Software Engineering Concepts: Invariants
Silently Written & Called Functions continued
Simple Class Example

CS 311 Data Structures and Algorithms

Lecture Slides

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Unit Overview
Advanced C++ & Software Engineering Concepts

Major Topics: Advanced C++

- ✓ The structure of a package
- ✓ Parameter passing
- ✓ Operator overloading
- (part) Silently written & called functions
- Pointers & dynamic allocation
- Managing resources in a class
- Templates
- Containers & iterators
- Error handling
- Introduction to exceptions
- Introduction to Linked Lists

Major Topics: S.E. Concepts

- ✓ Abstraction
- Invariants
- Testing
- Some principles

Review
The Structure of a Package

A **client** of a module is *code* that uses it.

Type conversion: take value and return value of another type.

- **Implicit**: `double d = 4.5 + 3;`
- **Explicit**: `double d = 4.5 + double(3);`
- No conversion: `double d = 4.5 + 3.0;`

`3` has type **`int`**.

To add **`3`** to **`4.5`** (which has type **`double`**), we must use a type conversion to get a **`double`**.

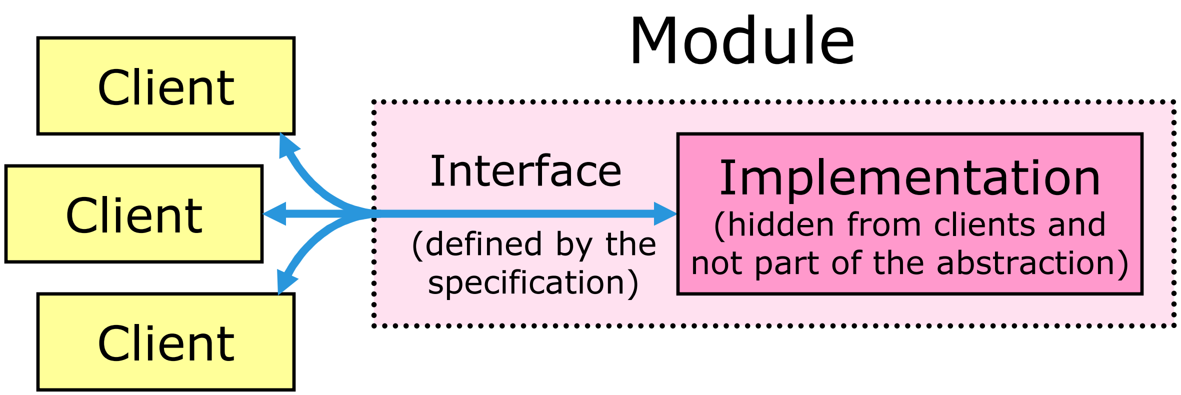
`3.0`, on the other hand, has type **`double`**.

Review
Software Engineering Concepts: Abstraction [1/2]

Abstraction: Separate the purpose of a module from its implementation.

Recall: Function, class, or other unit of code. Generally smaller than a *package*.

- **Functional abstraction**
- **Data abstraction**



Key term: **Abstract Data Type**

- An *abstract data type* (ADT) is a collection of data and a set of operations on the data.
- The implementation is not specified.
- ADTs will be a major topic of this course.

Review
Software Engineering Concepts: Abstraction [2/2]

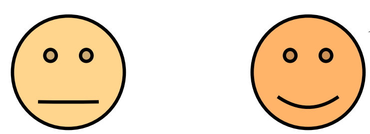
```
void printIntArray(const int arr[], std::size_t size)
{
    for (std::size_t i = 0; i < size; ++i)
        std::cout << arr[i] << " ";
    std::cout << std::endl;
}
```

(Functional) abstraction

Describe this function, in detail.

Function **printIntArray** is given an array of **int**s called "**arr**" and a **size_t** called "**size**". It executes a **for** loop in which local **size_t** variable **i** is initialized to **0**, the loop continues as long as "**i < size**" evaluates to **true**, and **i** is pre-incremented after each loop iteration. Inside the loop, a reference to an item in array **arr** is retrieved using the bracket operator, with parameter **i**, and then inserted in **cout** (using overloaded **operator<<**), followed by an array of **char**s containing a blank and a null. After the loop, stream manipulator **endl** is inserted in **cout**. The function then terminates.

Function **printIntArray** prints an array of **int**s to **cout**, given the array and its size. Items are separated by blanks, and followed by a blank and a newline.



Review
Parameter Passing [1/2]

	By value	By reference	By reference-to-const
Makes a copy	YES ☹*	NO ☺	NO ☺
Allows for polymorphism	NO ☹*	YES ☺	YES ☺
Allows passing of const values	YES ☺	NO ☹**	YES ☺
Allows implicit type conversions	YES ☺	NO ☹	YES ☺

*These are problems when we pass **objects**.

***Maybe* this is bad. When we want to send changes back to the client (which is a big reason for passing by reference), disallowing const values is a good thing.

So, for most purposes, *when we pass objects*, reference-to-const combines the best features of the other two methods.

Review
Parameter Passing [2/2]

We **pass parameters** by reference when we want to modify the client's copy.

```
void addThree(int & theInt)
{ theInt += 3; }
```

Otherwise, we generally pass:

- simple types by value.
- objects by reference-to-const.

```
void func(double d, const MyClass & q);
```

We usually **return** by value, unless we return an object not local to this function.

- Return by reference if we return a pre-existing object for the client to modify.
- Return by reference-to-const if we return a pre-existing object that the client should not modify (in particular, if the object is const).

```
int & arrayLookUp(int theArray[], int index);
const int & arrayLookUp(const int theArray[], int index);
```

Review
Operator Overloading

Operators can be implemented using global or member functions.

- Global: the parameters are the operands.
- Member: first operand is **`*this`**, the rest are parameters.
- Postfix increment & decrement (**`n++`**, **`n--`**) get a dummy **`int`** parameter, to distinguish them from the prefix versions (**`++n`**, **`--n`**).

Implement an operator using a member function, unless you have a good reason not to.

- Good Reason #1: To allow for implicit type conversions on the first argument. Applies to: non-modifying arithmetic, comparison, and bitwise operators.
  - For example: **`+ - * / % == != < <= > >=`**
- Good Reason #2: When you cannot make it a member, because it would have to be a member of a class you cannot modify.
  - Quintessential examples: stream insertion (**`<<`**) and extraction (**`>>`**).

We usually use operators only for operations that happen **quickly**.

- One exception: Assignment for container types.

Software Engineering Concepts: Invariants Basics [1/2]

An **invariant** is a condition that is always true at a particular point in an algorithm.

Example

- Suppose that **`myArray`** is an array of **`int`**'s with size **`myArraySize`**.
- We wish to set the variable **`myItem`** equal to **`myArray[i]`**, if possible.

```
if (i < 0)
{
    errorMessage("Error: i is too small");
    return;
}
// Invariant: i >= 0
if (i >= myArraySize)
{
    errorMessage("Error: i is too large");
    return;
}
// Invariant: (i >= 0) && (i < myArraySize)
myItem = myArray[i];
```

Software Engineering Concepts: Invariants Basics [2/2]

We use invariants:

- To ensure that we are allowed to perform various operations.
- To remind ourselves of the information that is implicitly known in a program.
- To document ways in which code can be used.
- To help us verify that our programs are correct.

Software Engineering Concepts: Invariants Pre & Post [1/3]

We are particularly interested in two special kinds of invariants: **preconditions** and **postconditions**.

A *precondition* is an invariant at the beginning of a function.

- The responsibility for making sure the precondition is true rests with the calling code.
- In practice, a precondition states **what must be true for the function to execute properly**.

A *postcondition* is an invariant at the end of a function.

- It tells what services the function has performed for the client code.
- The responsibility for making sure the postcondition is true rests with the function itself.
- In practice, postconditions **describe the function's effect using statements about objects & values**.

Software Engineering Concepts: Invariants Pre & Post [2/3]

Preconditions and postconditions are the basis of **operation contracts**.

- We think of a function call as the carrying out of a contract. The function says to the caller, "If you do this [preconditions], then I will do this [postconditions]."
- If the preconditions are met, then the function is required to make the postconditions true upon its (normal) termination.
  - We consider abnormal termination (exceptions) later.
- If the preconditions are not met, then the function can be considered to have no responsibilities.

Punch Line

- In this class, we write preconditions and postconditions for **every** function you write (except, possibly, **`main`**).
  - See the "Coding Standards".

Software Engineering Concepts: Invariants
Pre & Post [3/3]

Example

- Write reasonable pre- and postconditions for the following function, which is supposed to store the number 7 in the provided memory.

```
// store7
// Pre: ptr points to a block of memory large
//      enough to hold an int.
// Post: *ptr == 7.
void store7(int * ptr)
{
   *ptr = 7;
}
```

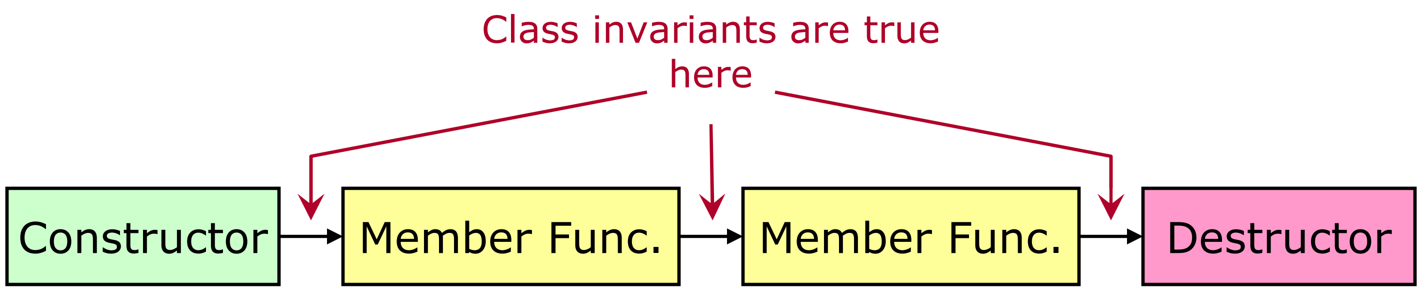
Preconditions:
What **must be true** for the function to execute properly?

Postconditions:
Describe the function’s effect using statements about objects & values.

Software Engineering Concepts: Invariants
Class Invariants [1/4]

Another important kind of invariant is a **class invariant**.

- A *class invariant* is an invariant that holds whenever an object of the class exists, and execution is not in the middle of a public member function call.



- Class invariants are preconditions of every public member function, except constructors.
- Class invariants are postconditions for every public member function, except the destructor.
- Since we know this, you do not need to list class invariants in the pre- and postcondition lists of public member functions.
- In practice, class invariants are **statements about data members** that indicate what it means for an object to be **valid** or **usable**.

Software Engineering Concepts: Invariants
Class Invariants [2/4]

Write reasonable class invariants for the following class.

Class invariants:
statements about data members that indicate what it means for an object to be **valid** or **usable**.

```
// class Date
// Invariants:
//     1 <= mo_ <= 12
//     1 <= day_ <= k, where k is no. of days in month mo_
class Date {
// Date: public functions
public:
    [Lots of code goes here]
// Date: data members
private:
    int mo_;    // Month 1..12
    int day_;   // Day 1..#days in month given by mo_
};  // End class Date
```

Software Engineering Concepts: Invariants
Class Invariants [3/4]

Think about dynamic allocation. In “C”, we do:

```
Foo * p = (Foo *)malloc(100 * sizeof(Foo));
```

In C++, we prefer:

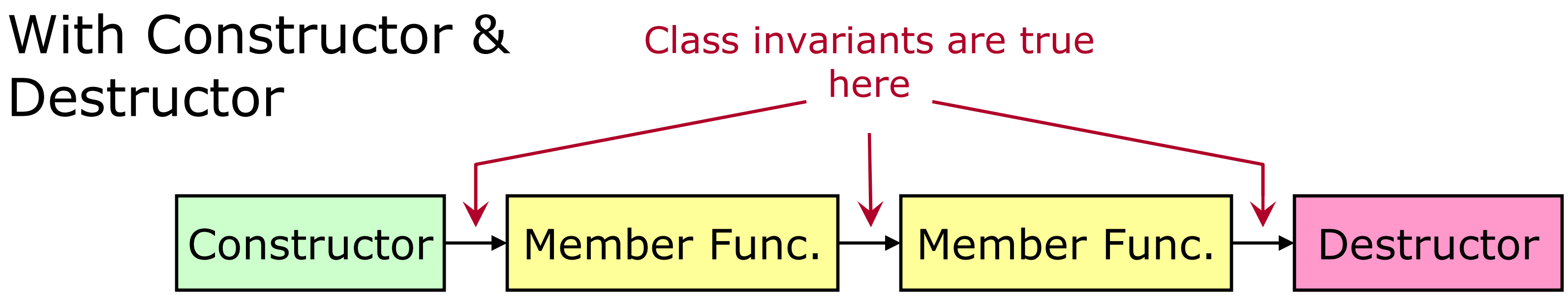
```
Foo * p = new Foo[100];
```

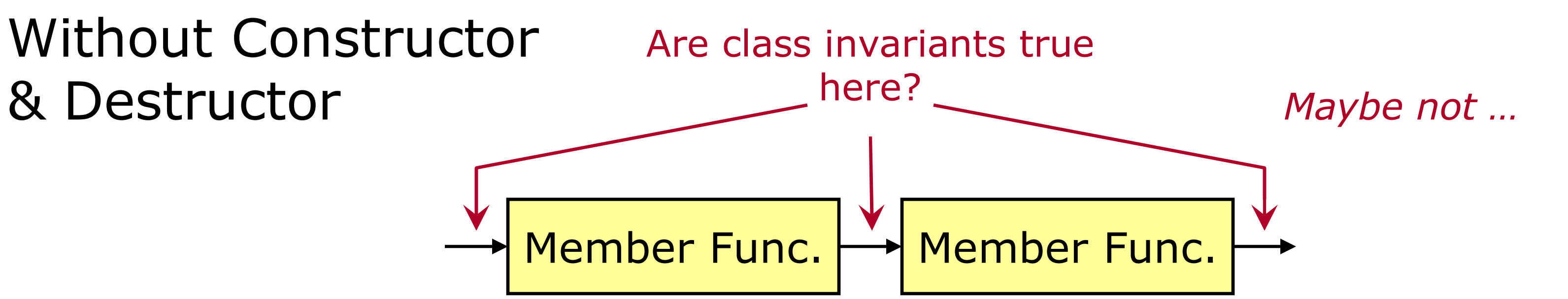
Why?

- Yes, it’s simpler and cleaner. What other reasons are there?
- Hint: The two lines of code above do not do the same thing.
- Another hint: We’re discussing invariants.
- *See the next slide.*

Software Engineering Concepts: Invariants
Class Invariants [4/4]

In C++, using "**new**" calls a constructor, thus ensuring that class invariants are true.





The job of a constructor is to make the class invariants true.

Review
Silently Written & Called Functions [1/2]

C++ will **silently write** four important member functions:

- Default ctor.
- Copy ctor.
- Copy assignment.
- Dctor.

"The Big Three"

When

- The default ctor is silently written when you declare no ctors.
- The other three are silently written when you do not declare them.

The silently written versions:

- Are **public**.
- Call the **corresponding functions** for all data members.

Review
Silently Written & Called Functions [2/2]

Some of these can be **silently called** as well.

- The default ctor is called when you declare a variable with no ctor parameters, and when you declare an array (or, generally, any container holding already initialized objects).
- The copy ctor is called when you pass by value and *maybe* when you return by value.
- The dctor is called:
  - On an automatic (local, non-static) object when it goes out of scope.
  - On a static object when the program ends.
  - On a non-static member object when the object it is a member of is destroyed.
  - On a dynamic object when you delete a pointer to it.

Silently Written & Called Functions continued
Commenting Them

Silently written functions are **good**.

- Do not waste effort. If the compiler will write a perfectly good function for you, then do not write it yourself.

So, use them often. And when you do, indicate this in a comment.

- This is a reminder that these functions exist and are part of the class design.

```
class Aardvark {
public:
    // Default ctor
    // Pre: None.
    // Post: None.
    Aardvark();

    // Compiler-generated copy ctor, copy assn, dctor are used.
```

Silently Written & Called Functions
When to Write Them?

When should you write these functions yourself?

- When you need them, but they are not written for you.
- When the silently written ones do not do what you want.

```
class Llama {
   …
private:
    int * p;
```

Should the copy ctor just copy **p** (**shallow** copy) or should it also copy the memory that **p** points to (**deep** copy)?

- The answer depends on what **p** is for.
- The silently written copy ctor does a shallow copy.

The Law of the Big Three

- **If you need to declare one of the Big Three** (copy ctor, copy assignment, dctor), **then you probably need to declare all of them.**
- This tends to happen when the class manages a resource (for example, dynamically allocated memory, an open file, etc.). More on this soon.

Silently Written & Called Functions
Eliminating Them [1/2]

We have covered:

- What the compiler writes for you.
- How & when to replace these with your own versions.

But sometimes we want to **eliminate** these functions.

Why would we want this?

- Most common reason: making objects uncopyable.
- This allows us to put strong controls on the creation and destruction of such objects.
- It also disallows passing by value.

So, how do we eliminate the copy ctor and copy assignment?

- If we do not ~~write~~ them, then the compiler will, right?
- If we do ~~write~~ them, then they exist, right?

  define declare

- Thus: declare them, but do not define them.
- But what if someone else defines them …

Silently Written & Called Functions
Eliminating Them [2/2]

How do we eliminate the copy ctor and copy assignment?

- **Declare** the copy ctor and copy assignment **`private`**.
- Do not **define** them.

```
class Mule {
private:
    // Uncopyable class.
    // Private copy ctor, copy assn. Do not define these.
    Mule(const Mule &);
    Mule & operator=(const Mule &);
```

Now **no one** can call these functions.

- You (the class author) cannot accidentally call them, because you did not define them.
- Client code *can* define them, but that does not matter; they cannot call them, because they are private.

Simple Class Example
Write It!

TO DO

- Write a simple class that stores and handles a **time of day**, in seconds.
  - Call it "**`TimeSec`**".
  - Give it reasonable ctors, etc.
    - Can we use silently written functions?
      - *Yes, for the Big Three.*
      - *We will write our own default ctor.*
  - Give it reasonable operators.
    - Like what?
      - *Pre & post* **`++`**, **`--`**.
      - *Equality & inequality:* **`==`**, **`!=`**.
      - *Stream insertion:* **`<<`**.
      - *Note: It would be reasonable to add more. We will not, but only due to time constraints.*

Partially done. See **`timesec.h`**, **`timesec.cpp`**, *on the web page.*

Simple Class Example
TO BE CONTINUED …

Simple Class Example will be continued next time.