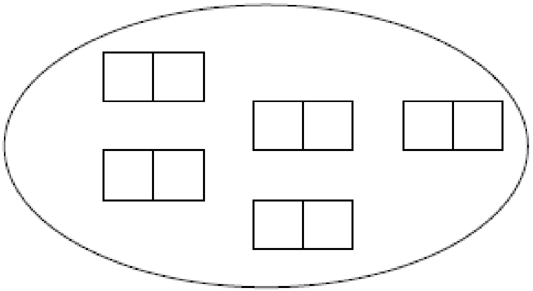


Associative Containers

set/multiset



map/multimap



STL Containers C++11

- **Sequence containers**

<array> <forward_list>

  - **`array`** (C-style array)
  - **`forward_list`** (singly linked list)

- **Associative containers**

<unordered_set>
<unordered_map>

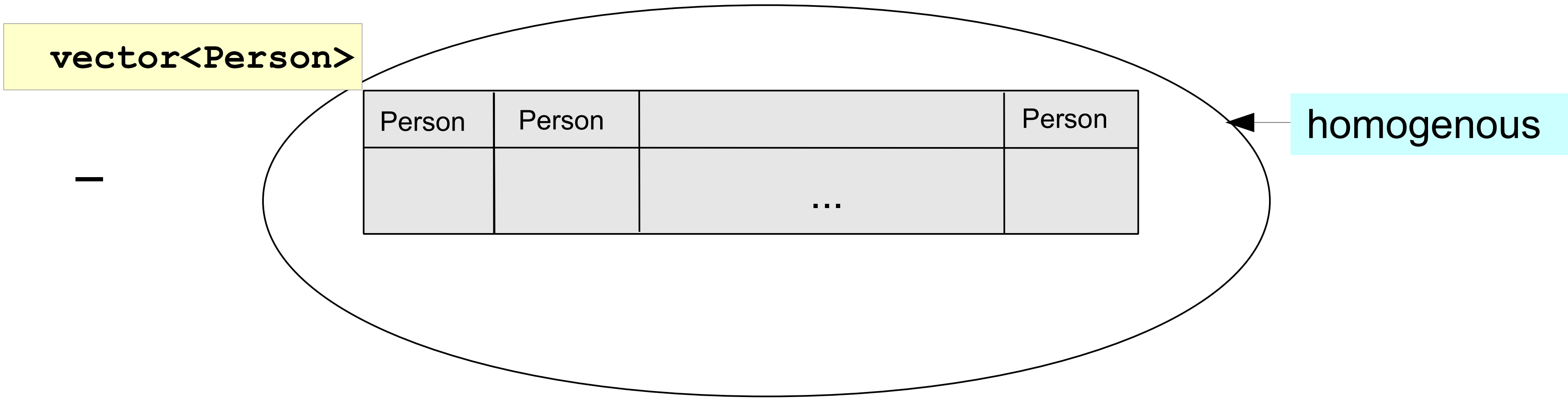
  - **`unordered_set, unordered_multiset`** (hash table)
  - **`unordered_map, unordered_multimap`** (hash table)

STL Containers

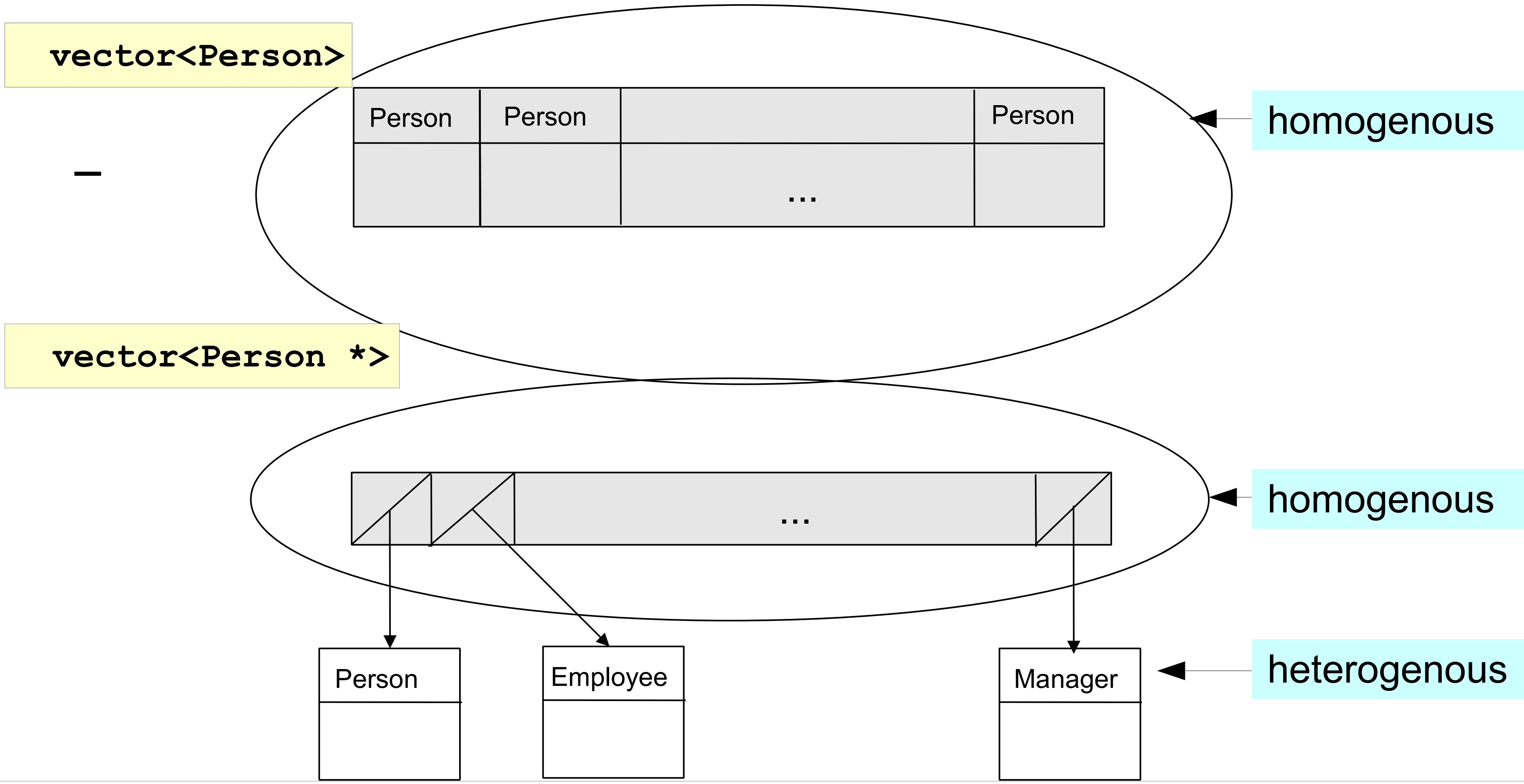
- homogeneous:
  - `vector<Person>, vector<Person*>`
- polymorphism
  - `vector<Person*>`

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

STL Containers



STL Containers

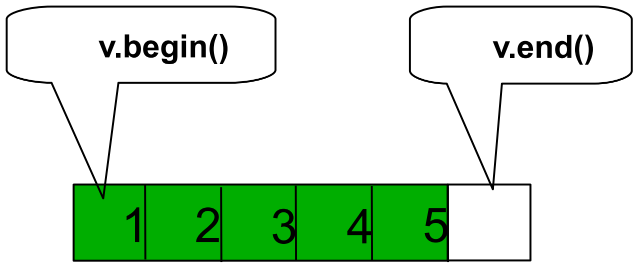


The `vector` container - constructors

```
vector<T> v;
   //empty vector

vector<T> v(n, value);
   //vector with n copies of value

vector<T> v(n);
   //vector with n copies of default for T
```

The `vector` container – add new elements

```
vector<int> v;

for( int i=1; i<=5; ++i){
    v.push_back( i );
}
```



The `vector` container

```
vector<int> v( 10 );
cout<<v.size()<<endl;//???
for( int i=0; i<v.size(); ++i ){
  cout<<v[ i ]<<endl;
}

for( int i=0; i<10; ++i){
  v.push_back( i );
}
cout<<v.size()<<endl;//???

for( auto& a: v ){
  cout<< a <<" ";
}
```

The `vector` container: typical errors

- *Find the error and correct it!*

```
vector<int> v;
cout<<v.size()<<endl;//???
for( int i=0; i<10; ++i ){
    v[ i ] = i;
}
cout<<v.size()<<endl;//???
for( int i=0; i<v.size(); ++i ){
    cout<<v[ i ]<<endl;
}
```

The `vector` container: `capacity` and `size`

```
vector<int> v;
v.reserve( 10 );

cout << v.size() << endl;//???
cout << v.capacity() << endl;//???
```

The `vector` container: `capacity` and `size`

```
vector<int> v;
v.reserve( 10 );

cout << v.size() << endl;//???
cout << v.capacity() << endl;//???

--------------------------------------

vector<int> gy( 256 );
ifstream ifs("szoveg.txt"); int c;
while( (c = ifs.get() ) != -1 ){
        gy[ c ]++;
}
```

Purpose?

The `vector` - indexing

```
int Max = 100;
vector<int> v(Max);
//???...
for (int i = 0; i < 2*Max; i++) {
  cout << v[ i ]<<" ";
}
--------------------------------------

int Max = 100;
vector<int> v(Max);
for (int i = 0; i < 2*Max; i++) {
  cout << v.at( i )<<" ";
}
```

The `vector` - indexing

```
int Max = 100;
vector<int> v(Max);
//???...
for (int i = 0; i < 2*Max; i++) {
  cout << v[ i ]<<" ";
}
---------------------------------------

int Max = 100;
vector<int> v(Max);
for (int i = 0; i < 2*Max; i++) {
  cout << v.at( i )<<" ";
}
```

Efficient

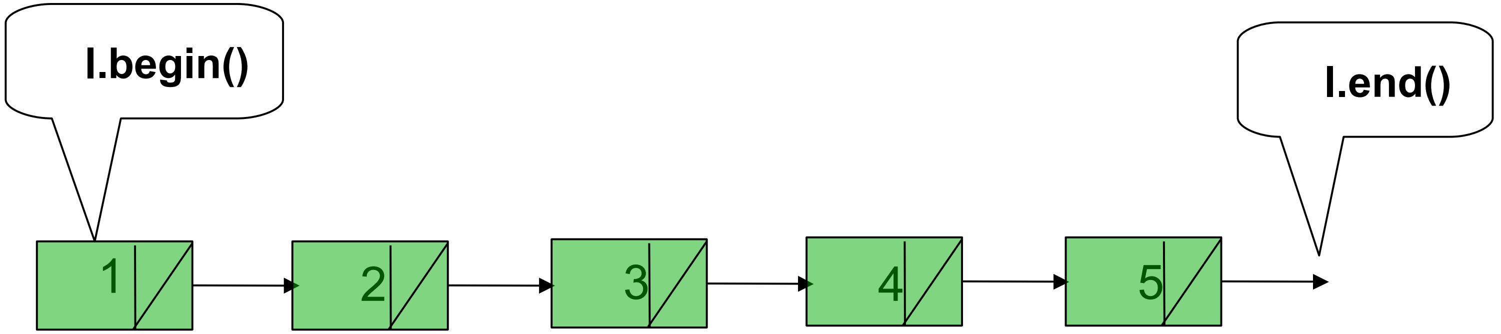
Safe

`out_of_range` exception

The `list` container

– doubly linked list

```
list<int> l;
for( int i=1; i<=5; ++i){
    l.push_back( i );
}
```



The `deque` container

- double ended vector

```
deque<int> l;
for( int i=1; i<=5; ++i){
    l.push_front( i );
}
```

Algorithms - `sort`

```
template <class RandomAccessIterator>
void sort ( RandomAccessIterator first,RandomAccessIterator last );
```

```
template <class RandomAccessIterator, class Compare>
void sort ( RandomAccessIterator first, RandomAccessIterator last,
            Compare comp );
```

- what to sort: **[first, last)**
- how to compare the elements:
  - **<**
  - **comp**

Algorithms - `sort`

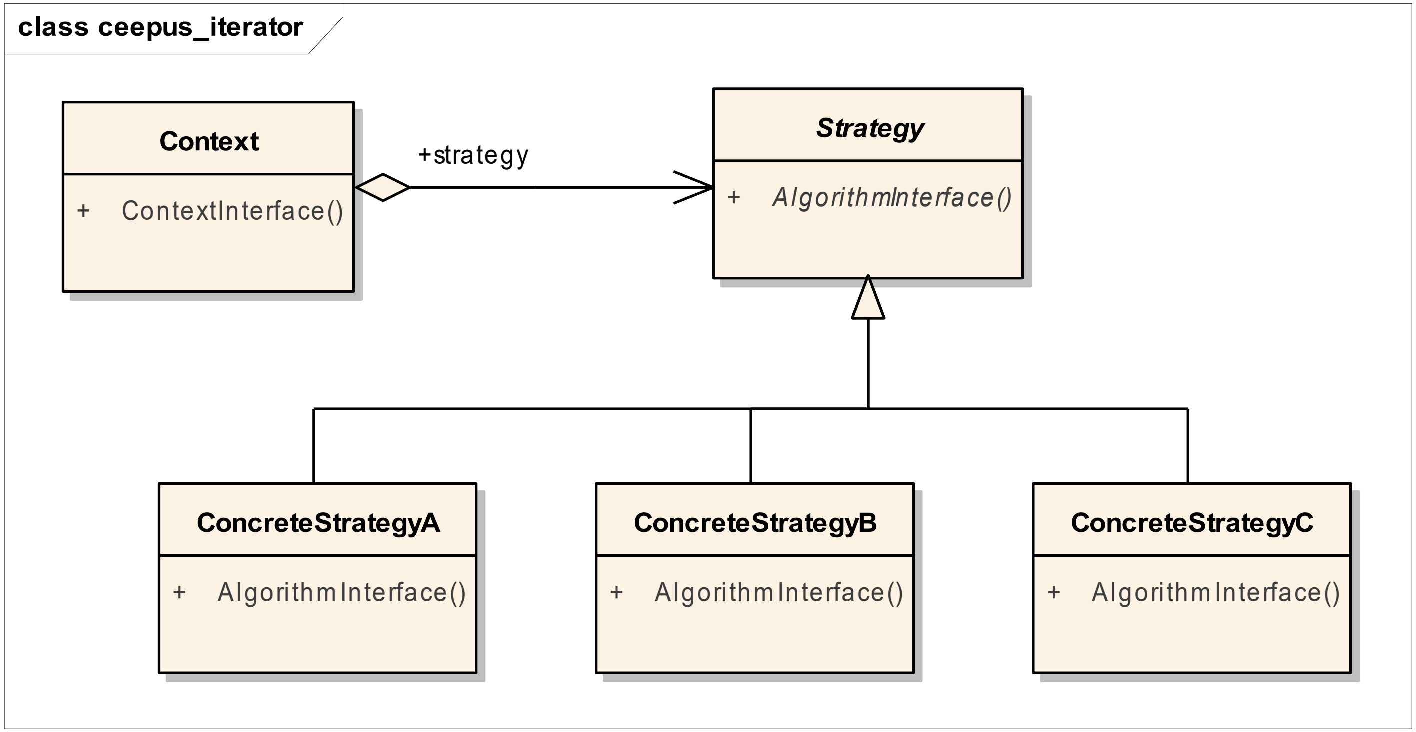
```
struct Rec {
  string name;
  string addr;
};
vector<Rec> vr;
// …
sort(vr.begin(), vr.end(), Cmp_by_name());
sort(vr.begin(), vr.end(), Cmp_by_addr());
```

Algorithms - `sort`

```
struct Cmp_by_name{
  bool operator()(const Rec& a, const Rec& b) const
  {
    return a.name < b.name;
  }
};
struct Cmp_by_addr{
  bool operator()(const Rec& a, const Rec& b) const
  {
    return a.addr < b.addr;
  }
};
```

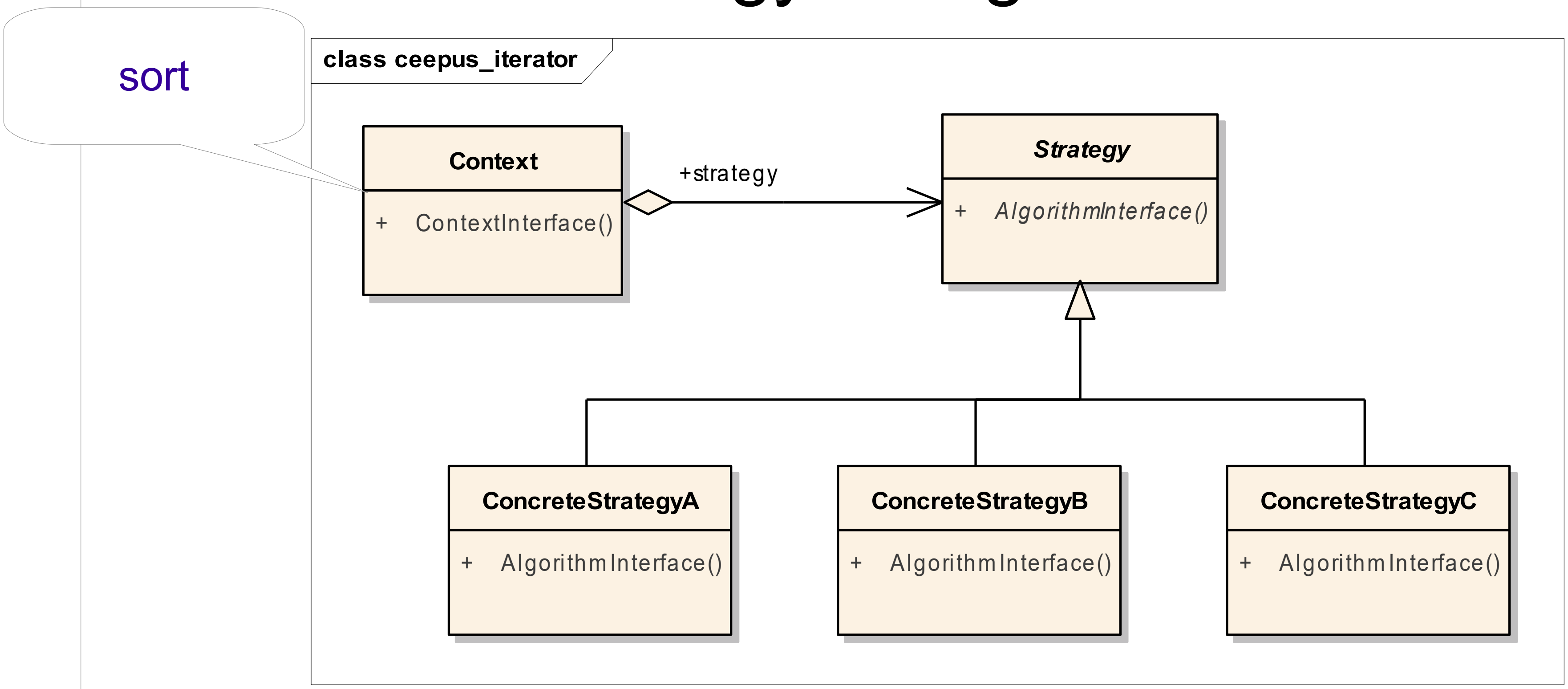
function object

Strategy Design Pattern



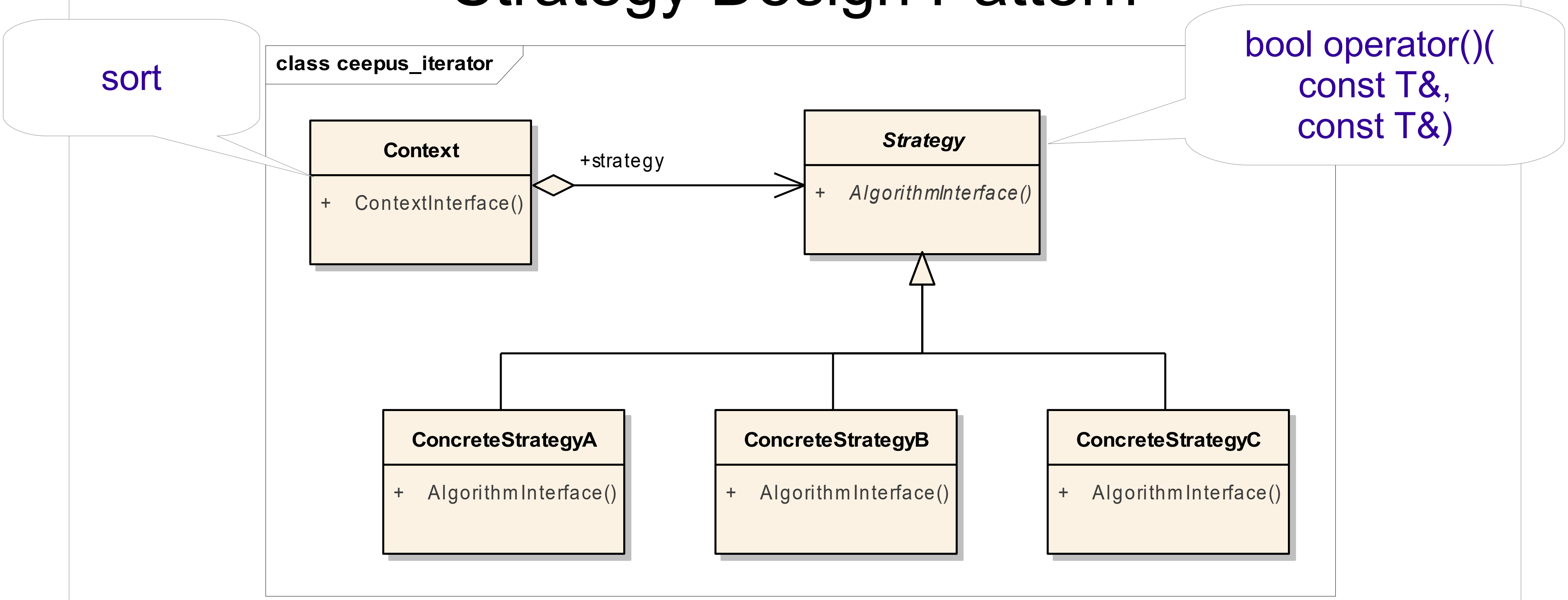
- Define a **family of algorithms**, encapsulate each one, and make them interchangeable.
- Strategy **lets the algorithm vary** independently from clients that use it.

Strategy Design Pattern



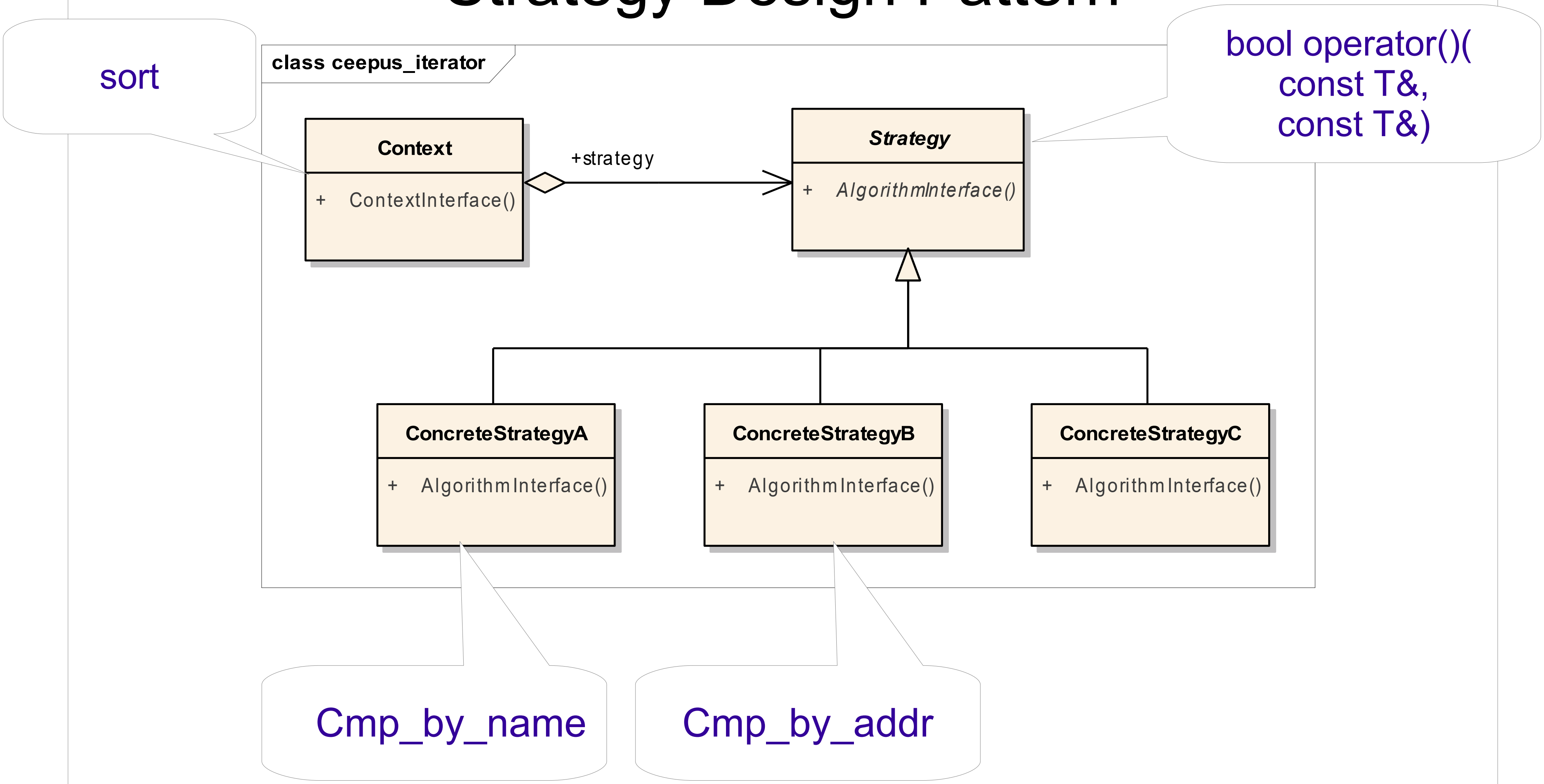
- Define a **family of algorithms**, encapsulate each one, and make them interchangeable.
- Strategy **lets the algorithm vary** independently from clients that use it.

Strategy Design Pattern



- Define a **family of algorithms**, encapsulate each one, and make them interchangeable.
- Strategy **lets the algorithm vary** independently from clients that use it.

Strategy Design Pattern



Iterators

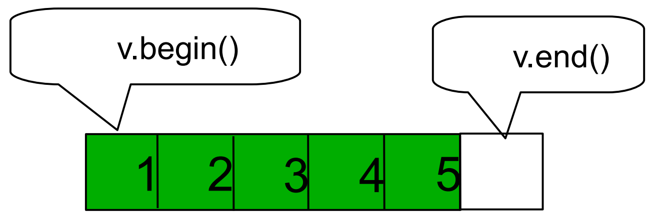
- The *container* manages the contained objects but does not know about *algorithms*

- The *algorithm* works on data but does not know the internal structure of *containers*

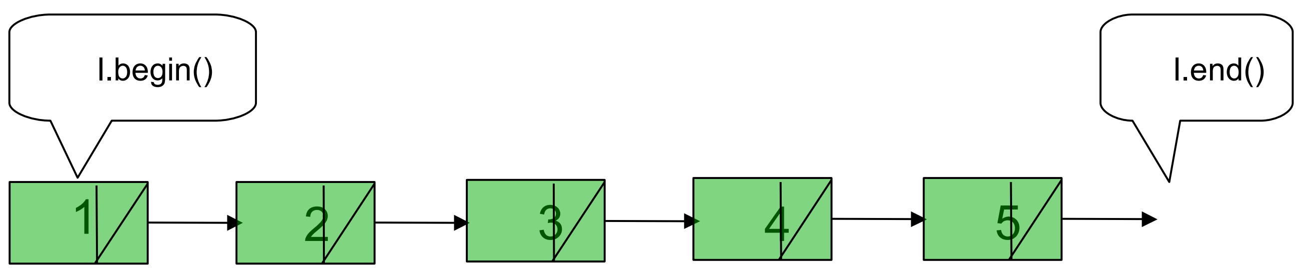
- *Iterators* fit containers to algorithms

Iterator - *the glue*

```
int x[]={1,2,3,4,5}; vector<int>v(x, x+5);
int sum1 = accumulate(v.begin(), v.end(), 0);
```




```
list<int> l(x, x+5);
double sum2 = accumulate(l.begin(), l.end(), 0);
```



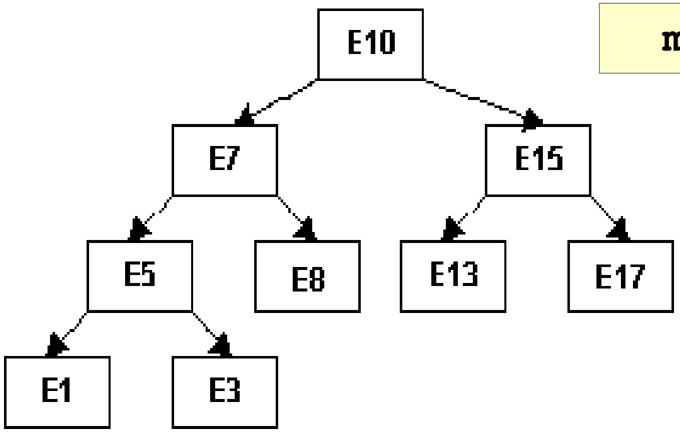
Iterator - *the glue*

```
template<class InIt, class T>
T accumulate(InIt first, InIt last, T init)
{
 while (first!=last) {
  init = init + *first;
  ++first;
 }
 return init;
}
```

The `set` container

`set< Key[, Comp = less<Key>]>`

usually implemented as a balanced binary search tree



`multiset:` allows duplicates

Source:http://www.cpp-tutor.de/cpp/le18/images/set.gif

The `set` container - usage

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

set<int> intSet;

set<Person> personSet1;

set<Person, PersonComp> personSet2;
```

The `set` container - usage

<

```
#include <set>

set<int> intSet;

set<Person> personSet1;



set<Person, PersonComp> personSet2;
```

The `set` container - usage

```
#include <set>

set<int> intSet;

set<Person> personSet1;

set<Person, PersonComp> personSet2;
```

<

bool operator<(const Person&, const Person&)

The `set` container - usage

```
#include <set>
```

```
<
```

```
set<int> intSet;
```

```
bool operator<(const Person&, const Person&)
```

```
set<Person> personSet1;
```

```
struct PersonComp{
    bool operator() ( const Person&, const Person& );
};
```

```
set<Person, PersonComp> personSet2;
```

The `set` container - usage

```
#include <set>


set<int> mySet;
while( cin >> nr ){
  mySet.insert( nr );
}
set<int>::iterator iter;
for (iter=mySet.begin(); iter!=mySet.end(); ++iter){
    cout << *iter << endl;
}
```

The `set` container - usage

```
set<int>::iterator iter;
for (iter=mySet.begin(); iter!=mySet.end(); ++iter){
    cout << *iter << endl;
}
----------------------------------------------------
for( auto& i: mySet ){
   cout<<i<<endl;
}
```

The `multiset` container - usage

```
multiset<int> mySet;
size_t nrElements = mySet.count(12);

multiset<int>::iterator iter;
iter = mySet.find(10);

if (iter == mySet.end()){
    cout<<"The element does not exist"<<endl;
}
```

?

The `multiset` container - usage

```
multiset<int> mySet;
auto a = mySet.find(10);

if (a == mySet.end()){
   cout<<"The element does not exist"<<endl;
}
```

The `set` container - usage

```
class PersonCompare;
class Person {
    friend class PersonCompare;
    string firstName;
    string lastName;
    int yearOfBirth;
public:
    Person(string firstName, string lastName, int yearOfBirth);
    friend ostream& operator<<(ostream& os, const Person& person);
};
```

The `set` container - usage

```
class PersonCompare {
 public:
   enum Criterion { NAME, BIRTHYEAR};
 private:
   Criterion criterion;
 public:
   PersonCompare(Criterion criterion) : criterion(criterion) {}
   bool operator()(const Person& p1, const Person& p2) {
       switch (criterion) {
           case NAME: //
           case BIRTHYEAR: //
       }
   }
};
```

function object

state

behaviour

The `set` container - usage

```
set<Person, PersonCompare> s( PersonCompare::NAME);
s.insert(Person("Biro", "Istvan", 1960));
s.insert(Person("Abos", "Gergely", 1986));
s.insert(Person("Gered","Attila", 1986));
----------------------------------------------------
for( auto& p: s){
    cout << p <<endl;
}
```

?

C++
2011

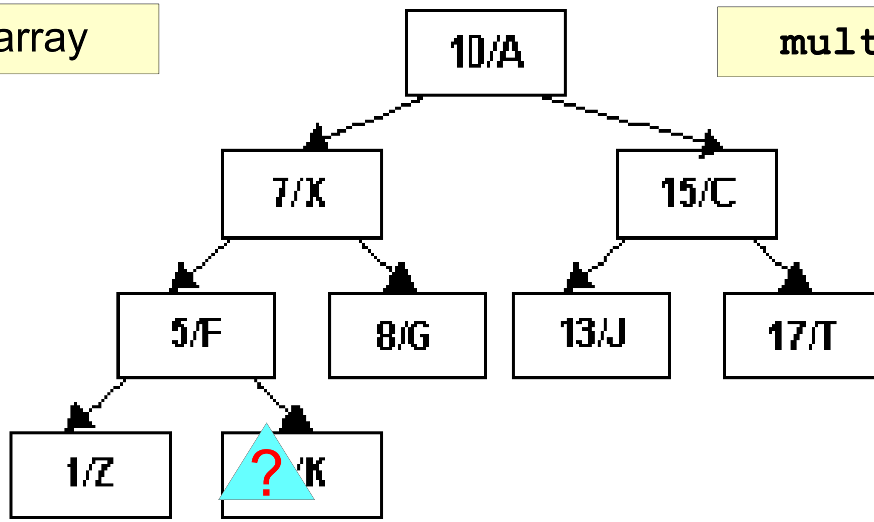
The `map` container

```
map< Key, Value[,Comp = less<Key>]>
```

usually implemented as a balanced binary tree

`map`: associative array

`multimap`: allows duplicates



Source: http://www.cpp-tutor.de/cpp/le18/images/map.gif

The `map` container - usage

```
#include <map>
map<string,int> products;

products.insert(make_pair("tomato",10));
----------------------------------------------
products["cucumber"] = 6;

cout<<products["tomato"]<<endl;
```

The `map` container - usage

```
#include <map>
map<string,int> products;

products.insert(make_pair("tomato",10));
----------------------------------------------
products["cucumber"] = 6;

cout<<products["tomato"]<<endl;
```

Difference between **[ ]** and **insert**!!!

The `map` container - usage

```
#include <map>
using namespace std;
int main ()
{
    map < string , int > m;
    cout << m. size () << endl; // 0
    if( m["c++"] != 0 ){
        cout << "not 0" << endl;
    }
    cout << m. size () << endl ; // 1
}
```

[ ] side effect

The `map` container - usage

```
typedef map<string,int>::iterator MapIt;
for(MapIt it= products.begin(); it != products.end(); ++it){
   cout<<(it->first)<<" : "<<(it->second)<<endl;
}
-------------------------------------------------

for( auto& i: products ){
    cout<<(i.first)<<" : "<<(i.second)<<endl;
}
```

C++
2011

The `multimap` container - usage

```
multimap<string, string> cities;
cities.insert(make_pair("HU", "Budapest"));
cities.insert(make_pair("HU", "Szeged"));
cities.insert(make_pair("RO", "Seklerburg"));
cities.insert(make_pair("RO", "Neumarkt"));
cities.insert(make_pair("RO", "Hermannstadt"));


typedef multimap<string, string>::iterator MIT;
pair<MIT, MIT> ret = cities.equal_range("HU");
for (MIT it = ret.first; it != ret.second; ++it)        {
    cout << (*it).first <<"\t"<<(*it).second<<endl;
}
```

The `multimap` container - usage

```
multimap<string, string> cities;
cities.insert(make_pair("HU", "Budapest"));
cities.insert(make_pair("HU", "Szeged"));
cities.insert(make_pair("RO", "Seklerburg"));
cities.insert(make_pair("RO", "Neumarkt"));
cities.insert(make_pair("RO", "Hermannstadt"));


auto ret = cities.equal_range("HU");
for (auto it = ret.first; it != ret.second; ++it){
    cout << (*it).first <<"\t"<<(*it).second<<endl;
}
```

C++
2011

The `multimap` container - usage

multimaps do not provide **operator[ ]**
Why???

```
multimap<string, string> cities;
cities.insert(make_pair("HU", "Budapest"));
cities.insert(make_pair("HU", "Szeged"));
cities.insert(make_pair("RO", "Seklerburg"));
cities.insert(make_pair("RO", "Neumarkt"));
cities.insert(make_pair("RO", "Hermannstadt"));


auto ret = cities.equal_range("HU");
for (auto it = ret.first; it != ret.second; ++it)      {
     cout << (*it).first <<"\t"<<(*it).second<<endl;
}
```

The `set/map` container - removal

```
void erase ( iterator position );

size_type erase ( const key_type& x );

void erase ( iterator first, iterator last );
```

The `set` – pointer key type

Output??

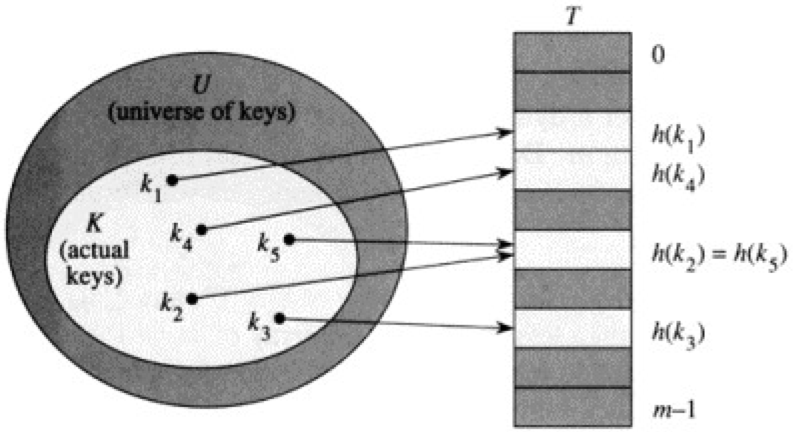
```
set<string *> animals;
animals.insert(new string("monkey"));
animals.insert(new string("lion"));
animals.insert(new string("dog"));
animals.insert(new string("frog"));

for( auto& i: animals ){
   cout<<*i<<endl;
}
```

The `set` – pointer key type

Corrected

```
struct StringComp{
   bool operator()(const string* s1,
                 const string * s2){
      return *s1 < *s2;
   }
};
set<string*, StringComp> animals;
animals.insert(new string("monkey"));
animals.insert(new string("lion"));
animals.insert(new string("dog"));
animals.insert(new string("frog"));

---------------------------------------------------------------------
for( auto& i: animals ){
    cout<<*i<<endl;
}
```

Hash Tables

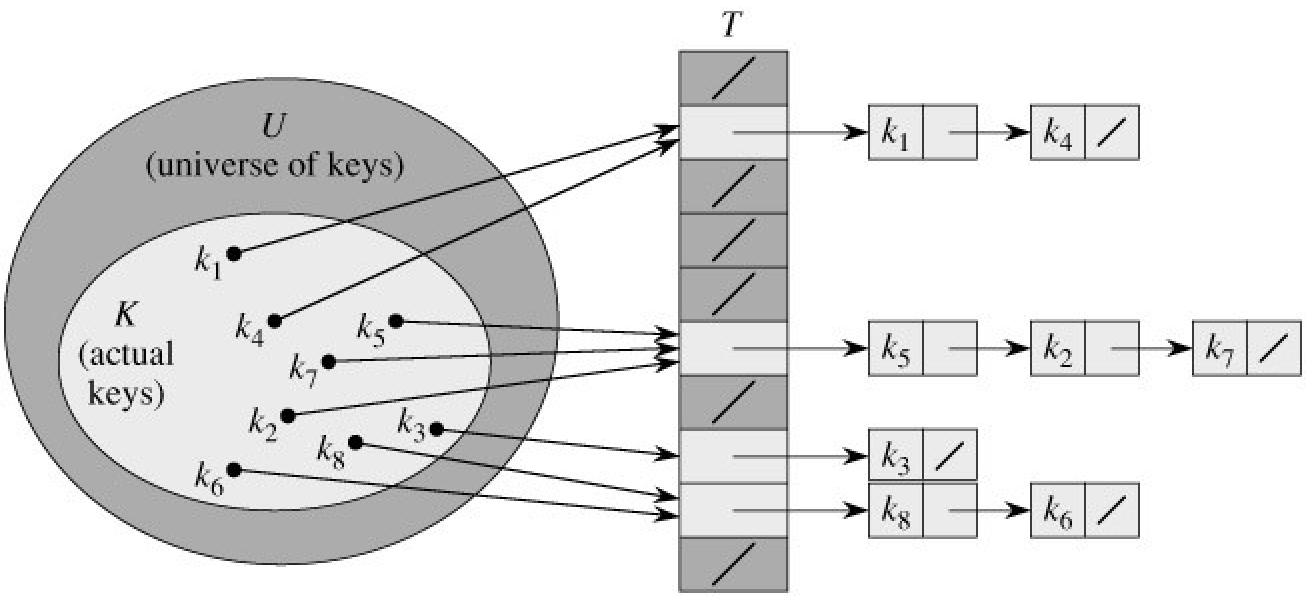


collision

http://web.eecs.utk.edu/~huangj/CS302S04/notes/extendibleHashing.htm

Hash Tables

Collision resolution by chaining



Source: http://integrator-crimea.com/ddu0065.html

Unordered Associative Containers - Hash Tables

- `unordered_set`
- `unordered_multiset`
- `unordered_map`
- `unordered_multimap`

C++
2011

Unordered Associative Containers

- The STL standard does not specify which collision handling algorithm is required
  - most of the current implementations use linear chaining
  - a lookup of a `key` involves:
    - a hash function call `h(key)` – calculates the index in the hash table
    - compares `key` with other keys in the linked list

Hash Function

- *perfect hash*: no collisions
- lookup time: `O(1)` - constant
- there is a default hash function for each STL hash container

The `unordered_map` container

```
template <class Key, class T,
          class Hash = hash<Key>,
          class Pred = std::equal_to<Key>,
          class Alloc= std::allocator<pair<const Key, T>>>
class unordered_map;
```

Template parameters:

- **Key – key type**
- **T – value type**
- **Hash – hash function type**
- **Pred – equality type**

The `unordered_set` container

```
template <class Key,
          class Hash = hash<Key>,
          class Pred = std::equal_to<Key>,
          class Alloc= std::allocator<pair<const Key, T>>>
class unordered_set;
```

Template parameters:

- **Key – key type**
- **Hash – hash function type**
- **Pred – equality type**

Problem

- Read a file containing double numbers. Eliminate the duplicates.
- Solutions???

Solutions

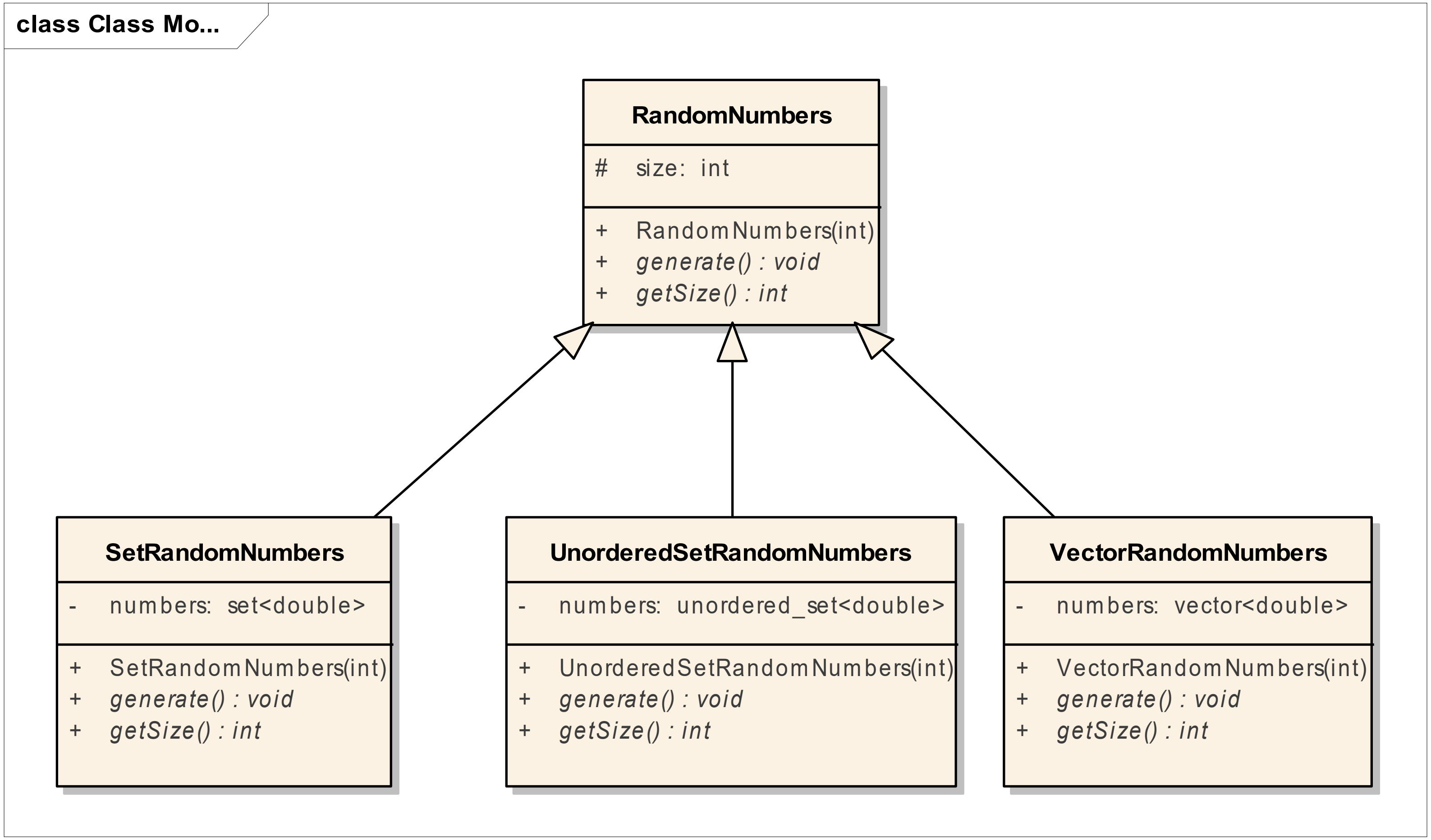
- vector<double> + sort + unique
- set<double>
- unordered_set<double>

- Which is the best? Why?
- What are the differences?

Elapsed time

#include <chrono>

```
auto begin =chrono::high_resolution_clock::now();
//Code to benchmark
auto end =   chrono::high_resolution_clock::now();
cout <<chrono::duration_cast<std::chrono::nanoseconds>
                         (end-begin).count()
     << "ns" << endl;
```


class Class Mo...
RandomNumbers
size: int
+ RandomNumbers(int)
+ generate() : void
+ getSize() : int
SetRandomNumbers
- numbers: set<double>
+ SetRandomNumbers(int)
+ generate() : void
+ getSize() : int
UnorderedSetRandomNumbers
- numbers: unordered_set<double>
+ UnorderedSetRandomNumbers(int)
+ generate() : void
+ getSize() : int
VectorRandomNumbers
- numbers: vector<double>
+ VectorRandomNumbers(int)
+ generate() : void
+ getSize() : int

Ellapsed time

Container	Time (mean)
vector	1.38 sec
set	3.04 sec
unordered_set	1.40 sec

Which container to use?

- implement a PhoneBook, which:
  - stores names associated with their phone numbers;
  - names are unique;
  - one name can have multiple phone numbers associated;
  - provides `O(1)` time search;

Which container to use?

– Usage:

```
PhoneBook pbook;
pbook.addItem("kata","123456");
pbook.addItem("timi","444456");
pbook.addItem("kata","555456");
pbook.addItem("kata","333456");
pbook.addItem("timi","999456");
pbook.addItem("elod","543456");
cout<<pbook<<endl;
```

unordered_map: example

```
class PhoneBook{
    unordered_map<string, vector<string> > book;
public:
    void addItem( string name, string phone);
    void removeItem( string name, string phone);
    vector<string> findItem( string name );
    friend ostream& operator<<( ostream& os,
                                 const PhoneBook& book);

};
```

unordered_map: example

```
typedef unordered_map<string, vector<string> >::iterator Iterator;

void PhoneBook::addItem( string name, string phone){
    Iterator it = this->book.find( name );
    if( it != book.end() ){
        it->second.push_back( phone );
    }else{
        vector<string> phones;
        phones.push_back(phone);
        book.insert( make_pair(name, phones ));
    }
}
```

`unordered_map:` example

```
typedef unordered_map<string, vector<string> >::iterator Iterator;

void PhoneBook::addItem( string name, string phone){
    Iterator it = this->book.find( name );
    if( it != book.end() ){
        vector<string> phones = it->second;
        phones.push_back( phone );
    }else{
        vector<string> phones;
        phones.push_back(phone);
        book.insert( make_pair(name, phones ));
    }
}
```

Find the error and correct it!

unordered_map: example

```
typedef unordered_map<string, vector<string> >::iterator Iterator;

void PhoneBook::addItem( string name, string phone){
    Iterator it = this->book.find( name );
    if( it != book.end() ){
        vector<string>& phones = it->second;
        phones.push_back( phone );
    }else{
        vector<string> phones;
        phones.push_back(phone);
        book.insert( make_pair(name, phones ));
    }
}
```

phone will be inserted into the map

C++/Java

	C++	Java
Objects	`X x;` `X * px = new X();`	`X x = new X();`

Parameter passing	`void f( X x );`
	`void f( X * px);`
	`void f( X& rx);`
	`void f( const X&rx);`
		`void f( X x );`
		`//pass through reference`

run-time binding	only for `virtual` functions	for each function (except static functions)
memory management	explicit (*2011 - smart pointers!)*	implicit (garbage collection)
multiple inheritance	yes	no
interface	no *(abstract class with pure virtual functions!*)	yes

Algorithms

Algorithms

- OOP **encapsulates** *data* and *functionality*
  - data + functionality = object
- The STL separates the *data* (**containers**) from the *functionality* (**algorithms**)
  - only partial separation

Algorithms – why separation?

STL principles:

- algorithms and containers are independent
- (almost) any algorithm works with (almost) any container
- iterators mediate between algorithms and containers
  - provides a standard interface to traverse the elements of a container in sequence

Algorithms

Which one should be used?

```
set<int> s;
set<int>::iterator it = find(s.begin(), s.end(), 7);
if( it == s.end() ){
   //Unsuccessful
}else{
  //Successful
}
```

```
set<int> s;
set<int>::iterator it = s.find(7);
if( it == s.end() ){
   //Unsuccessful
}else{
  //Successful
}
```

Algorithms

Which one should be used?

```
set<int> s;
set<int>::iterator it = find(s.begin(), s.end(), 7);
if( it == s.end() ){
   //Unsuccessful
}else{
  //Successful
}
```

O(n)

```
set<int> s;
set<int>::iterator it = s.find(7);
if( it == s.end() ){
   //Unsuccessful
}else{
  //Successful
}
```

O(log n)

Algorithm categories

- Utility algorithms
- Non-modifying algorithms
  - Search algorithms
  - Numerical Processing algorithms
  - Comparison algorithms
  - Operational algorithms
- Modifying algorithms
  - Sorting algorithms
  - Set algorithms

Utility Algorithms

- `min_element()`
- `max_element()`
- `minmax_element()` **C++11**
- `swap()`

Utility Algorithms

```
vector<int>v = {10, 9, 7, 0, -5, 100, 56, 200, -24};
auto result = minmax_element(v.begin(), v.end() );
cout<<"min: "<<*result.first<<endl;
cout<<"min position: "<<(result.first-v.begin())<<endl;
cout<<"max: "<<*result.second<<endl;
cout<<"max position: "<<(result.second-v.begin())<<endl;
return 0;
```

Non-modifying algorithms

Search algorithms

- `find()`, `find_if()`, `find_if_not()`, `find_first_of()`
- `binary_search()`
- `lower_bound()`, `upper_bound()`, `equal_range()`
- `all_of()`, `any_of()`, `none_of()`
- ...

Non-modifying algorithms

Search algorithms - Example

```
bool isEven (int i) { return ((i%2)==0); }

typedef vector<int>::iterator VIT;

int main () {
  vector<int> myvector={1,2,3,4,5};
  VIT it= find_if (myvector.begin(), myvector.end(), isEven);
  cout << "The first even value is " << *it << '\n';
  return 0;
```

auto

Non-modifying algorithms

Numerical Processing algorithms

- `count()`, `count_if()`
- `accumulate()`
- ...

Non-modifying algorithms

Numerical Processing algorithms - Example

```
bool isEven (int i) { return ((i%2)==0); }


int main () {
   vector<int> myvector={1,2,3,4,5};
   int n = count_if (myvector.begin(), myvector.end(), isEven);
   cout << "myvector contains " << n  << " even values.\n";
   return 0;
}
```

[ ] (int i){ return i %2 == 0; }

Non-modifying algorithms

Comparison algorithms

- `equal()`
- `mismatch()`
- `lexicographical_compare()`

Non-modifying algorithms

Problem

It is given **strange alphabet** – the order of characters are unusual.

Example for a strange alphabet: `{b, c, a}.`
Meaning: `'b'->1, c->'2', 'a' ->3`

In this alphabet: `“abc” >”bca”`

Questions:

- How to represent the alphabet (which container and why)?
- Write a function for string comparison using the strange alphabet.

Non-modifying algorithms

Comparison algorithms - Example

```
// strange alphabet: 'a' ->3, 'b'->1, c->'2'
map<char, int> order;


// Compares two characters based on the strange order
bool compChar( char c1, char c2 ){
    return order[c1]<order[c2];
}
// Compares two strings based on the strange order
bool compString(const string& s1, const string& s2){
    return lexicographical_compare(
        s1.begin(), s1.end(), s2.begin(), s2.end(), compChar);
}
```

Non-modifying algorithms

Comparison algorithms - Example

```
// strange alphabet: 'a' ->3, 'b'->1, c->'2'
map<char, int> order;

// Compares two strings based on the strange order
struct CompStr{
    bool operator()(const string& s1, const string& s2){
        return lexicographical_compare(
            s1.begin(), s1.end(), s2.begin(), s2.end(),
            [](char c1, char c2){return order[c1]<order[c2];} );
    }
}

set<string, CompStr> strangeSet;
```

Non-modifying algorithms

Operational algorithms

- `for_each()`

```
void doubleValue( int& x){
    x *= 2;
}

vector<int> v ={1,2,3};
for_each(v.begin(), v.end(), doubleValue);
```

Non-modifying algorithms

Operational algorithms

- `for_each()`

```
void doubleValue( int& x){
    x *= 2;
}

vector<int> v ={1,2,3};
for_each(v.begin(), v.end(), doubleValue);
```

```
for_each(v.begin(), v.end(), []( int& v){ v *=2;});
```

Modifying algorithms

- `copy()`, `copy_backward()`
- `move()`, `move_backward()` **C++11**
- `fill()`, `generate()`
- `unique()`, `unique_copy()`
- `rotate()`, `rotate_copy()`
- **`next_permutation()`, `prev_permutation()`**
- **`nth_element()`** -nth smallest element

Modifying algorithms

Permutations

```
void print( const vector<int>& v){
    for(auto& x: v){
        cout<<x<<"\t";
    }
    cout << endl;
}
int main(){
    vector<int> v ={1,2,3};
    print( v );
    while( next_permutation(v.begin(), v.end())){
        print( v );
    }
    return 0;
}
```

Modifying algorithms

nth_element

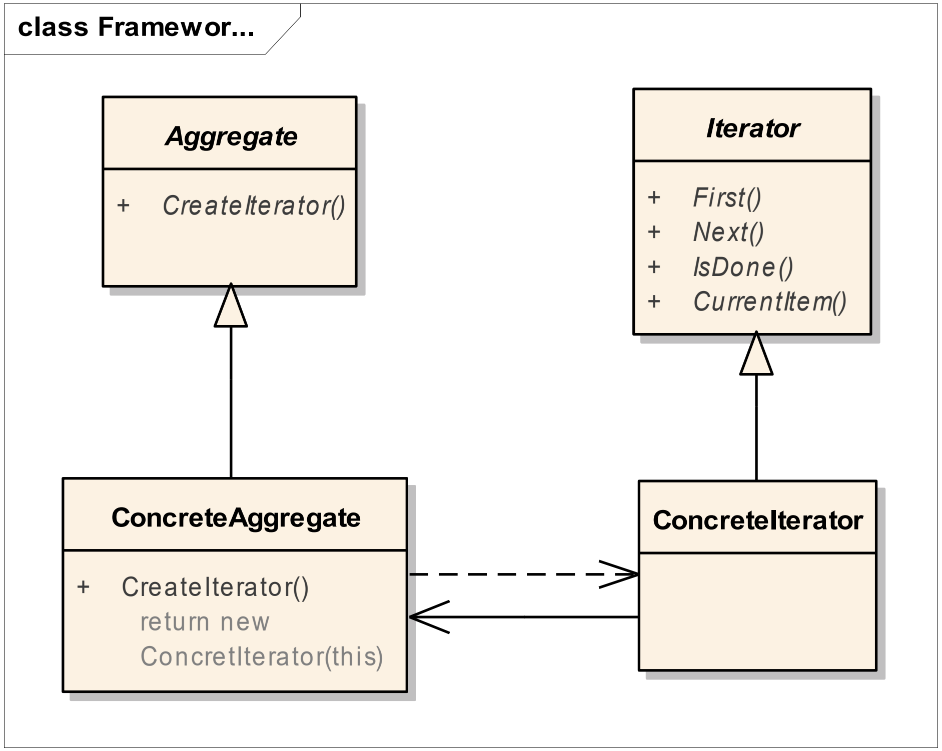
```
double median(vector<double>& v) {
    int n = v.size();
    if( n==0 ) throw domain_error("empty vector");
    int mid = n / 2;
    // size is an odd number
    if( n % 2 == 1 ){
        nth_element(v.begin(), v.begin()+mid, v.end());
        return v[mid];
    } else{
        nth_element(v.begin(), v.begin()+mid-1, v.end());
        double val1 = v[ mid -1 ];
        nth_element(v.begin(), v.begin()+mid, v.end());
        double val2 = v[ mid ];
        return (val1+val2)/2;
    }
}
```

Iterators

Outline

- Iterator Design Pattern
- Iterator Definition
- Iterator Categories
- Iterator Adapters

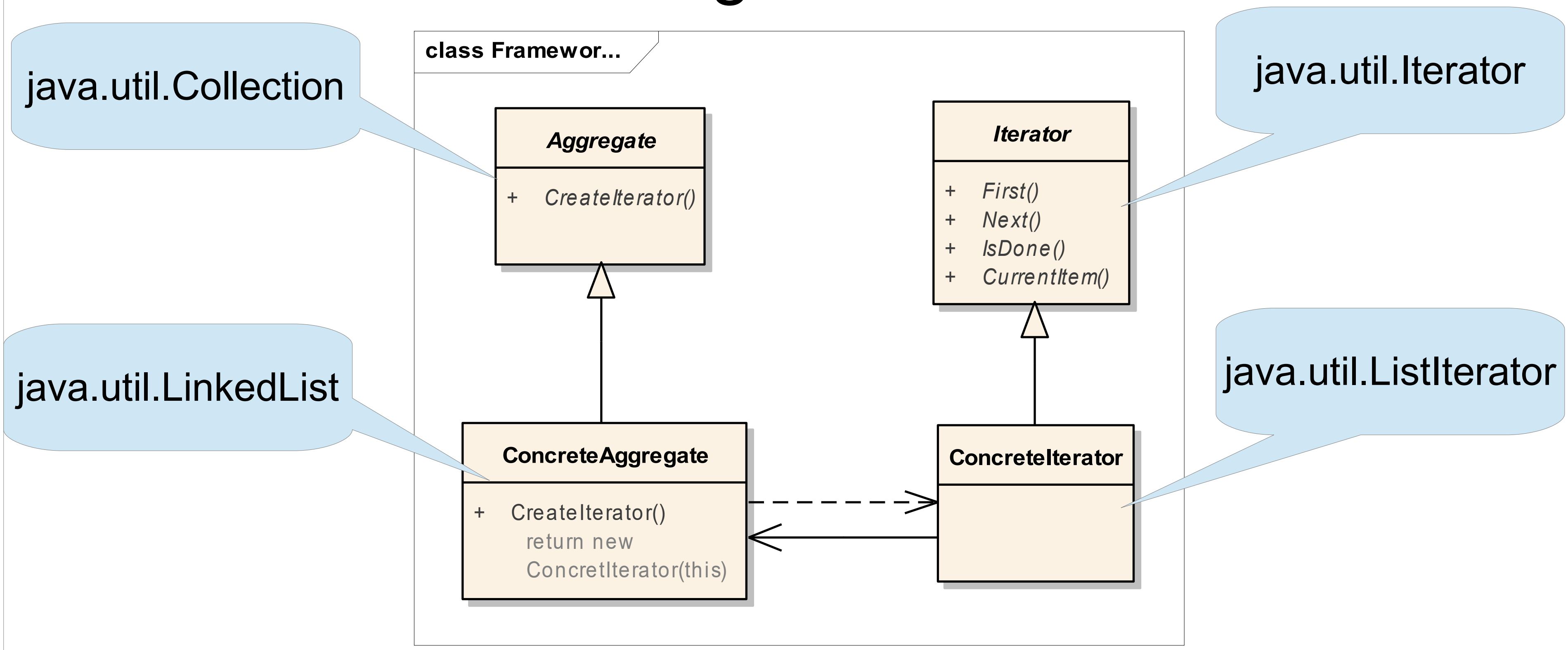
Iterator Design Pattern



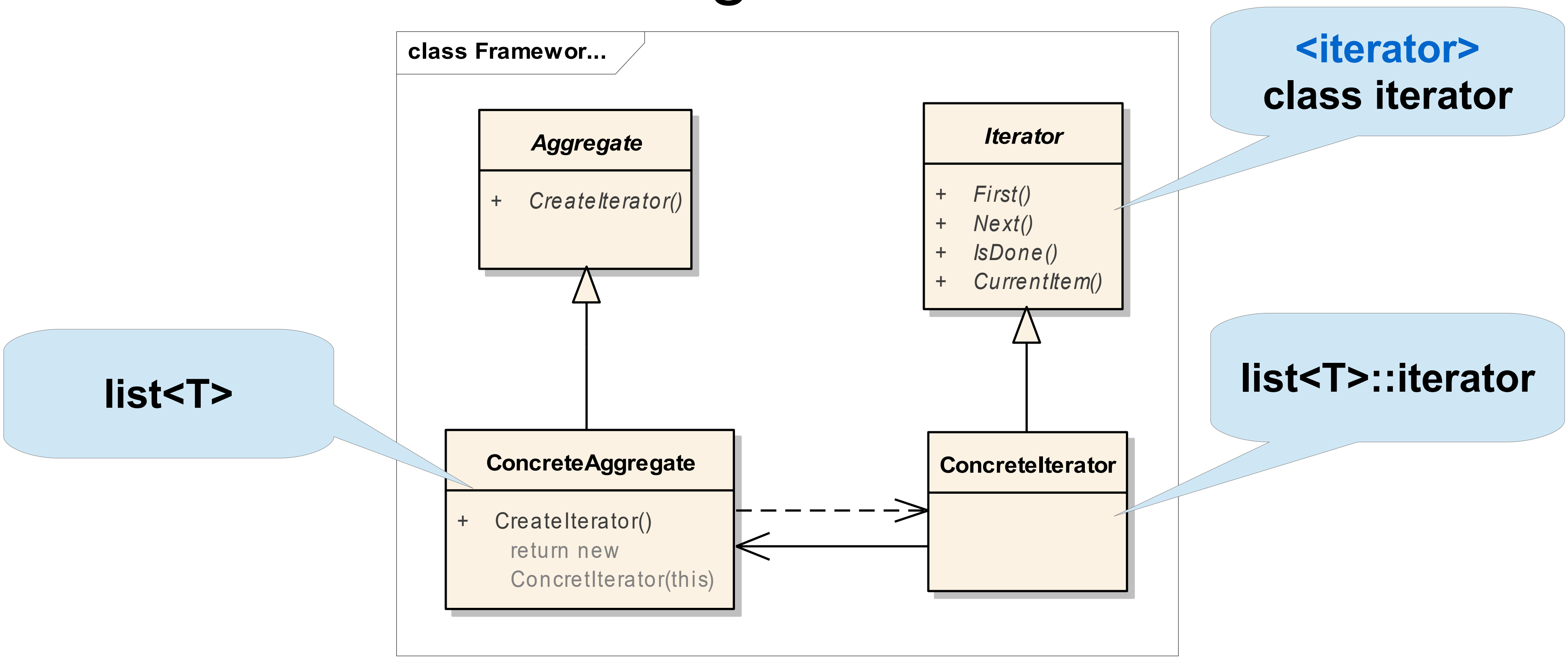
- Provide a **way to access the elements of an aggregate** object sequentially without exposing its underlying representation.

- The abstraction provided by the iterator pattern allows you to modify the collection implementation without making any change

Iterator Design Pattern - Java



Iterator Design Pattern - C++



Definition

- Each container provides an iterator
- Iterator – smart pointer – knows *how to iterate* over the elements of that specific container
- C++ containers provides iterators a common iterator interface

Base class

```
template <class Category, class T,
          class Distance = ptrdiff_t,
          class Pointer = T*,
          class Reference = T&>
  struct iterator {
    typedef T          value_type;
    typedef Distance   difference_type;
    typedef Pointer    pointer;
    typedef Reference  reference;
    typedef Category   iterator_category;
  };
```

does not provide any of the **functionality** an iterator is expected to have.

Iterator Categories

- Input Iterator
- Output Iterator
- Forward Iterator
- Bidirectional Iterator
- Random Access Iterator

Iterator Categories

- **Input Iterator:** read forward, `object=*it; it++;`
- **Output Iterator:** write forward, `*it=object; it++;`
- **Forward Iterator:** read and write forward
- **Bidirectional Iterator:** read/write forward/backward, `it++, it--;`
- **Random Access Iterator:** `it+n; it-n;`

Basic Operations

- `*it`: element access – get the element pointed to
- `it->member`: member access
- `++it, it++, --it, it--`: advance forward/ backward
- `==, !=`: equality

Input Iterator

```
template<class InIt, class T>
InIt find( InIt first, InIt last, T what)
{
 for( ; first != last; ++first )
   if( *first == what ){
      return first;
   }
 return first;
}
```

Input Iterator

```
template<class InIt, class Func>
Func for_each( InIt first, InIt last,
                              Func f){
 for( ;first != last; ++first){
   f( *first );
 }
 return f;
}
```

Output Iterator

```
template <class InIt, class OutIt>
OutIt copy( InIt first1, InIt last1,
                              OutIt first2){
   while( first1 != last1 ){
     *first2 = *first1;
     first1++;
     first2++;
   }
   return first2;
}
```

Forward Iterator

```
template < class FwdIt, class T >
void replace ( FwdIt first, FwdIt last,
       const T& oldv, const T& newv ){
 for (; first != last; ++first){
   if (*first == oldv){
     *first=newv;
   }
 }
}
```

Bidirectional Iterator

```
template <class BiIt, class OutIt>
OutIt reverse_copy ( BiIt first, BiIt
last, OutIt result){
    while ( first!=last ){
      --last;
      *result = *last;
      result++;
   }
   return result;
}
```

Find the second element!

```
template <class T, class It>
It findSecond(It first, It last, const T& what){
   ???
}
```

Find the second element!

```
template <class T, class It>
It findSecond(It first, It last, const T& what){
   while( first != last && *first != what ){
      ++first;
   }
   if( first == last ){
      return last;
   }
   ++first;
   while( first != last && *first != what ){
      ++first;
   }
   return first;
}
```

Containers & Iterators

- `vector` – Random Access Iterator
- `deque` - Random Access Iterator
- `list` – Bidirectional Iterator
- `set, map` - Bidirectional Iterator
- `unordered_set` – Forward Iterator

Iterator adapters

- Reverse iterators
- Insert iterators
- Stream iterators

Reverse iterators

- reverses the direction in which a bidirectional or random-access iterator iterates through a range.
- `++` ← → `--`
- `container.rbegin()`
- `container.rend()`

Insert iterators

- special iterators designed to allow algorithms that usually overwrite elements to instead insert new elements at a specific position in the container.
- the container needs to have an insert member function

Insert iterator - Example

```
//Incorrect
int x[] = {1, 2, 3};
vector<int> v;
copy( x, x+3, v.begin());
```

```
//Correct
int x[] = {1, 2, 3};
vector<int> v;
copy( x, x+3, back_inserter(v));
```

Insert iterator - Example

```
template <class InIt, class OutIt>
OutIt copy( InIt first1, InIt last1,OutIt first2){
   while( first1 != last1){
      *first2 = *first1;//overwrite → insert
      first1++;
      first2++;
   }
   return first2;
}
```

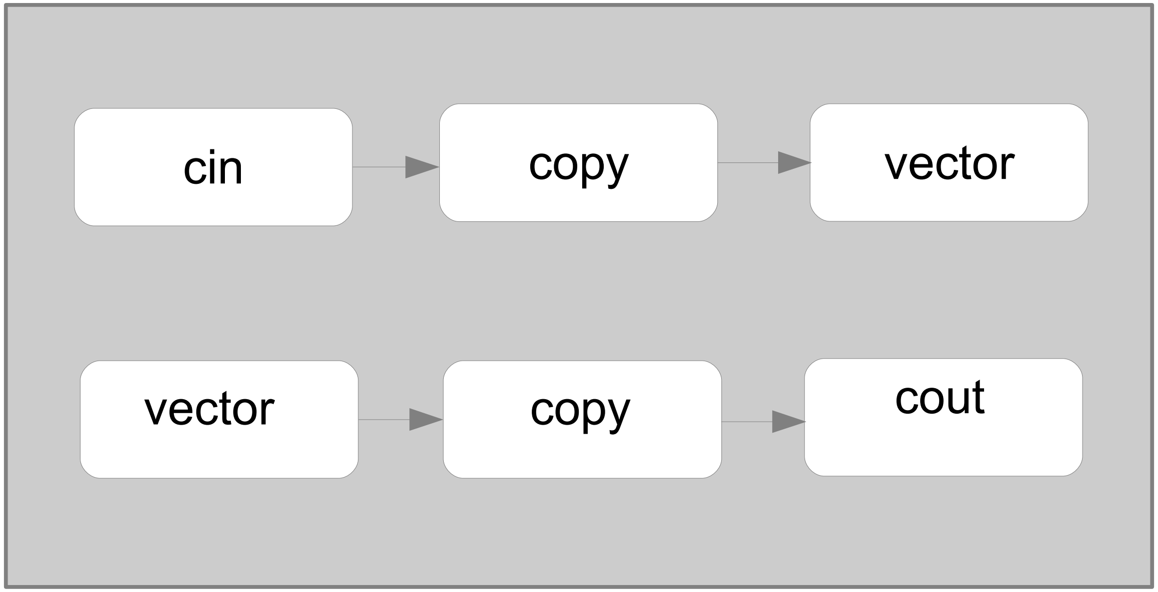
Types of insert iterators

*pos = value;

Type	Class	Function	Creation
Back inserter	back_insert_iterator	push_back(value)	back_inserter(container)
Front inserter	front_insert_iterator	push_front(value)	front_inserter(container)
Inserter	insert_iterator	insert(pos, value)	inserter(container, pos)

Stream iterators

- Objective: connect algorithms to streams



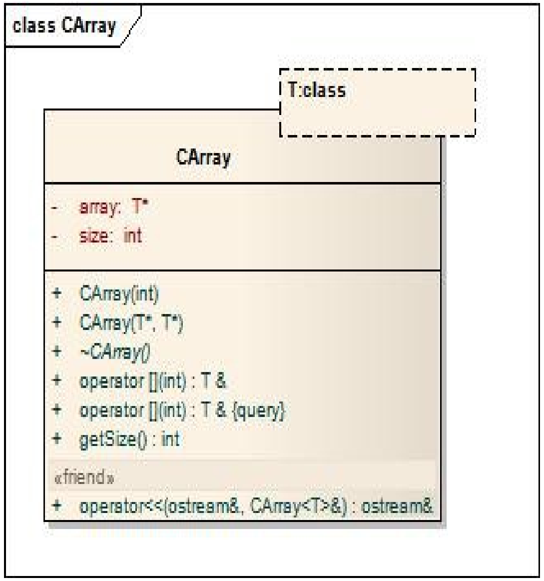
Stream iterator - examples

```
vector<int> v;
copy(v.begin(), v.end(),
ostream_iterator<int>(cout, ","));
```

```
copy(istream_iterator<int>(cin),
     istream_iterator<int>(),
     back_inserter(v));
```

Problem 1.

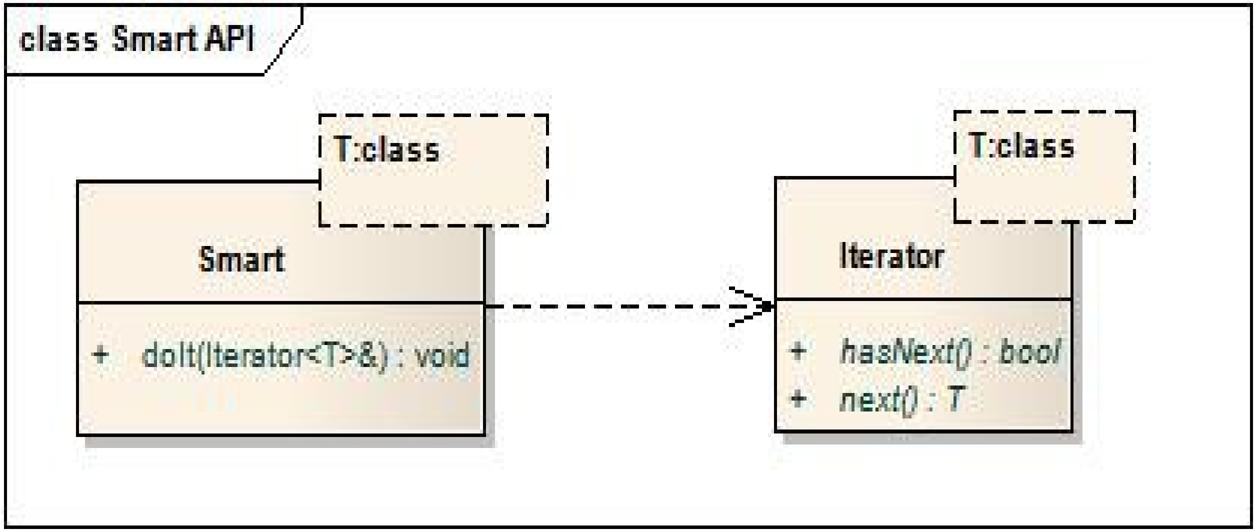
- It is given a CArray class




```
string str[]=
  {"apple", "pear", "plum",
"peach", "strawberry", "banana"};

CArray<string> a(str, str+6);
```

Problem 1.

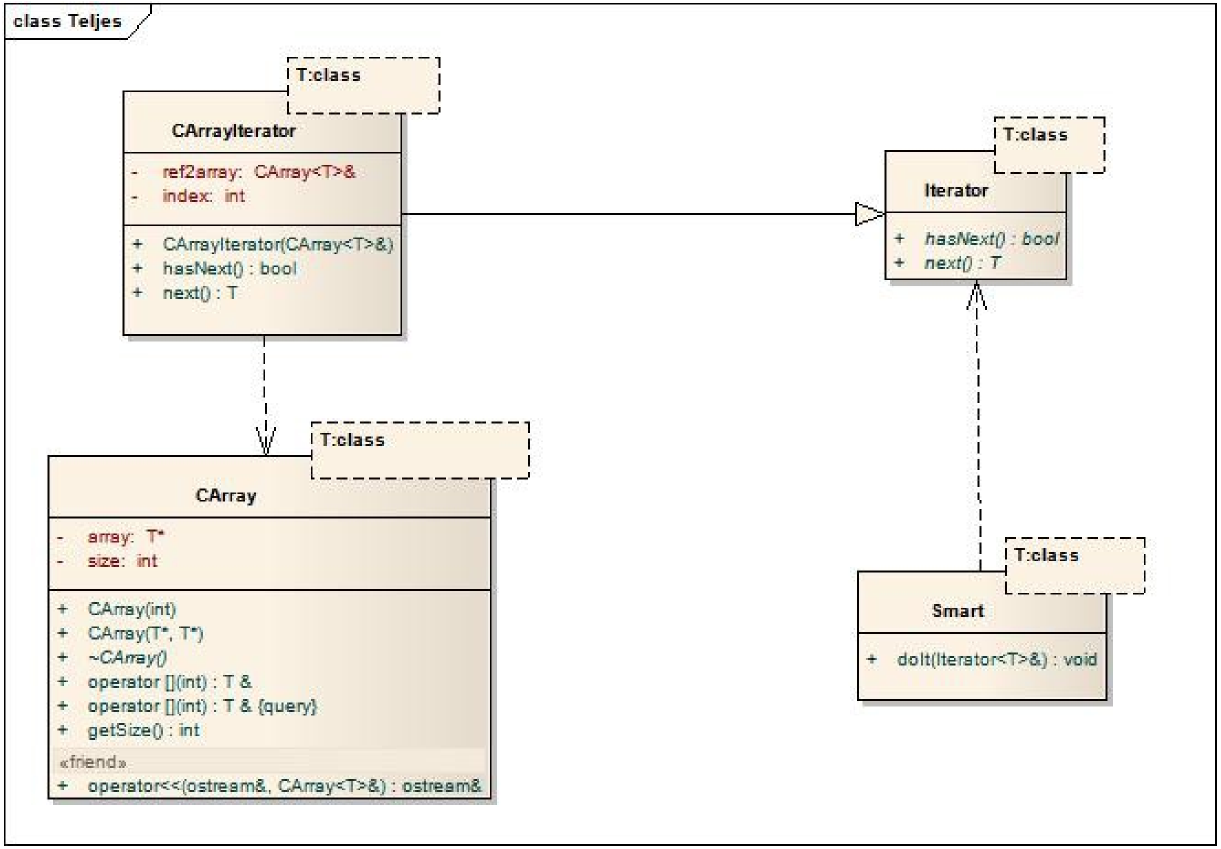
- It is given a Smart API too



Call the **doIt** function for **CArray**!

```
Smart<string> smart;
smart.doIt( ? );
```

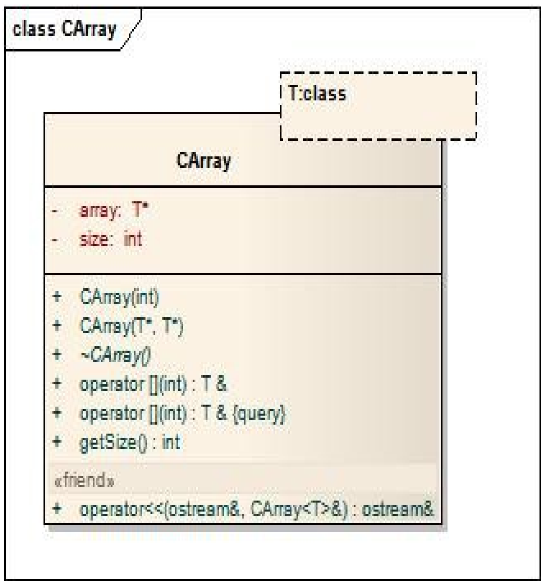
Problem 1. - Solution




```
string str[]= {"apple", "pear", "plum",  "peach", "strawberry"};
CArray<string> a(str, str+5);
CArrayIterator<string> cit ( a );
Smart<string> smart;
smart.doIt( cit );
```

Problem 2.

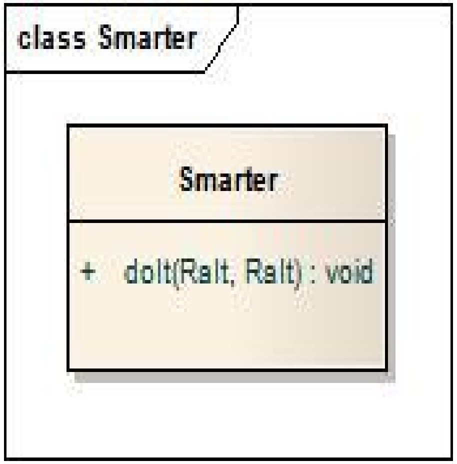
- It is given a CArray class




```
string str[]=
  {"apple", "pear", "plum",
"peach", "strawberry", "banana"};

CArray<string> a(str, str+6);
```

Problem 2.

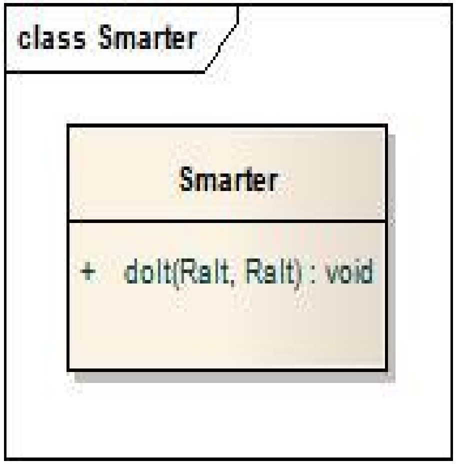
- It is given a Smarter API




```
class Smarter{
public:
  template <class RaIt>
  void doIt( RaIt first, RaIt last ){
    while(  first != last ){
      cout<< *first <<std::endl;
      ++first;
    }

  }
};
```

Problem 2.

- Call the doIt function in the given way!




```
CArray<string> a(str, str+6);
//...
Smarter smart;
smart.doIt( a.begin(), a.end() );
```

Problem 2. - Solution A.

```
template<class T>
class CArray{
public:

    class iterator{
        T* poz;
    public:  ...
    };


    iterator begin(){ return iterator(array);}
    iterator end(){ return iterator(array+size);}
private:
    T * array;
    int size;
};
```

Problem 2. - Solution A.

```
class CArray{
pub
class iterator{
    T* poz;
public:
    iterator( T* poz=0 ): poz( poz ){}
    iterator( const iterator& it ){ poz = it.poz; }
    iterator& operator=( const iterator& it ){
        if( &it == this ) return *this;
        poz = it.poz; return *this;}
    iterator operator++(){ poz++; return *this; }
    iterator operator++( int p ){
        iterator temp( *this ); poz++; return temp;}
    bool operator == ( const iterator& it )const{
        return poz == it.poz;}
    bool operator != ( const iterator& it )const{
        return poz != it.poz; }
pri
    T& operator*() const { return *poz;}
};
};
```

Problem 2. - Solution B.

```
class CArray{
public:

    typedef T * iterator;




    iterator begin(){ return array;}
    iterator end()  { return array+size;}
private:
    T * array;
    int size;
};
```

Carray → iterator

```
template <class T>
class CArray{
   T * data;
   int size;
public:
   ...
   typedef T*          iterator;
   typedef T           value_type;
   typedef T&          reference;
   typedef ptrdiff_t   difference_type;
   typedef T *         pointer;
};
```

Module 9

Function Objects & Lambdas

Function object

```
class FunctionObjectType {
public:
    return_type operator() (parameters) {
        Statements
    }
};
```

Function pointer vs. function object

- A *function object* may have a state
- Each *function object* has its own type, which can be passed to a template (e.g. set, map)
- A *function object* is usually faster than a function pointer

Function object as a sorting criteria

```
class PersonSortCriterion {
public:
    bool operator() (const Person& p1, const Person& p2)
const {
    if (p1.lastname() != p2.lastname() ){
        return p1.lastname() < p2.lastname();
    } else{
        return p1.firstname()<p2.firstname());
    }
};
```

```
// create a set with special sorting criterion
set<Person,PersonSortCriterion> coll;
```

Function object with internal state

```
class IntSequence{
private:
    int value;
public:
    IntSequence (int initialValue) : value(initialValue) {
    }
    int operator() () {
        return ++value;
    }
};
```

Function object with internal state

[Josuttis]

```
list<int> coll;

generate_n (back_inserter(coll), // start
                              9, // number of elements
              IntSequence(1)); // generates values,
                               // starting with 1
```

Function object with internal state

[Josuttis]

```
list<int> coll;

generate_n (back_inserter(coll), // start
                            9, // number of elements
               IntSequence(1)); // generates values,
                                // starting with 1
```

???

Function object with internal state + for_each

[Josuttis]

```
class MeanValue {
private:
    long num; // number of elements
    long sum; // sum of all element values
public:
    MeanValue () : num(0), sum(0) {}
    void operator() (int elem) {
        ++num; // increment count
        sum += elem; // add value
    }
    double value () {
        return static_cast<double>(sum) / num;
    }
};
```

function object with internal state + for_each

[Josuttis]

```
int main()
{
    vector<int> coll = { 1, 2, 3, 4, 5, 6, 7, 8 };

    MeanValue mv = for_each (coll.begin(), coll.end(),
                                                    MeanValue());
    cout << "mean value: " << mv.value() << endl;
}
```

Why to use the return value?

http://www.cplusplus.com/reference/algorithm/for_each/

Predicates

- Are function objects that return a boolean value
- A predicate should always be stateless

```
template <typename ForwIter, typename Predicate>
ForwIter std::remove_if(ForwIter beg, ForwIter end,
                        Predicate op)
```

Predefined function objects

```
Expression Effect

negate<type>() - param
plus<type>()   param1 + param2
minus<type>()  param1 - param2
multiplies<type>()param1 * param2
divides<type>() param1 / param2
modulus<type>() param1 % param2
equal_to<type>()param1 == param2
not_equal_to<type>() param1 !=
param2
less<type>() param1 < param2
greater<type>() param1 > param2
less_equal<type>() param1 <=
param2
```

```
Expression Effect

greater_equal<type>() param1 >=
param2
logical_not<type>() ! param
logical_and<type>() param1 &&
param2
logical_or<type>() param1 ||
param2
bit_and<type>() param1 & param2
bit_or<type>() param1 | param2
bit_xor<type>() param1 ^ param2
```

Syntactic sugar

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Lambdas

- a function that you can write *inline* in your source code

```
#include <iostream>

using namespace std;

int main()
{
    auto func = [] () { cout << "Hello world"; };
    func(); // now call the function
}
```

Syntactic sugar

Lambdas

- *no need to write a separate function or to write a function object*
- *set*

```
auto comp = [](string x, string y) {
                     return x > y;
            };
set<string, decltype(comp)> s(comp);
//...
for (auto& x : s) {
       cout << x << endl;
}
```

Syntactic sugar

Lambda syntax

```
[ ] ( )opt ->opt { }
```

[captures]	(params) ->ret { statements; }

[captures]

What outside variables are available, by value or by reference.

(params)

How to invoke it. Optional if empty.

-> ret

Uses new syntax. Optional if zero or one return statements.

{ statements; }

The body of the lambda

Herb Sutter: nwcpp.org/may-2011.html

Syntactic sugar

Examples

[captures]	(params) ->ret { statements; }

- Earlier in scope: Widget w;
- Capture w by value, take no parameters when invoked.

```
auto lamb = [w] { for( int i = 0; i < 100; ++i ) f(w); };
lamb();
```

- Capture w by reference, take a const int& when invoked.

```
auto da = [&w] (const int& i) { return f(w, i); };
int i = 42;
da( i );
```

Herb Sutter: nwcpp.org/may-2011.html

Syntactic sugar

Lambdas == Functors

[captures]   (params) ->ret { statements; }

```
class __functor {
    private:
        CaptureTypes  __captures;
    public:
        __functor( CaptureTypes captures )
        : __captures( captures ) { }

        auto operator() ( params ) → {  statements; }

};
```

Herb Sutter: nwcpp.org/may-2011.html

Syntactic sugar

Capture Example

[c1, &c2]

{ f(c1, c2); }

```
class __functor {
    private:
        C1 __c1; C2& __c2;
    public:
        __functor( C1 c1, C2& c2 )
        : __c1(c1), __c2(c2) { }

            void operator() () → {  f(__c1, __c2); }

};
```

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Syntactic sugar

Parameter Example

[ ]

(P1 p1, const P2& p2){ f(p1, p2); }

```
class __functor {

public:
      void operator() ( P1 p1, const P2& p2) {
                        f(p1, p2);
      }

};
```

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Syntactic sugar

Type of Lambdas

```
auto g = [&]( int x, int y ) { return x > y; };

map<int, int, ? > m( g );
```

Syntactic sugar

Type of Lambdas

```
auto g = [&]( int x, int y ) { return x > y; };

map<int, int, ? > m( g );
```

```
auto g = [&]( int x, int y ) { return x > y; };

map<int, int, decltype(g) > m( g );
```

Example

```
int x = 5;
int y = 12;
auto pos = find_if (
    coll.cbegin(), coll.cend(),       // range
    [=](int i){return i > x && i < y;}// search criterion
);
cout << "first elem >5 and <12: " << *pos << endl;
```

= symbols are passed by value

Example

```
vector<int> vec = {1,2,3,4,5,6,7,8,9};
int value = 3;
int cnt = count_if(vec.cbegin(),vec.cend(),
                       [=](int i){return i>value;});
cout << "Found " << cnt << " values > " << value <<
endl;
```

Module 10

Advanced C++

Outline

- Casting. RTTI
- Handling Errors
- Smart Pointers
- **Random Numbers**
- **Regular Expressions**

Casting & RTTI

Casting

- converting an expression of a given type into another type
- **traditional type casting:**
  - `(new_type) expression`
  - `new_type (expression)`
- **specific casting operators:**
  - **`dynamic_cast <new_type> (expression)`**
  - `reinterpret_cast <new_type> (expression)`
  - `static_cast <new_type> (expression)`
  - `const_cast <new_type> (expression)`

`static_cast<>()` vs. C-style cast

- `static_cast<>()` gives you a compile time checking ability, C-Style cast doesn't.
- You would better avoid casting, except `dynamic_cast<>()`

Run Time Type Information

- Determining the type of any variable during execution (runtime)
- Available only for **polymorphic classes** (having at least one virtual method)
- RTTI mechanism
  - **the `dynamic_cast<>` operator**
  - **the `typeid` operator**
  - **the `type_info` struct**

Casting Up and Down

```
class Super{
public:
    virtual void m1();
};
class Sub: public Super{
public:
    virtual void m1();
    void m2();
};
```

```
Sub mySub;
//Super mySuper = mySub;  // SLICE
Super& mySuper = mySub; // No SLICE
mySuper.m1(); // calls Sub::m1() - polymorphism
mySuper.m2(); // ???
```

dynamic_cast<>

```
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";
}
```

dynamic_cast<>

```
class Person{
   public: virtual void print(){cout<<"Person";};
};
class Employee:public Person{
   public: virtual void print(){cout<<"Employee";};
};
class Manager:public Employee{
   public: virtual void print(){cout<<"Manager";};
};

vector<Person*> v;
v.push_back(new Person());
v.push_back(new Employee());
v.push_back( new Manager());
...
```

dynamic_cast<>

```
class Person{
   public: virtual void print(){cout<<"Person";};
};
class Employee:public Person{
   public: virtual void print(){cout<<"Employee";};
};
class Manager:public Employee{
   public: virtual void print(){cout<<"Manager";};
};

vector<Person*> v;
v.push_back(new Person());
v.push_back(new Employee());
v.push_back( new Manager());
...
```

Write a code that counts the number of employees!

dynamic_cast<>

```
class Person{
   public: virtual void print(){cout<<"Pers
};
class Employee:public Person{
   public: virtual void print(){cout<<"Empl
};
class Manager:public Employee{
   public: virtual void pr
};

vector<Person*> v;
v.push_back(new Person())
v.push_back(new Employee(
v.push_back( new Manager(
...
```

Write a code that counts the number of employees!

```
Employee * p = nullptr;
for( Person * sz: v ){
    p = dynamic_cast<Employee *>( sz );
    if( p != nullptr ){
        ++counter;
    }
}
```

Which solution is better? (Solution 1)

```
void speak(const Animal& inAnimal) {
    if (typeid (inAnimal) == typeid (Dog)) {
        cout << "VauVau" << endl;
    } else if (typeid (inAnimal) == typeid (Bird)) {
        cout << "Csirip" << endl;
    }
}

….
Bird bird; Dog d;
speak(bird); speak( dog );
```

???

Which solution is better? (Solution 2)

```
class Animal{
public:
    virtual void speak()=0;
};
class Dog:public Animal{
public:
    virtual void speak(){cout<<"VauVau"<<endl;};
};
class Bird: public Animal{
public:
    virtual void speak(){cout<<"Csirip"<<endl;};
};
```

```
void speak(const Animal& inAnimal) {
    inAnimal.speak();
}
Bird bird; Dog d;
speak(bird); speak( dog );
```

typeid

```
class Person{
   public: virtual void pr
};
class Employee:public Pers
   public: virtual void pr
};
class Manager:public Employee{
   public: virtual void print(){cout<<"Manager";};
};

vector<Person*> v;
v.push_back(new Person())
v.push_back(new Employee(
v.push_back( new Manager(
...
```

Write a code that counts the number of employees (the exact type of the objects is Employee)!

```
counter = 0;
for( Person * sz: v ){
    if( typeid(*sz) == typeid(Employee) ){
        ++counter;
    }
}
```

Typeid usage

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

int main ()
{
      int * a;
      int b;
      a=0; b=0;
      if (typeid(a) != typeid(b))
      {
          cout << "a and b are of different types:\n";
          cout << "a is: " << typeid(a).name() << '\n';
          cout << "b is: " << typeid(b).name() << '\n';
      }
      return 0;
}
```

```
a and b are of different types:
a is: Pi
b is: i
```

Handling Errors

Handling Errors

- C++ provides Exceptions as an *error handling mechanism*

- Exceptions: to handle *exceptional* but *not unexpected* situations

Return type vs. Exceptions

Return type:

- caller may ignore
- caller may not propagate upwards
- doesn't contain sufficient information

Exceptions:

- easier
- more consistent
- safer
- cannot be ignored (your program fails to catch an exception → will terminate)
- can skip levels of the call stack

Exceptions

<stdexcept>

```
int SafeDivide(int num, int den)
{
  if (den == 0)
     throw invalid_argument("Divide by zero");
  return num / den;
}
int main()
{
  try {
     cout << SafeDivide(5, 2) << endl;
     cout << SafeDivide(10, 0) << endl;
     cout << SafeDivide(3, 3) << endl;
  } catch (const invalid_argument& e) {
     cout << "Caught exception: " << e.what() << endl;
  }
  return 0;
}
```

Discussion??!!!

<stdexcept>

Exceptions

```
int SafeDivide(int num, int den)
{
  if (den == 0)
     throw invalid_argument("Divide by zero");
  return num / den;
}
int main()
{
  try {
     cout << SafeDivide(5, 2) << endl;
     cout << SafeDivide(10, 0) << endl;
     cout << SafeDivide(3, 3) << endl;
  } catch (const invalid_argument& e) {
     cout << "Caught exception: " << e.what() << endl;
  }
  return 0;
}
```

It is recommended to catch exceptions by const reference.

HandExceptions

<stdexcept>

```
try {
  // Code that can throw exceptions
} catch (const invalid_argument& e) {
  // Handle invalid_argument exception
} catch (const runtime_error& e) {
  // Handle runtime_error exception
} catch (...) {
  // Handle all other exceptions
}
```

Any exception

Throw List

<stdexcept>

```
void func() throw (extype1, extype2){
  // statements
}
```

The throw list is not enforced at compile time!

<stdexcept>

Throw List

http://www.cplusplus.com/doc/tutorial/exceptions/

```
void func() throw (){
  // statements
}
```

```
void func() noexcept{
  // statements
}
```

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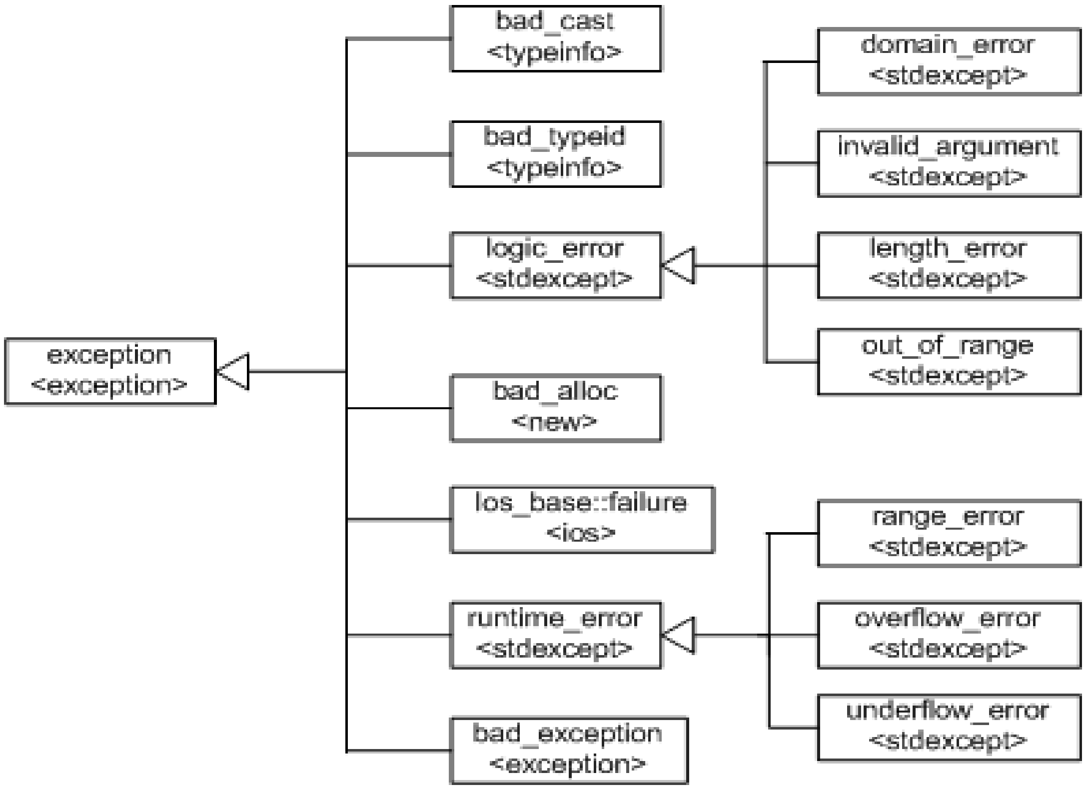
The Standard Exceptions

<stdexcept>

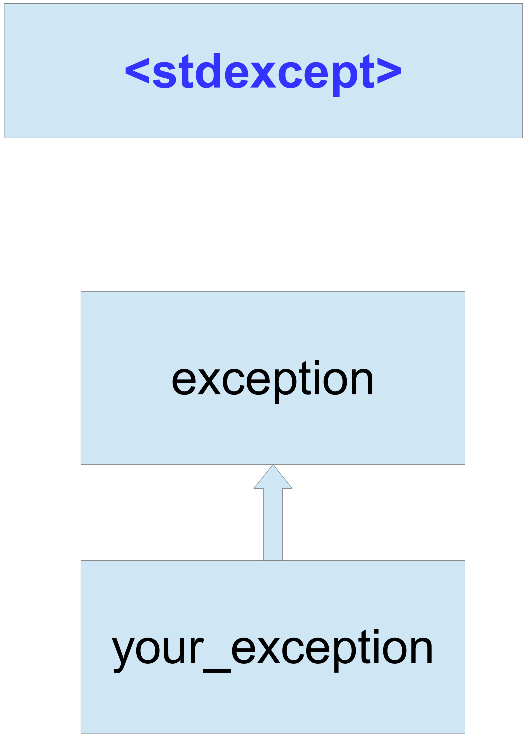
The C++ Exception Hierarchy



http://cs.stmarys.ca/~porter/csc/ref/cpp_standlib.html

User Defined Exception

– It is recommended to inherit directly or indirectly from the standard exception class



User Defined Exception

<stdexcept>

```
class FileError : public runtime_error{
public:
   FileError(const string& fileIn):runtime_error ("")
                                     , mFile(fileIn) {}
  virtual const char* what() const noexcept{
     return mMsg.c_str();
  }
  string getFileName() { return mFile; }
protected:
  string mFile, mMsg;
};
```

Smart Pointers

Outline

- The problem: **raw pointers**
- The solution: **smart pointers**
- Examples
- How to implement smart pointers

Why Smart Pointers?

- When to delete an object?
  - No deletion → **memory leaks**
  - Early deletion (others still pointing to) → **dangling pointers**
  - **Double-freeing**

Smart Pointer Types

- `unique_ptr`
- `shared_ptr`
- `weak_ptr`

```
#include <memory>
```

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It is recommended to use smart pointers!

Smart Pointers

- Behave like built-in (raw) pointers
- Also manage dynamically created objects
  - Objects get deleted in smart pointer destructor
- Type of ownership:
  - unique
  - shared

The good old pointer

```
void oldPointer(){
  Foo * myPtr = new Foo();
  myPtr->method();
}
```

Memory leak

The good Old pointer

```
void oldPointer1(){
   Foo * myPtr = new Foo();
   myPtr->method();
}
```

Memory leak

```
void oldPointer2(){
   Foo * myPtr = new Foo();
   myPtr->method();
   delete myPtr;
}
```

Could cause memory leak When?

The Old and the New

```
void oldPointer(){
   Foo * myPtr = new Foo();
   myPtr->method();
}
```

Memory leak

```
void newPointer(){
   shared_ptr<Foo> myPtr (new Foo());
   myPtr->method();
}
```

Creating smart pointers

```
void newPointer(){
  shared_ptr<Foo> myPtr (new Foo());
  myPtr->method();
}
```

```
void newPointer(){
  auto myPtr = make_shared<Foo>();
  myPtr->method();
}
```

Static
factory method

unique_ptr

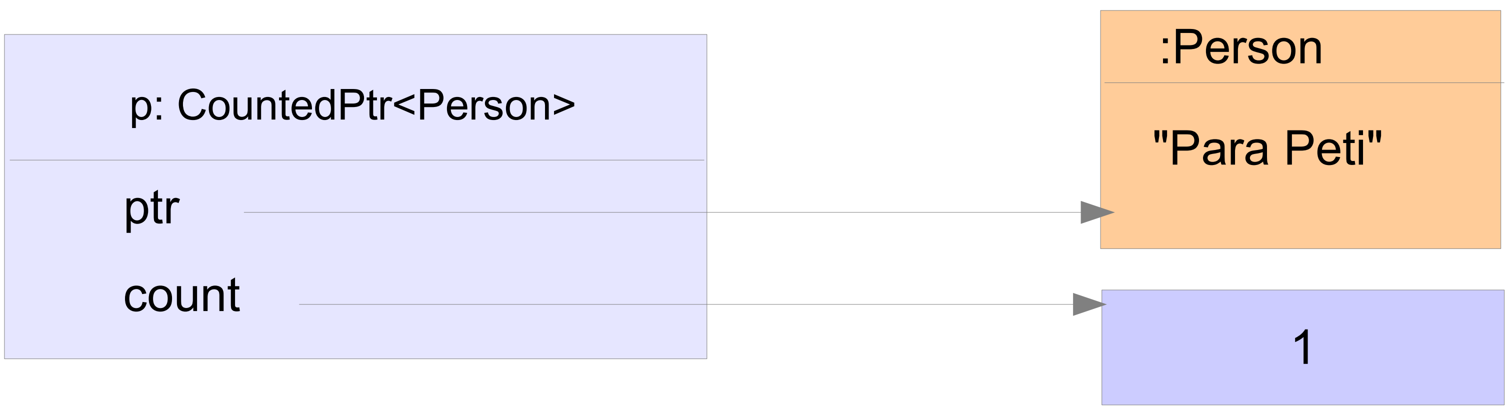
- it will automatically free the resource in case of the unique_ptr goes out of scope.

`shared_ptr`

- Each time a `shared_ptr` is assigned
  - a **reference count** is incremented (there is one more “owner” of the data)
- When a `shared_ptr` goes out of scope
  - the **reference count** is decremented
  - if **reference_count = 0** the object referenced by the pointer is freed.

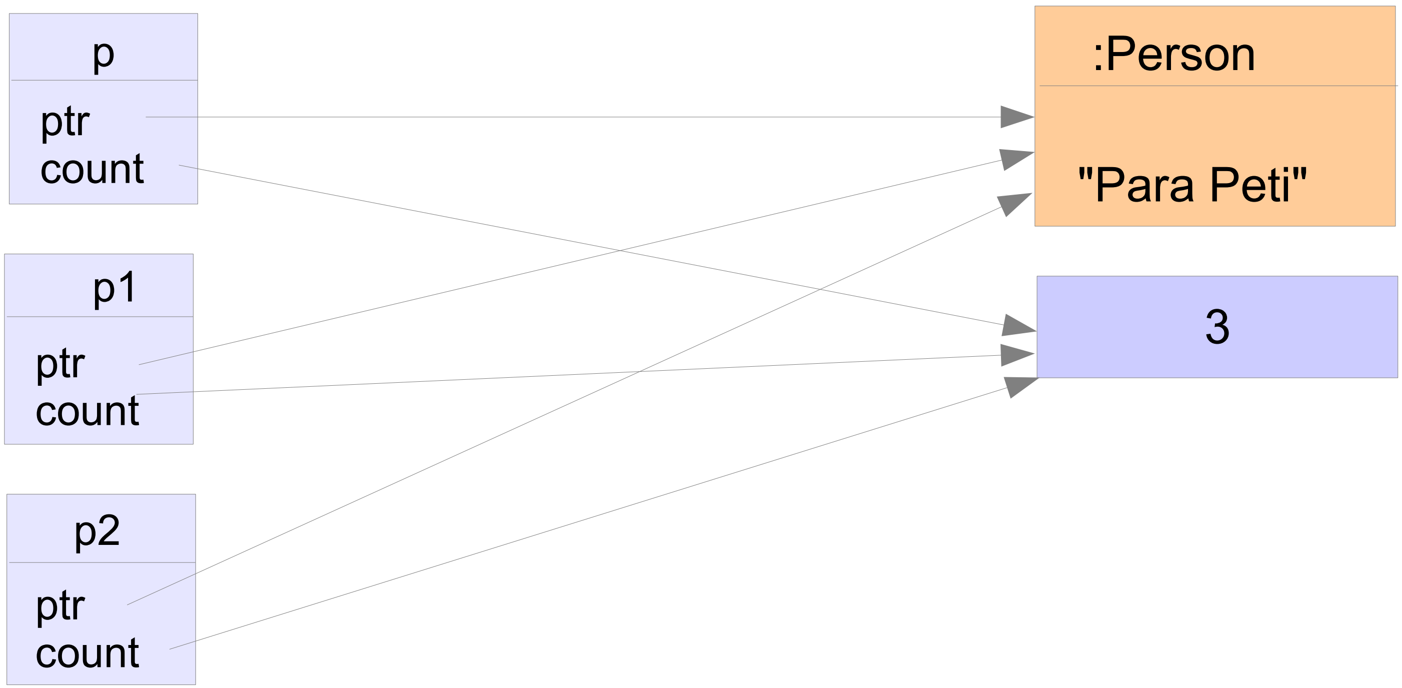
Implementing your own smart pointer class

```
CountedPtr<Person> p(new Person("Para Peti",1980));
```



Implementing your own smart pointer class

```
CountedPtr<Person> p1 = p;
CountedPtr<Person> p2 = p;
```



Implementation (1)

```
template < class T>
class CountedPtr{
   T * ptr;
   long * count;
public:
    ...
};
```

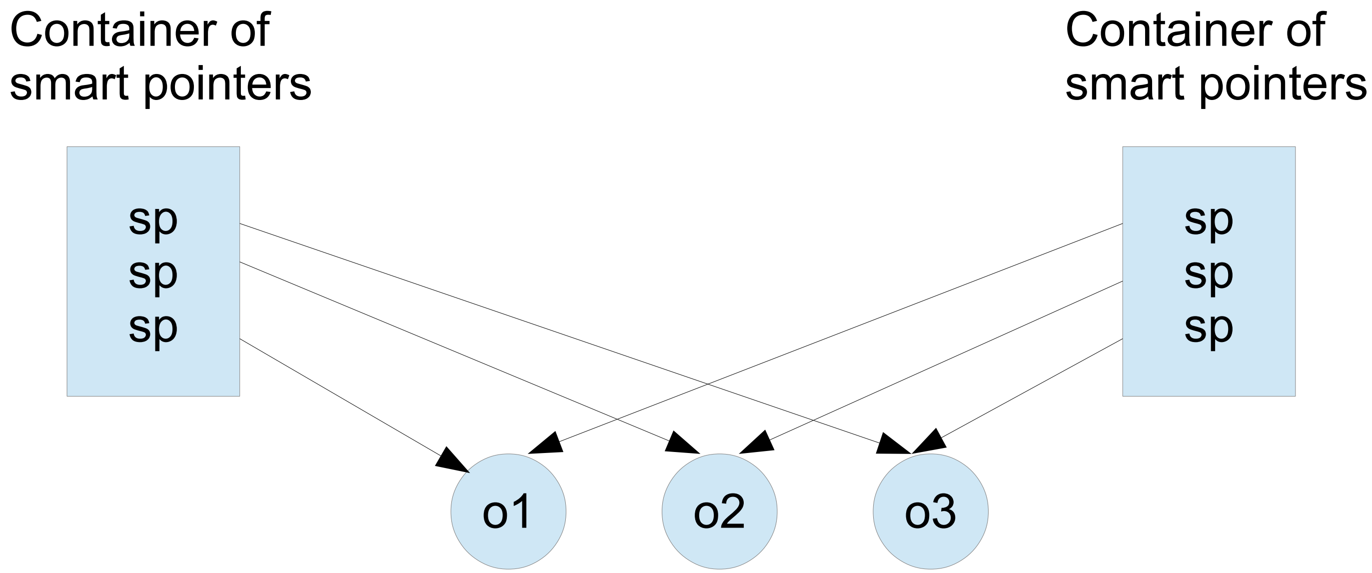
Implementation (2)

```
CountedPtr( T * p = 0 ):ptr( p ),
   count( new long(1)){
}

CountedPtr( const CountedPtr<T>& p ): ptr( p.ptr),
   count(p.count){
   ++(*count);
}

~CountedPtr(){
  --(*count);
  if( *count == 0 ){
    delete count; delete ptr;
  }
}
```

Implementation (3)

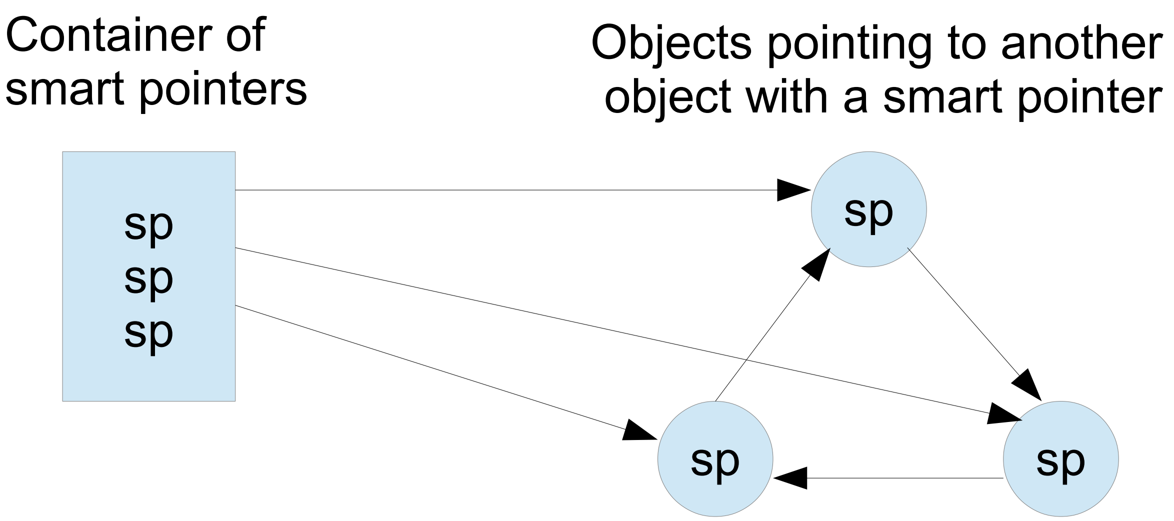
```
CountedPtr<T>& operator=( const CountedPtr<T>& p ){
   if( this != &p ){
      --(*count);
      if( *count == 0 ){ delete count; delete ptr; }
      this->ptr = p.ptr;
      this->count = p.count;
      ++(*count);
   }
   return *this;
}

T& operator*()  const{ return *ptr;}

T* operator->() const{ return  ptr;}
```

Shared ownership with `shared_ptr`



http://umich.edu/~eecs381/handouts/C++11_smart_ptrs.pdf

Problem with `shared_ptr`

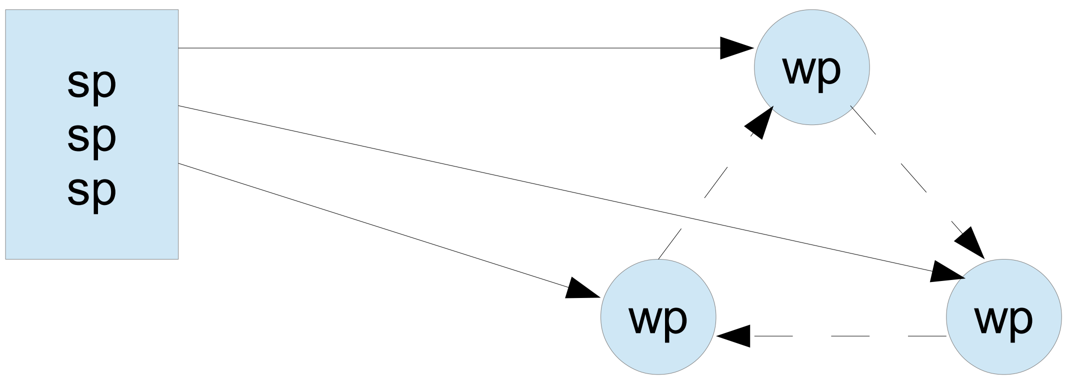


http://umich.edu/~eecs381/handouts/C++11_smart_ptrs.pdf

Solution: `weak_ptr`

Container of smart pointers

Objects pointing to another object with a **weak** pointer



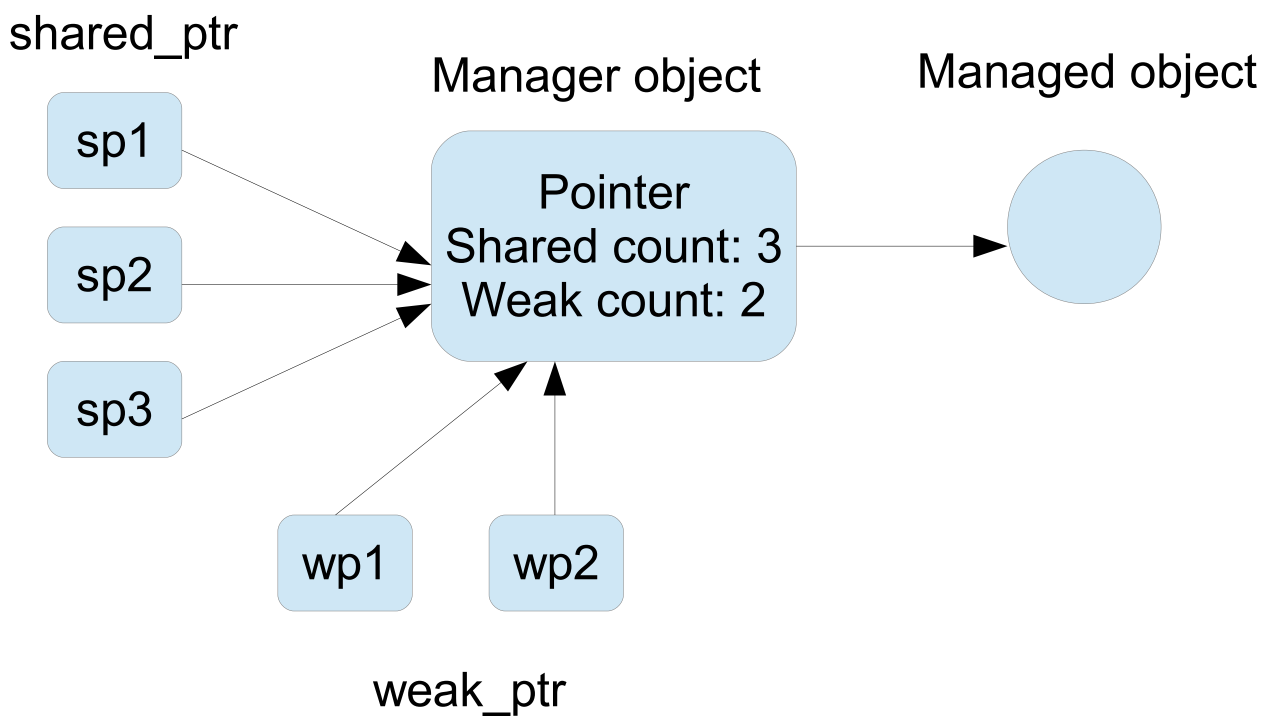
http://umich.edu/~eecs381/handouts/C++11_smart_ptrs.pdf

weak_ptr

- Observe an object, but does not influence its lifetime
- Like raw pointers - the weak pointers do not keep the pointed object alive
- Unlike raw pointers – the weak pointers know about the existence of pointed-to object

http://umich.edu/~eecs381/handouts/C++11_smart_ptrs.pdf

How smart pointers work



http://umich.edu/~eecs381/handouts/C++11_smart_ptrs.pdf

Restrictions in using smart pointers

- Can be used to refer to objects allocated with `new` (can be deleted with `delete`).
- Avoid using raw pointer to the object refered by a smart pointer.

http://umich.edu/~eecs381/handouts/C++11_smart_ptrs.pdf

Inheritance and `shared_ptr`

```
void greeting( shared_ptr<Person>& ptr ){
  cout<<"Hello "<<(ptr.get())->getFname()<<" "
                <<(ptr.get())->getLname()<<endl;
}

int main(int argc, char** argv) {
  shared_ptr<Person> ptr_person(new Person("John","Smith"));
  cout<<*ptr_person<<endl;
  greeting( ptr_person );

  shared_ptr<Manager> ptr_manager(new Manager("Black","Smith", "IT"));
  cout<<*ptr_manager<<endl;
  ptr_person = ptr_manager;
  cout<<*ptr_person<<endl;
  return 0;
}
```

unique_ptr usage

```
// p owns the Person
unique_ptr<Person> uptr(new Person("Mary", "Brown"));

unique_ptr<Person> uptr1( uptr ); //ERROR - Compile time

unique_ptr<Person> uptr2;         //OK. Empty unique_ptr

uptr2 = uptr1;                     //ERROR - Compile time
uptr2 = move( uptr );              //OK. uptr2 is the owner
cout<<"uptr2: "<<*uptr2<<endl;     //OK
cout<<"uptr : "<<*uptr <<endl;     //ERROR - Run time

unique_ptr<Person> uptr3 = make_unique<Person>("John","Dee");
cout<<*uptr3<<endl;
```

Static
Factory Method

`unique_ptr` usage (2)

```
unique_ptr<Person> uptr1 =
                        make_unique<Person>("Mary","Black");
unique_ptr<Person> uptr2 = make_unique<Person>("John","Dee");
cout<<*uptr2<<endl;

vector<unique_ptr<Person> > vec;
vec.push_back( uptr1  );
vec.push_back( uptr2 );

cout<<"Vec [";
for( auto e: vec ){
   cout<<*e<<" ";
}
cout<<"]"<<endl;
```

Find the errors
and correct them!!!

`unique_ptr` usage (2)

```
unique_ptr<Person> uptr1 =
                        make_unique<Person>("Mary","Black");
unique_ptr<Person> uptr2 = make_unique<Person>("John","Dee");
cout<<*uptr2<<endl;

vector<unique_ptr<Person> > vec;
vec.push_back( move( uptr1 ) );
vec.push_back( move( uptr2 ) );

cout<<"Vec [";
for( auto& e: vec ){
    cout<<*e<<" ";
}
cout<<"]"<<endl;
```

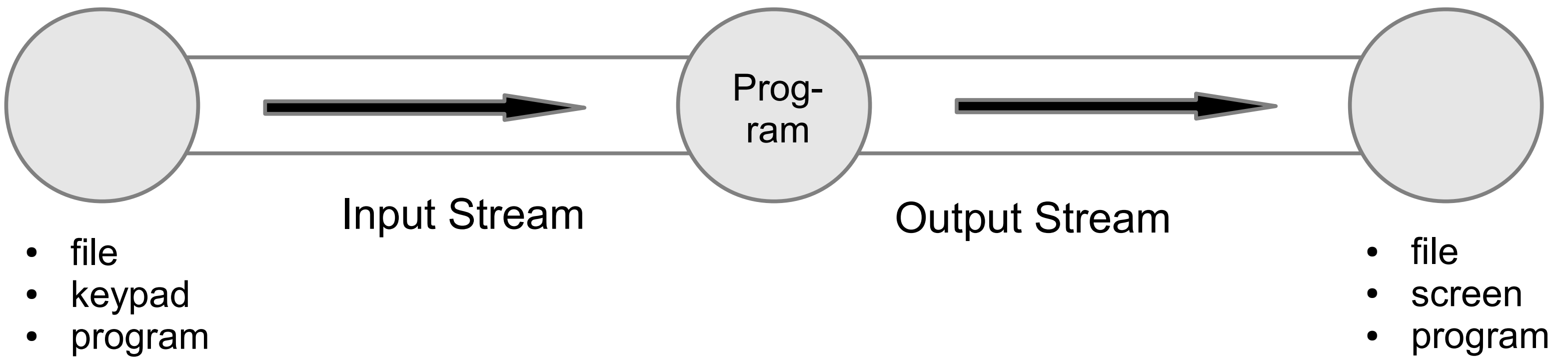
Module 11

I/O Streams

Outline

- Using Streams
- String Streams
- File Streams
- Bidirectional I/O

Using Streams



stream:
- is data flow
- direction
- associated source and destination

Using Streams

`cin` An input stream, reads data from the "input console."

`cout` A *buffered* output stream, writes data to the output console.

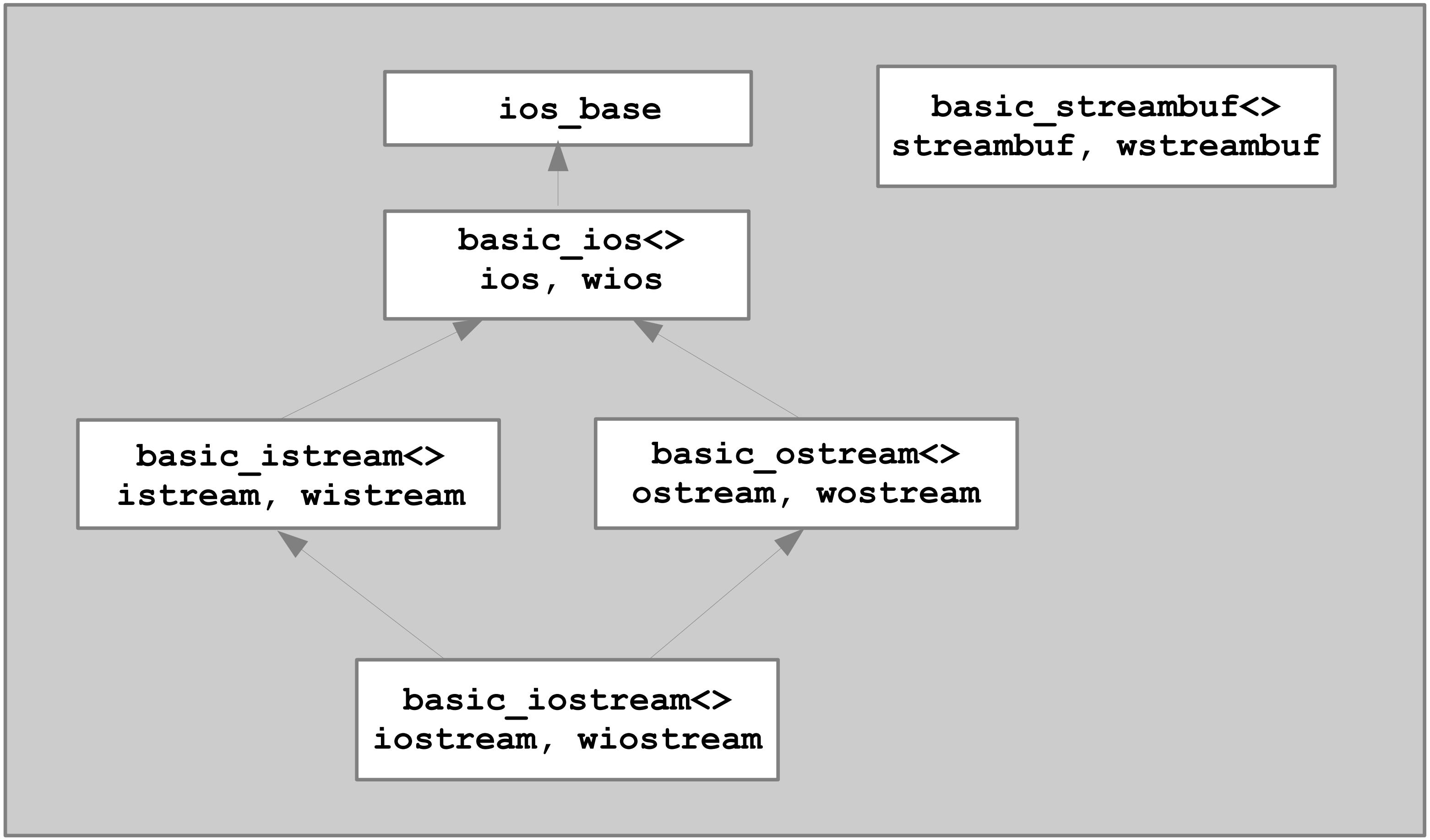
`cerr` An *unbuffered* output stream, writes data to the "error console"

`clog` A buffered version of `cerr`.

Using Streams

- Stream:
  - includes **data**
  - has a **current position**
    - *next read* or *next write*

Using Streams



Using Streams

- Output stream:
  - inserter operator <<
  - raw output methods (binary):
    - `put()`, `write()`

```
void rawWrite(const char* data, int dataSize){
    cout.write(data, dataSize);
}

void rawPutChar(const char* data, int charIndex)
{
    cout.put(data[charIndex]);
}
```

Using Streams

- Output stream:
  - most output streams buffer data (accumulate)
  - the stream will *flush* (write out the accumulated data) when:
    - an endline marker is reached ('\n', endl)
    - the stream is destroyed (e.g. goes out of scope)
    - the stream buffer is full
    - explicitly called `flush()`

Using Streams

- Manipulators:
  - objects that modify the behavior of the stream
    - `setw, setprecision`
    - `hex, oct, dec`
    - `C++11: put_money, put_time`

```
int i = 123;
printf("This should be '   123': %6d\n", i);
cout <<"This should be '   123': " << setw(6) << i << endl;
```

Using Streams

- Input stream:
  - extractor operator >>
    - will tokenize values according to white spaces
  - raw input methods (binary):
    - `get()`: avoids tokenization

reads an input having more than one word

```
string readName(istream& inStream)
{
     string name;
     char next;
     while (inStream.get(next)) {
          name += next;
     }
     return name;
}
```

Using Streams

- Input stream:
  - `getline()`: reads until end of line

reads an input having more than one word

```
string myString;
getline(cin, myString);
```

Using Streams

- Input stream:
  - `getline():` reads until end of line

reads an input having more than one word

```
string myString;
getline(cin, myString);
```

Reads up to new line character
Unix line ending: **'\n'**
Windows line ending: **'\r' '\n'**
The problem is that getline leaves the '\r' on the end of the string.

Using Streams

- Stream's state:
  - every stream is an object → has a state
  - stream's states:
    - **`good:`** OK
    - **`eof:`** End of File
    - **`fail:`** Error, last I/O failed
    - **`bad:`** Fatal Error

Using Streams

– Find the error!

```
list<int> a;
int x;
while( !cin.eof() ){
  cin>>x;
  a.push_back( x );
}
```

Input:
1
2
3
(empty line)

a: 1, 2, 3, 3

Using Streams

– Handling Input Errors:

- `while( cin )`
- `while( cin >> ch )`

```
int number, sum = 0;
while ( true ) {
    cin >> number;
    if (cin.good()){
        sum += number;
    } else{
            break;
    }
}
```

```
int number, sum = 0;
while ( cin >> number ){
    sum += number;
}
```

String Streams

- **<sstream>**
  - **ostringstream**
  - **istringstream**
  - **stringstream**

```
string s =”12.34”;
stringstream ss(s);
double d;
ss >> d;
```

```
double d =12.34;
stringstream ss;
ss<<d;
string s = “szam:”+ss.str()
```

File Streams

```
{
   ifstream ifs("in.txt");//Constructor
   if( !ifs ){
       //File open error

    }
   //Destructor call will close the stream
}
```

```
{
   ifstream ifs;
   ifs.open("in.txt");
   //...
   ifs.close();
   //...
}
```

File Streams

– Byte I/O

```
ifstream ifs("dictionary.txt");
// ios::trunc means that the output file will be
// overwritten if exists
ofstream ofs("dict.copy", ios::trunc);

char c;
while( ifs.get( c ) ){
   ofs.put( c );
}
```

File Streams

- Byte I/O
- Using **rdbuf()** - quicker

```
ifstream ifs("dictionary.txt");
// ios::trunc means that the output file will be
// overwritten if exists
ofstream ofs("dict.copy", ios::trunc);

if (ifs && ofs) {
        ofs << ifs.rdbuf();
}
```

Object I/O

– Operator overloading

```
istream& operator>>( istream& is, T& v ){
    //read v
    return is;
}

ostream& operator<<(ostream& is, const T& v ){
    //write v
    return os;
}
```