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LAB REPORT
on

OPERATING SYSTEMS

Submitted by

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CERTIFICATE

This is to certify that the Lab work entitled "**OPERATING SYSTEMS – 23CS4PCOPS**" carried out by **TANMAY BHARADWAJ (1BM22CS303),** who is bonafide student of **B. M. S. College of Engineering.** It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum during the year 2024. The Lab report has been approved as it satisfies the academic requirements in respect of a **OPERATING SYSTEMS - (23CS4PCOPS)** work prescribed for the said degree.

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Course Outcome

CO1	Apply the different concepts and functionalities of Operating System
CO2	Analyse various Operating system strategies and techniques .
CO3	Demonstrate the different functionalities of Operating System
CO4	Conduct practical experiments to implement the functionalities of Operating system.

Program -1

Write a C program to simulate the following non-pre-emptive CPU scheduling algorithm to find turnaround time and waiting time.

→ FCFS

```
#include <stdio.h>

struct Process {
    int pid;        // Process ID
    int burst_time; // Burst time
    int arrival_time; // Arrival time
    int waiting_time; // Waiting time
    int turnaround_time; // Turnaround time
};

void findWaitingTime(struct Process proc[], int n) {
    int service_time[n];
    service_time[0] = proc[0].arrival_time;
    proc[0].waiting_time = 0;


    for (int i = 1; i < n; i++) {
        service_time[i] = service_time[i-1] + proc[i-1].burst_time;
        proc[i].waiting_time = service_time[i] - proc[i].arrival_time;
        if (proc[i].waiting_time < 0)
            proc[i].waiting_time = 0;
    }
}
```

```c
void findTurnaroundTime(struct Process proc[], int n) {
    for (int i = 0; i < n; i++)
        proc[i].turnaround_time = proc[i].burst_time + proc[i].waiting_time;
}
void findAverageTime(struct Process proc[], int n) {
    int total_waiting_time = 0, total_turnaround_time = 0;
    findWaitingTime(proc, n);
    findTurnaroundTime(proc, n);
    printf("Processes  Burst time  Arrival time  Waiting time  Turnaround time\n");
    for (int i = 0; i < n; i++) {
        total_waiting_time += proc[i].waiting_time;
        total_turnaround_time += proc[i].turnaround_time;
        printf("   %d \t\t%d \t\t%d \t\t%d \t\t%d\n", proc[i].pid, proc[i].burst_time,
proc[i].arrival_time, proc[i].waiting_time, proc[i].turnaround_time);
    }
    printf("Average waiting time = %.2f\n", (float)total_waiting_time / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_turnaround_time / (float)n);
}

int main() {
    struct Process proc[] = {{1, 10, 0}, {2, 5, 1}, {3, 8, 2}};
    int n = sizeof(proc) / sizeof(proc[0]);
    findAverageTime(proc, n);
    return 0;
}
```

Output

```
Processes  Burst time  Arrival time  Waiting time  Turnaround time
   1           10            0              0               10
   2           5             1              9               14
   3           8             2              13              21
Average waiting time = 7.33
Average turnaround time = 15.00
```

→ SJF (pre-emptive)

```
#include <stdio.h>

struct Process {

    int pid;

    int burst_time;

    int arrival_time;

    int waiting_time;

    int turnaround_time;

};


void findWaitingTime(struct Process proc[], int n) {

    int complete = 0, t = 0, minm = 10000;

    int shortest = 0, finish_time;

    int check = 0;

    int rt[n];

    for (int i = 0; i < n; i++)

        rt[i] = proc[i].burst_time;


    while (complete != n) {
```

```
        for (int j = 0; j < n; j++) {
            if ((proc[j].arrival_time <= t) && (rt[j] < minm) && rt[j] > 0) {
                minm = rt[j];
                shortest = j;
                check = 1;
            }
        }
        if (check == 0) {
            t++;
            continue;
        }
        rt[shortest]--;
        minm = rt[shortest];
        if (minm == 0)
            minm = 10000;
        if (rt[shortest] == 0) {
            complete++;
            check = 0;
            finish_time = t + 1;
            proc[shortest].waiting_time = finish_time - proc[shortest].burst_time -
    proc[shortest].arrival_time;
            if (proc[shortest].waiting_time < 0)
                proc[shortest].waiting_time = 0;
        }
        t++;
```

```
    }
}

void findTurnaroundTime(struct Process proc[], int n) {
    for (int i = 0; i < n; i++)
        proc[i].turnaround_time = proc[i].burst_time + proc[i].waiting_time;
}

void findAverageTime(struct Process proc[], int n) {
    int total_waiting_time = 0, total_turnaround_time = 0;

    findWaitingTime(proc, n);
    findTurnaroundTime(proc, n);

    printf("Processes  Burst time  Arrival time  Waiting time  Turnaround time\n");

    for (int i = 0; i < n; i++) {
        total_waiting_time += proc[i].waiting_time;
        total_turnaround_time += proc[i].turnaround_time;
        printf("   %d \t\t%d \t\t%d \t\t%d \t\t%d\n", proc[i].pid, proc[i].burst_time,
proc[i].arrival_time, proc[i].waiting_time, proc[i].turnaround_time);
    }

    printf("Average waiting time = %.2f\n", (float)total_waiting_time / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_turnaround_time / (float)n);
```

```c
}

int main() {
    struct Process proc[] = {{1, 6, 0}, {2, 8, 1}, {3, 7, 2}, {4, 3, 3}};
    int n = sizeof(proc) / sizeof(proc[0]);

    findAverageTime(proc, n);

    return 0;
}
```

OUTPUT

```
Processes  Burst time  Arrival time  Waiting time  Turnaround time
   1           6            0             0              6
   2           8            1             15             23
   3           7            2             7              14
   4           3            3             3              6
Average waiting time = 6.25
Average turnaround time = 12.25
```

→ SJF (Non-preemptive)

```c
#include <stdio.h>

struct Process {
```

```
    int pid;
    int burst_time;
    int arrival_time;
    int waiting_time;
    int turnaround_time;
};
void findWaitingTime(struct Process proc[], int n) {
    int rt[n];
    for (int i = 0; i < n; i++)
        rt[i] = proc[i].burst_time;
    int complete = 0, t = 0, minm = 10000;
    int shortest = 0, finish_time;
    int check = 0;
    while (complete != n) {
        for (int j = 0; j < n; j++) {
            if ((proc[j].arrival_time <= t) && (rt[j] < minm) && rt[j] > 0) {
                minm = rt[j];
                shortest = j;
                check = 1;
            }
        }
        if (check == 0) {
            t++;
            continue;
```

```
        }
        rt[shortest]--;
        minm = rt[shortest];
        if (minm == 0)
            minm = 10000;
        if (rt[shortest] == 0) {
            complete++;
            check = 0;
            finish_time = t + 1;
            proc[shortest].waiting_time = finish_time - proc[shortest].burst_time -
proc[shortest].arrival_time;
            if (proc[shortest].waiting_time < 0)
                proc[shortest].waiting_time = 0;
        }
        t++;
    }
}

void findTurnaroundTime(struct Process proc[], int n) {
    for (int i = 0; i < n; i++)
        proc[i].turnaround_time = proc[i].burst_time + proc[i].waiting_time;
}

void findAverageTime(struct Process proc[], int n) {
    int total_waiting_time = 0, total_turnaround_time = 0;
```

```c
    findWaitingTime(proc, n);
    findTurnaroundTime(proc, n);

    printf("Processes  Burst time  Arrival time  Waiting time  Turnaround time\n");

    for (int i = 0; i < n; i++) {
        total_waiting_time += proc[i].waiting_time;
        total_turnaround_time += proc[i].turnaround_time;
        printf("   %d \t\t%d \t\t%d \t\t%d \t\t%d\n", proc[i].pid, proc[i].burst_time,
proc[i].arrival_time, proc[i].waiting_time, proc[i].turnaround_time);
    }

    printf("Average waiting time = %.2f\n", (float)total_waiting_time / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_turnaround_time / (float)n);
}

int main() {
    struct Process proc[] = {{1, 6, 0}, {2, 8, 1}, {3, 7, 2}, {4, 3, 3}};
    int n = sizeof(proc) / sizeof(proc[0]);

    findAverageTime(proc, n);

    return 0;
}
```

OUTPUT:

```
Processes  Burst time  Arrival time  Waiting time  Turnaround time
   1           6            0             0              6
   2           8            1             15             23
   3           7            2             7              14
   4           3            3             3              6
Average waiting time = 6.25
Average turnaround time = 12.25
```

Program-2

Write a C program to simulate the following CPU scheduling to find turnaround time and waiting time.

→ Priority (pre-emptive)

```
#include <stdio.h>

struct Process {
    int pid;
    int burst_time;
    int arrival_time;
    int priority;
    int waiting_time;
    int turnaround_time;
};


void findWaitingTime(struct Process proc[], int n) {
    int rt[n];
    for (int i = 0; i < n; i++)
        rt[i] = proc[i].burst_time;


    int complete = 0, t = 0, minm = 10000;
    int shortest = 0, finish_time;
    int check = 0;


    while (complete != n) {
```

```
        for (int j = 0; j < n; j++) {
            if ((proc[j].arrival_time <= t) && (proc[j].priority < minm) && rt[j] > 0) {
                minm = proc[j].priority;
                shortest = j;
                check = 1;
            }
        }
        if (check == 0) {
            t++;
            continue;
        }
        rt[shortest]--;
        minm = proc[shortest].priority;
        if (rt[shortest] == 0) {
            complete++;
            check = 0;
            finish_time = t + 1;
            proc[shortest].waiting_time = finish_time - proc[shortest].burst_time -
proc[shortest].arrival_time;
            if (proc[shortest].waiting_time < 0)
                proc[shortest].waiting_time = 0;
            minm = 10000;
        }
        t++;
    }
```

```
}

void findTurnaroundTime(struct Process proc[], int n) {
    for (int i = 0; i < n; i++)
        proc[i].turnaround_time = proc[i].burst_time + proc[i].waiting_time;
}

void findAverageTime(struct Process proc[], int n) {
    int total_waiting_time = 0, total_turnaround_time = 0;

    findWaitingTime(proc, n);
    findTurnaroundTime(proc, n);

    printf("Processes  Burst time  Arrival time  Priority  Waiting time  Turnaround time\n");

    for (int i = 0; i < n; i++) {
        total_waiting_time += proc[i].waiting_time;
        total_turnaround_time += proc[i].turnaround_time;
        printf("   %d \t\t%d \t\t%d \t\t%d \t\t%d \t\t%d\n", proc[i].pid, proc[i].burst_time,
proc[i].arrival_time, proc[i].priority, proc[i].waiting_time, proc[i].turnaround_time);
    }

    printf("Average waiting time = %.2f\n", (float)total_waiting_time / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_turnaround_time / (float)n);
}
```

```
int main() {

    struct Process proc[] = {{1, 6, 0, 2}, {2, 8, 1, 1}, {3, 7, 2, 3}, {4, 3, 3, 2}};

    int n = sizeof(proc) / sizeof(proc[0]);


    findAverageTime(proc, n);


    return 0;

}
```

```
Processes  Burst time  Arrival time  Priority  Waiting time  Turnaround time
   1           6              0             2              8               14
   2           8              1             1              0               8
   3           7              2             3              15              22
   4           3              3             2              11              14
Average waiting time = 8.50
Average turnaround time = 14.50
```

→ Priority (Non-preemptive)

```
#include <stdio.h>


struct Process {

    int pid;

    int burst_time;

    int arrival_time;

    int priority;

    int waiting_time;

    int turnaround_time;
```

```
};

void findWaitingTime(struct Process proc[], int n) {
    int completed[n];
    for (int i = 0; i < n; i++)
        completed[i] = 0;

    int t = 0;
    int completed_count = 0;

    while (completed_count < n) {
        int min_priority = 10000;
        int idx = -1;
        for (int i = 0; i < n; i++) {
            if (proc[i].arrival_time <= t && !completed[i] && proc[i].priority < min_priority) {
                min_priority = proc[i].priority;
                idx = i;
            }
        }

        if (idx != -1) {
            t += proc[idx].burst_time;
            proc[idx].waiting_time = t - proc[idx].burst_time - proc[idx].arrival_time;
            if (proc[idx].waiting_time < 0)
```

```
            proc[idx].waiting_time = 0;
        completed[idx] = 1;
        completed_count++;
      } else {
        t++;
      }
   }
}

void findTurnaroundTime(struct Process proc[], int n) {
   for (int i = 0; i < n; i++)
      proc[i].turnaround_time = proc[i].burst_time + proc[i].waiting_time;
}

void findAverageTime(struct Process proc[], int n) {
   int total_waiting_time = 0, total_turnaround_time = 0;

   findWaitingTime(proc, n);
   findTurnaroundTime(proc, n);

   printf("Processes  Burst time  Arrival time  Priority  Waiting time  Turnaround time\n");

   for (int i = 0; i < n; i++) {
      total_waiting_time += proc[i].waiting_time;
```

```
        total_turnaround_time += proc[i].turnaround_time;
        printf("   %d \t\t%d \t\t%d \t\t%d \t\t%d \t\t%d\n", proc[i].pid, proc[i].burst_time,
proc[i].arrival_time, proc[i].priority, proc[i].waiting_time, proc[i].turnaround_time);
    }

    printf("Average waiting time = %.2f\n", (float)total_waiting_time / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_turnaround_time / (float)n);
}

int main() {
    struct Process proc[] = {{1, 6, 0, 2}, {2, 8, 1, 1}, {3, 7, 2, 3}, {4, 3, 3, 2}};
    int n = sizeof(proc) / sizeof(proc[0]);

    findAverageTime(proc, n);

    return 0;
}
```

```
Processes  Burst time  Arrival time  Priority  Waiting time  Turnaround time
   1          6             0            2          0              6
   2          8             1            1          5              13
   3          7             2            3          15             22
   4          3             3            2          11             14
Average waiting time = 7.75
Average turnaround time = 13.75
```

→Round Robin (Experiment with different quantum sizes for RR algorithm)

```
#include <stdio.h>

struct Process {
    int pid;
    int burst_time;
    int arrival_time;
    int priority;
    int waiting_time;
    int turnaround_time;
};

void findWaitingTime(struct Process proc[], int n) {
    int completed[n];
    for (int i = 0; i < n; i++)
        completed[i] = 0;

    int t = 0;
    int completed_count = 0;

    while (completed_count < n) {
        int min_priority = 10000;
        int idx = -1;
```

```
        for (int i = 0; i < n; i++) {
            if (proc[i].arrival_time <= t && !completed[i] && proc[i].priority < min_priority) {
                min_priority = proc[i].priority;
                idx = i;
            }
        }

        if (idx != -1) {
            t += proc[idx].burst_time;
            proc[idx].waiting_time = t - proc[idx].burst_time - proc[idx].arrival_time;
            if (proc[idx].waiting_time < 0)
                proc[idx].waiting_time = 0;
            completed[idx] = 1;
            completed_count++;
        } else {
            t++;
        }
    }
}

void findTurnaroundTime(struct Process proc[], int n) {
    for (int i = 0; i < n; i++)
        proc[i].turnaround_time = proc[i].burst_time + proc[i].waiting_time;
}
```

```
void findAverageTime(struct Process proc[], int n) {
    int total_waiting_time = 0, total_turnaround_time = 0;

    findWaitingTime(proc, n);
    findTurnaroundTime(proc, n);

    printf("Processes  Burst time  Arrival time  Priority  Waiting time  Turnaround time\n");

    for (int i = 0; i < n; i++) {
        total_waiting_time += proc[i].waiting_time;
        total_turnaround_time += proc[i].turnaround_time;
        printf("   %d \t\t%d \t\t%d \t\t%d \t\t%d \t\t%d\n", proc[i].pid, proc[i].burst_time,
proc[i].arrival_time, proc[i].priority, proc[i].waiting_time, proc[i].turnaround_time);
    }

    printf("Average waiting time = %.2f\n", (float)total_waiting_time / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_turnaround_time / (float)n);
}

int main() {
    struct Process proc[] = {{1, 6, 0, 2}, {2, 8, 1, 1}, {3, 7, 2, 3}, {4, 3, 3, 2}};
    int n = sizeof(proc) / sizeof(proc[0]);

    findAverageTime(proc, n);
```

```
    return 0;

}
```

```
Processes  Burst time  Arrival time  Priority  Waiting time  Turnaround time
   1           6            0            2          0              6
   2           8            1            1          5              13
   3           7            2            3          15             22
   4           3            3            2          11             14
Average waiting time = 7.75
Average turnaround time = 13.75
```

Program 3

Write a C program to simulate multi-level queue scheduling algorithm considering the following scenario. All the processes in the system are divided into two categories – system processes and user processes. System processes are to be given higher priority than user processes. Use FCFS scheduling for the processes in each queue

```
#include <stdio.h>

#define MAX_PROCESSES 100

struct Process {

    int pid;

    int burst_time;

    int arrival_time;

    int waiting_time;

    int turnaround_time;

    int is_system_process; // 1 for system process, 0 for user process

};


void sortProcessesByArrival(struct Process proc[], int n) {

    struct Process temp;

    for (int i = 0; i < n - 1; i++) {

        for (int j = i + 1; j < n; j++) {

            if (proc[i].arrival_time > proc[j].arrival_time) {

                temp = proc[i];

                proc[i] = proc[j];

                proc[j] = temp;
```

```
            }
        }
    }
}

void calculateWaitingTime(struct Process proc[], int n) {
    int current_time = 0;

    for (int i = 0; i < n; i++) {
        if (current_time < proc[i].arrival_time) {
            current_time = proc[i].arrival_time;
        }
        proc[i].waiting_time = current_time - proc[i].arrival_time;
        current_time += proc[i].burst_time;
    }
}

void calculateTurnaroundTime(struct Process proc[], int n) {
    for (int i = 0; i < n; i++) {
        proc[i].turnaround_time = proc[i].burst_time + proc[i].waiting_time;
    }
}

void printProcesses(struct Process proc[], int n) {
```

```
    int total_waiting_time = 0;
    int total_turnaround_time = 0;

    printf("Processes  Burst time  Arrival time  Waiting time  Turnaround time  Type\n");
    for (int i = 0; i < n; i++) {
        total_waiting_time += proc[i].waiting_time;
        total_turnaround_time += proc[i].turnaround_time;
        printf("   %d \t\t%d \t\t%d \t\t%d \t\t%d \t\t%s\n", proc[i].pid, proc[i].burst_time,
proc[i].arrival_time, proc[i].waiting_time, proc[i].turnaround_time, proc[i].is_system_process ?
"System" : "User");
    }

    printf("Average waiting time = %.2f\n", (float)total_waiting_time / n);
    printf("Average turnaround time = %.2f\n", (float)total_turnaround_time / n);
}

int main() {
    struct Process proc[MAX_PROCESSES];
    int n;

    printf("Enter the number of processes: ");
    scanf("%d", &n);

    for (int i = 0; i < n; i++) {
```

```
        printf("Enter process ID, burst time, arrival time, and type (1 for system, 0 for user) for
process %d: ", i + 1);

        scanf("%d %d %d %d", &proc[i].pid, &proc[i].burst_time, &proc[i].arrival_time,
&proc[i].is_system_process);

    }


    struct Process system_queue[MAX_PROCESSES];

    struct Process user_queue[MAX_PROCESSES];

    int system_count = 0, user_count = 0;


    for (int i = 0; i < n; i++) {

        if (proc[i].is_system_process) {

            system_queue[system_count++] = proc[i];

        } else {

            user_queue[user_count++] = proc[i];

        }

    }


    sortProcessesByArrival(system_queue, system_count);

    sortProcessesByArrival(user_queue, user_count);


    printf("\nSystem Queue:\n");

    calculateWaitingTime(system_queue, system_count);

    calculateTurnaroundTime(system_queue, system_count);

    printProcesses(system_queue, system_count);
```

```c
    printf("\nUser Queue:\n");
    calculateWaitingTime(user_queue, user_count);
    calculateTurnaroundTime(user_queue, user_count);
    printProcesses(user_queue, user_count);


    return 0;
}
```

```
Enter the number of processes: 3
Enter process ID, burst time, arrival time, and type (1 for system, 0 for user) for process 1: 1 3 1 0
Enter process ID, burst time, arrival time, and type (1 for system, 0 for user) for process 2: 2 4 2 1
Enter process ID, burst time, arrival time, and type (1 for system, 0 for user) for process 3: 3 4 2 0

System Queue:
Processes  Burst time  Arrival time  Waiting time  Turnaround time  Type
   2           4             2              0               4              System
Average waiting time = 0.00
Average turnaround time = 4.00

User Queue:
Processes  Burst time  Arrival time  Waiting time  Turnaround time  Type
   1           3             1              0               3              User
   3           4             2              2               6              User
Average waiting time = 1.00
Average turnaround time = 4.50
```

Program 4

Write a C program to simulate Real-Time CPU Scheduling algorithms:

→ Rate- Monotonic

```
#include <stdio.h>


void findWaitingTime(int processes[], int n, int bt[], int wt[], int period[]) {
    wt[0] = 0;
    for (int i = 1; i < n; i++) {
        wt[i] = bt[i - 1] + wt[i - 1];
    }
}
void findTurnAroundTime(int processes[], int n, int bt[], int wt[], int tat[]) {
    for (int i = 0; i < n; i++) {
        tat[i] = bt[i] + wt[i];
    }
}
void findAvgTime(int processes[], int n, int bt[], int period[]) {
    int wt[n], tat[n];
    findWaitingTime(processes, n, bt, wt, period);
    findTurnAroundTime(processes, n, bt, wt, tat);


    printf("Processes   Burst time   Waiting time   Turnaround time   Period\n");
    for (int i = 0; i < n; i++) {
        printf(" %d ", (i + 1));
        printf("          %d ", bt[i]);
        printf("          %d ", wt[i]);
        printf("          %d ", tat[i]);
```

```
        printf("                    %d\n", period[i]);
    }
    int total_wt = 0, total_tat = 0;
    for (int i = 0; i < n; i++) {
        total_wt += wt[i];
        total_tat += tat[i];
    }
    printf("Average waiting time = %.2f\n", (float)total_wt / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_tat / (float)n);
}
void rateMonotonicScheduling(int processes[], int n, int bt[], int period[]) {
    // Sort by period
    for (int i = 0; i < n - 1; i++) {
        for (int j = 0; j < n - i - 1; j++) {
            if (period[j] > period[j + 1]) {
                int temp = period[j];
                period[j] = period[j + 1];
                period[j + 1] = temp;
                temp = bt[j];
                bt[j] = bt[j + 1];
                bt[j + 1] = temp;
                temp = processes[j];
                processes[j] = processes[j + 1];
                processes[j + 1] = temp;
            }
        }
    }
```

```
  findAvgTime(processes, n, bt, period);
}

int main() {
    int processes[] = {1, 2, 3};
    int n = sizeof(processes) / sizeof(processes[0]);
    int burst_time[] = {3, 1, 2};
    int period[] = {7, 4, 5};

    rateMonotonicScheduling(processes, n, burst_time, period);
    return 0;
}
```

```
Processes    Burst time    Waiting time    Turnaround time    Period
 1            1             0              1                   4
 2            2             1              3                   5
 3            3             3              6                   7
Average waiting time = 1.33
Average turnaround time = 3.33
```

→ Earliest-deadline First

```
#include <stdio.h>

void findWaitingTime(int processes[], int n, int bt[], int wt[], int deadline[]) {
    wt[0] = 0;
    for (int i = 1; i < n; i++) {
        wt[i] = bt[i - 1] + wt[i - 1];
    }
}
```

```
void findTurnAroundTime(int processes[], int n, int bt[], int wt[], int tat[]) {
    for (int i = 0; i < n; i++) {
        tat[i] = bt[i] + wt[i];
    }
}

void findAvgTime(int processes[], int n, int bt[], int deadline[]) {
    int wt[n], tat[n];
    findWaitingTime(processes, n, bt, wt, deadline);
    findTurnAroundTime(processes, n, bt, wt, tat);

    printf("Processes   Burst time   Waiting time   Turnaround time   Deadline\n");
    for (int i = 0; i < n; i++) {
        printf(" %d ", (i + 1));
        printf("%d ", bt[i]);
        printf("%d ", wt[i]);
        printf("%d ", tat[i]);
        printf("%d\n", deadline[i]);
    }

    int total_wt = 0, total_tat = 0;
    for (int i = 0; i < n; i++) {
        total_wt += wt[i];
        total_tat += tat[i];
    }

    printf("Average waiting time = %.2f\n", (float)total_wt / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_tat / (float)n);
```

```
}

void earliestDeadlineFirstScheduling(int processes[], int n, int bt[], int deadline[]) {
    // Sort by deadline
    for (int i = 0; i < n - 1; i++) {
        for (int j = 0; j < n - i - 1; j++) {
            if (deadline[j] > deadline[j + 1]) {
                int temp = deadline[j];
                deadline[j] = deadline[j + 1];
                deadline[j + 1] = temp;
                temp = bt[j];
                bt[j] = bt[j + 1];
                bt[j + 1] = temp;
                temp = processes[j];
                processes[j] = processes[j + 1];
                processes[j + 1] = temp;
            }
        }
    }

    findAvgTime(processes, n, bt, deadline);
}

int main() {
    int processes[] = {1, 2, 3};
    int n = sizeof(processes) / sizeof(processes[0]);
    int burst_time[] = {3, 1, 2};
    int deadline[] = {7, 4, 5};
```

```
    earliestDeadlineFirstScheduling(processes, n, burst_time, deadline);
    return 0;
}
```

```
Processes    Burst time    Waiting time    Turnaround time    Ratio
 1             3             0             3                  0.50
 2             2             3             5                  0.30
 3             1             5             6                  0.20
Average waiting time = 2.67
Average turnaround time = 4.67
```

→ Proportional scheduling

```
#include <stdio.h>

void findWaitingTime(int processes[], int n, int bt[], int wt[], float ratio[]) {
    wt[0] = 0;
    for (int i = 1; i < n; i++) {
        wt[i] = bt[i - 1] + wt[i - 1];
    }
}
void findTurnAroundTime(int processes[], int n, int bt[], int wt[], int tat[]) {
    for (int i = 0; i < n; i++) {
        tat[i] = bt[i] + wt[i];
    }
}

void findAvgTime(int processes[], int n, int bt[], float ratio[]) {
    int wt[n], tat[n];
```

```
    findWaitingTime(processes, n, bt, wt, ratio);
    findTurnAroundTime(processes, n, bt, wt, tat);

    printf("Processes   Burst time   Waiting time   Turnaround time   Ratio\n");
    for (int i = 0; i < n; i++) {
        printf(" %d ", (i + 1));
        printf("          %d ", bt[i]);
        printf("          %d ", wt[i]);
        printf("          %d ", tat[i]);
        printf("              %.2f\n", ratio[i]);
    }

    int total_wt = 0, total_tat = 0;
    for (int i = 0; i < n; i++) {
        total_wt += wt[i];
        total_tat += tat[i];
    }
    printf("Average waiting time = %.2f\n", (float)total_wt / (float)n);
    printf("Average turnaround time = %.2f\n", (float)total_tat / (float)n);
}

void proportionalScheduling(int processes[], int n, int bt[], float ratio[]) {
    for (int i = 0; i < n - 1; i++) {
        for (int j = 0; j < n - i - 1; j++) {
            if (ratio[j] < ratio[j + 1]) {
                float temp = ratio[j];
                ratio[j] = ratio[j + 1];
                ratio[j + 1] = temp;
```

```
                int temp_bt = bt[j];
                bt[j] = bt[j + 1];
                bt[j + 1] = temp_bt;
                int temp_proc = processes[j];
                processes[j] = processes[j + 1];
                processes[j + 1] = temp_proc;
            }
        }
    }
    findAvgTime(processes, n, bt, ratio);
}
int main() {
    int processes[] = {1, 2, 3};
    int n = sizeof(processes) / sizeof(processes[0]);
    int burst_time[] = {3, 1, 2};
    float ratio[] = {0.5, 0.2, 0.3}; // Example ratios

    proportionalScheduling(processes, n, burst_time, ratio);
    return 0;
}
```

```
Processes    Burst time    Waiting time    Turnaround time    Ratio
 1             3             0             3                  0.50
 2             2             3             5                  0.30
 3             1             5             6                  0.20
Average waiting time = 2.67
Average turnaround time = 4.67
```

Program 5

Write a C program to simulate producer-consumer problem using semaphores.

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>
#include <semaphore.h>

#define BUFFER_SIZE 5
int buffer[BUFFER_SIZE];
int in = 0, out = 0;

sem_t empty;
sem_t full;
pthread_mutex_t mutex;

void *producer(void *param) {
    int item;
    while (1) {
        item = rand() % 100;
        sem_wait(&empty);
        pthread_mutex_lock(&mutex);

        buffer[in] = item;
        printf("Producer produced %d at %d\n", item, in);
        in = (in + 1) % BUFFER_SIZE;
```

```
        pthread_mutex_unlock(&mutex);
        sem_post(&full);
        sleep(1);
    }
}

void *consumer(void *param) {
    int item;
    while (1) {
        sem_wait(&full);
        pthread_mutex_lock(&mutex);

        item = buffer[out];
        printf("Consumer consumed %d from %d\n", item, out);
        out = (out + 1) % BUFFER_SIZE;

        pthread_mutex_unlock(&mutex);
        sem_post(&empty);
        sleep(1);
    }
}

int main() {
    pthread_t tid1, tid2;
    pthread_attr_t attr;

    pthread_attr_init(&attr);
    pthread_mutex_init(&mutex, NULL);
```

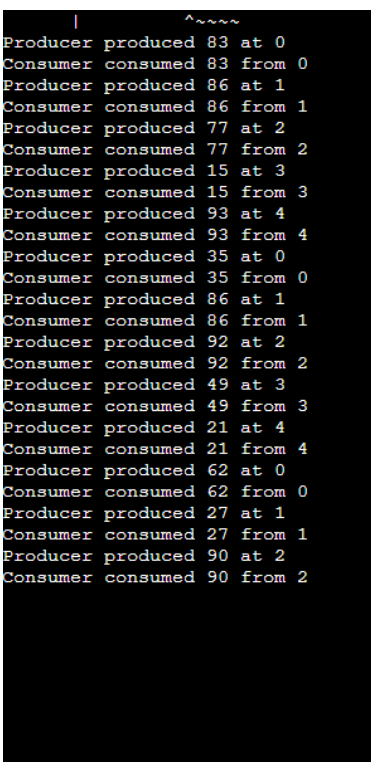
```
    sem_init(&empty, 0, BUFFER_SIZE);
    sem_init(&full, 0, 0);

    pthread_create(&tid1, &attr, producer, NULL);
    pthread_create(&tid2, &attr, consumer, NULL);

    pthread_join(tid1, NULL);
    pthread_join(tid2, NULL);

    pthread_mutex_destroy(&mutex);
    sem_destroy(&empty);
    sem_destroy(&full);

    return 0;
}
```



Program 6

Write a C program to simulate the concept of Dining-Philosophers problem.

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>
#include <semaphore.h>

#define N
sem_t forks[N];
sem_t mutex;

void *philosopher(void *num) {
    int id = *(int *)num;
    while (1) {
        printf("Philosopher %d is thinking.\n", id);
        sleep(1);

        sem_wait(&mutex);
        sem_wait(&forks[id]);
        sem_wait(&forks[(id + 1) % N]);

        printf("Philosopher %d is eating.\n", id);
        sleep(1);

        sem_post(&forks[id]); // Put down chopsticks
        sem_post(&forks[(id + 1) % N]);
```

```
        sem_post(&mutex);

        printf("Philosopher %d is done eating and starts thinking again.\n", id);
        sleep(1);
    }
}

int main() {
    pthread_t tid[N];
    int ids[N];

    sem_init(&mutex, 0, 1);

    for (int i = 0; i < N; i++) {
        sem_init(&forks[i], 0, 1);
        ids[i] = i;
    }

    for (int i = 0; i < N; i++) {
        pthread_create(&tid[i], NULL, philosopher, &ids[i]);
    }

    for (int i = 0; i < N; i++) {
        pthread_join(tid[i], NULL);
    }

    for (int i = 0; i < N; i++) {
        sem_destroy(&forks[i]);
```

```
    }
    sem_destroy(&mutex);

    return 0;
}
```

```
Philosopher 0 is thinking.
Philosopher 1 is thinking.
Philosopher 2 is thinking.
Philosopher 3 is thinking.
Philosopher 4 is thinking.
Philosopher 0 is eating.
Philosopher 0 is done eating and starts thinking again.
Philosopher 1 is eating.
Philosopher 0 is thinking.
Philosopher 1 is done eating and starts thinking again.
Philosopher 2 is eating.
Philosopher 3 is eating.
Philosopher 2 is done eating and starts thinking again.
Philosopher 1 is thinking.
Philosopher 2 is thinking.
Philosopher 4 is eating.
Philosopher 3 is done eating and starts thinking again.
Philosopher 3 is thinking.
Philosopher 0 is eating.
Philosopher 4 is done eating and starts thinking again.
Philosopher 4 is thinking.
Philosopher 1 is eating.
Philosopher 0 is done eating and starts thinking again.
Philosopher 1 is done eating and starts thinking again.
Philosopher 2 is eating.
Philosopher 0 is thinking.
Philosopher 2 is done eating and starts thinking again.
Philosopher 1 is thinking.
Philosopher 3 is eating.
Philosopher 2 is thinking.
Philosopher 4 is eating.
Philosopher 3 is done eating and starts thinking again.
```

Program 7

Write a C program to simulate Bankers algorithm for the purpose of deadlock avoidance.

```
#include <stdio.h>
#include <stdbool.h>

#define MAX_PROCESSES 5
#define MAX_RESOURCES 3

int main() {
    int n, m, i, j, k;
    n = 5;
    m = 3;

    int alloc[MAX_PROCESSES][MAX_RESOURCES] = { { 0, 1, 0 },
                                                { 2, 0, 0 },
                                                { 3, 0, 2 },
                                                { 2, 1, 1 },
                                                { 0, 0, 2 } };

    int max[MAX_PROCESSES][MAX_RESOURCES] = { { 7, 5, 3 },
                                              { 3, 2, 2 },
                                              { 9, 0, 2 },
                                              { 2, 2, 2 },
                                              { 4, 3, 3 } };

    int avail[MAX_RESOURCES] = { 3, 3, 2 };
```

```
int f[MAX_PROCESSES], ans[MAX_PROCESSES], ind = 0;
for (k = 0; k < n; k++) {
    f[k] = 0;
}

int need[MAX_PROCESSES][MAX_RESOURCES];
for (i = 0; i < n; i++) {
    for (j = 0; j < m; j++) {
        need[i][j] = max[i][j] - alloc[i][j];
    }
}
printf("Need matrix:\n");
for (i = 0; i < n; i++) {
    for (j = 0; j < m; j++) {
        printf("%d ", need[i][j]);
    }
    printf("\n");
}
int y = 0;
for (k = 0; k < n; k++) {
    for (i = 0; i < n; i++) {
        if (f[i] == 0) {
            bool flag = true;
            for (j = 0; j < m; j++) {
                if (need[i][j] > avail[j]) {
                    flag = false;
                    break;
                }    }
```

```
                if (flag) {
                    ans[ind++] = i;
                    for (y = 0; y < m; y++) {
                        avail[y] += alloc[i][y];
                    }
                    f[i] = 1;
                }
            }
        }
    }
    printf("Following is the SAFE Sequence:\n");
    for (i = 0; i < n - 1; i++) {
        printf(" P%d ->", ans[i]);
    }
    printf(" P%d\n", ans[n - 1]);

    return 0;
}
```

```
Need matrix:
7 4 3
1 2 2
6 0 0
0 1 1
4 3 1
Following is the SAFE Sequence:
 P1 -> P3 -> P4 -> P0 -> P2
```

Program 8

Write a C program to simulate deadlock detection

```
#include <stdio.h>

#include <stdbool.h>


#define MAX_PROCESSES 5

#define MAX_RESOURCES 3


void printMatrices(int processes, int resources, int
alloc[MAX_PROCESSES][MAX_RESOURCES], int
max[MAX_PROCESSES][MAX_RESOURCES], int
need[MAX_PROCESSES][MAX_RESOURCES], int avail[MAX_RESOURCES]) {
    printf("Allocation Matrix:\n");
    for (int i = 0; i < processes; i++) {
        for (int j = 0; j < resources; j++) {
            printf("%d ", alloc[i][j]);
        }
        printf("\n");
    }


    printf("\nMax Matrix:\n");
    for (int i = 0; i < processes; i++) {
        for (int j = 0; j < resources; j++) {
            printf("%d ", max[i][j]);
        }
        printf("\n");
    }
```

```
    printf("\nNeed Matrix:\n");
    for (int i = 0; i < processes; i++) {
        for (int j = 0; j < resources; j++) {
            printf("%d ", need[i][j]);
        }
        printf("\n");
    }

    printf("\nAvailable Resources:\n");
    for (int i = 0; i < resources; i++) {
        printf("%d ", avail[i]);
    }
    printf("\n");
}

void deadlockDetection(int processes, int resources, int
alloc[MAX_PROCESSES][MAX_RESOURCES], int
max[MAX_PROCESSES][MAX_RESOURCES], int avail[MAX_RESOURCES]) {
    int need[MAX_PROCESSES][MAX_RESOURCES];
    int work[MAX_RESOURCES];
    bool finish[MAX_PROCESSES];

    for (int i = 0; i < processes; i++) {
        for (int j = 0; j < resources; j++) {
            need[i][j] = max[i][j] - alloc[i][j];
        }
    }

    printMatrices(processes, resources, alloc, max, need, avail);
```

```
for (int i = 0; i < resources; i++) {
    work[i] = avail[i];
}
for (int i = 0; i < processes; i++) {
    finish[i] = false;
}
bool found;
do {
    found = false;
    for (int i = 0; i < processes; i++) {
        if (!finish[i]) {
            bool flag = true;
            for (int j = 0; j < resources; j++) {
                if (need[i][j] > work[j]) {
                    flag = false;
                    break;
                }
            }

            if (flag) {
                printf("\nProcess %d can be satisfied and is now finishing.\n", i);
                for (int k = 0; k < resources; k++) {
                    work[k] += alloc[i][k];
                }
                finish[i] = true;
                found = true;

                printf("New Available Resources:\n");
```

```
                for (int k = 0; k < resources; k++) {
                    printf("%d ", work[k]);
                }
                printf("\n");
            }
        }
    }
    } while (found);
    bool deadlock = false;
    printf("\nDeadlock Check:\n");
    for (int i = 0; i < processes; i++) {
        if (!finish[i]) {
            deadlock = true;
            printf("Process %d is in a deadlock.\n", i);
        }
    }
    if (!deadlock) {
        printf("No deadlock detected.\n");
    }
}
int main() {
    int processes = 5;
    int resources = 3;

    int alloc[MAX_PROCESSES][MAX_RESOURCES] = {
        { 0, 1, 0 },
        { 2, 0, 0 },
        { 3, 0, 2 },
```

```
        { 2, 1, 1 },
        { 0, 0, 2 }
    };
    int max[MAX_PROCESSES][MAX_RESOURCES] = {
        { 7, 5, 3 },
        { 3, 2, 2 },
        { 9, 0, 2 },
        { 2, 2, 2 },
        { 4, 3, 3 }
    };
    int avail[MAX_RESOURCES] = { 3, 3, 2 }; // Available resources
    deadlockDetection(processes, resources, alloc, max, avail);
    return 0;
}
```

OUTPUT:

```
Allocation Matrix:
0 1 0
2 0 0
3 0 2
2 1 1
0 0 2

Max Matrix:
7 5 3
3 2 2
9 0 2
2 2 2
4 3 3

Need Matrix:
7 4 3
1 2 2
6 0 0
0 1 1
4 3 1

Available Resources:
3 3 2
```

Program 9

Write a C program to simulate the following contiguous memory allocation techniques

a) Worst-fit

b) Best-fit

c) First-fit

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

#define MAX 25

void firstFit(int nb, int nf, int b[], int f[]) {
    int allocation[MAX];
    int allocated[MAX] = {0};
    for (int i = 0; i < nf; i++) {
        allocation[i] = -1;
        for (int j = 0; j < nb; j++) {
            if (allocated[j] == 0 && b[j] >= f[i]) {
                allocation[i] = j;
                allocated[j] = 1;
                break;
            }
        }
    }
```

```
    printf("\nFile_no:\tFile_size:\tBlock_no:\tBlock_size:");
    for (int i = 0; i < nf; i++) {
        if (allocation[i] != -1)
            printf("\n%d\t\t%d\t\t%d\t\t%d", i + 1, f[i], allocation[i] + 1, b[allocation[i]]);
        else
            printf("\n%d\t\t%d\t\t-\t\t-", i + 1, f[i]);
    }
}

void bestFit(int nb, int nf, int b[], int f[]) {
    int allocation[MAX];
    int allocated[MAX] = {0};
    for (int i = 0; i < nf; i++) {
        int bestIdx = -1;
        allocation[i] = -1;
        for (int j = 0; j < nb; j++) {
            if (allocated[j] == 0 && b[j] >= f[i]) {
                if (bestIdx == -1 || b[j] < b[bestIdx])
                    bestIdx = j;
            }
        }
        if (bestIdx != -1) {
            allocation[i] = bestIdx;
            allocated[bestIdx] = 1;
        }
    }
```

```
    printf("\nFile_no:\tFile_size:\tBlock_no:\tBlock_size:");
    for (int i = 0; i < nf; i++) {
        if (allocation[i] != -1)
            printf("\n%d\t\t%d\t\t%d\t\t%d", i + 1, f[i], allocation[i] + 1, b[allocation[i]]);
        else
            printf("\n%d\t\t%d\t\t-\t\t-", i + 1, f[i]);
    }
}

void worstFit(int nb, int nf, int b[], int f[]) {
    int allocation[MAX];
    int allocated[MAX] = {0};

    for (int i = 0; i < nf; i++) {
        int worstIdx = -1;
        allocation[i] = -1;
        for (int j = 0; j < nb; j++) {
            if (allocated[j] == 0 && b[j] >= f[i]) {
                if (worstIdx == -1 || b[j] > b[worstIdx])
                    worstIdx = j;
            }
        }
        if (worstIdx != -1) {
            allocation[i] = worstIdx;
            allocated[worstIdx] = 1;
        }
    }
```

```
    printf("\nFile_no:\tFile_size:\tBlock_no:\tBlock_size:");
    for (int i = 0; i < nf; i++) {
        if (allocation[i] != -1)
            printf("\n%d\t\t%d\t\t%d\t\t%d", i + 1, f[i], allocation[i] + 1, b[allocation[i]]);
        else
            printf("\n%d\t\t%d\t\t-\t\t-", i + 1, f[i]);
    }
}

int main() {
    int nb, nf, choice;

    printf("Memory Management Scheme");
    printf("\nEnter the number of blocks: ");
    scanf("%d", &nb);
    printf("Enter the number of files: ");
    scanf("%d", &nf);
    int b[nb], f[nf];
    printf("\nEnter the size of the blocks:\n");
    for (int i = 0; i < nb; i++) {
        printf("Block %d: ", i + 1);
        scanf("%d", &b[i]);
    }
    printf("Enter the size of the files:\n");
    for (int i = 0; i < nf; i++) {
        printf("File %d: ", i + 1);
        scanf("%d", &f[i]);
    }
```

```c
while (1) {
    printf("\n1. First Fit\n2. Best Fit\n3. Worst Fit\n4. Exit\n");
    printf("Enter your choice: ");
    scanf("%d", &choice);
    switch (choice) {
        case 1:
            printf("\n\tMemory Management Scheme - First Fit\n");
            firstFit(nb, nf, b, f);
            break;
        case 2:
            printf("\n\tMemory Management Scheme - Best Fit\n");
            bestFit(nb, nf, b, f);
            break;
        case 3:
            printf("\n\tMemory Management Scheme - Worst Fit\n");
            worstFit(nb, nf, b, f);
            break;
        case 4:
            printf("\nExiting...\n");
            exit(0);
            break;
        default:
            printf("\nInvalid choice.\n");
            break;
    }
}
```

```
    return 0;
}
```

OUTPUT:

```
Memory Management Scheme
Enter the number of blocks: 5
Enter the number of files: 4

Enter the size of the blocks:
Block 1: 100
Block 2: 500
Block 3: 200
Block 4: 300
Block 5: 600
Enter the size of the files:
File 1: 212
File 2: 417
File 3: 112
File 4: 426
```

```
1. First Fit
2. Best Fit
3. Worst Fit
4. Exit
Enter your choice: 1

        Memory Management Scheme - First Fit

File_no:        File_size:      Block_no:       Block_size:
1               212             2               500
2               417             5               600
3               112             3               200
4               426             -               -
1. First Fit
2. Best Fit
3. Worst Fit
4. Exit
Enter your choice: 2

        Memory Management Scheme - Best Fit

File_no:        File_size:      Block_no:       Block_size:
1               212             4               300
2               417             2               500
3               112             3               200
4               426             5               600
1. First Fit
2. Best Fit
3. Worst Fit
4. Exit
Enter your choice: 3

        Memory Management Scheme - Worst Fit

File_no:        File_size:      Block_no:       Block_size:
1               212             5               600
2               417             2               500
3               112             4               300
4               426             -               -
1. First Fit
2. Best Fit
3. Worst Fit
4. Exit
Enter your choice:
```

10. Write a C program to simulate page replacement algorithms

a) FIFO

b) LRU

c) Optimal

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

#define MAX_FRAMES 10
#define MAX_PAGES 25

void fifo(int pages[], int n, int capacity) {
    int frame[MAX_FRAMES], frameCount = 0, pageFaults = 0, frameIndex = 0;
    bool isPagePresent = false;

    for (int i = 0; i < n; i++) {
        isPagePresent = false;
        for (int j = 0; j < frameCount; j++) {
            if (frame[j] == pages[i]) {
                isPagePresent = true;
                break;
            }
        }

        if (isPagePresent == false) {
```

```
            if (frameCount < capacity) {
                frame[frameCount] = pages[i];
                frameCount++;
            } else {
                frame[frameIndex] = pages[i];
                frameIndex++;
                if (frameIndex >= capacity)
                    frameIndex = 0;
            }
            pageFaults++;
        }
    }
    printf("\nFIFO Page Replacement Algorithm:\n");
    printf("Total Page Faults: %d\n", pageFaults);
}

void lru(int pages[], int n, int capacity) {
    int frame[MAX_FRAMES], frameCount = 0, pageFaults = 0, counter[MAX_FRAMES];
    bool isPagePresent = false;

    for (int i = 0; i < n; i++) {
        isPagePresent = false;
        for (int j = 0; j < frameCount; j++) {
            if (frame[j] == pages[i]) {
                isPagePresent = true;
                counter[j] = i;
                break;
            }
```

```
        }

        if (isPagePresent == false) {
            if (frameCount < capacity) {
                frame[frameCount] = pages[i];
                counter[frameCount] = i;
                frameCount++;
            } else {
                int lru = 0;
                for (int j = 1; j < capacity; j++) {
                    if (counter[j] < counter[lru])
                        lru = j;
                }
                frame[lru] = pages[i];
                counter[lru] = i;
            }
            pageFaults++;
        }
    }
    printf("\nLRU Page Replacement Algorithm:\n");
    printf("Total Page Faults: %d\n", pageFaults);
}

void optimal(int pages[], int n, int capacity) {
    int frame[MAX_FRAMES], frameCount = 0, pageFaults = 0;
    bool isPagePresent = false;

    for (int i = 0; i < n; i++) {
```

```
isPagePresent = false;
for (int j = 0; j < frameCount; j++) {
    if (frame[j] == pages[i]) {
        isPagePresent = true;
        break;
    }
}

if (isPagePresent == false) {
    if (frameCount < capacity) {
        frame[frameCount] = pages[i];
        frameCount++;
    } else {
        int future[MAX_FRAMES] = {0};
        for (int j = 0; j < frameCount; j++) {
            bool isFound = false;
            for (int k = i + 1; k < n; k++) {
                if (pages[k] == frame[j]) {
                    future[j] = k;
                    isFound = true;
                    break;
                }
            }
            if (isFound == false)
                future[j] = n + 1;
        }
        int longest = 0;
        for (int j = 1; j < frameCount; j++) {
```

```
                if (future[j] > future[longest])
                    longest = j;
            }
            frame[longest] = pages[i];
        }
        pageFaults++;
    }
  }
  printf("\nOptimal Page Replacement Algorithm:\n");
  printf("Total Page Faults: %d\n", pageFaults);
}
int main() {
  int pages[MAX_PAGES], n, capacity;
  printf("Page Replacement Algorithms\n");
  printf("Enter the number of pages: ");
  scanf("%d", &n);
  printf("Enter the page reference string:\n");
  for (int i = 0; i < n; i++) {
    printf("Page %d: ", i + 1);
    scanf("%d", &pages[i]);
  }
  printf("Enter the number of frames: ");
  scanf("%d", &capacity);

  fifo(pages, n, capacity);
  lru(pages, n, capacity);
  optimal(pages, n, capacity);
  return 0;
```

```
}
```

OUTPUT:

```
Page Replacement Algorithms
Enter the number of pages: 10
Enter the page reference string:
Page 1: 1
Page 2: 2
Page 3: 1
Page 4: 4
Page 5: 6
Page 6: 4
Page 7: 2
Page 8: 1
Page 9: 56
Page 10: 3
Enter the number of frames: 3

FIFO Page Replacement Algorithm:
Total Page Faults: 7

LRU Page Replacement Algorithm:
Total Page Faults: 8

Optimal Page Replacement Algorithm:
Total Page Faults: 7
```