Course Overview
Expressions
Parameter Passing I

CS 311 Data Structures and Algorithms

Lecture Slides

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Course Overview

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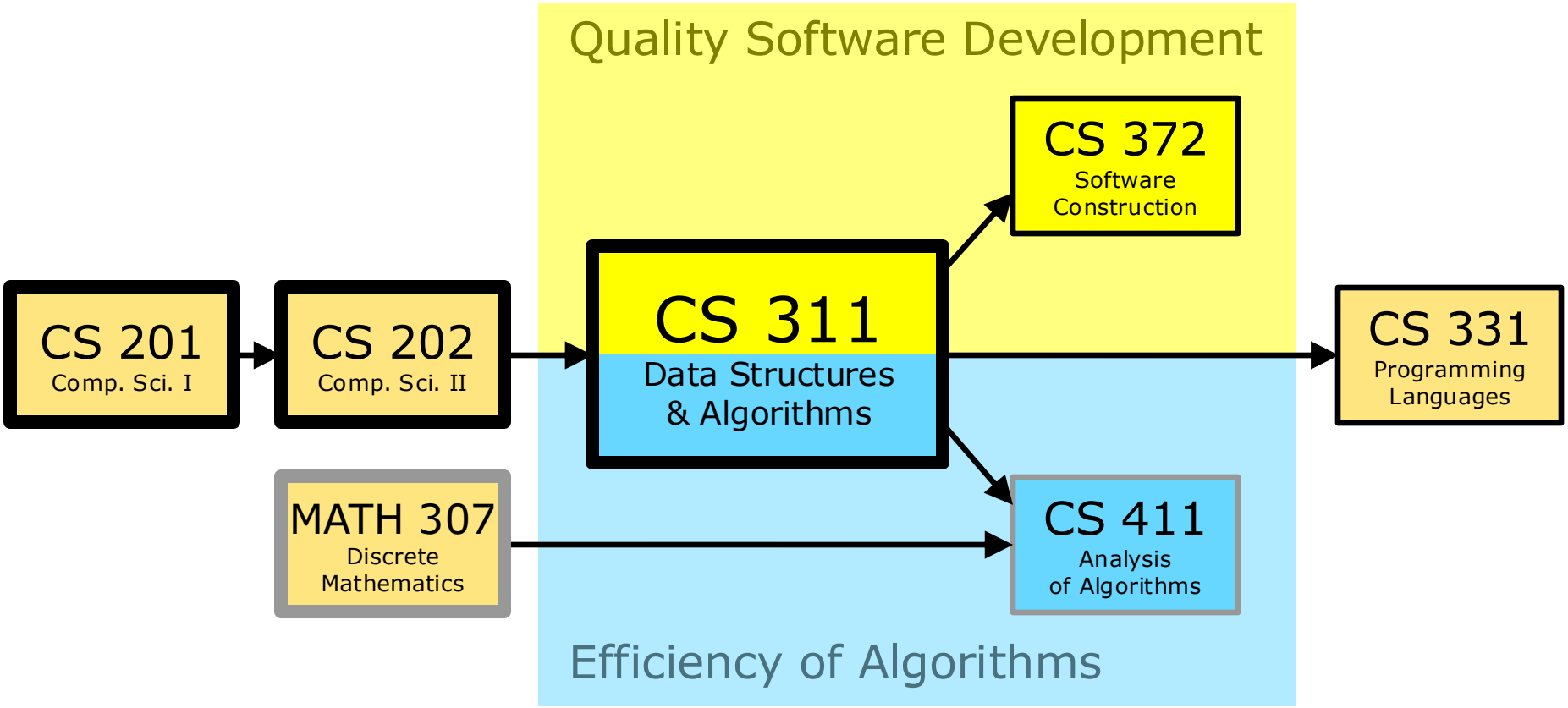
CS 311 in the Comp. Sci. & Comp. Eng. Programs



BS in Computer Science. All are required.

BA in Computer Science. Black border: required.

BS in Computer Engineering. Bold-border: required.
CS 331, CS 411: Approved electives. CS 372: Ask your advisor.

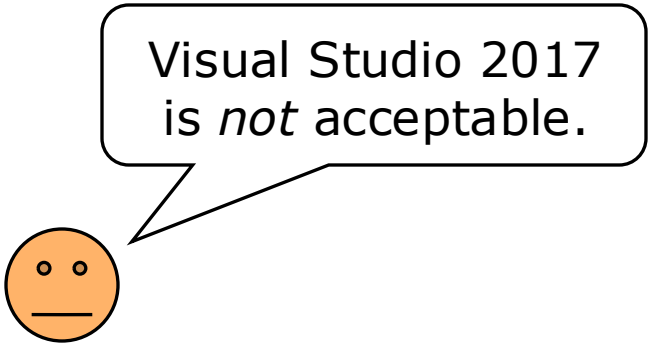
Course Overview
Goals

Upon successful completion of CS 311, you should:

- Have experience writing and documenting high-quality code.
- Understand proper error handling, enabling software components to support robust, reliable applications.
- Be able to perform basic analyses of algorithmic efficiency, including use of big-*O* and related notation.
- Be familiar with various standard algorithms, including those for searching and sorting.
- Understand what data abstraction is, and how it relates to software design.
- Be familiar with standard container data structures, including implementations and relevant trade-offs.

We will achieve these goals, in part, by doing an in-depth study of a particular programming language, along with its standard libraries: ISO C++ (2017 standard) and its Standard Template Library.

You will need to have access to an up-to-date C++ compiler. Any version of a major compiler released within the last couple of years should be fine.



You may use the CS labs (Duckering, 5th floor), which have appropriate C++ compilers available.

Course Overview
Topics

The following topics will be covered, roughly in order:

- Advanced C++
- Software Engineering Concepts
- Recursion
- Searching
- Algorithmic Efficiency
- Sorting
- Data Abstraction
- Basic Abstract Data Types & Data Structures:
  - Smart Arrays & Strings
  - Linked Lists
  - Stacks & Queues
  - Trees (various kinds)
  - Priority Queues
  - Tables
- Briefly: external data, graph algorithms.

Goal: Practical generic containers

A **container** is a data structure holding multiple items, usually all the same type.

A **generic** container is one that can hold objects of client-specified type.

Course Overview
Assignments

Your primary task this semester is to complete eight high-quality, tested, documented software projects. Descriptions of these will be posted on the class webpage as they are assigned.

1. High-Quality Class
2. Moderately Smart Array
3. Potpourri
   - Functions involving exceptions, Linked Lists, and recursion
4. Recursive Backtracking
5. Frightfully Smart Array
6. Linked Lists
7. Trees
8. Using Tables

We will be covering a lot of terminology and notation.

Terminology is the words we use when discussing some technical topic. When I introduce terminology, it is in boldface.

Some terminology (which you should already know): when we **add** the **numbers three** and **five**, we obtain the number **eight**.

Notation is the symbols we use in technical discussions.

Some notation (which you should already know): 3 + 5 = 8.

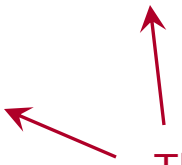
It is very important to know the terminology and notation we will be using. Without it, we cannot even begin to talk about the course material. So *watch out for it!*

Unit Overview
Advanced C++ & Software Engineering Concepts

Our first unit: Advanced C++ and Software Engineering Concepts.
Some of this will be review from CS 201 & 202.

Topics

- Advanced C++
  - Expressions
  - Parameter passing I
  - Operator overloading
  - Example class
  - Parameter passing II
  - Invisible functions I
  - Managing resources in a class
  - Containers & iterators
  - Invisible functions II
  - Error handling
  - Using exceptions
- Software Engineering Concepts
  - Abstraction
  - Assertions
  - Testing
  - Invariants



These two lists will be covered concurrently.

Later in the semester we will cover other advanced C++ topics.

Expressions

Expressions
What an Expression Is

An **expression** is something that has a value.

Evaluating an expression means determining its value.

Examples of C++ expressions:

- `abc`
- `42.7`
- `(n+3)*14-q+vv[6]`
- `foo(x)`
- `cout << "Hello!"`

Q. What is the value of this expression?

A. The value is `cout`.

So we can do this:

```
(cout << "Hello!") << x;
```

… which is the same as this:

```
cout << "Hello!" << x;
```

The following are *not* C++ expressions:

- `int abc;`
- `return abc;`
- `for (int i = 0; i < 10; ++i) cout << i << "\n";`
- `using std::cout;`

Expressions
Types [1/2]

We classify expressions according to the kind of value each represents. An expression's classification is its **type**.

```
int abc;
```

`int` is a type. `abc` is a variable of type `int`.

```
34          // Expression of type int
abc + 34    // Expression of type int
42.7        // Expression of type double
cout << x   // Expression of type std::ostream
vector<int> vv;
vv          // Expression of type std::vector<int>
vv[2]       // Expression of type int
```

Expressions
Types [2/2]

When we need a value whose type is different from that of a given expression, a **type conversion** may be done.

```
double dd = 34;  // 34 has type int;
                 //  this will be converted to double
```

Type conversions can be **explicit** (stated in the code) or **implicit**. The above type conversion is implicit. That below is explicit.

```
double dd2 = static_cast<double>(abc);
```

A type conversion creates a new value; it does not modify the original. For example, above, `abc` is unchanged.

Expressions
Lvalues & Rvalues [1/5]

Every C++ expression is either an Lvalue or an Rvalue.

An **Lvalue** (say "ELL value") has a value that persists beyond the current expression. For example, every variable is an Lvalue.

```
int abc;           // abc is an Lvalue
const double dd;   // dd is an Lvalue
```

If something is an Lvalue, then parts of it are also Lvalues. And something pointed to by a pointer is an Lvalue.

```
vv[3]      // vv is an Lvalue, and so is vv[3]
x.qq       // x is an Lvalue, and so is x.qq
*p         // *p is an Lvalue
```

Lvalues & Rvalues [2/5]

An Lvalue has a location in memory. We can take its address.

```
int * p = &abc;  // Legal because abc is an Lvalue
```

We can also pass an Lvalue by reference—if it is non-const.

```
void incr(int & n)
{ ++n; }

incr(abc);  // Legal because abc is a non-const Lvalue
```

Historically, "Lvalue" comes from the idea that we can put it on the left-hand side of an assignment operator (=). "L" stood for "left". But note that, in C++, a const variable is still an Lvalue.

Expressions
Lvalues & Rvalues [3/5]

An **Rvalue** (say "ARR value") is an expression that is not an Lvalue.

```
42.7         // 42.7 is an Rvalue
abc + 34     // abc + 34 is an Rvalue

int add(a, b)
{ return a+b; }

add(6, 8)    // add(6, 8) is an Rvalue
```

Expressions
Lvalues & Rvalues [4/5]

We cannot pass an Rvalue by reference.

```
incr(6);                    // DOES NOT COMPILE!
```

A C++ expression is either an Lvalue or an Rvalue, but *never both!*

In the following code, is `bb` an Lvalue or an Rvalue?

```
aa = bb;
```

Lvalues & Rvalues [5/5]

Why do we care about Lvalues & Rvalues?

As noted on previous slides, the distinction affects whether we can take the address of a value and whether we can pass it by reference.

Further, an Rvalue is something that we can expect is about to go away. That means that we can "mess it up" without causing problems. This can allow for code speed-ups. *More on this later.*

Parameter Passing I

Parameter Passing I
Overview

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

By value:

```
void p1(Foo x);          // Pass x by value
Foo r1();                // Return by value
```

By reference:

```
void p2(Foo & x);        // Pass x by reference
Foo & r2();              // Return by reference
```

By reference-to-const (some people say “const reference”):

```
void p3(const Foo & x); // Pass x by reference-to-const
const Foo & r3();        // Return by reference-to-const
```

Parameter Passing I
Details — By Value [1/2]

```
void p1(Foo x);
Foo r1();
```

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

- Below, `x` (in `p1`) is a copy of `y`. Modifying `x` does nothing to `y`.

```
Foo y;
p1(y);
```

The copy is made with an **implicit** function call to the `Foo` **copy constructor** or **move constructor**.

- This may be slow, if `y` is a large object.
- And if Foo has no copy/move constructor, then it is impossible.

Parameter Passing I
Details — By Value [2/2]

Passing by value does *not* allow for proper handling of derived classes, including calling of virtual functions.

```
class Base { … };
class Derived : public Base { … };

void ff(Base bb);

Derived dd;
ff(dd);  // This might cause problems
```

Parameter Passing I
Details — By Reference [1/2]

```
void p2(Foo & x);
Foo & r2();
```

When passing by reference, no copy is made. The original and passed versions are the *same object*.

```
Foo y;
p2(y);  // Modifying x inside p2 will modify y
```

Be careful when returning by reference. Do not return a value that goes away when the function ends.

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

BAD! ☹

Parameter Passing I
Details — By Reference [2/2]

Passing by reference *does* allow for proper handling of derived classes, including calling of virtual functions.

```
class Base { … };
class Derived : public Base { … };

void ff(Base & bb);

Derived dd;
ff(dd);  // No problem
```

Note

Only non-const Lvalues can be passed by reference.

Parameter Passing I
Details — By Reference-to-Const [1/2]

```
void p3(const Foo & x);
const Foo & r3();
```

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 done.

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

As with by-reference, be careful returning by reference-to-const.

Details — By Reference-to-Const [2/2]

Like passing by reference, passing by reference-to-const allows for proper handling of derived classes, including calling of virtual functions.

Const variables may be passed by reference-to-const. The passed version is not modifiable.

In fact, *any value at all* may be passed by reference-to-const.

Parameter Passing I
Details — Summary of the Three

	By Value	By Reference	By Reference-to-Const
Makes a copy	YES ☹*	NO ☺	NO ☺
Allows for polymorphism	NO ☹**	YES ☺	YES ☺
Allows implicit type conversions	YES ☺	NO ☹	YES ☺
Allows passing of:	Any copyable value ☺	Non-const Lvalues ☹?***	Any value ☺

*This is a problem when we pass values that take time to copy, like large objects.

**This is a problem when we use inheritance, as we often do with 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 many purposes, *when we pass objects*, reference-to-const combines the best features of the first two methods.

Parameter Passing I
Usage — Normal

For most parameter passing, we pass either by value or by reference-to-const.

- By value: simple types (`int`, `char`, etc.), pointers, iterators.
- By reference-to-const: larger objects, or things we are not sure of.

```
template<typename T>
void f1(const T & x);  // x might be a large object (?)
```

We normally return by value.

```
Foo f2();
```

But there are special cases where we may use other methods …

Parameter Passing I
Usage — Special [1/2]

We pass by reference, if we want to send the value of the parameter back to the caller.

```
// Convert seconds after midnight to hrs, mins, secs.
void secsToHMS(int secs, int & h, int & m, int & s);
```

Parameter Passing I
Usage — Special [2/2]

We *might* return by reference or by reference-to-const, if we are returning a value that is not going away.

- The former if the caller gets to modify the value; the latter if not.
- Idea: You are returning an Lvalue to the caller.

```
class BunchOfInts {
public:
    int & operator[](std::size_t index)
    { return _theInts[index]; }
    const int & operator[](std::size_t index) const
    { return _theInts[index]; }

private:
    int _theInts[100];
};
```