

ADTs & Templates

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Today's Plan

Recap

Useful C++ / OOP

ADTs

Templates

Intro to Inheritance

Maybe More useful C++ /
OOP



Announcements

- All on Gradescope? All on Blackboard?
- Contact HelpDesk
(studenthelpdesk@hunter.cuny.edu) if you need to update your email, make sure both BlackBoard and CUNYfirst
- Schedule updated on course webpage (note everything shifted including midterm) — visit regularly!!!

Announcements



Announcements

Me on the 
Discussion Board



Announcements

- Please don't be shy to get help — **UTAs in Lab** and **BB Discussion Board!!!!** - WE ARE HERE TO HELP!
- **START EARLY!!!!** Projects will become more involved, the earlier you expose potential problems the likelier we will be able to help you fix them!!!
- Apologies for disclosing email recipients

Announcements

Project1A SUBMISSION WILL BE USED AS PROOF OF ATTENDANCE!!!

Project1A is a multi-file program: 3 separate files: CourseMember.hpp (I gave it to you), CourseMember.cpp (your implementation **MUST MATCH EXACTLY** all names/prototypes in CourseMember.hpp), main.cpp (for testing purposes). You **SUBMIT ONLY CourseMember.cpp**

Separate compilation (**Programming Rules**): CourseMember.hpp (definition/function prototypes) CourseMember.cpp (implementation) main.cpp (usually testing in this course)

To test your code on the lab machines remotely, you must first **sftp** the files to eniac, then **ssh** to one of the lab machines through eniac and compile/run (read the **Programming Rules**)

Project1A: ClassMember does not have default constructor by "design choice"

Recap

OPP

Abstraction

Encapsulation

Information Hiding

Classes

Public Interface

Private Implementation

Constructors / Destructors

Interface

SomeClass.hpp
(same as **SomeClass.h**)

Include Guards:

Tells linker “include only if it has not been included already by some other module”

Implementation

```
#ifndef SOME_CLASS_H_
#define SOME_CLASS_H_

#include <someLibrary>
#include "AnotherClass.h"

class SomeClass
{
public:
    SomeClass(); //Constructor
    int methodOne();
    bool methodTwo();
    bool methodThree(int
                        someParameter);

private:
    int data_member_one_;
    bool data_member_two_;

}; //end SomeClass

#endif
```

```
#include "SomeClass.hpp"

SomeClass::SomeClass()
{
    //implementation here
}

int SomeClass::methodOne()
{
    //implementation here
}

bool SomeClass::methodTwo()
{
    //implementation here
}

bool SomeClass::methodThree(int
someParameter)
{
    //implementation here
}
```

Questions?

Overloading Functions

Same name, different parameter list (different function prototype)

```
int someFunction()  
{  
    //implementation here  
}  
// end someFunction
```

```
int someFunction(string  
some_parameter )  
{  
    //implementation here  
}  
// end someFunction
```

```
int main()  
{
```

```
    int x = someFunction();
```

```
    int y = someFunction(my_string);
```

```
    //more code here
```

```
} // end main
```

Default Arguments

```
void point(int x = 3, int y = 4);
```

```
point(1,2); // calls point(1,2)  
point(1);   // calls point(1,4)  
point();    // calls point(3,4)
```

Order Matters!

Parameters without default arguments must go first.

Default Arguments

```
void point(int x = 3, int y = 4);
```

```
point(1,2); // calls point(1,2)  
point(1);   // calls point(1,4)  
point();    // calls point(3,4)
```

Order Matters!
Parameters without default arguments must go first.

Similarly:

```
CourseMember(int id, string first = "", string last = "");
```

```
CourseMember(143); // calls CourseMember(143,"", "")
```

```
CourseMember(143, "Gina"); // calls CourseMember("143","Gina", "")
```

```
CourseMember(423, "Nina", "Moreno"); // calls CourseMember(423,"Nina","Moreno")
```

Enum

A user defined datatype that consist of integral constants

Why? Readability

Type name (like `int`)

Possible values:
like 0,1, 2, ...

```
enum season {SPRING, SUMMER, AUTUMN, WINTER};
```

```
enum ta_role {LAB_ASSISTANT, LECTURE_ASSISTANT, BOTH};
```

By default = 0, 1, 2, ...

To change default:

```
enum ta_role {LAB_ASSISTANT = 5, LECTURE_ASSISTANT = 10, BOTH = 20};
```

Abstract Data Type

Data and Abstraction

Operations on data are central to most solutions

Think abstractly about data and its management

Typically need to

Add data

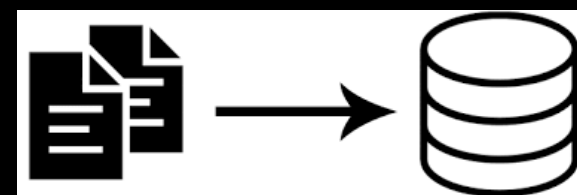
Remove data

Retrieve

Reorganize data

Ask questions about data

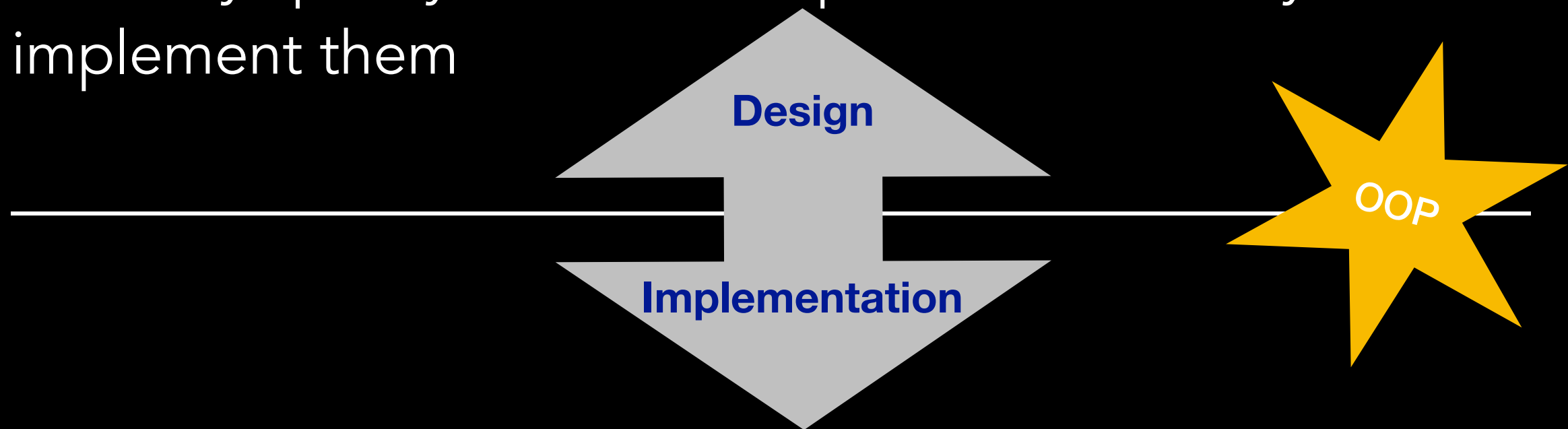
Modify data



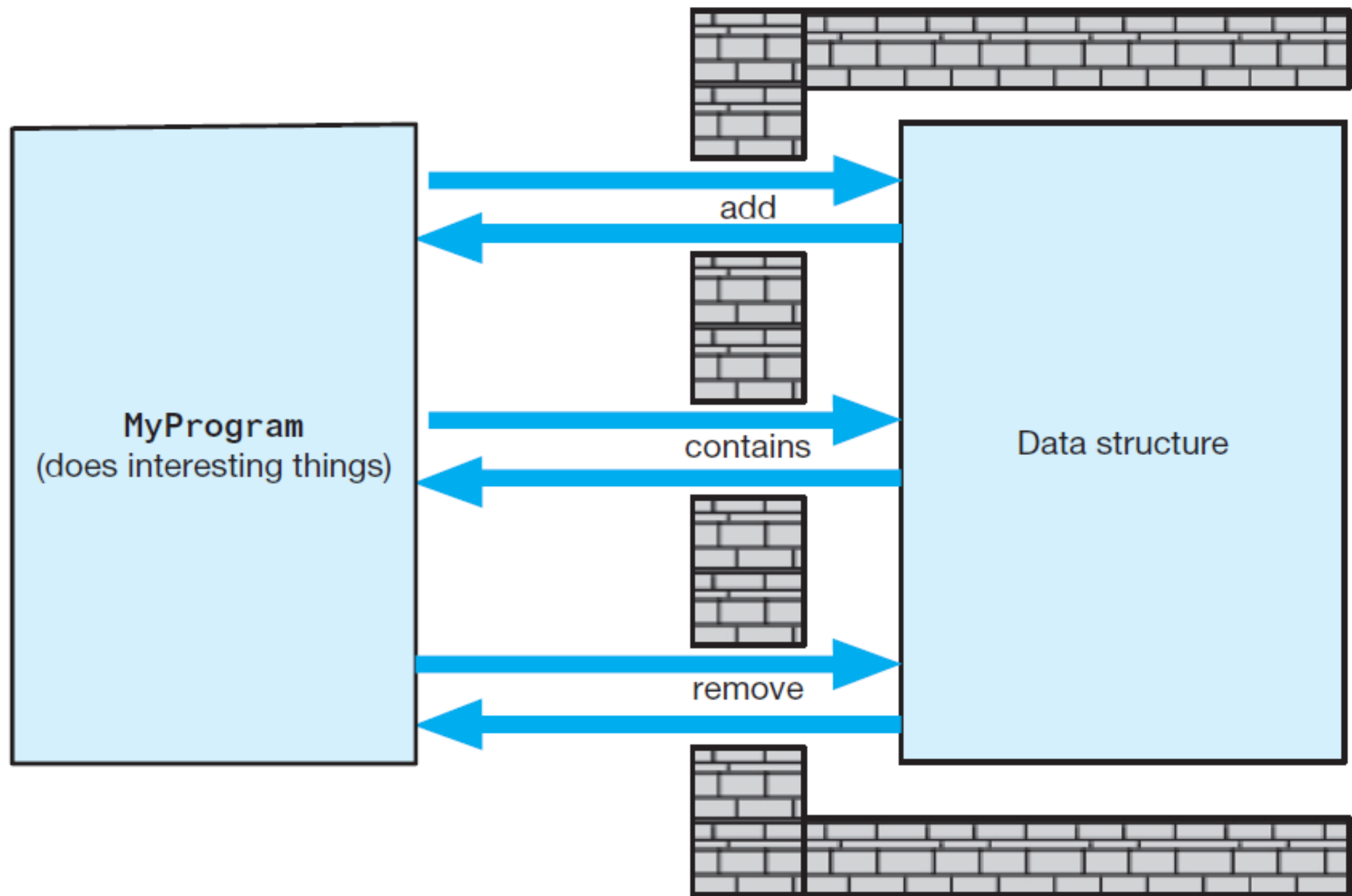
Abstract Data Type

A collection of data (container) and a set of operations on the data

Carefully specify and ADT's operations before you implement them

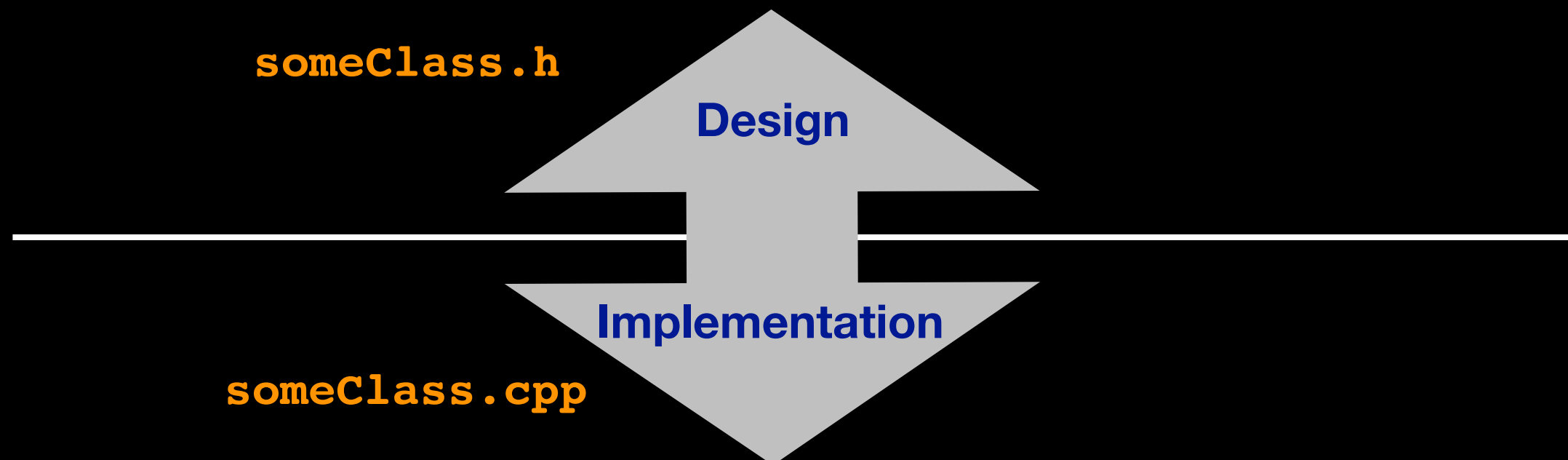


In C++ member variables and member functions implement the Data Structure



Class

```
class someClass
{
    access_specifier    // can be private, public or protected
    data_members        // variables used in class
    member_functions    // methods to access data members
}                      // end someClass
```



Designing an ADT

What data does the problem require?

- Names

- IDs

- Numerical data

What operations are necessary on that data?

- Initialize

- Display

- Calculations

- Add

- Remove

- Change

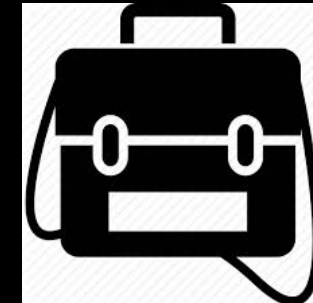
Throughout the semester we will consider several ADTs

Let's start from the simplest possible!

Design the Bag ADT



Contains things



Container or Collection of Objects

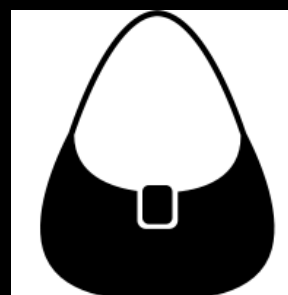
Objects are of same type



No particular order



Can contain duplicates



Lecture Activity

Design step 1 — Identify Behaviors

Bag Operations:

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.
- ...

Design step 1: Identify Behaviors

Bag Operations:

1. Get the number of items currently in the bag
2. See whether the bag is empty
3. Add an object to the bag
4. Remove an occurrence of a specific object from the bag, if possible
5. Remove all objects from the bag
6. Count the number of times a certain object is found in the bag
7. Test whether the bag contains a particular object
8. Look at all the objects that are in the bag

Specify Data and Operations

Pseudocode

//Task: reports the current number of objects in Bag

//Input: none

//Output: the number of objects currently in Bag

getCurrentSize()

//Task: checks whether Bag is empty

//Input: none

//Output: true or false according to whether Bag is empty

isEmpty()

//Task: adds a given object to the Bag

//Input: new_entry is an object

//Output: true or false according to whether addition succeeds

add(new_entry)

//Task: removes an object from the Bag

//Input: an_entry is an object

//Output: true or false according to whether removal succeeds

remove(an_entry)

Specify Data and Operations

//Task: removes all objects from the Bag

//Input: none

//Output: none

clear()

//Task: counts the number of times an object occurs in Bag

//Input: an_entry is an object

//Output: the int number of times an_entry occurs in Bag

getFrequencyOf(an_entry)

//Task: checks whether Bag contains a particular object

//Input: an_entry is an object

//Output: true or false according to whether an_entry is in Bag

contains(an_entry)

//Task: gets all objects in Bag

//Input: none

//Output: a vector containing all objects currently in Bag

toVector()

Vector

A container similar to a one-dimensional array

Different implementation and operations

STL (C++ Standard Template Library)

```
#include <vector>
```

```
...
```

```
std::vector<type> vector_name;
```

e.g.

```
std::vector<string> student_names;
```

In this course cannot use STL for projects unless specified so by instructions

What's next?

Finalize the interface for your ADT => write the actual code

... but we have a problem!!!

What's next?

Finalize the interface for your ADT => write the actual code

... but we have a problem!!!

We said Bag contains objects of same type

What type?

To specify member function prototype we need to know

```
//Task: adds a given object to the Bag  
//Input: new_entry is an object  
//Output: true or false according to whether addition succeeds  
bool add(type??? new_entry);
```

Templates

Motivation

We don't want to write a new Bag ADT for each type of object we might want to store

Want to parameterize over some arbitrary type

Useful when implementing an ADT without locking the actual type

An example are STL containers

e.g. `vector<type>`

Declaration

```
#ifndef BAG_H_
#define BAG_H_
template<class T> // this is a template definition
class Bag
{

    //class declaration here

}
#include "Bag.cpp" ← Explained next
#endif //BAG_H_
```


Declaration

```
#ifndef BAG_H_
#define BAG_H_
template<class T> // this is a template definition
class Bag
{

    //class declaration

}
#include "Bag.cpp"
#endif //BAG_H_
```

The book uses `ItemType`
I'm going to change it to `T` which is often used

`class` here could be replaced by `typename`
often interchangeable but can make a difference in some
cases, we will not go into the details here

for this course we will use `class`

Implementation

```
#include "Bag.h"
```

```
template<class T>
```

```
bool Bag<T>::add(const T& new_entry){
```

```
    //implementation here
```

```
}
```

```
    //more member function implementation here
```

Instantiation

```
#include "Bag.h"

int main()
{

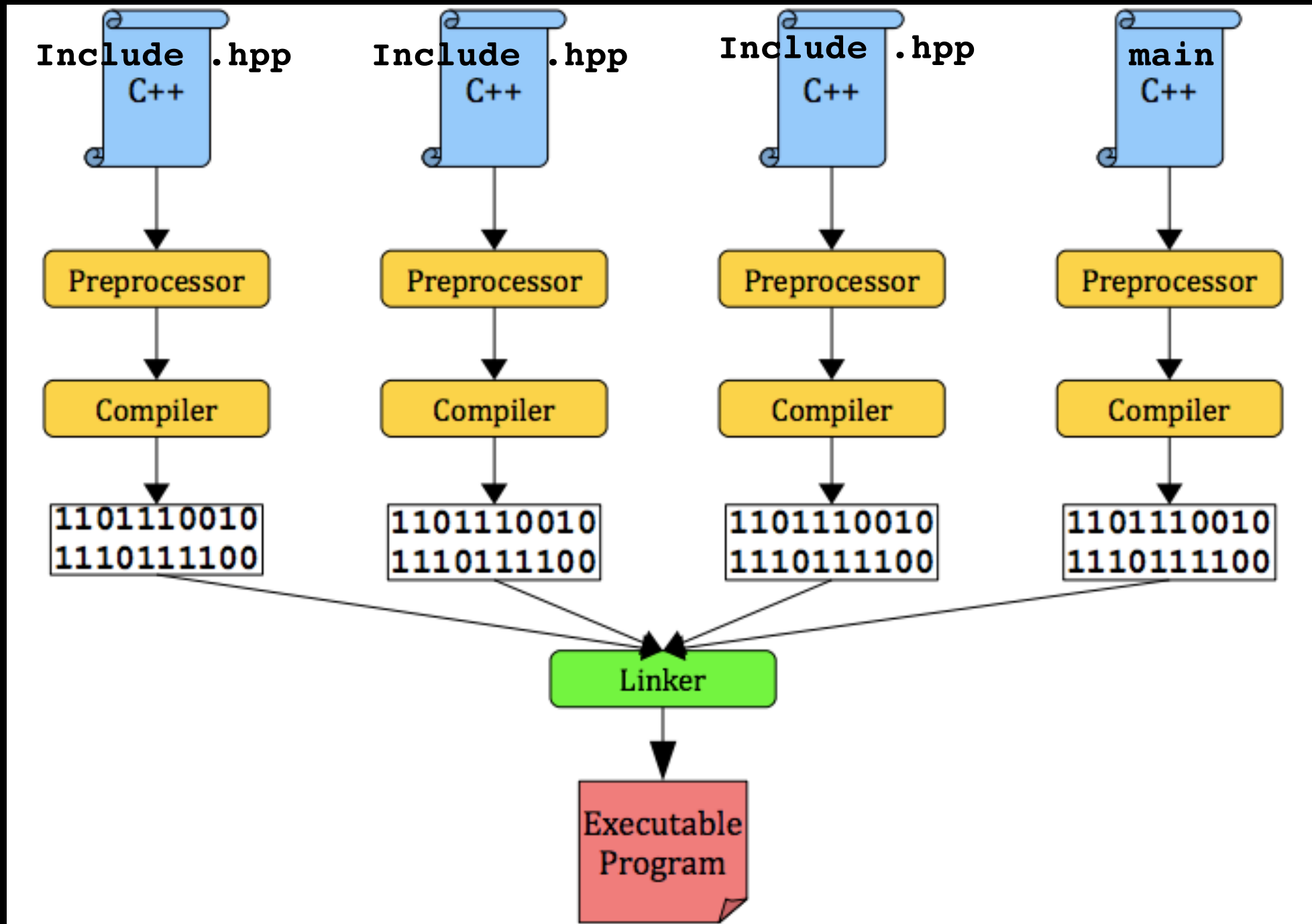
    Bag<string> string_bag;
    Bag<int> int_bag;
    Bag<someObject> some_object_bag;

    //stuff here

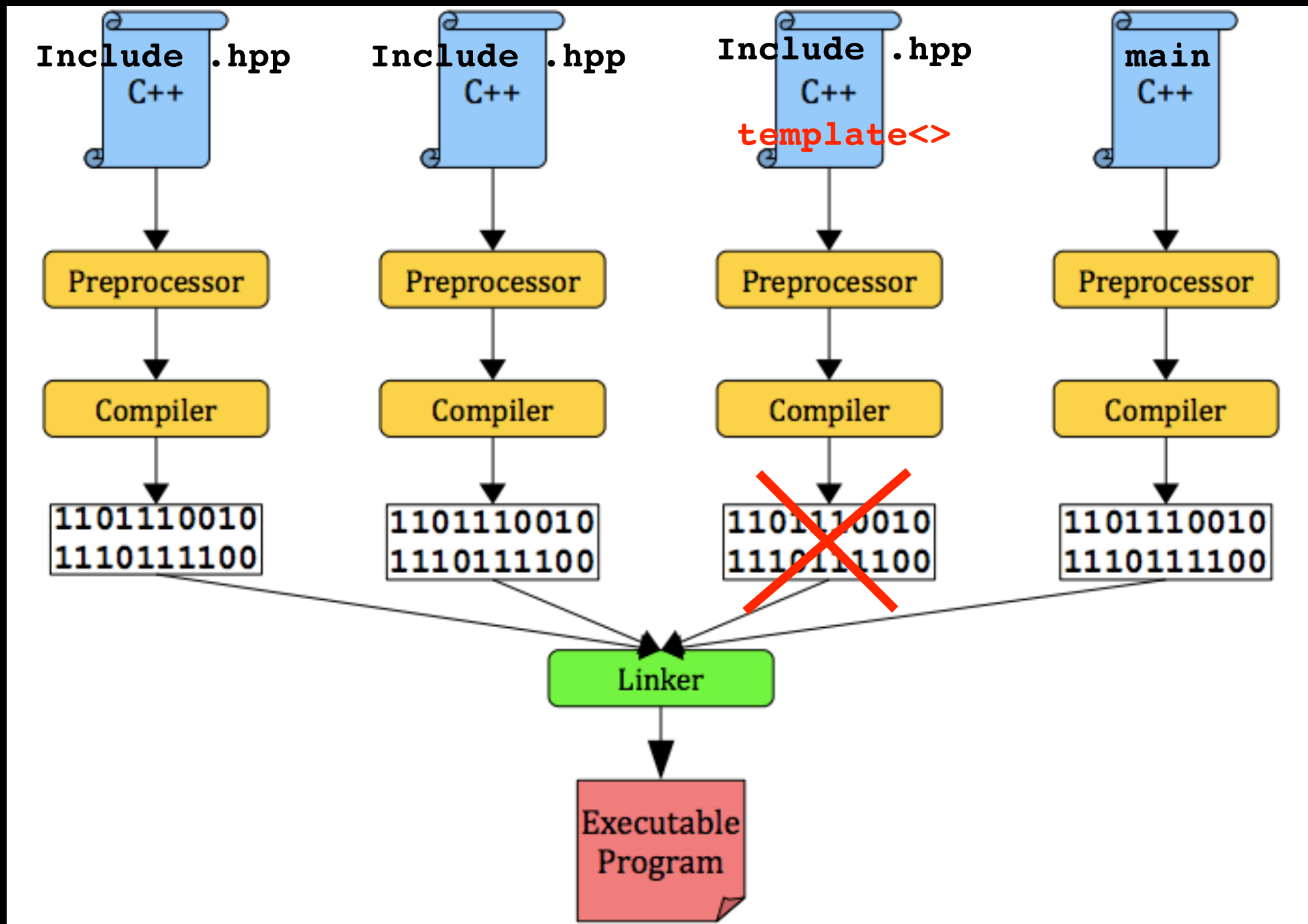
    return 0;

}; // end main
```

Separate Compilation



Linking with Templates



Linking with Templates

Always `#include` the `.cpp` file in the `.hpp` file

```
#ifndef MYTEMPLATE_H_
#define MYTEMPLATE_H_
template<class T>
class MyTemplate
{

//stuff here

} //end MyTemplate
#include "MyTemplate.cpp" ←
#endif //MYTEMPLATE_H_
```



**Make sure you understand
and don't have problems
with multi-file compilation
using templates**

Do not add `MyClass.cpp` to project in your environment and do not include it in the command to compile

```
g++ -o my_program main.cpp ←
NOT g++ -o my_program MyTemplate.cpp main.cpp
```

Lecture Activity

```
template<class T> // this is a template definition
class MyTemplate
{
    void setData(T some_data); //mutator
    T getData() const; //accessor

private:
    T my_data_; //this is the only private data member
}
```

Write a `main()` function that instantiates 3 different `MyTemplate` objects with different types (e.g. `int`, `string`, `bool`) and makes calls to their member functions and show the output. E.g:

```
MyTemplate<double> double_object;
double_object.setData(3.0);
cout << double_object.getData() << endl; // outputs 3.0
```

Try It At Home

Write a dummy `MyTemplate` interface and implementation
(`MyTemplate.hpp`, `MyTemplate.cpp`)

Test it in `main()`

Make sure you can compile a templated class

(REMEMBER YOU DON'T COMPILE IT!!!)

YOU WILL THANK ME



Inheritance

From General to Specific

What if we could *inherit* functionality from one class to another?

We can!!!

Inherit **public** members of another class

Basic Inheritance

```
class Printer
{
public:
    //Constructor, destructor

    void setPaperSize(const int size);
    void setOrientation(const string& orientation);
    void printDocument(const string& document);
private:
    // stuff here
}; //end Printer
```

Basic Inheritance

```
class Printer
{
public:
    //Constructor, destructor

    void setPaperSize(const int size);
    void setOrientation(const string& orientation);
    void printDocument(const string& document);
private:
    // stuff here
}; //end Printer
```


```
class BatchPrinter
{
public:
    //Constructor, destructor
    void addDocument(const string& document);
    void printAllDocuments();
private:
    vector<string> documents;
}; //end BatchPrinter
```

Basic Inheritance

```
class Printer
{
public:
    //Constructor, destructor

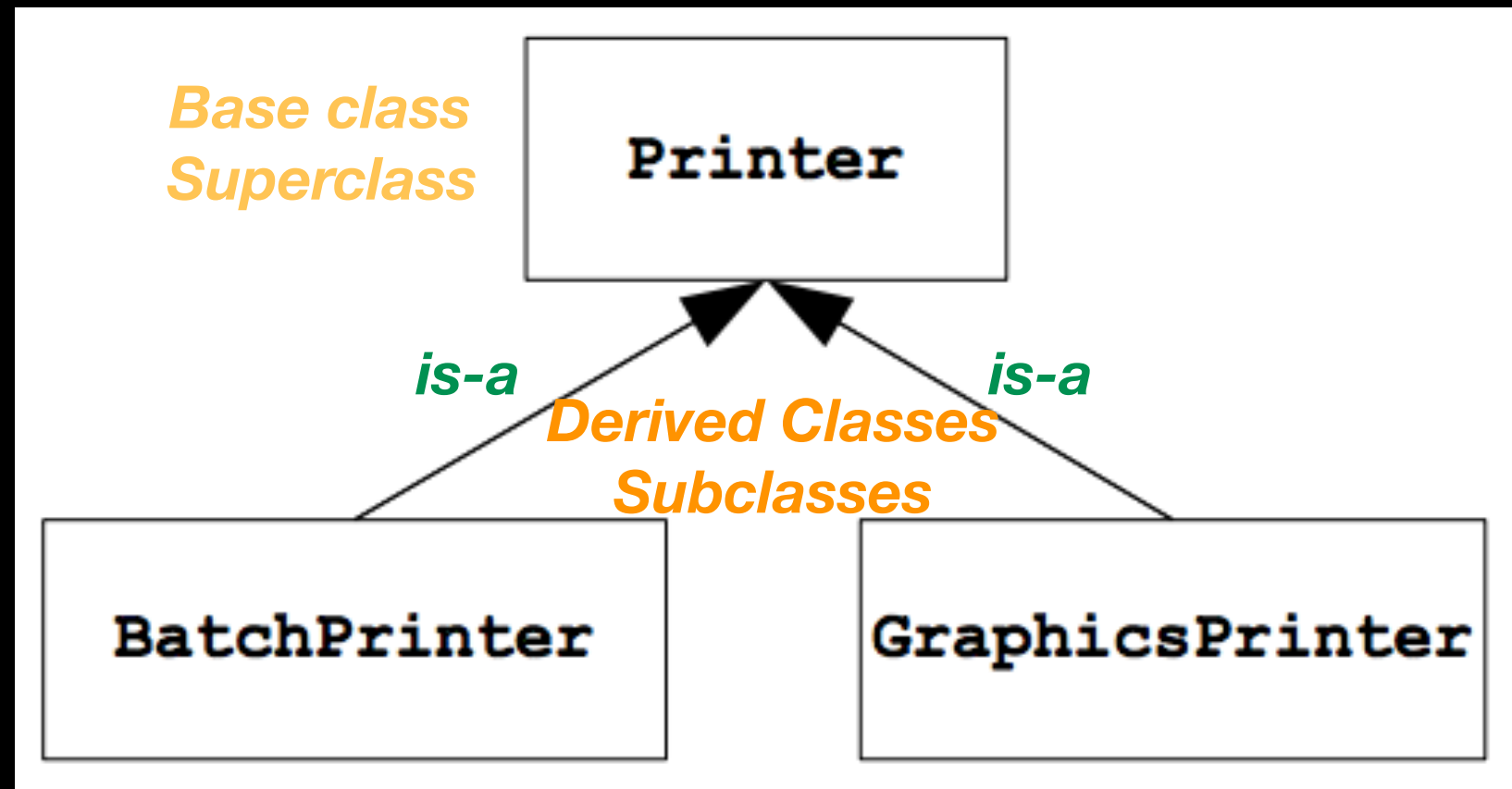
    void setPaperSize(const int size);
    void setOrientation(const string& orientation);
    void printDocument(const string& document);
private:
    // stuff here
}; //end Printer
```

**Inherited members are *public*
could be *private* or
protected – more on this later**



```
class BatchPrinter: public Printer // inherit from printer
{
public:
    //Constructor, destructor
    void addDocument(const string& document);
    void printAllDocuments();
private:
    vector<string> documents;
}; //end BatchPrinter
```

Basic Inheritance



```
void initializePrinter(Printer& p) //some initialization function
BatchPrinter batch;
initializePrinter(batch); //legal because batch is-a printer
```

Think of argument types as specifying **minimum requirements**

Overloading vs Overriding

Overloading (independent of inheritance): Define new function with same name but different parameter list (different signature or prototype)

```
int someFunction(){ }  
int someFunction(string some_string){ }
```

Overriding: Rewrite function with *same signature* in derived class

```
int BaseClass::someMethod(){ }  
int DerivedClass::someMethod(){ }
```

```
class Printer
{
public:
    //Constructor, destructor

    void setPaperSize(const int size);
    void setOrientation(const string& orientation);
    void printDocument(const string& document);
private:
    // stuff here
}; //end Printer
```

```
class GraphicsPrinter: public Printer    // inherit from printer
{
public:
    //Constructor, destructor
    void setPaperSize(const int size);
    void printDocument(const Picture& picture); //some Picture object

private:
    //stuff here
}; //end GraphicsPrinter
```

Overrides setPaperSize()

Overloads printDocument()

main()

```
Printer base_printer;  
GraphicsPrinter graphics_printer;  
Picture picture;  
// initialize picture here  
string document;  
// initialize document here
```

```
base_printer.setPaperSize(11); //calls Printer function  
graphics_printer.setPaperSize(60); // Overriding!!!  
graphics_printer.setOrientation("landscape"); //inherited
```

```
graphics_printer.printDocument(string); //calls Printer inherited function  
graphics_printer.printDocument(picture); // Overloading!!!
```

Printer

setPaperSize(int)
setOrientation(string)
printDocument(string)

GraphicsPrinter

setPaperSize(int)
printDocument(Picture)

protected access specifier

```
class SomeClass
{
    public:
        // public members available to everyone

    protected:
        // protected members available to class members
        // and derived classes

    private:
        // private members available to class members ONLY

};          // end SomeClass
```

Important Points about Inheritance

Derived class inherits all public and protected members of base class

Does not have access to base class private members

Does not inherit constructor and destructor

Does not inherit assignment operator

Does not inherit friend functions and friend classes

Constructors

A class needs user-defined constructor if must initialize data members

Base-class constructor **always** called before derived-class constructor

If base class has only parameterized constructor, derived class **must supply constructor** that calls base-class constructor explicitly

Constructors

INTERFACE

```
class BaseClass()  
{  
public:  
    //stuff here  
  
private:  
    //stuff here  
}; //end BaseClass
```

```
class DerivedClass: public BaseClass  
{  
public:  
    DerivedClass();  
    //stuff here  
  
private:  
    //stuff here  
}; //end DerivedClass
```

IMPLEMENTATION

```
DerivedClass::DerivedClass()  
{  
    //implementation here  
}
```

main()

```
DerivedClass my_derived_class;  
//BaseClass compiler-supplied default constructor called  
//then DerivedClass constructor called
```

Constructors

INTERFACE

```
class BaseClass()  
{  
public:  
    BaseClass();  
    //may also have other  
    //constructors  
private:  
    //stuff here  
}; //end BaseClass
```

```
class DerivedClass: public BaseClass  
{  
public:  
    DerivedClass();  
    //stuff here  
private:  
    //stuff here  
}; //end DerivedClass
```

IMPLEMENTATION

```
BaseClass::BaseClass()  
{  
    //implementation here  
}
```

```
DerivedClass::DerivedClass()  
{  
    //implementation here  
}
```

main()

```
DerivedClass my_derived_class;  
//BaseClass default constructor called  
//then DerivedClass constructor called
```

Constructors

INTERFACE

```
class BaseClass()  
{  
public:  
    BaseClass(int value);  
    //stuff here  
  
private:  
    int base_member_;  
}; //end BaseClass
```

```
class DerivedClass: public BaseClass  
{  
public:  
    DerivedClass();  
    //stuff here  
  
private:  
    //stuff here  
}; //end DerivedClass
```

IMPLEMENTATION

```
BaseClass::  
BaseClass(int value):  
base_member_(value)  
{  
    //implementation here  
}  
main()
```

```
DerivedClass::DerivedClass()  
{  
    //implementation here  
}
```

DerivedClass my_derived_class; 
//PROBLEM!!! there is no default constructor to be called
//for BaseClass

Constructors

INTERFACE

```
class BaseClass()  
{  
public:  
    BaseClass(int value);  
    //stuff here  
  
private:  
    int base_member_;  
}; //end BaseClass
```

```
class DerivedClass: public BaseClass  
{  
public:  
    DerivedClass();  
    //stuff here  
  
private:  
    static const int INITIAL_VAL = 0;  
}; //end DerivedClass
```

IMPLEMENTATION

```
BaseClass::  
BaseClass(int value):  
base_member_(value)  
{  
    //implementation here  
}
```

```
DerivedClass::DerivedClass():  
BaseClass(INITIAL_VAL)  
{  
    //implementation here  
}
```

Fix



```
main()
```

```
DerivedClass my_derived_class;  
// BaseClass constructor explicitly called by DerivedClass  
//constructor
```


Destructors

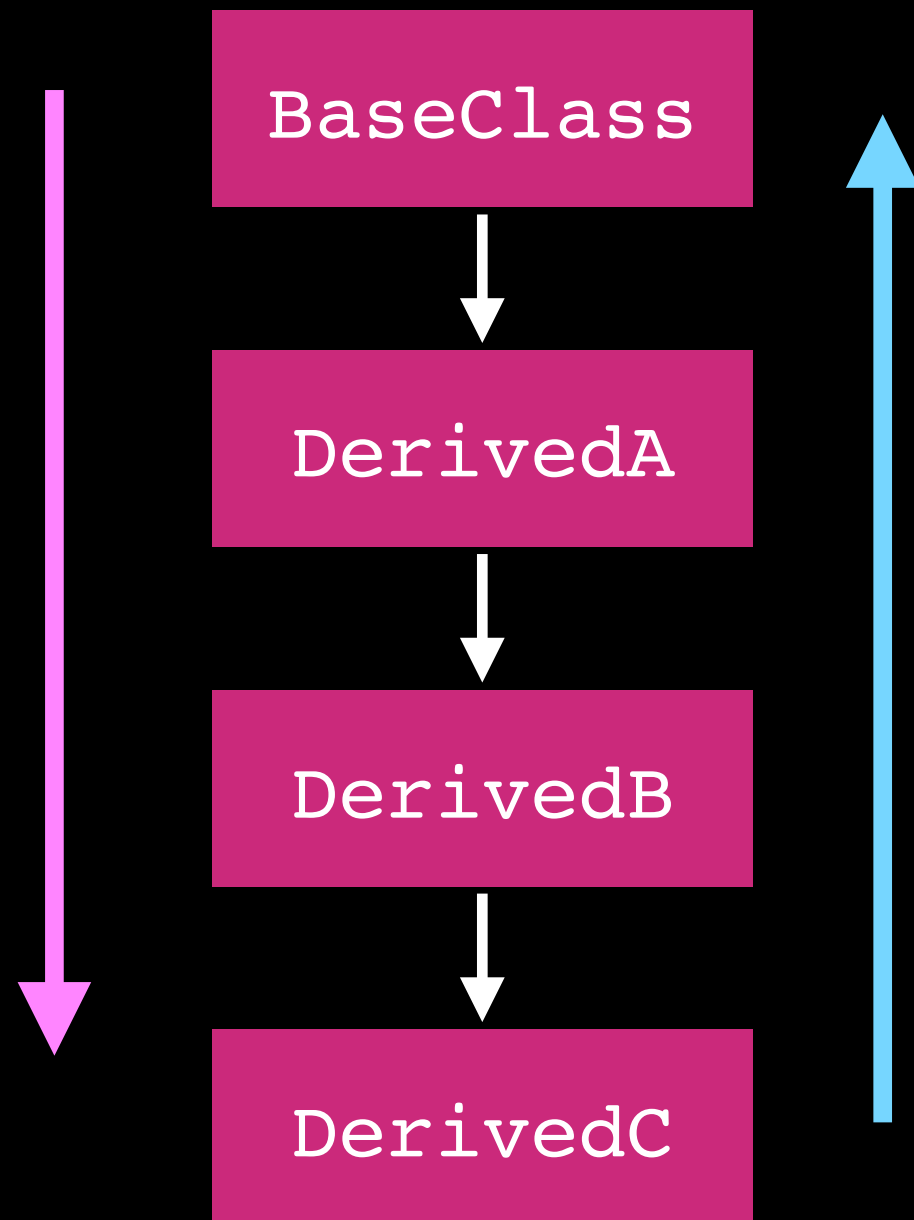
Destructor invoked if:

- program execution left scope containing object definition
- `delete` operator was called on object that was created dynamically

Destructors

Derived class destructor **always** causes base class destructor to be called implicitly

Derived class destructor is called **before** base class destructor



Order of calls to **constructors**
when instantiating a **DerivedC** object:

```
BaseClass()  
DerivedA()  
DerivedB()  
DerivedC()
```

Order of calls to **destructors**
when instantiating a **DerivedC** object:

```
~DerivedC()  
~DerivedB()  
~DerivedA()  
~BaseClass()
```

Basic Inheritance

No runtime cost

In memory `DerivedClass` is simply `BaseClass` with extra members tacked on the end

Basically saving to re-write `BaseClass` code

Address	1000	baseX	<- BaseClass members
	1004	baseY	
	1008	derX	<- DerivedClass -specific members
	1012	derY	

Abstract Class

A class that **does not implement** one or more of its members

Cannot be instantiated

Marked by:

virtual method prototype =0;

Inheritance as Interface

Client interface: use templates and abstract classes to completely specify ADT (BagInterface.h)

Includes only public members of Bag

It is only an interface (no implementation)

Enforce information hiding

Client only needs interface to use ADT

Client cannot see private declaration

```
template<class ItemType>
class BagInterface
{
public:
```

Means: “this method will not modify the object”

```
/** Gets the current number of entries in this bag.
@return The integer number of entries currently in the bag. */
virtual int getCurrentSize() const = 0;
```

```
/** Checks whether this bag is empty.
@return True if the bag is empty, or false if not. */
virtual bool isEmpty() const = 0;
```

For now think of this as saying:
“I’m only declaring this but will not implement it.”
It will force derived class to implement it.

```
/** Adds a new entry to this bag.
@post If successful, new_entry is stored in the bag
and the count of items in the bag has increased by 1.
@param new_entry The object to be added as a new entry.
@return True if addition was successful, or false if not. */
virtual bool add(const ItemType& new_entry) = 0;
```

```
/** Removes one occurrence of a given entry from this bag, if possible.
@post If successful, an_entry has been removed from the bag
and the count of items in the bag has decreased by 1.
@param an_entry The entry to be removed.
@return True if removal was successful, or false if not. */
virtual bool remove(const ItemType& an_entry) = 0;
```

Means: “this method will not modify the parameter”

```

/** Removes all entries from this bag.
@post  Bag contains no items, and the count of items is 0. */
virtual void clear() = 0;

/** Counts the number of times a given entry appears in bag.
@param an_entry  The entry to be counted.
@return  The number of times an_entry appears in the bag. */
virtual int getFrequencyOf(const ItemType& an_entry) const = 0;

/** Tests whether this bag contains a given entry.
@param an_entry  The entry to locate.
@return  True if bag contains an_entry, or false otherwise. */
virtual bool contains(const ItemType& an_entry) const = 0;

/** Fills a vector with all entries that are in this bag.
@return  A vector containing all the entries in the bag. */
virtual std::vector<ItemType> toVector() const = 0;

}; // end BagInterface

```


Recap

We designed a Bag ADT by defining the operations on the data

We templated it so we can store any data type

We used abstract class to fully specify a public interface without locking any implementation detail

NEXT: Implementation

Friend Functions

Functions that are **not members** of the class but **CAN access private members** of the class

Friend Functions

Functions that are **not members** of the class but **CAN access private members** of the class

Violates Information Hiding!!!

Yes, so don't do it unless appropriate and controlled



Friend Functions


DECLARATION:

```
class SomeClass
{
    public:
        // public member functions go here
        friend returnType someFriendFunction( parameter list);
    private:
        int some_data_member_;

}; // end SomeClass
```

IMPLEMENTATION (SomeClass.cpp):

Not a member function



```
returnType someFriendFunction( parameter list)
{
    // implementation here
    some_data_member_ = 35; //has access to private data
}
```

Operator Overloading

Desirable operator (=, +, -, == ...) behavior may not be well defined on objects


```
class SomeClass
{
    public:
        // public data members and member functions go here
        friend bool operator==(const SomeClass& object1,
                               const SomeClass& object2);

    private:
        // private members go here
}; // end SomeClass
```

Operator Overloading

IMPLEMENTATION (SomeClass.cpp):

Not a member function



```
bool operator==(const SomeClass& object1,  
                const SomeClass& object2)  
{  
    return ( (object1.memberA_ == object2.memberA_) &&  
            (object2.memberB_ == object2.memberB_) && ... );  
}
```