Task 1: Process Management Simulator

Overview

In this task, I've implemented a process management simulator that mimics the behavior of operating system processes. The simulator supports key system calls such as `fork` and `exec`, allowing for the creation of child processes, duplication of the parent process's address space, and the ability for the child to replace its memory image with a new program using `exec`. The simulator also manages process states (ready, running, blocked), handles process termination, and maintains process hierarchies.

Key Features

1. **Process Creation and Forking**: The simulator allows the creation of child processes using the `fork` system call. The child process inherits the address space of the parent process.
2. **Exec System Call**: The `exec` system call replaces the current process's memory image with a new program.
3. **Process States**: Processes can be in one of three states: `READY`, `RUNNING`, or `BLOCKED`.
4. **Process Termination**: The simulator supports terminating processes and cleaning up resources.
5. **Process Hierarchies**: The simulator maintains parent-child relationships between processes.

Files and Their Roles

1. `process_simulator.cpp`

This file contains the implementation of the process management simulator. It defines the `Process` and `ProcessManager` classes, which handle process creation, execution, and termination.

Code Snippet:

```cpp
#include <iostream>
#include <vector>
#include <unordered_map>
#include <memory>
#include <string>

enum class ProcessState { READY, RUNNING, BLOCKED };

class Process {
private:
    int pid;
```

```cpp
    int ppid;
    ProcessState state;
    std::vector<uint8_t> addressSpace;
    std::vector<std::shared_ptr<Process>> children;

public:
    Process(int pid, int ppid = 0) :
        pid(pid), ppid(ppid), state(ProcessState::READY) {
        addressSpace.resize(1024, 0); // Simple 1KB address space
    }

    int getPid() const { return pid; }
    int getPPid() const { return ppid; }
    ProcessState getState() const { return state; }
    void setState(ProcessState newState) { state = newState; }

    std::shared_ptr<Process> fork() {
        auto child = std::make_shared<Process>(getNextPid(), pid);
        child->addressSpace = addressSpace; // Copy address space
        children.push_back(child);
        return child;
    }

    bool exec(const std::string& program) {
        // Simulate loading new program
        addressSpace.clear();
        addressSpace.resize(1024, 0);
        // Simulate program loading
        std::cout << "Executing program: " << program << " in process " << pid << std::endl
        return true;
    }

private:
    static int getNextPid() {
        static int nextPid = 1;
        return nextPid++;
    }
};

class ProcessManager {
private:
    std::unordered_map<int, std::shared_ptr<Process>> processes;
    std::shared_ptr<Process> currentProcess;

public:
    ProcessManager() {
```

```
        // Create init process
        auto init = std::make_shared<Process>(0);
        processes[0] = init;
        currentProcess = init;
    }

    std::shared_ptr<Process> fork() {
        if (!currentProcess) return nullptr;
        auto child = currentProcess->fork();
        processes[child->getPid()] = child;
        return child;
    }

    bool exec(const std::string& program) {
        if (!currentProcess) return false;
        return currentProcess->exec(program);
    }

    bool terminateProcess(int pid) {
        if (processes.find(pid) == processes.end()) return false;
        processes.erase(pid);
        return true;
    }

    void switchProcess(int pid) {
        if (processes.find(pid) != processes.end()) {
            if (currentProcess)
                currentProcess->setState(ProcessState::READY);
            currentProcess = processes[pid];
            currentProcess->setState(ProcessState::RUNNING);
        }
    }
};

// Example usage
int main() {
    ProcessManager pm;

    // Create child process
    auto child = pm.fork();
    std::cout << "Created child process: " << child->getPid() << std::endl;

    // Execute new program in child
    pm.switchProcess(child->getPid());
    pm.exec("new_program.exe");
```

```
    // Terminate child
    pm.terminateProcess(child->getPid());

    return 0;
}
```

How to Run:

1. Compile the file using a C++ compiler (e.g., `g++`):

   ```
   g++ process_simulator.cpp -o process_simulator
   ```

2. Run the compiled program:

   ```
   ./process_simulator
   ```

3. The program will simulate the creation of a child process, execution of a new program, and termination of the child process.

---

2. `virtual_memory.cpp`

This file implements a simple virtual memory system with paging. It simulates a process with virtual memory addresses that are mapped to physical memory using a page table. The system handles page faults and implements the LRU (Least Recently Used) page replacement algorithm.

Code Snippet:

```
// Virtual Memory System with Paging
#include <iostream>
#include <vector>
#include <unordered_map>
#include <list>
#include <cstdint>

const size_t PAGE_SIZE = 4096;
const size_t NUM_PAGES = 256;
const size_t NUM_FRAMES = 128;

struct Page {
    uint8_t data[PAGE_SIZE];
    bool dirty = false;
    bool present = false;
};

struct PageTableEntry {
    uint32_t frame_number;
```

```cpp
    bool present;
    bool dirty;
};

class VirtualMemory {
private:
    std::vector<Page> physical_memory;
    std::vector<PageTableEntry> page_table;
    std::list<uint32_t> lru_list;
    std::unordered_map<uint32_t, std::list<uint32_t>::iterator> page_to_lru;
    size_t free_frames;

public:
    VirtualMemory() :
        physical_memory(NUM_FRAMES),
        page_table(NUM_PAGES),
        free_frames(NUM_FRAMES) {
        for (auto& pte : page_table) {
            pte.present = false;
            pte.dirty = false;
        }
    }

    uint8_t read(uint32_t virtual_address) {
        uint32_t page_number = virtual_address / PAGE_SIZE;
        uint32_t offset = virtual_address % PAGE_SIZE;

        if (!page_table[page_number].present) {
            handlePageFault(page_number);
        }

        // Update LRU
        updateLRU(page_number);

        uint32_t frame_number = page_table[page_number].frame_number;
        return physical_memory[frame_number].data[offset];
    }

    void write(uint32_t virtual_address, uint8_t value) {
        uint32_t page_number = virtual_address / PAGE_SIZE;
        uint32_t offset = virtual_address % PAGE_SIZE;

        if (!page_table[page_number].present) {
            handlePageFault(page_number);
        }
```

```cpp
        // Update LRU and mark page as dirty
        updateLRU(page_number);
        page_table[page_number].dirty = true;

        uint32_t frame_number = page_table[page_number].frame_number;
        physical_memory[frame_number].data[offset] = value;
        physical_memory[frame_number].dirty = true;
    }

private:
    void handlePageFault(uint32_t page_number) {
        uint32_t frame_number;

        if (free_frames > 0) {
            frame_number = NUM_FRAMES - free_frames;
            free_frames--;
        } else {
            // Use LRU to select page to evict
            uint32_t victim_page = lru_list.back();
            frame_number = page_table[victim_page].frame_number;

            // Write back if dirty
            if (page_table[victim_page].dirty) {
                writePageToDisk(victim_page, frame_number);
            }

            page_table[victim_page].present = false;
            lru_list.pop_back();
            page_to_lru.erase(victim_page);
        }

        // Load page from disk
        loadPageFromDisk(page_number, frame_number);
        page_table[page_number].frame_number = frame_number;
        page_table[page_number].present = true;
        page_table[page_number].dirty = false;
    }

    void updateLRU(uint32_t page_number) {
        if (page_to_lru.find(page_number) != page_to_lru.end()) {
            lru_list.erase(page_to_lru[page_number]);
        }
        lru_list.push_front(page_number);
        page_to_lru[page_number] = lru_list.begin();
    }
```

```cpp
    void writePageToDisk(uint32_t page_number, uint32_t frame_number) {
        // Simulate writing to disk
        std::cout << "Writing page " << page_number << " to disk" << std::endl;
    }

    void loadPageFromDisk(uint32_t page_number, uint32_t frame_number) {
        // Simulate loading from disk
        std::cout << "Loading page " << page_number << " from disk to frame "
                  << frame_number << std::endl;
    }
};

int main() {
    VirtualMemory vm;

    // Example usage
    vm.write(0, 42);
    vm.write(PAGE_SIZE, 84);

    std::cout << "Value at address 0: " << (int)vm.read(0) << std::endl;
    std::cout << "Value at address " << PAGE_SIZE << ": "
              << (int)vm.read(PAGE_SIZE) << std::endl;

    return 0;
}
```

How to Run:

1. Compile the file using a C++ compiler (e.g., `g++`):

   ```
   g++ virtual_memory.cpp -o virtual_memory
   ```

2. Run the compiled program:

   ```
   ./virtual_memory
   ```

3. The program will simulate virtual memory operations, including reading and writing to memory, handling page faults, and swapping pages using the LRU algorithm.

---

3. `web_server.cpp`

This file implements a multithreaded web server using POSIX threads (Pthreads). The server can handle multiple client requests concurrently, with each request being handled by a different thread. The implementation ensures proper thread synchronization, avoids race conditions, and supports graceful thread shutdown when the server exits.

Code Snippet:

```
// Multithreaded Web Server
#include <iostream>
#include <pthread.h>
#include <queue>
#include <string>
#include <unistd.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <atomic>
#include <signal.h>

const int MAX_THREADS = 10;
const int PORT = 8080;

struct ThreadPool {
    std::queue<int> clientQueue;
    pthread_t threads[MAX_THREADS];
    pthread_mutex_t queueMutex;
    pthread_cond_t queueCond;
    std::atomic<bool> shutdownFlag{false};

    ThreadPool() {
        pthread_mutex_init(&queueMutex, NULL);
        pthread_cond_init(&queueCond, NULL);
    }

    ~ThreadPool() {
        pthread_mutex_destroy(&queueMutex);
        pthread_cond_destroy(&queueCond);
    }
};

ThreadPool* pool;

void* handleClient(void* arg) {
    char buffer[1024];

    while (!pool->shutdownFlag) {
        int clientSocket;

        pthread_mutex_lock(&pool->queueMutex);
        while (pool->clientQueue.empty() && !pool->shutdownFlag) {
            pthread_cond_wait(&pool->queueCond, &pool->queueMutex);
        }
```

```
        if (pool->shutdownFlag) {
            pthread_mutex_unlock(&pool->queueMutex);
            break;
        }

        clientSocket = pool->clientQueue.front();
        pool->clientQueue.pop();
        pthread_mutex_unlock(&pool->queueMutex);

        // Handle client request
        read(clientSocket, buffer, sizeof(buffer));

        // Simple HTTP response
        std::string response = "HTTP/1.1 200 OK\r\nContent-Length: 13\r\n\r\nHello, World!";
        write(clientSocket, response.c_str(), response.length());

        close(clientSocket);
    }
    return NULL;
}

void signalHandler(int sig) {
    if (pool) {
        pool->shutdownFlag = true;
        pthread_cond_broadcast(&pool->queueCond);
    }
}

int main() {
    int serverSocket = socket(AF_INET, SOCK_STREAM, 0);
    struct sockaddr_in address;
    address.sin_family = AF_INET;
    address.sin_addr.s_addr = INADDR_ANY;
    address.sin_port = htons(PORT);

    bind(serverSocket, (struct sockaddr *)&address, sizeof(address));
    listen(serverSocket, 5);

    pool = new ThreadPool();
    signal(SIGINT, signalHandler);

    // Create thread pool
    for (int i = 0; i < MAX_THREADS; i++) {
        pthread_create(&pool->threads[i], NULL, handleClient, NULL);
    }
```

```cpp
    while (!pool->shutdownFlag) {
        int clientSocket = accept(serverSocket, NULL, NULL);
        if (clientSocket < 0) continue;

        pthread_mutex_lock(&pool->queueMutex);
        pool->clientQueue.push(clientSocket);
        pthread_cond_signal(&pool->queueCond);
        pthread_mutex_unlock(&pool->queueMutex);
    }

    // Cleanup
    for (int i = 0; i < MAX_THREADS; i++) {
        pthread_join(pool->threads[i], NULL);
    }

    close(serverSocket);
    delete pool;
    return 0;
}
```

How to Run:

1. Compile the file using a C++ compiler (e.g., `g++`):

   ```
   g++ web_server.cpp -o web_server -lpthread
   ```

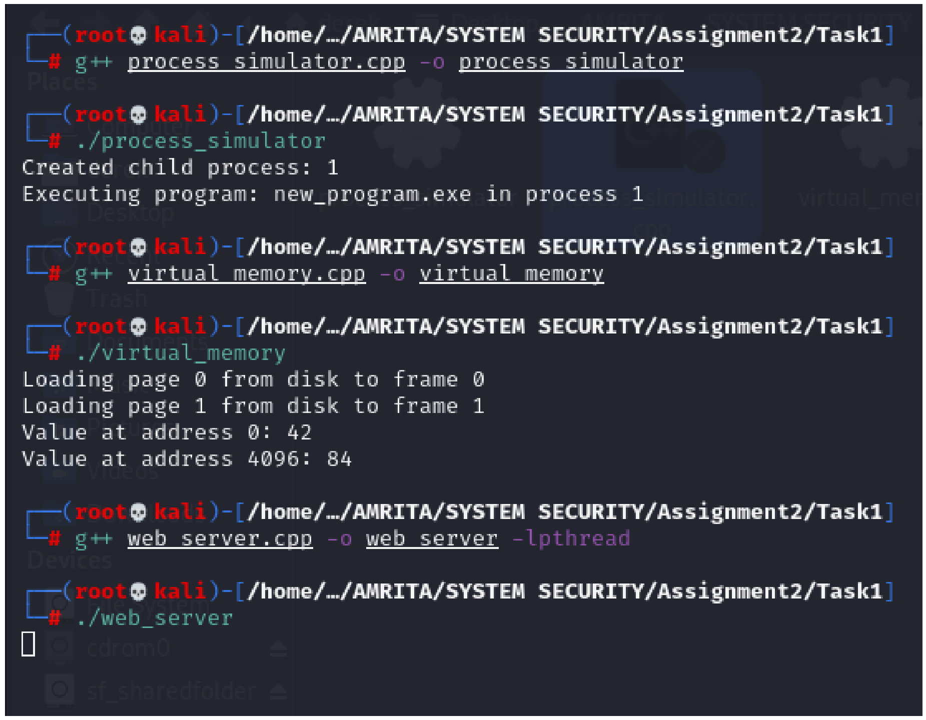
   (Note: The `-lpthread` flag is required to link the pthread library.)

2. Run the compiled program:

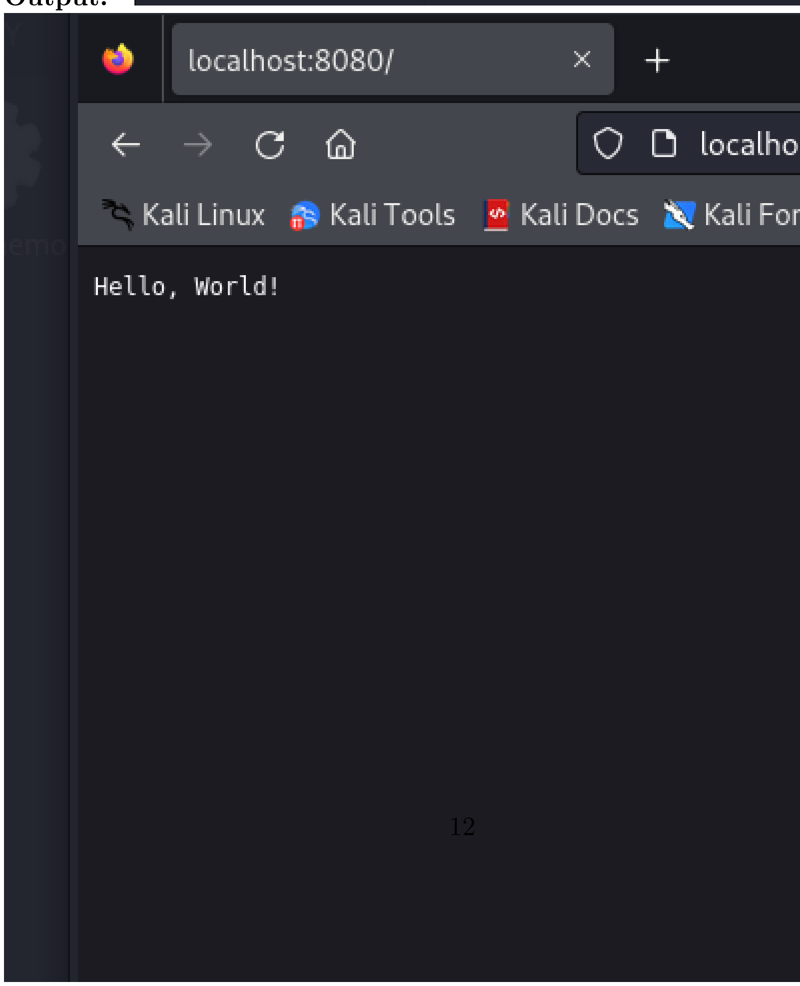
   ```
   ./web_server
   ```

3. The server will start listening on port 8080. You can send HTTP requests to `http://localhost:8080` using a browser or a tool like `curl`.

4. To shut down the server gracefully, press `Ctrl+C`. The server will handle the shutdown signal and terminate all threads properly.


┌──(root💀kali)-[/home/…/AMRITA/SYSTEM SECURITY/Assignment2/Task1]
└─# g++ process_simulator.cpp -o process_simulator
┌──(root💀kali)-[/home/…/AMRITA/SYSTEM SECURITY/Assignment2/Task1]
└─# ./process_simulator
Created child process: 1
Executing program: new_program.exe in process 1
┌──(root💀kali)-[/home/…/AMRITA/SYSTEM SECURITY/Assignment2/Task1]
└─# g++ virtual_memory.cpp -o virtual_memory
┌──(root💀kali)-[/home/…/AMRITA/SYSTEM SECURITY/Assignment2/Task1]
└─# ./virtual_memory
Loading page 0 from disk to frame 0
Loading page 1 from disk to frame 1
Value at address 0: 42
Value at address 4096: 84
┌──(root💀kali)-[/home/…/AMRITA/SYSTEM SECURITY/Assignment2/Task1]
└─# g++ web_server.cpp -o web_server -lpthread
┌──(root💀kali)-[/home/…/AMRITA/SYSTEM SECURITY/Assignment2/Task1]
└─# ./web_server

Output:


localhost:8080/
Kali Linux
Kali Tools
Kali Docs
Hello, World!

Conclusion

Task 1 consists of three main components: 1. **Process Management Simulator**: Simulates process creation, execution, and termination. 2. **Virtual Memory System**: Simulates virtual memory management with paging and page fault handling. 3. **Multithreaded Web Server**: Implements a concurrent web server using POSIX threads.

Each component is implemented in a separate file, and the instructions for compiling and running each program are provided above. These programs demonstrate key concepts in operating systems, including process management, memory management, and concurrent server design.

Task 2: Multithreaded Web Server

Overview

In Task 2, I've implemented a multithreaded web server using POSIX threads (Pthreads). The server is designed to handle multiple client requests concurrently, with each request being processed by a separate thread. The implementation ensures proper thread synchronization, avoids race conditions, and supports graceful thread shutdown when the server exits. Additionally, the server uses a thread pool for efficient resource management.

Key Features

1. **Multithreading**: Each client request is handled by a separate thread, allowing the server to process multiple requests simultaneously.
2. **Thread Pooling**: A pool of threads is created to handle incoming requests efficiently, reducing the overhead of creating and destroying threads for each request.
3. **Graceful Shutdown**: The server can shut down gracefully, ensuring all threads complete their tasks before exiting.
4. **Thread Synchronization**: Proper synchronization mechanisms (e.g., mutexes and condition variables) are used to avoid race conditions and ensure thread safety.

Files and Their Roles

1. `webserver.cpp`

This file contains the implementation of the multithreaded web server. It defines a `ThreadPool` class to manage the thread pool and handle client requests concurrently.

Code Snippet:

```
// webserver.cpp
#include <iostream>
#include <string>
#include <pthread.h>
#include <unistd.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <vector>
#include <queue>
#include <signal.h>
#include <cstring>

#define PORT 8080
#define THREAD_POOL_SIZE 10
#define MAX_CONNECTIONS 100

struct ThreadPool {
    std::queue<int> tasks;
    pthread_t* threads;
    pthread_mutex_t mutex;
    pthread_cond_t condition;
    bool shutdown;

    ThreadPool(size_t num_threads) : shutdown(false) {
        pthread_mutex_init(&mutex, NULL);
        pthread_cond_init(&condition, NULL);
        threads = new pthread_t[num_threads];
    }

    ~ThreadPool() {
        delete[] threads;
        pthread_mutex_destroy(&mutex);
        pthread_cond_destroy(&condition);
    }
};

ThreadPool* pool = nullptr;

void send_http_response(int client_socket) {
    const char* response =
        "HTTP/1.1 200 OK\r\n"
        "Content-Type: text/html\r\n"
        "Connection: close\r\n"
        "\r\n"
```

```
        "<html><body><h1>Hello from Multithreaded Server!</h1></body></html>";

    write(client_socket, response, strlen(response));
}

void* handle_connection(void* arg) {
    char buffer[1024];

    while (true) {
        int client_socket;

        pthread_mutex_lock(&pool->mutex);
        while (pool->tasks.empty() && !pool->shutdown) {
            pthread_cond_wait(&pool->condition, &pool->mutex);
        }

        if (pool->shutdown && pool->tasks.empty()) {
            pthread_mutex_unlock(&pool->mutex);
            break;
        }

        client_socket = pool->tasks.front();
        pool->tasks.pop();
        pthread_mutex_unlock(&pool->mutex);

        // Handle client request
        ssize_t bytes_read = read(client_socket, buffer, sizeof(buffer) - 1);
        if (bytes_read > 0) {
            buffer[bytes_read] = '\0';
            std::cout << "Received request from client\n";
            send_http_response(client_socket);
        }

        close(client_socket);
    }
    return nullptr;
}

void signal_handler(int sig) {
    if (pool) {
        pthread_mutex_lock(&pool->mutex);
        pool->shutdown = true;
        pthread_cond_broadcast(&pool->condition);
        pthread_mutex_unlock(&pool->mutex);
    }
}
```

```cpp
int main() {
    int server_socket = socket(AF_INET, SOCK_STREAM, 0);
    if (server_socket == -1) {
        std::cerr << "Failed to create socket\n";
        return 1;
    }

    // Set socket options
    int opt = 1;
    if (setsockopt(server_socket, SOL_SOCKET, SO_REUSEADDR, &opt, sizeof(opt))) {
        std::cerr << "setsockopt failed\n";
        return 1;
    }

    // Configure server address
    struct sockaddr_in address;
    address.sin_family = AF_INET;
    address.sin_addr.s_addr = INADDR_ANY;
    address.sin_port = htons(PORT);


    // Bind socket
    if (bind(server_socket, (struct sockaddr*)&address, sizeof(address)) < 0) {
        std::cerr << "Bind failed\n";
        return 1;
    }

    // Listen for connections
    if (listen(server_socket, MAX_CONNECTIONS) < 0) {
        std::cerr << "Listen failed\n";
        return 1;
    }

    // Initialize thread pool
    pool = new ThreadPool(THREAD_POOL_SIZE);

    // Set up signal handler
    signal(SIGINT, signal_handler);

    // Create worker threads
    for (int i = 0; i < THREAD_POOL_SIZE; i++) {
        if (pthread_create(&pool->threads[i], NULL, handle_connection, NULL) != 0) {
            std::cerr << "Failed to create thread\n";
            return 1;
        }
```

```
    }

    std::cout << "Server started on port " << PORT << std::endl;

    // Accept connections
    while (!pool->shutdown) {
        int client_socket = accept(server_socket, NULL, NULL);
        if (client_socket < 0) continue;

        pthread_mutex_lock(&pool->mutex);
        pool->tasks.push(client_socket);
        pthread_cond_signal(&pool->condition);
        pthread_mutex_unlock(&pool->mutex);
    }

    // Wait for threads to finish
    for (int i = 0; i < THREAD_POOL_SIZE; i++) {
        pthread_join(pool->threads[i], NULL);
    }

    close(server_socket);
    delete pool;
    return 0;
}
```

How to Run:

1. Compile the file using a C++ compiler (e.g., `g++`):

   ```
   g++ webserver.cpp -o webserver -lpthread
   ```

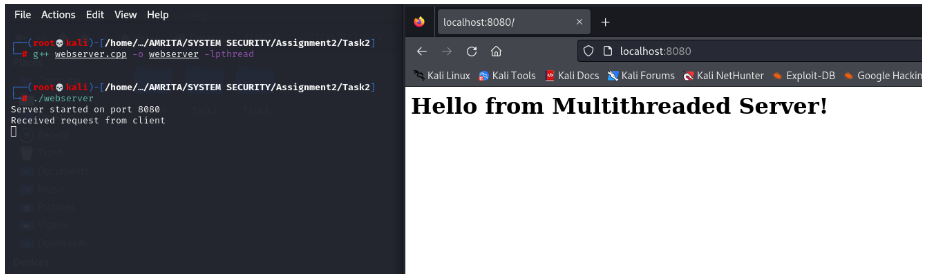
   (Note: The `-lpthread` flag is required to link the pthread library.)

2. Run the compiled program:

   ```
   ./webserver
   ```

3. The server will start listening on port 8080. You can send HTTP requests to `http://localhost:8080` using a browser or a tool like `curl`.

4. To shut down the server gracefully, press `Ctrl+C`. The server will handle the shutdown signal and terminate all threads properly.

Output: 

Conclusion

Task 2 focuses on building a multithreaded web server that can handle multiple client requests concurrently. The server uses a thread pool to manage resources efficiently and ensures proper thread synchronization to avoid race conditions. The implementation also supports graceful shutdown, allowing the server to exit cleanly without leaving threads hanging.

The `webserver.cpp` file contains the complete implementation of the server, and the instructions for compiling and running the program are provided above. This task demonstrates key concepts in concurrent programming, including thread management, synchronization, and resource pooling.

Task 3: Virtual Memory System with Paging

Overview

In Task 3, I've implemented a simple virtual memory system with paging. The program simulates a process with virtual memory addresses that are mapped to physical memory using a page table. The system handles page faults and implements the **LRU (Least Recently Used)** page replacement algorithm to bring pages into memory when a page fault occurs. The system also keeps track of which pages are in memory and handles page swaps with minimal overhead.

Key Features

1. **Virtual Memory Simulation**: The program simulates virtual memory addresses and maps them to physical memory using a page table.
2. **Page Fault Handling**: When a page fault occurs (i.e., the requested page is not in memory), the system loads the required page from disk into memory.
3. **LRU Page Replacement**: The **Least Recently Used (LRU)** algorithm is used to decide which page to replace when a page fault occurs.
4. **Page Table Management**: The system maintains a page table to track which pages are in memory and their corresponding frames in physical

memory.
5. **Disk Simulation**: The program simulates reading from and writing to disk when pages are swapped in and out of memory.

Files and Their Roles

1. `virtual_memory.cpp`

This file contains the implementation of the virtual memory system. It defines a `VirtualMemory` class that handles virtual memory operations, including reading, writing, and page fault handling.

```
#include <iostream>
#include <unordered_map>
#include <list>
#include <vector>
#include <cstdint>

class VirtualMemory {
private:
    static const int PAGE_SIZE = 4096;
    static const int FRAME_COUNT = 128;
    static const int PAGE_COUNT = 256;

    struct Page {
        int frame_number = -1;
        bool present = false;
        bool dirty = false;
        std::vector<uint8_t> data;

        Page() : data(PAGE_SIZE, 0) {}
    };

    std::vector<Page> pages;
    std::vector<bool> frames;
    std::list<int> lru_list;
    std::unordered_map<int, std::list<int>::iterator> page_to_lru;

    int allocateFrame() {
        if (lru_list.size() < FRAME_COUNT) {
            for (int i = 0; i < FRAME_COUNT; i++) {
                if (!frames[i]) {
                    frames[i] = true;
                    return i;
                }
            }
        }
```

```
        int victim_page = lru_list.back();
        lru_list.pop_back();
        page_to_lru.erase(victim_page);

        int frame = pages[victim_page].frame_number;
        if (pages[victim_page].dirty) {
            writePageToDisk(victim_page);
        }

        pages[victim_page].present = false;
        pages[victim_page].frame_number = -1;
        return frame;
    }

    void updateLRU(int page_number) {
        if (page_to_lru.find(page_number) != page_to_lru.end()) {
            lru_list.erase(page_to_lru[page_number]);
        }
        lru_list.push_front(page_number);
        page_to_lru[page_number] = lru_list.begin();
    }

    void handlePageFault(int page_number) {
        int frame = allocateFrame();
        loadPageFromDisk(page_number, frame);
        pages[page_number].frame_number = frame;
        pages[page_number].present = true;
        pages[page_number].dirty = false;
        updateLRU(page_number);
    }

    void writePageToDisk(int page_number) {
        std::cout << "Writing page " << page_number << " to disk" << std::endl;
    }

    void loadPageFromDisk(int page_number, int frame) {
        std::cout << "Loading page " << page_number << " into frame " << frame << std::endl;
    }

public:
    VirtualMemory() : pages(PAGE_COUNT), frames(FRAME_COUNT, false) {}

    uint8_t read(int virtual_address) {
        int page_number = virtual_address / PAGE_SIZE;
        int offset = virtual_address % PAGE_SIZE;
```

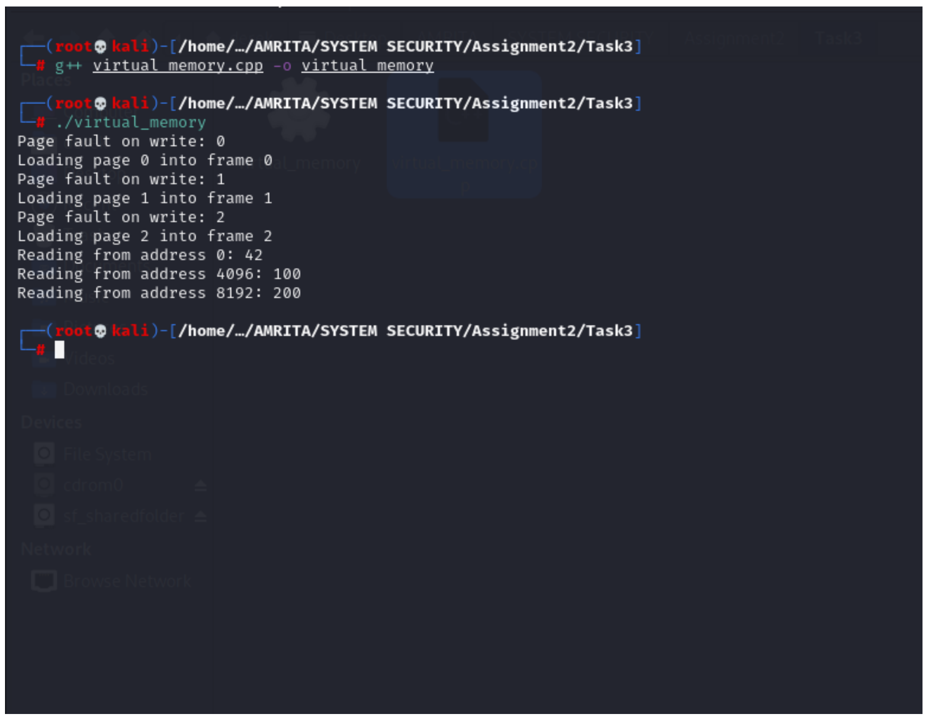
```cpp
        if (!pages[page_number].present) {
            std::cout << "Page fault on read: " << page_number << std::endl;
            handlePageFault(page_number);
        }

        updateLRU(page_number);
        return pages[page_number].data[offset];
    }

    void write(int virtual_address, uint8_t value) {
        int page_number = virtual_address / PAGE_SIZE;
        int offset = virtual_address % PAGE_SIZE;

        if (!pages[page_number].present) {
            std::cout << "Page fault on write: " << page_number << std::endl;
            handlePageFault(page_number);
        }

        pages[page_number].data[offset] = value;
        pages[page_number].dirty = true;
        updateLRU(page_number);
    }
};

int main() {
    VirtualMemory vm;

    // Test virtual memory operations
    vm.write(0, 42);
    vm.write(4096, 100);  // Write to second page
    vm.write(8192, 200);  // Write to third page

    std::cout << "Reading from address 0: " << (int)vm.read(0) << std::endl;
    std::cout << "Reading from address 4096: " << (int)vm.read(4096) << std::endl;
    std::cout << "Reading from address 8192: " << (int)vm.read(8192) << std::endl;

    return 0;
}
```

How to Run:
1. Compile the file using a C++ compiler (e.g., `g++`):
   ```bash
   g++ virtual_memory.cpp -o virtual_memory
   ```

2. Run the compiled program:

   ```
   ./virtual_memory
   ```

3. The program will simulate virtual memory operations, including reading and writing to memory, handling page faults, and swapping pages using the LRU algorithm.
4. The output will display the results of memory operations, such as loading pages from disk, writing pages to disk, and reading values from memory.

Output: 

Conclusion

Task 3 focuses on implementing a virtual memory system with paging. The system simulates virtual memory addresses, handles page faults, and uses the LRU algorithm for page replacement. The program demonstrates key concepts in memory management, including:

- **Virtual Memory**: Simulating virtual addresses and mapping them to physical memory.
- **Page Fault Handling**: Loading pages from disk when they are not in memory.

- **LRU Algorithm**: Replacing the least recently used page when memory is full.

The `virtual_memory.cpp` file contains the complete implementation of the virtual memory system, and the instructions for compiling and running the program are provided above. This task provides a hands-on understanding of how operating systems manage memory and handle page faults efficiently.