University of St Andrews

MARTINMAS 2022-23 EXAMINATION DIET
SCHOOL OF COMPUTER SCIENCE

MODULE CODE: **CS3104**

MODULE TITLE: Operating Systems

EXAM DURATION: 3 hours

EXAM INSTRUCTIONS
a. Answer all three questions
b. Each question carries 20 marks

This assessment consists of exam-style questions and you should answer as you would in an exam. You cannot copy or paraphrase text or material from other sources and present this as your own work. Your exam answers should be entirely your own work without unacknowledged input from others. If you are in any doubt, you should clearly acknowledge the origin of any material, text passages or ideas presented (e.g. through references). You must not co-operate with any other person when completing the exam, which must be entirely your own work. You must not share any information about the exam with another person (e.g. another student) or act on any such information you may receive. Any attempt to do so will be dealt with under the University's Policy for Good Academic Practice and may result in severe sanctions. You must submit your completed assessment on MMS within 3 hours of you downloading the exam. Assuming you have revised the module contents beforehand, answering the questions should take no more than three hours.
Some question may have word limits. These will be stated at the start of the question (or part question) and may be mandatory or advisory.

1. OS Concepts

(a) A lab has one server with 64 processor cores and 256GB RAM for researchers to run experiments that may require up to 8 cores and 64GB RAM. The lab manager has scheduled individual researchers to use the machine exclusively for a fixed period. Is this the best approach? Justify your answer and explain alternate approaches that could be used. Prepare a case to persuade the lab manager that your approach is better. [6 marks]

(b) Which type of virtualised services available on the cloud would you recommend for the following two scenarios and why?

(i) A company hosts an e-commerce website on its internal servers. However, there is insufficient capacity to handle the number of user requests during certain times of the year, and the company needs to hire servers during this time. [2 marks]

(ii) A start-up company must process millions of transactions for a software product they are developing. They do not have the budget to make upfront investments for setting up their in-house scalable database to process the transactions. [2 marks]

(c) Three protection mechanisms discussed in class are:

- dual-mode operation,
- hardware interrupts, and
- memory protection.

(i) Briefly summarise the benefits of these protection mechanisms in a modern mobile OS like Android or iOS. [2 marks]

(ii) For each of the three protection mechanisms, explain which part of the process is performed by the OS, and which by the hardware. [3 marks]

(iii) Show (using an example) for each of the three protection mechanisms how absence of that mechanism could result in a malicious program disrupting the operation of the kernel. Please note that this question is not about disrupting other user-space processes but about disrupting the OS. [5 marks]

[Total marks 20]

2. Filesystems

(a) A hard disk has the following queue of disk cylinders to be accessed:

[129, 94, 69, 55, 162, 52, 74]

Assume a disk cylinder range of 0-199, with the head starting at 60. Give the order of access under both a Shortest Seek Time First (SSTF) and LOOK schedule (assume the disk head is currently moving up). Which of the above disk scheduling methods provides the least disk head movement? [4 marks]

(b) Explain the linked allocation and indexed allocation schemes for file data blocks. [2 marks]

(c) Assume there are 64 data blocks in a disk and each block is 512 bytes. Answer the following and explain any assumptions made:

(i) What is the total disk size required by the pointers in the linked allocation scheme? [1 mark]

(ii) A file is stored using the linked allocation scheme in the following sequence of block addresses 12, 17, 45, 9, 55, 3. Data from block address 55 needs to be read. What is the time overhead in reading this data if 4ms is required for the disk head to access a block? Provide justification for your answer. [2 marks]

(iii) What is the size of the index block for the above sequence of block addresses? Provide justification for your answer. [2 marks]

(iv) How many blocks can be addressed by an index block? Based on your answer, explain whether your file system has a good design. [3 marks]

(d) A RAID system has 5 disks, each with 100 GiB of storage.

(i) How much disk space is available to the user for storing data on both the entire system and each disk in both RAID 4 and RAID 5? Provide any justification for your answers. [4 marks]

(ii) Describe scenarios in which RAID 6 would be preferable to RAID 5 and provide any justification. [2 marks]

[Total marks 20]

3. Virtual Memory

(a) A PC has three storage devices that can be used for swap space. Due to the difference in their speeds, servicing a page fault will take a different amount of time depending on which device is used. The devices are:

(i) A magnetic hard disk with a page fault service time of 8ms;

(ii) A solid-state drive with a page fault service time of 2ms; and

(iii) A USB memory stick with a page fault service time of 20ms.

Memory access time (MA) for accessing RAM on this machine is 250ns. For each of the three cases above, calculate the page fault rate required to keep the slowdown caused by swapping to less than 80%. Make sure to include your calculation and reasoning in your answers.

[4 marks]

(b) A computer uses a single-level page table with a page size of 4KiB and four protection/reference bits: valid bit (v), read-only bit (r), executable bit (x), and modified/dirty bit (m). An excerpt from the page table of process P1 is shown in Table 1 below:

Table 1

index	**frame**	**valid**	**read-only**	**executable**	**modified**
a01	101	1	0	0	0
a02	fad	0	1	0	0
a03	100	1	0	0	1
a04	ca7	1	1	1	0

In the table, indices and frame numbers are shown in hexadecimal representation. Protection bits are set if their value is 1 (i.e. if the "modified" bit is 1, the page has been modified). Explain what would happen in the following three cases:

(i) P1 accesses logical memory address `a0202c`. [2 marks]

(ii) OS decides to allocate frame number `100` to page `b12` belonging to process P2. [2 marks]

(iii) OS decides to allocate frame number `ca7` to page `c13` belonging to process P2. [2 marks]

(c) A program contains the following code:

```
int array[2048];
int j = 1;

void run() {
    int i;
    int size = 2048;

    while(j) {
        for(i = 0; i < size; i += 512)
            array[i] = 'a';
        j--;
    }
}
```

The code is compiled on a 32-bit system (so an integer is 4 bytes) without any optimisations such as loop unrolling. The system uses paging and virtual memory, with a page size of 4KiB. At the start of the `while` loop, the variables correspond to logical memory addresses shown in Table 2:

Table 2

Variable	Page number	Offset	Location
array	0001b	000	data segment
j	0001d	0a1	data segment
i	702dc	000	stack
size	702dc	008	stack

(i) Write down the reference string produced by this code, starting from the `while` loop. Explain your reasoning. [5 marks]

(ii) Show the page replacement process using the clock algorithm on this code. Assume that there are exactly 3 frames available to this process and that the instruction fetches can be ignored. [5 marks]

[Total marks 20]

***** END OF PAPER *****