CS323 Operating Systems

Operating Systems Summary

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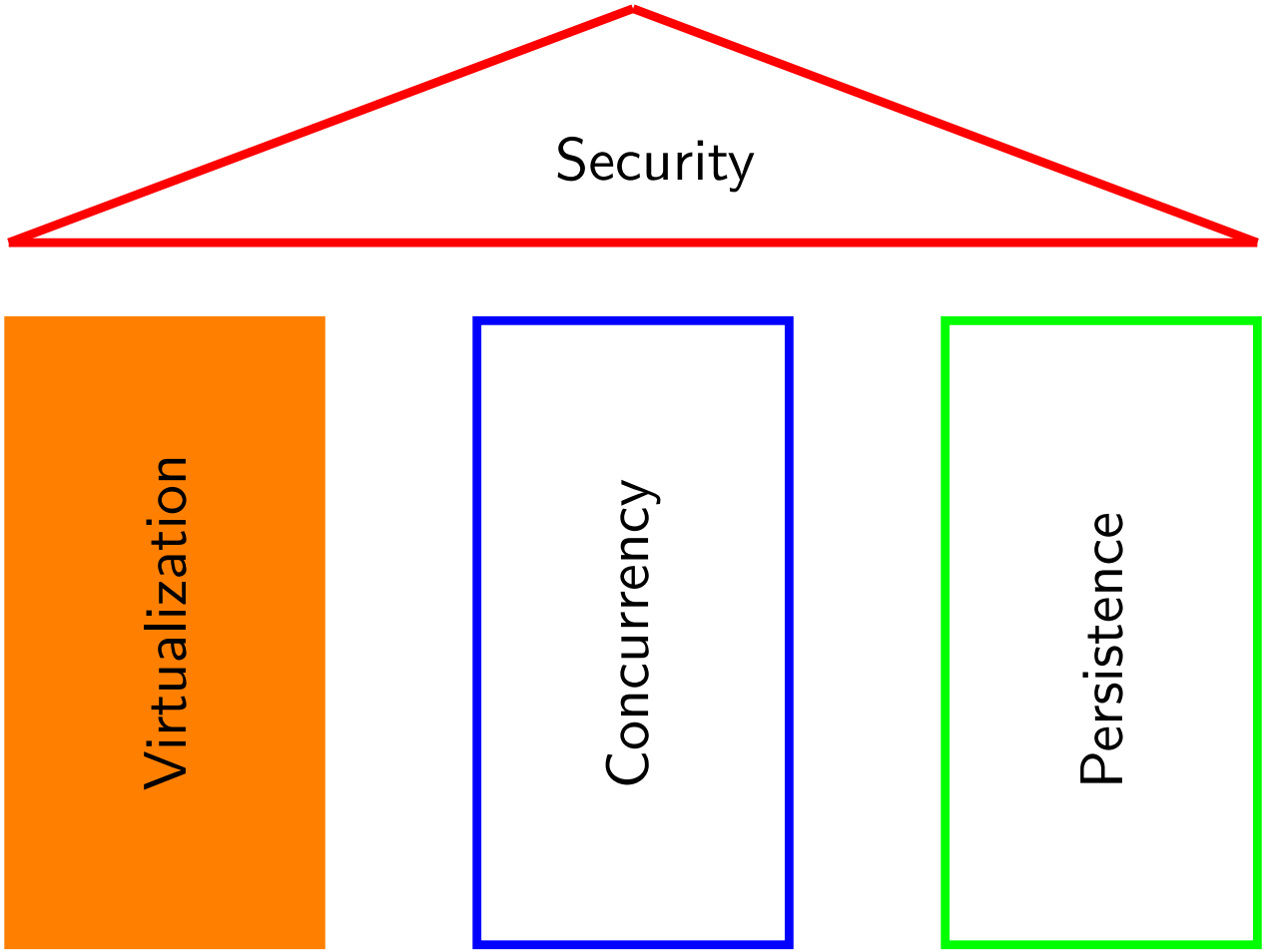
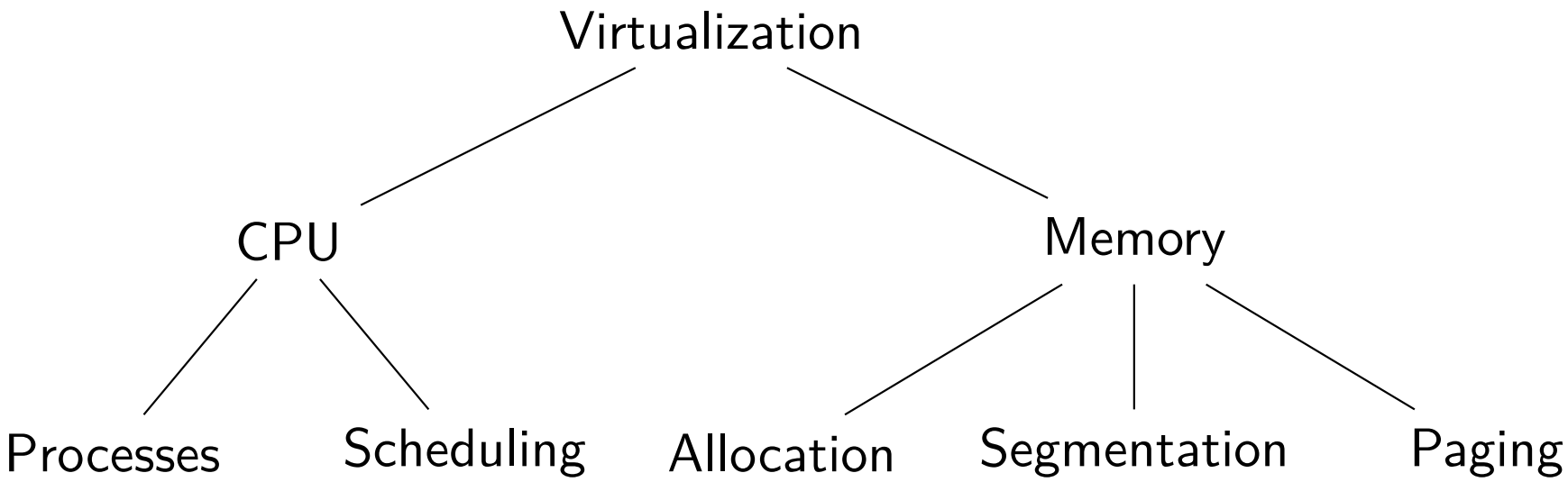
Virtualization



Virtualization: Summary



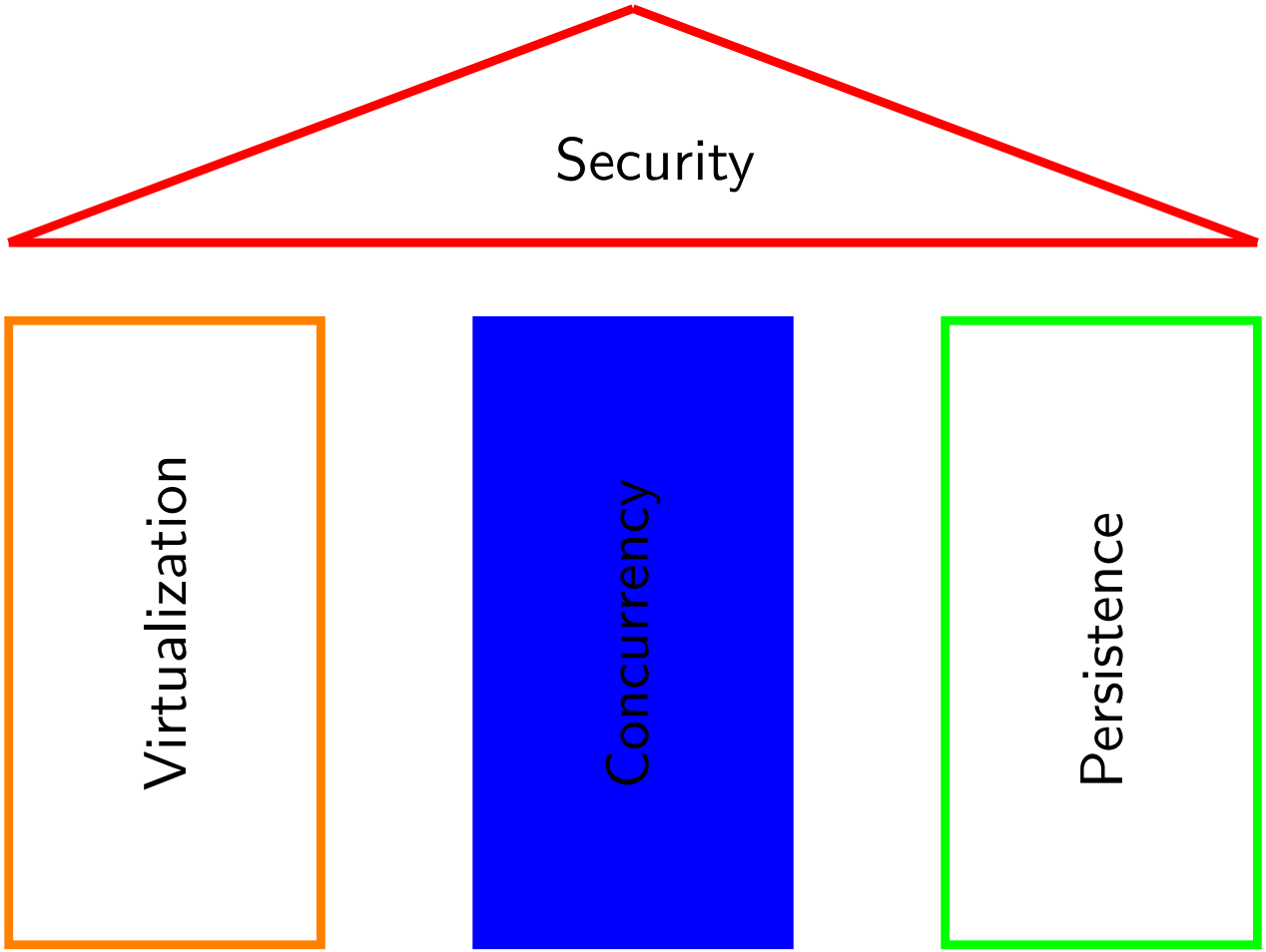
CPU Virtualization: Processes and Scheduling

- Processes are a purely virtual concept
- Separating policies and mechanisms enables modularity
- Schedulers need to optimize for different metrics: utilization, turnaround, response time, fairness and forward progress
  - FIFO: simple, non-preemptive scheduler
  - SJF: non-preemptive, prevents process jams
  - STFC: preemptive, prevents jams of late processes
  - RR: preemptive, great response time, bad turnaround
  - MLFQ: preemptive, most realistic
  - CFS: fair scheduler by virtualizing time
- Past behavior is good predictor for future behavior

Memory Virtualization: Segmentation and Paging

- OS manages access to constrained resources
  - Principle: limited direct execution (bare metal when possible, intercept when needed)
  - ***CPU:*** time sharing between processes (low switching cost)
  - ***Memory:*** space sharing (disk I/O is slow, so time sharing is expensive)
- ***Fragmentation:*** space lost due to internal or external padding
- ***Paging:*** MMU fully translates between virtual and physical addresses
  - One flat page table (array)
  - Multi-level page table
  - Pros? Cons? What are size requirements?
- Paging and swapping allows process to execute with only the working set resident in memory, remaining pages can be stored on disk

Concurrency



Concurrency topics

- Abstraction: locks to protect shared data structures
- Mechanism: interrupt-based locks
- Mechanism: atomic hardware locks
- Busy waiting (spin locks) versus wait queues
- Condition variables
- Semaphores
- Signaling through condition variables and semaphores

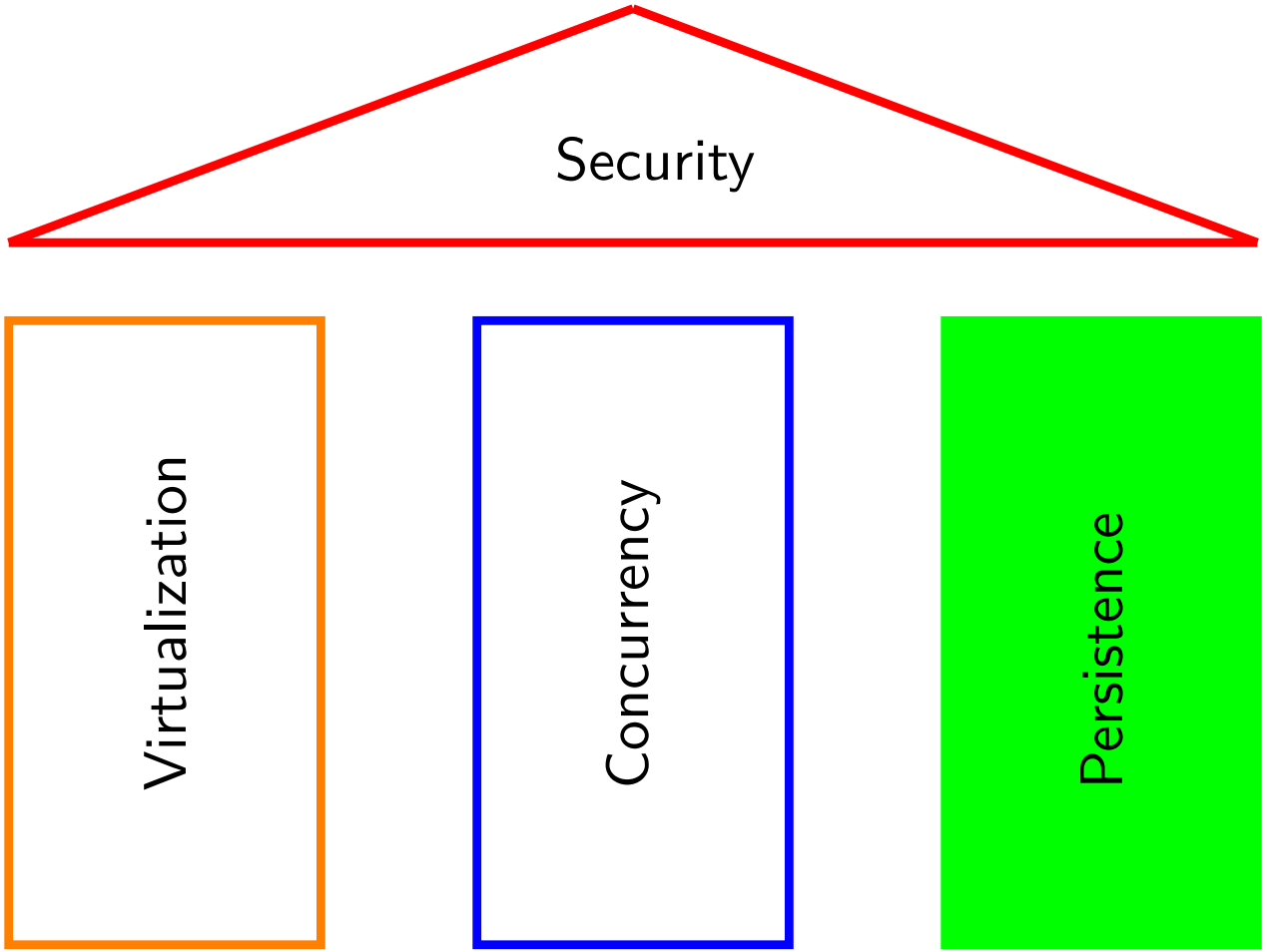
Difference parallelism and concurrency

- ***Parallelism:*** multiple threads (or processes) working on a single task using multiple CPU cores (i.e., stuff happens at the same physical time)
- ***Concurrency:*** tasks can start, run, and complete in overlapping time periods (i.e., tasks run at the same virtual time)

Concurrency summary

- Spin lock, CV, and semaphore synchronize multiple threads/processes
  - ***Spin lock:*** atomic access, no ordering, spinning
  - ***Condition variable:*** atomic access, queue, OS primitive
  - ***Semaphore:*** shared access to critical section with (int) state
- All three primitives are equally powerful
  - Each primitive can be used to implement both other primitives
  - Performance may differ!
- Synchronization is challenging and may introduce different types of bugs such as atomicity violation, order violation, or deadlocks.

Persistence



Persistence Topics

- Device interaction and device drivers
- IO Scheduling and harddrive throughput
  - Disk layout
  - Disk virtualization (RAID)
- Filesystem API
- Filesystem implementation
  - Inodes and devices
  - File descriptors
  - File names
- Crash resistance
- Journaling

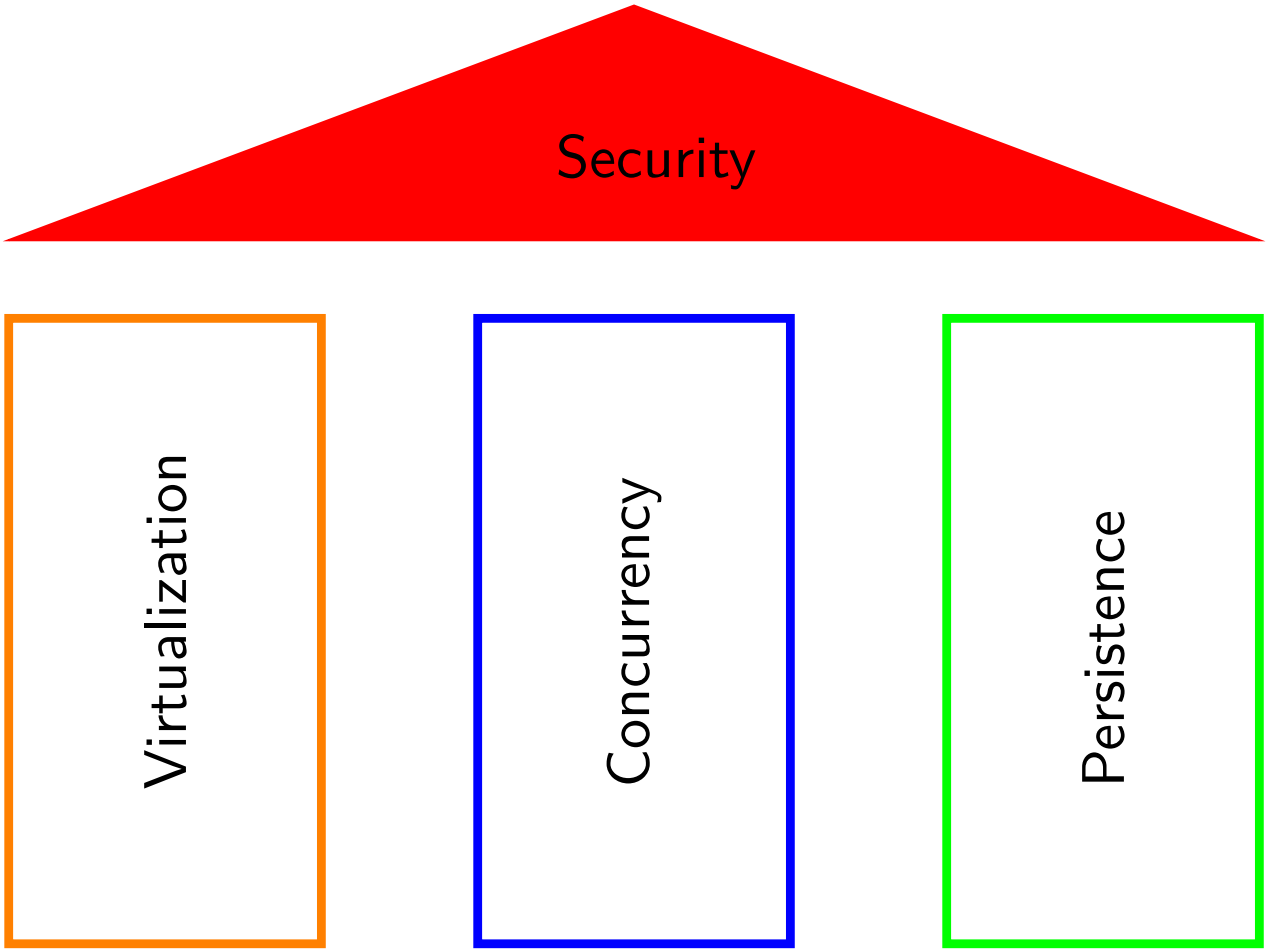
IO/Driver Summary

- Overlap IO and computation as much as possible!
  - Use interrupts
  - Use DMA
- Driver classes provide common interface
- Storage: read/write/seek of blocks
- Minimize random IO (i.e., quick sort is really bad on HDDs)
- Carefully schedule IO on slow devices
- RAID virtualizes disks

Filesystem summary

- Filesystem API: handle interaction with the file system
- Three ways to identify a file
  - File names (for humans)
  - Inodes and devices (on the disk)
  - File descriptors (for a process)
- Filesystem implementation
  - Inodes for metadata
  - Bitmaps for inodes/data blocks
  - Superblock for global metadata
- Crash resistance: filesystem check (FSCK)
- Journaling: keep track of metadata, enforce atomicity
  - All modern filesystems use journaling
  - FSCK still useful due to bitflips/bugs

Security



Two topics: testing and mitigations

- Testing helps developers find as many bugs as possible
  - Fuzzing generates test cases
  - Sanitization detects policy violations
- Mitigations detect policy violations at runtime, stop exploits

Testing summary

- Software testing finds bugs before an attacker can exploit them
- Manual testing: write test cases to trigger exceptions
- Fuzz testing automates and randomizes testing
- Sanitizers allow early bug detection, not just on exceptions
- AddressSanitizer is the most commonly used sanitizer and enforces probabilistic memory safety by recording metadata for every allocated object and checking every memory read/write.

Mitigations Summary

- Deployed mitigations do not stop all attacks
- ***Data Execution Prevention*** stops code injection attacks, but does not stop code reuse attacks
- ***Address Space Layout Randomization*** is probabilistic, shuffles memory space, prone to information leaks
- ***Stack Canaries*** are probabilistic, do not protect against direct overwrites, prone to information leaks
- ***Control-Flow Integrity*** restricts control-flow hijack attacks, does not protect against data-only attacks

Learning goals

Figure 1: Understading OS' will help your career!

Learning goals: class

- Learn core concepts
- Become aware of design decisions and policies
  - Virtualization: CPU and Memory
  - Concurrency: performance trade-offs
  - Persistence: correctness and recovery
  - Security: software testing versus mitigations

Learning goals: labs

- Lab 0: practice C programming and debugging
- Lab 1: thread scheduling and memory allocation
- Lab 2: concurrency and message passing
- Lab 3: simple file system
- Lab 4: software security testing

But the main goal was to become better programmers, i.e., using a specification to implement and test a prototype, then integrate it into the overall system.

Final Exam: Outline

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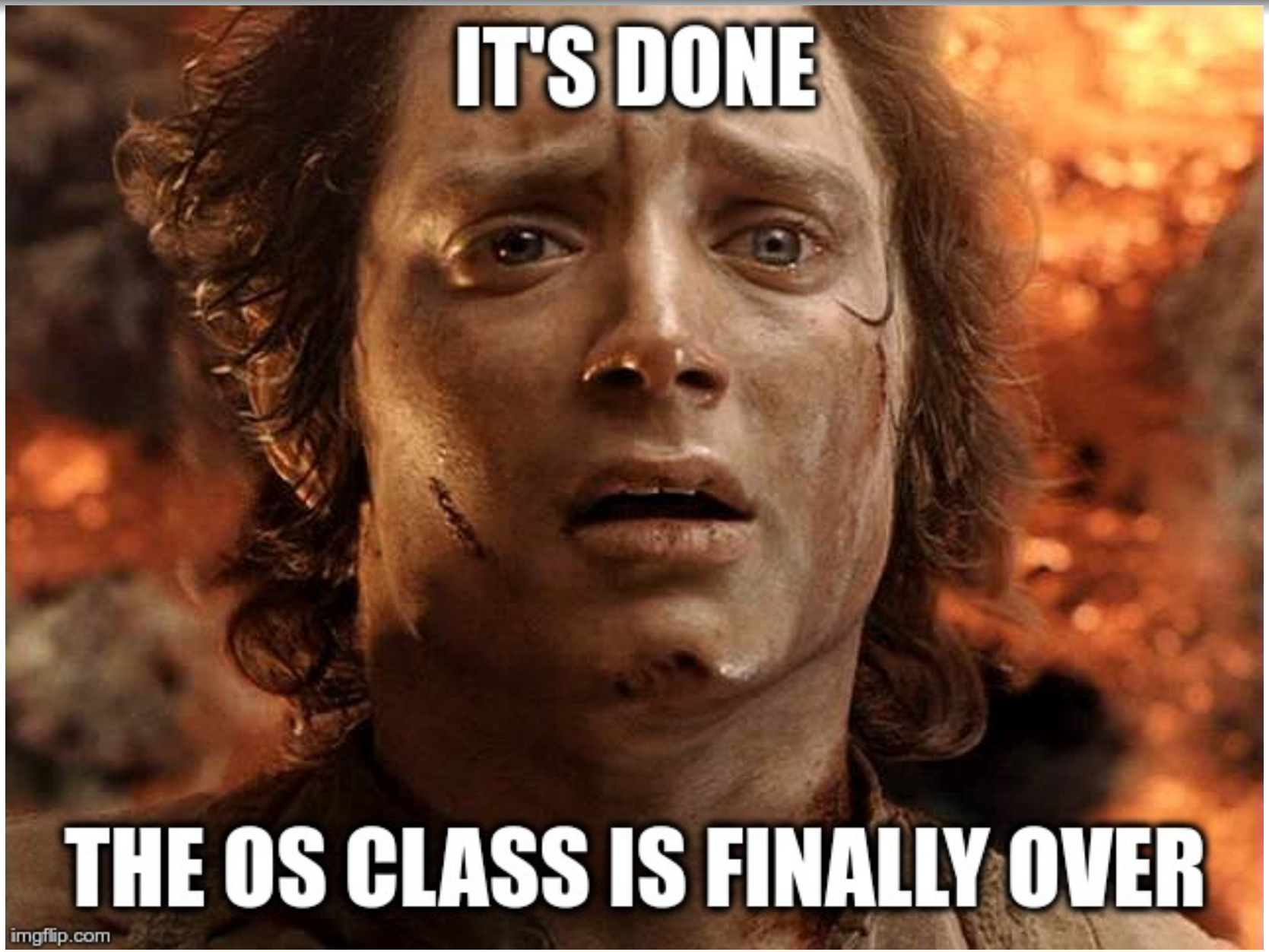
- Answers will be
  - Numbers (e.g., 15 pages)
  - Code (merging for buddy allocator)
  - Prose (why you don't temporally separate memory)

Prepare for the exam

- Watch the lectures and read the book chapters
- Solve the exercises
- Solve the practice midterm/final
- Create summaris and indexes
- Ask questions on Moodle

All done?



Feedback

- Feedback is appreciated, be as detailed as possible
  - For good statistics, I need all of you to respond!
  - Be open and positive!
- What was great? What can be improved?
- Be as detailed as possible
  - How can I improve the class?
  - How can I improve the labs?
  - Was the workload and distribution reasonable?
- Let me know what else you were missing!

All done?

Figure 3: Keep your curiosity going, the HexHive lab offers fun {BSc|MSc} software/systems security projects. Talk to us!