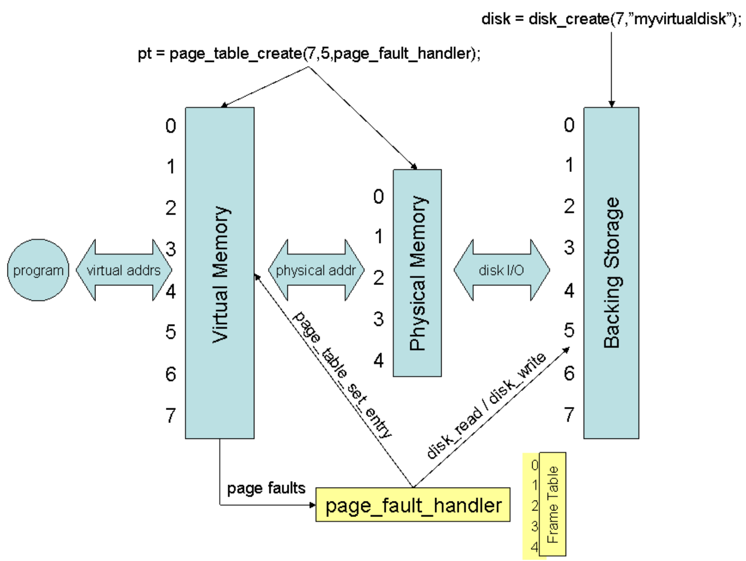
CSCI 5103: Operating Systems
Fall 2015
Instructor: Jon Weissman
Project 2: Virtual Memory
Due: Nov 11th (midnight)

1. Overview

In this project, you will implement simple but fully functional demand paged virtual memory. You will learn also learn about the closely related concept of memory mapped files. Although virtual memory is normally implemented in the operating system kernel, it can also be implemented at the user level. This is exactly the technique used by modern virtual machines, so you will be learning an advanced technique without having the headache of writing kernel-level code. The following figure gives an overview of the components:



We will provide you with code that implements a "virtual" page table and a "virtual" disk. The virtual page table will create a small virtual and physical memory, along with methods for updating the page table entries and protection bits. When an application uses the virtual memory, it will result in page faults that call a custom handler. Most of your job is to implement a page fault handler that will trap page faults and identify the correct course of action, which generally means updating the page table, and moving data back and forth between the disk and physical memory. Once your system is working correctly, you will evaluate the performance of several page replacement algorithms on a selection of simple programs across a range of memory sizes. You will write a short lab report that explains the experiments, describes your results, and draws conclusions about the behavior of each algorithm.

2. Getting Started

Begin by downloading the source code and building it. Look through main.c and notice that the program simply creates a virtual disk and page table, and then attempts to run one of our three "programs" using the virtual memory. Look at the paging code and learn how the various system calls are being used. Because no mapping has been made between virtual and physical memory, a page fault happens immediately:

```
% ./virtmem 100 10 rand sort
page fault on page #0
```

The program exits because the page fault handler isn't written yet. That is your job! Try this as a getting started exercise. If you run the program with an equal number of pages and frames, then we don't actually need a disk. Instead, you can simply make page N map directly to frame N, and do nothing else. So, modify the page fault handler to do exactly that:

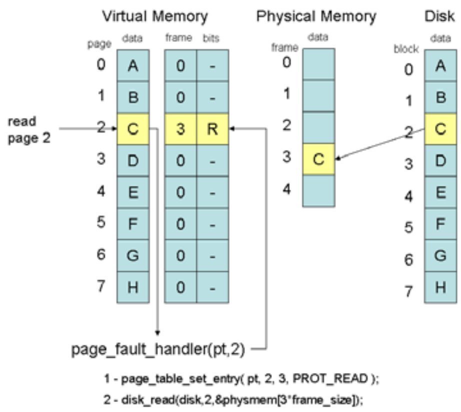
```
page_table_set_entry(pt,page,page,PROT_READ|PROT_WRITE);
```

With that page fault handler, all of the example programs will run, cause a number of page faults, but then run to completion. Congratulations, you have written your first fault handler. Of course, when there are fewer frames than pages, then this simple scheme will not do. Instead, we must keep recently used pages in the physical memory, other pages on disk, and update the page table appropriately as they move back and forth.

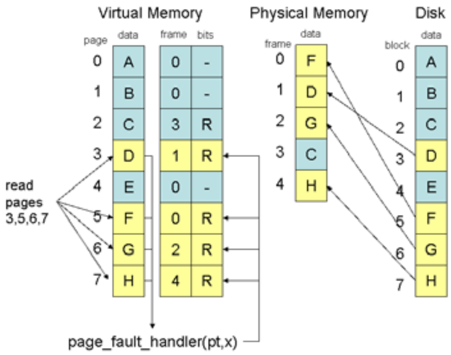
3. Example Operation

The virtual page table is very similar to what we have discussed in class, except that it does not have a reference or dirty bit for each page. The system supports a read bit (PROT_READ), a write bit (PROT_WRITE), and an execute bit (PROT_EXEC), which is enough to make it work.

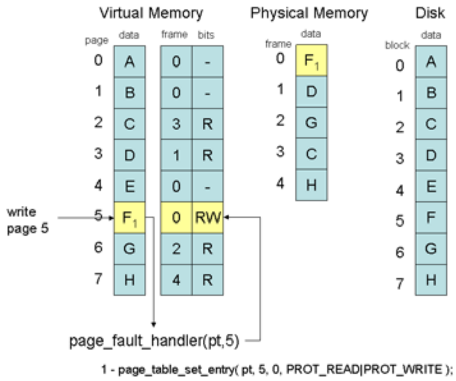
1) Let's work through an example, starting with the figure at the right. Suppose that we begin with nothing in physical memory. If the application begins by trying to read page 2, this will result in a page fault. The page fault handler choose a free frame, say frame 3. It then adjusts the page table to map page 2 to frame 3, with read permissions. Then, it loads page 2 from disk into page 3. When the page fault handler completes, the read operation is re-attempted, and succeeds.



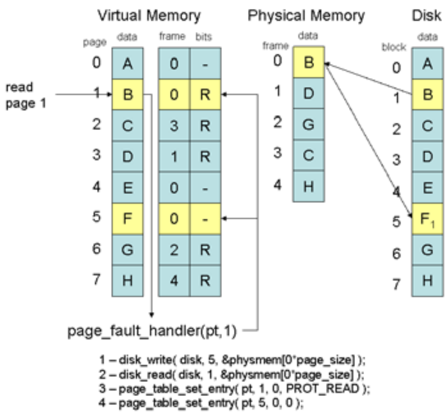
2) The application continues to run, reading various pages. Suppose that it reads pages 3, 5, 6, and 7, each of which result in a page fault, and must be loaded into memory as before. Now physical memory is fully in use.



3) Now suppose that the application attempts to write to page 5. Because this page only has the R bit set, a page fault will result. The page fault handler looks at the current page bits, and upon seeing that it already has the PROT_READ bit set, adds the PROT_WRITE bit. The page fault handler returns, and the application can continue. Page 5, frame 1 is modified.



4) Now suppose that the application reads page 1. Page 1 is not currently paged into physical memory. The page fault handler must decide which frame to remove. Suppose that it picks page 5, frame 0 at random. Because page 5 has the PROT_WRITE bit set, we know that it is dirty. So, the page fault handler writes page 5 back to the disk, and reads page 1 in its place. Two entries in the page table are updated to reflect the new situation.



4. Essential Requirements

Your program must be invoked as follows:

```
./virtmem npages nframes     rand|fifo|custom     scan|sort|focus
```

npages is the number of pages and ***nframes*** is the number of frames to create in the system. The third argument is the page replacement algorithm. You must implement **rand** (random replacement), **fifo** (first-in-first-out), and **custom**, an algorithm of your own invention. The final argument specifies which built-in program to run:

scan, sort, or focus. Each accesses memory using a slightly different pattern. You are welcome (and encouraged) to implement additional programs with other patterns.

You may only modify the code inside file **main.c**. Your job is to implement three page replacement algorithms. **rand** and **fifo** as discussed in class. You should create a third algorithm, **custom** that does a better job than **rand** or **fifo**. (Better means results in fewer disk reads and writes.) I strongly encourage you to choose something simple. How realistic is your algorithm?

A complete and correct program will run each of the sample programs to completion with only the following output:

- The single line of output from scan, sort, or focus.
- A summary of the number of page faults, disk reads, and disk writes over the course of the program.

You may certainly add some printfs while testing and debugging your program, but the final version should not have any extraneous output.

You will also turn in a lab report that has the following elements:

- In your own words, briefly explain the purpose of the experiments and the experimental setup. Be sure to clearly state on which machine you ran the experiments, and exactly what your command line arguments were, so that we can reproduce your work in case of any confusion.
- Very carefully describe the custom page replacement algorithm that you have used. Make sure to give enough detail that someone else could reproduce your algorithm, even without your code.
- Measure and graph the number of page faults, disk reads, and disk writes for each program and each page replacement algorithm using 100 pages and a varying number of frames between 1 and 100. Spend some time to make sure that your graphs are nicely laid out, correctly labelled, and easy to read. Do not use colored backgrounds.

Explain the nature of the results. If one algorithm performs better than another under certain conditions, then point that out, explain the conditions, and explain why it performs better.

5. Project Group

All students should work in groups of size 2 or 3. If you have difficulty in finding a partner, we encourage you to use the forum to find your partner. **<u>Only ONE submission is needed for each group</u>. Please include all students' name in a group on every documents and source codes**

6. Deliverables

a. Design document describing your implementation. Not to exceed 3 pages.
b. Testing description, including a list of cases attempted (also must include negative cases) and the results
c. Source code, makefiles and/or a script to start the system, and executables (**<u>No object files</u>**)

7. Grading

The grade for this assignment will include the following components:

a) Correct implementation of demand paging with any arbitrary access pattern and amount of virtual and physical memory. (50%)

b) A lab report which is clearly written using correct English, contains an appropriate description of your experiments, contains correct results that are clearly presented, and draws appropriate conclusions. (30%)

c) Thorough attention to and handling of all possible error conditions, including user error. (10%)

d) Good coding style, including clear formatting, sensible variable names, and useful comments. (10%)

8. Acknowledgement

We acknowledge Professor Douglas Thain for creating this lab.