

CSCI 4320 (Principles of Operating Systems), Fall 2007

Homework 4

Assigned: October 24, 2007.

Due: November 2, 2007, at 5pm.

Credit: 60 points.

1 Reading

Be sure you have read Chapter 4.

2 Problems

Answer the following questions. You may write out your answers by hand or using a word processor or other program, but please submit hard copy, either in class or in my mailbox in the department office.

1. (5 points) Consider a computer system with 10,000 bytes of memory whose MMU uses the simple base register / limit register scheme described in chapter 1 of the textbook (pages 26–27), and suppose memory is currently allocated as follows:
 - Locations 0–1999 are reserved for use by the operating system.
 - Process *A* occupies locations 4000–5999.
 - Process *B* occupies locations 6000–8999.
 - Other locations are free.

Answer the following questions about this system.

- (a) What value would need to be loaded into the base register if we performed a context switch to restart process *A*?
 - (b) What memory locations would correspond to the following virtual (program) addresses in process *A*?
 - 100
 - 4000
2. (5 points) Now consider a computer system using paging to manage memory; suppose it has 64K (2^{16}) bytes of memory and a page size of 4K bytes, and suppose the page table for some process (call it process *A*) looks like the following.

Page number	Present/absent bit	Page frame number
0	1	5
1	1	4
2	1	2
3	0	?
4	0	?
5	1	7
6	0	?
...	0	?
15	0	?

Answer the following questions about this system.

- (a) What memory locations would correspond to the following virtual (program) addresses for process *A*? (Here, the addresses will be given in hexadecimal, i.e., base 16, to make the needed calculations simpler. Your answers should also be in hexadecimal. Notice that if you find yourself converting between decimal and hexadecimal, *you are doing the problem the hard way*. Stop and think whether there is an easier way.)
- 0x1420
 - 0x2ff0
 - 0x4008
 - 0x0010
- (b) If we want to guarantee that this system could support 16 concurrent processes and give each an address space of 64K bytes, how much disk space would be required for storing out-of-memory pages? Explain your answer (i.e., show/explain how you calculated it). Assume that the first page frame is always in use by the operating system and will never be paged out. You may want to make additional assumptions; if you do, say what they are.
3. (10 points) Now consider a much bigger computer system, one in which addresses (both physical and virtual) are 32 bits and the system has 2^{32} bytes of memory. (You can express your answers in terms of powers of 2, if that is convenient.) Answer the following questions about this system.
- (a) What is the maximum size in bytes of a process's address space on this system?
- (b) Is there a logical limit to how much main memory this system can make use of? That is, could we buy and install as much more memory as we like, assuming no hardware constraints? (Assume that the sizes of physical and virtual addresses don't change.)
- (c) If page size is 4K (2^{12}) and each page table entry consists of a page frame number and four additional bits (present/absent, referenced, modified, and read-only), how much space is required for each process's page table? (You should express the size of each page table entry in bytes, not bits, assuming 8 bits per byte and rounding up if necessary.)
- (d) Suppose instead the system uses a single inverted page table (as described in chapter 4, pages 213–214), in which each entry consists of a page number, a process ID, and four additional bits (free/in-use, referenced, modified, and read-only), and at most 64 processes are allowed. How much space is needed for this inverted page table? (You should express the size of each page table entry in bytes, not bits, assuming 8 bits per byte and

rounding up if necessary.) How does this compare to the amount of space needed for 64 regular page tables?

4. (5 points) Consider a small computer system with only four page frames. Suppose you have implemented the aging algorithm for page replacement, using 4-bit counters and updating the counters after every clock tick, and suppose the R bits for the four pages are as follows after the first four clock ticks.

Time	R bit (page 0)	R bit (page 1)	R bit (page 2)	R bit (page 3)
after tick 1	0	1	1	1
after tick 2	1	0	1	1
after tick 3	1	0	1	0
after tick 4	1	1	0	1

What are the values of the counters (in binary) for all pages after these four clock ticks? If a page needed to be removed at that point, which page would be chosen for removal?

5. (5 points) Tanenbaum says, in one of the questions at the end of the chapter, that although the 8086 processor provided no support for virtual memory, there were companies that sold computer systems that used an unmodified 8086 processor and did paging. How do you think they managed this? (*Hint*: Think about the logical location of the MMU.)
6. (5 points) The operating system designers at Acme Computer Company have been asked to think of a way of reducing the amount of disk space needed for paging. One person proposes never saving pages that only contain program code, but simply paging them in directly from the file containing the executable. Will this work always, never, or sometimes? If “sometimes”, when will it work and when will it not? (*Hint*: Search your recollections of CSCI 2321 — or another source — for a definition of “self-modifying code”.)
7. (5 points) A computer at Acme Company used as a compute server (i.e., to run batch jobs) is observed to be running slowly (turnaround times longer than expected). The system uses demand paging, and there is a separate disk used exclusively for paging. The sysadmins are puzzled by the poor performance, so they decide to monitor the system. It is discovered that the CPU is in use about 20% of the time, the paging disk is in use about 98% of the time, and other disks are in use about 5% of the time. For each of the following, say whether it would be likely to increase CPU utilization and why.
- Installing a faster CPU.
 - Installing a larger paging disk.
 - Increasing the number of processes (degree of multiprogramming).
 - Decreasing the number of processes (degree of multiprogramming).
 - Installing more main memory.
 - Installing a faster paging disk.
8. (5 points) How long it takes to access all elements of a large data structure can depend on whether they’re accessed in contiguous order (i.e., one after another in the order in which they’re stored in memory), or in some other order. The classic example is a 2D array, in which performance of nested loops such as

```
for (int r = 0; r < ROWS; ++r)
    for (int c = 0; c < COLS; ++c)
        array[r][c] = foo(r,c);
```

can change drastically for a large array if the order of the loops is reversed. Give an explanation for this phenomenon based on what you have learned from our discussion of memory management. For extra credit, give another explanation that might also be true for a computer such as one of our lab machines.

3 Programming Problems

Do the following programming problems. You will end up with at least one code file per problem. Submit your program source (and any other needed files) by sending mail to `bmassing@cs.trinity.edu`, with each file as an attachment. Please use a subject line that mentions the course number and the assignment (e.g., “csci 4320 homework 4”). You can develop your programs on any system that provides the needed functionality, but I will test them on one of the department’s Fedora 7 Linux machines, so you should probably make sure they work in that environment before turning them in.

1. (5 points) Write a program or programs to demonstrate the phenomenon described in problem 8. Turn in your program(s) and output showing differences in execution time. (It’s probably simplest to just put this output in a text file and send that together with your source code file(s).) I’d prefer programs in C, C++, or Java, but anything that can be compiled and executed on one of the F7 lab machines is fine (as long as you tell me how to compile and execute what you turn in, if it’s not C/C++ or Java). You don’t have to develop and run your programs on one of the FC5 lab machines, but if you don’t, (1) tell me what system you used instead, and (2) be sure your programs at least compile and run on one of the lab machines, even if they don’t necessarily give the same timing results as on the system you used.

Possibly helpful hints:

- An easy way to measure how long program `mypgm` takes on a Linux system is to run it by typing `time mypgm`. Another way is to run it with `/usr/bin/time mypgm`. (This gives more/different information — try it.) If you’d rather put something in the program itself to collect and print timing information, for C/C++ programs you could use the function in `timer.h`¹ to obtain starting and ending times for the section of the code you want to time, or for Java programs you could use `System.currentTimeMillis`.
- Your program doesn’t have to use a 2D array (you might be able to think of some other data structure that produces the same result). If you do use a 2D array, though, keep in mind the following:
 - To the best of my knowledge, C and C++ allocate local variables on the stack, which may be limited in size. Dynamically allocated variables (i.e., those allocated with `malloc` or `new`) aren’t subject to this limit.
 - Dynamic allocation of 2D arrays in C is full of pitfalls. It may be easier to just allocate a 1D array and fake accessing it as a 2D array (e.g., the element in `x[i][j]`, if `x` is a 2D array, is at offset `i*ncols+j`).

¹http://www.cs.trinity.edu/~bmassing/Classes/CS4320_2007fall/Homeworks/HW04/Problems/timer.h

2. (10 points) Write a program to simulate at least one of page replacement algorithms described in the text. (FIFO is probably the simplest choice.) Your program should accept the following inputs:

- The number of pages, and a list of page references, each in the form "R pagenumber" (for a read reference) or "W pagenumber" (for a write/modify reference). Here is [sample input](#)².
- A command-line argument giving the number of page frames. (The point of providing this separately from the rest of the input is to make it easy to observe how things change if you vary the amount of memory, other things being equal.)
- *Added 10/31:* Additional inputs as needed for particular algorithms — for example, a command-line argument that specifies how often to clear the R bits in all page-table entries. (In a real system this would probably be done at fixed time intervals; you could simplify by doing it every so many memory references.) If you do this, document it somewhere (preferably in program comments).

Your program should print the following output:

- Total number of page references.
- Number of page references that changed the page ('W').
- Number of page faults.
- Number of times a page had to be written out.

Make the following assumptions:

- Initially memory is empty.
- All memory references are valid — if the page is not in memory, it can be read in from disk. (You don't have to simulate that part, just count how often it happens.)

You will get full credit for correctly simulating one algorithm, extra credit for simulating more than one. You could even try implementing the optimal algorithm — since you have full knowledge of "the future", this is possible!

You may find it useful to start from this stripped-down version of my solution-in-work (in Java this time, comments in the classes should explain what they all do).

- [PageReplacerTest.java](#)³.
- [PageReference.java](#)⁴.
- [PageReplacer.java](#)⁵.
- [PageReplacerFIFO.java](#)⁶.

²http://www.cs.trinity.edu/~bmassing/Classes/CS4320_2007fall/Homeworks/HW04//Problems/PRA-example-in

³http://www.cs.trinity.edu/~bmassing/Classes/CS4320_2007fall/Homeworks/HW04/Problems/PageReplacerTest.java

⁴http://www.cs.trinity.edu/~bmassing/Classes/CS4320_2007fall/Homeworks/HW04/Problems/PageReference.java

⁵http://www.cs.trinity.edu/~bmassing/Classes/CS4320_2007fall/Homeworks/HW04/Problems/PageReplacer.java

⁶http://www.cs.trinity.edu/~bmassing/Classes/CS4320_2007fall/Homeworks/HW04/Problems/PageReplacerFIFO.java

- [PageReplacerStats.java](#)⁷.

⁷http://www.cs.trinity.edu/~bmassing/Classes/CS4320_2007fall/Homeworks/HW04/Problems/PageReplacerStats.java