CSC212
Data Structures

COMPUTER SCIENCE
CITY COLLEGE OF NEW YORK

Lecture 1: Introduction

Instructor: George Wolberg
Department of Computer Science
City College of New York

Outline of this lecture

- Course Objectives and Schedule
  - WHAT (Topics)
  - WHY (Importance)
  - WHERE (Goals)
  - HOW (Information and Schedule)

- The Phase of Software Development
  - Basic design strategy
  - Pre-conditions and post-conditions
  - Running time analysis

Topics (WHAT)

- Data Structures
  - specification, design, implementation and use of
    - basic data types (arrays, lists, queues, stacks, trees…)
- OOP and C++
  - C++ classes, container classes , Big Three
- Standard Template Library (STL)
  - templates, iterators
  - ADTs in our DS course cut-down version of STL
- Recursion, Searching and Sorting Algorithms
  - important techniques in many applications

Importance (WHY)

- Data Structures (how to organize data) and Algorithms (how to manipulate data) are the cores of today's computer programming

- The behavior of Abstract Data Types (ADTs) in our Date Structures course is a cut-down version of Standard Template Library (STL) in C++

- Lay a foundation for other aspects of "real programming" – OOP, Recursion, Sorting, Searching

Goals (WHERE)

understand the data types inside out

- Implement these data structures as classes in C++
- Determine which structures are appropriate in various situations
- Confidently learn new structures beyond what are presented in this class
- also learn part of the OOP and software development methodology

Course Information (HOW)

- Objectives
  - Data Structures, with C++ and Software Engineering
- Textbook and References
  - Texbook: **Data Structures and Other Objects Using C++ , by Michael Main and Walter Savitch, 4th Ed., 2011.**
  - Reference: *C++ How to Program* by Dietel & Dietel, 8th Ed., Prentice Hall 2011
- Prerequisites
  - CSc103 C++ (Intro to Computing), CSc 104 (Discrete Math Structure I)
- Assignments and Grading
  - **6-7 programming assignments** roughly every 2 weeks (50%)
  - **2 in-class writing exams** (50%)
- Computing Facilities
  - PCs: Microsoft Visual C++ ; Unix / Linux : g++
  - also publicly accessible at Computer Science labs

Tentative Schedule (HOW)

(14 weeks = 28 classes = 23 lectures + 3 reviews + 2 exams, 6-7 assignments)

- Week 1. The Phase of Software Development (Ch 1)
- Week 2. ADT and C++ Classes (Ch 2)
- Week 3. Container Classes (Ch 3)
- Week 4. Pointers and Dynamic Arrays (Ch 4)
- Reviews and the 1st exam (Ch. 1-4)
- Week 5. Linked Lists (Ch. 5)
- Week 6 Template and STL (Ch 6)
- Week 7. Stacks (Ch 7) and Queues (Ch 8)
- Week 8. Recursion (Ch 9)
- Reviews and the 2nd exam (Ch. 5-9)
- Week 9/10. Trees (Ch 10, Ch 11)
- Week 11. Searching and Hashing (Ch 12)
- Week 12. Sorting (Ch 13)
- Week 13. Graphs (Ch 15)
- Reviews and the 3rd exam (mainly Ch. 10-13)

Course Web Page

You can find all the information at

http://www-cs.ccny.cuny.edu/~wolberg/cs212/index.html

or via my web page:

http://www-cs.ccny.cuny.edu/~wolberg

-Come back frequently for the updating of lecture schedule, programming assignments and exam schedule

- Reading assignments & programming assignments

Piazza

- All class-related discussion will be done on Piazza.
- Ask questions on Piazza (rather than via emails)
- Benefit from collective knowledge of classmates
- Ask questions when struggling to understand a concept.
- You can even do so anonymously.

Signup: piazza.com/ccny.cuny/fall2020/csc212kl

Class link: piazza.com/ccny.cuny/fall2020/csc212kl/home

Outline

- Course Objectives and Schedule
  - Information
  - Topics
  - Schedule
- The Phase of Software Development
  - Basic design strategy
  - Pre-conditions and post-conditions
  - Running time analysis

Phase of Software Development

- Basic Design Strategy – four steps (Reading: Ch.1)
    - Specify the problem - Input/Output (I/O)
    - Design data structures and algorithms (**pseudo code**)
    - Implement in a language such as C++
    - Test and debug the program (Reading Ch 1.3)
- Design Technique
    - Decomposing the problem
- Two Important Issues (along with design and Implement)
    - **Pre-Conditions and Post-Conditions**
    - **Running Time Analysis**

Preconditions and Postconditions

- An important topic: **preconditions** and **postconditions**.
- They are a method of specifying what a function accomplishes.

For use with *Data Structures and Other Objects Using C++* by Michael Main and Walter Savitch.

Preconditions and Postconditions

Frequently a programmer must communicate precisely **what** a function accomplishes, without any indication of **how** the function does its work.

Can you think of a situation where this would occur ?

Example

- You are the head of a programming team and you want one of your programmers to write a function for part of a project.

What are Preconditions and Postconditions?

- One way to specify such requirements is with a pair of statements about the function.
- The **precondition** statement indicates what must be true before the function is called.
- The **postcondition** statement indicates what will be true when the function finishes its work.

Example

```
void write_sqrt( double x)

//   Precondition:  x  >=  0.
//   Postcondition:  The square root of x has
//   been written to the standard output.
```

Example

```
void write_sqrt( double x)

//   Precondition:  x  >=  0.
//   Postcondition:  The square root of x has
//   been written to the standard output.
```

- The precondition and postcondition appear as comments in your program.
- They are usually placed after the function’s parameter list.

Example

```
void write_sqrt( double x)

//   Precondition:  x  >=  0.
//   Postcondition:  The square root of x has
//   been written to the standard output.
```

- In this example, the precondition requires that

  x >= 0

  be true whenever the function is called.

Example

Which of these function calls meet the precondition ?

```
write_sqrt( -10 );
write_sqrt( 0 );
write_sqrt( 5.6 );
```

Example

Which of these function calls meet the precondition ?

```
write_sqrt( -10 );
write_sqrt( 0 );
write_sqrt( 5.6 );
```

The second and third calls are fine, since the argument is greater than or equal to zero.

Example

Which of these function calls meet the precondition ?

```
write_sqrt( -10 );
write_sqrt( 0 );
write_sqrt( 5.6 );
```

But the first call violates the precondition, since the argument is less than zero.

Example

```
void write_sqrt( double x)

//   Precondition:  x  >=  0.
//   Postcondition:  The square root of x has
//   been written to the standard output.
```

Another Example

```
bool is_vowel( char letter )
//   Precondition:  letter is an uppercase or
//   lowercase letter (in the range 'A' ... 'Z' or 'a' ... 'z') .
//   Postcondition:  The value returned by the
//   function is true if letter is a vowel;
//   otherwise the value returned by the function is
//   false.
```

Another Example

What values will be returned by these function calls ?

```
is_vowel( 'A' );
is_vowel(' Z' );
is_vowel( '?' );
```

Another Example

What values will be returned by these function calls ?

```
is_vowel( 'A' );
is_vowel(' Z' );
is_vowel( '?' );
```

true

false

Nobody knows, because the precondition has been violated.

Consequence of Violation

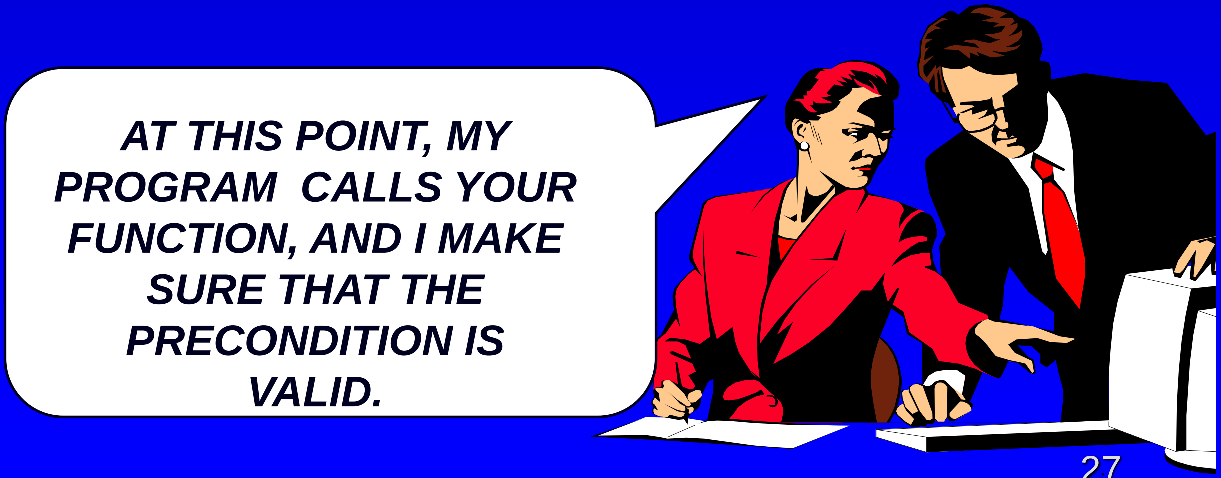
Who is responsible for the crash ?

```
write_sqrt(-10.0);
is_vowel( '?' );
```

Violating the precondition might even crash the computer.

Always make sure the precondition is valid . . .

- The programmer who calls the function is responsible for **ensuring that the precondition is valid** when the function is called.



. . . so the postcondition becomes true at the function's end.

- The programmer who writes the function counts on the precondition being valid, and **ensures that the postcondition becomes true** at the function's end.
- The precondition is enforced in C++ through use of assert() function.

A Quiz

The famous skyline was dark on Aug 14th, 2003.

Bates for NEWS

Suppose that you call a function, and you neglect to make sure that the precondition is valid.

Who is responsible if this inadvertently causes a 1-day long blackout in NYC or other disaster?

- ☐ You
- ☐ The programmer who wrote that Power Supply function
- ☐ Mayor Bloomberg

Rosamilio NEWS

Out of Penn Station

A Quiz

Suppose that you call a function, and you neglect to make sure that the precondition is valid.
Who is responsible if this inadvertently causes a 1-day long blackout in NYC or other disaster?

- You

  The programmer who calls a function is responsible for ensuring that the precondition is valid.

Out of Penn Station

On the other hand, careful programmers also follow these rules:

- When you write a function, you should make every effort to detect when a precondition has been violated.
- If you detect that a precondition has been violated, then print an error message and halt the program.

On the other hand, careful programmers also follow these rules:

- When you write a function, you should make every effort to detect when a precondition has been violated.
- If you detect that a precondition has been violated, then print an error message and halt the program...
- ...rather than causing a chaos.

The famous skyline was dark on Aug 14th, 2003.

Bates for NEWS

Example

```
void write_sqrt( double x)
//   Precondition:  x  >=  0.
//   Postcondition:  The square root of x has
//   been written to the standard output.
{
     assert(x >= 0);

   . . .
```

- The assert function (described in Section 1.1) is useful for detecting violations of a precondition.

Advantages of Using Pre- and Post-conditions

- Concisely describes the behavior of a function...
- ... without cluttering up your thinking with details of how the function works.
- At a later point, you may reimplement the function in a new way ...
- ... but programs (which only depend on the precondition/postcondition) will still work with no changes.

Summary of pre- and post-conditions

Precondition

- The programmer who calls a function ensures that the precondition is valid.
- The programmer who writes a function can bank on the precondition being true when the function begins execution. Careful programmers enforce this anyway!

Postcondition

- The programmer who writes a function ensures that the postcondition is true when the function finishes executing.

Phase of Software Development

- Basic Design Strategy – four steps (Reading: Ch.1)
  - Specify Input/Output (I/O)
  - Design data structures and algorithms
  - Implement in a language such as C++
  - Test and debug the program (Reading Ch 1.3)
- Design Technique
  - Decomposing the problem
- Two Important Issues (along with design and Implement)
  - **Pre-Conditions and Post-Conditions**
  - **Running Time Analysis**

Running Time Analysis – Big O

- Time Analysis
  - Fast enough?
  - How much longer if input gets larger?
  - Which among several is the fastest?

Example : Stair Counting Problem

- How many steps ?

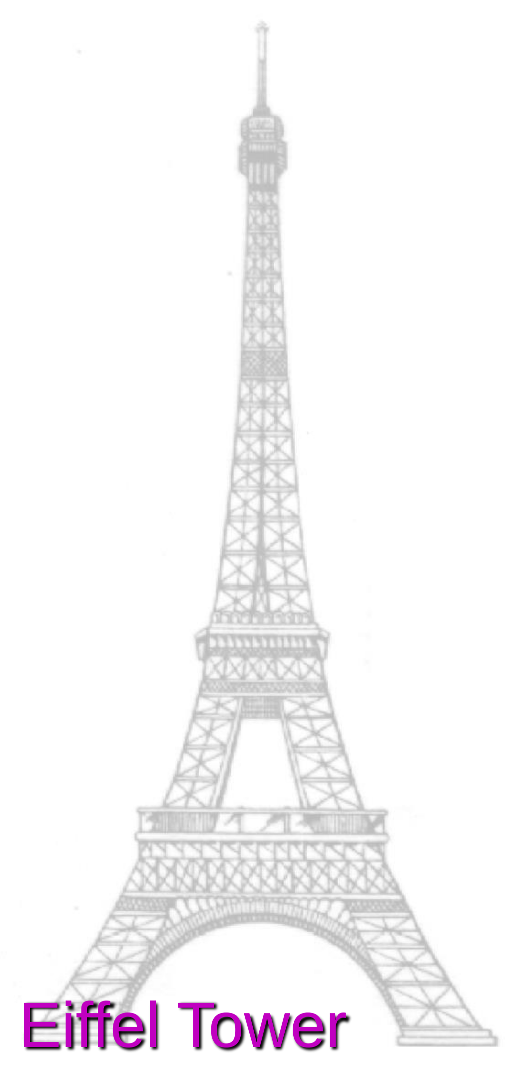
1789 (Birnbaum)

1671 (Joseph Harriss)

1652 (others)

1665 (Official Eiffel Tower Website)

- Find it out yourself !



Eiffel Tower

Example : Stair Counting Problem

- Find it out yourself !
  - Method 1: Walk down and keep a tally

Each time a step down, make a mark

  - Method 2 : Walk down, but let Judy keep the tally

Down+1, hat, back, Judy make a mark

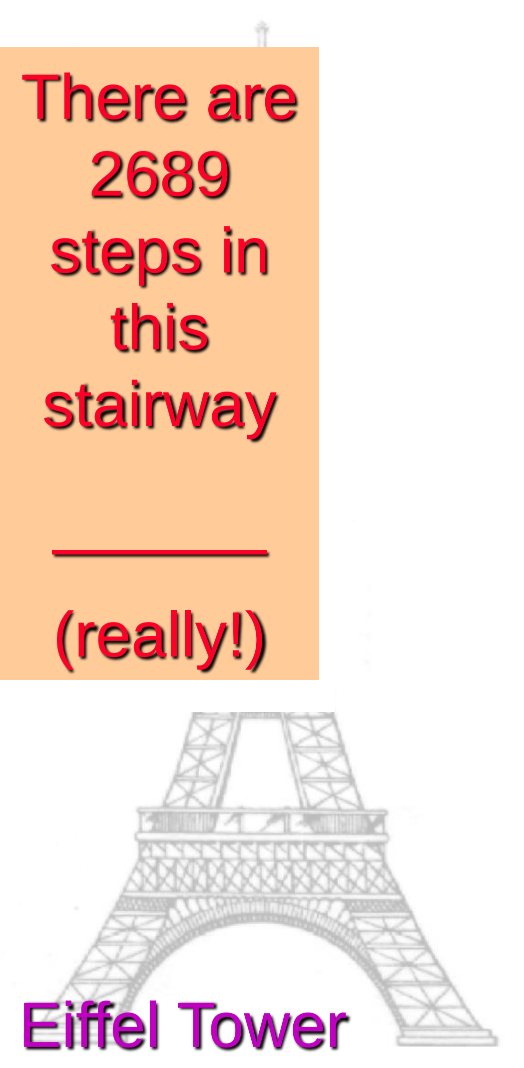
  - Method 3: Jervis to the rescue

One mark per digit

There are 2689 steps in this stairway

______

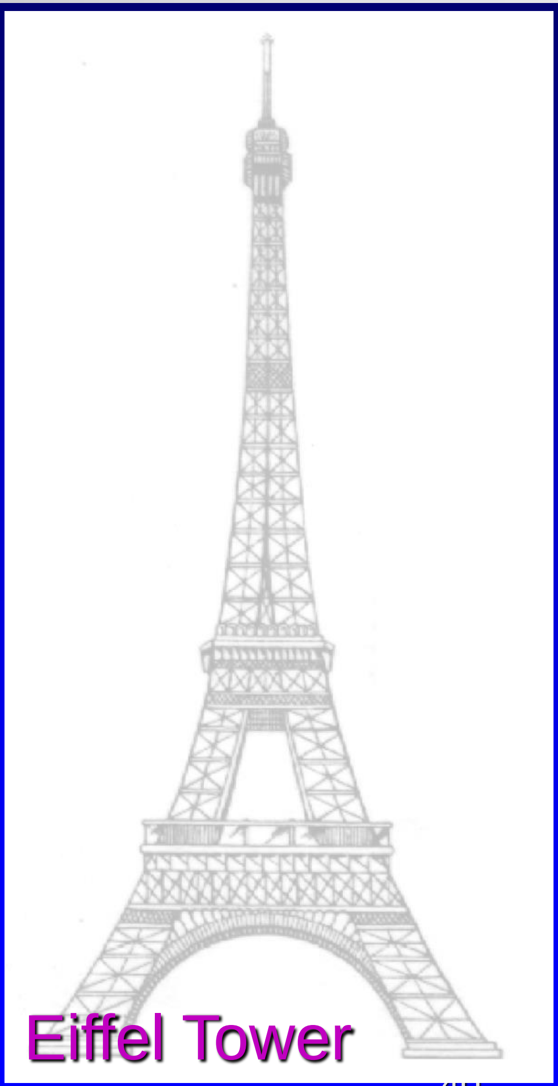
(really!)



Eiffel Tower

Example : Stair Counting Problem

- How to measure the time?
  - Just measure the actual time
    - vary from person to person
    - depending on many factors
  - Count certain operations
    - each time walk up/down, 1 operation
    - each time mark a symbol, 1 operation


Eiffel Tower

Example : Stair Counting Problem

- Find it out yourself !
  - Method 1: Walk down and keep a tally

2689 (down) + 2689 (up) + 2689 (marks)
= 8067

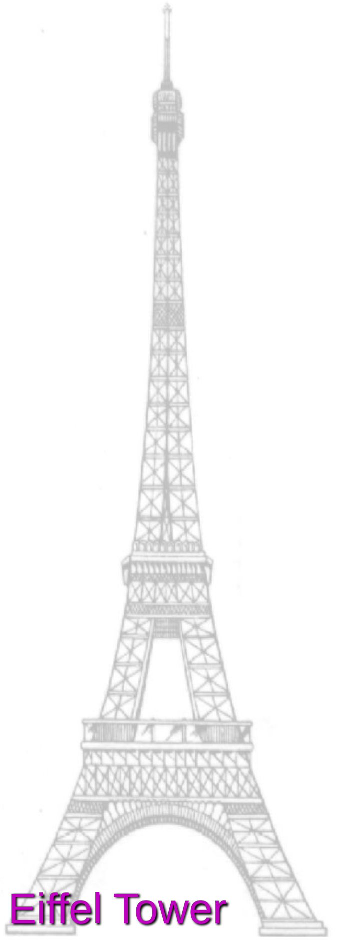
  - Method 2 : Walk down, let Judy keep tally

Down: 3,616,705 = 1+2+…+2689
Up: 3,616,705 = 1+2+…+2689
Marks: 2,689 = 1+1+…+1

7,236,099 !

  - Method 3: Jervis to the rescue

only 4 marks !


Eiffel Tower

Example : Stair Counting Problem

- Size of the Input : n
  - Method 1: Walk down and keep a tally

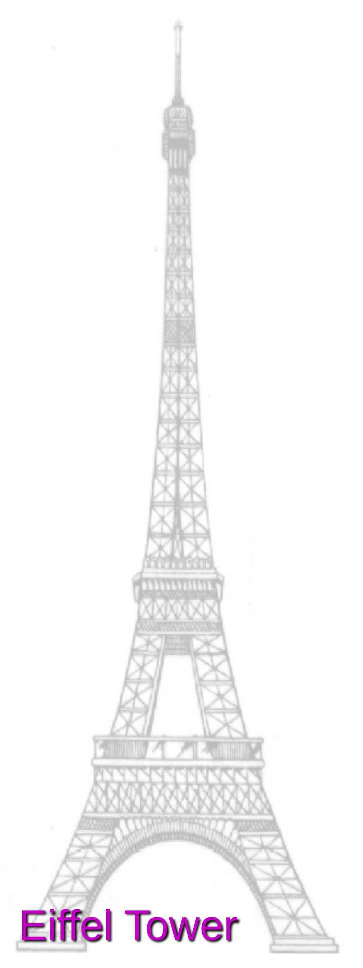
3n

  - Method 2 : Walk down, let Judy keep tally

$n+2(1+2+\ldots+n) = n+(n+1)n = n^2+2n$

    - Trick: Compute twice the amount
      - and then divided by two
  - Method 3: Jervis to the rescue

The number of digits in n = $[\log_{10} n]+1$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Example : Stair Counting Problem

- Big-O Notation – the order of the algorithm
    - Use the largest term in a formula
    - Ignore the multiplicative constant
  - Method 1: Linear time

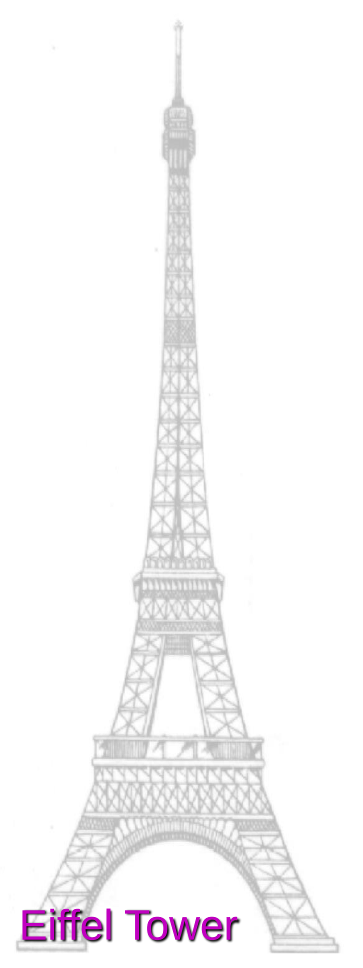
$3n \Rightarrow O(n)$

  - Method 2 : Quadratic time

$n^2+2n \Rightarrow O(n^2)$

  - Method 3: Logarithmic time

$[\log_{10} n]+1 \Rightarrow O(\log n)$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George Wolberg, 2020

A Quiz

Number of operations	Big-O notation
n^2+5n	$O(n^2)$
$100n+n^2$	$O(n^2)$
$(n+7)(n-2)$	$O(n^2)$
$n+100$	$O(n)$
number of digits in $2n$	$O(\log n)$

Big-O Notation

- The order of an algorithm generally is more important than the speed of the processor

Input size: n	O(log n)	O (n)	O (n^2)
# of stairs: n	[$\log_{10} n$]+1	3n	n^2+2n
10	2	30	120
100	3	300	10,200
1000	4	3000	1,002,000

Time Analysis of C++ Functions

- Example- Quiz (5 minutes)
  - Printout all item in an integer array of size N

```
for (i=0;  i< N; i++ )
{
          val = a[i];
          cout << val;
}
```

2 C++ operations or more?

- Frequent linear pattern
  - A loop that does a fixed amount of operations N times requires O(N) time

Time Analysis of C++ Functions

- Another example
  - Printout char one by one in a string of length N

```
for (i=0;  i< strlen(str); i++ )
{
        c = str[i];
        cout << c;
}
```

$O(N^2)$!

- What is a single operation?
  - If the function calls do complex things, then count the operation carried out there
  - Put a function call outside the loop if you can!

Time Analysis of C++ Functions

- Another example
  - Printout char one by one in a string of length N

```
N = strlen(str);
for (i=0;  i<N; i++ )
{
          c = str[i];
          cout << c;
}
```

O(N)!

- What is a single operation?
  - If the function calls do complex things, then count the operation carried out there
  - Put a function call outside the loop if you can!

Time Analysis of C++ Functions

- Worst case, average case and best case
  - search a number x in an integer array a of size N

```
for (i=0;  (i< N) && (a[i] != x); i++ );

if (i < N) cout << “Number ” << x << “is at location ” << i << endl;
else cout << “Not Found!” << endl;
```

- Can you provide an exact number of operations?
  - Best case: 1+2+1
  - Worst case: 1+3N+1
  - Average case: 1+3N/2+1

Testing and Debugging

- Test: run a program and observe its behavior
  - input -> expected output?
  - how long ?
  - software engineering issues
- Choosing Test Data : two techniques
  - boundary values
  - fully exercising code (tool: profiler)
- Debugging… find the bug after an error is found
  - rule: never change if you are not sure what’s the error
  - tool: debugger

Summary

- Often ask yourselves FOUR questions
  - WHAT, WHY, WHERE & HOW
    - Topics – DSs, C++, STL, basic algorithms
    - Data Structure experts
    - Schedule – 23 lectures, 7 assignments, 2 exams
    - some credits (10) for attending the class
    - Information – website
- Remember and apply two things (Ch 1)
  - Basic design strategy
  - Pre-conditions and post-conditions
  - Running time analysis
  - Testing and Debugging (reading 1.3)

Reminder ...

Lecture 2: ADT and C++ Classes

Reading Assignment before the next lecture:

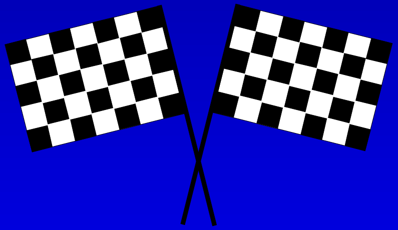
Chapter 1

Chapter 2, Sections 2.1-2.3

Office Hours:

Tuesdays 12:00 pm - 1:00 pm
(Location: NAC 8/202N)

check website for details



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