AMRITA VISHWA VIDYAPEETHAM
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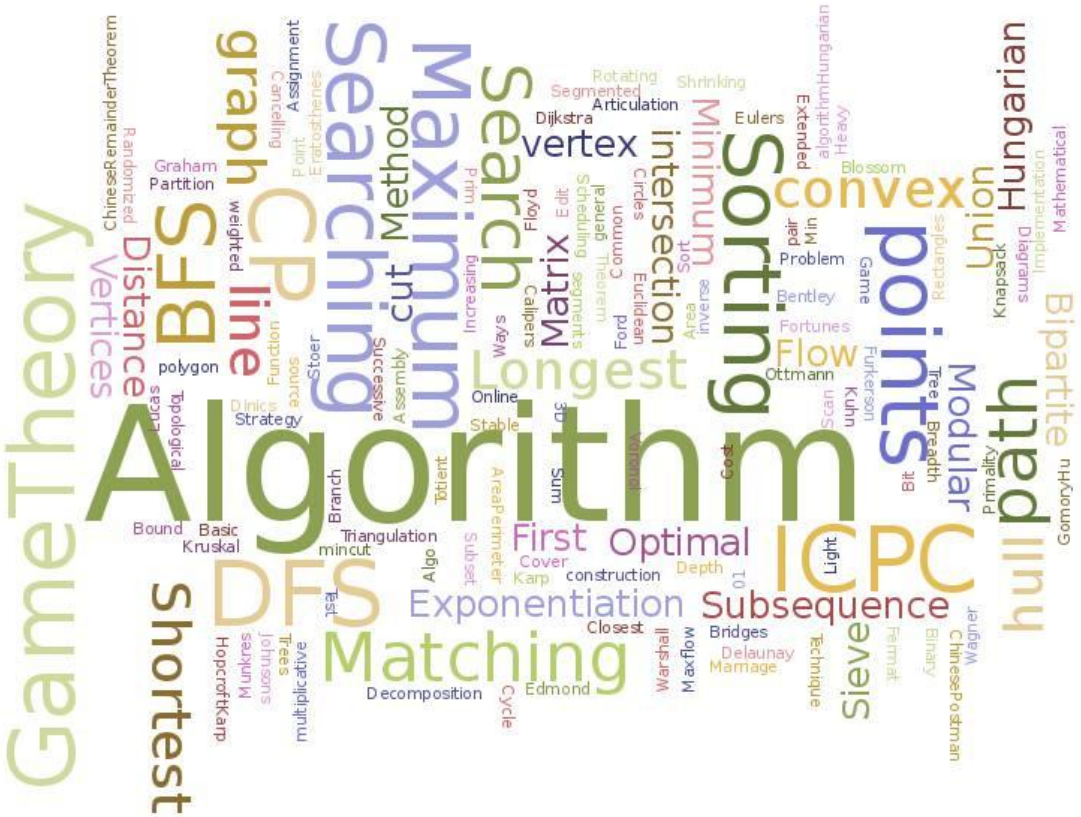
SCHOOL OF COMPUTING

Design and Analysis of Algorithms Lab 6 Report

(Course Code: 23CSE211)



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Programs and Their Space Complexities Date: 27-11-2025

1. Write a program to find the sum of first *n* natural numbers using a function.

2. Write a program to find the sum of squares of first *n* natural numbers.

3. Write a program to find the sum of cubes of first *n* natural numbers.

4. Write a program to find factorial of a number using a recursive function.

5. Write a program to find the transpose of a 3×3 matrix.

6. Write a program to print the Fibonacci series using recursion.

Solutions:

Write a program to find the sum of first *n* natural numbers using a function.

```c
#include <stdio.h>

int sumOfNums(int n){
  return ((n*(n+1))/2);
}

int main(){
  int  n;
  scanf("%d", &n);
  int sum = sumOfNums(n);
  printf("The sum is: %d\n", sum);
}
```

Justification: Uses the formula n(n+1)/2, which calculates the total directly.
Space Complexity: O(1)

Write a program to find the sum of squares of first *n* natural numbers.

```c
#include <stdio.h>

int sumOfSquaresNums(int n){
  return ((n*(n+1)*(2*n+1))/6);
}

int main(){
  int  n;
  scanf("%d", &n);
  int sum = sumOfSquaresNums(n);
  printf("The sum is: %d\n", sum);
}
```

Justification: Uses the formula n(n+1)(2n+1)/6, computes the sum directly.

Space Complexity: O(1)

Write a program to find the sum of cubes of first *n* natural numbers.

```c
#include <stdio.h>

int sumOfCubeNums(int n){
  return ((n*n*(n+1)*(n+1))/4);
}

int main(){
  int  n;
  scanf("%d", &n);
  int sum = sumOfCubeNums(n);
  printf("The sum is: %d\n", sum);
}
```

Justification: Uses the formula $[(n(n+1))/2]^2$, which calculates the total directly.

Space Complexity: O(1)

Write a program to find factorial of a number using a recursive function.

```c
#include <stdio.h>

int factorial(int n){
    if(n ==0 || n == 1){
      return 1;
    }
    else{
      return n*factorial(n-1);
    }
}

int main(){
  int n;
  scanf("%d", &n);
  int res = factorial(n);
  printf("The factorial is: %d\n", res);
}
```

Justification: Uses recursive calls that reduce n step-by-step until the base case is reached.
Space Complexity: O(n)

Write a program to find the transpose of a 3×3 matrix.

```c
#include <stdio.h>

int main(){
  int arr[3][3];
  for(int i = 0; i<3; i++){
    for(int j = 0; j<3; j++){
      scanf("%d", &arr[j][i]);
      }
  }

  for(int i = 0; i<3; i++){
    for(int j = 0; j<3; j++){
      printf("%d ", arr[i][j]);
      }
      printf("\n");
  }
}
```

Justification: Uses a fixed 3×3 array and stores each element directly in its transposed position during input.

Space Complexity: O(1)

Write a program to print the Fibonacci series using recursion.

```c
#include <stdio.h>

int fibonacci(int n){
  if(n == 1){
    return 0;
  } else if (n == 2){
    return 1;
  }
  else{
    return fibonacci(n-1) + fibonacci(n-2);
  }
}

int main(){
  int n;
  scanf("%d", &n);
  for(int i = 1; i⩽n; i++){
    printf("%d ", fibonacci(i));
  }
}
```

Justification: Uses recursive calls that expand until the base cases are reached.
Space Complexity: O(n)

Sorting Techniques Date: 04-12-2025

1. Bubble Sort in C
2. Insertion Sort in C
3. Selection Sort in C
4. Bucket Sort in C
5. Heap Sort in C (Max Heap)
6. Heap Sort in C (Min Heap)

Bubble Sort in C

```c
#include <stdio.h>

void bubbleSort(int a[], int n) {
    for(int i = 0; i < n-1; i++) {
        for(int j = 0; j < n-i-1; j++) {
            if(a[j] > a[j+1]) {
                int temp = a[j];
                a[j] = a[j+1];
                a[j+1] = temp;
            }
        }
    }
}

int main() {
    int a[] = {5, 1, 4, 2, 8};
    int n = sizeof(a)/sizeof(a[0]);
    bubbleSort(a, n);
    for(int i = 0; i < n; i++) printf("%d ", a[i]);
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> gcc bubblesort.c
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> ./a.exe
1 2 4 5 8
PS C:\Users\sarva\OneDrive\Desktop\daa-lab>
```

Time Complexity (Worst): $O(n^2)$

Justification: Every pass compares and swaps almost all elements.

Space Complexity (Worst): O(1)

Justification: In-place sorting using only a temporary variable

Insertion Sort in C

```c
#include <stdio.h>

void insertionSort(int a[], int n){
    for (int i = 1; i < n; i++){
        int key = a[i];
        int j = i - 1;

        while (j >= 0 && a[j] > key){
            a[j + 1] = a[j];
            j--;
        }
        a[j + 1] = key;
    }
}

int main(){
    int a[] = {12, 11, 13, 5, 6};
    int n = sizeof(a) / sizeof(a[0]);

    insertionSort(a, n);

    for (int i = 0; i < n; i++)
        printf("%d ", a[i]);
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> gcc insertionsort.c
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> ./a.exe
5 6 11 12 13
PS C:\Users\sarva\OneDrive\Desktop\daa-lab>
```

Time Complexity (Worst): $O(n^2)$

Justification: Each new element may shift through the entire sorted portion.

Space Complexity (Worst): $O(1)$

Justification: Uses the same array for sorting.

Selection Sort in C

```c
#include <stdio.h>

void selectionSort(int a[], int n){
    for (int i = 0; i < n - 1; i++){
        int min = i;
        for (int j = i + 1; j < n; j++)
            if (a[j] < a[min])
                min = j;

        int temp = a[i];
        a[i] = a[min];
        a[min] = temp;
    }
}

int main(){
    int a[] = {64, 25, 12, 22, 11};
    int n = sizeof(a) / sizeof(a[0]);

    selectionSort(a, n);

    for (int i = 0; i < n; i++)
        printf("%d ", a[i]);
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> gcc selectionsort.c
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> ./a.exe
11 12 22 25 64
PS C:\Users\sarva\OneDrive\Desktop\daa-lab>
```

Time Complexity (Worst): $O(n^2)$

Justification: Always scans remaining elements to find the minimum.

Space Complexity (Worst): $O(1)$

Justification: Only one extra variable is used.

Bucket Sort in C

```c
#include <stdio.h>

#define MAX 100

void bucketSort(int a[], int n){
    int bucket[MAX] = {0};

    for (int i = 0; i < n; i++)
        bucket[a[i]]++;

    int k = 0;
    for (int i = 0; i < MAX; i++)
        while (bucket[i]--)
            a[k++] = i;
}

int main(){
    int a[] = {4, 1, 3, 4, 2, 8, 7};
    int n = sizeof(a) / sizeof(a[0]);
    bucketSort(a, n);
    for (int i = 0; i < n; i++)
        printf("%d ", a[i]);
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> gcc bucketsort.c
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> ./a.exe
1 2 3 4 4 7 8
PS C:\Users\sarva\OneDrive\Desktop\daa-lab>
```

Time Complexity (Worst): $O(n^2)$

Justification: All elements may fall into a single bucket.

Space Complexity (Worst): $O(n + k)$

Justification: Requires extra buckets plus storage for all elements.

Heap Sort using Max Heap in C

```c
#include <stdio.h>

void heapifyMax(int a[], int n, int i){
    int largest = i;
    int left = 2 * i + 1;
    int right = 2 * i + 2;

    if (left < n && a[left] > a[largest])
        largest = left;
    if (right < n && a[right] > a[largest])
        largest = right;

    if (largest != i){
        int temp = a[i];
        a[i] = a[largest];
        a[largest] = temp;

        heapifyMax(a, n, largest);
    }
}

void heapSortMax(int a[], int n){
    for (int i = n / 2 - 1; i >= 0; i--)
        heapifyMax(a, n, i);

    for (int i = n - 1; i >= 0; i--){
        int temp = a[0];
        a[0] = a[i];
        a[i] = temp;

        heapifyMax(a, i, 0);
    }
}

int main(){
    int a[] = {10, 7, 9, 2, 15};
    int n = sizeof(a) / sizeof(a[0]);
    heapSortMax(a, n);
    for (int i = 0; i < n; i++)
        printf("%d ", a[i]);
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> gcc maxheapsort.c
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> ./a.exe
2 7 9 10 15
PS C:\Users\sarva\OneDrive\Desktop\daa-lab>
```

Time Complexity (Worst): O(n log n)

Justification: Each of the n deletions requires heapify (log n).

Space Complexity (Worst): O(1)

Justification: Array-based heap uses no extra memory.

Heap Sort using Min Heap in C

```c
#include <stdio.h>

void heapifyMin(int a[], int n, int i){
    int smallest = i;
    int left = 2 * i + 1;
    int right = 2 * i + 2;

    if (left < n && a[left] < a[smallest])
        smallest = left;
    if (right < n && a[right] < a[smallest])
        smallest = right;

    if (smallest != i){
        int temp = a[i];
        a[i] = a[smallest];
        a[smallest] = temp;

        heapifyMin(a, n, smallest);
    }
}

void heapSortMin(int a[], int n){
    for (int i = n / 2 - 1; i >= 0; i--)
        heapifyMin(a, n, i);

    for (int i = n - 1; i >= 0; i--){
        int temp = a[0];
        a[0] = a[i];
        a[i] = temp;

        heapifyMin(a, i, 0);
    }
}

int main(){
    int a[] = {12, 3, 19, 6, 5};
    int n = sizeof(a) / sizeof(a[0]);
    heapSortMin(a, n);
    for (int i = 0; i < n; i++)
        printf("%d ", a[i]);
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> gcc minheapsort.c
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> ./a.exe
19 12 6 5 3
PS C:\Users\sarva\OneDrive\Desktop\daa-lab>
```

Time Complexity (Worst): O(n log n)

Justification: Same heap operations as max heap.

Space Complexity (Worst): O(1)

Justification: Sorting is done in-place.

Path Tracing Algorithms Date: 04-12-2025

1. Breadth first search in C
2. Depth first search in C

Breadth First Search in C

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

#define MAX 100

typedef struct Node{
    int vertex;
    struct Node *next;
} Node;

Node *adjList[MAX];
int visited[MAX];
int queue[MAX];
int front = 0, rear = -1;

void addEdge(int u, int v){
    Node *newNode = (Node *)malloc(sizeof(Node));
    newNode->vertex = v;
    newNode->next = adjList[u];
    adjList[u] = newNode;
}

void BFS(int start){
    visited[start] = 1;
    queue[++rear] = start;

    printf("BFS Traversal: ");

    while (front <= rear){
        int curr = queue[front++];
        printf("%d ", curr);

        Node *temp = adjList[curr];
        while (temp != NULL){
            if (!visited[temp->vertex]){
                visited[temp->vertex] = 1;
                queue[++rear] = temp->vertex;
            }
            temp = temp->next;
        }
    }
}
```

```c
int main(){
    int n = 5;
    for (int i = 0; i < n; i++)
        adjList[i] = NULL;

    addEdge(0, 1);
    addEdge(0, 2);
    addEdge(1, 3);
    addEdge(2, 4);

    BFS(0, n);
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> gcc bfs.c
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> ./a.exe
BFS Traversal: 0 2 1 4 3
PS C:\Users\sarva\OneDrive\Desktop\daa-lab>
```

Time Complexity (Worst Case): O(V + E)

Justification for Time Complexity: BFS visits every vertex once and checks every edge once while exploring adjacency lists. Hence total work is proportional to the number of vertices plus edges.

Space Complexity (Worst Case): O(V)

4. Justification for Space Complexity: The queue can hold up to V vertices in the worst case, and the visited[] array also requires O(V). (Adjacency list is part of input storage.)

Depth First Search in C

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

#define MAX 100

typedef struct Node{
    int vertex;
    struct Node *next;
} Node;

Node *adjList[MAX];
int visited[MAX];

void addEdge(int u, int v){
    Node *newNode = (Node *)malloc(sizeof(Node));
    newNode->vertex = v;
    newNode->next = adjList[u];
    adjList[u] = newNode;
}

void DFS(int v){
    visited[v] = 1;
    printf("%d ", v);

    Node *temp = adjList[v];
    while (temp != NULL){
        if (!visited[temp->vertex]){
            DFS(temp->vertex);
        }
        temp = temp->next;
    }
}

int main(){
    int n = 5;
    for (int i = 0; i < n; i++){
        adjList[i] = NULL;
        visited[i] = 0;
    }

    addEdge(0, 1);
    addEdge(0, 2);
    addEdge(1, 3);
    addEdge(2, 4);

    printf("DFS Traversal: ");
    DFS(0);

    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> gcc dfs.c
PS C:\Users\sarva\OneDrive\Desktop\daa-lab> ./a.exe
DFS Traversal: 0 2 4 1 3
PS C:\Users\sarva\OneDrive\Desktop\daa-lab>
```

Time Complexity (Worst Case): O(V + E)

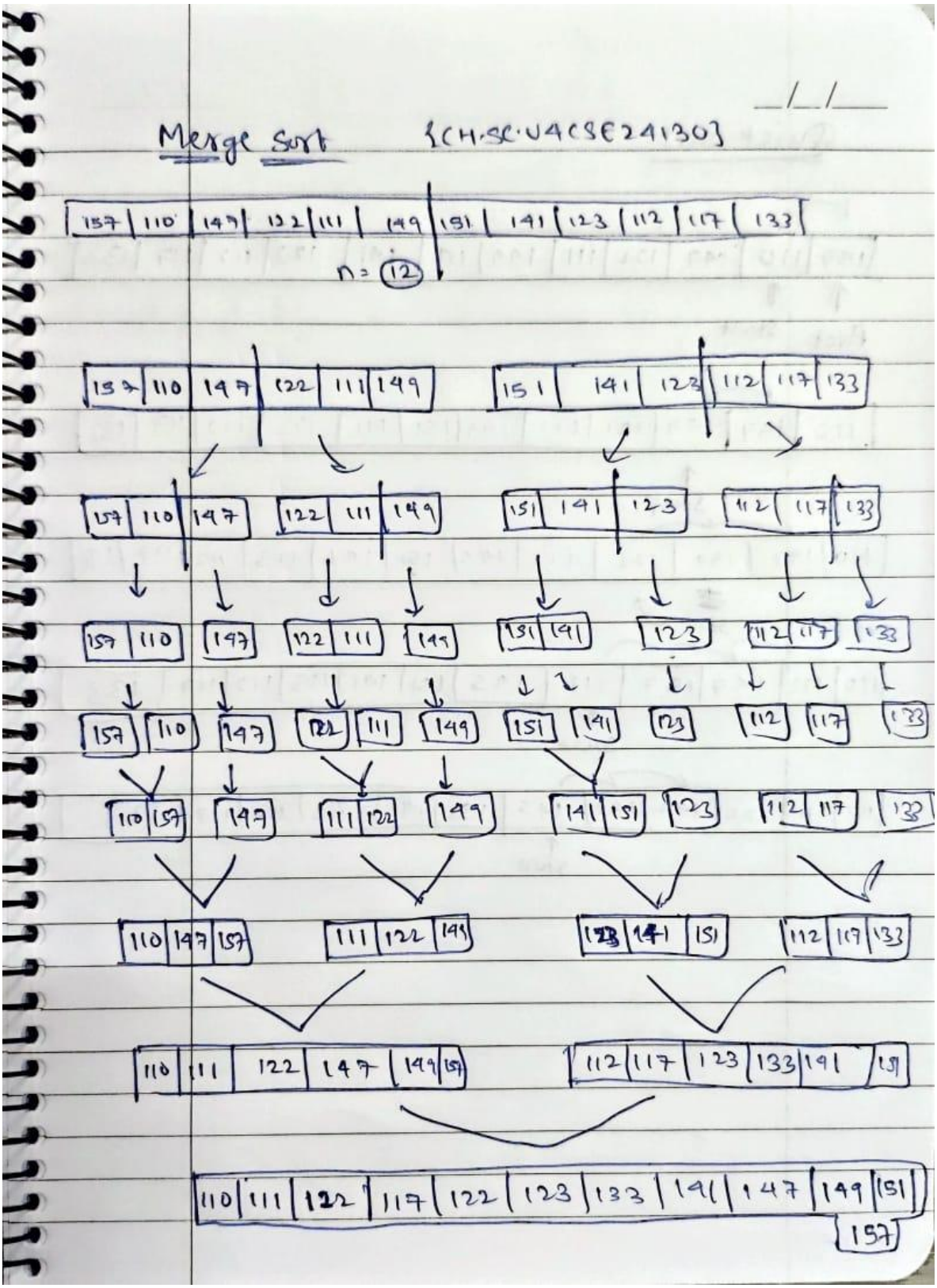
Justification for Time Complexity: DFS recursively explores every vertex and inspects all edges exactly once through the adjacency list, giving a total cost of V + E.

Space Complexity (Worst Case): O(V)

Justification for Space Complexity: The recursion stack can grow up to V levels (in a straight-chain graph), and the visited[] array stores V entries.

Divide & Conquer Techniques Date: 03-01-2026

1. Merge Sort
2. Quick Sort



Merge Sort Code:

```c
#include <stdio.h>

// Function to merge two subarrays
void merge(int arr[], int left, int mid, int right) {
    int i, j, k;
    int n1 = mid - left + 1;
    int n2 = right - mid;
    int L[n1], R[n2];

    // Copy data to temp arrays
    for (i = 0; i < n1; i++)
        L[i] = arr[left + i];
    for (j = 0; j < n2; j++)
        R[j] = arr[mid + 1 + j];

    i = 0;
    j = 0;
    k = left;

    // Merge the temp arrays back into arr[]
    while (i < n1 && j < n2) {
        if (L[i] <= R[j]) {
            arr[k++] = L[i++];
        } else {
            arr[k++] = R[j++];
        }
    }

    // Copy remaining elements
    while (i < n1)
        arr[k++] = L[i++];

    while (j < n2)
        arr[k++] = R[j++];
}


// Recursive merge sort function
void mergeSort(int arr[], int left, int right) {
    if (left < right) {
        int mid = left + (right - left) / 2;
        mergeSort(arr, left, mid);
        mergeSort(arr, mid + 1, right);
        merge(arr, left, mid, right);
    }
}

// Main function
int main() {
    int n;
    printf("Enter number of elements: ");
    scanf("%d", &n);
    int arr[n];
    printf("Enter %d elements:\n", n);
    for (int i = 0; i < n; i++) {
        scanf("%d", &arr[i]);
    }
    mergeSort(arr, 0, n - 1);
    printf("Sorted array:\n");
    for (int i = 0; i < n; i++) {
        printf("%d ", arr[i]);
    }
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> gcc mergesort.c
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> ./a.exe
Enter number of elements: 12
Enter 12 elements:
157 110 147 122 111 149 151 141 123 112 117 133
Sorted array:
110 111 112 117 122 123 133 141 147 149 151 157
```

Justifications:

- **Time Complexity (Best, Average & Worst Case): O(n log n)**
- **Justification for Time Complexity:**

  The array is always divided into two equal parts, and merging checks all elements every time. This process repeats log n times, so the total time is n log n.

- **Space Complexity (Worst Case): O(n)**
- **Justification for Space Complexity:**

  An extra array is used to store elements while merging, which requires space equal to the number of elements.

__/__/____

Quick sort

157	110	147	122	111	149	151	141	123	112	117	133

↑ start ↑ end

Pivot = 157 increment start till any number <= decrement end till any number. Pivot. <Pivot

133	110	147	122	111	149	151	141	123	112	117	157

↑ ↑ start ↑

Pivot = 133

117	110	122	111	123	112	133	149	151	141	147	157

↑ Pivot

112	110	111	117	122	123	133	149	151	141	147	157

↑ pivot

111	110	112	117	122	123	133	149	151	141	147	157

↑ pivot

110	111	112	117	122	123	133	149	151	141	147	157

↑ Pivot

110	111	112	117	122	123	133	147	141	149	151	157

↑ pivot

110	111	112	117	122	123	133	141	147	149	151	157

Quick Sort Code:

```c
#include <stdio.h>

// Function to swap two elements
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

// Partition function
int partition(int arr[], int low, int high) {
    int pivot = arr[high];   // Choosing last element as pivot
    int i = low - 1;
    for (int j = low; j < high; j++) {
        if (arr[j] ⩽ pivot) {
            i++;
            swap(&arr[i], &arr[j]);
        }
    }
    swap(&arr[i + 1], &arr[high]);
    return i + 1;
}

// Quick Sort function
void quickSort(int arr[], int low, int high) {
    if (low < high) {
        int pi = partition(arr, low, high);
        quickSort(arr, low, pi - 1);
        quickSort(arr, pi + 1, high);
    }
}

int main() {
    int n;
    printf("Enter number of elements: ");
    scanf("%d", &n);
    int arr[n];
    printf("Enter %d elements:\n", n);
    for (int i = 0; i < n; i++) {
        scanf("%d", &arr[i]);
    }
    quickSort(arr, 0, n - 1);
    printf("Sorted array:\n");
    for (int i = 0; i < n; i++) {
        printf("%d ", arr[i]);
    }
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> gcc quicksort.c
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> ./a.exe
Enter number of elements: 12
Enter 12 elements:
157 110 147 122 111 149 151 141 123 112 117 133
Sorted array:
110 111 112 117 122 123 133 141 147 149 151 157
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab>
```

Justifications:

- **Time Complexity (Worst Case): O(n^2)**
- **Justification for Time Complexity:**

  If the pivot is always the smallest or largest element, the array gets divided very unevenly. In this case, comparisons keep increasing for each step, leading to n × n operations.

- **Space Complexity (Worst Case): O(n)**
- **Justification for Space Complexity:**

  In the worst case, recursive calls go one by one, so the recursion stack stores up to n function calls.

Balancing BST

Date: 08-01-2026

1. Balancing BST (AVL Rotations)
2. Balancing BST (Red Black Tree)

AVL Code:

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

/* ---------- NODE STRUCTURE ---------- */
struct Node{
    int key;
    struct Node *left;
    struct Node *right;
    int height;
};

/* ---------- UTILITY FUNCTIONS ---------- */
int max(int a, int b){
    return (a > b) ? a : b;
}

int height(struct Node *n){
    if (n == NULL)
        return 0;
    return n->height;
}

/* ---------- CREATE NODE ---------- */
struct Node *newNode(int key){
    struct Node *node = (struct Node *)malloc(sizeof(struct Node));
    node->key = key;
    node->left = NULL;
    node->right = NULL;
    node->height = 1; // new node is initially added at leaf
    return node;
}


/* ---------- RIGHT ROTATION ---------- */
struct Node *rightRotate(struct Node *y){
    struct Node *x = y->left;
    struct Node *T2 = x->right;

    // Perform rotation
    x->right = y;
    y->left = T2;

    // Update heights
    y->height = max(height(y->left), height(y->right)) + 1;
    x->height = max(height(x->left), height(x->right)) + 1;

    // Return new root
    return x;
}
```

```c
/* ---------- LEFT ROTATION ---------- */
struct Node *leftRotate(struct Node *x){
    struct Node *y = x->right;
    struct Node *T2 = y->left;

    // Perform rotation
    y->left = x;
    x->right = T2;

    // Update heights
    x->height = max(height(x->left), height(x->right)) + 1;
    y->height = max(height(y->left), height(y->right)) + 1;

    // Return new root
    return y;
}

/* ---------- BALANCE FACTOR ---------- */
int getBalance(struct Node *n){
    if (n == NULL)
        return 0;
    return height(n->left) - height(n->right);
}
```

```c
/* ---------- INSERT ---------- */
struct Node *insert(struct Node *node, int key){
    // 1. Normal BST insertion
    if (node == NULL)
        return newNode(key);
    if (key < node->key)
        node->left = insert(node->left, key);
    else if (key > node->key)
        node->right = insert(node->right, key);
    else
        return node; // Duplicate keys not allowed

    // 2. Update height
    node->height = 1 + max(height(node->left), height(node->right));
    // 3. Get balance factor
    int balance = getBalance(node);
    // 4. Rotations
    // LL Case
    if (balance > 1 && key < node->left->key)
        return rightRotate(node);
    // RR Case
    if (balance < -1 && key > node->right->key)
        return leftRotate(node);
    // LR Case
    if (balance > 1 && key > node->left->key){
        node->left = leftRotate(node->left);
        return rightRotate(node);
    }
    // RL Case
    if (balance < -1 && key < node->right->key){
        node->right = rightRotate(node->right);
        return leftRotate(node);
    }
    return node;
}
```

```c
/* ---------- INORDER TRAVERSAL ---------- */
void inorder(struct Node *root){
    if (root != NULL){
        inorder(root->left);
        printf("%d ", root->key);
        inorder(root->right);
    }
}

/* ---------- MAIN ---------- */
int main(){
    struct Node *root = NULL;

    int keys[] = {157, 110, 147, 122, 111, 149, 151, 141, 123, 112, 117, 133};
    int n = sizeof(keys) / sizeof(keys[0]);

    for (int i = 0; i < n; i++)
        root = insert(root, keys[i]);

    printf("Inorder traversal of AVL Tree:\n");
    inorder(root);

    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> gcc avl_rotations.c
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> ./a.exe
Inorder traversal of AVL Tree:
110 111 112 117 122 123 133 141 147 149 151 157
```

Time & Space Complexities table with justifcations:

Operation	Time Complexity	Justification
Search	O(log n)	Height is logarithmic
Insert	O(log n)	BST insert + constant rotations
Delete	O(log n)	Rebalancing bounded by height
Traversal	O(n)	Visit every node
Rotation	O(1)	Constant pointer updates
Space	O(n)	Store all nodes

Red Black Tree Code:

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

/* ---------- COLORS ---------- */
#define RED 1
#define BLACK 0

/* ---------- NODE STRUCTURE ---------- */
struct Node{
    int data;
    int color;
    struct Node *left, *right, *parent;
};

struct Node *root = NULL;

/* ---------- CREATE NODE ---------- */
struct Node *createNode(int data){
    struct Node *node = (struct Node *)malloc(sizeof(struct Node));
    node->data = data;
    node->color = RED; // New node is always RED
    node->left = node->right = node->parent = NULL;
    return node;
}


/* ---------- LEFT ROTATION ---------- */
void leftRotate(struct Node *x){
    struct Node *y = x->right;
    x->right = y->left;
    if (y->left != NULL)
        y->left->parent = x;
    y->parent = x->parent;
    if (x->parent == NULL)
        root = y;
    else if (x == x->parent->left)
        x->parent->left = y;
    else
        x->parent->right = y;
    y->left = x;
    x->parent = y;
}

/* ---------- RIGHT ROTATION ---------- */
void rightRotate(struct Node *y){
    struct Node *x = y->left;
    y->left = x->right;
    if (x->right != NULL)
        x->right->parent = y;
    x->parent = y->parent;
    if (y->parent == NULL)
        root = x;
    else if (y == y->parent->left)
        y->parent->left = x;
    else
        y->parent->right = x;

    x->right = y;
    y->parent = x;
}
```

```c
/* ---------- FIX VIOLATIONS ---------- */
void fixInsert(struct Node *z){
    while (z != root && z->parent->color == RED){
        if (z->parent == z->parent->parent->left){
            struct Node *y = z->parent->parent->right; // Uncle
            // Case 1: Uncle is RED
            if (y != NULL && y->color == RED){
                z->parent->color = BLACK;
                y->color = BLACK;
                z->parent->parent->color = RED;
                z = z->parent->parent;
            }
            // Case 2 & 3
            else{
                if (z == z->parent->right){
                    z = z->parent;
                    leftRotate(z);
                }
                z->parent->color = BLACK;
                z->parent->parent->color = RED;
                rightRotate(z->parent->parent);
            }
        }
        else{
            struct Node *y = z->parent->parent->left; // Uncle
            if (y != NULL && y->color == RED){
                z->parent->color = BLACK;
                y->color = BLACK;
                z->parent->parent->color = RED;
                z = z->parent->parent;
            }
            else{
                if (z == z->parent->left){
                    z = z->parent;
                    rightRotate(z);
                }
                z->parent->color = BLACK;
                z->parent->parent->color = RED;
                leftRotate(z->parent->parent);
            }
        }
    }
    root->color = BLACK;
}

/* ---------- INSERT ---------- */
void insert(int data){
    struct Node *z = createNode(data);
    struct Node *y = NULL;
    struct Node *x = root;
    while (x != NULL){
        y = x;
        if (z->data < x->data)
            x = x->left;
        else
            x = x->right;
    }
    z->parent = y;
    if (y == NULL)
        root = z;
    else if (z->data < y->data)
        y->left = z;
    else
        y->right = z;
    fixInsert(z);
}
```

```c
/* ---------- INORDER TRAVERSAL ---------- */
void inorder(struct Node *node){
    if (node != NULL){
        inorder(node->left);
        printf("%d(%s) ", node->data,
               node->color == RED ? "R" : "B");
        inorder(node->right);
    }
}

/* ---------- MAIN ---------- */
int main(){
    int keys[] = {157, 110, 147, 122, 111, 149, 151, 141, 123, 112, 117, 133};
    int n = sizeof(keys) / sizeof(keys[0]);

    for (int i = 0; i < n; i++)
        insert(keys[i]);

    printf("Inorder Traversal of Red-Black Tree:\n");
    inorder(root);

    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> gcc red_black.c
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> ./a.exe
Inorder Traversal of Red-Black Tree:
110(B) 111(R) 112(R) 117(B) 122(R) 123(B) 133(R) 141(B) 147(R) 149(R) 151(B) 157(R)
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab>
```

Time & Space Complexities table with justifcations:

Operation	Time Complexity	Justification
Search	O(log n)	Search follows a single root-to-leaf path. Height of Red-Black Tree is O(log n), so comparisons are logarithmic.
Insertion	O(log n)	BST insertion takes O(log n) due to bounded height. Fix-up involves recoloring and at most two rotations, each O(1).
Deletion	O(log n)	BST deletion is O(log n). Fix-up may propagate up the tree but height is logarithmic and each step is constant time.
Traversal	O(n)	Each node is visited exactly once during traversal.
Rotation	O(1)	Rotations involve a constant number of pointer changes, independent of tree size.
Height	O(log n)	Red-Black properties limit height to at most 2 log(n + 1).
Space	O(n)	One node is stored per element in the tree.

Quick Operations Date: 22-01-2026

1. Quick Sort
2. Quick Select

Quick Sort Code:

```c
#include <stdio.h>

// Function to swap two elements
void swap(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

// Partition function
int partition(int arr[], int low, int high) {
    int pivot = arr[high];   // Choosing last element as pivot
    int i = low - 1;
    for (int j = low; j < high; j++) {
        if (arr[j] <= pivot) {
            i++;
            swap(&arr[i], &arr[j]);
        }
    }
    swap(&arr[i + 1], &arr[high]);
    return i + 1;
}

// Quick Sort function
void quickSort(int arr[], int low, int high) {
    if (low < high) {
        int pi = partition(arr, low, high);
        quickSort(arr, low, pi - 1);
        quickSort(arr, pi + 1, high);
    }
}

int main() {
    int n;
    printf("Enter number of elements: ");
    scanf("%d", &n);
    int arr[n];
    printf("Enter %d elements:\n", n);
    for (int i = 0; i < n; i++) {
        scanf("%d", &arr[i]);
    }
    quickSort(arr, 0, n - 1);
    printf("Sorted array:\n");
    for (int i = 0; i < n; i++) {
        printf("%d ", arr[i]);
    }
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> gcc quicksort.c
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> ./a.exe
Enter number of elements: 12
Enter 12 elements:
157 110 147 122 111 149 151 141 123 112 117 133
Sorted array:
110 111 112 117 122 123 133 141 147 149 151 157
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab>
```

Time and Space Complexities:

Time Complexity

Worst Case: $O(n^2)$

Justification:

- Occurs when the pivot is always the smallest or largest element (e.g., already sorted or reverse-sorted array with last-element pivot).
- One partition has size $n - 1$, the other has size 0.
- Recursion depth becomes n.

Space Complexity

Worst Case: O(n)

Justification:

- Highly unbalanced partitions cause recursion depth to become n.
- Stack space grows linearly.

Quick Select Code:

```c
#include <stdio.h>

// Swap function
void swap(int *a, int *b){
    int temp = *a;
    *a = *b;
    *b = temp;
}

// Partition function
int partition(int arr[], int low, int high){
    int pivot = arr[high];
    int i = low - 1;

    for (int j = low; j < high; j++){
        if (arr[j] <= pivot){
            i++;
            swap(&arr[i], &arr[j]);
        }
    }

    swap(&arr[i + 1], &arr[high]);
    return i + 1;
}

// Quick Select function
int quickSelect(int arr[], int low, int high, int k){
    if (low <= high){
        int pi = partition(arr, low, high);

        if (pi == k)
            return arr[pi];
        else if (pi > k)
            return quickSelect(arr, low, pi - 1, k);
        else
            return quickSelect(arr, pi + 1, high, k);
    }

    return -1; // Invalid case
}

// Driver code
int main(){
    int arr[] = {7, 10, 4, 3, 20, 15};
    int n = sizeof(arr) / sizeof(arr[0]);
    int k = 2; // 0-based index (2 means 3rd smallest)
    int result = quickSelect(arr, 0, n - 1, k);
    printf("K-th smallest element: %d\n", result);
    return 0;
}
```

Output:

```
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> gcc quickselect.c
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab> ./a.exe
K-th smallest element: 7
PS C:\Users\sarva\OneDrive\Desktop\Archives\daa-lab>
```

Time and Space Complexities:

Time Complexity

Worst Case: $O(n^2)$

Justification:

- Pivot is always the smallest or largest element.
- Each partition reduces problem size by only 1.

Space Complexity

Worst Case: O(n)

Justification:

- Unbalanced recursion leads to n recursive calls on the stack.