1. (10 points) Under what circumstances do page faults occur? Describe the actions taken by an OS when a page fault occurs.

2. (10 points) A certain computer provides its users with a virtual memory space of $2^{32}$ bytes. The computer has $2^{18}$ bytes of physical memory. The virtual memory is implemented by paging, and the page size is 4,096 bytes. A user process generates the virtual address 11123456 (base 10). Explain how the system establishes the corresponding physical location. Distinguish between hardware and software operations.

3. (15 points) Assume that we have a demand-paged memory. The page table is held in registers. It takes 8 milliseconds to service a page fault if an empty frame is available or if the replaced page is not modified, and 20 milliseconds if the replaced page is modified. Memory-access time is 100 nanoseconds. Assume that the page to be replaced is modified 70 percent of the time. What is the maximum acceptable page-fault rate for an effective access time of no more than 200 nanoseconds?

4. (20 points) Introducing the VU-2004 computer system:

   Assume that we will have 128 MB of physical memory, and that we want to keep our OS storage requirements low (< 4 MB). In addition to the above assumptions, assume that our computer system has physical memory divided into 32768 frames. Further, assume that our hardware supports a virtual address space of $2^{32}$ bytes and support demand paging.

   1) How big will each frame be?
   2) In a virtual address, how many bits can be used for the offset?
   3) How many entries can a process’ page map table have?
   4) Assuming each page map entry requires 8 bytes, is it possible to keep the entire page map in memory?

5. (10 points) Question 10.10 in the text

6. (25 points) Consider the following page-reference string:
   1, 2, 3, 4, 2, 1, 5, 6, 2, 1, 2, 3, 7, 6, 3, 2, 1, 2, 3, 6.

   How many page faults would occur for the following replacement algorithms, assuming three, four, and five frames for the process? Remember that all frames are initially empty, so your first unique pages will all cost one fault each. LRU replacement, FIFO replacement, optimal replacement.

6. (10 points) Question 10.17 in the text