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School of Informatics

# WRITTEN EXAMINATION

Course Operating systems G1F, 6hp

Course Operating systems G1F, 7.5hp

Sub-course

Course code IT390G IT391G

Credits for written examination 6hp

Date 2025-10-30 Examination time 14:15-19:30

Examination responsible András Márki

Teachers concerned Simon Butler

Aid at the exam/appendices

Other

Instructions

- ☐ Take a new sheet of paper for each teacher.
- ☒ Take a new sheet of paper when starting a new question.
- ☒ Write only on one side of the paper.
- ☒ Write your name and personal ID No. on all pages you hand in.
- ☒ Use page numbering.
- ☒ Don´t use a red pen.
- ☒ Mark answered questions with a cross on the cover sheet.

Grade points

ECTS A: >=80% of points on the whole exam AND >= 25% on all of parts 1-2
ECTS B >=72.5% of points on the whole exam AND >= 25% on all of parts 1-2
ECTS C >=65% of points on the whole exam AND >= 25% on all of parts 1-2
ECTS D >= 57.5% of points on the whole exam AND >= 25% on all of parts 1-2
ECTS E >= 50% of points on the whole exam AND >= 25% on all of parts 1-2
ECTS F <50% of points on the whole exam OR <25% on any of parts 1-2 on their own

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**Examination results should be made public within 18 working days**

*Good luck!*

Total number of pages

**Before you start:** multiple-answer questions can have multiple correct answers. To get full marks, you should have selected all correct answers, and you should not have selected any wrong answer; **each correctly completed / not completed alternative is rewarded with 0,2 marks**. Enter the answer to the first part of the exam directly into the exam paper. Answers given otherwise do not count. Select an option by drawing a cross in the box. If you change your mind, fill in the whole box.

Properly completed responses: 

Amended response: 

For the parts where we expect a computation, please make sure you answered all questions and do have your computations present. Computations are preferably answered on the writing sheets. For the figures, please make sure that all necessary parts are present.

As you are answering on the sheets, you must write your name and (Swedish) person number even on the exam sheets.

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# Part 1 (MARD):

- Describe and compare terms, techniques, and algorithms in process and thread handling, for example scheduling, communication, synchronization, and deadlock handling,

## 1 Process concepts (10 Points)

1.1 What characterizes a CPU-bound process? (1p)

| | |
|---|---|
| ☐ | Usual for computation-heavy applications |
| ☐ | Uses the I/O mostly via interrupts run on the kernel. |
| ☐ | Is limited by the GPU |
| ☐ | Heavily dependent on a fast disk subsystem |
| ☐ | Usually requires high memory bandwidth. |

1.2 Which of the following buses are necessary for communication between the CPU and the memory? (1 Point)

| | |
|---|---|
| ☐ | Terrestrial Lookalike bus |
| ☐ | Address bus |
| ☐ | Control bus |
| ☐ | Instruction bus |
| ☐ | Data bus |

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1.3 In Unix, you usually both need two system calls for process creation, fork() and exec(). Explain their purpose and describe when only one of them is sufficient to be used. (2p)

1.4 Give an explanation of when it is sufficient to only have a short-time scheduler in the operating system and give another example when having a medium-term scheduler is also preferred. Give a short motivation for both examples (2p).

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1.5 When switching between processes, the PCB (Process control block) needs to be saved for the process that is switched out and reloaded for the process that is switched in.

- Process switching is overhead as it takes resources, but no user-relevant work is done. Why do we still need to do it? (2p)
- What is the program counter and why do we need to store it in the PCB? (2p)

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# 2 Threads (Total: 10 Points)

## 2.1 What is true about thread cancellation? (1p)

| | |
|---|---|
| ☐ | Thread cancellation is enabled by default. |
| ☐ | A thread can disable its cancellation. |
| ☐ | Deferred cancellation checks the target thread periodically if it should be cancelled |
| ☐ | Asynchronous cancellation terminates the target thread immediately |
| ☐ | Thread cancellation occurs only when all previous instructions are disregarded |

## 2.2 What is true about Amdahl's law? (1p)

| | |
|---|---|
| ☐ | The more serial part a program has, the more it will scale with more processor cores. |
| ☐ | The expected speedup is smaller or equivalent to 1 / (serial_portion + (1-serial_portion)/number_of_processing_cores). |
| ☐ | Doubling the number of processors can yield up to 137% speedup according to the law. |
| ☐ | Independent of how your program works, there will be no speedup when increasing the number of processors over 32. |
| ☐ | Amdahl's law defines an upper bound on the amount of processes in a system. |

## 2.3 What is true about the Windows Thread implementation? (1 Point)

| | |
|---|---|
| ☐ | Addresses security attributes and stack size. |
| ☐ | Uses more parameters for thread creation than Java |
| ☐ | Uses more parameters for thread creation than C++11 and onward |
| ☐ | Still useful for C programs |
| ☐ | Actual implementation |

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2.4 Draw the one-to-one multithreading model. Make sure to label the necessary parts accordingly. (2 Points)

2.5 Give (1) two examples on the benefits and (2) two examples on the drawbacks of using threads (2p).

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2.6 Draw a comparison between a single-threaded and multithreaded process, displaying the inner structure of both. Make sure to label the necessary parts accordingly. (You can draw this on an extra sheet) (3 Points).

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# 3 Process scheduling (10 Points)

## 3.1 What is true about homogenous multiprocessing? (1p)

| | |
|---|---|
| ☐ | CPU cores can physically differ within the same CPU |
| ☐ | The instruction set of the CPU cores can differ within the CPU |
| ☐ | It is a common solution when raw computation strength matters |
| ☐ | Cannot create issues with CPU scheduling that can mostly solved on OS level |
| ☐ | It is an uncommon concept that is only important for legacy systems |

## 3.2 What is true about the evaluation of scheduling algorithms? (1p)

| | |
|---|---|
| ☐ | Turing traversal gives results for every possible workload input |
| ☐ | Simulations can be done on an A4 page |
| ☐ | Analytical evaluations require mathematical models for their input |
| ☐ | Implementing a scheduling algorithm within a real system is usually the most expensive |
| ☐ | Deterministic modeling can be time-consuming for a project |

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3.3 Why and how do we need different goals for a real-time and batch process? Motivate your answer! (2p).

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3.4 Scheduling algorithms: Assume the following processes arrive for execution at the indicated time with the specified priority and the length of their CPU-burst time given in milliseconds. (You can give your answer on the extra sheet)

| Process | Burst time (ms) | Priority | Arrival time (ms) |
|---|---|---|---|
| P1 | 3 | 1 | 0 |
| P2 | 2 | 2 | 1 |
| P3 | 2 | 4 | 3 |
| P4 | 4 | 1 | 3 |
| P5 | 3 | 2 | 4 |

- Give a Gantt chart illustrating the execution of these processes using FCFS, Round Robin (quantum=2), and Priority (Non-pre-emptive). (3 Points)
- Calculate the average waiting time for each of the above scheduling algorithms. (3 Points)

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# 4 Synchronization (10 Points)

4.1 If you have two threads modifying the same variable int var = 5 in parallel, with their respective code being (without synchronization) (1p):

| **Thread A**<br>**var=var+5** | **Thread B**<br>**var=var-5** |
|---|---|

| | |
|---|---|
| ☐ | It is possible to get var = 5 as a result |
| ☐ | It is possible to get var = 0 as a result |
| ☐ | It is possible to get var = 25 as a result. |
| ☐ | It is possible to get var = 10 as a result |
| ☐ | The result of the variable var can be different after each execution of the code above |

4.2 Which of the following criteria should a proper solution to the critical-section problem fulfill? (1p)

| | |
|---|---|
| ☐ | Using Hungarian notation to answer |
| ☐ | Suspension of disbelief |
| ☐ | Mutual inclusion |
| ☐ | Regression of output |
| ☐ | The Trolley solution |

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4.3 Regard the following questions about classical problems:

- What is the bounded-buffer problem? Why is its entry and exit section a critical section on its own? (2p)
- What is the readers-writers problem? Why does it have a starvation issue? (2p)
- What is the dining-philosophers problem? How does an asymmetrical solution help solve the problem? (2p)

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4.4 What happens if you use a semaphore incorrectly? (2p)

i) Signal (mutex) ... Wait (mutex)

ii) Signal (mutex) ... Signal (mutex).

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# 5 Deadlocks (10 Points)

## 5.1 What are the common methods for handling deadlocks? (1p)

| | |
|---|---|
| ☐ | Using the "Ostrich" algorithm |
| ☐ | Using the "Otter" algorithm |
| ☐ | Using the "Honeybadger" algorithm |
| ☐ | Using the "Mushroom" algorithm |
| ☐ | Using the "Snake" algorithm |

## 5.2 When recovering from a deadlock and aborting one process at a time (selecting them as victims), which of the following factors can be considered to choose a potential process as a victim? (1p)

| | |
|---|---|
| ☐ | User logon time |
| ☐ | Default system date format |
| ☐ | How many victims are needed |
| ☐ | Priority of the process |
| ☐ | Type of process |

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5.3 For a deadlock to arise, four conditions must be met simultaneously. What are the conditions and what do they mean in practice? (4p)

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5.4 Apply the banker's algorithm to the example below and determine if a safe sequence exists. The total amount the resource are: A=6, B=8, C=10. Write down the intermediate results for each step. (4 Points) (You can give your answer on the extra sheet)

| | Allocation | | | Max | | |
|---|---|---|---|---|---|---|
| | A | B | C | A | B | C |
| P0 | 0 | 0 | 0 | 0 | 2 | 6 |
| P1 | 1 | 1 | 0 | 2 | 2 | 3 |
| P2 | 1 | 1 | 3 | 2 | 2 | 3 |
| P3 | 2 | 3 | 1 | 2 | 3 | 4 |
| P4 | 1 | 3 | 3 | 4 | 3 | 3 |

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# Part 2 (BUTS):

- describe and compare terms, techniques, and algorithms in primary memory management, for example addressing, address binding, paging, segmentation, and virtual memory;
- describe and compare terms, techniques, and algorithms in secondary memory management, for example file allocation and scheduling of disc operations;
- discuss the problems of protection and security in modern operating systems

## 6 Memory management (10 Points)

### 6.1 Which of the following statements about memory management are true? (1 point)

| | |
|---|---|
| ☐ | User mode processes (programs) can adjust the base and limit registers defining the space the process occupies in memory. |
| ☐ | Copy on write is designed to slow down process forking. |
| ☐ | The physical address space used by a process are defined by a pair of base and limit registers. |
| ☐ | A logical address is a memory address used by the CPU. |
| ☐ | Re-entrant or read-only code is used by shared processes. |

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6.2 Which of the following statements about memory management are true? (1 point)

| | |
|---|---|
| ☐ | Individual processes always use contiguous frames in physical memory. |
| ☐ | Memory protection schemes can be implemented in page tables by adding bits to each entry to indicate whether the frame is read-only, executable, and so on. |
| ☐ | Paging divides physical memory into fixed size blocks called frames. |
| ☐ | Copy on write allows processes to share pages with child processes when the child is forked. |
| ☐ | There is no internal fragmentation when using memory paging. |

6.3 Which of following statements about contiguous memory allocation are true? (1 point)

| | |
|---|---|
| ☐ | Operating system processes are loaded into low memory addresses. |
| ☐ | The worst fit algorithm provides the optimal solution to contiguous memory allocation. |
| ☐ | The worst-fit algorithm places the process in the memory hole that leaves the biggest possible external fragment. |
| ☐ | The first fit algorithm always assigns processes to the smallest available memory space. |
| ☐ | Contiguous memory allocation schemes prevent internal fragmentation. |

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6.4 Given a page size of 4096 bytes (4KB) and a process that requests 16840 bytes in memory:

1. Calculate how many pages of memory the operating system allocates to the process (2 points)
2. Calculate the number of bytes of memory in the internal fragment (1 point)

Show the steps in your calculations.

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6.5 Increasing memory sizes in modern computers mean that simple page tables can become so large that they are impractical. Hierarchical and hashed page tables provide solutions.
a) Describe the structure of a two-level hierarchical paging scheme (hierarchical page table), and explain why hierarchical schemes with more layers are slow in use (2 points)
b) Describe the structure of a hashed page table and the mechanism used to find the frame address mapped to a page in virtual memory (2 points)

(Note that you may use diagrams to support your answers, but answers without a written explanation will receive 0 marks)

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# 7 Virtual memory (10 points)

7.1 Which of the following statements about virtual memory management are true? (1 point)

| | |
|---|---|
| ☐ | A page fault occurs when a requested page is not found in memory. |
| ☐ | A hashed page table generally requires more memory accesses in operation than a nested hierarchical page table. |
| ☐ | Code needs to be in memory to execute, but an entire program does not |
| ☐ | Dirty victim frames are always written to the backing store when they are swapped out. |
| ☐ | Demand paging ensures that only code and data used by a program is loaded into memory. |

7.2 Which of the following statements about frame allocation are correct? (1 point)

| | |
|---|---|
| ☐ | Equal allocation of frames increases the number of page faults for large programs. |
| ☐ | A high page fault rate can cause the operating system to spend more time replacing pages in memory than doing computation. |
| ☐ | Global allocation of frames allows processes to take frames from other processes. |
| ☐ | A proportional allocation scheme allocates frames according to the size of the process. |
| ☐ | Global allocation of frames gives improved program throughput and is thus appropriate for hard real-time operating systems. |

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7.3 Which of the following statements about page replacement algorithms are true? (1 point)

| | |
|---|---|
| ☐ | Belady's Anomaly is observed for some reference strings when the number of frames allocated to a process is increased when using the optimal page replacement algorithm. |
| ☐ | Modified frames are selected as victim frames before unmodified frames in the enhanced second chance algorithm. |
| ☐ | Page buffering can be used to cache pages so that recently used pages can be reloaded more quickly. |
| ☐ | The OPT page replacement algorithm is commonly implemented in SSDs. |
| ☐ | Valid/invalid bits are used to support page replacement. |

7.4 A translation lookaside buffer (TLB) is a hardware device used to implement memory paging.

a. What does a TLB do? (1 point)
b. How does a TLB search for entries internally? (1 point)
c. Why are TLBs too small to map the whole memory? (1 point)

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7.5 Given the page reference string:

7, 0, 4, 2, 3, 6, 6, 3, 1, 4, 3, 3, 2, 6, 1, 1, 5, 2, 7, 2

Assuming demand paging with a page table of three frames, how many page faults would occur with the following replacement algorithms?
a. FIFO replacement (2 points)
b. Optimal replacement (2 points)

For each algorithm, write a page table showing the state of the page table following each request in the reference string. Clearly mark each request that causes a page fault.

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# 8 File systems (10 Points)

## 8.1 Which of the following statements about files and directories are true? (1 point)

| | |
|---|---|
| ☐ | An operating system needs a policy for deleting shared files. |
| ☐ | The execute (x) file attribute on Unix/Linux systems is meaningful when used with a directory. |
| ☐ | Operating systems generally interpret file contents as either human-readable text or a binary format. |
| ☐ | Open files are never cached in memory. |
| ☐ | In a tree file structure two files in the same directory (folder) can have the same name. |

## 8.2 Which of the following statements are true about disk scheduling? (1 point)

| | |
|---|---|
| ☐ | Disk scheduling algorithms are constrained by the physical properties of hard disk drives. |
| ☐ | Solid state disks and hard disk drives use identical disk scheduling algorithms. |
| ☐ | C-Look and C-Scan read and write data requests when the head moves in both directions. |
| ☐ | FIFO is an efficient disk scheduling algorithm. |
| ☐ | The Look algorithms reduces the number of sectors the head visits compared to the Scan family of algorithms. |

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8.3 Which of the following statements about disk drives are true? (1 point)

| | |
|---|---|
| ☐ | A disk drive can read data from multiple platters at the same time. |
| ☐ | The free-space list is created and used by the disk controller. |
| ☐ | RAID is used to reduce the consequences of disk failure. |
| ☐ | Striping is used in RAID systems as a means of error detection. |
| ☐ | A physical disk can be partitioned into volumes that are treated as logical disks. |

8.4 Indexed allocation of file blocks provides good random access to file contents compared to linked allocation. Briefly describe three disadvantages of indexed allocation (1 point each)

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8.5 Operating systems use file control blocks containing metadata about each file. Name four items of metadata you would expect to find in a file control block and briefly explain how each item metadata is used (1 point each)

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# 9 Protection and security (10 Points)

## 9.1 Information security concerns threats to the confidentiality, integrity, and availability of data. Which of the following statements are true? (1 point)

| | |
|---|---|
| ☐ | Unix file permissions can help support the protection of confidentiality and integrity of data. |
| ☐ | Integrity of data means that data should be protected against authorised modification. |
| ☐ | Authorisation is used to ensure access to the right resource. |
| ☐ | A capability list represents a column in an access matrix. |
| ☐ | Redundant data centers do not support the availability of data. |

## 9.2 Which of the following statements about network security are true? (1 point)

| | |
|---|---|
| ☐ | Using another user's authentication details is not a masquerade attack. |
| ☐ | Physical security of data centers is an important component of the process of securing a computer network. |
| ☐ | A firewall can protect a network against malicious actions in tunnelled traffic. |
| ☐ | A buffer overflow is an error on a disk that can be exploited to execute malicious code. |
| ☐ | Authentication, authorization, and accounting are used to prevent theft of services. |

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9.3 Which of the following statements about cryptography are correct? (1 Points)

| | |
|---|---|
| ☐ | A private key can be distributed in cleartext to anyone who wants to communicate with holder of the public key. |
| ☐ | Block encryption algorithms such as DES are computationally expensive compared to public key cryptography. |
| ☐ | Public key cryptography can be used to support the distribution of keys for a symmetric encryption algorithm |
| ☐ | There are no known algorithms to determine whether a number is prime or not. |
| ☐ | Public key cryptography can be used to protect data streams. |

9.4 Versions of the Microsoft Authenticator phone app for Android released before mid-2025 contained a password store as well as Microsoft's proprietary OTP implementation, and passkey support.

a) Was Microsoft's decision to remove the password saving feature reasonable? (1 point)

b) Explain your response to (a) from a security perspective (3 points)

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9.5 Public key cryptography uses an asymmetric encryption scheme with pairs of public and private encryption keys. An important component of what is known as Public Key Infrastructure (PKI) is a digital certificate.

a) What does a digital certificate consist of? (1 point)

b) Using your answer from (a) explain the problem that a digital certificate solves and how it solves it? (2 points)