Software Engineering Concepts: Abstraction
Parameter Passing
Operator Overloading
Silently Written & Called Functions

CS 311 Data Structures and Algorithms
Lecture Slides
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Unit Overview
Advanced C++ & Software Engineering Concepts

Major Topics: Advanced C++

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- The structure of a package
- Parameter passing
- Operator overloading
- 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.

Functions & classes have:

- **Declarations** (possibly many)
- A **definition** (just one)

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`.

Conventions for C++ packages:

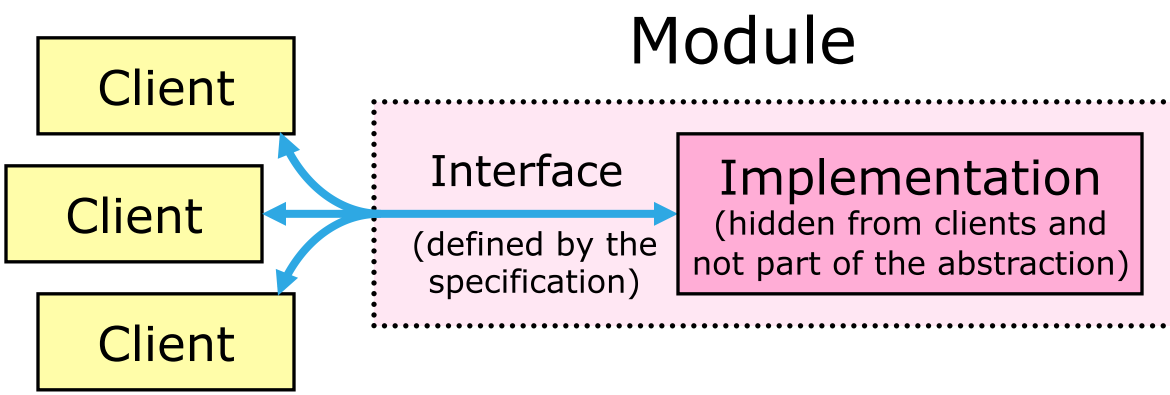
- **Header** File (`.h`)
  - Intended to be included by other files.
  - Has `#ifndef` to avoid multiple inclusion.
  - Contains class definition(s).
- **Source** File (`.cpp` or other suffix)
  - Intended to be separately compiled.
  - Includes header.
  - Contains most member function definitions.

Software Engineering Concepts: Abstraction
What Is It?

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

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

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



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.

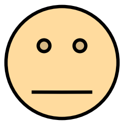
Software Engineering Concepts: Abstraction Example

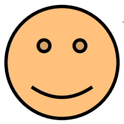
```cpp
void printIntArray(const int arr[], std::size_t size)
{
    for (std::size_t i = 0; i < size; ++i)
        std::cout << arr[i] << " ";
    std::cout << std::endl;
}
```

(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.

Parameter Passing
Three Ways — Introduction

C++ provides three ways to pass a parameter or return value:

- **By value**.

```
void byv1(Foo x);   // Pass x by value
Foo byv2();         // Return by value
```

- **By reference**.

```
void byr1(Foo & x);   // Pass x by reference
Foo & byr2();         // Return by reference
```

- **By reference-to-const**.
  - Often called “const reference”.

```
void byrc1(const Foo & x);   // Pass x by reference-to-const
const Foo & byrc2();         // Return by reference-to-const
```

We now look at each of these in detail.

Parameter Passing
Three Ways — By Value

```
void byv1(Foo x);
Foo byv2();
```

Passing by value means that a **copy** is made.

- Below, **`x`** (in **`byv1`**) is a copy of **`y`**. Modifying **`x`** does nothing to **`y`**.

```
Foo y;
byv1(y);
```

- This copy is created using a hidden (implicit) function call to **`Foo`**'s **copy constructor**.
  - This may be slow, if **`y`** is a large object.
  - And if **`Foo`** has no copy constructor, it is impossible.

Passing by value does **not** allow for proper calling of virtual functions.

What changes if we declare **`x`** to be **`const`**?

- Then **`x`** cannot be modified. But this is irrelevant to the caller.

Parameter Passing
Three Ways — By Reference

```
void byr1(Foo & x);
Foo & byr2();
```

When passing by reference, no copy is made.

- Instead, the original and the passed version are the **same object**. (This is sometimes called an **alias**.)
- Below, `x` (in `byr1`) is the same object as y (outside `byr1`). Modifying `x` will modify `y`.

```
Foo y;
byr1(y);
```

Passing by reference allows for proper calling of virtual functions.
Only non-const values can be passed by reference.
Be careful when returning by reference.

- Do not return a value that will be destroyed when the function returns.
- In particular, never return a (non-static) local variable by reference.

```
int & squareThis(int n)
{ int square = n * n; return square; }
```

BAD! ☹

Parameter Passing
Three Ways — By Reference-to-Const

```
void byrc1(const Foo & x);
const Foo & byrc2();
```

When passing by reference-to-const, no copy is made.

- Instead, the original and the passed version are the same object …
- … **unless** they are of different types; implicit type conversions *may* be applied.

```
void h(const double & x);
const double dd;
const int ii;
h(dd);  // x is dd
h(ii);  // Legal, but x is not ii
```

Passing by reference-to-const allows for proper calling of virtual functions.

When passing this way, the passed version cannot be modified.

- Thus, const variables may be passed.

As before, be careful when returning by reference-to-const.

Parameter Passing
Three Ways — Summary

	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.

Parameter Passing
Rules of Thumb

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 (such as built in types and iterators) and small objects 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);
```

Operator Overloading
Global & Member [1/2]

C++ allows **overloading** of most of the standard operators.

- Define standard operators for new types.
- No new operators, no changes in **precedence**, **associativity**, or number of **operands**.
- An operator's name, as a function, is "**`operator`**" plus its symbol, e.g., "**`operator-`**".

Subtraction for a class **`MyNum`** (new numerical type) as a **global** function:

```
MyNum operator-(const MyNum & a, const MyNum & b);
```

It could also be a **member** function; the first operand is the object (**`*this`**):

```
class MyNum {
public:
    MyNum operator-(const MyNum & b) const; // first operand is *this
};

MyNum MyNum::operator-(const MyNum & b) const
{  // Continue as usual
```

Which is better?

Operator Overloading
Global & Member [2/2]

Suppose there is an implicit conversion from **`double`** to **`MyNum`**.

- If we write **`MyNum – MyNum`** as a global, then we get, for free,
  - **`MyNum - double`**
  - **`double – MyNum`**
- But if it is a member, then we only get the first one above.

General Rule: Implement an overloaded 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 operand, in a non-modifying arithmetic, comparison, or bitwise operator.
- Thus, the following should generally be implemented using global functions:
  - Arithmetic: **`+ - * / %`**
  - Comparison: **`== != < <= > >=`**
  - Bitwise: **`& | ^ ~`**

But not **`+=`**, **`*=`**, etc.
Make these members!

Operator Overloading
Distinguishing

Operators with the same symbol are distinguished by their parameters.

```
MyNum operator-(const MyNum & a, const MyNum & b); // a-b
MyNum operator-(const MyNum & a);                  // -a
```

Some cannot be distinguished by the parameters we would *expect*.

- In particular, "**++a**" and "**a++**". The latter gets a dummy **int** parameter.

```
class MyNum {
public:
    MyNum & operator++();   // ++a
    MyNum operator++(int);  // a++
```

Note the different **return** methods.

- Why are they different?

Operator Overloading
Stream Operators [1/2]

To input or print our objects we use C++ standard-library streams.

- We will look at stream **insertion** (`operator<<`).
- Stream **extraction** (`operator>>`) is similar.

The stream insertion operator:

- Takes an output stream (`std::ostream`) and some object.
- Returns the output stream.

This all makes the following work:

```
cout << a << b;
```

which is the same as

```
(cout << a) << b;
```

Returns `cout`, which can then be reused with `b`.

Operator Overloading
Stream Operators [2/2]

Stream insertion:

- **Must** be global.
  - Otherwise, member of **`std::ostream`**, which we cannot write.
  - This is “Good Reason #2”.
- Gets its stream by (non-const!) reference.
  - Because it modifies the stream (by outputting to it).
- Gets its object to be printed by reference-to-const.

```
std::ostream & operator<<(std::ostream & theStream,
                          const MyClass & theObject)
{
    theStream << theObject.x << ", " << theObject.y;
        // An example;
        //  in practice, do whatever is appropriate.
    return theStream;
}
```

Operator Overloading
Final Comments

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.
- More on this when we discuss efficiency.

Silently Written & Called Functions
Introduction [1/2]

Here is a simple class **Dog**:

```
// class Dog
// What member functions does this have?
// Invariants: None.
class Dog {

// ***** Dog: Data members *****
private:
    int a;
    double b;
    Cat c;
};  // End class Dog
```

How many member functions does class **Dog** have?

- Answer:

Silently Written & Called Functions Introduction [1/2]

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class Dog {

// ***** Dog: Data members *****
private:
    int a;
    double b;
    Cat c;
};  // End class Dog
```

How many member functions does class **Dog** have?

- Answer: 6. *See the next slide …*

Silently Written & Called Functions
Introduction [2/2]

- Class **`Dog`** has 6 silently written member functions (prototypes below).
  - “Ctor” means constructor, and “dctor” means destructor.

```
class Dog {
public:
    Dog();                                 // 1. Default ctor
    Dog(const Dog & other);                // 2. Copy ctor
    Dog & operator=(const Dog & rhs);      // 3. Copy assignment
    ~Dog();                                // 4. Dctor
    const Dog * operator&() const;         // 5. Address-of (const)
    Dog * operator&();                     // 6. Address-of
```

You **can** redefine the address-of operators, but don’t.

- The silently written versions do “**`return this;`**”. Anything else is confusing.

You may need to write the other four. Next we look closer at these.

Silently Written & Called Functions
Default Ctor [1/2]

A **default constructor** is a ctor with no parameters.

- The silently written version calls the default ctor for all data members, as shown below.

Initializer List

```
class Dog {
public:
    Dog():a(), b(), c()
    {}
```

Empty function body (common)

Note: Every ctor has an **initializer list**.

- *Before* the function body, all data members are constructed. (Why?)
- Initializers give parameters for these ctors. They are called in the order *declared*.
- If a data member is left out of the initializer list, then it is default constructed.
- Using initializers properly leads to efficient code.

```
Dog():a(3) // a is modified once (constructor).
{}

Dog()      // a is modified twice (default constructor, assignment).
{ a = 3; }
```

Silently Written & Called Functions
Default Ctor [2/2]

The default ctor is **silently written** when you declare **no** ctors.
The default ctor is **called** …

- When you call it explicitly:

```
myFunc(Dog());
```

- When you declare an object with no ctor parameters:

```
Dog mutt;
```

- **Not** when you try to explicitly call it (why?):

```
Dog mutt(); // What does this do?
```

- For each item in an array, when you declare the array:

```
Dog puppies[27];  // Default ctor called 27 times
```

Silently Written & Called Functions
Copy Ctor [1/2]

A **copy constructor** is a constructor that takes an object of the same type as that being constructed.

- The parameter should be passed by reference-to-const.
- The silently written version calls the copy ctor for all data members, as shown below.

```
class Dog {
public:
    Dog(const Dog & other)
        :a(other.a), b(other.b), c(other.c)
    {}
```

Note the initializer list and empty function body, as before.

Silently Written & Called Functions
Copy Ctor [2/2]

The copy ctor is **silently written** when you do not declare it.
The copy ctor is **called** …

- When you call it explicitly.

```
myFunc(Dog(mutt));  // Make copy of mutt & pass to myFunc
```

- When you declare an object with one parameter of the same type:

```
Dog mutt(purebred);
Dog mutt = purebred;  // Same as above
```

- When you pass an object by value:

```
void myFunc2(Dog x);  // Parameter x is by-value
myFunc2(mutt);        // Copy ctor creates copy of mutt
```

- And *maybe* when we return by value (the call can be optimized away), see Return Value Optimization
  - Conclusion: your copy ctor had better to do a real copy (right?).

```
Dog myFunc3()
{ return Dog(); }     // MAYBE copy ctor is called here.
```

Silently Written & Called Functions
Copy Assignment

Copy assignment is assignment (“**=**”) in which both sides have the same type.

- The parameter should be passed by reference to const.
- The return value should be a reference to the object assigned to.
- The silently written version does copy assignment for all data members.

```
class Dog {
public:
    Dog & operator=(const Dog & rhs)  // Not a ctor; no initializers
    {
        a = rhs.a;
        b = rhs.b;
        c = rhs.c;
        return *this;
    } //Note this code is bad if Dog contains pointers. (Why?)
```

Copy assignment is **silently written** when you do not declare it.
Copy assignment is **called** only when you call it explicitly:

```
mutt = purebred;
```

Silently Written & Called Functions
Dctor [1/2]

The **destructor** is the function called when an object is destroyed.

- The silently written version does nothing, except that dctors for all data members are automatically called.

```
class Dog {
public:
    ~Dog()
    {}  // Dctors for data members are called
        //  after the function body has executed.
```

Silently Written & Called Functions
Dctor [2/2]

The dctor is **silently written** when you do not declare it.
The dctor is **called** …

- For an automatic object, when the object goes out of scope:

```
void func()
{
    Dog x;
}  // x.~Dog() is called before leaving
```

- For a static object, when the program ends.
- For a member object, when the object it is a member of is destroyed.
- For an object allocated with **`new`**, when you **`delete`** a pointer to it:

```
Dog * p = new Dog;
Dog * array = new Dog[27];
delete p;          // Dctor called for *p
delete [] array;   // Dctor called 27 times
```

- When you call it explicitly (which does not happen much):

```
Dog * q = new Dog;
q->~Dog();  // Destroy *q without deallocating memory.
```

Silently Written & Called Functions Summary

Silent Writing

- The default ctor is silently written when you declare no ctors.
- Each of the other three (copy ctor, copy assignment, dctor) is silently written when you do not declare it.
- For all four, the silently written versions are public; they call the corresponding functions for all data members.

Silent Calling

- The default ctor is called when you declare an object with no ctor parameters, and when you declare an array.
  - In general, to be able to put a type in a container, that type must be default constructable.
- The copy ctor is called when you pass by value, and *maybe* when you return by value.
- The dctor is called:
  - For an automatic object, when it goes out of scope.
  - For a static object, when the program ends.
  - For a member object, when the object it is a member of is destroyed.
  - For an object allocated with **`new`**, when you **`delete`** a pointer to it.

Silently Written & Called Functions Example

TO DO

- Look at some code that does odd, unexpected things using silently written & silently called functions.

Silently Written & Called Functions
TO BE CONTINUED …

Silently Written & Called Functions will be continued next time.