CSC 345 – Project #3: Virtual Memory Manager

Due: Apr 12, 2019, before midnight

Objective:
Understand how the virtual memory management works.

Due Date:
Apr 12, 2019, 11:55pm

Project Details:
See the attached description for the detailed instructions.

Program Requirements (70 pts):

- (10 points) Correctly read in input logical addresses.
- (10 points) Correctly translated the input addresses into physical addresses.
- (10 points) Correctly retrieved the values stored in the physical addresses.
- (10 points) Implemented FIFO based TLB update.
- (10 points) Correctly counted number of page faults
- (10 points) Correctly counted number of TLB hits.
- (10 points) Implemented FIFO based page replacement algorithm. (main_pr)

Note: Teams with 3-people or 1-person will be graded with a different rubric, which can be found at the end of this document.

Formatting Requirements

- Comment the part of your modified code.
- In a separate file (**report.pdf**), clearly describe which requirements you implemented.
- In another separate file (**discussion.pdf**), attach your group discussion log including date/time.
- Put all your files into a zip file, e.g.,

```
./project3.zip       // your zip submission
./project3           // extracted subdirectory inside your zip file
|- report.pdf        // your project report
|- discussion.pdf    // your group discussion log
|- main.c            // your program without page replacement
|- Makefile          // makefile
|- main_pr.c         // VMM with page replacement (FIFO-based)
```

  and put your implementations inside.
- Your Makefile should compile each source as a separate executable program. For example, main.c should compile to make **main**, main_pr.c should compile to make **main_pr**, etc.
- Please do **not** include provided files (e.g. addresses.txt) in the submission.

What to turn in

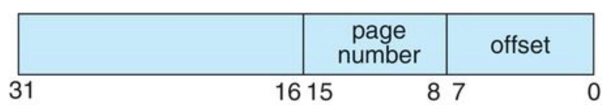
- Zip the folder containing your source file(s) and Makefile, then submit it through Canvas by the deadline. There will be a penalty for not providing any working Makefile.

Designing a Virtual Memory Manager

This project consists of writing a program that translates logical to physical addresses for a virtual address space of size 2^{16} = 65,536 bytes. Your program will read from a file containing logical addresses and, using a TLB and a page table, will translate each logical address to its corresponding physical address and output the value of the byte stored at the translated physical address. Your learning goal is to use simulation to understand the steps involved in translating logical to physical addresses. This will include resolving page faults using demand paging, managing a TLB, and implementing a page-replacement algorithm.

Specifics

Your program will read a file containing several 32-bit integer numbers that represent logical addresses. However, you need only be concerned with 16-bit addresses, so you must mask the rightmost 16 bits of each logical address. These 16 bits are divided into (1) an 8-bit page number and (2) an 8-bit page offset. Hence, the addresses are structured as shown as:



Other specifics include the following:

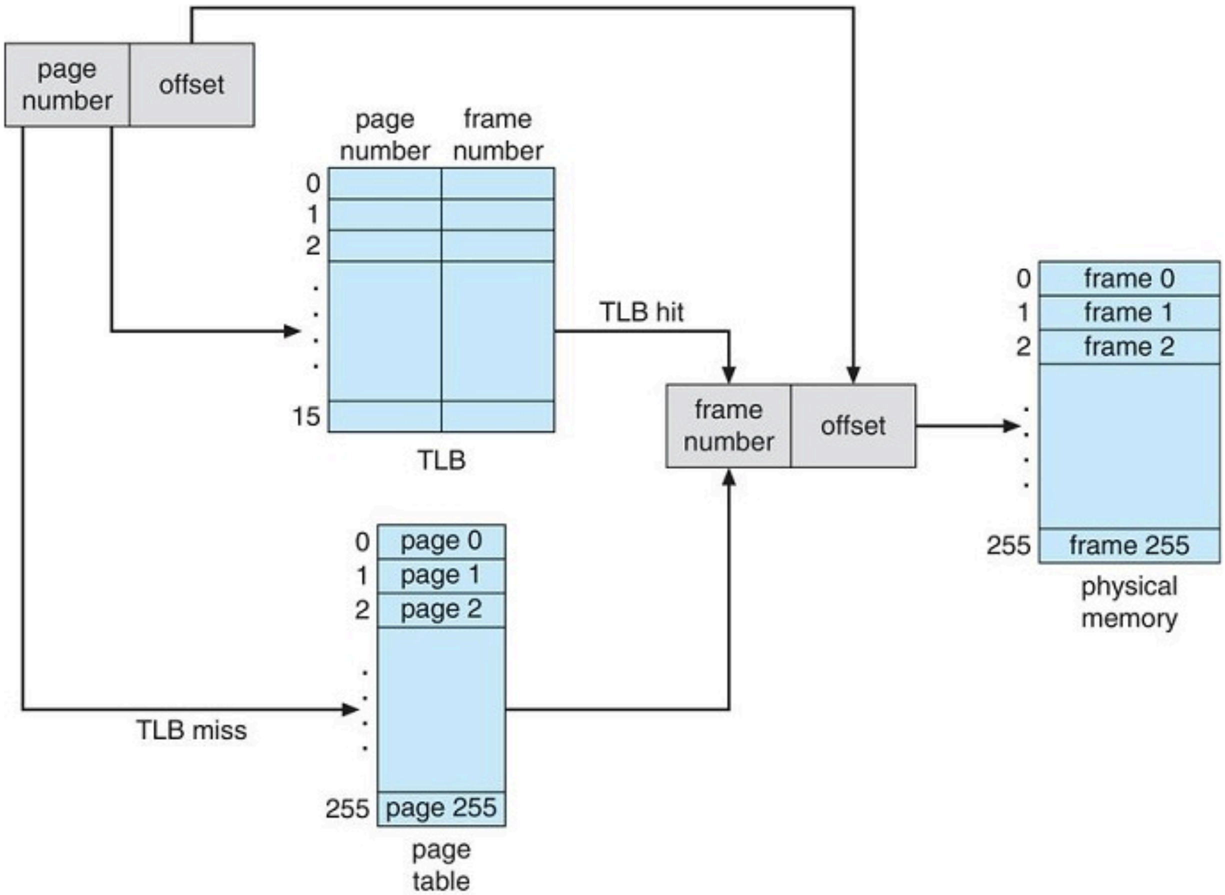
- 2^8 entries in the page table
- Page size of 2^8 bytes
- 16 entries in the TLB
- Frame size of 2^8 bytes
- 256 frames
- Physical memory of 65,536 bytes (256 frames × 256-byte frame size)

Additionally, your program need only be concerned with reading logical addresses and translating them to their corresponding physical addresses. You do **not** need to support writing to the logical address space.

Address Translation

Your program will translate logical to physical addresses using a TLB and page table as outlined in Section 9.3. First, the page number is extracted from the logical address, and the TLB is consulted. In the case of a TLB hit, the frame number is obtained from the

TLB. In the case of a TLB miss, the page table must be consulted. In the latter case, either the frame number is obtained from the page table, or a page fault occurs. A visual representation of the address-translation process is:



Handling Page Faults

Your program will implement **demand paging** as described in Section 10.2. The backing store is represented by the file **`BACKING_STORE.bin`**, a *binary* file of size 65,536 bytes. When a page fault occurs, you will read in a 256-byte page from the file `BACKING_STORE` and store it in an available page frame in physical memory. For example, if a logical address with page number 15 resulted in a page fault, your program would read in page 15 from `BACKING_STORE` (remember that pages begin at 0 and are 256 bytes in size) and store it in a page frame in physical memory. Once this frame is stored (and the page table and TLB are updated), subsequent accesses to page 15 will be resolved by either the TLB or the page table.

You will need to treat `BACKING_STORE.bin` as a random-access file so that you can randomly seek to certain positions of the file for reading. We suggest using the standard C library functions for performing I/O, including `fopen()`, `fread()`, `fseek()`, and `fclose()`.

The size of physical memory is the same as the size of the virtual address space—65,536 bytes—so you do not need to be concerned about page replacements during a page fault.

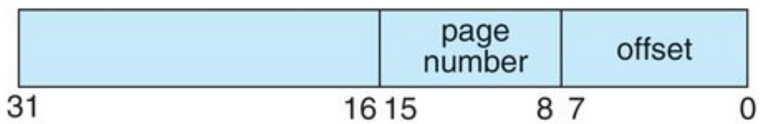
Later, we describe a modification to this project using a smaller amount of physical memory; at that point, a page-replacement strategy will be required.

Test File

We provide the file **`addresses.txt`**, which contains integer values representing logical addresses ranging from 0 *to* 65535 (the size of the virtual address space). Your program will open this file, read each logical address and translate it to its corresponding physical address, and output the value of the signed byte at the physical address.

How to Begin

First, write a simple program that extracts the page number and offset based on:



from the following integer numbers:

`1, 256, 32768, 32769, 128, 65534, 33153`

Perhaps the easiest way to do this is by using the operators for bit-masking and bit-shifting. Once you can correctly establish the page number and offset from an integer number, you are ready to begin.

Initially, we suggest that you bypass the TLB and use only a page table. You can integrate the TLB once your page table is working properly. Remember, address translation can work without a TLB; the TLB just makes it faster. When you are ready to implement the TLB, recall that it has only sixteen entries, so you will need to use a replacement strategy when you update a full TLB. You may use either a FIFO or an LRU policy for updating your TLB.

How to Run Your Program

Your program should run as follows:

```
./main addresses.txt
```

Your program will read in the file `addresses.txt`, which contains 1,000 logical addresses ranging from 0 to 65535. Your program is to translate each logical address to a physical address and determine the contents of the signed byte stored at the correct physical address. Recall that in the C language, the `char` data type occupies a byte of storage, so we suggest using `char` values.

Your program is to output the following values:

- The logical address being translated (the integer value being read from `addresses.txt`). (**out1.txt**)
- The corresponding physical address (what your program translates the logical address to). (**out2.txt**)
- The signed byte value stored in physical memory at the translated physical address. (**out3.txt**)

NOTE: Put numbers in plain text, ***without*** any extra characters or messages. For out1.txt, out2.txt, and out3.txt, your output files should only have 1,000 lines of numbers each, if addresses.txt had 1,000 lines of addresses values.

We also provide the file `correct.txt`, which contains the correct output values for the file `addresses.txt`. You should use this file to determine if your program is correctly translating logical to physical addresses. Note that correct.txt is not exactly the same as out1.txt, ... , out3.txt as it contains tags (e.g. "Virtual address: ", "Physical address:", and "Value: "). In out1.txt, ... out3.txt, you should include numbers only.

Statistics

After completion, your program is to report the following statistics:

- **1.** Page-fault rate—The percentage of address references that resulted in page faults.
- **2.** TLB hit rate—The percentage of address references that were resolved in the TLB.

Since the logical addresses in `addresses.txt` were generated randomly and do not reflect any memory access locality, do not expect to have a high TLB hit rate.

Page Replacement

Thus far, this project has assumed that physical memory is the same size as the virtual address space. In practice, physical memory is typically much smaller than a virtual address space. This phase of the project now assumes using a smaller physical address space with 128 page frames rather than 256. This change will require modifying your program so that it keeps track of free page frames as well as implementing a page-replacement policy using either FIFO or LRU (Section 10.4) to resolve page faults when there is no free memory.

Program Requirements for 3-person team (70 pts):

- (10 points) Correctly read in input logical addresses.
- (10 points) Correctly translated the input addresses into physical addresses.
- (10 points) Correctly retrieved the values stored in the physical addresses.
- (10 points) Implemented FIFO based TLB update.
- (10 points) Correctly counted number of page faults and TLB hits.
- (10 points) Implemented FIFO based page replacement algorithm. (main_pr1)
- (10 points) Implemented LRU based page replacement algorithm. (main_pr2)

```
./project3.zip      // your zip submission
./project3          // extracted subdirectory inside your zip file
|- report.pdf       // your project report
|- discussion.pdf   // your group discussion log
|- main.c           // your program without page replacement
|- Makefile         // makefile
|- main_pr1.c       // VMM with page replacement (FIFO-based)
|- main_pr2.c       // VMM with page replacement (LRU-based)
```

Program Requirements for 1-person team (70 pts):

- (10 points) Correctly read in input logical addresses.
- (10 points) Correctly translated the input addresses into physical addresses.
- (10 points) Correctly retrieved the values stored in the physical addresses.
- (10 points) Implemented FIFO based TLB update. (main1)
- (10 points) Implemented LRU based TLB update. (main2)
- (10 points) Correctly counted number of page faults and TLB hits.
- (10 points) Devise and conduct statistical experiments to compare FIFO and LRU-based TLB update methods. Include your analysis in the PDF.

```
./project3.zip      // your zip submission
./project3          // extracted subdirectory inside your zip file
|- report.pdf       // your project report
|- discussion.pdf   // your group discussion log
|- main1.c          // your program without page replacement, FIFO TLB
|- main2.c          // your program without page replacement, LRU TLB
|- Makefile         // makefile
```