Lecture 1 Introduction

CS101 Algorithms and Data Structures

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Outline

- What will we learn from this course?
- How we manage this course?

Why do we study this course?

Why do we study this course?

We asked ChatGPT and got the answers:

LI

I am an undergrad in CS, why do I need to study algorithms and data structures? List three top reasons.

Certainly! Here are the three top reasons why, as an undergrad in Computer Science, you need to study algorithms and data structures:

1. **Foundational Knowledge**: Algorithms and data structures are the core building blocks of computer science. They form the essence of problem-solving using computers and underpin almost all areas of computing, from systems programming to artificial intelligence.
2. **Efficiency in Problem Solving**: As you develop software or tackle computational problems, the choice of the right algorithm or data structure can dramatically affect performance. Understanding them ensures that you can design solutions that are both time-efficient and space-efficient, crucial for handling large datasets or real-time applications.
3. **Technical Interviews & Career Advancement**: If you're aspiring to work in the tech industry, proficiency in algorithms and data structures is a common assessment criterion during interviews. Many top tech companies value this knowledge highly, considering it a benchmark for assessing problem-solving skills and computer science competency.

Why do we study this course in the age of AI?

We asked ChatGPT and got the answers:

LI

I can just ask LLM to do algorithms and coding. Why do I need to study algorithms and data structures? List three top reasons.

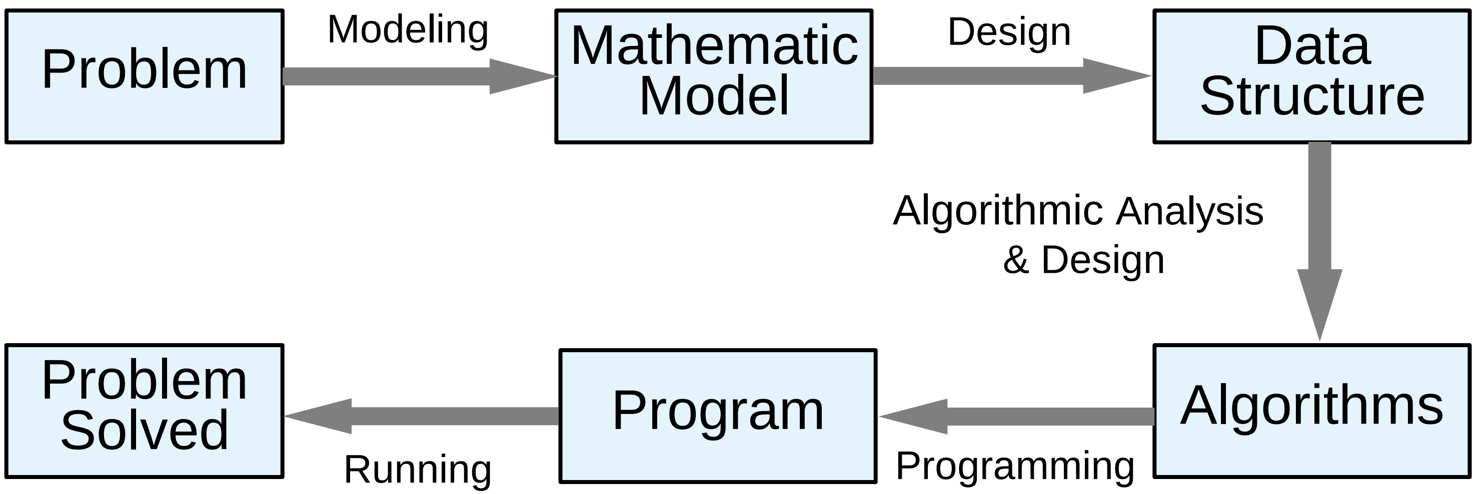
Absolutely! Here are the top three reasons:

1. **Deep Understanding & Optimization**: While LLM can generate algorithms and code, a profound understanding of algorithms and data structures allows you to evaluate, refine, and optimize these solutions. Without this foundational knowledge, you might accept inefficient or overly complex solutions provided by the LLM without questioning.
2. **Debugging & Troubleshooting**: Even if a machine learning model generates code, problems and bugs can arise. Understanding the underlying algorithms and data structures is vital to effectively diagnose, troubleshoot, and resolve issues, ensuring robust and reliable software.
3. **Versatility & Independence**: Relying solely on LLM limits your flexibility. A foundational understanding allows you to tailor solutions to specific needs, adapt to new challenges, and ensures you're not completely dependent on a tool that might not always grasp the nuanced requirements or constraints of every project.

Definition of Data Structure

- A data structure is a scheme for organizing data in the memory of a computer.
- The way in which the data is organized affects the performance of an algorithm for different tasks.
- 数据结构（data structure）是计算机中存储、组织数据的方式。通常情况下，精心选择的数据结构可以带来最优效率的算法（algorithm）。

How to combat problems via a computer



Ex1 How to arrange books on the bookshelf?

Ex1 How to arrange books on the bookshelf?

- The following two operations are essential for efficiently arranging your books:
  - **Operation 1:** how to insert new books?
  - **Operation 2:** how to find/access an existing book?

Ex1 How to arrange books on the bookshelf?

- **Method 1:** randomly insert new books.
  - **Operation 1:** how to insert new books?

    Insert the book wherever there is an available space.

    Nice and easy!

  - **Operation 2:** how to find/access an existing book?

    It depends …

Ex1 How to arrange books on the bookshelf?

- **Method 2:** insert new books according to the alphabets order of the first letter.
  - **Operation 1:** how to insert new books?

    EX: we bought a new book “Algorithm”.
  - **Operation 2:** how to find/access an existing book?

    EX: Binary search!

Ex1 How to arrange books on the bookshelf?

- **Discussion 1:** is **Method 2** absolutely better/more efficient than **Method 1**?

> **Method 1:** randomly insert new books.
>
> **Method 2:** insert new books according to the alphabets order of the first letter.

- **Discussion 2:** how can we further improve **Method 2**?

Ex1 How to arrange books on the bookshelf?

- **Method 3: cluster books according to different topics** (computer science, economics, agriculture, politics…), then insert new books according to the alphabets order of the first letter.
  - **Operation 1:** how to insert new books?

    EX: we bought a new book “Algorithm”.
  - **Operation 2:** how to find/access an existing book?

    EX: Binary search for topic first, then binary search for book title.
- **Discussion 3:** how much space we should preserve for each topic?

How many topics is an optimism option?

The efficiency of a method/algorithm highly depends on the organization&amount of the data.

Ex2 How to implement a function PrintN?

- Implement a function named PrintN, when input a positive integer N, print all the positive integer from 1 to N.

```
void PrintN ( int N )
{ int i;
  for ( i=1; i<=N; i++ ) {
        printf( "%d\n" , i);
}
return;
}
```

Loop implementation

```
void PrintN ( int N )
{ if (N);
   PrintN( N-1);
   printf( "%d\n" , N);
}
return;
}
```

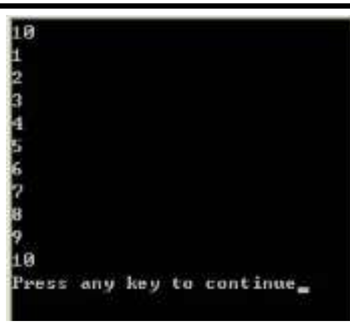
Recursive implementation

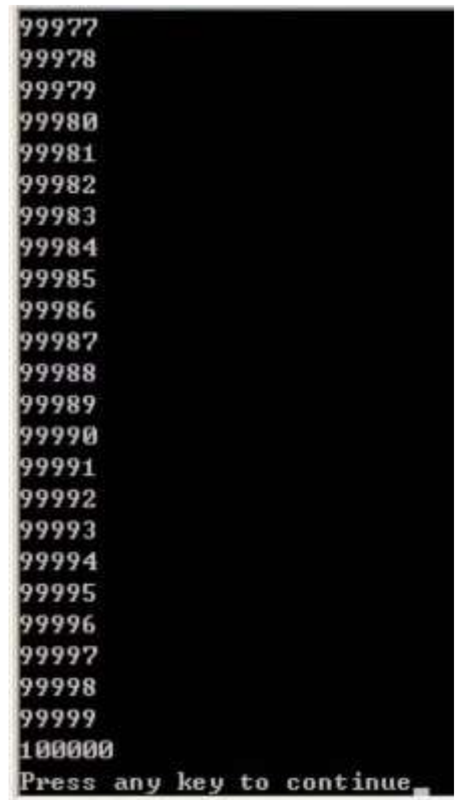
- Let N = 100, 1000, 10000, 100000, … …

Ex2 How to implement a function PrintN?

- Implement a function named PrintN, when input a positive integer N, print all the positive integer from 1 to N.

```
# include <stdio.h>
void PrintN ( int N );
int main ()
{ int N;
  scanf (“%d”, &N);
  PrintN(N);
  return 0;
}
```





Loop implementation

The efficiency of a method/algorithm depends on the occupation of RAM.

Ex3 compute the summation for a polynomial at a fixed value x.

$$f(x) = a_0 + a_1 x + a_2 x^2 + \cdots + a_{n-1} x^{n-1} + a_n x^n$$

```
double fpoly1 ( int n, double a[ ], double x )
{ int i;
  double p = a[0];
  for (i = 1; i <=n; i++)
       p += (a[i] * pow( x, i) );
  return p;
}
```

$$f(x) = a_0 + x(a_1 + x(a_2 + \cdots x(a_{n-1} + x(a_n)) \cdots))$$

```
double fpoly2 ( int n, double a[ ], double x )
{ int i;
  double p = a[n];
  for (i = n; i > 0; i-- )
       p = a[i-1]  + x* p;
  return p;
}
```

- clock(): capture consumed time for running a function. The unit of the captured time is ***clock tick***, which depends on the CPU.
- CLOCKS_PER_SEC is a constant that presents the number of ***clock ticks*** per second.

```c
#include <stdio.h>
#include <time.h>

clock_t  start, stop;
/* Clock_t is the variable returned by function clock(). */
double duration;
/* Record the running time for a function. Time unit is second. */
int main ()
{
   start = clock ();  /* Start timing. */
   Myfunction();
   stop = clock ();  /* Stop timing. */
   duration = ((double) (stop - start))/CLOCKS_PER_SEC;

  return 0;
}
```

Ex3 compute the summation for a polynomial $f(x) = \sum_{i=0}^{9} i \cdot x^i$ at a fixed value $x = 1.1$, $f(1.1)$.

```
double fpoly1 ( int n, double a[ ], double x )
{ int i;
  double p = a[0];
  for (i = 1; i <=0; i++)
       p += (a[i] * pow( x, i) );
  return p;
}
```

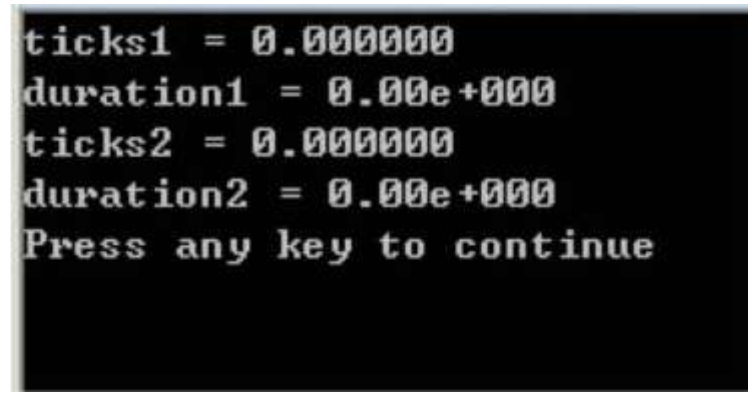
```
double fpoly2 ( int n, double a[ ], double x )
{ int i;
  double p = a[n];
  for (i = n; i > 0; i-- )
       p = a[i-1]  + x* p;
  return p;
}
```

$$f(x) = \sum_{i=0}^{9} i \cdot x^i$$

```
#include <stdio.h> #include <time.h> #include <math.h>
clock_t start, stop;
double duration;
#define MAXN 10  /*maximum order of the polynomial */
double fpoly1 ( int n, double a[ ], double x )
double fpoly2 ( int n, double a[ ], double x )
int main ()
{  int i;
   double a[MAXN]; /*save the coefficient of the
polynomial*/
   for ( i=0; i<MAXN; i++) a[i] = (double) i;

   start = clock ();
   fpoly1(MAXN-1, a, 1.1);
   stop = clock ();
   duration = ((double) (stop - start))/CLOCKS_PER_SEC;
   prinft ("ticks1 = %f\n",(double) (stop - start));
   prinft ("duration1 = %6.2e\n", duration));

   start = clock ();
  fpoly2(MAXN-1, a, 1.1);
  stop = clock ();
  duration = ((double) (stop - start))/CLOCKS_PER_SEC;
  prinft ("ticks1 = %f",(double) (stop - start));
  prinft ("duration1 = %6.2e\n", duration));
 return 0;
}
```



```c
#include <stdio.h>
#include <time.h>
#include <math.h>
……
#define MAXK 1e7
/*maximum repeat time of the test function */
……
int main ()
{ ……

  start = clock ();
  for ( i=0; i<MAXK; i++)
        fpoly1(MAXN-1, a, 1.1);  /* repeat the test function to get enough clock ticks*/
  stop = clock ();
  duration = ((double) (stop - start))/CLOCKS_PER_SEC/MAXK;
   /* compute running time for single function duration */
  printf (“ticks1 = %f\n”,(double) (stop - start));
  printf (“duration1 = %6.2e\n”, duration));

   ……

  return 0;
}
```

```
ticks1 = 10093.000000
duration1 = 1.01e-006
ticks2 = 1375.000000
duration2 = 1.38e-007
Press any key to continue
```

The efficiency of a method/algorithm depends on the design of the algorithm.

Definition of Data Structure

- ***Data structure***, way in which data are stored for efficient search and retrieval.
- Different data structures are suited for different ***operations***.
- ***Algorithm*** is a procedure for solving a mathematical pro blem in a finite number of steps that frequently involves repetition of an operation.

Abstract Data Type (ADT 抽象数据类型)

- Abstract: The method that we describe the data type, does not depend on the implementations.
  - Not related to the computer that stores the data.
  - Not related to the physical structure that stores the data.
  - Not related to the algorithm and language that implements the operation.

- We only care about “*how to design*” the objective data sets and related operations, not how to “*implement*” a data structure.

EX4 Abstract data type of a $\boldsymbol{matrix}$

Array?
Structural array? Orthogonal list?

- Data type: $Matrix$
- Objects: a $M \times N$ matrix $\mathrm{A}_{\mathrm{M}\times N} = (a_{ij})$ $(i = 1, \cdots, M; j = 1, \cdots, N)$ is composed by a number of $M \times N$ array of $< a, i, j >$, where a present the value of the matrix element, i present the no. of row, and j present the no. of column.
- Operations: for an arbitrary matrix $\mathrm{A}, \mathrm{B}, \mathrm{C} \in Matrix$, and integers i, j, M, N
- $Matrix\ create\ (int\ M, int\ N)$: return an empty matrix of $M \times N$;
- $int\ GetMaxRow(\ Matrix\ A\ )$: return the number of rows;
- $int\ GetMaxCol(\ Matrix\ A\ )$: return the number of columns;
- $ElementType\ GetEntry(\ Matrix\ A, int\ i, int\ j)$: return the element of matrix A in row i, column j;
- M$atrix\ Add\ (Matrix\ A,\ Matrix\ B)$: if the dimension of matrix A and B are the same, return matrix $C = A + B,$ otherwise error;
- $Matrix\ multiply\ (Matrix\ A,\ Matrix\ B)$: if the number of columns of matrix A is equals to the number of rows of matrix B, return matrix $C = AB$, otherwise return error;
- ……

The elements are added in order of rows or columns? C,C++,Python,…?

Outline

- What will we learn from this course?
- How we manage this course?

Course info

- **Instructors**
  - Yuyao Zhang zhangyy8@shanghaitech.edu.cn SIST 3-420
  - Dengji Zhao zhaodj@shanghaitech.edu.cn SIST 1A-304E
  - Xin Liu liuxin7@shanghaitech.edu.cn SIST 2-302H
  - Hao Geng genghao@shanghaitech.edu.cn SIST 3-332

Course info

- **TA Team**
  - We have 11 TAs who are capable to help
  - They will help on Piazza, Quiz and Homework
  - Will see them online and offline
  - Don’t cheat!!!

Course info

- **Classes**
  - Wed 8:15-9:55; Fri 8:15-9:55
- **Review/Quizzes/Discussions**
  - Format: 5 groups, about 45 students each (Week 3-16 Weekly)
  - Length: 60mins each time
  - Location: TBA
  - Time: TBA
  - Instructors: all TAs
  - Contents: quizzes, and homework solutions

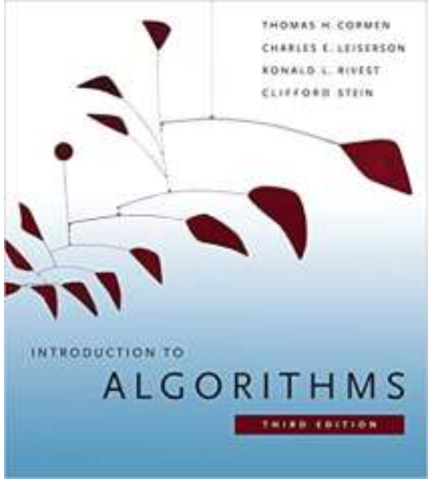
Course info

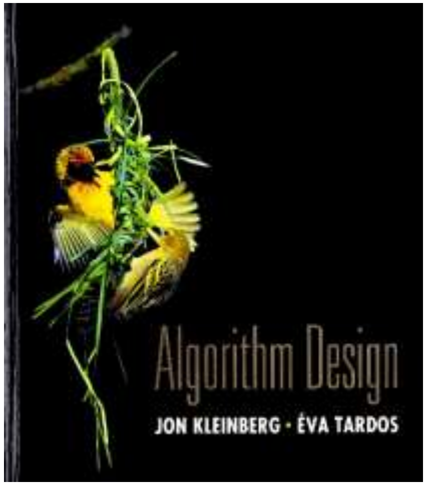
- Piazza Course Forum
  - piazza.com/shanghaitech.edu.cn/fall2024/cs101

    You are encouraged to ask questions and participate in discussions
  - Course schedule, slides, office hour etc. are published on the forum
  - Invitation will be sent to your ShanghaiTech email
- Office Hours
  - Location and Time: see course forum
- Homework
  - Submit to gradescope : see course forum

Course info

- Reference Book
  - Introduction to Algorithms (3rd ed.). Cormen, Thomas H., Leiserson, Charles E., Rivest, Ronald L., Stein, Clifford. MIT Press. ISBN，9780262033848.
  - Algorithm design. Jon Kleinberg, Éva Tardos. Pearson. ISBN, 978-0321295354.





Tentative Course Schedule

Week	**Date**	**Content**
1	9/18 Wed	Introduction
	9/20 Fri	Elementary Data Structures: Array Lists, Stack and Queue
2	9/25 Wed	Big O/Theta/Omega
	9/27 Fri	Hash Table
3	10/2	National Day
	10/4	National Day
4	10/9 Wed	Sorting: Insertion, Bubble
	10/11 Fri	Sorting: Merge
5	10/16 Wed	Sorting: Quick
	10/18 Fri	Divide and Conquer
6	10/23 Wed	Trees: Introduction, BFS, DFS (MCTS)
	10/25 Fri	Binary Trees
7	10/30 Wed	Heap and Heap Sort
	11/01 Fri	Binary Search Trees + Huffman Coding
8	11/06 Wed	Balanced Binary Search Trees: AVL
	11/08 Fri	Disjoint sets + Graphs: Introduction

Tentative Course Schedule

Week	Date	Content
9	11/13 Wed	Middle Term Exam
	11/15 Fri	Graphs: Traversal, Graph Cut for Image Segmentation
10	11/20 Wed	Minimum Spanning Trees
	11/22 Fri	Greedy
11	11/27 Wed	Topological Sorts
	11/29 Fri	Shortest Path Algorithm: Dijkstra
12	12/04 Wed	A*
	12/06 Fri	Floyd-Warshall Algorithm
13	12/11 Wed	Dynamic Programming
	12/13 Fri	Knapsack Problem
14	12/18 Wed	Heuristic DP (Intro to Reinforcement Learning)
	12/20 Fri	Reductions
15	12/25 Wed	P+NP
	12/27 Fri	NPC
16	01/01 Wed	New Year’s Day
	01/03 Fri	Review

Course Policy

- **Grading**
  - Exams (45%): middle term: 20%; final: 25%
  - Weekly Homework (20%): non-programming questions
  - Programming Tasks (20%): 4 programming tasks (each lasts 3 weeks)
  - In-Class Quizzes (15%): in lectures and discussions

Course Policy

- Plagiarism
  - All assignments must be done individually
    - You cannot copy directly from any other source
    - You cannot share solutions with any other students
    - Plagiarism detection software will be used on all the assignments
  - Ways of collaboration
    - You may discuss together or help another student such as debugging his or her code; however, you cannot dictate or give the exact solutions.

Course Policy

- Plagiarism
  - Punishment
    - When one student copied from another student, both students are responsible.
    - Zero point on the assignment or exam in question.
    - For programming assignment, one violation result in “-10”.
    - Disqualified from receiving any awards recommended by the school and from any competitive studying opportunities (e.g., international exchange).
    - Repeated violation will result in a F grade for this course as well as further punishment at the school/university level.

Plagiarism: Example 1

- Alex and Bob were roommates.
- Bob let Alex use his laptop to complete an assignment.
- Alex copied Bob’s solution for the assignment.

Plagiarism: Example 2

- Leslie asked if Morgan could send her his code so that she could look at it (promising, of course, not to copy it).
- Morgan sent the code.
- Leslie copied it and handed it in.

Plagiarism: Example 3

- Garry and Harry worked together on a single source file initially and then worked separately to finish off the details.
- The result was still noticeably similar with finger-print-like characteristics which left no doubt that some of the code had a common source.

Plagiarism: Example 4

- Jordan uploaded the projects to GITHUB.com without setting appropriate permissions. Kasey found this site, downloaded the projects and submitted them. Both are guilty.
  - This applies to any public forum, news group, etc., not just gitub.com…

Real Plagiarism Examples

- Copied a piece of the codes from others or online repositories.
- Copied someone's solution from his/her USB drive.
- Copied a piece of others' codes and change all the variable/function names.
- Unusual solutions appeared in different submissions.

Take Home Message

- Algorithms and Data Structure is ~~one of~~ the most important course during your undergraduate.

- You will sometimes feel it very tough, but please always keep on going, we are here to help.