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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:  $\geq 80\%$  of points on the whole exam AND  $\geq 25\%$  on all of parts 1-2

ECTS B  $\geq 72.5\%$  of points on the whole exam AND  $\geq 25\%$  on all of parts 1-2

ECTS C  $\geq 65\%$  of points on the whole exam AND  $\geq 25\%$  on all of parts 1-2

ECTS D  $\geq 57.5\%$  of points on the whole exam AND  $\geq 25\%$  on all of parts 1-2

ECTS E  $\geq 50\%$  of points on the whole exam AND  $\geq 25\%$  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 an I/O-bound process? (1p)

<input type="checkbox"/>	Usual for computation-heavy applications
<input type="checkbox"/>	Uses the I/O mostly via interrupts run on the kernel.
<input type="checkbox"/>	Is limited by intermittent ordering
<input type="checkbox"/>	Heavily dependent on a fast disk subsystem
<input type="checkbox"/>	Usually requires high memory bandwidth.

#### 1.2 Which of the following registers are necessary for communicating between the CPU and the memory? (1p)

<input type="checkbox"/>	Memory buffer register (MBR)
<input type="checkbox"/>	Memory arbitration register kernel instruction vector (MARK IV)
<input type="checkbox"/>	Memory address register (MAR)
<input type="checkbox"/>	Random access register (RAR)
<input type="checkbox"/>	Temporary translation lookaside register (TRLR)



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

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



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1.6 There are multiple reasons why it is beneficial to have cooperating processes. Give two examples for each of the following software aspects of how inter-process cooperation is beneficial for:

- (i) Information sharing (1p)
- (ii) Computation speedup (1p)
- (iii) Modularity (1p)
- (iv) Convenience (1p)



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## 2 Threads (Total: 10 Points)

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

<input type="checkbox"/>	Thread cancellation is enabled by default.
<input type="checkbox"/>	Thread cancellation occurs only when the thread is finished with its execution
<input type="checkbox"/>	Deferred cancellation checks the target thread periodically if it should be cancelled
<input type="checkbox"/>	Asynchronous cancellation terminates the target thread immediately
<input type="checkbox"/>	A thread can disable its cancellation.

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

<input type="checkbox"/>	The more parallel part a program has, the more it will scale with more processor cores.
<input type="checkbox"/>	The expected speedup is smaller or equivalent to $1 / (\text{serial\_portion} + (1 - \text{serial\_portion}) / \text{number\_of\_processing\_cores})$ .
<input type="checkbox"/>	Doubling the number of processors can yield up to 249% speedup according to the law.
<input type="checkbox"/>	Independent of how your program works, there will be no speedup when increasing the number of processors over 128.
<input type="checkbox"/>	Amdahl's law gives an upper bound on how much speedup we can expect of program using multiple processors when more processors are added to the system.

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

<input type="checkbox"/>	Addresses security attributes and stack size.
<input type="checkbox"/>	Uses less parameters for thread creation than Java
<input type="checkbox"/>	Uses less parameters for thread creation than C++11 and onward
<input type="checkbox"/>	Not in use for C programs
<input type="checkbox"/>	Is a specification but not an implementation



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2.4 Draw the many-to-many 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 non-homogenous multiprocessing? (1p)

<input type="checkbox"/>	CPU cores can physically differ within the same CPU
<input type="checkbox"/>	The instruction set of the CPU cores can differ within the CPU
<input type="checkbox"/>	It is a common solution on low-power devices to increase battery time
<input type="checkbox"/>	Can create issues with CPU scheduling that can mostly solved on OS level
<input type="checkbox"/>	It is an uncommon concept that is only important for legacy systems

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

<input type="checkbox"/>	Deterministic modeling can be time-consuming for a project
<input type="checkbox"/>	Simulations can be done on a whiteboard
<input type="checkbox"/>	Analytical evaluations require mathematical models for their input
<input type="checkbox"/>	Implementing a scheduling algorithm within a real system is usually the most expensive
<input type="checkbox"/>	Gödel evaluation gives results for every possible workload input



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3.4 Why and how do we need different goals for an interactive and batch process? Motivate your answer! (2p).



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3.5 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	2	1	0
P2	1	2	1
P3	2	2	2
P4	4	4	3
P5	3	1	3

- 3.5.1 Give a Gantt chart illustrating the execution of these processes using FCFS, Round Robin (quantum=2), and Priority (Pre-emptive). (3 Points)
- 3.5.2 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 = 3` in parallel, with their respective code being (without synchronization) (1p):

**Thread A**

**`var=var+2`**

**Thread B**

**`var=var-2`**

<input type="checkbox"/>	It is possible to get <code>var = 5</code> as a result
<input type="checkbox"/>	It is possible to get <code>var = 1</code> as a result
<input type="checkbox"/>	It is possible to get <code>var = 3</code> as a result.
<input type="checkbox"/>	It is possible to get <code>var = -1</code> as a result
<input type="checkbox"/>	The result of the variable <code>var</code> can be different after each execution of the above code

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

<input type="checkbox"/>	Disregard all previous instructions defined as deadlocks
<input type="checkbox"/>	Bounded waiting
<input type="checkbox"/>	Mutual exclusion
<input type="checkbox"/>	Progress
<input type="checkbox"/>	The prisoner dilemma



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4.3 Regard the following questions about classical problems:

- 4.3.1 What is the bounded-buffer problem? Why is its entry and exit section a critical section on its own? (2p)
- 4.3.2 What is the readers-writers problem? Why does it has a starvation issue? (2p)
- 4.3.3 What is the dining-philosophers problem? Why does an asymmetric solution help solving 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)

<input type="checkbox"/>	Allow the system to recover from deadlocks
<input type="checkbox"/>	Ignore that the problem exists
<input type="checkbox"/>	Using a homogenous CPU architecture
<input type="checkbox"/>	Using the “Capybara” algorithm, where all processes can chill with each other
<input type="checkbox"/>	Ensure that the system will never enter a deadlock

### 5.2 Which of the following conditions must hold simultaneously for a deadlock to arise? (1p)

<input type="checkbox"/>	No preemption
<input type="checkbox"/>	Mutual exclusion
<input type="checkbox"/>	Disregard previous instructions
<input type="checkbox"/>	Hold and wait
<input type="checkbox"/>	Circular wait

### 5.3 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)

<input type="checkbox"/>	User logon time
<input type="checkbox"/>	Resources needed by the process to complete
<input type="checkbox"/>	How many victims are needed
<input type="checkbox"/>	Priority of the process
<input type="checkbox"/>	Type of process (interactive or batch)



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5.4 For a deadlock to arise, four conditions must be met simultaneously. Can you avoid some of these conditions below? If yes, can you see any side-effects by doing so? (Hint: Consider deadlock avoidance and prevention algorithms with your answer.)

- Mutual exclusion (1p)
- Hold and wait (1p)
- No pre-emption (1p)
- Circular wait (1p)



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5.5 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	0
P1	1	1	2	1	2	2
P2	1	2	3	2	2	3
P3	2	2	2	4	4	4
P4	1	3	2	3	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)

<input type="checkbox"/>	Windows DLL and Linux dynamic shared objects are examples of execution time linking.
<input type="checkbox"/>	User mode processes (programs) can not adjust the base and limit registers defining the space the process occupies in memory.
<input type="checkbox"/>	Link time binding prevents running processes being moved in memory.
<input type="checkbox"/>	Pages in virtual memory are always smaller than frames in physical memory.
<input type="checkbox"/>	If code is compiled with relocatable addresses the operating system can choose where to load a process into memory.



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

<input type="checkbox"/>	A single process always uses contiguous frames in physical memory.
<input type="checkbox"/>	Searches (look-ups) in a translation look aside buffer (TLB) depend on the number of entries in the TLB and have a computational complexity of $O(n)$ .
<input type="checkbox"/>	There will be internal fragmentation for most processes when using memory paging.
<input type="checkbox"/>	Copy on write allows processes to share pages with child processes when the child is forked.
<input type="checkbox"/>	Inverted page tables can be used to reduce the amount of memory required for page table.

6.3 Which of the following statements about segmentation are true? (1 point)

<input type="checkbox"/>	There is always internal fragmentation when using segmentation to manage memory
<input type="checkbox"/>	The segmentation approach to memory management uses segments of memory that are all the same size.
<input type="checkbox"/>	Memory protection policies can be implemented for each segment.
<input type="checkbox"/>	Protection bits can be used to share code and data at segment level.
<input type="checkbox"/>	Memory management using segmentation is not a dynamic storage allocation problem.



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6.4 Given a page size of 4096 bytes (4KB) and a process that requests 16522 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)

<input type="checkbox"/>	A page fault occurs when the wrong page is found in memory.
<input type="checkbox"/>	A page fault may mask (hide) an illegal memory access by a process.
<input type="checkbox"/>	The time to service a page fault has no impact on memory access time.
<input type="checkbox"/>	With a single level page table, each data access in a program requires at least three memory accesses.
<input type="checkbox"/>	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)

<input type="checkbox"/>	Local allocation of frames results in highly variable process execution time each time a process is run.
<input type="checkbox"/>	In a proportional allocation scheme the number of frames allocated to a process changes in relation to the number of processes loaded in memory,
<input type="checkbox"/>	Global allocation of frames means that processes to are assigned a fixed number of frames when the process starts.
<input type="checkbox"/>	The Flashman frame allocation algorithm provides a solution that prevents thrashing.
<input type="checkbox"/>	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)

<input type="checkbox"/>	The process unionisation algorithm implements a fair selection policy for victim frames.
<input type="checkbox"/>	The most frequently used (MFU) algorithm considers pages with least use were most recently loaded into memory and are likely to be used soon.
<input type="checkbox"/>	Page buffering can be used to cache pages so that recently used pages can be reloaded more quickly.
<input type="checkbox"/>	The second chance and enhanced second chance algorithms are approximations of the least recently used (LRU) algorithm.
<input type="checkbox"/>	Implementation of the OPT page replacement algorithm is impossible.

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? (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: 0, 7, 4, 2, 5, 5, 3, 6, 6, 3, 1, 4, 3, 3, 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. LRU replacement (2 points)
- b. FIFO 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)

<input type="checkbox"/>	An operating system allows multiple processes to open the same file simultaneously and each process maintains a pointer to the last read or write locate it used within the file.
<input type="checkbox"/>	File extensions that indicate file type, e.g. .exe, .txt, .c and .tex, are used by the operating system to ensure only the correct program is used.
<input type="checkbox"/>	The operating system's seek instruction on a file is used to find files in storage.
<input type="checkbox"/>	In a tree file structure all files have unique names.
<input type="checkbox"/>	A file owned by the root user and root group with the Unix file permission 700 (in octal) can not be read by any other system user.

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

<input type="checkbox"/>	The Scan algorithms reduces the number of sectors the read/write head visits compared to the Look family of algorithms.
<input type="checkbox"/>	The analysis of a disk scheduling algorithm is true for one or many platters.
<input type="checkbox"/>	Disk scheduling algorithms are used only when there is a queue of requests.
<input type="checkbox"/>	C-Look and C-Scan read and write data requests when the head moves in only one direction.
<input type="checkbox"/>	The shortest seek time first (SSTF) algorithm can lead to starvation for some processes.



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

<input type="checkbox"/>	Contiguous allocation of file blocks is an efficient method of disk management.
<input type="checkbox"/>	Disk drives used for storage in server systems spin at low speeds to reduce rotational latency.
<input type="checkbox"/>	RAID is used to reduce the mean time to repair (MTTR).
<input type="checkbox"/>	Striping is used in RAID systems to improve the speed of reading and writing data.
<input type="checkbox"/>	RAID 1 duplicates each disk in the array to improve data storage reliability.

8.4 The arms in hard disk drives holding the read/write heads move together so that data is always read from a single cylinder. Give two reasons, each with a clear explanation, why manufacturers might choose not to implement drives where the arms move independently so that data could be read from multiple cylinders. (4 points)



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8.5 Indexed allocation of file blocks provides good random access to file contents compared to linked allocation. Clearly and briefly describe three disadvantages of indexed allocation (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)

<input type="checkbox"/>	A ransomware attack encrypts a user's data and is a threat to the availability of data.
<input type="checkbox"/>	Integrity of data means that data should be protected against unauthorized modification.
<input type="checkbox"/>	Humans are the strongest part of any security system.
<input type="checkbox"/>	Sharing passwords and other credentials supports the availability of data and is not a security threat.
<input type="checkbox"/>	An operating system sends encrypted data from a computer to the operating system's developers without the knowledge of the computer user. This could be a threat against the confidentiality of data.

9.2 Which of the following statements about network security are true?

(1 point)

<input type="checkbox"/>	A private key can be distributed in cleartext to anyone who wants to communicate with holder of the public key.
<input type="checkbox"/>	In a replay attack transmission of a valid message is delayed by the attacker.
<input type="checkbox"/>	Port scanning can be used to identify network services running on a computer.
<input type="checkbox"/>	A DMZ describes a network containing internet-facing servers that is isolated from a company's internal network.
<input type="checkbox"/>	A firewall can inspect and discard network packets.



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

<input type="checkbox"/>	The contents of an encrypted message can (normally) only be read by the intended recipient.
<input type="checkbox"/>	Cryptography can be used to support the identification of the source of a network packet.
<input type="checkbox"/>	When using a digital signature, the sender uses their private key to encrypt a hash of a message and the receiver uses a public key to decrypt the message and confirm the sender's identity.
<input type="checkbox"/>	Alice leaves the room without locking her computer. While she is away, Carol uses Alice's computer to send an insulting email to a senior manager. This is an example of a masquerade attack.
<input type="checkbox"/>	Carol has a copy of Bob's public key and is able to read the contents of a message Alice has encrypted with Bob's public key and sent to Bob.

9.4 Explain what two factor authentication is (2 points), and how two-factor and other multi-factor authentication schemes improve on the use of passwords alone (2 points).



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9.5 Public key cryptography uses an asymmetric encryption scheme where a public key can be used to encrypt a message that can only be decrypted with a private key.

- i) Explain what a digital certificate is? (1 point)
- ii) Explain the problem that a digital certificate solves and how it solves it? (2 point)