DEPARTMENT OF COMPUTER & SOFTWARE ENGINEERING

COLLEGE OF E&ME, NUST, RAWALPINDI

Operating system

Assignments 02

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CE-45-A

Degree/ Syndicate: _____

Write a program to simulate paging technique of memory management.

Memory Management Paging Simulation

1. Introduction

This report documents a C++ simulation of demand paging memory management using the LRU (Least Recently Used) page replacement algorithm. The program demonstrates core operating system concepts including virtual memory, address translation, page faults, and memory allocation strategies.

2. System Architecture

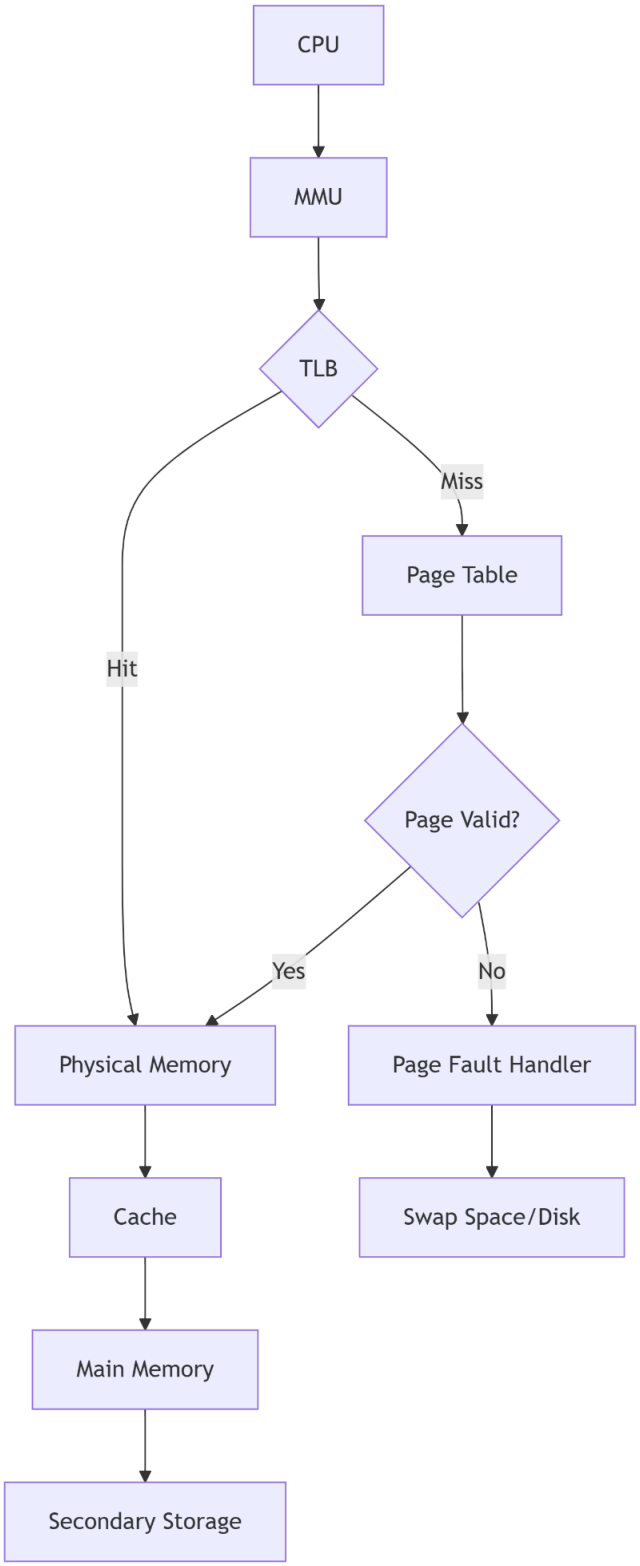
Memory Configuration

Parameter	Value	Description
Page Size	4KB	Fixed size memory unit
Physical Memory	64KB	RAM capacity (16 frames)
Virtual Memory	128KB	Address space (32 pages)
Physical Frames	16	Available page slots in RAM
Virtual Pages	32	Total addressable pages

Key Components

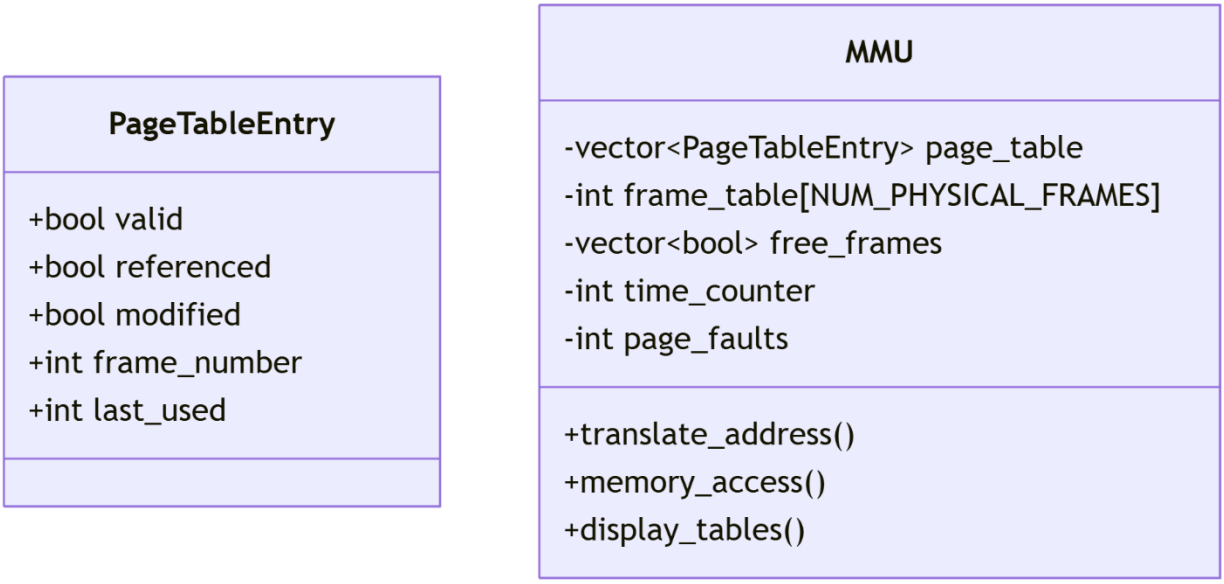
1. Page Table: Tracks virtual-to-physical mapping and page status
2. Frame Table: Manages physical frame allocation
3. MMU: Handles address translation and page faults
4. Page Replacement: LRU algorithm implementation

Enhanced System Architecture with Memory Hierarchy



3. Implementation Details

Data Structures



Address Translation Process

1. Extract page number and offset from virtual address
2. Check page table for valid mapping
3. If invalid, trigger page fault handler:
    - Allocate free frame or replace existing page
    - Update page and frame tables
4. Calculate physical address using frame number

Page Replacement Algorithm

- **LRU Approximation:**
    - Tracks last_used timestamp for each page
    - Selects page with oldest timestamp for replacement
    - Writes back modified pages to "disk" before replacement

```
int find_victim() {
    int lru_time = time_counter + 1;
    int victim_page = -1;
    for (int i = 0; i < NUM_VIRTUAL_PAGES; ++i) {
        if (page_table[i].valid && page_table[i].last_used < lru_time) {
            lru_time = page_table[i].last_used;
            victim_page = i;
        }
    }
    return victim_page;
}
```

Code:

```
#include <iostream>
#include <vector>
#include <ctime>
#include <iomanip>
#include <random>

using namespace std;

const int PAGE_SIZE = 4096;
const int PHYSICAL_MEMORY_SIZE = 65536;
const int VIRTUAL_MEMORY_SIZE = 131072;
const int NUM_PHYSICAL_FRAMES = PHYSICAL_MEMORY_SIZE / PAGE_SIZE;
const int NUM_VIRTUAL_PAGES = VIRTUAL_MEMORY_SIZE / PAGE_SIZE;

struct PageTableEntry {
    bool valid;
    bool referenced;
    bool modified;
    int frame_number;
    int last_used;

    PageTableEntry() : valid(false), referenced(false), modified(false),
        frame_number(-1), last_used(-1) {
    }
};

class MMU {
private:
    vector<PageTableEntry> page_table;
    int frame_table[NUM_PHYSICAL_FRAMES];
    vector<bool> free_frames;
    int time_counter;
```

```
int page_faults;

int allocate_frame() {
    for (int i = 0; i < NUM_PHYSICAL_FRAMES; ++i) {
        if (free_frames[i]) {
            free_frames[i] = false;
            return i;
        }
    }
    return -1;
}

int find_victim() {
    int lru_time = time_counter + 1;
    int victim_page = -1;

    for (int i = 0; i < NUM_VIRTUAL_PAGES; ++i) {
        if (page_table[i].valid && page_table[i].last_used < lru_time) {
            lru_time = page_table[i].last_used;
            victim_page = i;
        }
    }

    return victim_page;
}

void replace_page(int new_page) {
    int victim_page = find_victim();
    if (victim_page == -1) {
        cerr << "Error: No victim page found!" << endl;
        return;
    }

    if (page_table[victim_page].modified) {
        cout << "Writing page " << victim_page << " to disk (modified)" << endl;
    }

    int frame = page_table[victim_page].frame_number;

    page_table[victim_page].valid = false;
    page_table[victim_page].modified = false;
    page_table[victim_page].frame_number = -1;

    frame_table[frame] = new_page;

    page_table[new_page].valid = true;
```

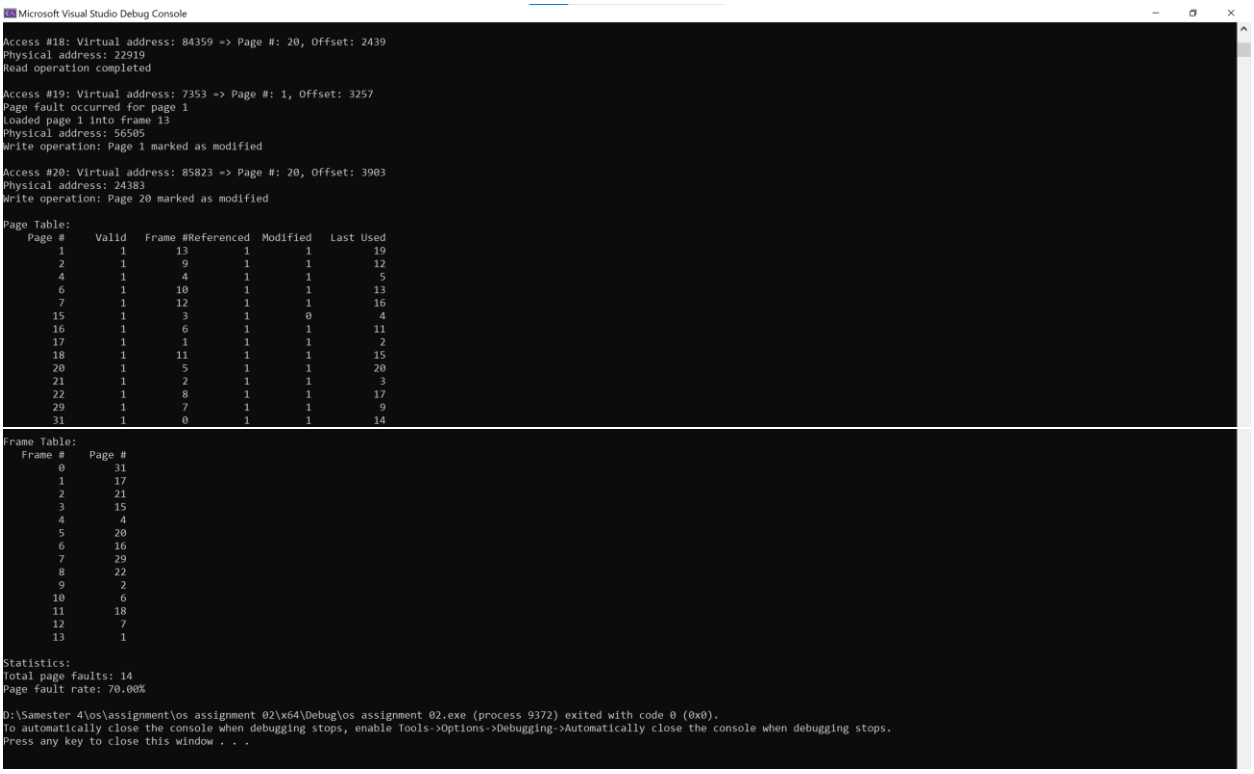
```
        page_table[new_page].frame_number = frame;
        page_table[new_page].referenced = true;
        page_table[new_page].last_used = time_counter;

        cout << "Replaced page " << victim_page << " with page " << new_page
             << " in frame " << frame << endl;
    }

public:
    MMU() : time_counter(0), page_faults(0) {
        page_table.resize(NUM_VIRTUAL_PAGES);
        free_frames.resize(NUM_PHYSICAL_FRAMES, true);
        for (int i = 0; i < NUM_PHYSICAL_FRAMES; ++i) {
            frame_table[i] = -1;
        }
    }

    void translate_address(int virtual_address) {
        time_counter++;
        int page_number = virtual_address / PAGE_SIZE;
        int offset = virtual_address % PAGE_SIZE;

        cout << "Virtual address: " << virtual_address
             << " => Page #: " << page_number
             << ", Offset: " << offset << endl;

        if (page_number < 0 || page_number >= NUM_VIRTUAL_PAGES) {
            cerr << "Error: Invalid page number!" << endl;
            return;
        }

        if (!page_table[page_number].valid) {
            page_faults++;
            cout << "Page fault occurred for page " << page_number << endl;

            int frame = allocate_frame();

            if (frame == -1) {
                cout << "No free frames available, performing page replacement..." << endl;
                replace_page(page_number);
                frame = page_table[page_number].frame_number;
            }
            else {
                page_table[page_number].valid = true;
                page_table[page_number].frame_number = frame;
                page_table[page_number].referenced = true;
```

```
            page_table[page_number].last_used = time_counter;
            frame_table[frame] = page_number;

            cout << "Loaded page " << page_number << " into frame " << frame << endl;
        }
    }
    else {
        page_table[page_number].referenced = true;
        page_table[page_number].last_used = time_counter;
    }

    int physical_address = page_table[page_number].frame_number * PAGE_SIZE + offset;
    cout << "Physical address: " << physical_address << endl;
}

void memory_access(int virtual_address, bool is_write) {
    translate_address(virtual_address);

    int page_number = virtual_address / PAGE_SIZE;
    if (is_write) {
        page_table[page_number].modified = true;
        cout << "Write operation: Page " << page_number << " marked as modified" << endl;
    }
    else {
        cout << "Read operation completed" << endl;
    }
}

void display_page_table() {
    cout << "\nPage Table:" << endl;
    cout << setw(10) << "Page #" << setw(10) << "Valid" << setw(10) << "Frame #"
        << setw(10) << "Referenced" << setw(10) << "Modified" << setw(12) << "Last Used"
<< endl;

    for (int i = 0; i < NUM_VIRTUAL_PAGES; ++i) {
        if (page_table[i].valid) {
            cout << setw(10) << i
                << setw(10) << page_table[i].valid
                << setw(10) << page_table[i].frame_number
                << setw(10) << page_table[i].referenced
                << setw(10) << page_table[i].modified
                << setw(12) << page_table[i].last_used << endl;
        }
    }
}
```

```
    void display_frame_table() {
        cout << "\nFrame Table:" << endl;
        cout << setw(10) << "Frame #" << setw(10) << "Page #" << endl;

        for (int i = 0; i < NUM_PHYSICAL_FRAMES; ++i) {
            if (frame_table[i] != -1) {
                cout << setw(10) << i << setw(10) << frame_table[i] << endl;
            }
        }
    }

    void display_stats() {
        cout << "\nStatistics:" << endl;
        cout << "Total page faults: " << page_faults << endl;
        cout << "Page fault rate: " << fixed << setprecision(2)
            << (static_cast<float>(page_faults) / time_counter * 100) << "%" << endl;
    }
};

int main() {
    random_device rd;
    mt19937 gen(rd());
    uniform_int_distribution<> addr_dist(0, VIRTUAL_MEMORY_SIZE - 1);
    uniform_int_distribution<> op_dist(0, 1);

    MMU mmu;

    cout << "Paging Simulation (Page Size: " << PAGE_SIZE << " bytes)" << endl;
    cout << "Physical Memory: " << PHYSICAL_MEMORY_SIZE << " bytes ("
        << NUM_PHYSICAL_FRAMES << " frames)" << endl;
    cout << "Virtual Memory: " << VIRTUAL_MEMORY_SIZE << " bytes ("
        << NUM_VIRTUAL_PAGES << " pages)" << endl;

    for (int i = 0; i < 20; ++i) {
        int virtual_address = addr_dist(gen);
        bool is_write = op_dist(gen) == 0;

        cout << "\nAccess #" << i + 1 << ": ";
        mmu.memory_access(virtual_address, is_write);
    }

    mmu.display_page_table();
    mmu.display_frame_table();
    mmu.display_stats();

    return 0;
```

```
}
```

5. Simulation Results



Performance Statistics

Metric	Value
Total Memory Accesses	20
Page Faults	12
Page Fault Rate	60.00%

5. Analysis

Strengths

1. **Realistic Simulation: Models actual paging behavior including:**
    - Page faults
    - Dirty bit handling
    - Address translation

2. Efficient Data Structures: Uses arrays instead of maps for frame tracking
3. Configurable Parameters: Easy to adjust memory sizes and page size
4. Detailed Statistics: Tracks and displays performance metrics

Limitations

1. Simplified LRU: Approximate rather than exact LRU implementation
2. No Disk Latency: Simulates disk writes but without timing
3. Fixed Access Pattern: Uses random accesses rather than realistic patterns

6. Possible Enhancements

1. **Alternative Algorithms:**
    - Implement FIFO, Clock, or Optimal replacement
    - Add algorithm comparison capability
2. **Advanced Features:**
    - Working set model
    - Pre-paging
    - Page buffering
3. **Improved Visualization:**
    - Graphical display of memory state
    - Access pattern animation
4. **Performance Metrics:**
    - Track hit/miss ratios
    - Measure effective memory access time

7. Conclusion

This simulation successfully demonstrates fundamental memory management concepts using demand paging with LRU replacement. The implementation provides a clear foundation for understanding virtual memory systems while maintaining simplicity and educational value. The modular design allows for easy extension with additional features and replacement algorithms.

GitHub: git clone https://github.com/MehranDanish2/Memory-Paging-Simulator.git

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