CPP

Modern C++
Object-Oriented Programming

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C++ - Object-Oriented Programming

Course content

- Introduction to C++
- Object-oriented programming
- Generic programming and the STL
- Object-oriented design

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.**

AI tools

- GitHub Copilot (free for education)
- Codeium
- OpenAI - ChatGPT
- Google - Bard

Be careful!
Use it wisely!

[AI usage - Google form]

Module 1

Introduction to C++

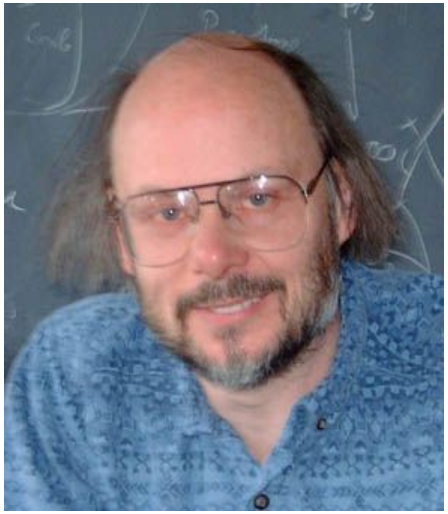
Introduction to C++

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, weak_ptr`
  - Error handling with exceptions
  - References
  - The `const` modifier

Introduction to C++

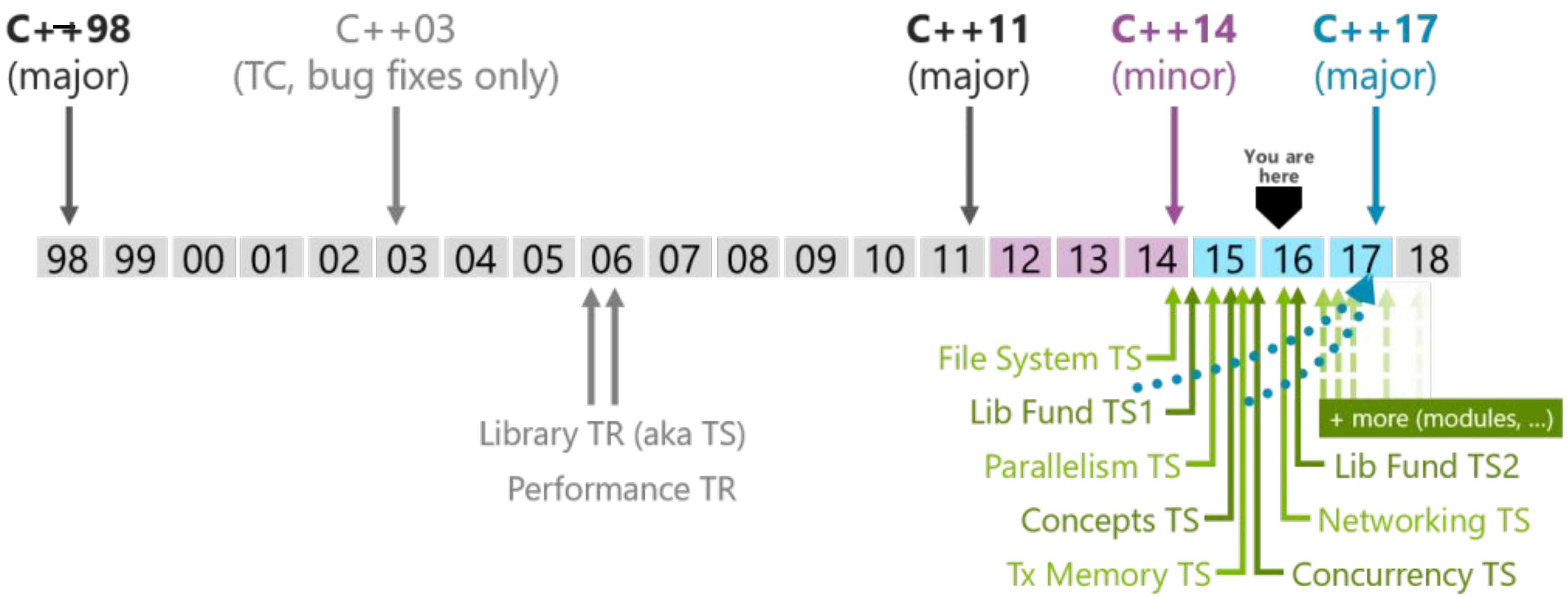
History and evolution



- 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)
    - 2017 (C++17, major)
    - 2020 (C++20, major)

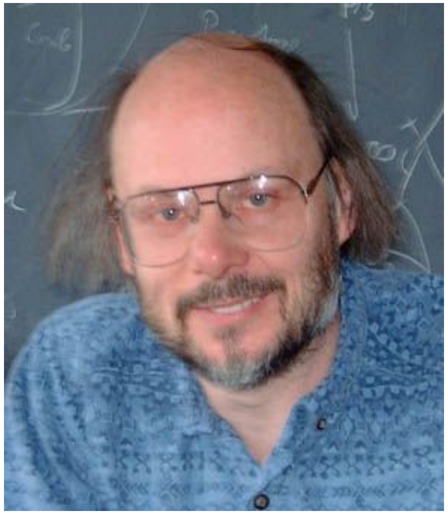
Introduction to C+

History and evolution



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

C++: The Evolution of a Programming Language



TIOBE Index

- The TIOBE Programming Community index is an indicator of the **popularity of programming languages**.
- The index is updated once a month.
- The ratings are based on
  - the **number of skilled engineers** world-wide,
  - **courses** and **third party vendors**.
- Popular search engines such as Google, Bing, Yahoo!, Wikipedia, Amazon, YouTube and Baidu are used to calculate the ratings.

Stack Overflow Survey

https://survey.stackoverflow.co/2023/

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 (*Standalone functions*)
  - Object-oriented programming (*Classes and objects*)
  - Generic programming (*Templates*)
  - Functional programming (*Lambdas*)

Introduction to C++

Portability

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

Introduction to C++

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++17`

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;
}
```

Introduction to C++

Building a C++ program: 3 steps

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

Introduction to C++

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

Preprocessor

```
#include <iostream>
using namespace std;
#define PI 3.14159
int main () {
  cout << "Value of PI :" << PI << endl;
  return 0;
}
```

```
$ g++ -E main.cpp >main.preprocessed
```

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

int main () {
  cout << "Value of PI :" << 3.14159 << endl;
  return 0;
}
```

Introduction to C++

Header files

- C++ header

```
#include <iostream>
```

- C header

```
#include <cstdio>
```

- User defined header

```
#include "myheader.h"
```

Introduction to C++

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;
```

Introduction to C++

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()

Namespaces

```
#include <iostream>


namespace myns{
    int toupper(int ch) {
        std::cout << "sajat" << std::endl;
        if (ch >= 'a' && ch <= 'z'){
            return ch - ('a' - 'A');
        }
        return ch;
    }
}
```

```
int main(){
    std::cout << myns::toupper('a') << std::endl;
    std::cout << toupper('a') << std::endl;
    return 0;
}
```

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Variables

- can be declared almost anywhere in your code

```
double d;      // uninitialized

int i = 10;  // initialized

int j {10};  // initialized,  uniform initialization
```

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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 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;
    }
}
```

Introduction to C++

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;
    }
}
```

Introduction to C++

Pointers and dynamic memory

- **compile time array**

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

- **run time array**

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

Introduction to C++

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;
```

Introduction to C++

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
```

Introduction to C++

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
```

Introduction to C++

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);
```

Introduction to C++

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

Introduction to C++

Exceptions: exception

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

double divide( double m, double n){
    if( n == 0 ){
        throw 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++

Output?

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

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

int main() {
    cout<<divide(1,0)<<endl;
    cout<<divide(1,0)<<endl;
    cout<<"END"<<endl;
}
```

Introduction to C++

Exceptions: domain_error

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

double divide( double m, double n){
    if( n == 0 ){
        throw domain_error("Division by zero");
    }else{
        return m/n;
    }
}

int main() {
    try{
        cout<<divide(1,0)<<endl;
    }catch( const domain_error& e){
        cout<<"Exception: "<<e.what()<<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 classes:

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

What type of resource?

OOP: Classes and objects

Class = Type (Data + Operations)

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

OOP: Classes and objects

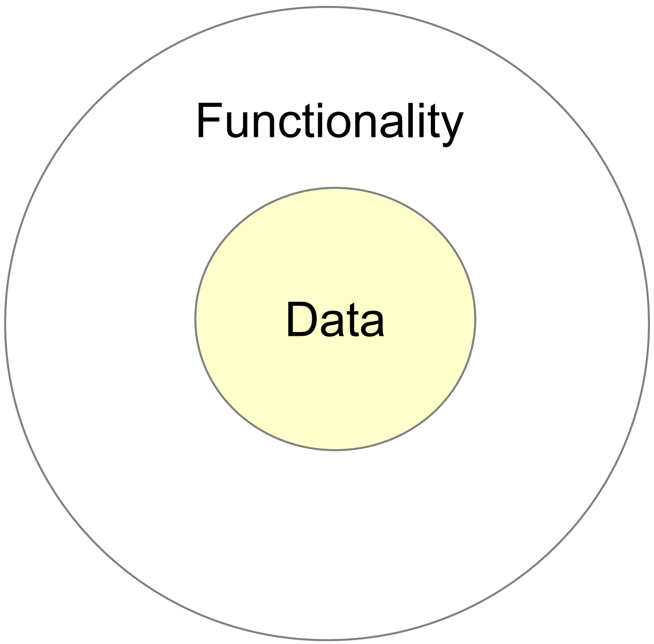
Object = Instance of a class

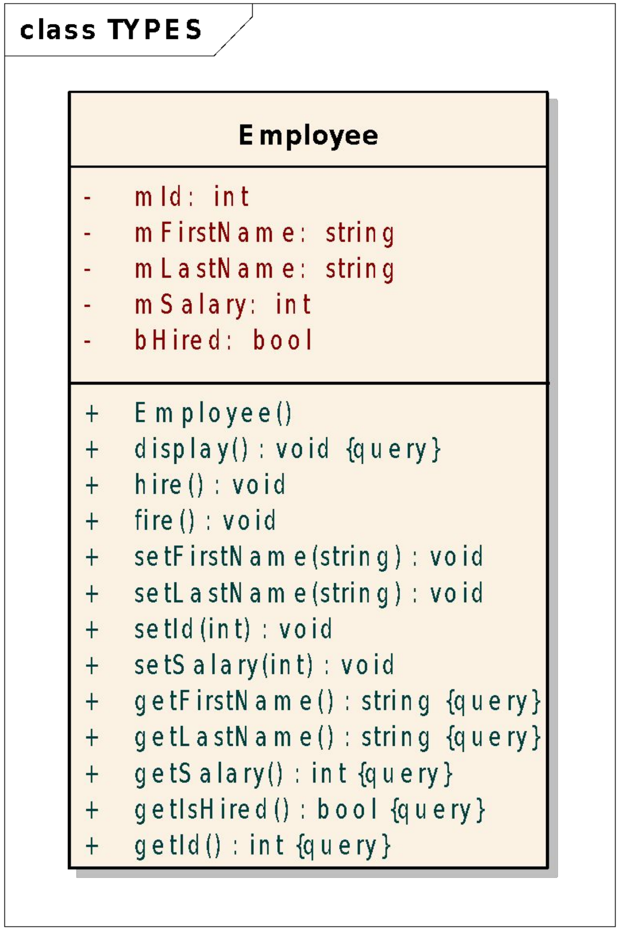
- An employee object: `Employee emp;`
  - **Properties** are the characteristics that describe an object.
    - *What makes this object different?*
      - `id, firstName, lastName, salary, hired`
  - **Behaviors** answer the question:
    - *What can we do to this object?*
      - `hire(), fire(), display(), 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[4] {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

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

- 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() {
}
```

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

- memory allocation
- constructor call on each allocated object

OOP: Classes and objects

Object creation – constructors:

- *Compiler-generated default constructor*

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

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

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( double ){}
};

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

`int` → `double` conversion

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

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

Delegating Constructor (C++11)

```
class SomeType{
  int number;

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

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

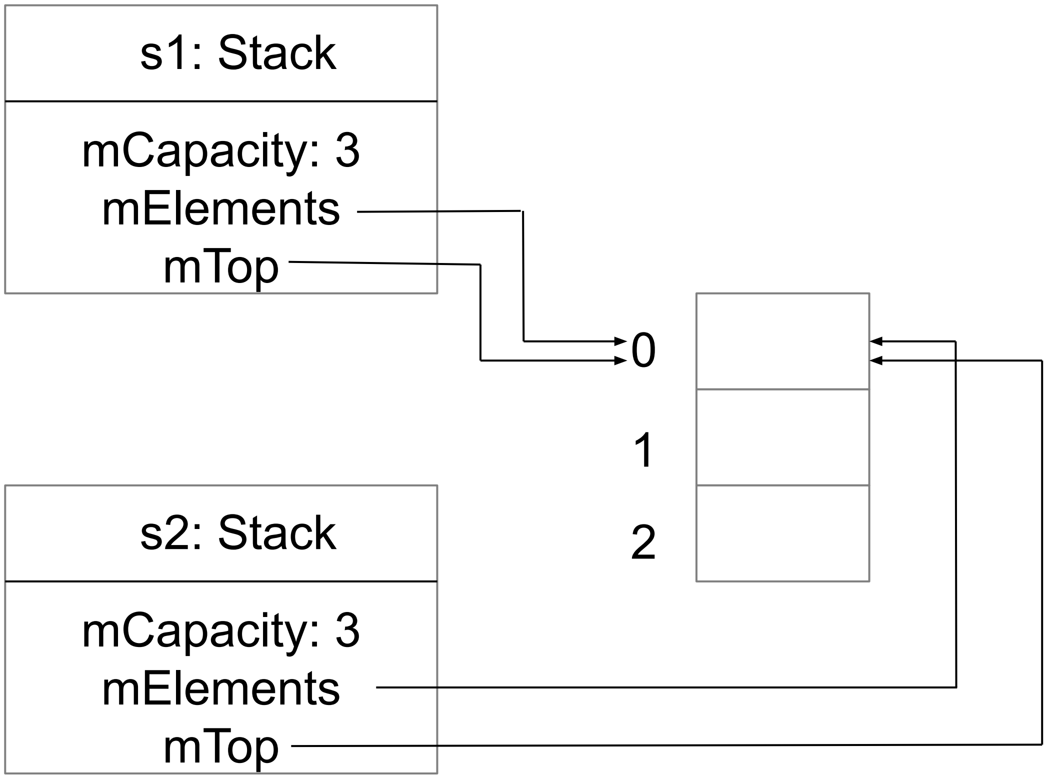
OOP: Classes and objects

```cpp
//Stack.h

#ifndef STACK_H
#define  STACK_H

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

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

```cpp
//Stack.cpp

#include "Stack.h"

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

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

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

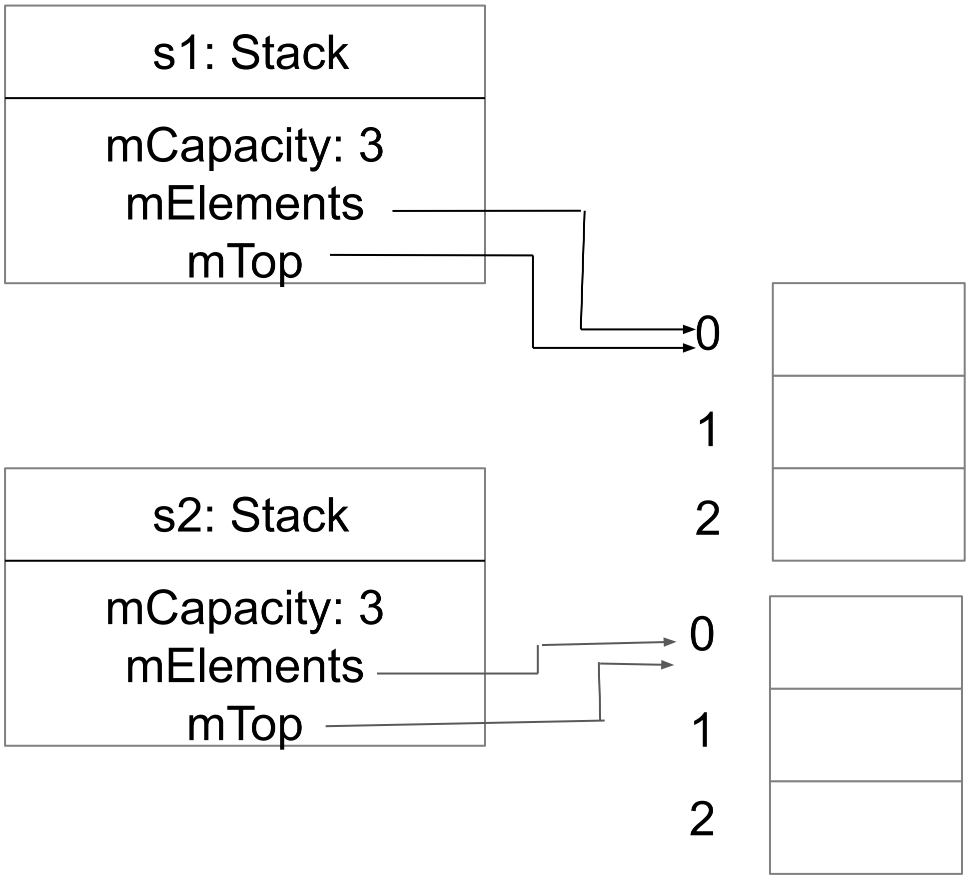
Copy constructor: `T ( const T&)`

```
//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

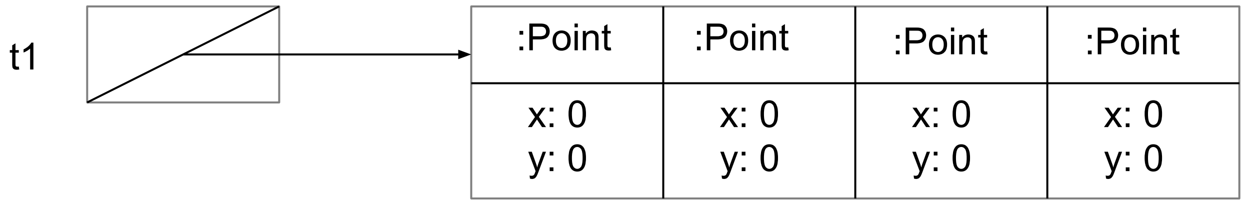
Array of objects

```
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];

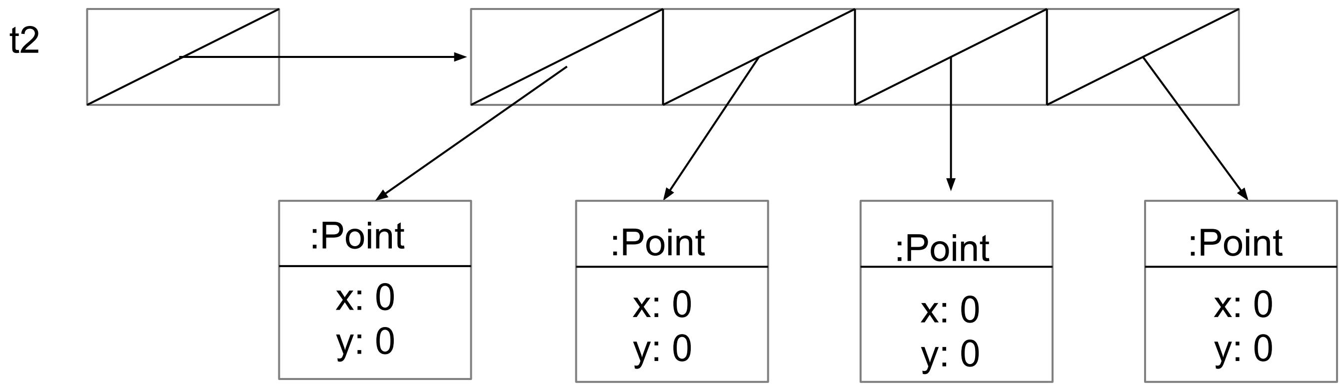
Point t1[4];



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

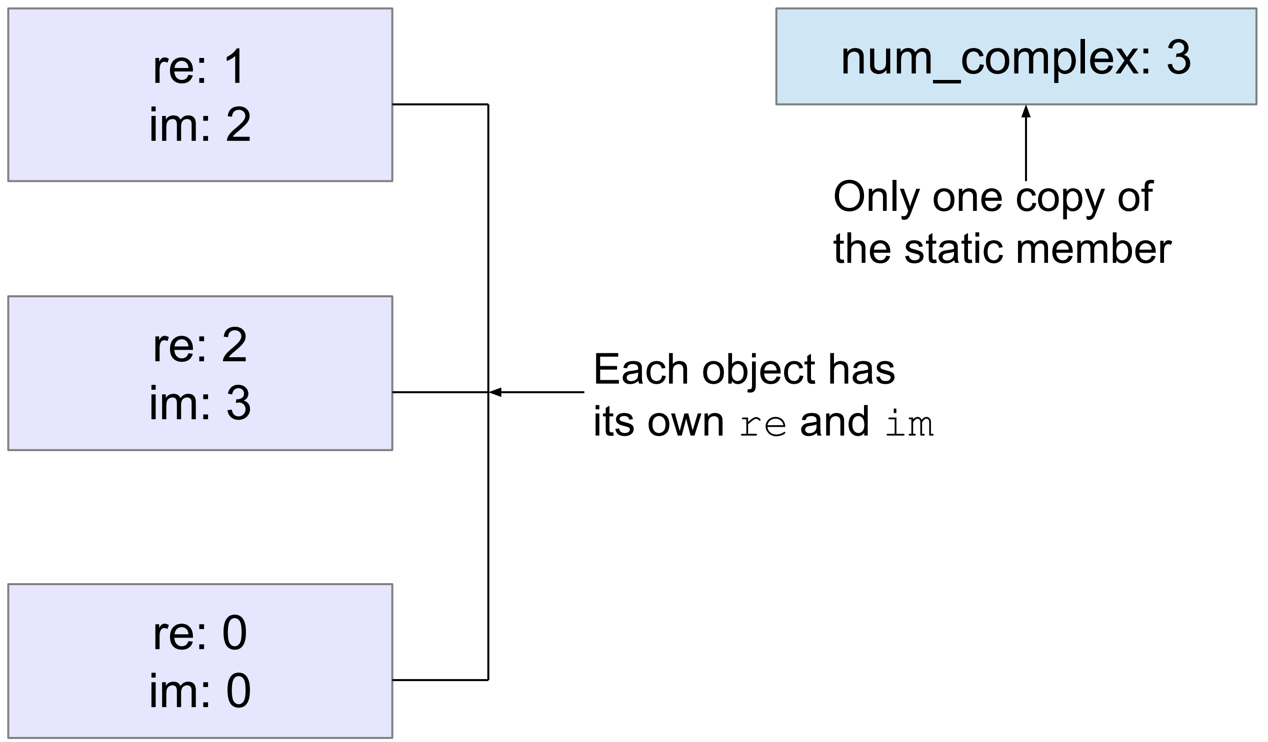
elegant

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

cout<<"#complex:"<<Complex::getNumComplex()<<endl;

cout<<"#complex: "<<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 polymorphically
  - 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

```
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

C++03

- Returning a reference to a `const` object

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

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

Copy constructor invocation

More efficient

The reference should be to a non-local object

OOP: Advanced class features

C++11

– Returning a reference to a `const` object

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

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

EFFICIENT!
MOVE
constructor
invocation

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 (Usage: `A::B  b;`)

OOP: Advanced class features

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

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

- 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)

```
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(){
     if (data != nullptr) {
         delete[] data;
     }
}
```

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

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

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

Move constructor

- **Shallow copy** of the argument
- **Ownership transfer** to the new object (**this**)
- Leave the **argument** (**that**) in valid state: destructor will be called on **that**

OOP: Advanced class features

– **Move** constructor – Stack class

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

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

Destructor will be invoked on rhs!!!

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)

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

OOP: Advanced class features

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

Reference to a static variable → **lvalue**

A temporary copy of instance → **rvalue**

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

Output?

Module 4

Object-Oriented Programming

Operator overloading

OOP: Operator overloading

Content

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

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

```
#ifndef COMPLEX_H
#define COMPLEX_H

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

OOP: Operator overloading

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

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

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

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

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

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

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

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

OOP: Operator overloading

- Inserter/Extractor operators (standalone func.)

```
//complex.cpp

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

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

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 [] this->mElements;
   this->mCapacity = 0;
   this_>mElements = nullptr;
   //copy rhs - right hand side
   this->mCapacity = rhs.mCapacity;
   this->mElements = new double[ mCapacity ];
   int nr = rhs.mTop - rhs.mElements;
   std::copy(rhs.mElements,rhs.mElements+nr,this->mElements);
   mTop = mElements + nr;
 }
 return *this;
}
```

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);`
- When it is called?

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

OOP: Operator overloading

- **Move** assignment operator example

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

OOP: Advanced class features

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

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 ){
        this->size = 10;
    }
    this->mSize = size;
    this->mElems = new double[ mSize ];
}

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

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

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

#include<stdexcept>

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

- Relational and equality operators
  - used for **search** and **sort**

```
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)

```
class CompareStrings {
    static int counter;
public:
    bool operator()(const string &s1, const string &s2) {
        ++counter;
        return s1 < s2;
    }
    static int getCounter() {
        return counter;
    }
};
```

OOP: Operator overloading

- Usage:

```
int CompareStrings :: counter = 0;

int main() {
    vector<string> fruits{
        "apple", "orange", "banana"
    };

    sort(fruits.begin(), fruits.end(), CompareStrings());

    cout << "#comparisons: " << CompareString::getCounter() << endl;
    return 0;
}
```

Function object

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";
   return ss.str();
}
```

```
//usage
Complex z(1, 2);
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:

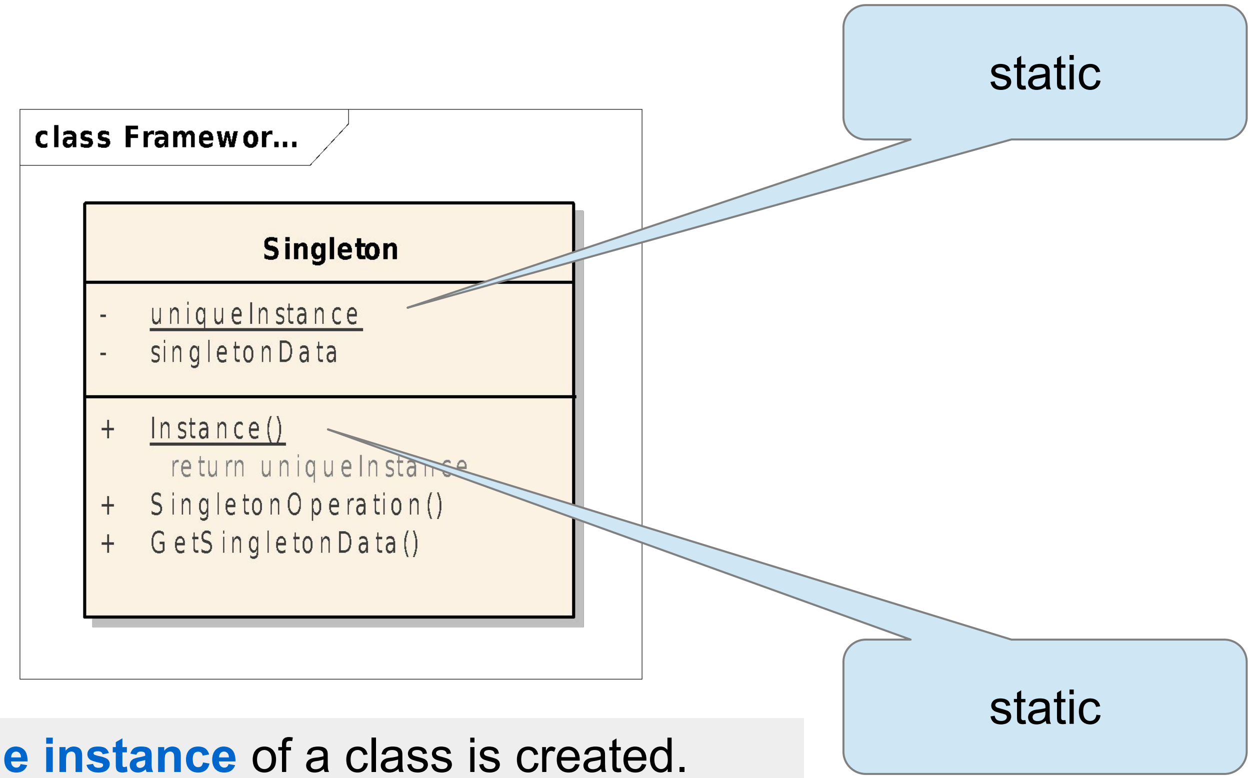
```
Start
Hello
Stop
```

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

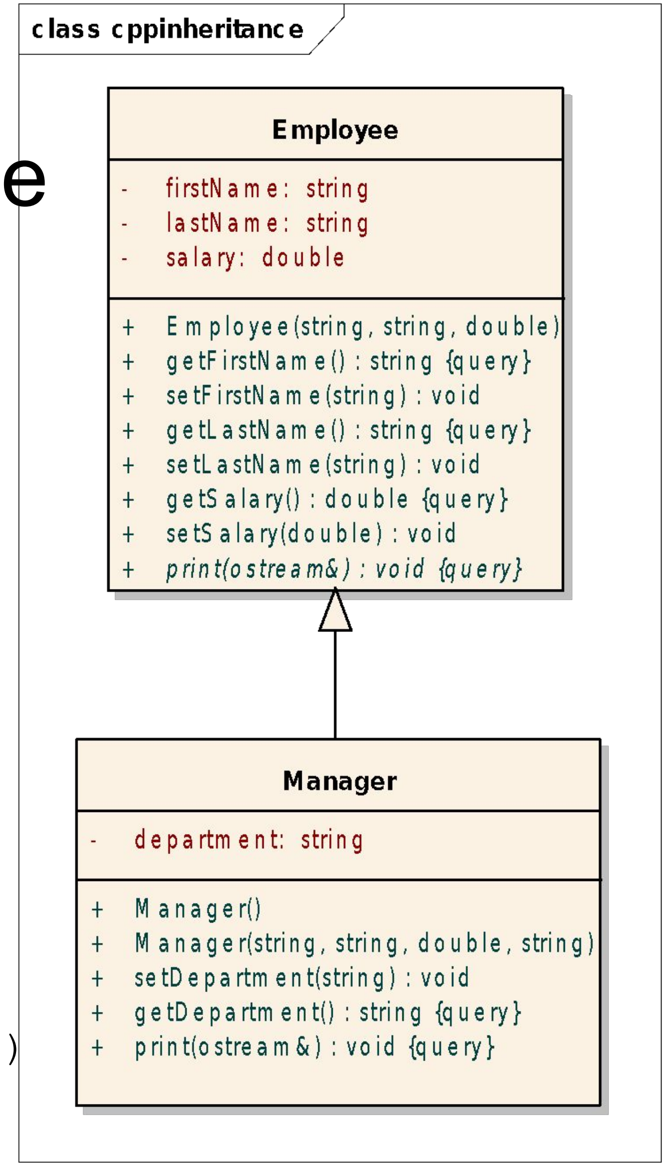
Public Inheritance

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(){
}
```

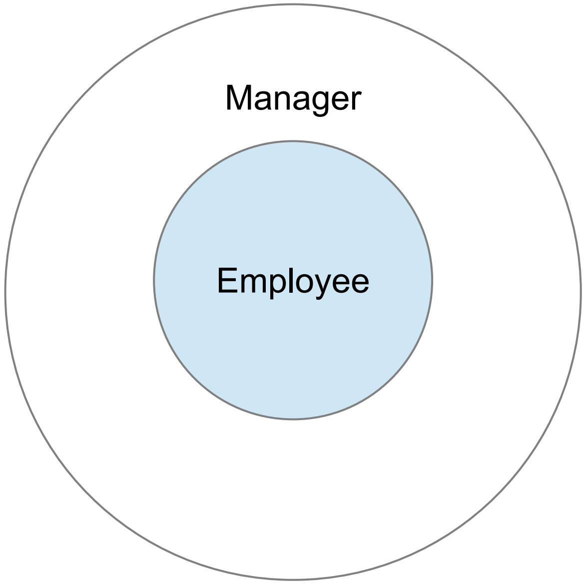
Employee's constructor invocation → Default constructor can be invoked implicitly

```
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

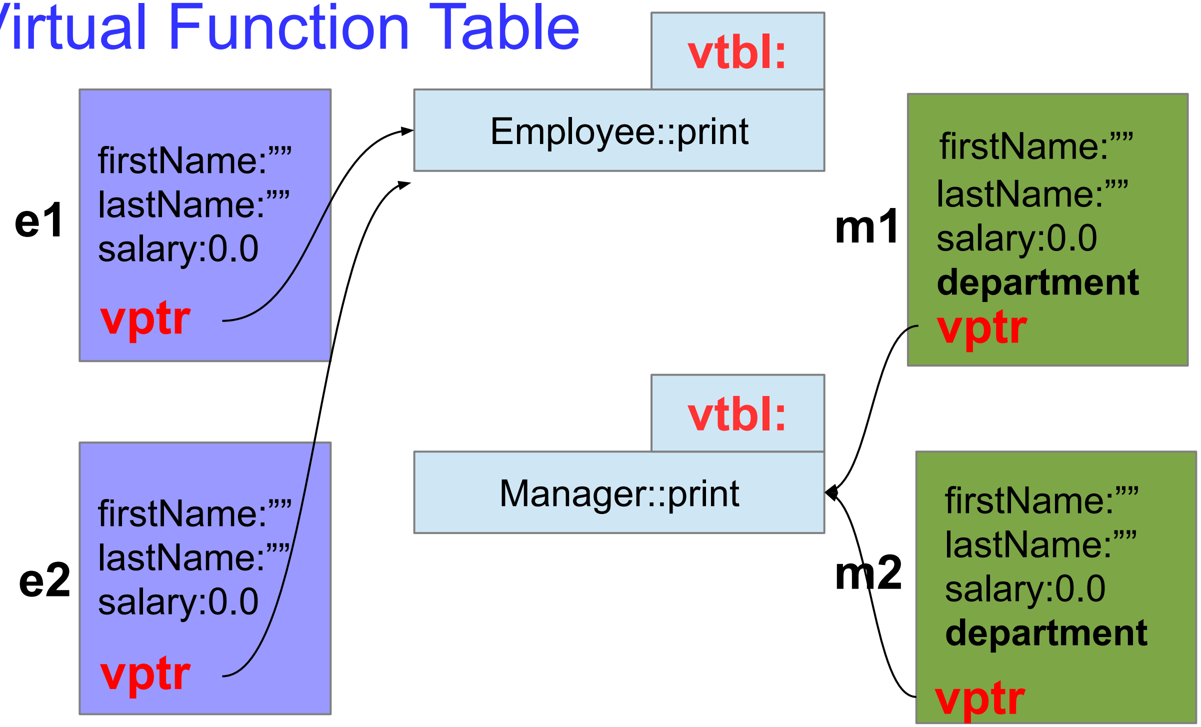
– Polymorphism

- 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

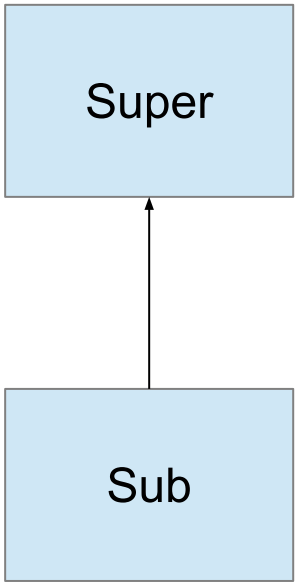
Object relationships

OOP: Object relationships

- The **is-a** relationship
  - public inheritance
  - multiple public inheritance

- The **has-a** relationship
  - composition (strong containment)
  - aggregation (weak containment)
  - *private inheritance*

OOP: Object relationships

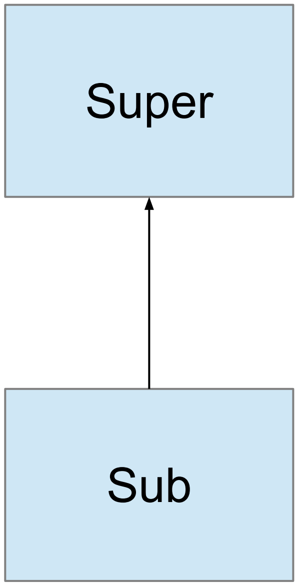


- The *is-a* relationship – *Client's view (1)*
  - works in only *one direction:*
    - every **Sub** object **is** also **a** **Super** one
    - but **Super** object **is not a** **Sub**

```
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

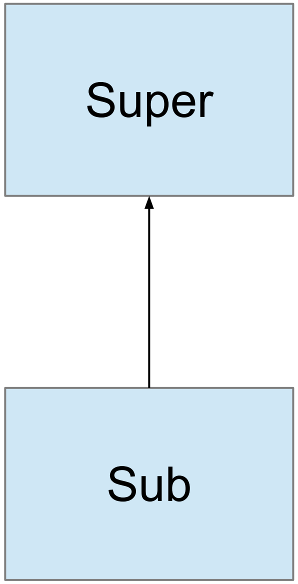
- The *is-a* relationship – *Client's view (2)*




```
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 **methods**
  - 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();
```

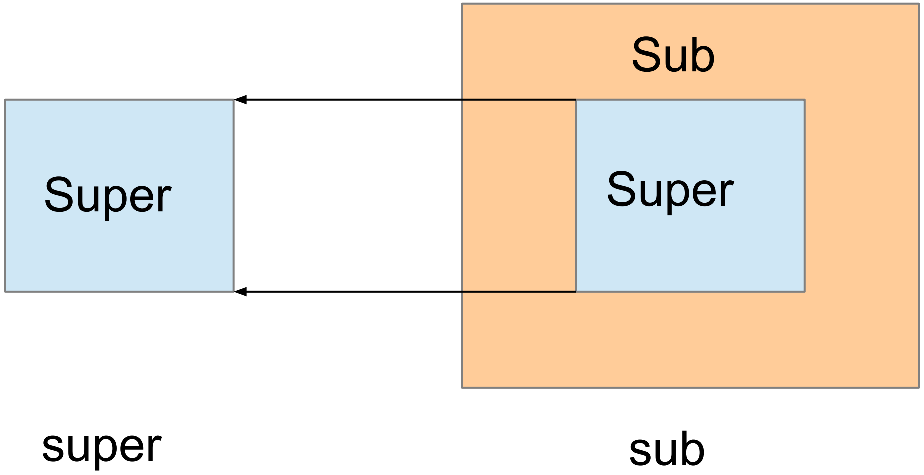
OOP: Object relationships

– 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();
```



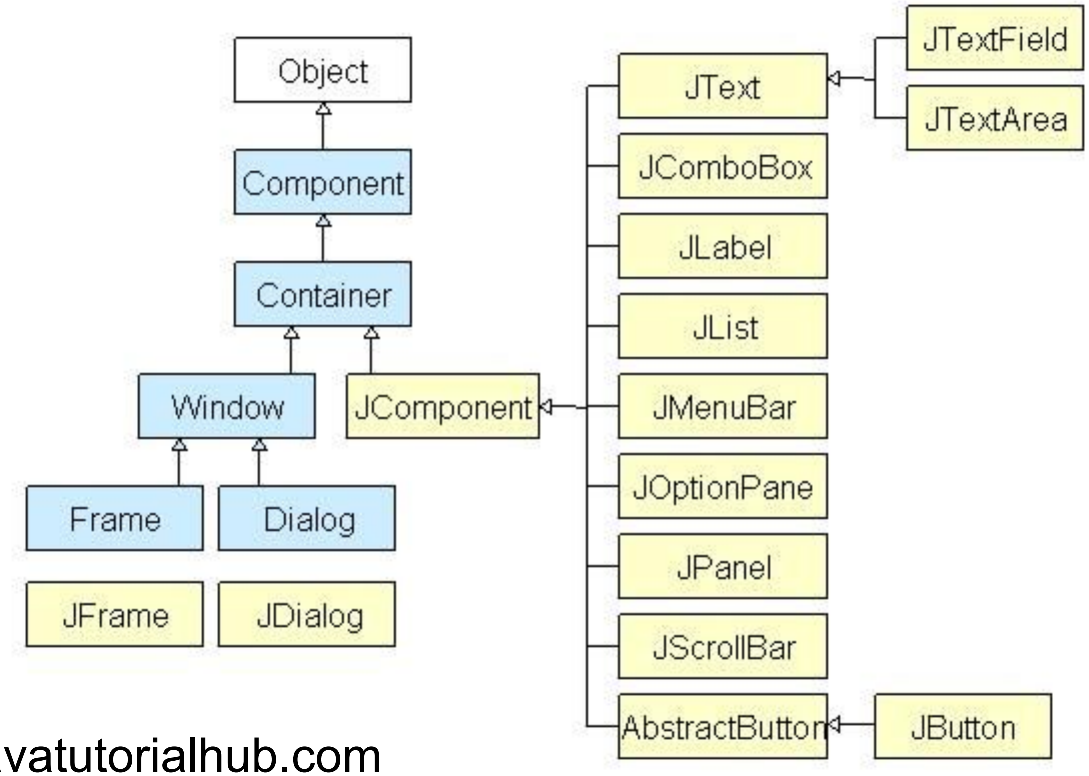
OOP: Object relationships

- 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

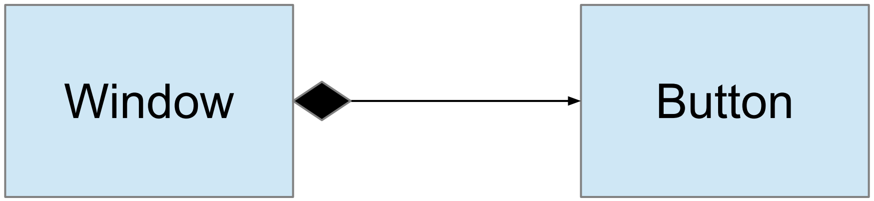
– Inheritance for polymorphism



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**

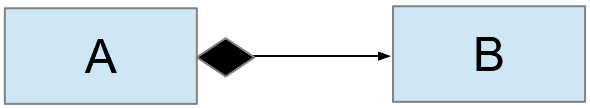
```
class B;

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

```
class B;

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

```
class B;

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

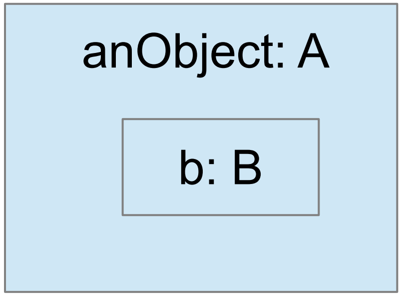
OOP: Object relationships

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



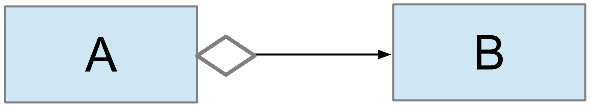

```
class B;

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

```
A anObject;
```



OOP: Object relationships

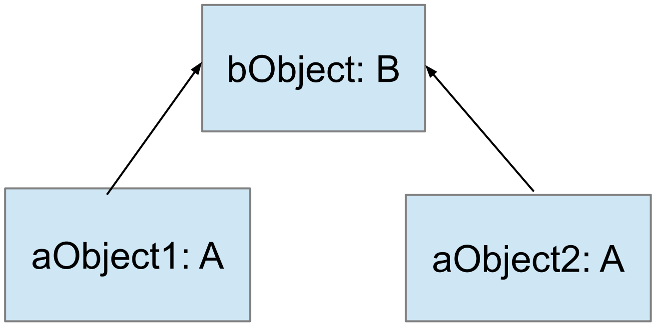
- Implementing the *has-a* relationship



  - 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

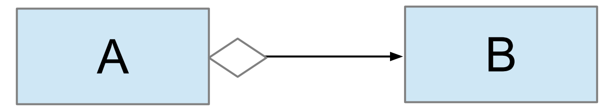
```
class B;

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

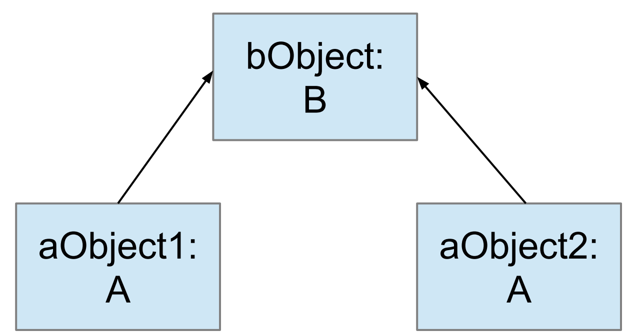


- An object **A** has an object **B**

weak containment

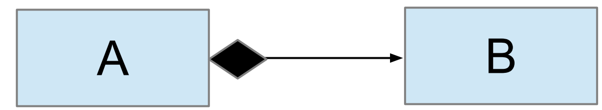
```
class B;

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

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



OOP: Object relationships

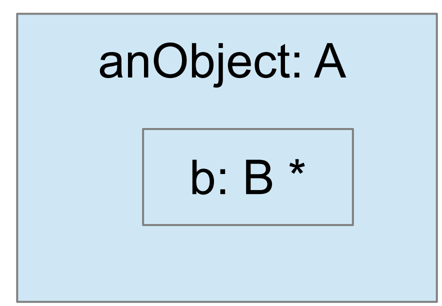
- Implementing the *has-a* relationship
  - An object **A** has an object **B**



strong containment

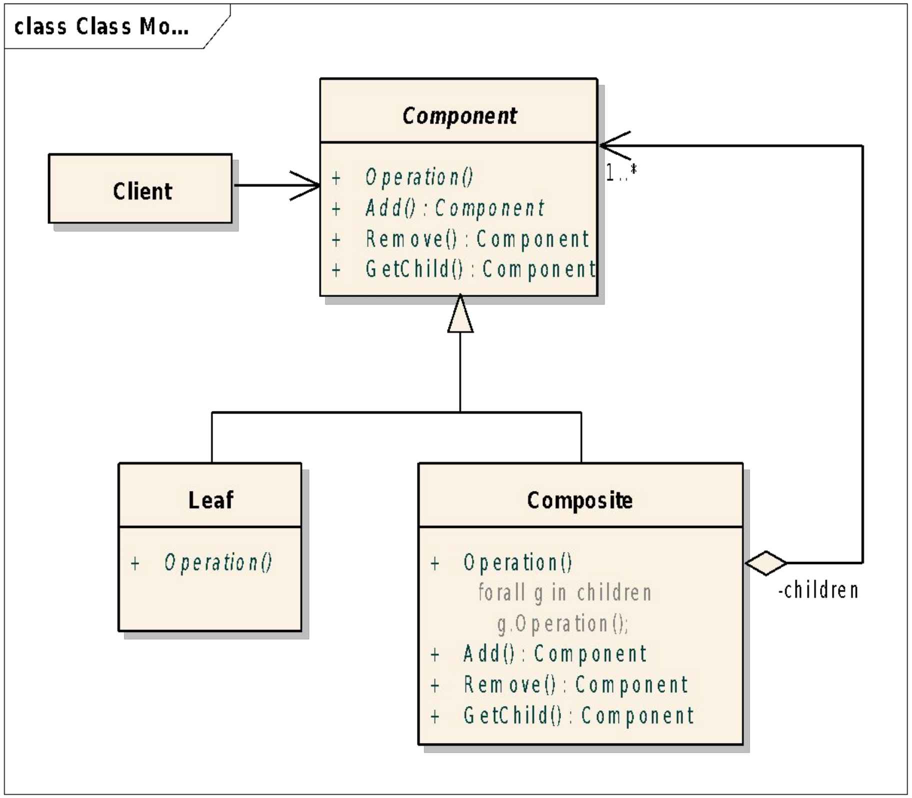
```
class B;

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

```
Usage:
    A aObject;
```

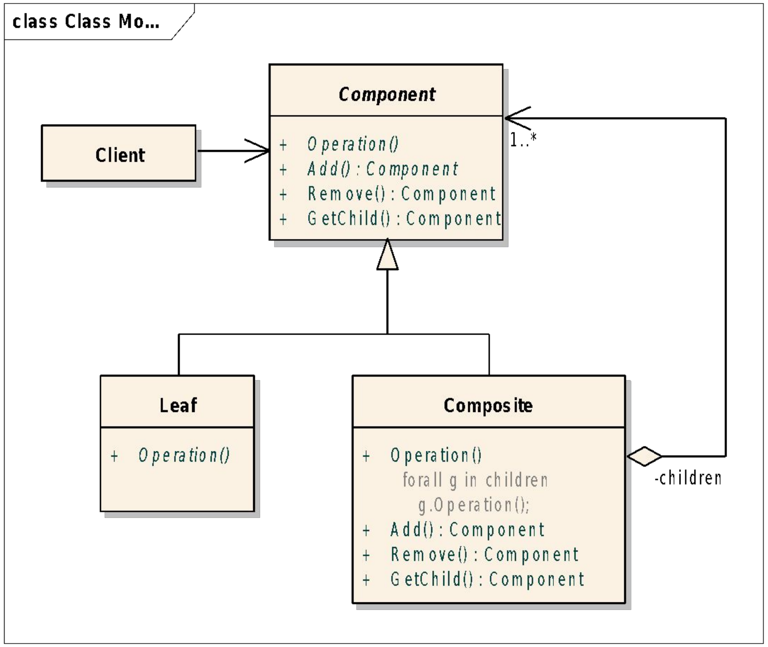


OOP: Object relationships

- 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

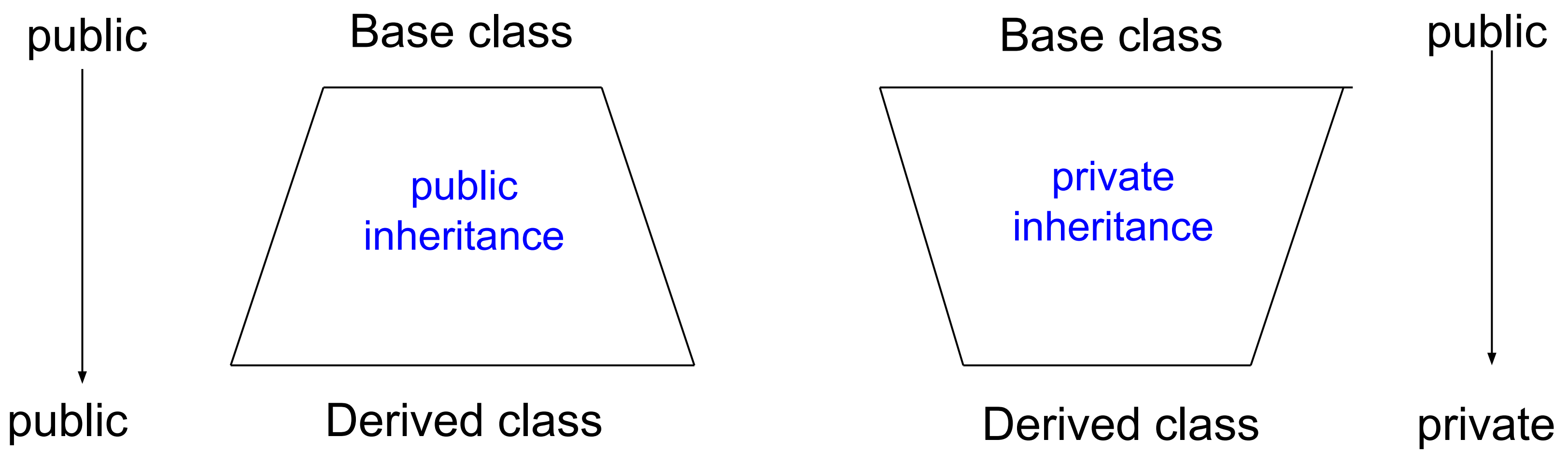
Examples:

- 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

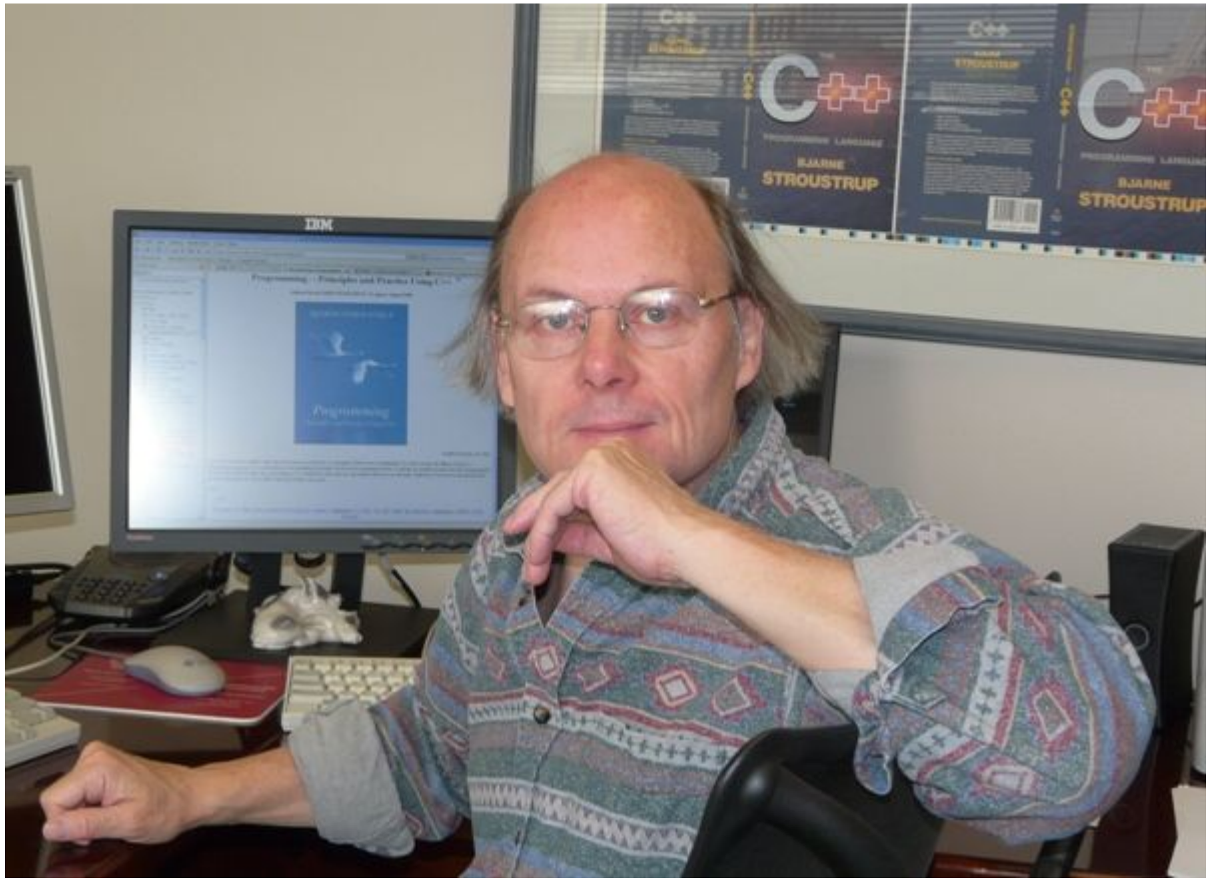
```
class Super{
public:
    Super(){}
    virtual void someMethod(double d) const{
            cout<<"Super"<<endl;
     }
};
class Sub : public Super{
public:
    Sub(){}
    virtual void someMethod(double d) const override{
            cout<<"Sub"<<endl;
     }
};

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



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

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

```
vector<int> v{ 1, 3, 2, 4, 5, 7};
printContainer(v, "Integers: ");
```

Examples

Implement the following template functions!

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

template <typename Iterator, typename T>
Iterator binarysearch( Iterator first, Iterator 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

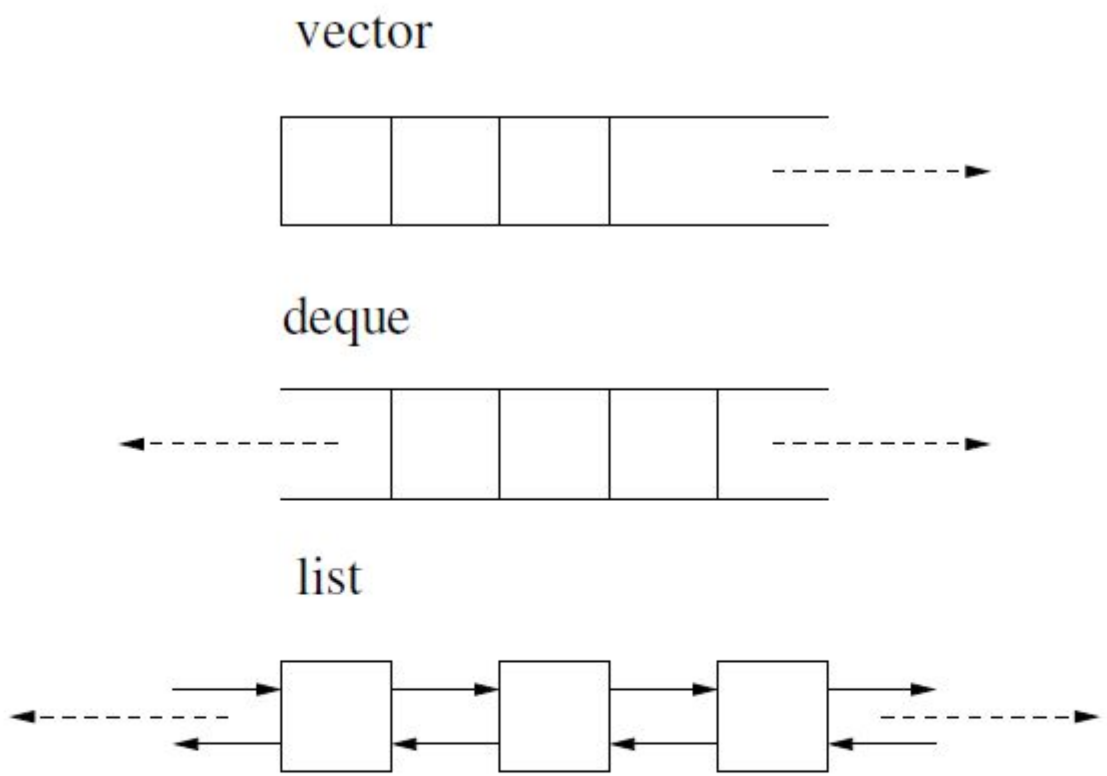
Basic STL Containers

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

Container adapters

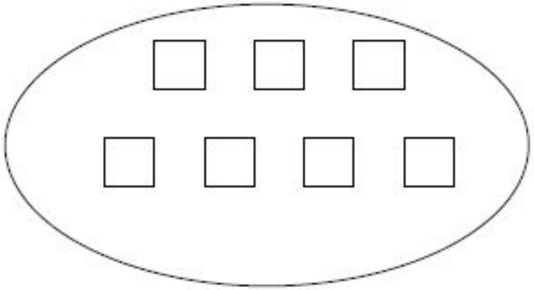
- **Associative containers**
  - provide fast retrieval of data based on keys
    - **`set, multiset, map, multimap`** — **`<set> <map>`**

Sequence Containers

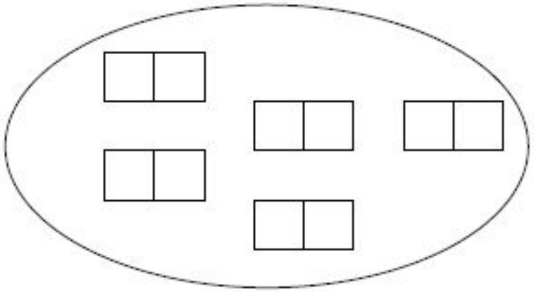


Associative Containers

set/multiset



map/multimap



STL Containers C++11

- **Sequence containers**
  - **`array`** (C-style array)
  - **`forward_list`** (singly linked list)
- **Associative containers**
  - **`unordered_set, unordered_multiset`** (**hash table**)
  - **`unordered_map, unordered_multimap`** (**hash table**)

`<array>`
`<forward_list>`

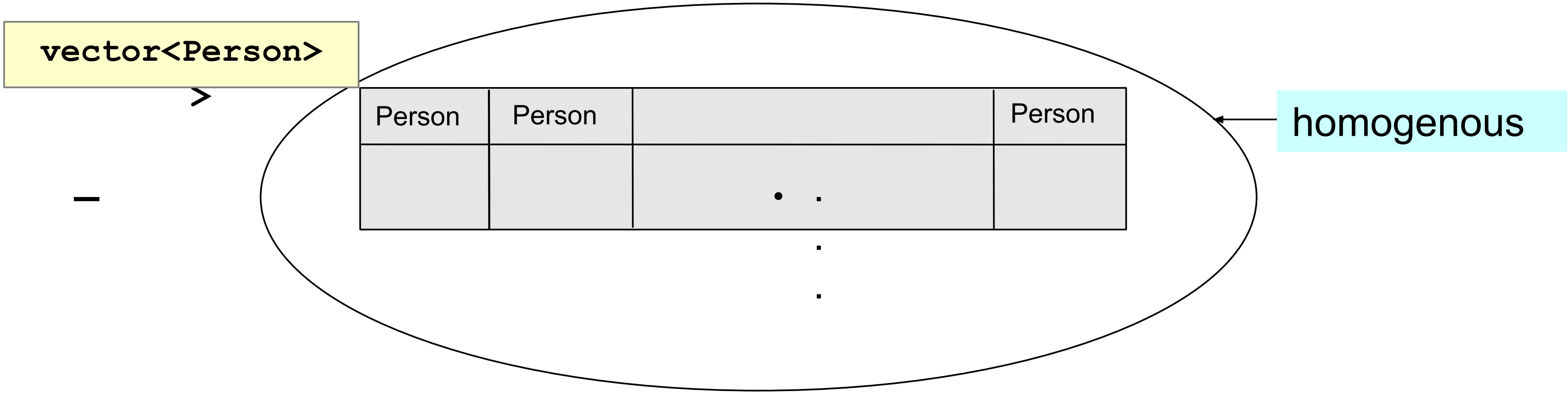
`<unordered_set>`
`<unordered_map>`

STL Containers

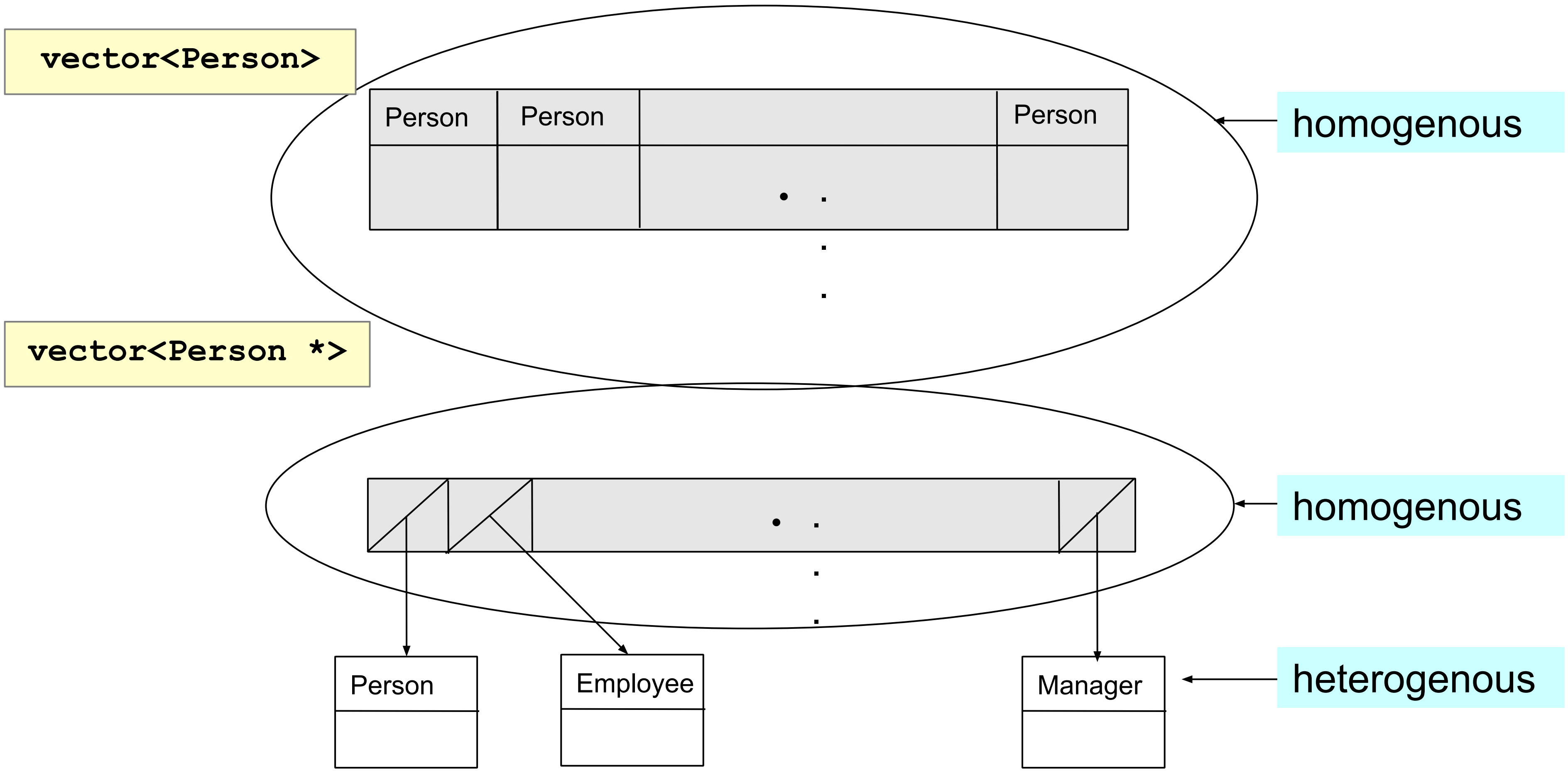
- homogeneous:
  - `vector<Person>, vector<Person*>`
- polymorphism
  - `vector<Person*>`

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

STL Containers



STL Containers



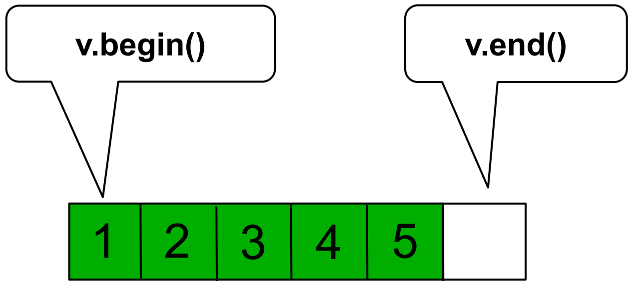
The `vector` container - constructors

```
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 );
}
```

```
vector<int> v {1,2,3,4,5};
```



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 <<" ";
}
```

push_back **vs.** emplace_back

```
vector<Point> v;

for( int i=0; i<10; ++i){
    v.emplace_back(i, i);

    v.emplace_back(Point(i,i));

    v.push_back(Point(i,i));
}
```

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

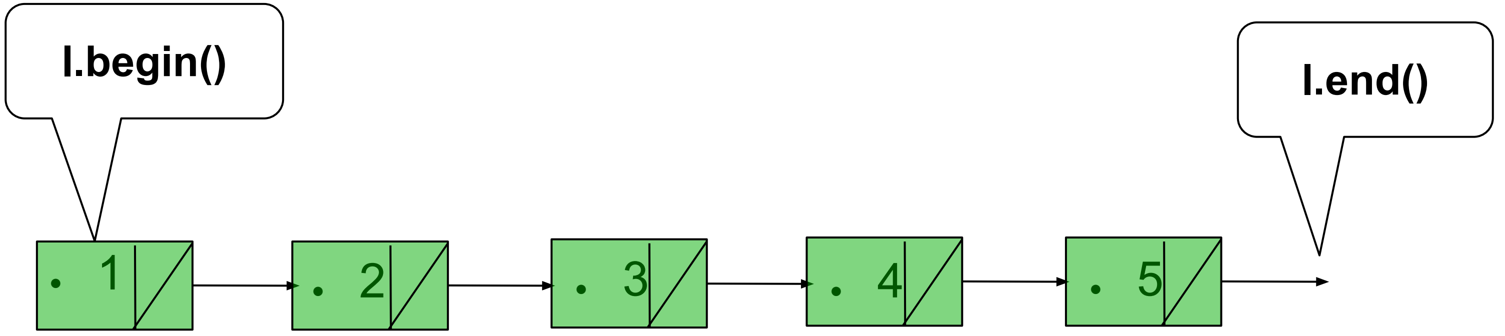
Safe

`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`

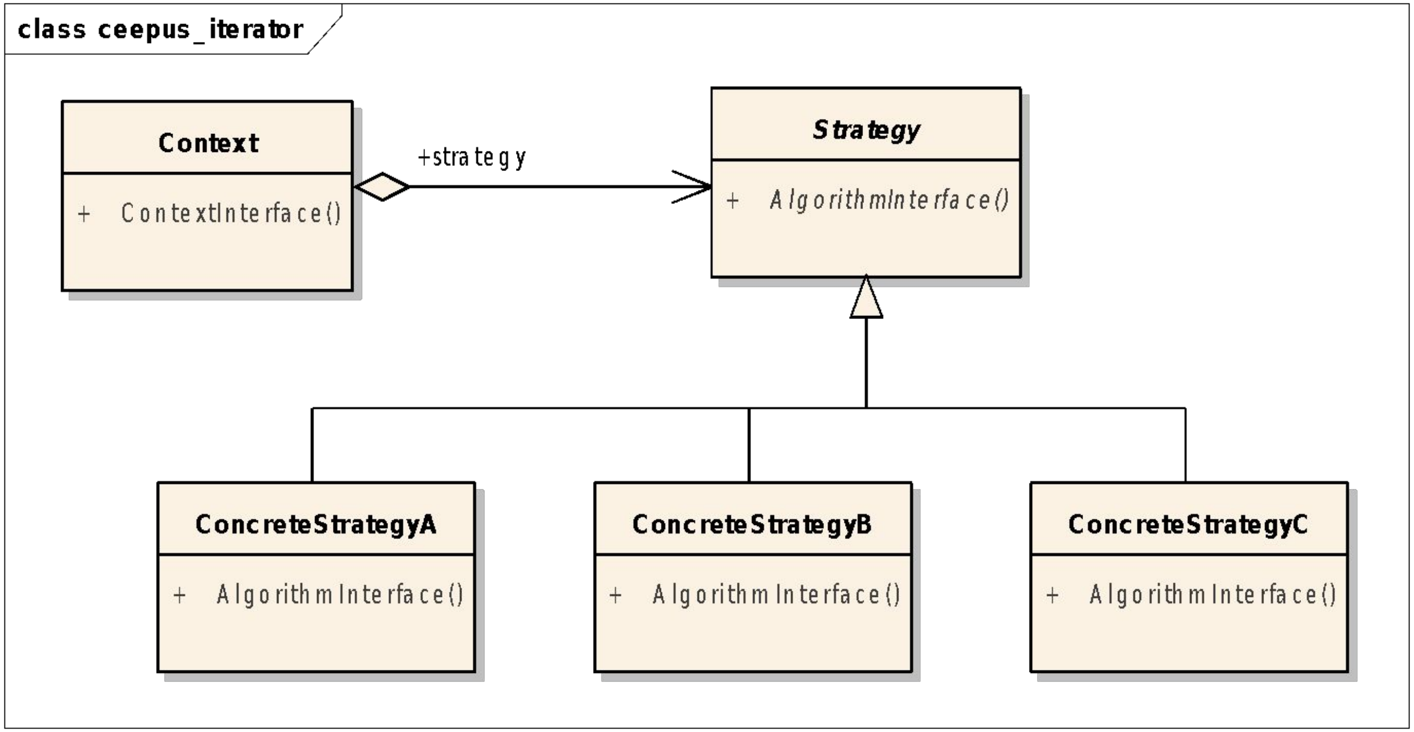
```
struct Rec {
    string name;
    string addr;
};
vector<Rec> vr;
// …
sort(vr.begin(), vr.end(), Cmp_by_name());
sort(vr.begin(), vr.end(), Cmp_by_addr());
```

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;
   }
};
```

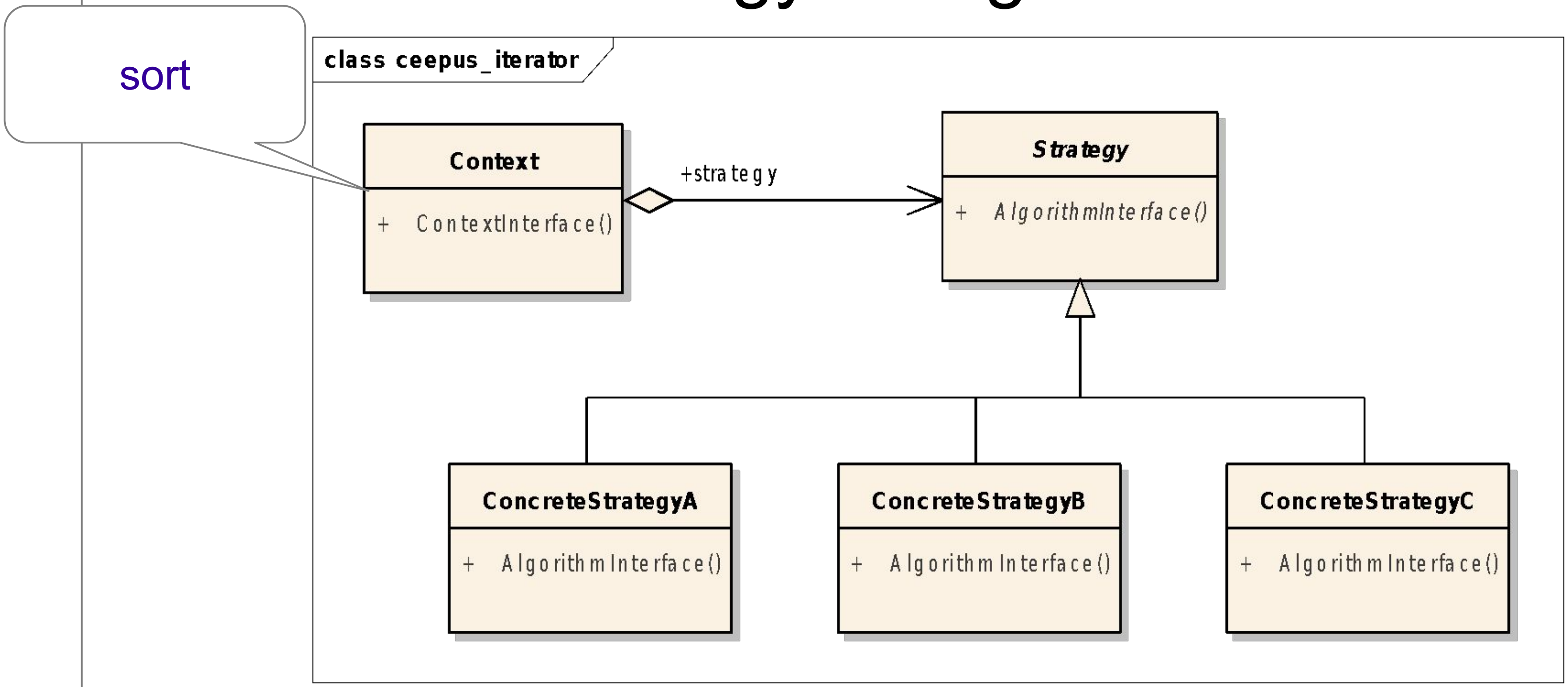
function object

Strategy Design Pattern



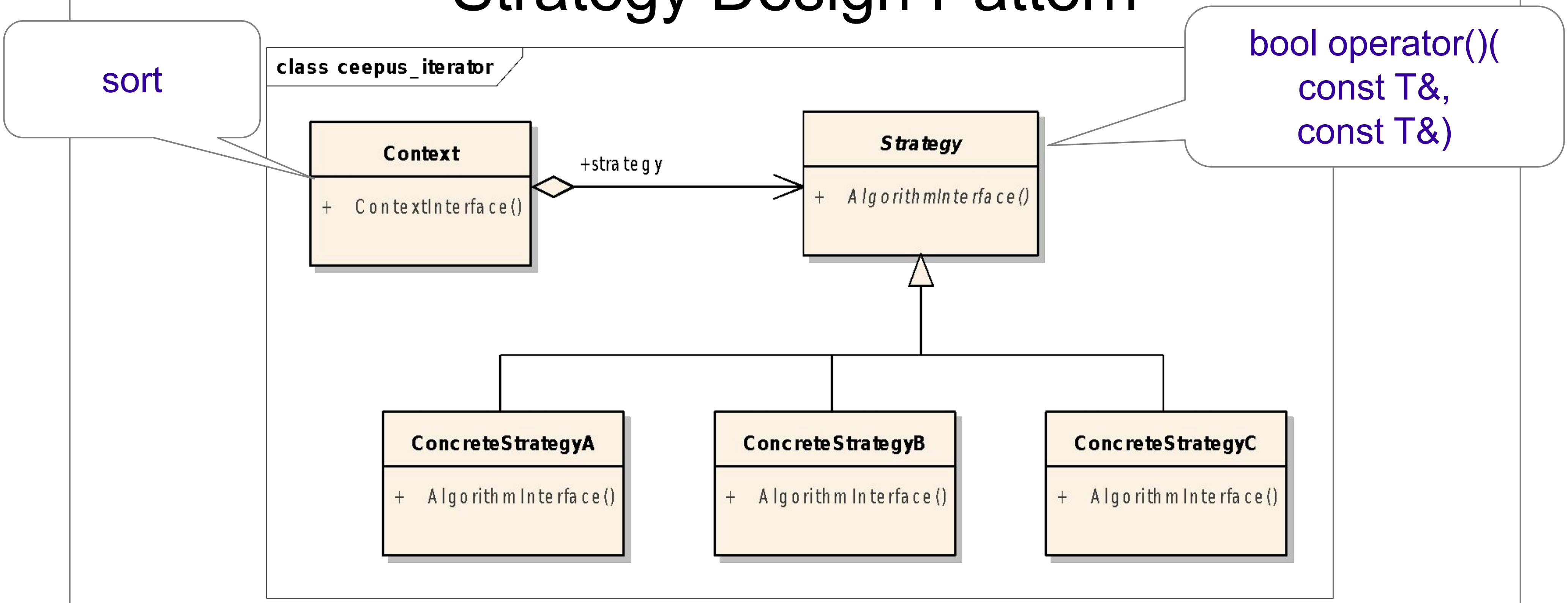
- Define a **family of algorithms**, encapsulate each one, and make them interchangeable.
- Strategy **lets the algorithm vary** independently from clients that use it.

Strategy Design Pattern



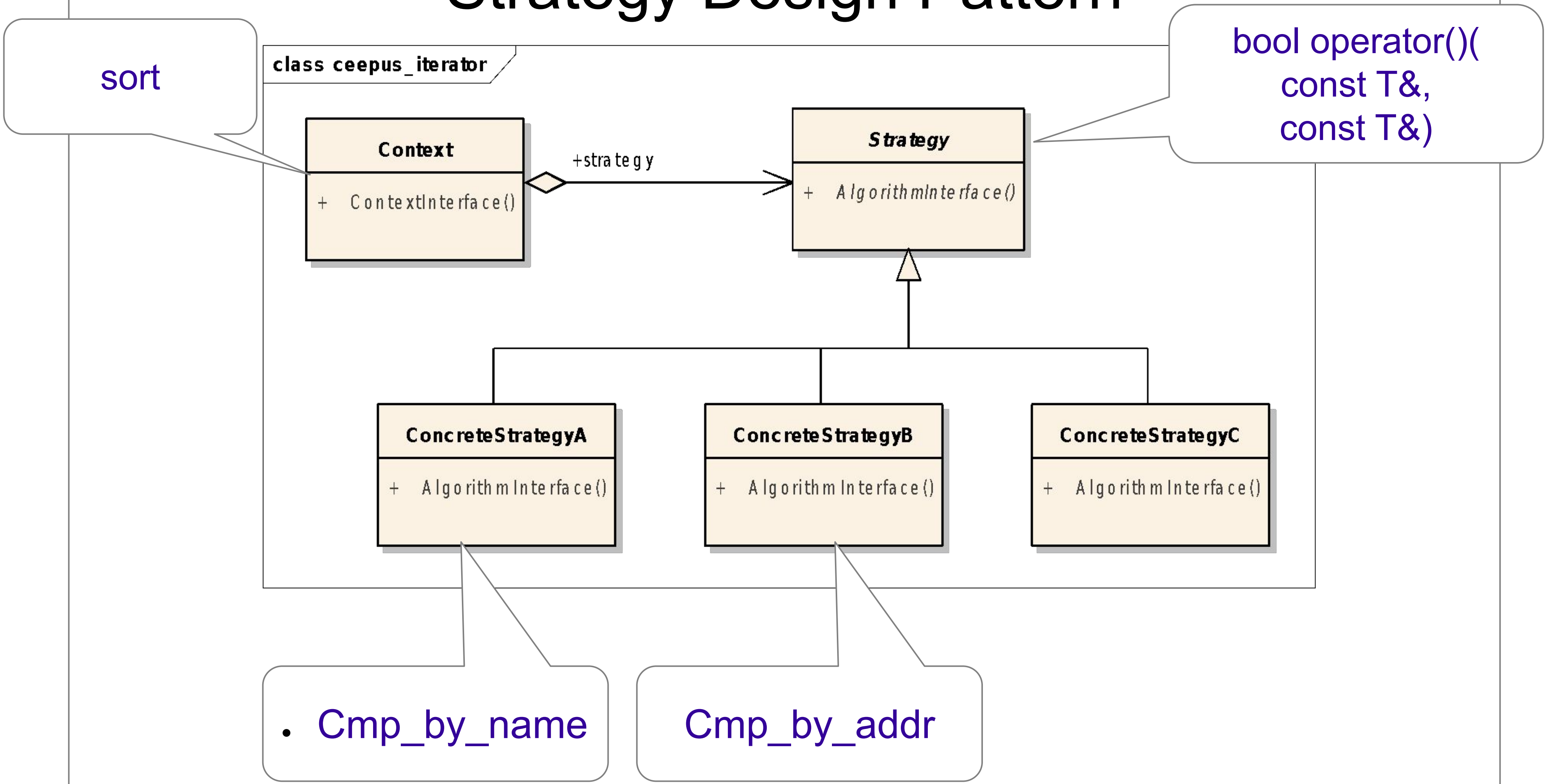
- Define a **family of algorithms**, encapsulate each one, and make them interchangeable.
- Strategy **lets the algorithm vary** independently from clients that use it.

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

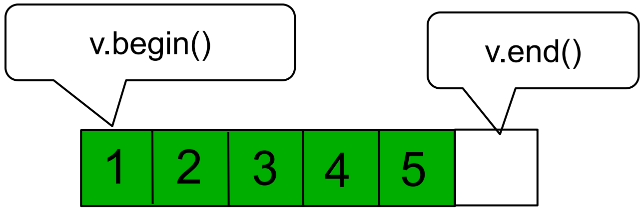
- The *container* manages the contained objects but does not know about *algorithms*

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

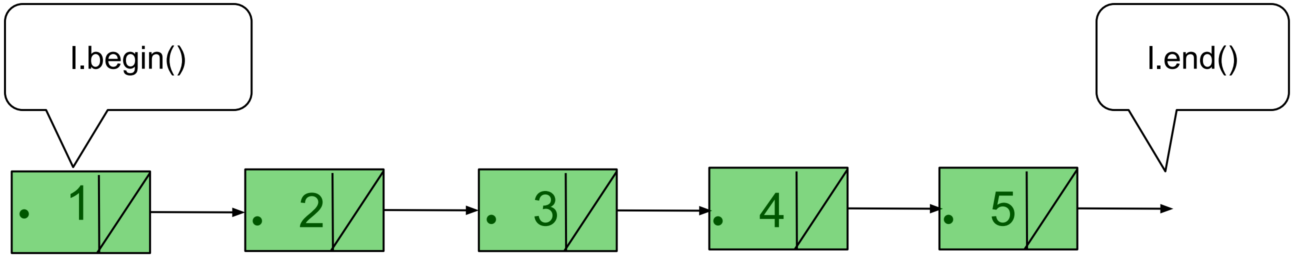
- *Iterators* fit containers to algorithms

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*

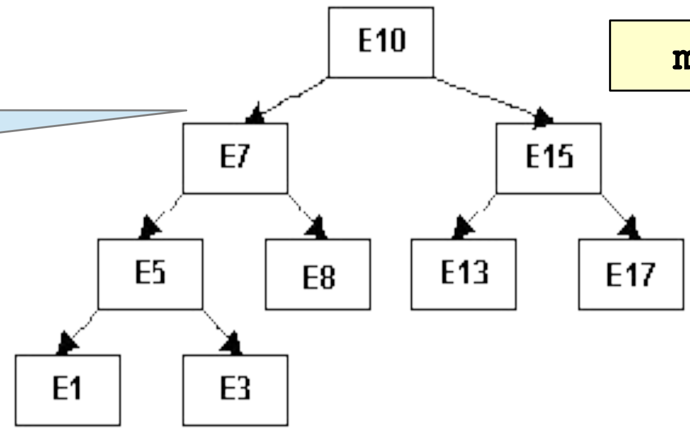
```
template<class InIt, class T>
T accumulate(InIt first, InIt last, T init){
    while (first!=last) {
        init = init + *first;
        ++first;
    }
    return init;
}
```

The `set` container

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

usually implemented as a balanced binary search tree

Find the Error!



`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

`. <`

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

```
#include <set>

set<int> intSet;

set<Person> personSet1;



set<Person, PersonComp> personSet2;
```

The `set` container - usage

- `<`

```
#include <set>
```

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

```
set<int> intSet;

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;
}
```

?

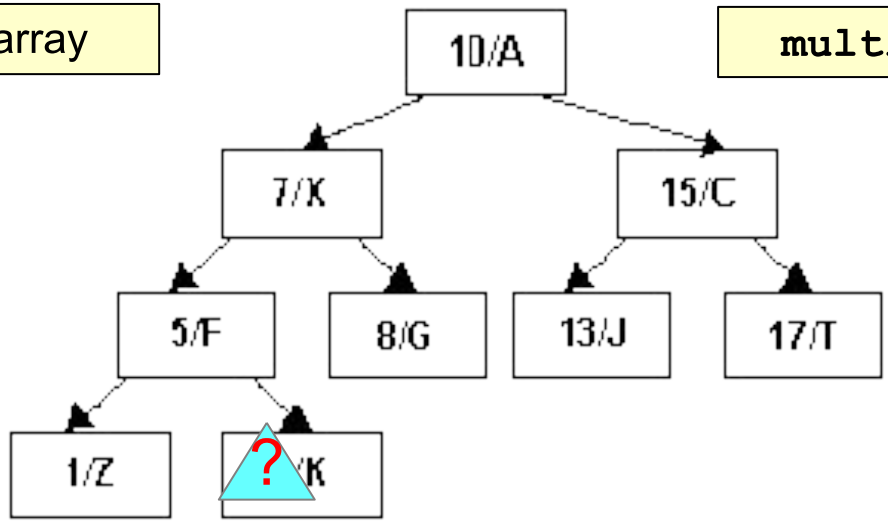
C++
2011

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.insert({"onion",3});

products["cucumber"] = 6;
cout<<products["tomato"]<<endl;
```

The `map` container - usage

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

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

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

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

Difference between [ ] and insert

```
map<string, int> products;

products.insert({"tomato", 10});
printProducts(products); //Output?

products.insert({"tomato", 100});
printProducts(products); //Output?

products["tomato"] = 100;
printProducts(products); //Output?
```

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;
}
-----------------------------------------------------
for( auto& [key, value]: products ){
     cout<< key <<" : "<< value<<endl;
}
```

C++ 2011

C++ 2017

The `multimap` container - usage

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


for (auto& [country, city]: cities){
     cout << country <<"\t"<< city <<endl;
}
```

C++ 2017

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& [country, city]: cities){
    cout << country <<"\t"<< city <<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??

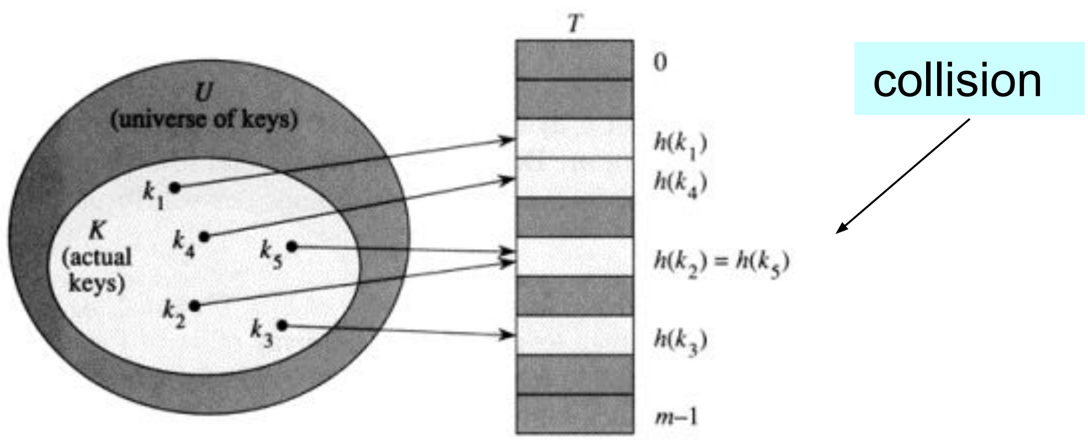
```
set<string *> animals;
animals.insert(new string("monkey"));
animals.insert(new string("lion"));
animals.insert(new string("dog"));
animals.insert(new string("frog"));

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& animal: animals ){
     cout<< *animal <<endl;
}
```

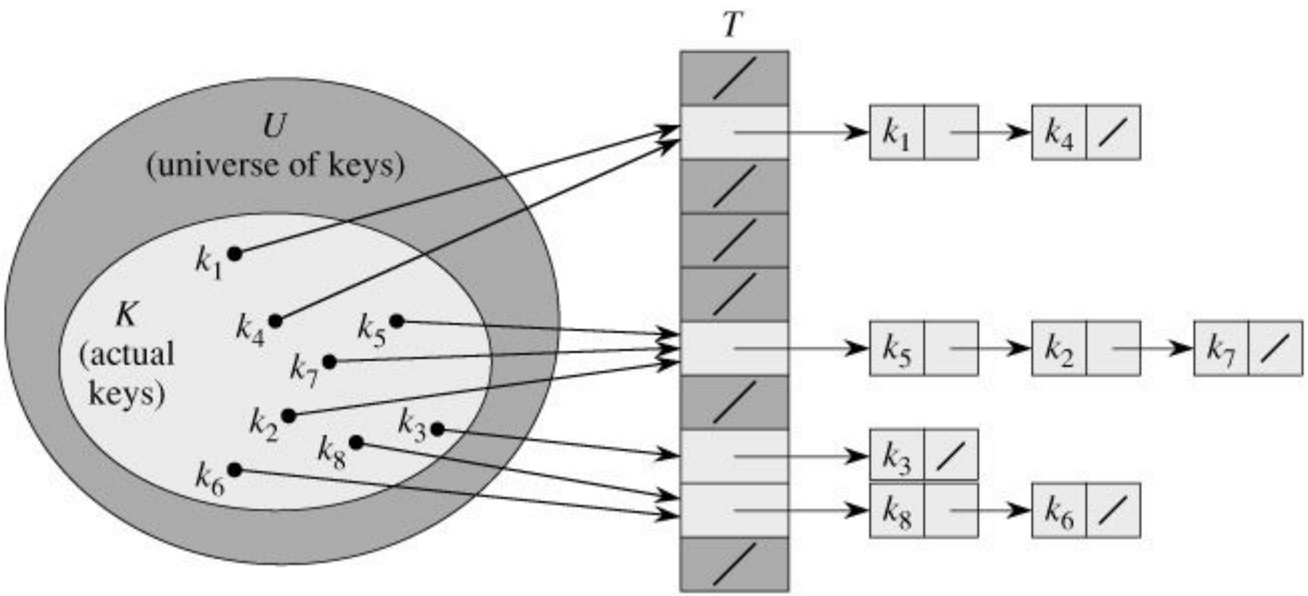
Hash Tables



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

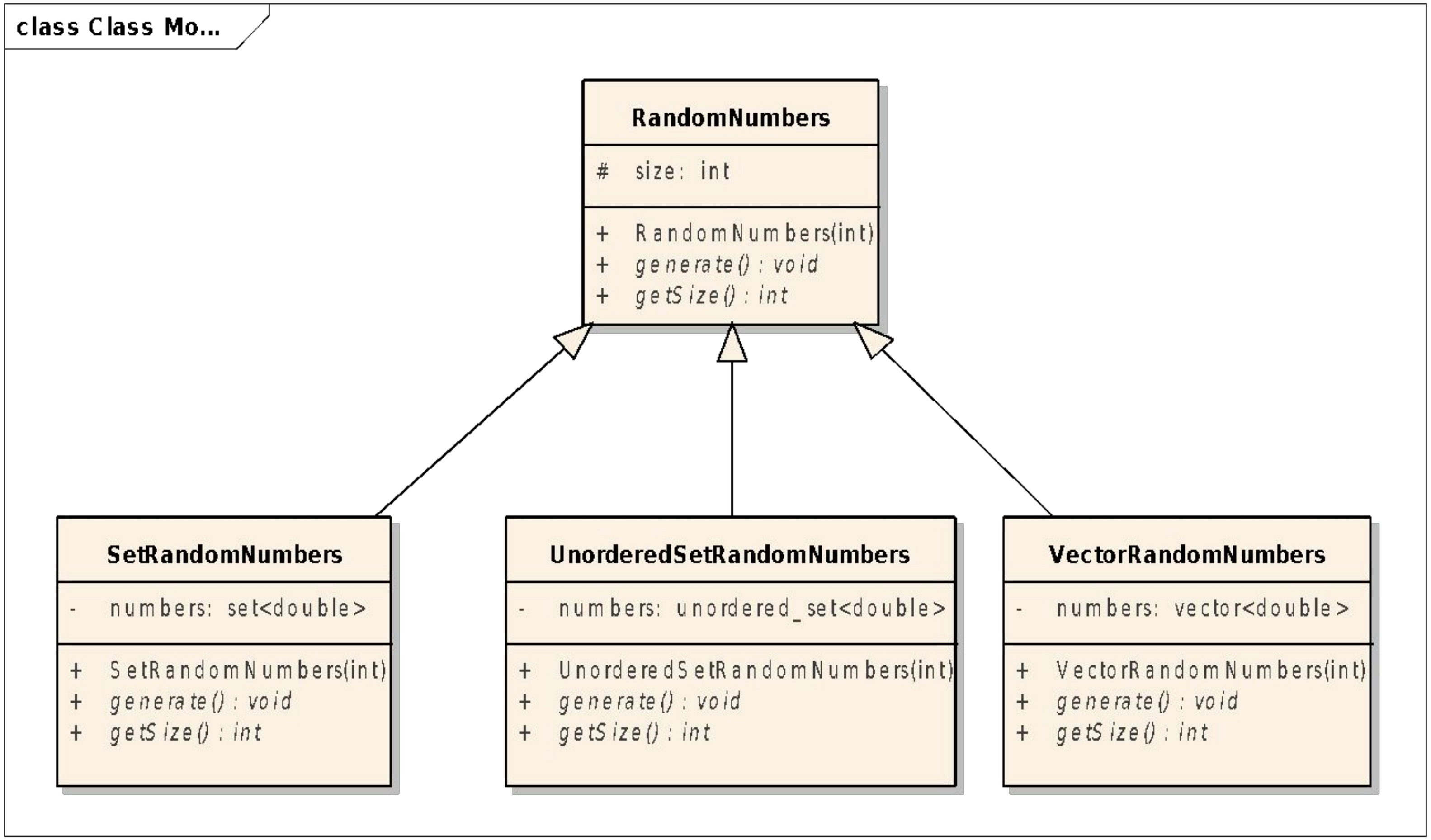
- vector<double> + sort + unique
- set<double>
- unordered_set<double>

- 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(const string& name, const string& phone);

   bool removeItem(const string& name, const string& phone);

   vector<string> findItem(const string& name);

   friend ostream& operator<<(ostream& os, const PhoneBook& book);

};
```

`unordered_map`: example

```
void PhoneBook::addItem(const string &name, const string &phone){
    this->book[name].push_back(phone);
}

bool PhoneBook::removeItem(const string &name, const string &phone){
      // Locate the name → use  map.at(key) + try - catch
      // If the name does not exist
      //            → return false
      // Else
      //     locate the given phone in the vector associated to the
      //     name and delete it
      //      In case of empty phone list delete the map entry too
      //              → return true
}
```

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;
```

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 characters are in an unusual order.

Example for a strange alphabet:

- `{b, c, a}`
- `'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 +=v;});
```

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

Transformations

```
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

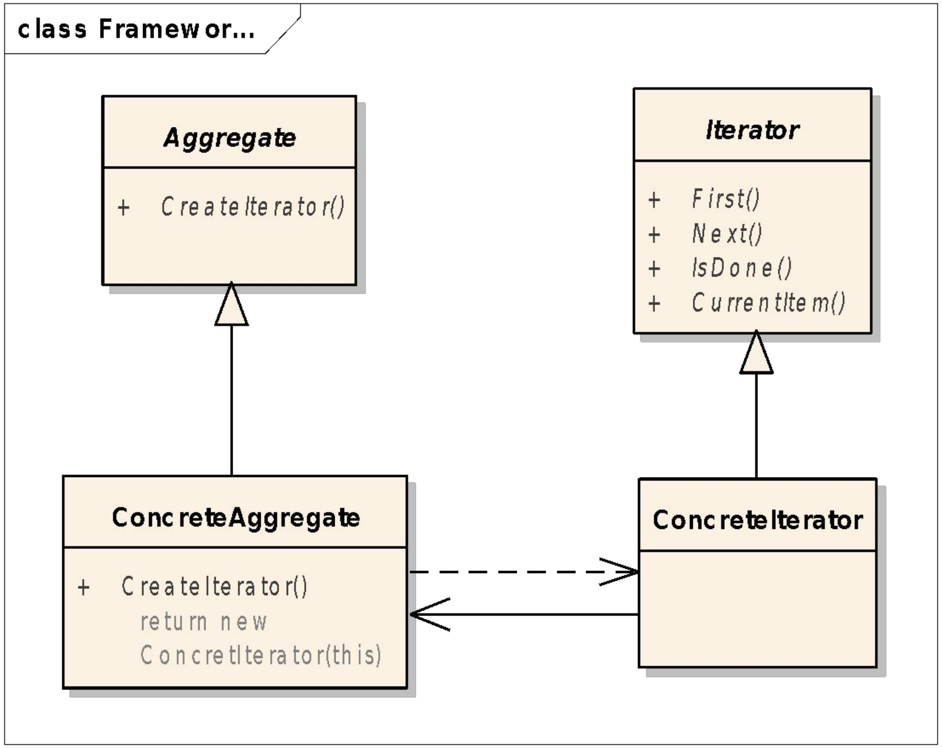
```
double median(vector<double>& v) {
    int n = v.size();
    if( n==0 ) throw domain_error("empty vector");
    int mid = n / 2;
    // size is an odd number
    if( n % 2 == 1 ){
        nth_element(v.begin(), v.begin()+mid, v.end());
        return v[mid];
    } else{
        nth_element(v.begin(),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

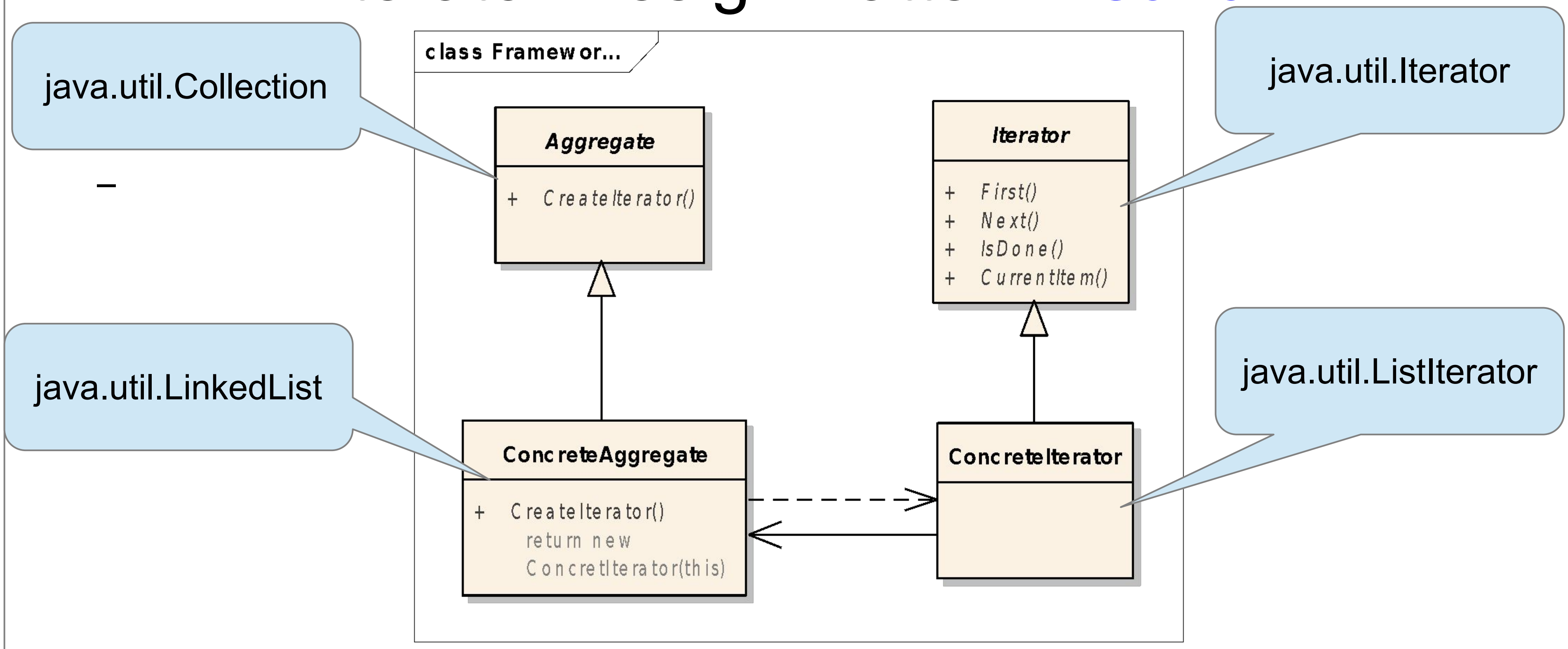
Iterator Design Pattern



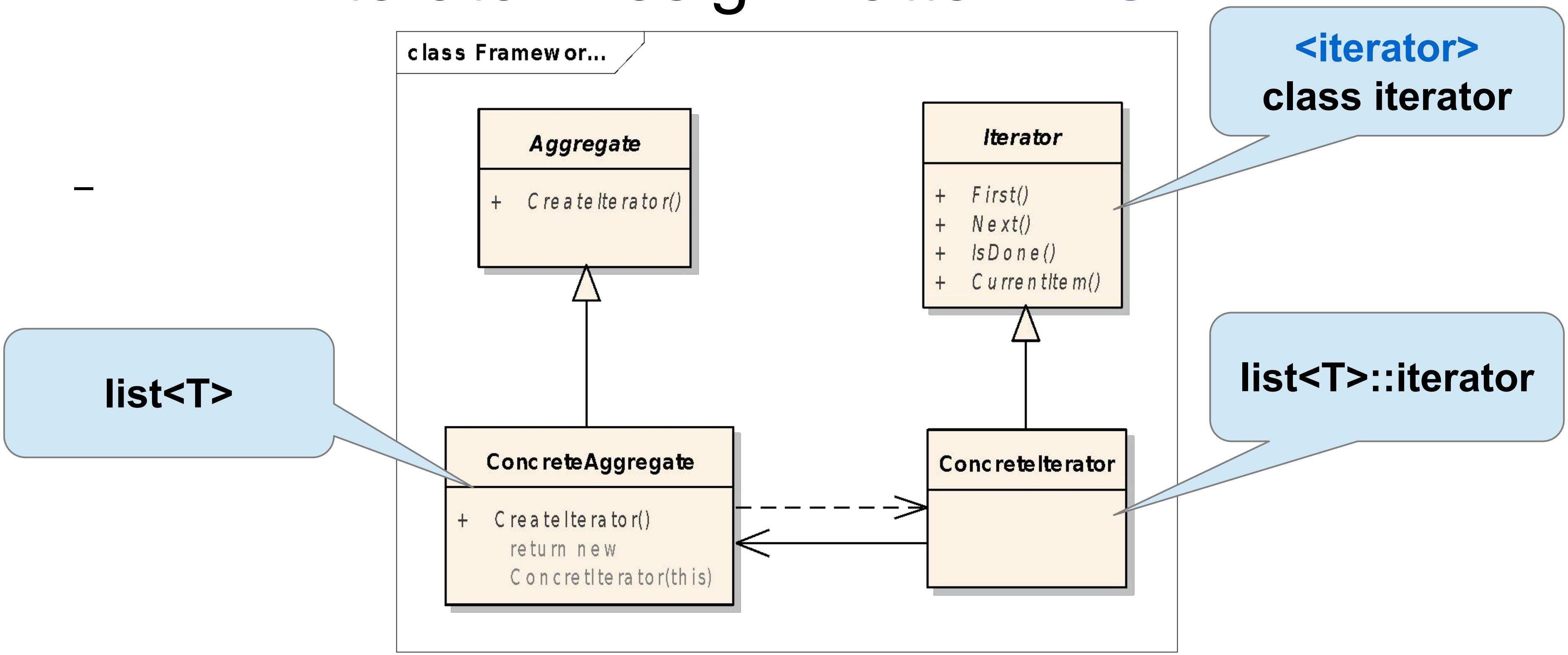
–

- 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& oldValue, const T& newValue ){
 for (; first != last; ++first){
     if (*first == oldValue){
         *first = newValue;
     }
 }
}
```

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 occurrence of an element!

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

Find the second occurrence of an element!

```
template <class T, class It>
It secondOccurrence(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;
}
```

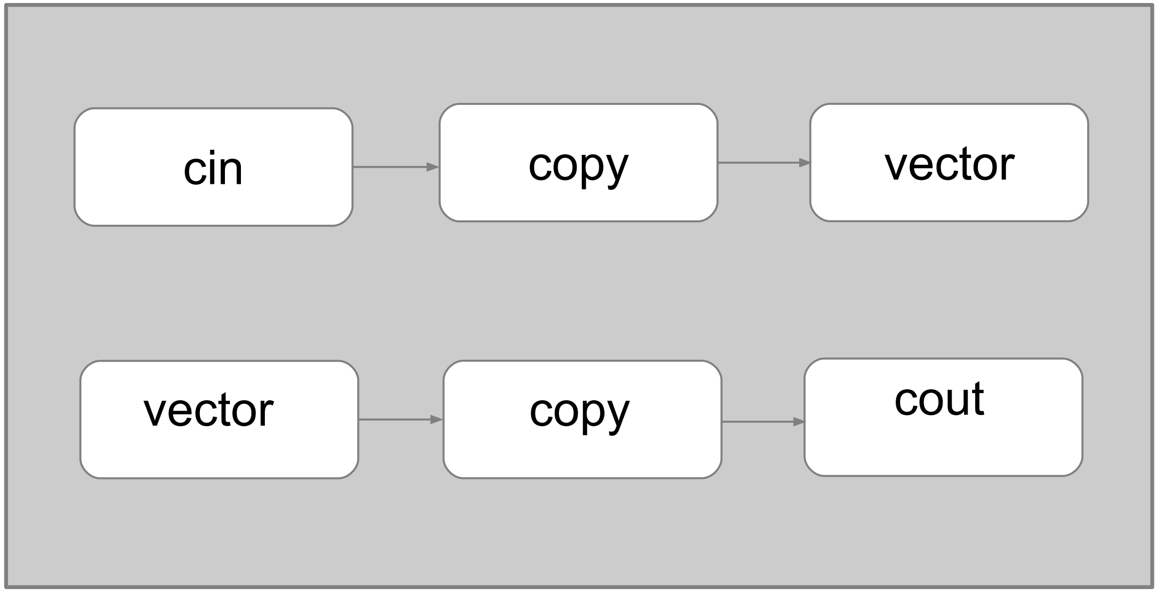
Types of insert iterators

```
*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



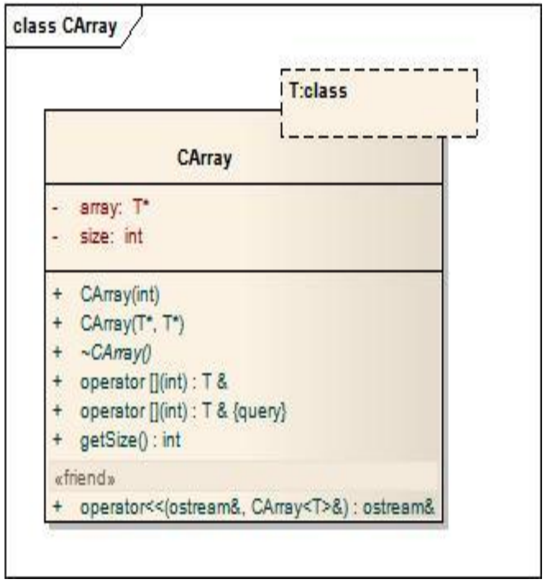
Stream iterator - examples

```
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.

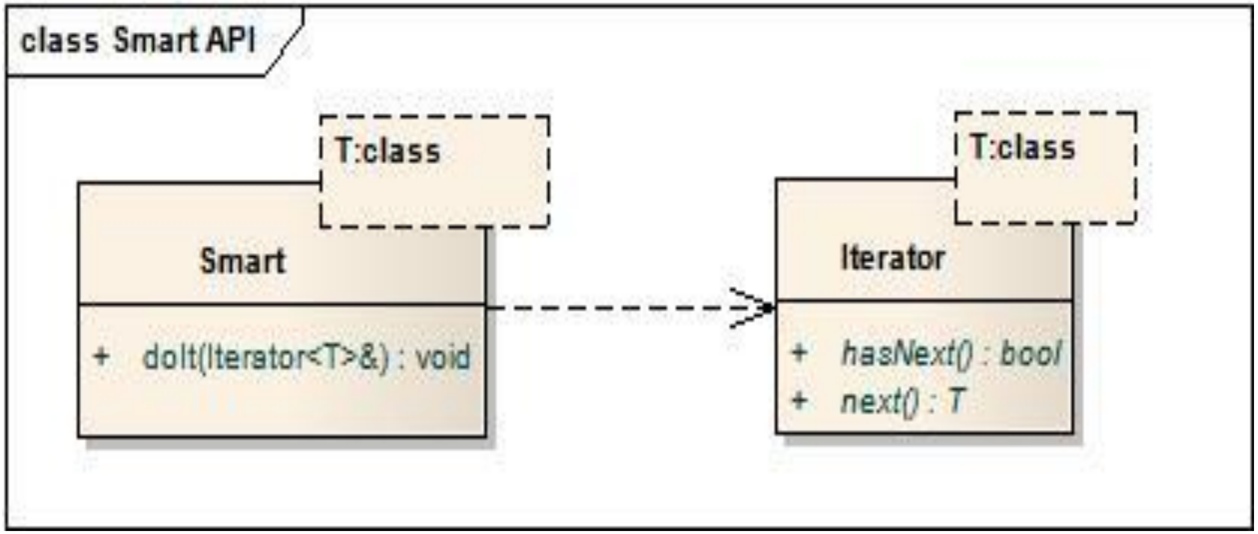
- It is given a CArray class




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

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

Problem 1.

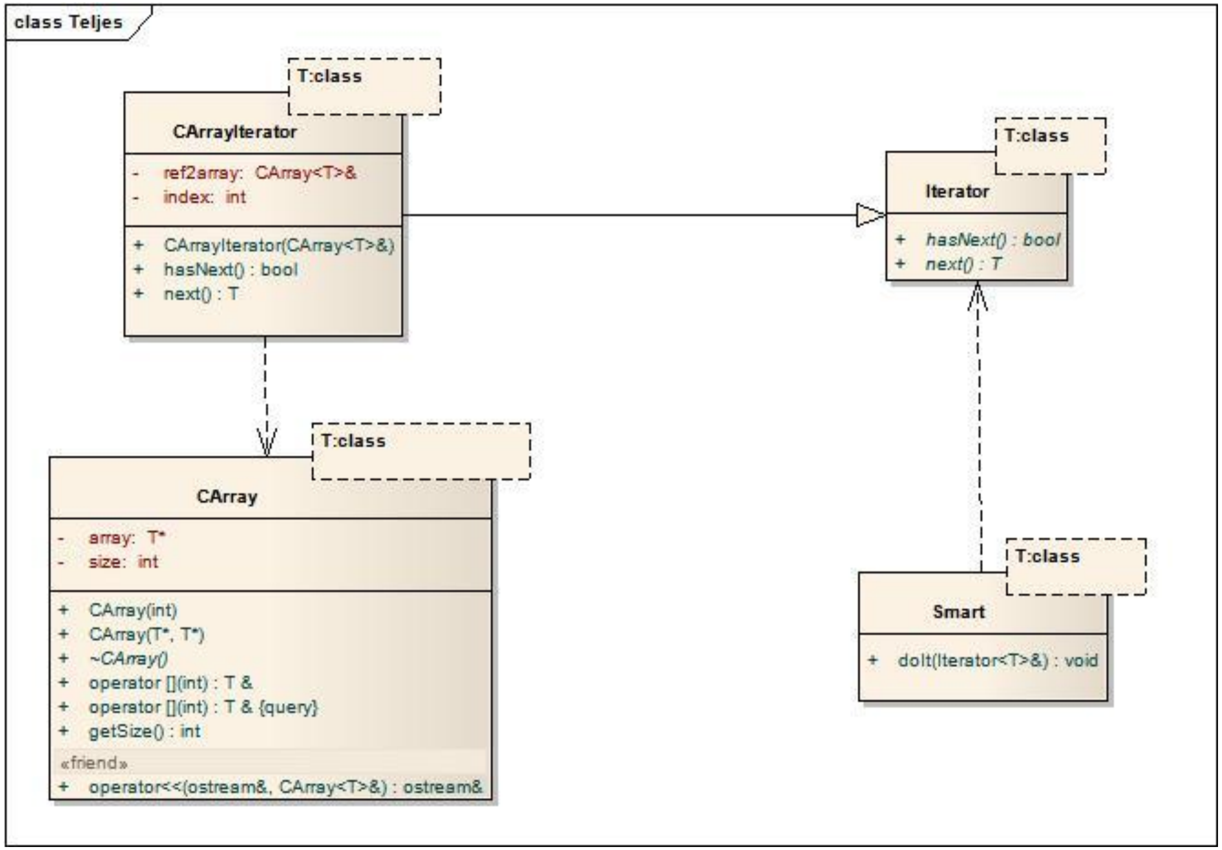
- It is given a Smart API too



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

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

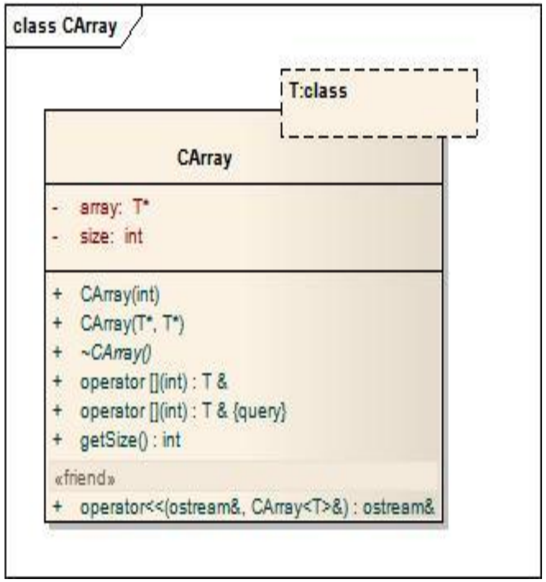
Problem 1. - Solution




```
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.

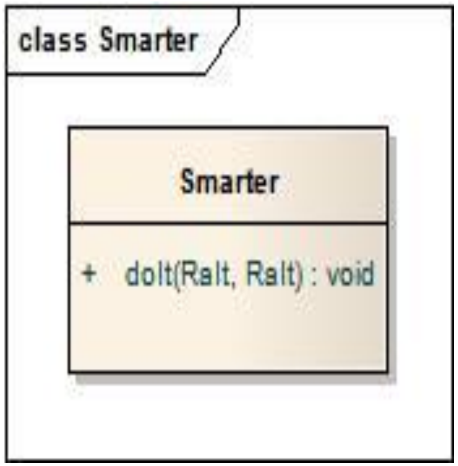
- It is given a CArray class




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

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

Problem 2.

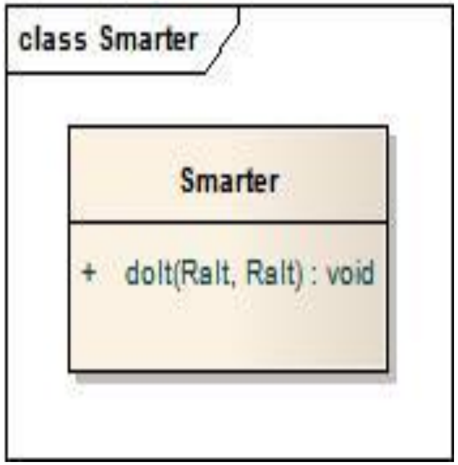
- It is given a Smarter API




```
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
pri
        int size;
};
```

```
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; }
        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
...
```

Lambdas

Syntactic sugar

C++ 2011

- 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 ) → ret
                                   { 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
- Move Semantics (Move constructor, Move assignment)
- **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<<"Person";};
};
class Employee:public Person{
   public: virtual void print(){cout<<"Employee";};
};
class Manager:public Empl
   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 print
};
class Employee:public Person{
   public: virtual void print
};
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/

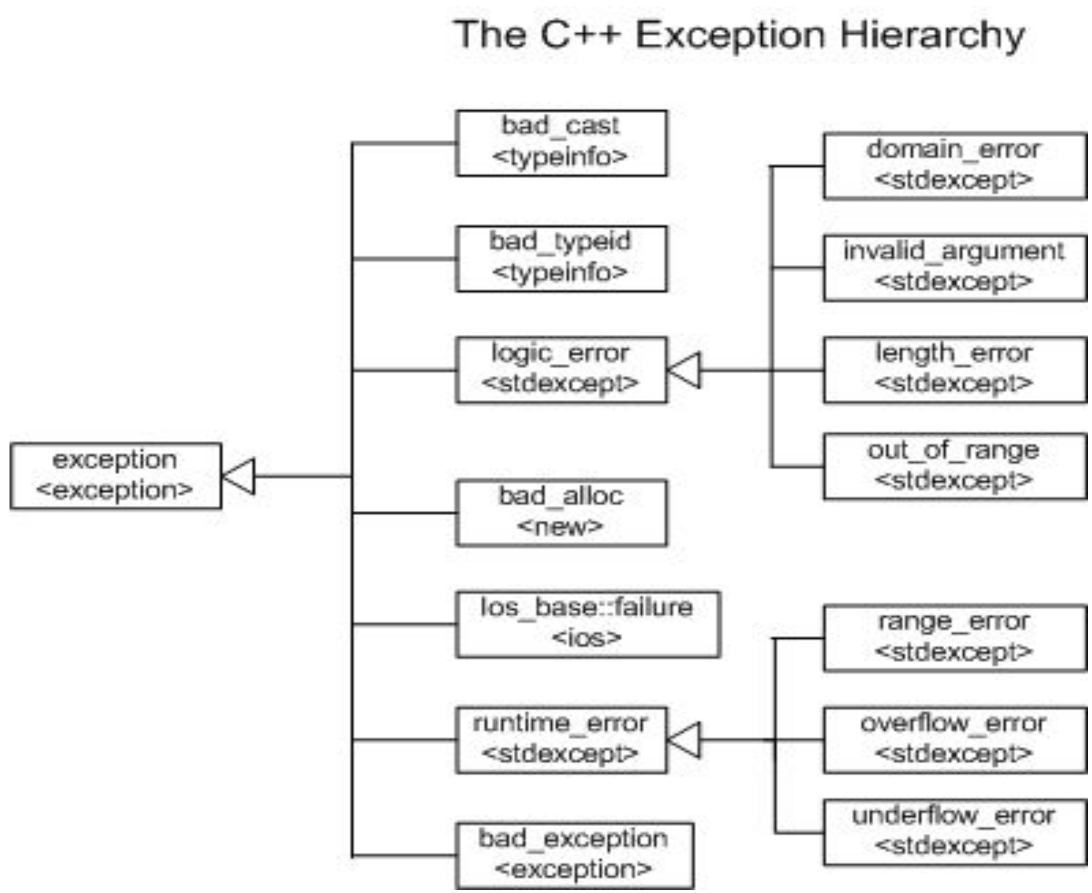
```
void func() throw (){
  // statements
}
```

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

C++
2011

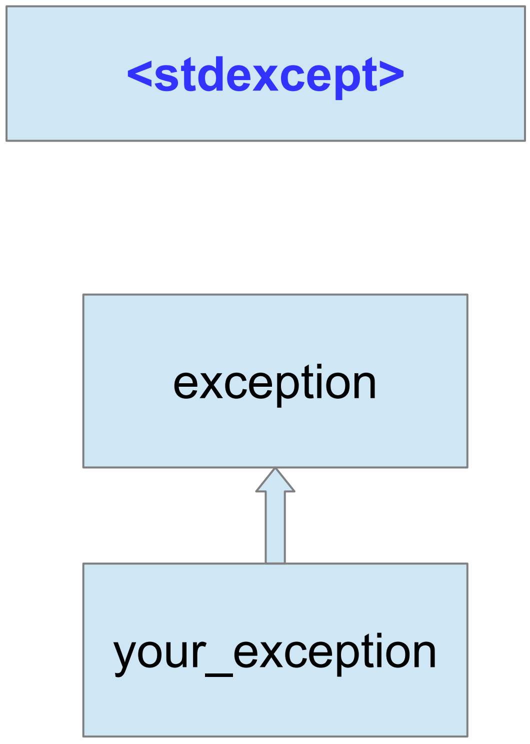
The Standard Exceptions

<stdexcept>



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

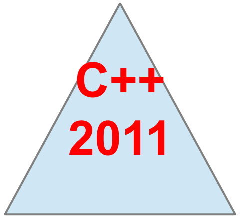
Why Smart Pointers?

- 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>
```



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`

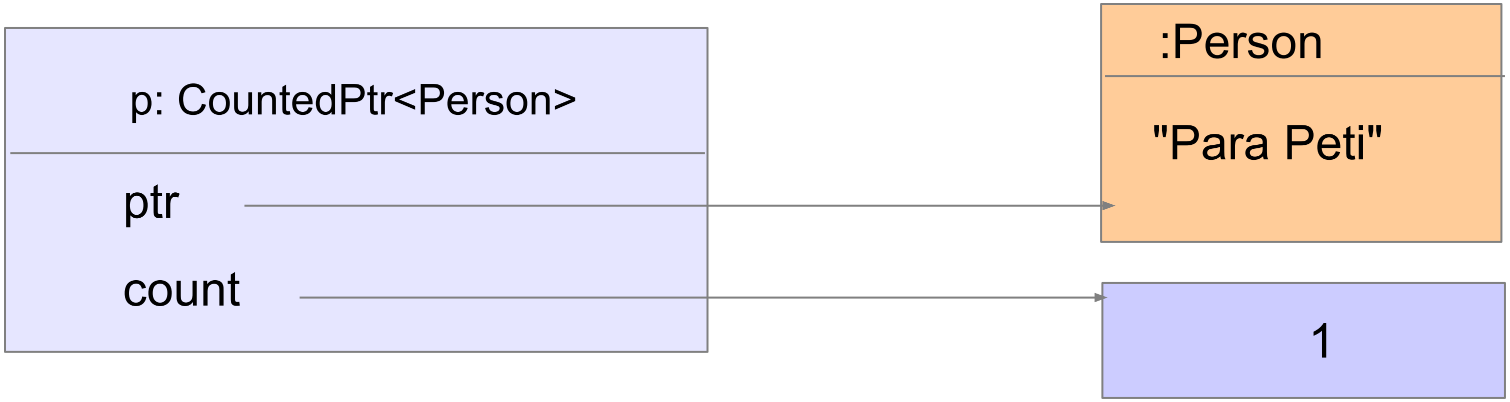
- it will automatically free the resource in case of the unique_ptr goes out of scope.

`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.

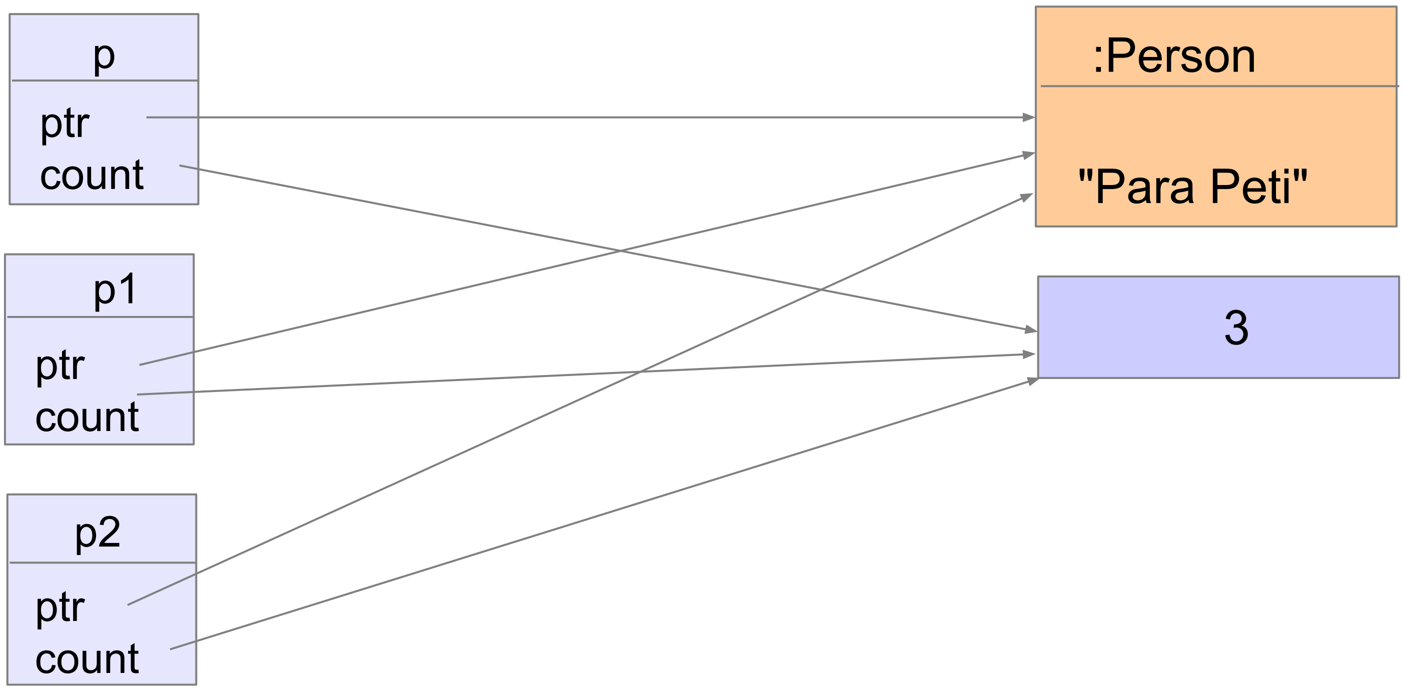
Implementing your own smart pointer class

```
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:
    ...
};
```

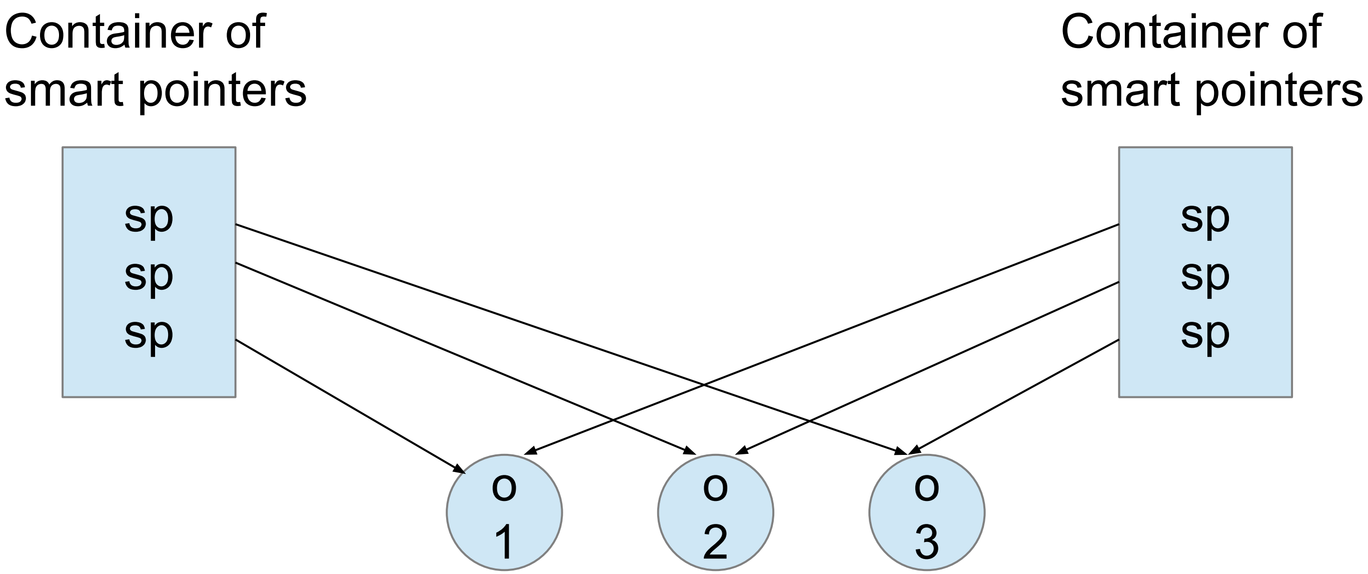
Implementation (2)

```
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)

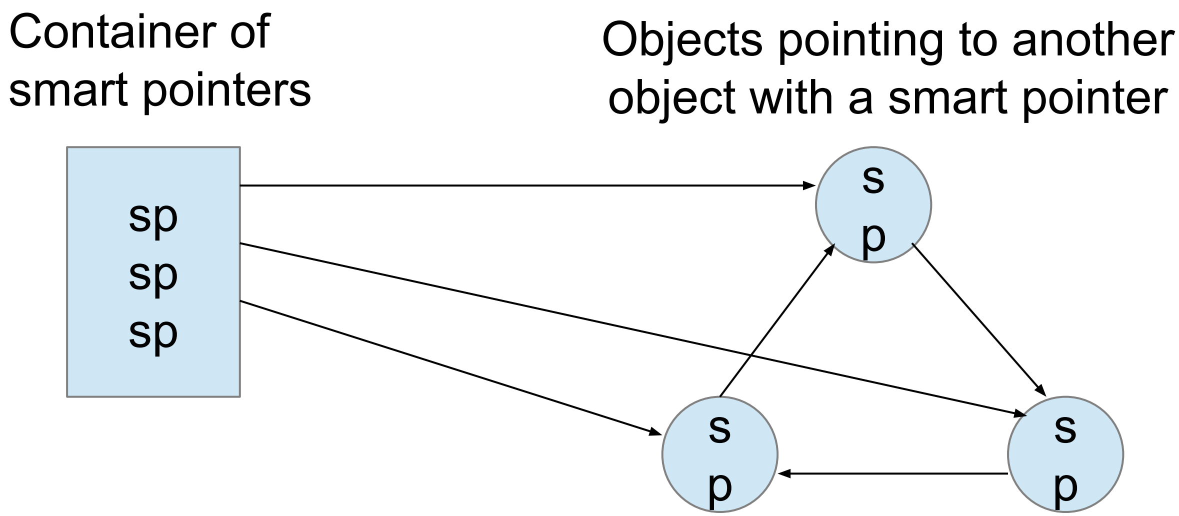
```
CountedPtr<T>& operator=( const CountedPtr<T>& p ){
   if( this != &p ){
      --(*count);
      if( *count == 0 ){ delete count; delete ptr; }
      this->ptr = p.ptr;
      this->count = p.count;
      ++(*count);
   }
   return *this;
}

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

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

Shared ownership with `shared_ptr`



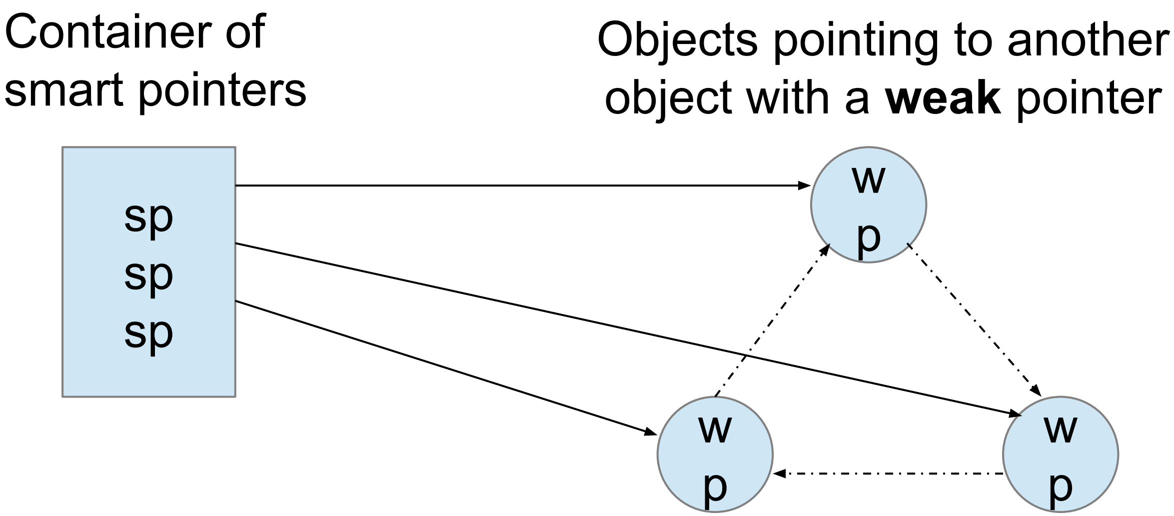
[Using C++11's Smart Pointers]

Problem with `shared_ptr`



[Using C++11's Smart Pointers]

Solution: `weak_ptr`



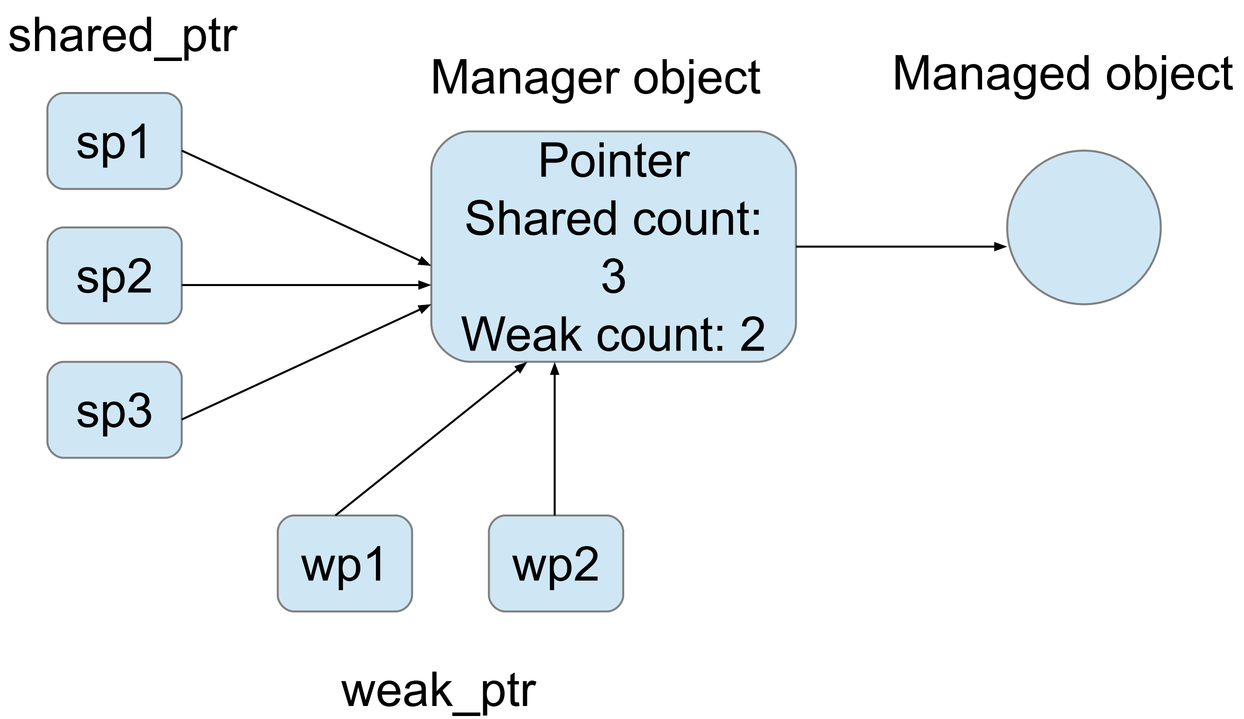
[Using C++11's Smart Pointers]

`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

[Using C++11's Smart Pointers]

How smart pointers work



[Using C++11's Smart Pointers]

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 referred by a smart pointer.

[Using C++11's Smart Pointers]()

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;
```

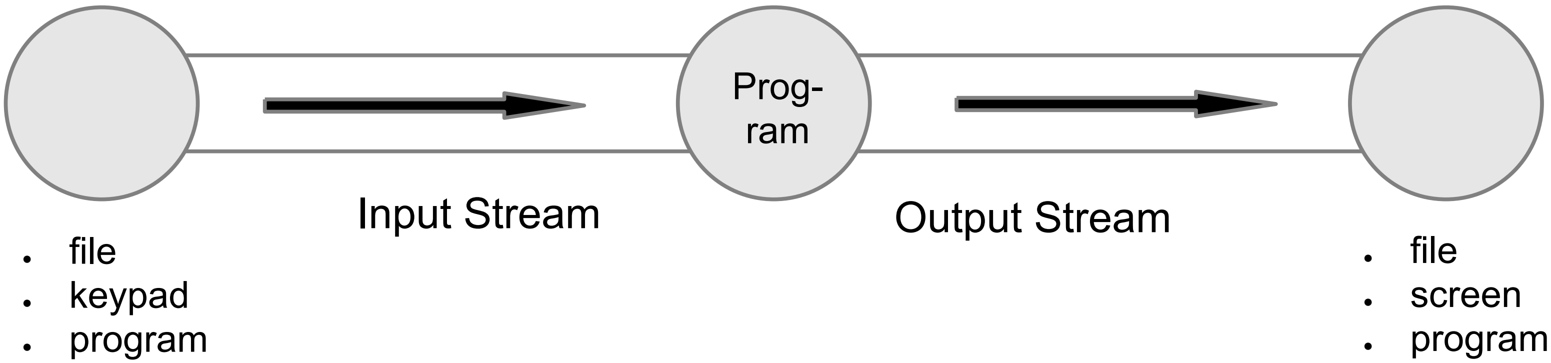
Module 11

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.

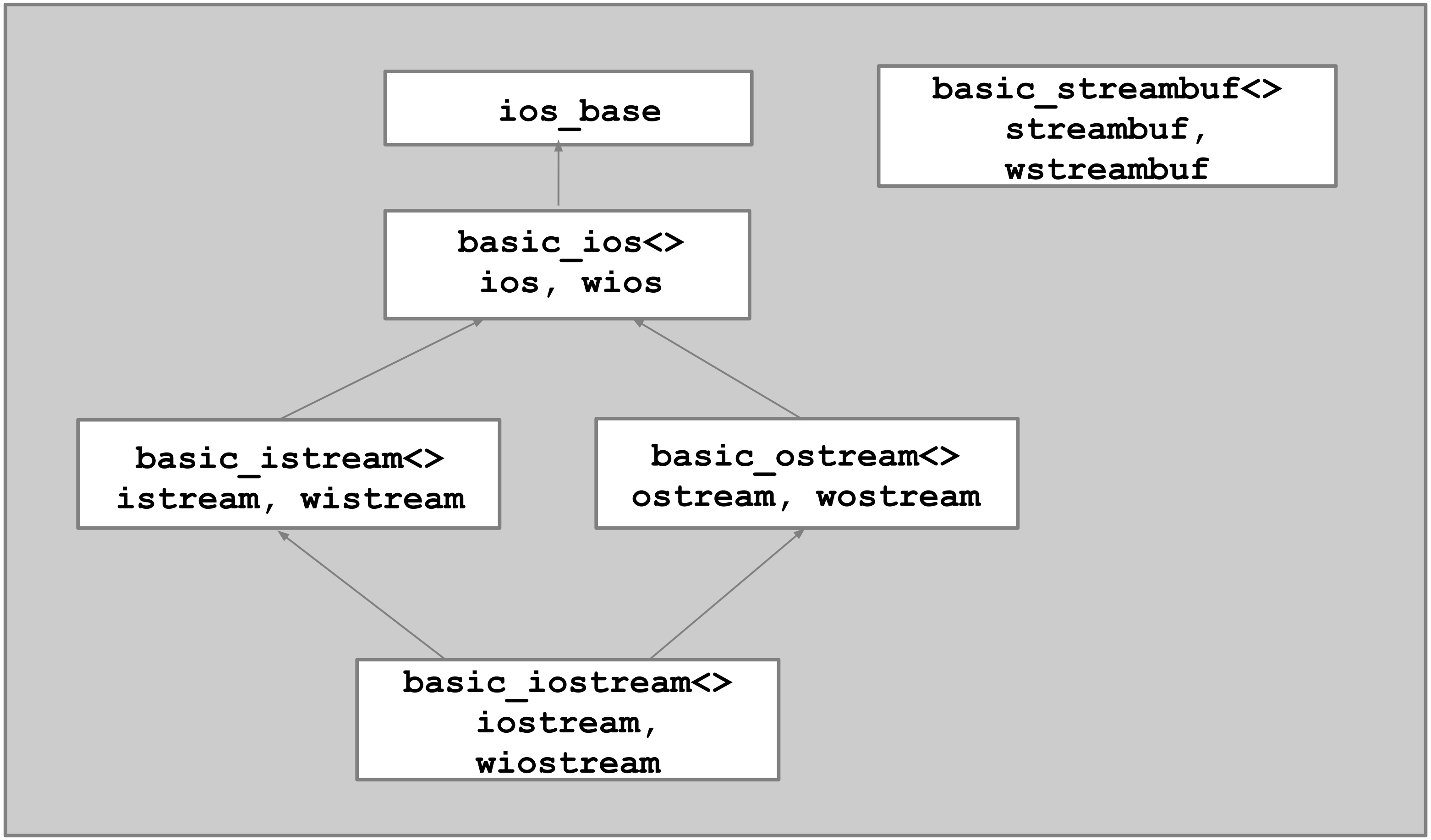
`cerr` An *unbuffered* output stream, writes data to the "error console"

`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;
}
```

Module 12

Concurrency

Outline

- High-level interface: `async()` and `future`
- Low-level interface: `thread`, `promise`
- Synchronizing threads
- Mutexes and locks: `mutex`, `lock_guard`, `unique_lock`
- Atomics

Problem

Find all words matching a pattern in a dictionary!

Pattern: `a..l.`

Word: `apple, apply, ...`

Single-threaded Solution (1)

```
 string pattern ="a..l.";
// Load the words into the deque
ifstream f( "dobbsdict.txt" );
if ( !f ) {
    cerr << "Cannot open dobbsdict.txt in the current directory\n";
    return 1;
}
string word;
deque<string> backlog;
while ( f >> word ){
    backlog.push_back( word );
 }
// Now process the words and print the results
vector<string> words = find_matches(pattern, backlog);
cerr << "Found " << words.size()<< " matches for " << pattern<< endl;
for ( auto s : words ){
    cout << s << "\n";
 }
```

Single-threaded Solution (2)

```
inline bool match( const string &pattern, string word )
{
    if ( pattern.size() != word.size() )
        return false;
    for ( size_t i = 0 ; i < pattern.size() ; i++ )
        if ( pattern[ i ] != '.' && pattern[ i ] != word[ i ] )
            return false;
    return true;
}
```

```
vector<string> find_matches( string pattern, deque<string> &backlog )
{
    vector<string> results;
    for ( ; ; ) {
        if ( backlog.size() == 0 ) { return results;}
        string word = backlog.front();
        backlog.pop_front();
        if ( match( pattern, word ) ){ results.push_back( word );}
    }
     return results;
}
```

Multi-threaded Solution (1)

```
string pattern ="a..l.";
// Load the words into the deque
ifstream f( "dobbsdict.txt" );
if ( !f ) {
    cerr << "Cannot open sowpods.txt in the current directory\n";
    return 1;
}
string word;
deque<string> backlog;
while ( f >> word ){ backlog.push_back( word );}
// Now process the words and print the results

auto f1 = async( launch::async, find_matches, pattern, ref(backlog) );
auto f2 = async( launch::async, find_matches, pattern, ref(backlog) );
auto f3 = async( launch::async, find_matches, pattern, ref(backlog) );

print_results( f1, pattern, 1 );
print_results( f2, pattern, 2 );
print_results( f3, pattern, 3 );
```

Worker thread
Returns a **std::future** object

Multi-threaded Solution (1)

```
 string pattern ="a..l.";
// Load the words into the deque
ifstream f( "dobbsdict.txt" );
if ( !f ) {
    cerr << "Cannot open sowpods.txt in the current directory\n";
    return 1;
}
string word;
deque<string> backlog;
while ( f >> word ){ backlog.push_back( word );}
// Now process the words and print the results

auto f1 = async( launch::async, find_matches, pattern, ref(backlog) );
auto f2 = async( launch::async, find_matches, pattern, ref(backlog) );
auto f3 = async( launch::async, find_matches, pattern, ref(backlog) );

print_results( f1, pattern, 1 );
print_results( f2, pattern, 2 );
print_results( f3, pattern, 3 );
```

parameter as a **reference**

Multi-threaded Solution (2)

```
template<class ASYNC>
void print_results( ASYNC &f, string &pattern, int threadno )
{
    vector<string> words =  f.get();
    cerr << "Found " << words.size()<< " matches for " << pattern
         << " in thread " << threadno<< endl;
    for ( auto s : words ){ cout << s << "\n";}
}
```

std::future<>::get()
-returns the return value of the async function
-blocks until the thread is complete

Multi-threaded Solution (3)

```
std::mutex m;

vector<string> find_matches( string pattern, deque<string> &backlog )
{
    vector<string> results;
    for ( ; ; ) {
        m.lock();
        if ( backlog.size() == 0 ) {
            m.unlock();
            return results;
        }
        string word = backlog.front();
        backlog.pop_front();
        m.unlock();
        if ( match( pattern, word ) )
            results.push_back( word );
    }
}
```

Performance

Multi-threaded *vs.* ***Single-threaded*** *solution!!!*

Futures

Objectives

- makes easy to *get* the computed *result back* from a thread,
- able to transport an *uncaught exception* to another thread.

2. When a function has calculated the return value
3. Put the value in a **promise** object
4. The value can be retrieved through a **future**

inter-thread communication channel

Futures

```
future<T> fut = …// launch a thread or async
T result = fut.get();
```

- if the other thread has not yet finished the call to get() will block
- avoid blocking:

```
if( fut.wait_for( 0 ) ){
    T result = fut.get();
} else{
    ...
}
```

mutex [Gregoire]

```
int val;
mutex valMutex;
valMutex.lock();
if (val >= 0) {
   f(val);
}
else {
   f(-val);
}
valMutex.unlock();
```

mutex = mutual exclusion

Helps to control the **concurrent access** of a resource

mutex

```
int val;
mutex valMutex;
valMutex.lock();
if (val >= 0) {
    f(val);
}
else {
    f(-val);
}
valMutex.unlock();
```

What happens in case of an exception?

`mutex` vs. `lock_guard<mutex>`

```
int val;
mutex valMutex;
valMutex.lock();
if (val >= 0) {
   f(val);
}
else {
   f(-val);
}
valMutex.unlock();
```

```
int val;
mutex valMutex;
lock_guard<mutex>  lg(valMutex);
if (val >= 0) {
   f(val);
}
else {
   f(-val);
}
```

RAII principle (*Resource Acquisition Is Initialization*)

lock_guard<mutex>

```
int val;
mutex valMutex;
{
   lock_guard<mutex>  lg(valMutex);
   if (val >= 0) {
      f(val);
   }
   else {
      f(-val);
   }
}
```

Constructor: acquires the resource

Destructor: releases the resource

Destructor is always called
even in case of an exception!!!

RAII principle (*Resource Acquisition Is Initialization*)

unique_lock<mutex>

```
unique_lock = lock_guard + lock() & unlock()
```

Multithreaded Logger [Gregoire]

```
class Logger {
public:
    Logger();
    void log(const string& entry);
protected:
    void processEntries();
    mutex mMutex;
    condition_variable mCondVar;
    queue<string> mQueue;
    thread mThread;    // The background thread.
private:
    // Prevent copy construction and assignment.
    Logger(const Logger& src);
    Logger& operator=(const Logger& rhs);
};
```

Multithreaded Logger [Gregoire]

```
Logger::Logger() {
    // Start background thread.
    mThread = thread{&Logger::processEntries, this};
}
```

```
void Logger::log(const std::string& entry) {
    // Lock mutex and add entry to the queue.
    unique_lock<mutex> lock(mMutex);
    mQueue.push(entry);
    // Notify condition variable to wake up thread.
    mCondVar.notify_all();
}
```

Multithreaded Logger [Gregoire]

```
void Logger::processEntries()
{
  ofstream ofs("log.txt");
  if (ofs.fail()){ … return; }
  unique_lock<mutex> lock(mMutex);
  while (true) {
     // Wait for a notification.
     mCondVar.wait(lock);
     // Condition variable is notified → something is in the queue.
     lock.unlock();
     while (true) {
        lock.lock();
          if (mQueue.empty()) {
               break;
          } else {
               ofs << mQueue.front() << endl;
               mQueue.pop();
          }
          lock.unlock();
     }
 }
}
```

Usage: Multithreaded Logger [Gregoire]

```
void logSomeMessages(int id, Logger& logger)
{
     for (int i = 0; i < 10; ++i) {
          stringstream ss;
          ss << "Log entry " << i << " from thread " << id;
          logger.log(ss.str());
     }
}
int main()
{
     Logger logger;
     vector<thread> threads;
     // Create a few threads all working with the same Logger instance.
     for (int i = 0; i < 10; ++i) {
          threads.push_back(thread(logSomeMessages, i, ref(logger)));
     }
     // Wait for all threads to finish.
     for (auto& t : threads) {
          t.join();
     }
     return 0;
}
```

Problem: Multithreaded Logger [Gregoire]

end of main() → terminate abruptly `Logger` thread

Solution: Multithreaded Logger [Gregoire]

```
class Logger
{
public:
     Logger();
     // Gracefully shut down background thread.
     virtual ~Logger();
     // Add log entry to the queue.
     void log(const std::string& entry);
protected:
     void processEntries();
     bool mExit;
     ...
};
```

Solution: Multithreaded Logger [Gregoire]

```
void Logger::processEntries()
{
   …
     while (true) {
          // Wait for a notification.
          mCondVar.wait(lock);
          // Condition variable is notified, so something is in the queue
          // and/or we need to shut down this thread.
          lock.unlock();
          while (true) {
               lock.lock();
               if (mQueue.empty()) {
                    break;
               } else {
                    ofs << mQueue.front() << endl;
                    mQueue.pop();
               }
               lock.unlock();
          }
          if (mExit) break;
     }
}
```

Solution: Multithreaded Logger [Gregoire]

```
Logger::Logger() : mExit(false)
{
// Start background thread.
mThread = thread{&Logger::processEntries, this};
}
Logger::~Logger()
{
     // Gracefully shut down the thread by setting mExit
     // to true and notifying the thread.
     mExit = true;
     // Notify condition variable to wake up thread.
     mCondVar.notify_all();
     // Wait until thread is shut down.
     mThread.join();
}
```

Solution: Multithreaded Logger [Gregoire]

```
Logger::Logger() : mExit(false)
{
// Start background thread.
mThread = thread{&Logger::processEntries, this};
}
Logger::~Logger()
{
     // Gracefully shut down the thread by setting mExit
     // to true and notifying the thread.
     mExit = true;
     // Notify condition variable to wake up thread.
     mCondVar.notify_all();
     // Wait until thread is shut down.
     mThread.join();
}
```

Solution: Multithreaded Logger [Gregoire]

?

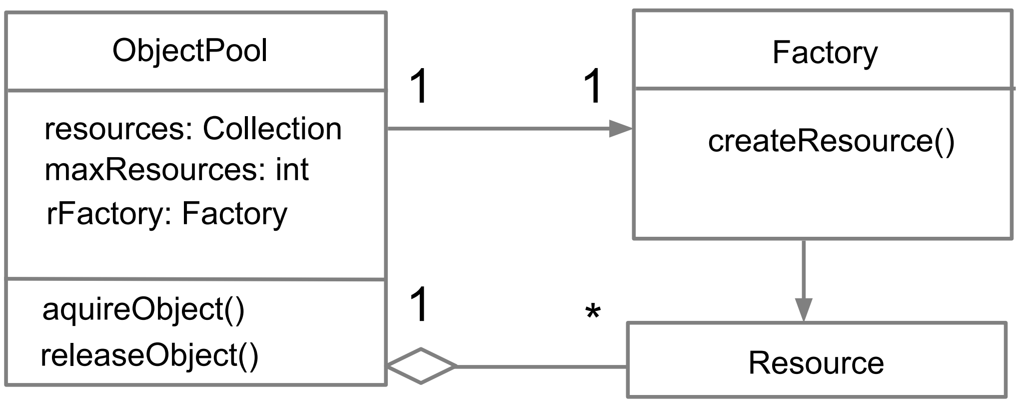
Deadlock

Solution: Multithreaded Logger [Gregoire]

It can happen that this remaining code from the main() function, including the Logger destructor, is executed before the Logger background thread has started its processing loop. When that happens, the Logger destructor will already have called notify_all() before the background thread is waiting for the notifi cation, and thus the background thread will miss this notifi cation from the destructor.

Object Pool

Thread Pool



Object Pool

C++ implementation [Gregoire]

```
template <typename T>
class ObjectPool{
public:
  ObjectPool(size_t chunkSize = kDefaultChunkSize)
                          throw(std::invalid_argument, std::bad_alloc);
  shared_ptr<T> acquireObject();
  void releaseObject(shared_ptr<T> obj);
protected:
  queue<shared_ptr<T>> mFreeList;
  size_t mChunkSize;
  static const size_t kDefaultChunkSize = 10;
  void allocateChunk();
private:
  // Prevent assignment and pass-by-value
  ObjectPool(const ObjectPool<T>& src);
  ObjectPool<T>& operator=(const ObjectPool<T>& rhs);
};
```

Object Pool

C++ implementation [Gregoire]

```
template <typename T>
ObjectPool<T>::ObjectPool(size_t chunkSize)
                                throw(std::invalid_argument,
std::bad_alloc) {
    if (chunkSize == 0) {
        throw std::invalid_argument("chunk size must be positive");
    }
    mChunkSize = chunkSize;
    allocateChunk();
}
```

Object Pool

C++ implementation [Gregoire]

```
template <typename T>
void ObjectPool<T>::allocateChunk()
{
   for (size_t i = 0; i < mChunkSize; ++i) {
      mFreeList.push(std::make_shared<T>());
   }
}
```

Object Pool

C++ implementation [Gregoire]

```
template <typename T>
shared_ptr<T> ObjectPool<T>::acquireObject()
{
   if (mFreeList.empty()) {
      allocateChunk();
   }
   auto obj = mFreeList.front();
   mFreeList.pop();
   return obj;
}
```

Object Pool

C++ implementation [Gregoire]

```
template <typename T>
void ObjectPool<T>::releaseObject(shared_ptr<T> obj)
{
   mFreeList.push(obj);
}
```