IT2001
Data Structures
and
Algorithms

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Slides and figures have been collected from various publicly available Internet sources for preparing the lecture slides of IT2001 course. I acknowledge and thank all the original authors for their contribution to prepare the content.

Introduction

- A famous quote: Program = Algorithm + Data Structure.
- All of you have programmed; thus, have already been exposed to algorithms and data structures.
  - Perhaps you have not seen them as separate entities.
  - Perhaps you have seen data structures as simple programming constructs (provided by libraries).
  - However, data structures are quite distinct from algorithms, and very important in their own right.

Data Structures and Algorithms

- Study of Data Structures & Algorithms: Fundamental to Computer Science
- Not only Computer Science and Engineering, but also other allied engineering disciplines such as
  - Computer Integrated Manufacturing,
  - Product Design,
  - Commerce, and
  - Communication Engineering, to list a few

Data Structures and Algorithms

- It is offered as a core or an elective course, enabling students to have the much-needed foundation for efficient programming, leading to better problem-solving skill.

Data Structures

- How does Google find the documents matching your query so fast?
  - Uses sophisticated algorithms to create index structures, which are just data structures.
- With the amount of data created by the new technologies, the need to organize, search, and update MASSIVE amounts of information FAST is more severe than ever before.

What is data?

- **Data**
  - A collection of facts from which conclusion may be drawn.
  - e.g., Temperature 35°C; Conclusion: It is hot.
- **Types of data**
  - Textual: name
  - Numeric: Roll no
  - Audio: your voice
  - Visual data: images and videos

Data Types & Data Structures

- Applications/programs read data, store data temporarily, process it and finally output results.
- It plays a vital role in enhancing the performance of a software or a program as the main function of the software is to store and retrieve the user's data as fast as possible

Data Types & Data Structures

- Data is classified into **data types**. e.g., char, float, int, etc.
- A data type is
  - a **domain** of allowed values and
  - set of **operations** on these values.
- Compiler signals an error if wrong operation is performed on data of a certain type.
  - For example, `char x,y,z; z = x*y` is not allowed.

Data Types & Data Structures

Data Type	Domain	Operations
boolean	0,1	and, or, =, etc.
char	ASCII	=, <>, <, etc.
integer	-maxint to +maxint	+, _, =, ==, <>, <, etc.

- **Simple Data** types: also known as atomic data types
  - have no component parts. e.g., int, char, float, etc.

21 3.14 ‘a’

What is data structure?

- A particular way of storing and organizing data in a computer so that it can be used efficiently and effectively.
- Data structure is the logical or mathematical model of a particular organization of data.
- A group of data elements grouped together under one name.
  - For example, an array of integers

What the course is About

- Data Structures
  - Data Structures define how data is stored in RAM
  - How to efficiently store, access, manage data
  - Data structures effect algorithm’s performance
- Analysis:
  - How to predict an algorithm’s performance
  - How well an algorithm scales up
  - How to compare different algorithms for a problem

Data Structures and Algorithms

- Efficient problem-solving using computers, irrespective of the discipline or application, calls for the design of efficient algorithms
  - Inclusion of appropriate data structures is of critical importance to the design of efficient algorithms
- In other words, good algorithm design must go hand in hand with appropriate data structures for efficient program design to solve a problem

Example Algorithms

- Two algorithms for computing the Factorial
- Which one is better?

```
int factorial (int n) {
  if (n <= 1)    return 1;
  else   return n * factorial(n-1);
     }
```

```
int factorial (int n) {
     if (n<=1)    return 1;
        else {
           fact = 1;
           for (k=2; k<=n; k++)
               fact *= k;
               return fact;
           }
        }
```

Examples of famous algorithms

- Euclid algorithm
- Newton's root finding
- Fast Fourier Transform
- Compression (Huffman, Lempel-Ziv, GIF, MPEG)
- DES, RSA encryption
- Simplex algorithm for linear programming
- Shortest Path Algorithms (Dijkstra, Bellman-Ford)
- Error correcting codes (CDs, DVDs)
- TCP congestion control, IP routing
- Pattern matching (Genomics)
- Search Engines

Role of algorithms in the modern world

- Enormous amount of data
  - E-commerce (Amazon, Ebay, Flipcart)
  - Network traffic (telecom billing, monitoring)
  - Search engines (Google)
  - Database transactions (Sales, inventory)
  - Scientific measurements (astrophysics, geology)
  - Sensor networks, RFID tags
  - Bioinformatics (genome, protein bank)

Why study data structures (and algorithms)

- Using a computer?
  - Solve computational problems?
  - Want it to go faster?
  - Ability to process more data?
- Technology vs. Performance/cost factor
  - Technology can improve things by a constant factor
  - Good algorithm design can do much better and may be cheaper
  - Supercomputer cannot rescue a bad algorithm
- Data structures and algorithms as a field of study
  - Old enough to have basics known
  - New discoveries
  - Rapidly increasing application areas

Data Structures

- The representation of a particular data structure in the main memory of a computer is called as storage structure.
- The storage structure representation in auxiliary memory is called as file structure.
- **Algorithm + Data Structure = Program**
- **Data Structure study covers the following points**
  1) Representation of data in memory
  2) Operations performs on data
  3) Amount of memory require to store
  4) Amount of time require to process

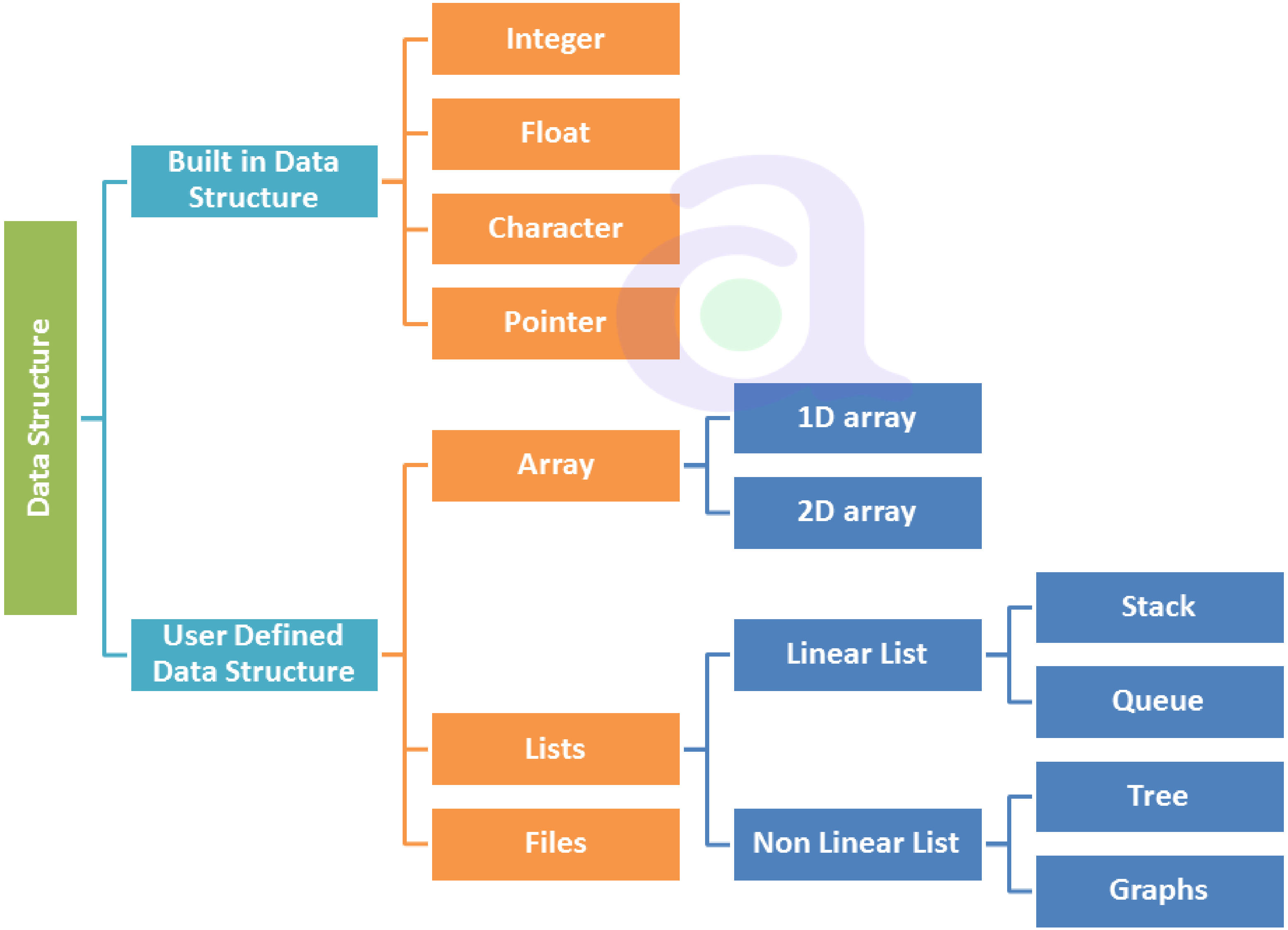
Operation on Data Structures

- Design of efficient data structure must take operations to be performed on the DS into account. The most commonly used operations on DS are broadly categorized into following types
- **Create:** This operation results in reserving memory for program elements.
  - Creation of DS may take place either during compile-time or run-time.
- **Delete:** This operation destroys memory space allocated for specified data structure .
- **Selection:** This operation deals with accessing a particular data within a data structure.
- **Update:** It updates or modifies the data in the data structure.
- **Search:** It finds the presence of desired data item in the list of items

Operation on Data Structures

- Design of efficient data structure must take operations to be performed on the DS into account. The most commonly used operations on DS are broadly categorized into following types
- **Sorting:** This is a process of arranging all data items in a DS in particular order, for example either ascending order or in descending order.
- **Splitting:** It is a process of partitioning single list to multiple list.
- **Merging:** It is a process of combining data items of two different sorted list into single sorted list.
- **Traversing:** It is a process of visiting each and every node of a list in systematic manner.

Source: https://www.researchgate.net/publication/347303319_Data_Structure_Ppt



Types Of DS

The DS are divided into two types:

1) Primitive
2) Non primitive

Non primitive divided into two type

1) Linear DS
2) Nonlinear DS

Primitive Data Types

- Primitive Data Structure are basic structure and directly operated upon by machine instructions.
- Primitive data structures have different representations on different computers.
- These data types are available in most programming languages as built-in type.
  - **Integer:** It is a data type which allows all values without fraction part.
  - **Float:** It is a data type which is use for storing fraction numbers.
  - **Character:** It is a data type which is used for character values.
  - **Pointer:** A variable that hold memory address of another variable are called pointer.

Non-Primitive Data Type

- These are more sophisticated data structures.
- These are derived from primitive data structure.
- The non – primitive data structures emphasize structuring of a group of homogeneous or heterogeneous data items.
- Example of non – primitive data types are Array, List, and File etc.
- A non – primitive data type is further divided into
  - Linear and non – Linear data structure.

Array: An array is a fixed size sequenced collection of elements of the same data type.

List: An ordered set containing variable number of elements is called as List.

File: A file is a collection of logically related information. It can be viewed as a large list of records consisting of various fields.

Course Structure

- Notion of Algorithm, Space and Time Complexity, Analyzing algorithms
- Static & Dynamic Memory Management: Arrays, Stacks, Queues, Linked Lists
- Trees, Binary Trees, Tree Traversals, Applications of Binary Tree
- Graphs and their representations, Graph Traversal Algorithms, Minimum Spanning Tree, Shortest Paths
- Searching Algorithms: Sequential Search, Binary Search
- Sorting Algorithms: Quick sort, Merge sort, Insertion sort, Selection sort, Heap & Heap sort
- Binary Search Tree, Balanced Tree, AVL Tree
- Files, Indexing: Hashing, Tree Indexing: B-tree
- Basic Algorithm Design Paradigms: Divide & Conquer, Greedy method, Dynamic Programming, Back tracking, Branch and Bound [Discussion with the help of some example which are already discussed].

Text Books

- Textbook
  - Introduction to Algorithms, Cormen, Leiserson, and Rivest, MIT Press/McGraw-Hill, Cambridge (Theory)
  - *Fundamentals of Data Structures* by Ellis Horowitz, Sartaj Sahni, Galgotia Booksource
- References
  - *Data Structures and Algorithm Analysis in C or C++ by Mark Allen Weiss*
  - *Data Structures* by Seymour Lipschutz, Schaum's Outlines, TMH
  - The C Programming language, Kernigham & Ritchie
  - Other material will be posted

Grading Scheme

- Assignments: for your practice only
- Quiz1: 10%
- Quiz2:10%
- Mid Sem: 25%
- End Sem: 35%
- Lab work: 20%

Algorithm

- An algo is a sequence of computational steps that transform the input into output
  - The statement of the problem specifies in general terms the desired input/output relationship
  - The algo describes a specific computational procedure for achieving that input/output relationship
- An algorithm can be specified
  - in natural language like English,
  - as a computer program, or
  - as a hardware design
- The only requirement is that the specification must provide a precise description of the computational procedure to be followed

Algorithm

- Example: sorting
  - Fundamental operation in CS; a number of sorting algorithms are available
  - Which algorithm is best for a given application depends on a number of factors:
    - The number of items to be sorted
    - The extent to which the items are already sorted
    - Possible restrictions on the item values
    - The kind of storage device to be used
- Goal: To learn techniques of algorithm design and analysis so that you can
  - Develop algorithms on your own
  - Show that they give the correct answer, and
  - Understand their efficiency

Algorithm as a Technology

- Suppose computers are infinitely fast and computer memory is free
  - would you have any reason to study algorithms?
  - You would still like to demonstrate that your solution method terminates and does so with the correct answer
- Of course, computers may be fast, but not infinitely fast and memory may be cheap, but it is not free
- Computing time and memory space: bounded resources
- These resources should be used wisely, and algorithms that are efficient in terms of time/space will help you do so
- Algorithms devised to solve the same problem often differ dramatically in their efficiency
- These differences can be much more significant than differences due to h/w and s/w

Algorithm as a Technology: Efficiency

- Consider two sorting methods:
  - Insertion sort
    - Takes time roughly equal to c_1n^2 to sort n items
    - c_1 is a constant that does not depend on n
  - Merge sort
    - Takes time roughly equal to $c_2n\log_2 n$ to sort n items
    - c_2 is another constant that also does not depend on n
  - Usually, $c_1 < c_2$
- The constant factors are far less significant in the running time than the input size n
- Insertion sort is usually faster than merge sort for small input sizes, but once the input size n becomes large enough, merge sort's advantage of $\log_2 n$ Vs n will more than compensate for the difference in constant factors

No matter how much smaller c_1 is than c_2, there will always be a crossover point beyond which merge sort is faster

Algorithm as a Technology: Efficiency

- Computer A: faster: running insertion sort
  - speed: 1 billion instructions/sec (10^9 inst/sec)
- Computer B: slower: running merge sort
  - speed: 10 million instructions/sec (10^7 inst/sec)
- Input size: n= 1 million numbers
- To make the difference even more dramatic
  - Insertion sort: written in m/c language and takes $2n^2$ instructions
  - Merge sort: written in high-level language and takes $50n\log_2 n$ instructions
- To sort 1 million numbers:
  - Computer A takes: 2000 secs
  - Computer B takes: ~100 secs
- By using an algorithm whose running time grows more slowly, computer B runs 20 times faster than computer A
- The advantage of merge sort is even more pronounced when we sort 10 million numbers

Insertion sort takes approx 2.3 days

merge sort takes under 20 mins

In general, as the problem size increases, so does the relative advantage of merge sort

Algorithms and other Technologies

- So, algorithms are also a technology like computer hardware
- Total system performance depends on choosing efficient algorithms as much as on choosing fast h/w

Algorithms and other Technologies

- Moreover, even an application that does not require algorithmic content at the application level relies heavily upon algorithms
- Does the application rely on fast h/w?

  The h/w design used algorithm

- Does the application rely on GUIs?

  The design of any GUI relies on algorithm

- Does the application rely on networking?

  Routing in networks relies heavily on algorithm

- Does the application written in a language other than machine language?

  Then it is processed by compiler, interpreter, or assembler, all of which make extensive use of algorithm

Algorithms and other Technologies

- Algorithms are at the core of most technologies used in contemporary computers
- Furthermore, with the ever-increasing capacities of computers, we can use them to solve larger problems than ever before
- At larger problem sizes, the differences in efficiencies between algorithms become particularly prominent

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