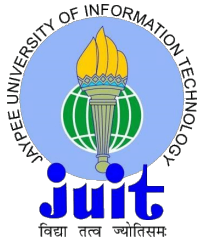

DATA STRUCTURES

(Course Code: 25B11CI318)

Overview

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What is a Data Structure?

Definition

A **data structure** is a logical or mathematical model that defines how data is organized, stored, and related, along with the operations that can be performed on it to achieve efficient computation.

Formal Definition (Horowitz & Sahni)

A data structure is a collection of data elements whose organization is characterized by the relationships among the data elements and the operations that can be performed on the data.

Mathematical Representation

A data structure d is represented as

$$\boxed{d = (D, F, A)}$$

where

D – Domain / Data Values

A finite set of data elements (domain of values).

A – Axiom/ Rules

A set of rules that specify how the functions operate and interact with the data values.

F – Functions / Operations

A set of operations that manipulate the data.

- Insert, Delete,
- Search,
- Traverse
- Update

Example: Linked List

Consider the linked list

$$10 \longrightarrow 20 \longrightarrow 30 \longrightarrow \texttt{NULL}$$

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Data (D):

Example: Linked List

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Data (D): $\{10, 20, 30\}$

Operations (F):

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Operations (F): $\{\text{Insert}, \text{Delete}, \text{Search}, \text{Traverse}, \text{Update}\}$

Axiom (A):

Example: Linked List

Consider the linked list

$$10 \longrightarrow 20 \longrightarrow 30 \longrightarrow \texttt{NULL}$$

Data (D): $\{10, 20, 30\}$

Operations (F): $\{\text{Insert}, \text{Delete}, \text{Search}, \text{Traverse}, \text{Update}\}$

Axiom (A): Rule: To get to 30, you must pass through 10 and 20 first.

$$\boxed{\mathit{LinkedList} = (D, F, A)}$$

Example: Stack

Consider the following stack:

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Data (D): $\{10, 20, 30\}$

Axiom (A): Elements are organized as **LIFO** (Last-In, First-Out) principle.

Functions (F): $\{\text{Push}, \text{Pop}, \text{Peek}, \text{IsEmpty}, \text{IsFull}\}$

$$\boxed{Stack = (D, F, A)}$$

Classification of Data Structures

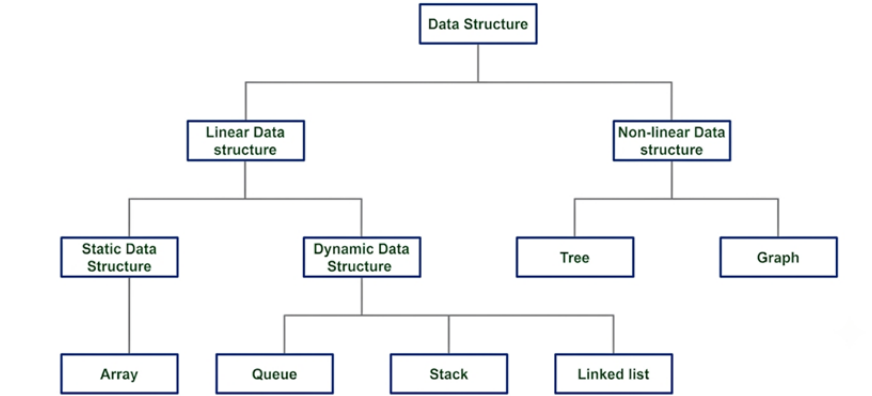

Figure: Classification of Data Structures

Classification of Data Structures

Data structures are broadly classified into two categories:

1. **Linear Data Structures**
   - Elements are arranged sequentially.
   - Each element (except the first and last) has a unique predecessor and successor.
2. **Non-linear Data Structures**
   - Elements are organized hierarchically or as a network.
   - One element can be connected to multiple elements.

Linear Data Structures

A **Linear Data Structure** stores elements in a sequential order.

Types

- **Static Data Structure**
  - Memory size is fixed.
  - Example: **Array**
- **Dynamic Data Structure**
  - Memory size can grow or shrink during execution.
  - Examples:
    - Linked List
    - Stack
    - Queue

Non-linear Data Structures

A **Non-linear Data Structure** organizes data in a hierarchical or network form.

Examples include:

- **Tree**
  - Hierarchical organization.
  - Used in file systems, databases, expression trees.
- **Graph**
  - Collection of vertices connected by edges.
  - Used in social networks, maps, routing algorithms.

What is an Array?

Definition

An array is a collection of elements of the same data type stored in **contiguous memory locations**.

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Example

$$A = \{10, 20, 30, 40, 50\}$$

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Example

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Properties

- Same data type
- Fixed size
- Continuous memory
- Indexed access

Array Representation

10	20	30	40	50
0	1	2	3	4

Index

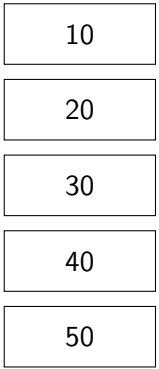
Each element is accessed using its index.

$$A[0] = 10$$

$$A[3] = 40$$

Characteristics of Arrays

- Homogeneous
- Fixed size
- Random access
- Contiguous memory
- Cache friendly



Memory Representation of an Array

Example:

$$int\ A[5] = \{10, 20, 30, 40, 50\}$$

Assume:

- Base Address = 1000
- Size of Integer = 4 Bytes

Index 0	Index 1	Index 2	Index 3	Index 4
10	**20**	**30**	**40**	**50**
1000	1004	1008	1012	1016

Observation

Array elements are stored in **contiguous (adjacent)** memory locations.

Address Calculation Formula

For a one-dimensional array,

$$\boxed{Address(A[i]) = Base + i \times Size}$$

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Example

$$Base = 1000, \qquad Size = 4$$

Find address of

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Example

$$Base = 1000, \qquad Size = 4$$

Find address of

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Important

Index always starts from 0.

Declaration and Initialization

Declaration

```
1 int A[5];
2 float marks[100];
3 char name[20];
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1 int A[5];
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```
1 int A[5]={10,20,30,40,50};
2
3 int B[]={5,10,15,20};
4
5 int C[5]={1,2};
```

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int A[5]={10,20,30,40,50};

int B[]={5,10,15,20};

int C[5]={1,2};
```

Note

If fewer values are provided, the remaining elements are initialized to zero.

Traversal of an Array

Traversal means visiting every element exactly once.

```
for(int i=0;i<n;i++)
{
    printf("%d ",A[i]);
}
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$$\boxed{\textit{Time Complexity} = O(n)}$$

Accessing Array Elements

Given

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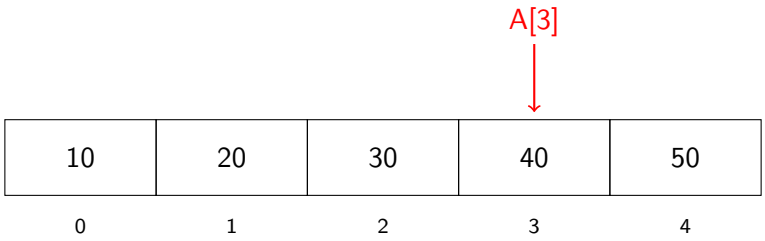

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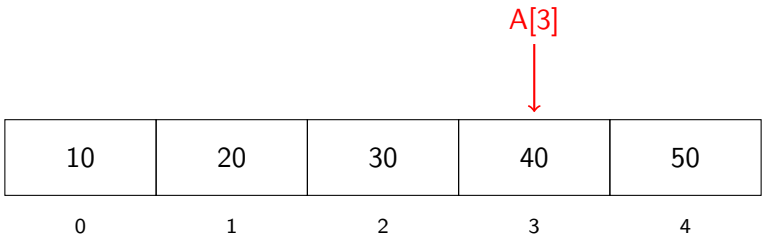

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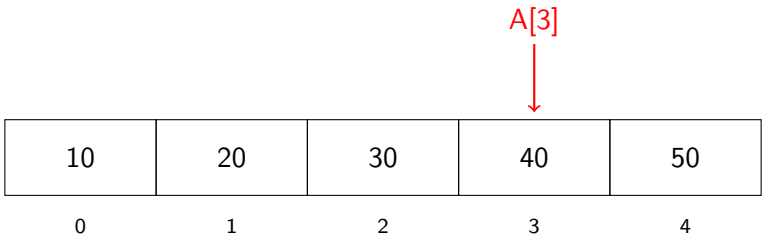

$$A[0] = 10$$

Updating an Array Element

Suppose

$$A = \{10, 20, 30, 40, 50\}$$

Replace

$$40 \rightarrow 45$$

Updating an Array Element

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```
A[3]=45;
```

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Updated Array

10 20 30 45 50

Updating an Array Element

Suppose

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Replace

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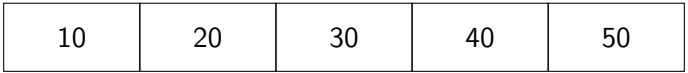
Updated Array

10 20 30 45 50

$$\boxed{\textit{Time Complexity} = O(1)}$$

Insertion in an Array

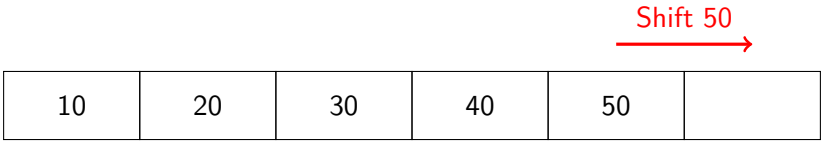
Insert 25 at Position 2



Current Array

Insertion in an Array

Insert 25 at Position 2



Time Complexity $= O(n)$

Insertion in an Array

Insert 25 at Position 2

Insertion Completed

$$\boxed{\text{Time Complexity } = O(n)}$$

Deletion from an Array

Delete 30

Deletion from an Array

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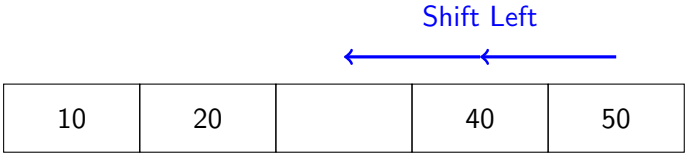

$O(n)$

Deletion from an Array

Delete 30

Deletion Completed

$O(n)$

Linear Search

Search Key = 40

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Algorithm

```
for(i=0;i<n;i++)
{
 if(A[i]==key)
   return i;
}
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Time Complexity

$O(n)$

Binary Search

Sorted Array

10	20	30	40	50	60	70

Search = 60

Binary Search

Sorted Array

10 20 30 40 50 60 70

Search = 60

Step 1

Middle =40

Discard Left Half

Binary Search

Sorted Array

10 20 30 40 50 60 70

Search = 60

Step 1

Middle =40

Discard Left Half

Step 2

Remaining

50 60 70

Middle =60; Found

Binary Search

Sorted Array

10 20 30 40 50 60 70

Search = 60

Step 1

Middle =40

Discard Left Half

Step 2

Remaining

50 60 70

Middle =60; Found

$O(\log n)$

Time Complexity Analysis

Operation	Best	Worst
Access	O(1)	O(1)
Traversal	O(n)	O(n)
Linear Search	O(1)	O(n)
Binary Search	O(1)	O(log n)
Insertion	O(1)	O(n)
Deletion	O(1)	O(n)
Updating	O(1)	O(1)

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Operation	Best	Worst
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Updating	O(1)	O(1)

Insertion and deletion require shifting elements.

Advantages and Disadvantages

Advantages

- Random Access
- Simple Implementation
- Cache Friendly
- Less Memory Overhead
- Fast Retrieval

Disadvantages

- Fixed Size
- Expensive Insertion
- Expensive Deletion
- Memory Wastage
- Overflow Possible

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If insertion and deletion are expensive,
what data structure can solve this problem?

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Linked List