Design and Analysis of Algorithms

CSE 5311

Lecture 1 Administration & Introduction

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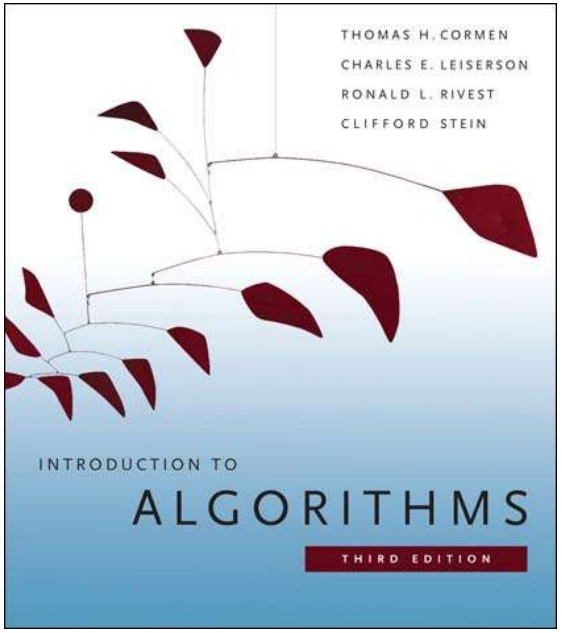
Department of Computer Science and Engineering

Administration

- **Course CSE5311**
  - What: Design and Analysis of Algorithms
  - When: Friday 1:00 ~ 3:50pm
  - Where: Online
  - Who: Junzhou Huang (Office ERB 650) jzhuang@uta.edu
  - Office Hour: Friday 3:50 ~ 5:50pm and/or appointments
  - Homepage: http://ranger.uta.edu/~huang/teaching/CSE5311.htm
    (**You're required to check this page regularly**)
- **Lecturer**
  - PhD in CS from Rutgers, the State University of New Jersey
  - Research areas: machine learning, computer vision, medical imaging informatics
- **GTA**
  - Chunyuan Li (Office ERB 426), chuanyuan.li@mavs.uta.edu
  - Office hours: Wed. 9:00am ~ 12:00pm and/or appointments

Study Materials

- **Prerequisites**
  - Algorithms and Data Structure (CSE 2320)
  - Theoretical Computer Science (CSE 3315)
  - What this really means:
    - You have working experience s on software development.
    - You know compilation process and programming
    - Elementary knowledge of math and algorithms
- **Text book**
  - Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest and Clifford Stein, **Introduction to Algorithms**, third edition
  - https://mitpress.mit.edu/books/introduction-algorithms



Study Materials

- **Text book**
  - We will not cover all the chapters of the book
  - We will not cover all sections of the covered chapters
  - We will not fully follow the order of the book
  - The contents uncovered in slides/lectures are optional
- **Recommended Reference**
  - Robert Sedgewick, **Algorithms in C**. Addison - Wesley, 1990

- **Acknowledgments**
  - Class notes partially based on 5311 classes taught at UTA in prior years
  - Material from textbook site
  - Lots of material available on the web (via google search, wikipedia)

Grading

- **Distribution**
  - 20% Projects
  - 35% Midterm Exam
  - 40% Final Exam
  - 5% Class Participation

    100%
- **Attention**
  - Homework is as important as any other aspects of your grade!
  - Attendance though not mandatory, but is HIGHLY encouraged.
  - The university makeup policy will be strictly adhered to. Generally, no make-up exams/quizzes except for university sanctioned reasons.
  - When missing an exam/quiz due to unavoidable circumstances, PLEASE notify the instructor and request a makeup approval **ahead of time**.

Final Grade

- **Final Letter Grade**
  - [90 100] --- A
  - [80 90) --- B
  - [70 80) --- C
  - [60 70) --- D
  - [00 60) --- F
- **Attention**
  - Final letter grades will be assigned based on absolute percentage
  - [ ] denotes inclusion and ( ) denotes exclusion.
  - The instructor reserves the right to move the thresholds down based on the distribution of final percentages, but they will not move up.

Assignments

- **Homework assignments**
  - Assigned in class, typically due one week later at the start of next lecture
  - Automatic 20% deduction for each day late
  - Homework is not accepted more than 3 days late
- **Projects**
  - Assigned in class, typically due 1~3 weeks later after assignments
  - They are not created equally.
- **Collaboration**
  - You may discuss assignments with others, but must write up them individually. Please identify collaborators on your assignment cover sheet
  - Failure to comply with this policy is a violation of academic integrity
- **Start early! Start early! Start early !!!**

Information

- **Course Webpage**
  - Check the web page regularly (2 times per week).
  - Announcements, assignments, and lecture notes will be posted there.
- **Grade Appeal**
  - You may appeal the grade in writing (email) within 5 class days.
  - Appealed to the appropriate GTA firstly, then to the instructor, if necessary.
  - Please refer to the UTA Catalog for the detailed guide of grade appeals.
- **Drop Policy**
  - The university withdrawal policy will be strictly adhered to.
- **Others**
  - Accommodating students with disabilities
  - Student Support Services
  - Etc.

Questions

Course Overview

- **What is it?**
  - Algorithms
  - Design and Analysis
- **Why is a CS course?!?**
  - The key of the computer science
- **Will I really ever use this stuff again?**
  - Definitely, analysis and design
  - Necessary knowledge for a CS student
  - You may not become a professional algorithm designer but you definitely need know how to analysis and design the algorithms for the problems in your future career and even in your life
- **How to succeed in this course?**

Why Are You In This Class?

- **Something interesting about you**
  - Why you picked your major?
  - Life Plan
- **To learn background in order to take more advanced classes in computer science and engineering**
  - Database, big data analytics, compiler, Computer Network, Embedded Systems, artificial intelligent, machine learning, data mining, computer vision, etc.
- **Understand the effect of an algorithm on the code you write or read**
  - Learn how to efficiently use and control the computer
- **To have the necessary background to understand innovations in intelligent design or related others**
  - Your desktop, laptop, ipad, iphone, google search, facebook social network, etc.
- **Necessary to become a professional algorithm designer?**
  - But to be able to read and understand
  - To be able to understand innovative ideas

What?

- ***The theoretical study of design and analysis of computer algorithms***
- **Basic goals for an algorithm**
  - Always correct
  - Always terminates
- **Our class: performance**
  - Performance often draws the line between what is possible and what is impossible.
- **Design and Analysis of Algorithms**
  - **Analysis:** predict the cost of an algorithm in terms of resources and performance
  - **Design:** design algorithms which minimize the cost

Machine Model

- **Generic Random Access Machine (RAM)**
  - Executes operations sequentially
  - Set of primitive operations: Arithmetic. Logical, Comparisons, Function calls
- **Simplifying assumption**
  - All operations cost 1 unit
  - Eliminates dependence on the speed of our computer
  - Otherwise impossible to verify and to compare

The Problem of Sorting

Input: sequence $\langle a_1, a_2, \ldots, a_n \rangle$ of numbers.

Output: permutation $\langle a'_1, a'_2, \ldots, a'_n \rangle$ such that $a'_1 \le a'_2 \le \cdots \le a'_n$.

Example:

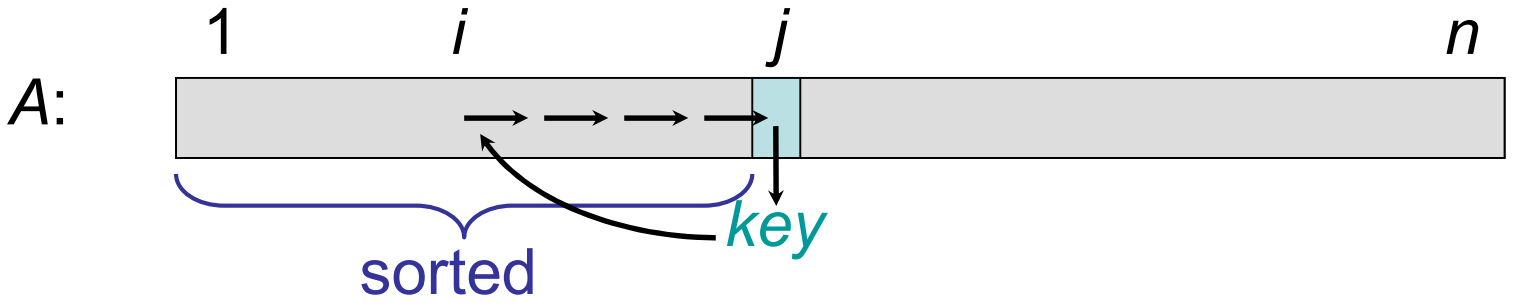
Input: 8 2 4 9 3 6

Output: 2 3 4 6 8 9

Insertion sort

"pseudocode"

```
INSERTION-SORT (A, n)        ▷ A[1 . . n]
    for j ← 2 to n
        do key ← A[ j]
           i ← j – 1
           while i > 0 and A[i] > key
               do A[i+1] ← A[i]
                  i ← i – 1
           A[i+1] = key
```



Example of Insertion Sort

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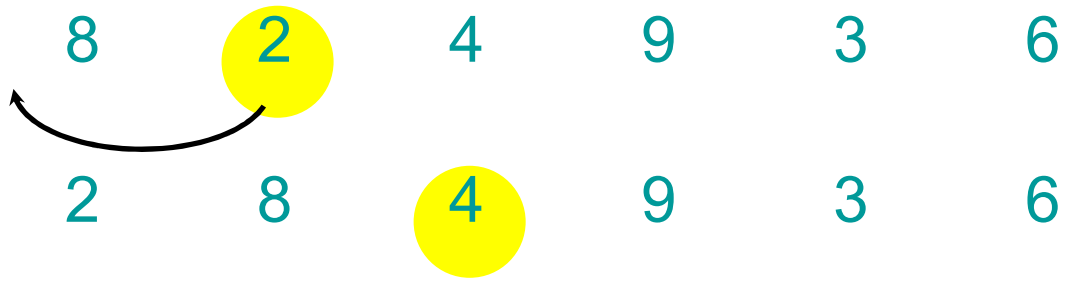

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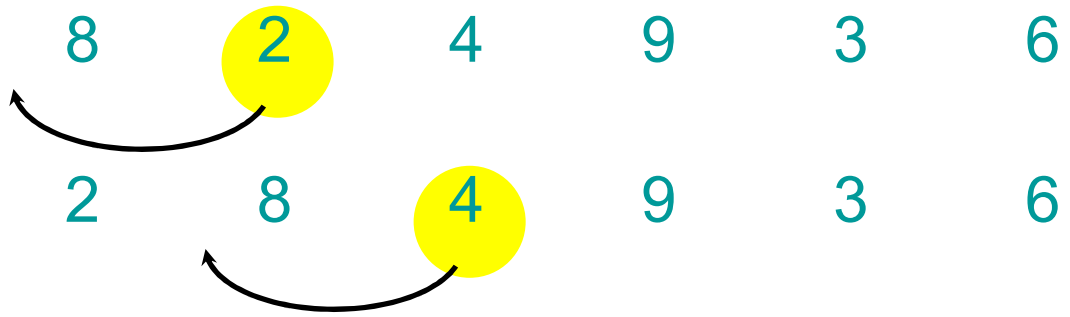

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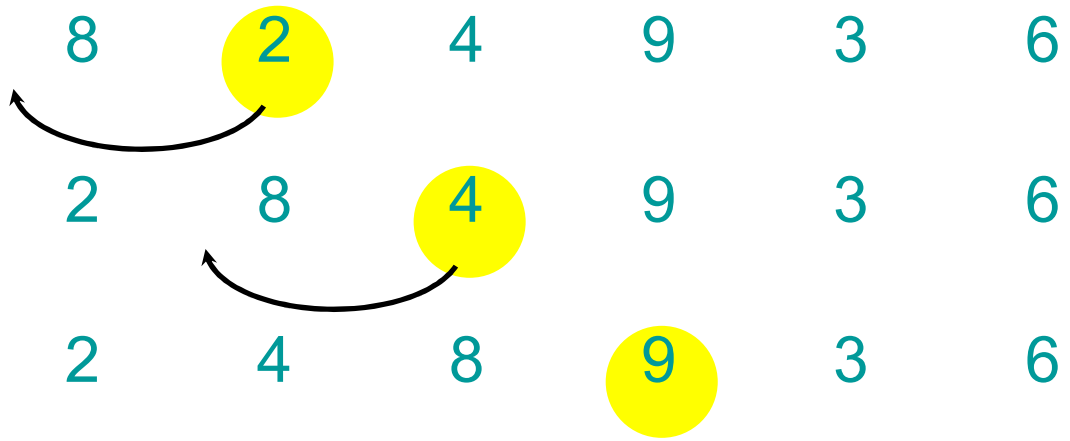

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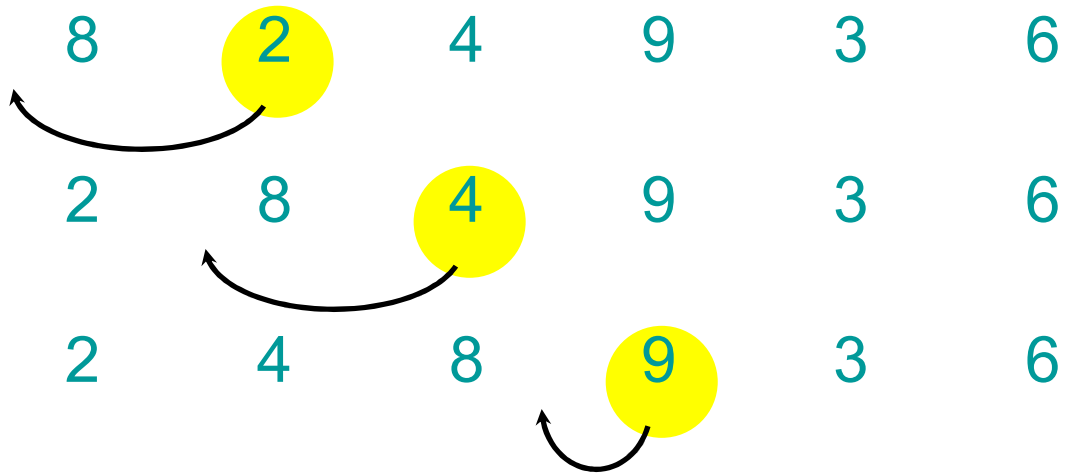

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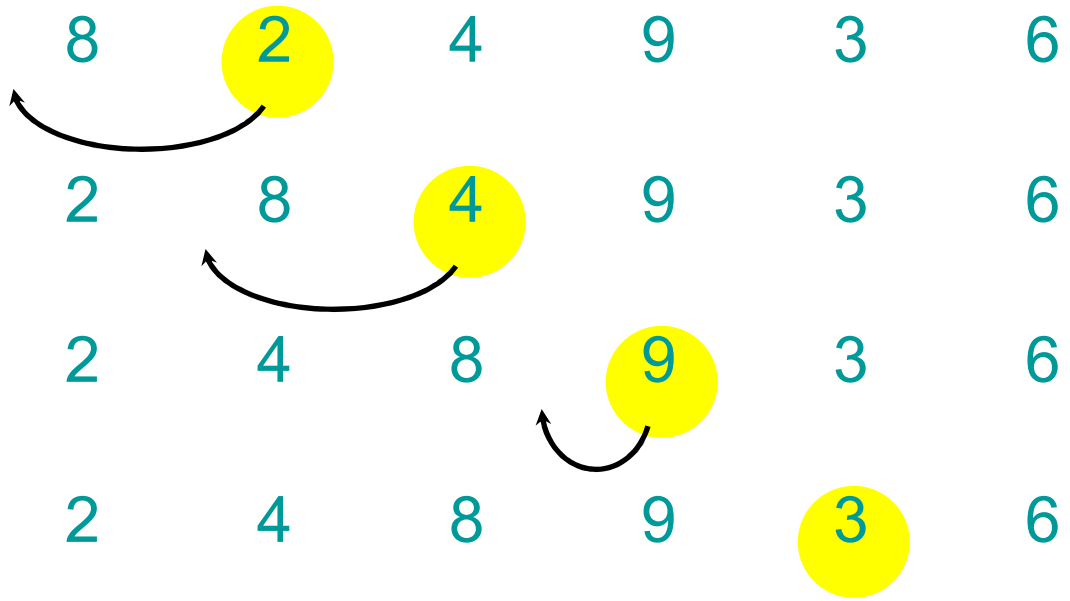

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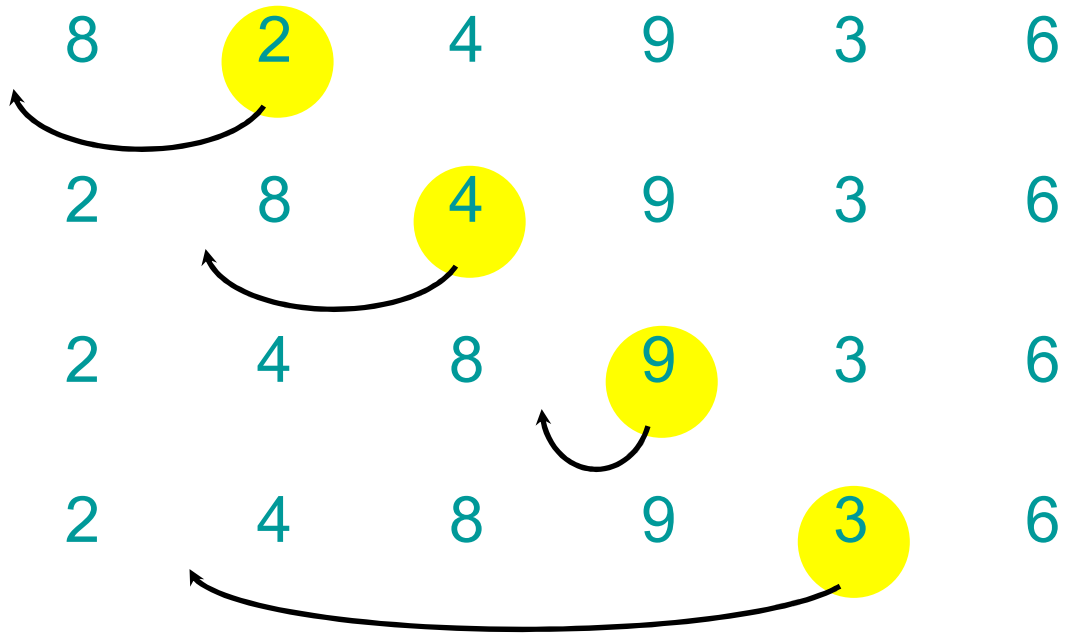

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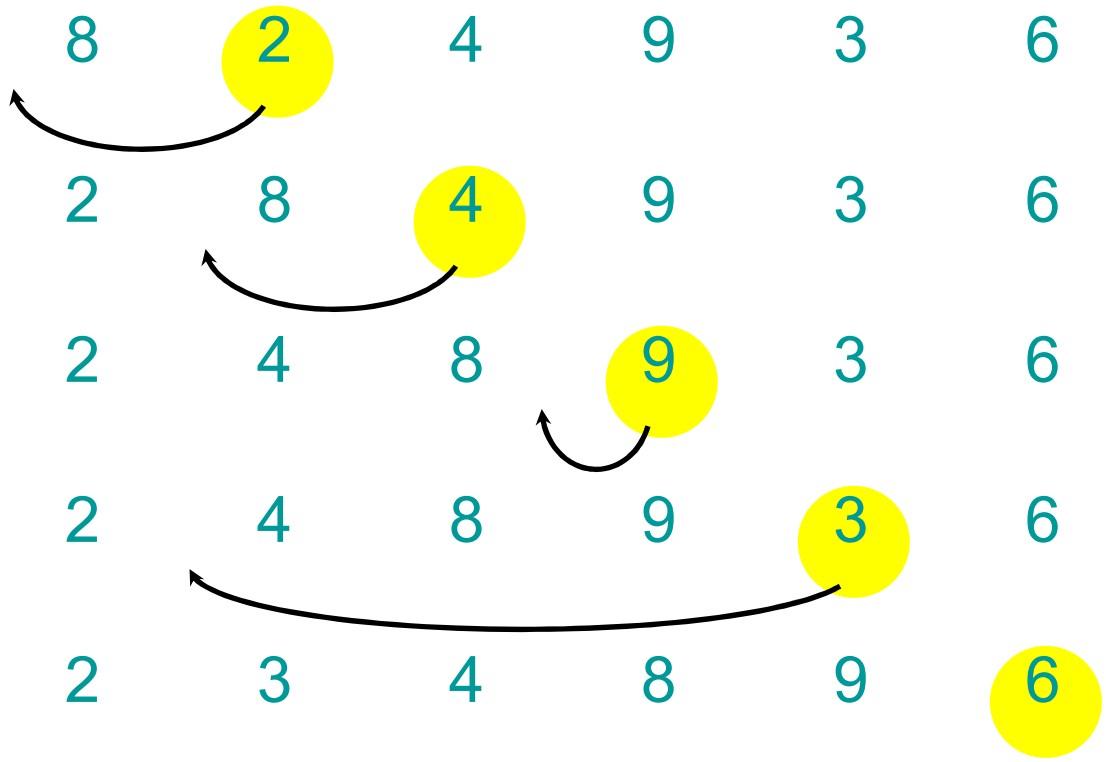

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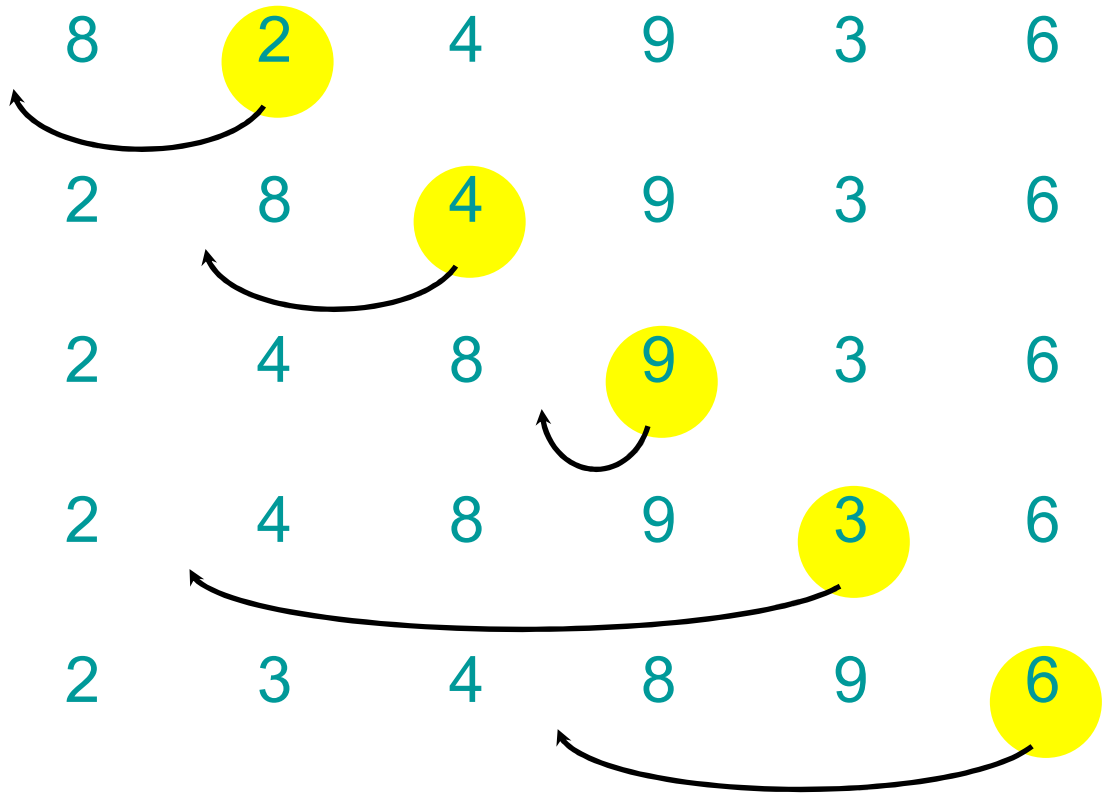

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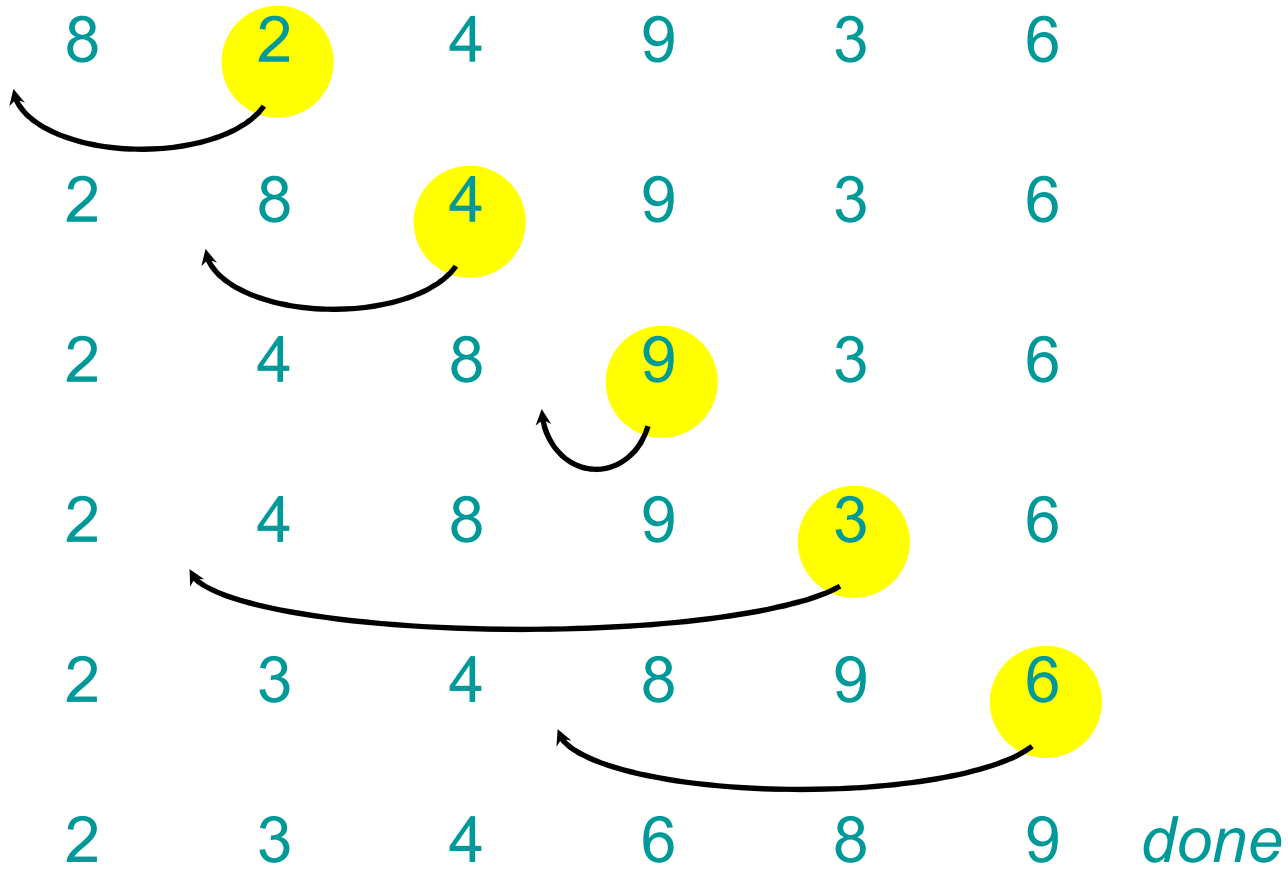

Running Time

- **Running Time**
  - Depends on the input
  - An already sorted sequence is easier to sort.
- **Major Simplifying Convention**
  - Parameterize the running time by the size of the input, since short sequences are easier to sort than long ones.
  - $T_A(n)$ = time of A on length n inputs. Generally, we seek upper bounds on the running time, to have a guarantee of performance.
- **Kinds of analyses**
  - **Worst-case:** (usually) T(n) = maximum time of algorithm on any input of size n
  - **Average-case:** (sometimes) T(n) = expected time of algorithm over all inputs of size n. Need assumption of statistical distribution of inputs.
  - **Best-case:** (Never) Cheat with a slow algorithm that works fast on some input.

Measuring Algorithm Complexity

- **How long does it take to execute a program?**
  - Efficient algorithm, the better
- **How long does it take to go from point A to Point B**

- **Need to know:**
  - Speed: Walk/driving
  - Distance: variable
  - Traffic condition
  - Walk?
  - Driving?

Analysis

- **Simplifications**
  - Ignore actual and abstract statement costs
  - Order of growth is the interesting measure:
    Highest-order term is what count
    Doing asymptotic analysis
    As the input size grows larger it is the high order term that dominates

- **Teaching Goals**
  - Show that by knowing more about the underlying algorithm design and analysis, one can be more effective as a computer scientist or engineer.

Upper Bound Notation

- **Definition**
  - In general, a function f(n) is O(g(n)) if there exist positive constants c and n_0 such that $f(n) \le c \cdot g(n)$ for all $n \ge n_0$
  - Formally, $O(g(n)) = \{ f(n): \exists$ positive constants c and n_0 such that $f(n) \le c \cdot g(n)$ $\forall\ n \ge n_0$

- **A polynomial of degree k is $O(n^k)$**
- **Proof:**

  Suppose $f(n) = b_k n^k + b_{k-1} n^{k-1} + \ldots + b_1 n + b_0$

  Let $a_i = | b_i |$

  $f(n) \le a_k n^k + a_{k-1} n^{k-1} + \ldots + a_1 n + a_0$

$$\le \quad n^k \sum a_i \frac{n^i}{n^k} \quad \le \quad n^k \sum a_i \quad \le \quad cn^k$$

Upper Bound Notation

- **We say InsertionSort's run time is $O(n^2)$**
  - Properly we should say run time is *in* $O(n^2)$; Read O as "Big-O"
- **Proof**
  - Suppose runtime is $an^2 + bn + c$;
  - If any of a, b, and c are less than 0 replace the constant with its absolute value
  - $an^2 + bn + c \leq (a + b + c)n^2 + (a + b + c)n + (a + b + c)$

    $\leq 3(a + b + c)n^2$

    for $n \geq 1$; Let $c' = 3(a + b + c)$ and let $n_0 = 1$
- **Questions**
  - Is InsertionSort $O(n^3)$?
  - Is InsertionSort $O(n)$?

Lower Bound Notation

- **Definition**
  - In general a function f(n) is $\Omega(g(n))$ if $\exists$ positive constants c and n_0 such that $0 \leq c \cdot g(n) \leq f(n) \quad \forall\ n \geq n_0$
- **We say InsertionSort's run time is $\Omega(n)$**
- **Proof**
  - Suppose run time is $a \cdot n + b$
  - Assume a and b are positive (what if b is negative?)

$a \cdot n \leq a \cdot n + b$

Asymptotic Tight Bound

- **Asymptotic Tight Bound Θ**
  - A function f(n) is Θ(g(n)) if ∃ positive constants c_1, c_2, and n_0 such that $c_1\, g(n) \le f(n) \le c_2\, g(n)$, $\forall\ n \ge n_0$
  - **Theorem:** f(n) is Θ(g(n)) iff f(n) is both O(g(n)) and Ω(g(n))
  - **Proof:** self practice
- **Other Asymptotic Tight Bounds**
  - A function f(n) is o(g(n)) if ∃ positive constants c and n_0 such that $f(n) < c\, g(n)$ $\forall\ n \ge n_0$
  - A function f(n) is ω(g(n)) if ∃ positive constants c and n_0 such that $c\, g(n) < f(n)$ $\forall\ n \ge n_0$
  - Intuitively,
    - o() is like <
    - ω() is like >
    - Θ() is like =
    - O() is like ≤
    - Ω() is like ≥

Course Goals

- **Teaching Style**
  - Algorithm courses have been traditionally taught by following textbooks and covering basic concepts and algorithms for different problems.
  - We're going to follow this style and additionally cover some fresh problems and algorithms appeared in FLG interviewing.
- **Teaching Goals**
  - Show that by knowing more about the underlying algorithm design and analysis, one can be more effective as a computer scientist or engineer.
  - Write programs that are more reliable and efficient for the specific goal.
  - Understand how program performance depends on underlying factors including the designed algorithm.
  - Learn how to implement an effective and efficient software system according to the request and the available resources (memory, communication, disk, GPU, etc.)

Course Expectation

- **What to expect from the course:**
  - Will cover key issues and concepts in class.
  - Recitations will provide review and teach you the ideas you need.
  - Programming Projects (Don't freak out… yet)
  - A mid-term exam and a final exam
  - Practice homework sets
- **What do I expect of you:**
  - Come to class
  - Read the textbook (Listening to me is not good enough)
  - Work through the problems in the textbook (not really homework… but it helps)
  - Do the projects
  - Ask questions (IMPORTANT)

Questions