CSE312 HW1 BONUS REPORT

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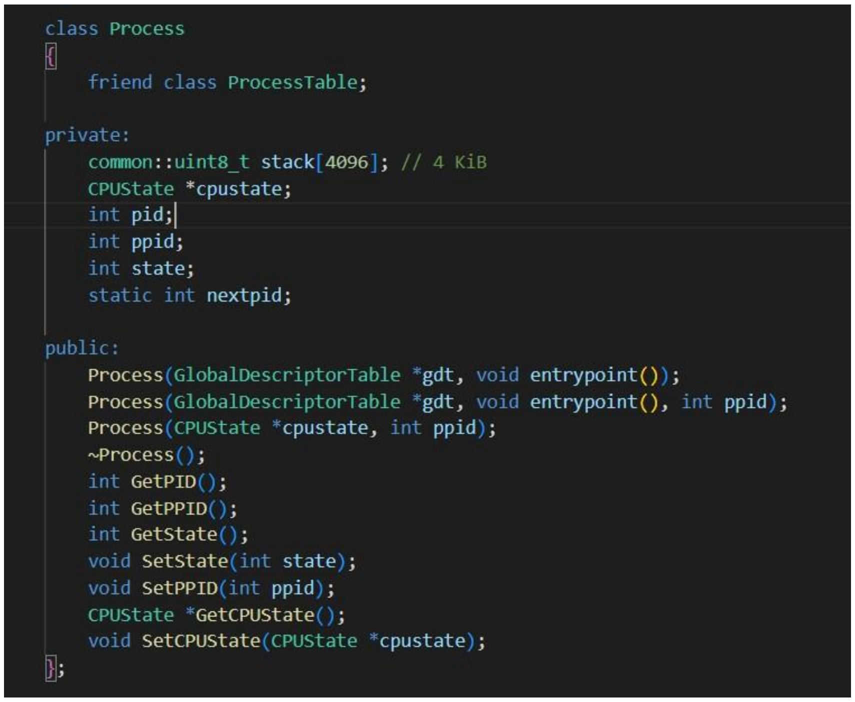
1) Problem Solution Approach

The purpose of this project is to write an operating system that supports multiprogramming. For this, a ready-made operating system whose source code belongs to Viktor Engelmann is used. Additions have been made to support multiprogramming and support some POSIX system calls. The operating system is coded using C++ and of course assembly. The system contains interrupt algorithms, scheduling algorithm so, it supports multiprogramming. There are 2 class structure used for multiprogramming. They are Process and ProcessTable.

Process

The Process class represents a single process in an operating system. It has private data members including a stack array of size 4096 bytes, a pointer to CPUState, an integer PID, an integer PPID (parent process ID), and an integer state. The class also has a static data member nextpid which is used to assign the next available PID to a new process. Constructor takes a GlobalDescriptorTable pointer and an entry point function pointer as arguments and creates a new process with a new stack and CPU state.



```cpp
class Process
{
    friend class ProcessTable;

private:
    common::uint8_t stack[4096]; // 4 KiB
    CPUState *cpustate;
    int pid;
    int ppid;
    int state;
    static int nextpid;

public:
    Process(GlobalDescriptorTable *gdt, void entrypoint());
    Process(GlobalDescriptorTable *gdt, void entrypoint(), int ppid);
    Process(CPUState *cpustate, int ppid);
    ~Process();
    int GetPID();
    int GetPPID();
    int GetState();
    void SetState(int state);
    void SetPPID(int ppid);
    CPUState *GetCPUState();
    void SetCPUState(CPUState *cpustate);
};
```

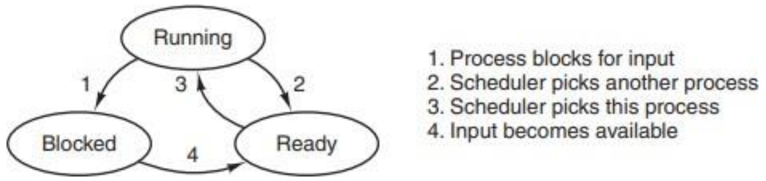
Process Class

The Process class also has several member functions:

- GetPID: Returns the PID of the process.
- GetPPID: Returns the parent process ID of the process.
- GetState: Returns the state of the process.
- SetState: Sets the state of the process to a given value.
- SetPPID: Sets the parent process ID of the process to a given value.
- GetCPUState: Returns a pointer to the CPU state of the process.
- SetCPUState: Sets the CPU state of the process to a given value.

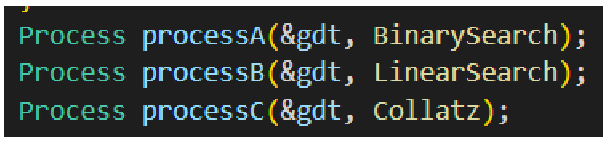
The GlobalDescriptorTable (GDT) is a data structure that stores the global segment descriptors for the CPU in an operating system. The GDT is used to set up memory segments for various purposes such as code, data, and stack.

The entrypoint function in the given code is a function pointer that represents the starting point of the process code. When a process is created, the entrypoint function is passed to the constructor of the Process class, and it is used to set up the CPU state of the process. The CPU state includes the instruction pointer (IP) and the stack pointer (SP), which are set to the entry point and the stack of the process respectively. When the process is scheduled to run by the operating system, the CPU starts executing instructions from the entry point of the process.


Running
Blocked
Ready
1
2
3
4
1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

Process States

The process state should be READY, RUNNING and BLOCKED. Any process's state READY when process is created. State turns RUNNING when the process is added process table and scheduling algorithm. State turns BLOCKED when the process is terminated.



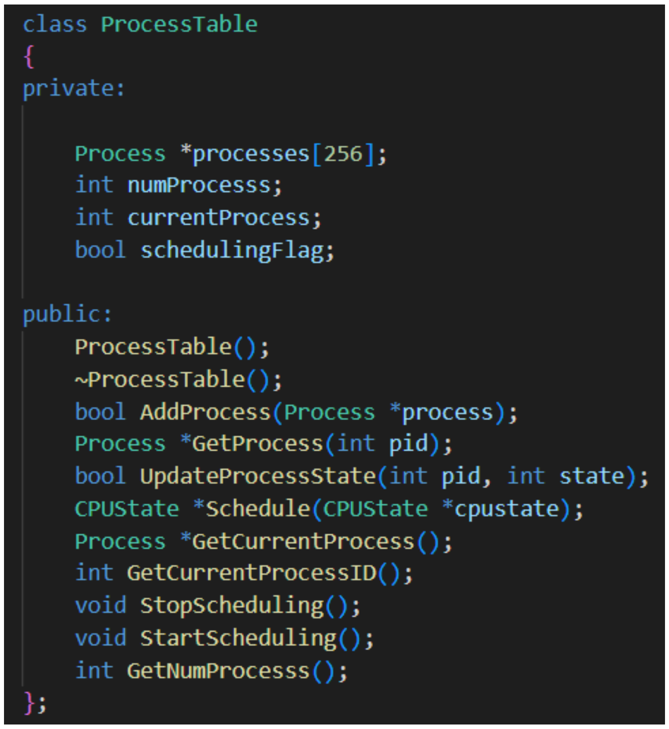
```
Process processA(&gdt, BinarySearch);
Process processB(&gdt, LinearSearch);
Process processC(&gdt, Collatz);
```

Examples Create Process

To implement the process model, the operating system maintains a table (an array of structures), called the process table, with one entry per process. (Some authors call these entries process control blocks.) This entry contains important information about the process' state, including its program counter, stack pointer,memory allocation, the status of its open files, its accounting and scheduling infor mation, and everything else about the process that must be saved when the process is switched from running to ready or blocked state so that it can be restarted later as if it had never been stopped.

Process Table

The ProcessTable class represents a table of processes in an operating system. The class has private data members including an array of process pointers, an integer to store the number of processes, an integer to store the index of the current process, and a boolean flag to indicate whether scheduling is allowed or not.



```
class ProcessTable
{
private:

    Process *processes[256];
    int numProcesss;
    int currentProcess;
    bool schedulingFlag;

public:
    ProcessTable();
    ~ProcessTable();
    bool AddProcess(Process *process);
    Process *GetProcess(int pid);
    bool UpdateProcessState(int pid, int state);
    CPUState *Schedule(CPUState *cpustate);
    Process *GetCurrentProcess();
    int GetCurrentProcessID();
    void StopScheduling();
    void StartScheduling();
    int GetNumProcesss();
};
```

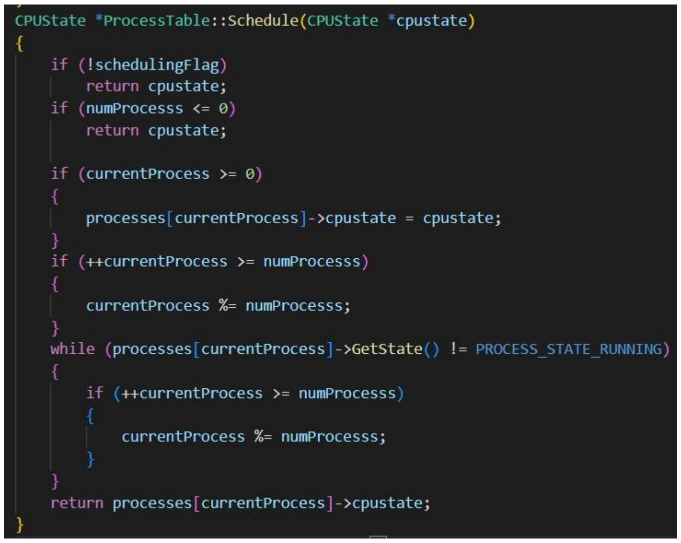
Process Table Class

The ProcessTable class has several member functions:

- AddProcess: Adds a process to the process array.
- GetProcess: Returns a process with a given PID.
- UpdateProcessState: Updates the state of a process with a given PID.
- Schedule: Selects the next process to run based on the scheduling algorithm implemented in the operating system and returns the CPUState pointer of the next process to run.
- GetCurrentProcess: Returns a pointer to the current process.
- GetCurrentProcessID: Returns the PID of the current process.
- StopScheduling: Disables the scheduling flag, indicating that the scheduler should not allow processes to run.
- StartScheduling: Enables the scheduling flag, indicating that the scheduler should allow processes to run.
- GetNumProcesss: Returns the number of processes in the process array.

Scheduling

In round-robin scheduling, each process is given a fixed time slice to execute on the CPU. Once the time slice expires, the scheduler selects the next process in a circular manner, regardless of the process priority. The Schedule function in the ProcessTable class implements the round-robin scheduling algorithm by selecting the next running process in a circular fashion and returning its CPU state pointer, which is used to switch context to that process and allow it to run on the CPU for its time slice.



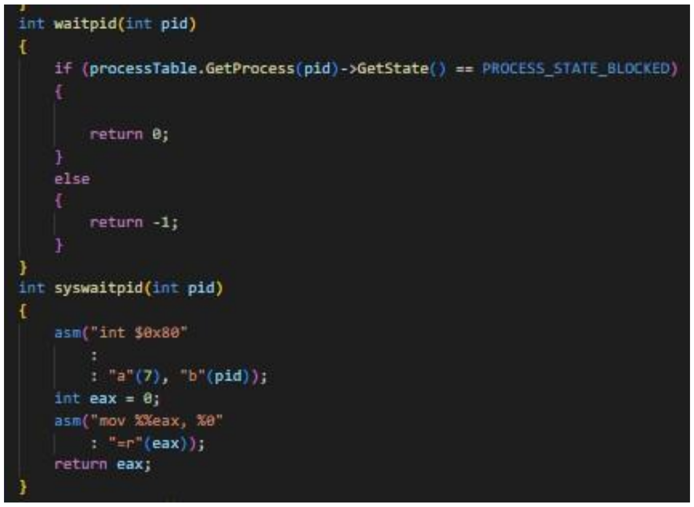
```
CPUState *ProcessTable::Schedule(CPUState *cpustate)
{
    if (!schedulingFlag)
        return cpustate;
    if (numProcesss <= 0)
        return cpustate;

    if (currentProcess >= 0)
    {
        processes[currentProcess]->cpustate = cpustate;
    }
    if (++currentProcess >= numProcesss)
    {
        currentProcess %= numProcesss;
    }
    while (processes[currentProcess]->GetState() != PROCESS_STATE_RUNNING)
    {
        if (++currentProcess >= numProcesss)
        {
            currentProcess %= numProcesss;
        }
    }
    return processes[currentProcess]->cpustate;
}
```

Scheduling Algorithm

System Calls

WaitPid

The waitpid system call takes a process ID as an argument and checks if the corresponding process is in a blocked state. If the process is blocked, indicating that it is currently waiting for an event, waitpid returns 0. Otherwise, it returns -1 to indicate that the process is not blocked. The syswaitpid function is a wrapper around the waitpid system call that invokes the system call using an interrupt instruction (int $0x80) and returns the value of the eax register after the interrupt has been handled, which contains the return value of waitpid.

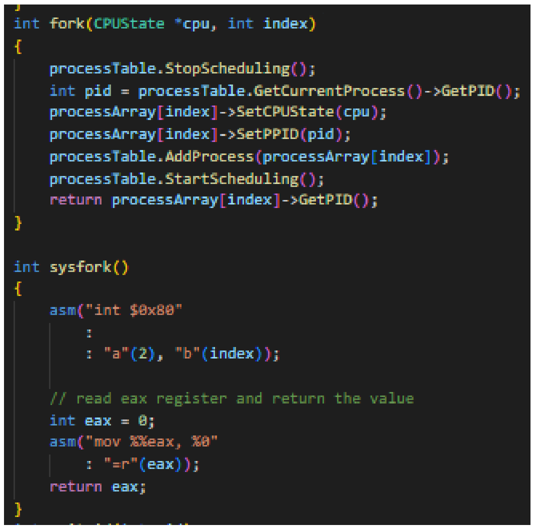


```
int waitpid(int pid)
{
    if (processTable.GetProcess(pid)->GetState() == PROCESS_STATE_BLOCKED)
    {

        return 0;
    }
    else
    {
        return -1;
    }
}
int syswaitpid(int pid)
{
    asm("int $0x80"
        :
        : "a"(7), "b"(pid));
    int eax = 0;
    asm("mov %%eax, %0"
        : "=r"(eax));
    return eax;
}
```

Waitpid System Call

Fork

The fork system call creates a new process by duplicating the calling process, called the parent process, resulting in the creation of a new child process. The child process is an exact copy of the parent process, except for its unique process ID and the fact that it has a different memory space. The fork system call takes no arguments and returns the process ID of the child process to the parent process and 0 to the child process. The new process is placed at the end of the process table and is eligible for scheduling by the operating system. The parent process and the child process execute independently of each other, each with their own CPU state and program counter.



```
int fork(CPUState *cpu, int index)
{
    processTable.StopScheduling();
    int pid = processTable.GetCurrentProcess()->GetPID();
    processArray[index]->SetCPUState(cpu);
    processArray[index]->SetPPID(pid);
    processTable.AddProcess(processArray[index]);
    processTable.StartScheduling();
    return processArray[index]->GetPID();
}

int sysfork()
{
    asm("int $0x80"
        :
        : "a"(2), "b"(index));

    // read eax register and return the value
    int eax = 0;
    asm("mov %%eax, %0"
        : "=r"(eax));
    return eax;
}
```

Fork System Call

2) Bonus Part

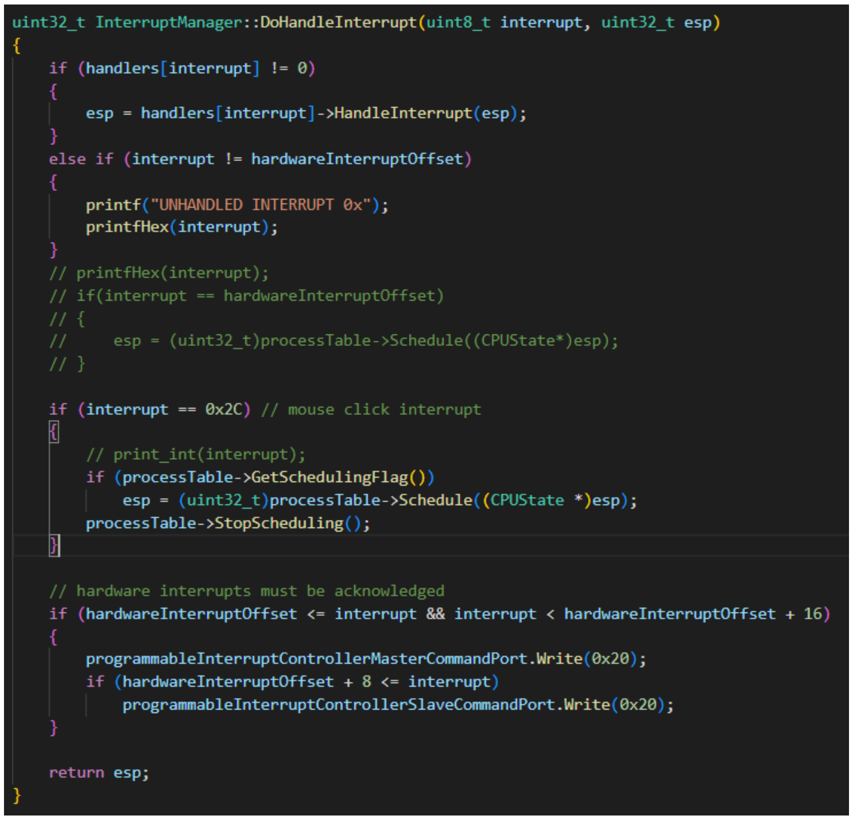
New features have been added for the bonus part of this assignment. These are:

- Transitions between processes are now provided with mouse click interrupt instead of timer interrupt. So context switch is provided when mouse click interrupt comes.

- Inputs used for the programs in the first assignment have been started to be taken with the keyboard.

- **According to the updated assignment, input is taken from the user when the operating system first stands up. Then, when we click with the mouse, context switches occur.**

Context Switch



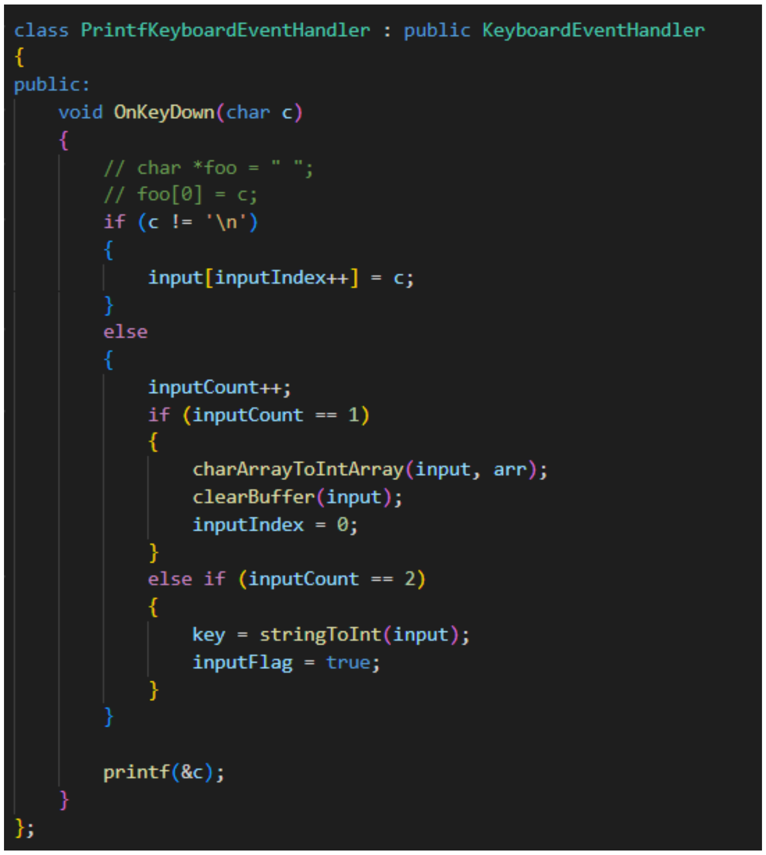
```
uint32_t InterruptManager::DoHandleInterrupt(uint8_t interrupt, uint32_t esp)
{
    if (handlers[interrupt] != 0)
    {
        esp = handlers[interrupt]->HandleInterrupt(esp);
    }
    else if (interrupt != hardwareInterruptOffset)
    {
        printf("UNHANDLED INTERRUPT 0x");
        printfHex(interrupt);
    }
    // printfHex(interrupt);
    // if(interrupt == hardwareInterruptOffset)
    // {
    //     esp = (uint32_t)processTable->Schedule((CPUState*)esp);
    // }

    if (interrupt == 0x2C) // mouse click interrupt
    {
        // print_int(interrupt);
        if (processTable->GetSchedulingFlag())
            esp = (uint32_t)processTable->Schedule((CPUState *)esp);
        processTable->StopScheduling();
    }

    // hardware interrupts must be acknowledged
    if (hardwareInterruptOffset <= interrupt && interrupt < hardwareInterruptOffset + 16)
    {
        programmableInterruptControllerMasterCommandPort.Write(0x20);
        if (hardwareInterruptOffset + 8 <= interrupt)
            programmableInterruptControllerSlaveCommandPort.Write(0x20);
    }

    return esp;
}
```

Interrupt Handling

The DoHandleInterrupt function in interrupt.cpp is used to handle interrupts. In this function, scheduling was taking place when the timer interrupt came under normal conditions. However, as requested in the bonus part of this assignment, scheduling was run when the mouse click interrupt came.

The interrupt number of mouse interrupt is **0x2C**. Scheduling is run when this interrupt is caught.

Keyboard Inputs



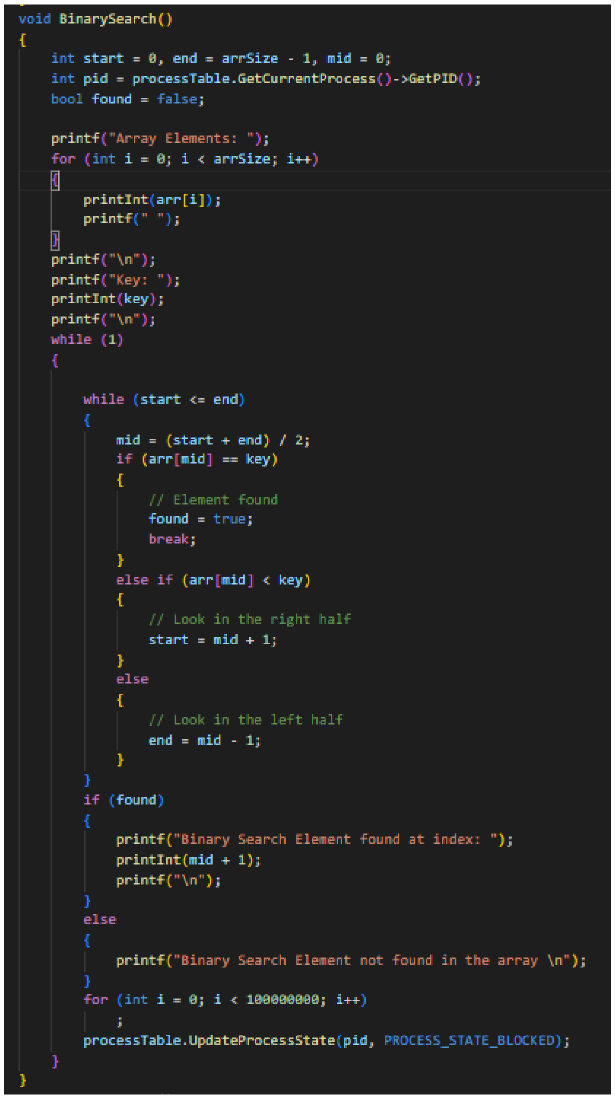
```
class PrintfKeyboardEventHandler : public KeyboardEventHandler
{
public:
    void OnKeyDown(char c)
    {
        // char *foo = " ";
        // foo[0] = c;
        if (c != '\n')
        {
            input[inputIndex++] = c;
        }
        else
        {
            inputCount++;
            if (inputCount == 1)
            {
                charArrayToIntArray(input, arr);
                clearBuffer(input);
                inputIndex = 0;
            }
            else if (inputCount == 2)
            {
                key = stringToInt(input);
                inputFlag = true;
            }
        }

        printf(&c);
    }
};
```

Keyboard Input Handling

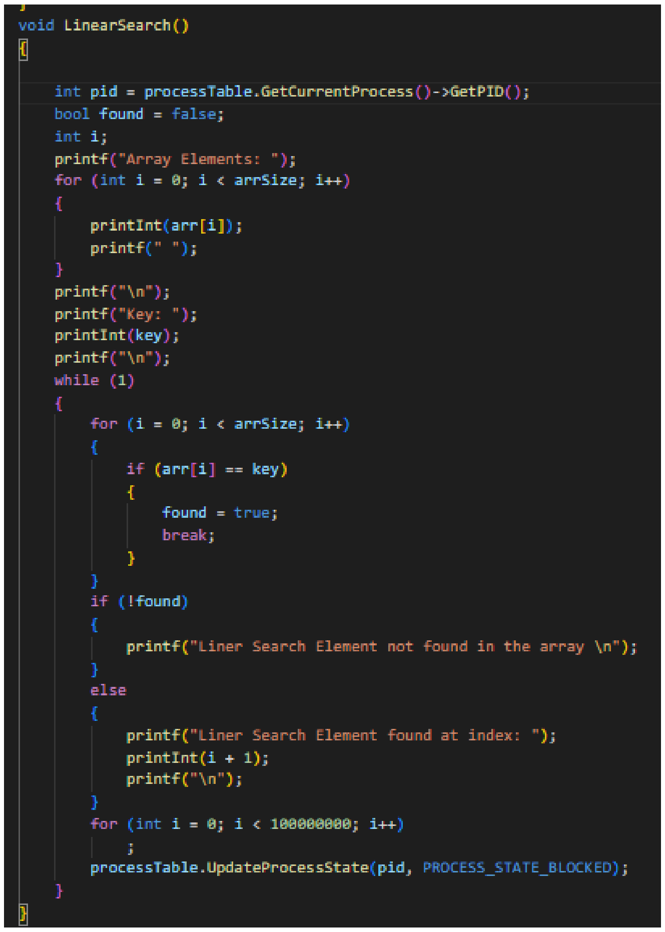
The Keyboard Event Handler class in kernel.cpp is used to detect inputs from the keyboard. Before the processes start, the required inputs are taken from the user and saved in an array. It is then used in processes.

3) Test Cases

The project has been tested with 3 different program: Binary Search, Linear Search and Collatz:

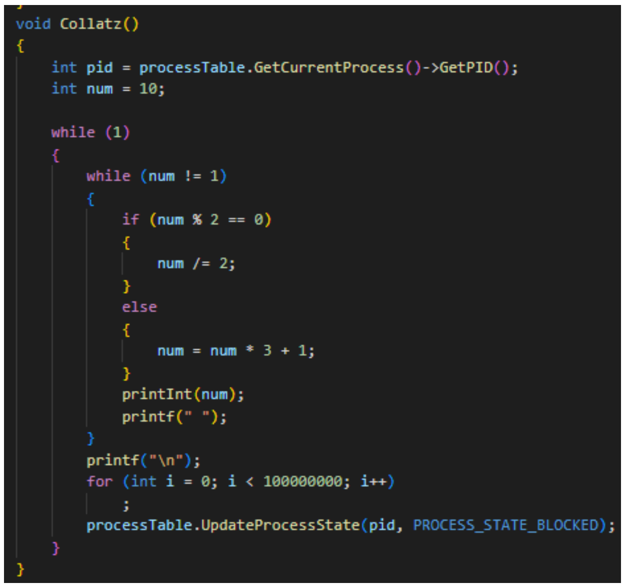


```
void BinarySearch()
{
    int start = 0, end = arrSize - 1, mid = 0;
    int pid = processTable.GetCurrentProcess()->GetPID();
    bool found = false;

    printf("Array Elements: ");
    for (int i = 0; i < arrSize; i++)
    {
        printInt(arr[i]);
        printf(" ");
    }
    printf("\n");
    printf("Key: ");
    printInt(key);
    printf("\n");
    while (1)
    {

        while (start <= end)
        {
            mid = (start + end) / 2;
            if (arr[mid] == key)
            {
                // Element found
                found = true;
                break;
            }
            else if (arr[mid] < key)
            {
                // Look in the right half
                start = mid + 1;
            }
            else
            {
                // Look in the left half
                end = mid - 1;
            }
        }
        if (found)
        {
            printf("Binary Search Element found at index: ");
            printInt(mid + 1);
            printf("\n");
        }
        else
        {
            printf("Binary Search Element not found in the array \n");
        }
        for (int i = 0; i < 100000000; i++)
            ;
        processTable.UpdateProcessState(pid, PROCESS_STATE_BLOCKED);
    }
}
```



```
void LinearSearch()
{

    int pid = processTable.GetCurrentProcess()->GetPID();
    bool found = false;
    int i;
    printf("Array Elements: ");
    for (int i = 0; i < arrSize; i++)
    {
        printInt(arr[i]);
        printf(" ");
    }
    printf("\n");
    printf("Key: ");
    printInt(key);
    printf("\n");
    while (1)
    {
        for (i = 0; i < arrSize; i++)
        {
            if (arr[i] == key)
            {
                found = true;
                break;
            }
        }
        if (!found)
        {
            printf("Liner Search Element not found in the array \n");
        }
        else
        {
            printf("Liner Search Element found at index: ");
            printInt(i + 1);
            printf("\n");
        }
        for (int i = 0; i < 100000000; i++)
            ;
        processTable.UpdateProcessState(pid, PROCESS_STATE_BLOCKED);
    }
}
```

Binary Search Program **Linear Search Program**



```
void Collatz()
{
    int pid = processTable.GetCurrentProcess()->GetPID();
    int num = 10;

    while (1)
    {
        while (num != 1)
        {
            if (num % 2 == 0)
            {
                num /= 2;
            }
            else
            {
                num = num * 3 + 1;
            }
            printInt(num);
            printf(" ");
        }
        printf("\n");
        for (int i = 0; i < 100000000; i++)
            ;
        processTable.UpdateProcessState(pid, PROCESS_STATE_BLOCKED);
    }
}
```

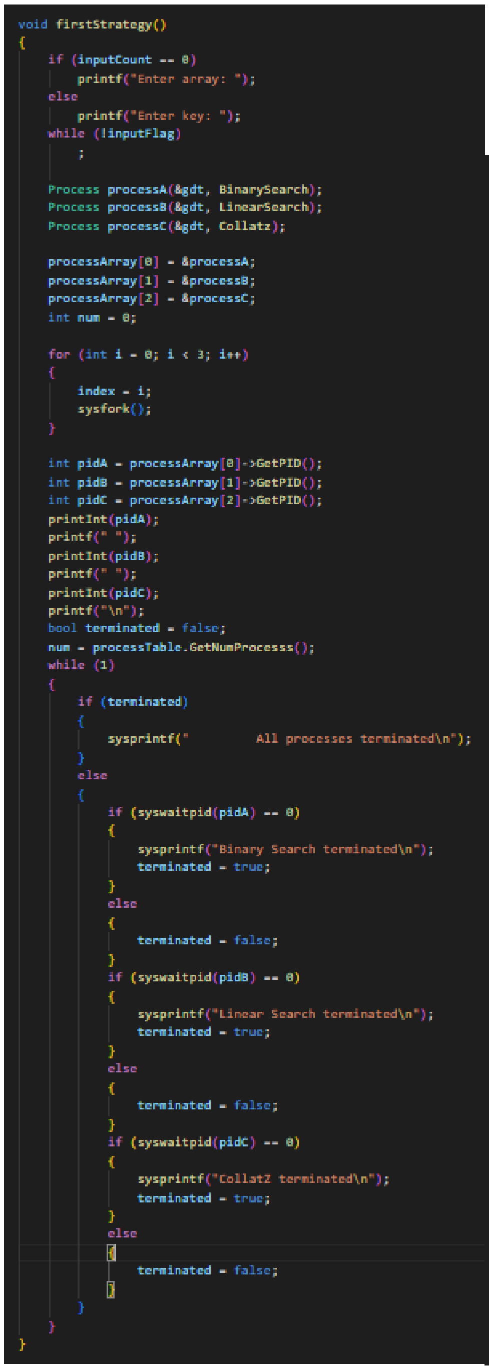
Collatz Program

The project has been tested with 3 different kernel methods:

In the first strategy init process will initialize Process Table, load 3 different programs (listed below) to the memory start them and will enter an infinite loop until all the processes terminate.

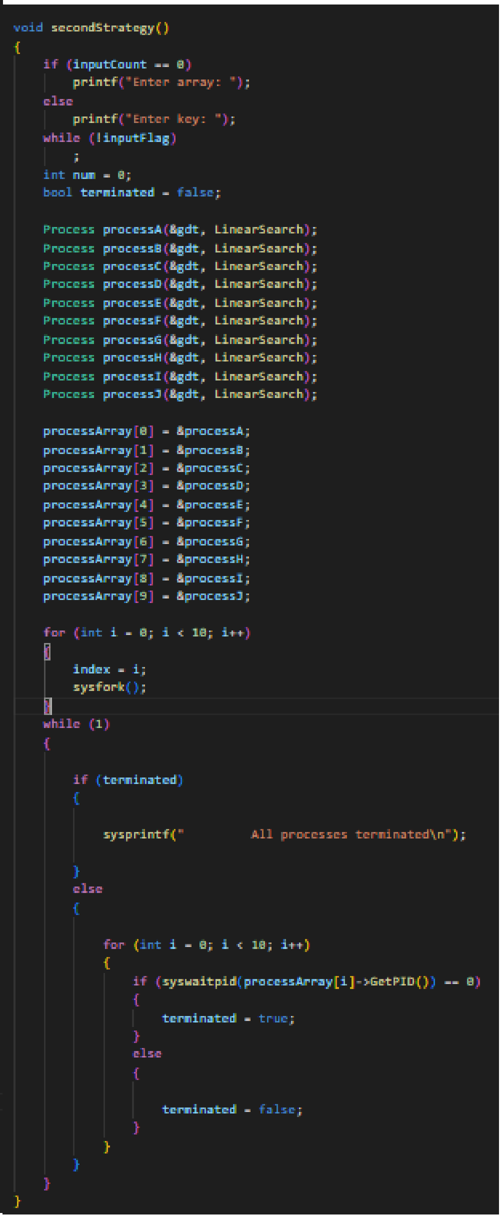
Second strategy is randomly choosing one of the programs and loads it into memory 10 times (Same II program 10 different processes), start them and will enter an infinite loop until all the processes terminate.

Final Strategy is choosing 2 out 3 programs randomly and loading each program 3 times start them and will enter an infinite loop until all the processes terminate.



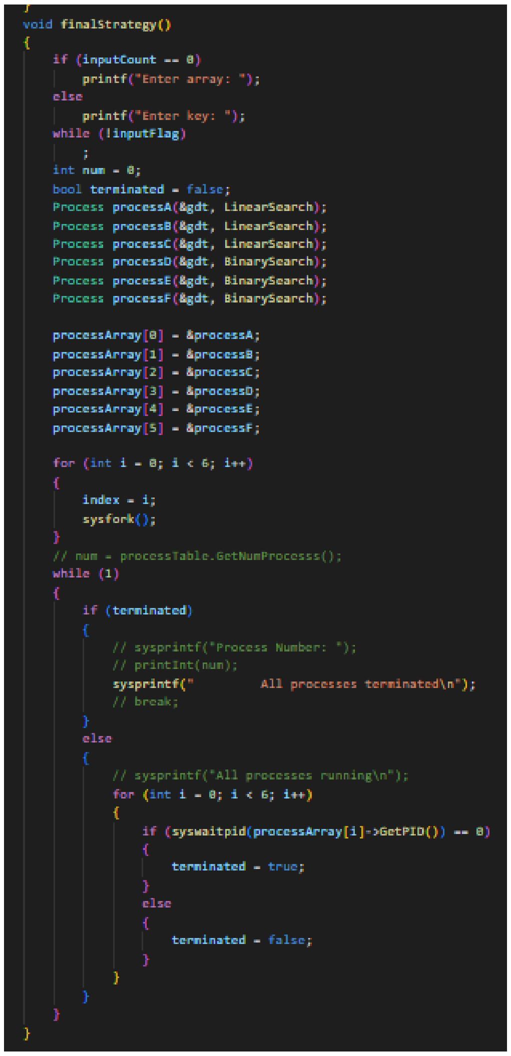
```
void firstStrategy()
{
    if (inputCount == 0)
        printf("Enter array: ");
    else
        printf("Enter key: ");
    while (!inputFlag)
        ;

    Process processA(&gdt, BinarySearch);
    Process processB(&gdt, LinearSearch);
    Process processC(&gdt, Collatz);

    processArray[0] = &processA;
    processArray[1] = &processB;
    processArray[2] = &processC;
    int num = 0;

    for (int i = 0; i < 3; i++)
    {
        index = i;
        sysfork();
    }

    int pidA = processArray[0]->GetPID();
    int pidB = processArray[1]->GetPID();
    int pidC = processArray[2]->GetPID();
    printInt(pidA);
    printf(" ");
    printInt(pidB);
    printf(" ");
    printInt(pidC);
    printf("\n");
    bool terminated = false;
    num = processTable.GetNumProcesss();
    while (1)
    {
        if (terminated)
        {
            sysprintf("         All processes terminated\n");
        }
        else
        {
            if (syswaitpid(pidA) == 0)
            {
                sysprintf("Binary Search terminated\n");
                terminated = true;
            }
            else
            {
                terminated = false;
            }
            if (syswaitpid(pidB) == 0)
            {
                sysprintf("Linear Search terminated\n");
                terminated = true;
            }
            else
            {
                terminated = false;
            }
            if (syswaitpid(pidC) == 0)
            {
                sysprintf("CollatZ terminated\n");
                terminated = true;
            }
            else
            {
                terminated = false;
            }
        }
    }
}
```

First Strategy



```
void secondStrategy()
{
    if (inputCount == 0)
        printf("Enter array: ");
    else
        printf("Enter key: ");
    while (!inputFlag)
        ;
    int num = 0;
    bool terminated = false;

    Process processA(&gdt, LinearSearch);
    Process processB(&gdt, LinearSearch);
    Process processC(&gdt, LinearSearch);
    Process processD(&gdt, LinearSearch);
    Process processE(&gdt, LinearSearch);
    Process processF(&gdt, LinearSearch);
    Process processG(&gdt, LinearSearch);
    Process processH(&gdt, LinearSearch);
    Process processI(&gdt, LinearSearch);
    Process processJ(&gdt, LinearSearch);

    processArray[0] = &processA;
    processArray[1] = &processB;
    processArray[2] = &processC;
    processArray[3] = &processD;
    processArray[4] = &processE;
    processArray[5] = &processF;
    processArray[6] = &processG;
    processArray[7] = &processH;
    processArray[8] = &processI;
    processArray[9] = &processJ;

    for (int i = 0; i < 10; i++)
    {
        index = i;
        sysfork();
    }
    while (1)
    {

        if (terminated)
        {

            sysprintf("         All processes terminated\n");

        }
        else
        {

            for (int i = 0; i < 10; i++)
            {
                if (syswaitpid(processArray[i]->GetPID()) == 0)
                {
                    terminated = true;
                }
                else
                {

                    terminated = false;
                }
            }
        }
    }
}
```

Second Strategy



```
}
void finalStrategy()
{
    if (inputCount == 0)
        printf("Enter array: ");
    else
        printf("Enter key: ");
    while (!inputFlag)
        ;
    int num = 0;
    bool terminated = false;
    Process processA(&gdt, LinearSearch);
    Process processB(&gdt, LinearSearch);
    Process processC(&gdt, LinearSearch);
    Process processD(&gdt, BinarySearch);
    Process processE(&gdt, BinarySearch);
    Process processF(&gdt, BinarySearch);

    processArray[0] = &processA;
    processArray[1] = &processB;
    processArray[2] = &processC;
    processArray[3] = &processD;
    processArray[4] = &processE;
    processArray[5] = &processF;

    for (int i = 0; i < 6; i++)
    {
        index = i;
        sysfork();
    }
    // num = processTable.GetNumProcesss();
    while (1)
    {
        if (terminated)
        {
            // sysprintf("Process Number: ");
            // printInt(num);
            sysprintf("          All processes terminated\n");
            // break;
        }
        else
        {
            // sysprintf("All processes running\n");
            for (int i = 0; i < 6; i++)
            {
                if (syswaitpid(processArray[i]->GetPID()) == 0)
                {
                    terminated = true;
                }
                else
                {
                    terminated = false;
                }
            }
        }
    }
}
```

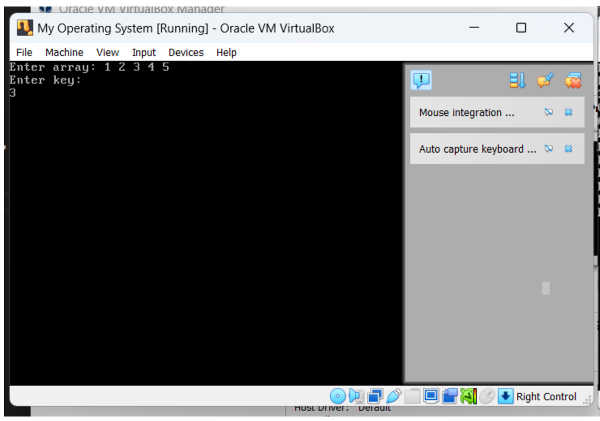
Final Strategy

The first strategy is a program that creates three processes (processA, processB, and processC) and waits for each process to terminate before printing a message indicating whether it has terminated or is still running. The program uses a loop that checks whether each process has terminated and sets a flag to true if it has. If all processes have terminated, the loop ends and the program prints a message indicating that all processes have terminated.

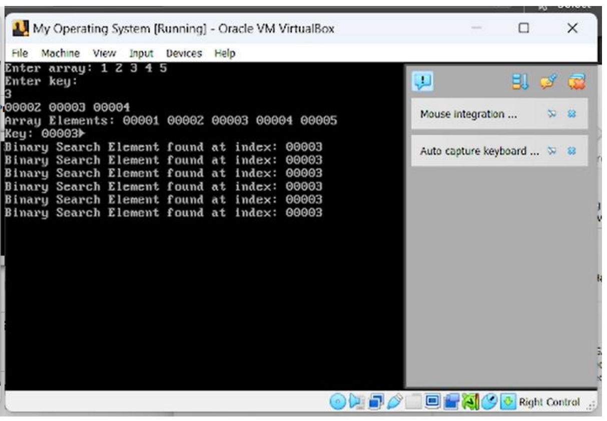
The second strategy is a program that creates ten instances of the Process class with the LinearSearch function pointer, and adds them to an array processArray. The program then enters a loop that forks a new process for each instance in processArray. This means that a total of ten processes will be created, each executing the LinearSearch function. The program then enters a loop that checks whether each process has terminated, using the syswaitpid function. If a process has terminated, the program sets a flag terminated to true. If all processes have terminated, the loop ends and the program prints a message indicating that all processes have terminated. Otherwise, the loop continues and prints a message indicating which processes are still running. The program prints out a message for each process indicating whether it is still running or has terminated. The messages indicate which process is running or has terminated and are printed to the console using the sysprintf function. Overall, the second strategy creates multiple instances of the Process class, forks a new process for each instance, and manages them using a loop that waits for each process to terminate before printing out a message indicating whether the process has terminated or is still running.

The final strategy is a program that creates six instances of the Process class, with three instances running the LinearSearch function and three instances running the BinarySearch function, and adds them to an array processArray. The program then enters a loop that forks a new process for each instance in processArray. This means that a total of six processes will be created, with three executing the LinearSearch function and three executing the BinarySearch function. The program then enters a loop that checks whether each process has terminated, using the syswaitpid function. If a process has terminated, the program sets a flag terminated to true. If all processes have terminated, the loop ends and the program prints a message indicating that all processes have terminated. Otherwise, the loop continues and prints a message indicating which processes are still running. The program prints out a message for each process indicating whether it is still running or has terminated. The messages indicate which process is running or has terminated and are printed to the console using the sysprintf function. Overall, the final strategy creates multiple instances of the Process class, forks a new process for each instance, and manages them using a loop that waits for each process to terminate before printing out a message indicating whether the process has terminated or is still running. This strategy includes a mix of processes running different functions, with three executing LinearSearch and three executing BinarySearch.

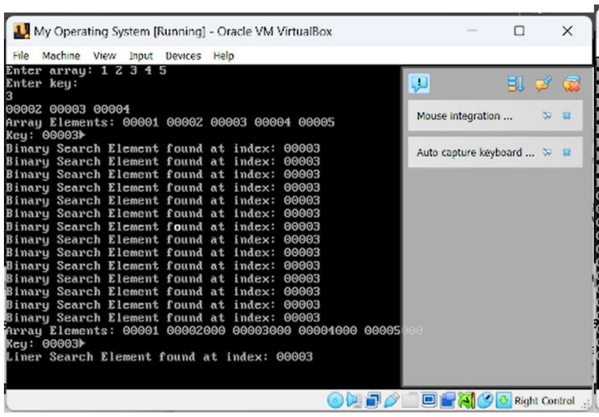
Outputs


My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

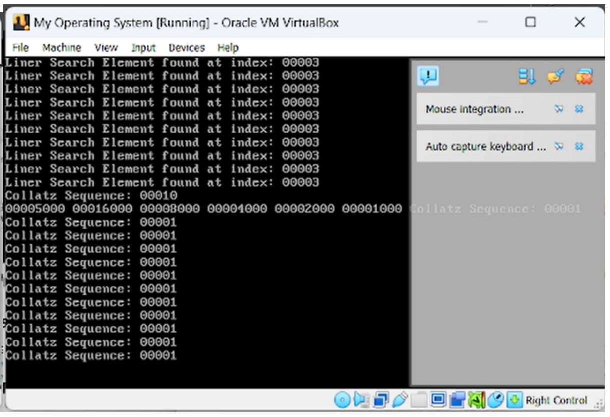
```
Enter array: 1 2 3 4 5
Enter key:
3
```


My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

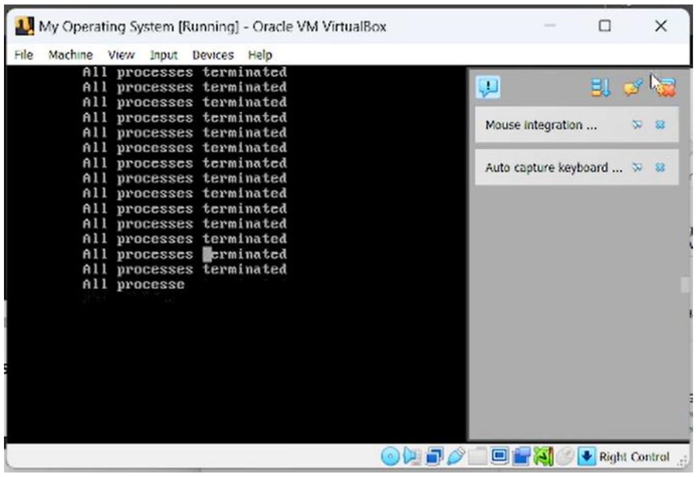
```
Enter array: 1 2 3 4 5
Enter key:
3
00002 00003 00004
Array Elements: 00001 00002 00003 00004 00005
Key: 00003▸
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
```


My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

```
Enter array: 1 2 3 4 5
Enter key:
3
00002 00003 00004
Array Elements: 00001 00002 00003 00004 00005
Key: 00003▸
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Array Elements: 00001 00002000 00003000 00004000 00005000
Key: 00003▸
Liner Search Element found at index: 00003
```


My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

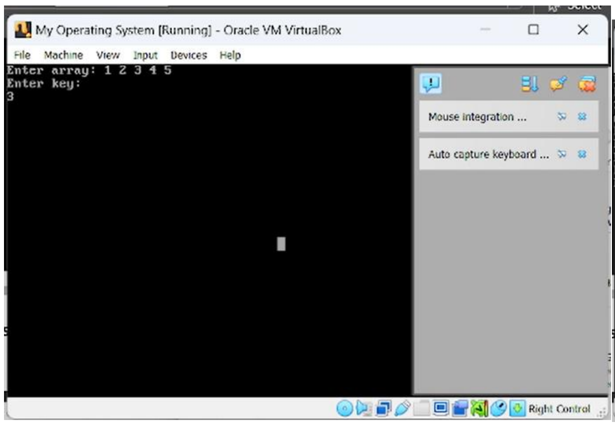
```
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Collatz Sequence: 00010
00005000 00016000 00008000 00004000 00002000 00001000 Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
Collatz Sequence: 00001
```


My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

```
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processes terminated
          All processe
```

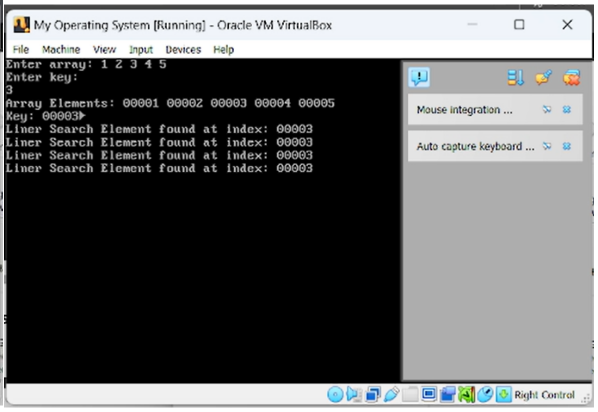
First Strategy Outputs

When mouse is clicked, context switch is occurred…



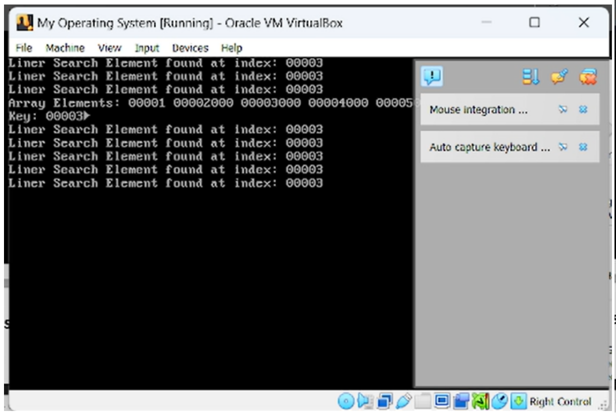
My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

```
Enter array: 1 2 3 4 5
Enter key:
3
```



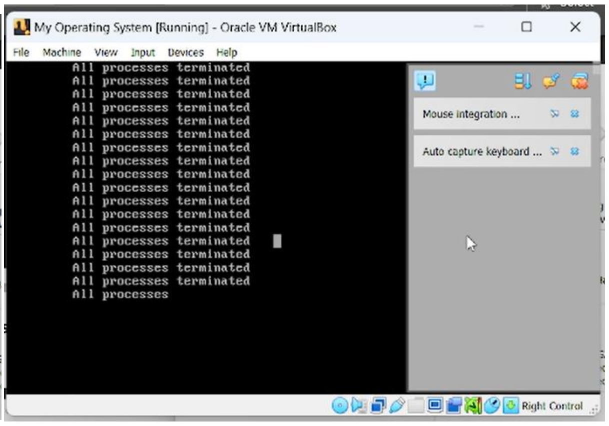
My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

```
Enter array: 1 2 3 4 5
Enter key:
3
Array Elements: 00001 00002 00003 00004 00005
Key: 00003▸
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
```



My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

```
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Array Elements: 00001 00002000 00003000 00004000 00005
Key: 00003▸
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
```

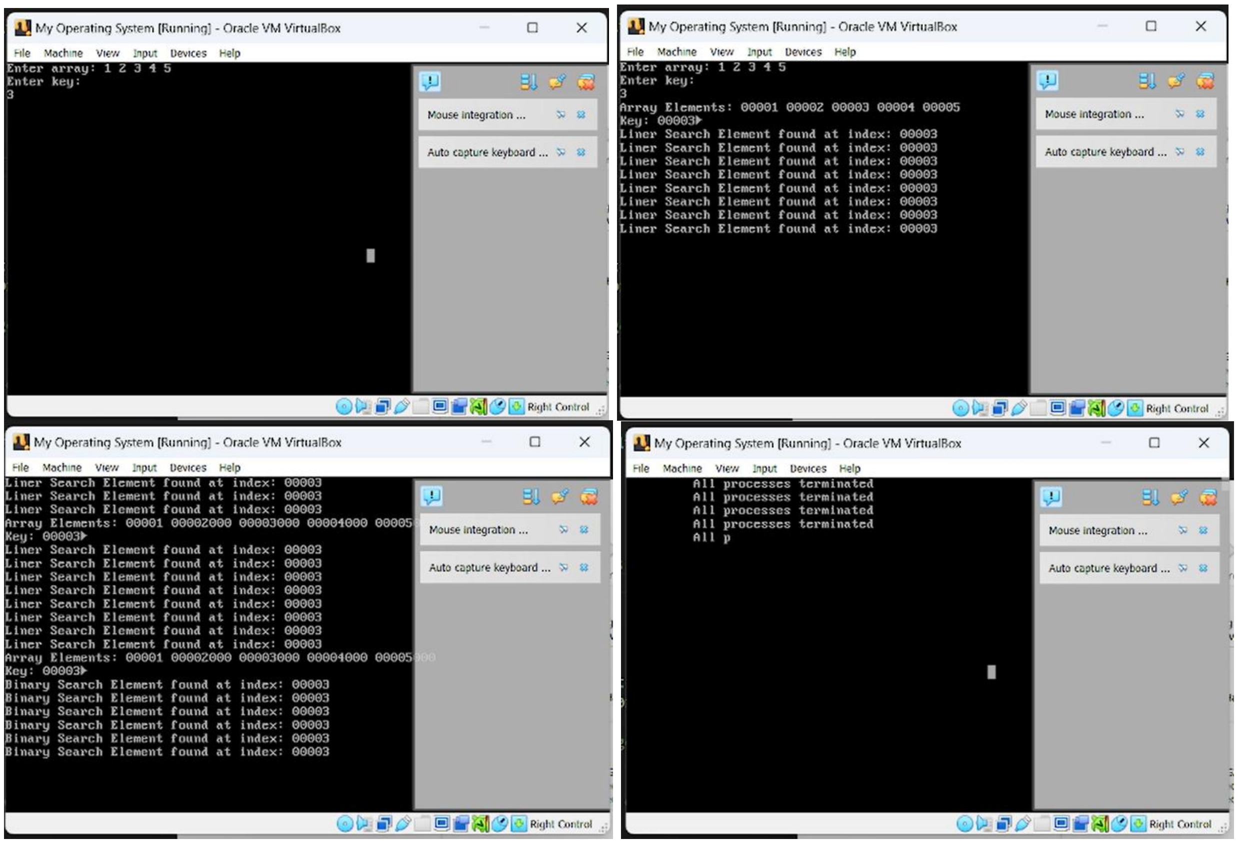


My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

```
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All processes
```

Second Strategy Output

When mouse is clicked, context switch is occurred…


My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Mouse integration ...
Auto capture keyboard ...
Right Control

```
Enter array: 1 2 3 4 5
Enter key:
3
```

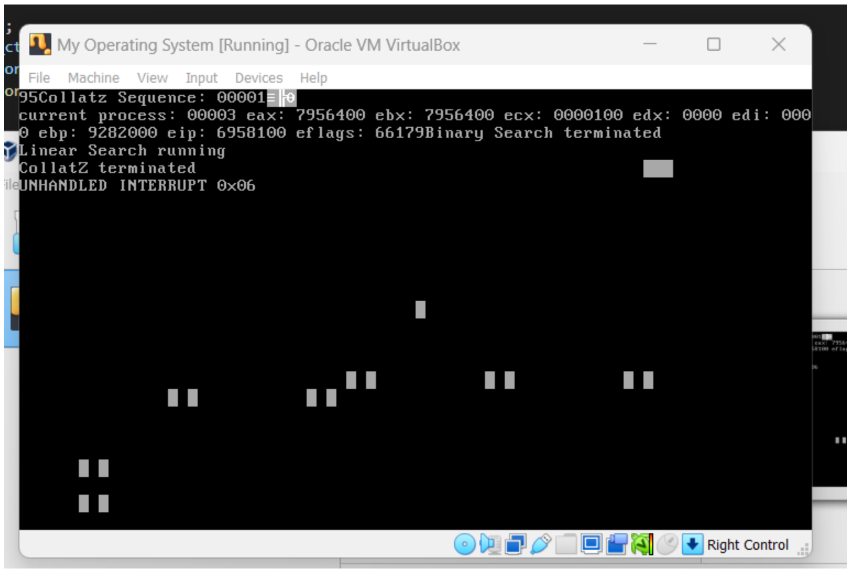
```
Enter array: 1 2 3 4 5
Enter key:
3
Array Elements: 00001 00002 00003 00004 00005
Key: 00003▶
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
```

```
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Array Elements: 00001 00002000 00003000 00004000 00005
Key: 00003▶
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Liner Search Element found at index: 00003
Array Elements: 00001 00002000 00003000 00004000 00005000
Key: 00003▶
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
Binary Search Element found at index: 00003
```

```
         All processes terminated
         All processes terminated
         All processes terminated
         All processes terminated
         All p
```

Third Strategy Output

When mouse is clicked, context switch is occurred…


My Operating System [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Right Control

```
95Collatz Sequence: 00001≡╟0
current process: 00003 eax: 7956400 ebx: 7956400 ecx: 0000100 edx: 0000 edi: 000
0 ebp: 9282000 eip: 6958100 eflags: 66179Binary Search terminated
Linear Search running
CollatZ terminated
UNHANDLED INTERRUPT 0x06
```

Cpu State Output (When Scheduling)