

CS343: Operating Systems

Syllabus - Spring 2022

Course Staff

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Location and Time

Lecture time: 9:30 - 10:50 PM Central, Tuesdays and Thursdays

Location: [Pancoe Abbott Auditorium](#), [Pancoe-NSUHS Life Sciences Pavilion](#)

I strongly encourage keeping up with the course lectures. Much of the difficulty in CS343 comes from the new concepts, which we take care to introduce in lecture. We will attempt to record all lecture sessions so that you can later review them if you want, but the expectation is that students will attend class.

Overview

This course introduces you to the basic, foundational concepts and principles of operating systems, many of which generalize to other areas of computer science and engineering. You will learn many of these concepts and principles by applying them in practice on a modern machine through labs that are designed to put you in the shoes of a systems-level developer. OS (and systems more broadly) is very much a learn-by-doing kind of area.

The following concepts and principles are included:

- **OS Structure:** kernel, device drivers, file systems, network stacks, schedulers, system calls, libraries, toolchains, language virtual machines, user interface/shell, applications, etc.
- **OS Models:** monolithic kernel, microkernel, virtual machine monitor/hypervisor, jail/zone/container, exokernel, unikernel, ...
- **OS Abstractions:** thread, name space, address space, process, IPC, virtual machine, container, file, directory stream, plus abstraction design within the kernel (devices, file systems, ...)
- **Concurrency Sources:** multiprocessors, devices, interrupts, threads, processes, horror stories, ...
- **Concurrency Challenges:** memory system coherence/consistency, race conditions, deadlock, livelock, horror stories, ...
- **Concurrency Control:** interrupt control, atomics, spinlocks, critical sections, blocking vs waiting, mutexes, semaphores, condvars, monitors, barriers, lockfree/waitfree models, plus typical synchronization problems such as producer-consumer, reader-writer, and dining philosophers.
- **Scheduling and Resource Management:** theory, FCFS, GPS, SRPT, dynamic priority (e.g. Unix), lottery, fixed priority, preemptive vs non-preemptive, real-time vs non-real-time, horror stories, ...
- **Virtual Memory:** hardware-software co-design, paging, swapping, segmentation and (possibly) current alternatives.
- **Device Drivers:** interrupts, DMA vs PIO, MMIO vs PMIO, atomics, hardware memory barriers, software memory barriers.
- **Protection and Security:** kernel/user mode, mode/ring transitions, role of encryption, interaction with virtual memory, horror stories.
- **Memory management:** page allocation versus heap allocation, garbage collection, allocation in special contexts (e.g. interrupt context), page replacement, working set.
- **File systems:** issues/interfaces, data structures on block devices, examples (V7, FAT+, ext2+)
- **Principles:** policy versus mechanism, orthogonality, worse-is-better, lazy evaluation, caching, end-to-end argument, mythical man-month, no silver bullet, hardware/software co-design

Note that we will prioritize among these points so that if more time is needed to cover a high priority topic, there may be less or no coverage of a lower priority topic.

The hardware environment that we will focus on is Intel/AMD machines running in 64-bit mode ("x86-64" or "x64"), which is the commonplace platform for systems ranging from laptops to supercomputers today¹. Your lab work will be done on Linux in the C programming language². Two of your labs (on concurrency and scheduling) will be done in user-level Linux. The remaining labs will be in the context of the Nautilus kernel framework ("NK"), a research kernel developed at Northwestern and other institutions. The experience you gain in NK will generalize to the Linux kernel, for the most part³.

Textbook

Modern Operating Systems, Fourth Edition,

Andrew S. Tanenbaum and Herbert Bos,

Pearson, 2014, (ISBN-13: 978-0133591620, ISBN-10: 013359162X)

We also considered several other books for this course, which may be useful as further references:

- Remzi Arpaci-Dusseau, and Andrea Arpaci-Dusseau, *Operating Systems: Three Easy Pieces*, 2018. [freely available]
- Abraham Silberschatz, Peter Galvin, and Greg Gagne, *Operating Systems Concepts*, 10th edition, Wiley, 2018.
- Thomas Anderson, and Michael Dahlin, *Operating Systems: Principles and Practice*, Recursive, 2014.
- William Stallings, *Operating Systems: Internals and Design Principles*, 9th edition, Pearson, 2017.

The CS213 textbook: *Computer Systems: A Programmer's Perspective* (Byrant & O'Hallaron) is also a good reference for this course as it provides a "what every programmer should know" treatment of some of the topics we will cover, including threads, processes, virtual memory, and the various Linux/Unix system call interfaces.

¹ Most of what you learn about x64 vis a vis OS will generalize to the other main platform, ARM, which is the basis for phones and tablets, as well as the next generation of Macs.

² Linux is the common OS on everything except laptops and desktops. It is also the OS underlying Android. C is the lingua franca of low-level software development.

³ In the design of this course, we considered several other options. The most desirable would have been to have you work within the Linux kernel itself. This proved to be intractable from a pedagogical point of view. The complexity we would have to shield you from, particularly in a lab based on paging, would have been overwhelming to manage. We also considered the teaching OS xv6 for IA32 and for RISC-V. IA32 and RISC-V both would require revisiting material students have already learned, for x64, in CS213, plus xv6 for IA32 would have made a device driver lab particularly challenging to pull off. Another consideration was to use CMU's Pebbles OS specification and have students build Pebbles from scratch as in CMU's course. This was also limited to IA32, and seemed intractable to execute in a single quarter. The intent behind using NK is to give a view inside a modern, x64 codebase with clear internal interfaces that has a development model (e.g., Kbuild, C, etc) that is similar to Linux.

Pre-requisites

CS213 or CE205 or equivalent: computer organization and introduction to systems

CS214 or equivalent: data structures

CS211 or equivalent: C programming experience and Unix environments

Any version of CS 213 or CE 205 is acceptable, but we will expect that you have seen basic concepts such as the existence of exceptional control flow and virtual memory, and the typical Unix system calls for processes, threads, and files+I/O. The syllabus shown in pdinda.org/ics is a good starting point.

Any version of CS 214 is acceptable, but we will expect that you have seen basic data structures, algorithms, and their implementation. These include linked lists, balanced search trees, hashing and hash tables, heaps, graphs, sorting, etc.

Experience with C or C++ in part means familiarity with arrays, structs, unions, and, most importantly, pointers and pointer-based data structures. Low-level pointer-based mechanisms are used throughout an OS, and by the underlying hardware.

CS343 satisfies one of the Systems Breadth, Tech Elective, and Project requirements in the Computer Science curriculum for both McCormick and Weinberg. CS343 also satisfies one of the Software Systems area requirements for the Computer Engineering curriculum in McCormick.

Communication

All course materials will be posted to Canvas including grades, lecture materials, and class recordings. Campuswire will be used for course discussions and questions. **All questions should go to Campuswire rather than to email.** We will enroll you in Campuswire. Office hours will also be available, with the regular schedule available on Canvas. Office hour appointments can also be made with the instructors or TA by Campuswire post to “instructors and TAs”.

Class Structure

Schedule

The course schedule is available on the Canvas homepage for the course. Be aware that it is subject to change, although warnings will be given to students for any major changes.

Labs

We will have five programming labs. Except for the first lab, labs should be done in groups of up to three. **Start looking for a partner on day one.**

There are five labs. 60% of the grade in the class will be based on lab work, with a breakdown as follows:

- 5% Getting Started Lab (done individually)
- 10% Producer-Consumer Lab
- 15% Queueing/Scheduling Lab
- 15% Device Driver Lab
- 15% Paging Lab

We will use GitHub Classroom for disseminating and handing in labs. It is important that you and your partners make sure that your repositories are private. Only your group and the course staff should be able to see your repos.

The Producer-Consumer Lab and Queueing/Scheduling Lab are user-level Linux labs. The others are all done within a research kernel developed at Northwestern. All hardware is x86-64. All code is in C.

Midterm Exams

There will be two midterm exams. The exams will hopefully be given in person, although this is subject to change based on Northwestern public health concerns. One will take place near the middle of the class, with results returned to students before the drop deadline. The other will take place during the class exam slot of exam week.

Exams are taken individually. Students will be allowed the use of some amount of notes, which the instructor will provide guidance on in advance.

Midterm exams are not cumulative and focus on their own part of the course. However, the nature of the course is that the material in the second half builds on knowledge from the first half.

Grades

Percentage grades will be converted to letter grades using the standard letter grade system (93% A, 90% A-, 87% B+, etc.). However, these grade bins may be moved at the instructor's discretion for the advantage of students. Note that the percent grade displayed by Canvas is not always accurate and may not take late penalties or slip days into account, as described below.

Each category of assignment has a total value, which is divided as explained above.

Category	Count	Total Value
Labs	5	60%
Midterm Exam 1	1	20%
Midterm Exam 2	1	20%

Late Policy

Midterm exams may not be taken late without prior coordination by the instructor.

Labs may be submitted late with a penalty of a 20% reduction in maximum points per day late. For example, a homework assignment submitted two days late has a maximum score of 60%. Lateness is rounded up to the whole day, so an assignment that is five minutes late has the same penalty as an assignment 23 hours late.

Slip Days

To help you more flexibly manage deadlines, we will give you **three slip days**, which allow you to submit a lab assignment late without penalty. Slip days are used in units of whole days, meaning a lab submitted five minutes late consumes an entire slip day. Slip days may only be applied to lab assignments, not exams.

You do not need to notify staff that you are using a slip day. We will track the total number of late days for your submissions and automatically apply slip days to optimize their usage. Slip days will not be assessed against lab assignments you did not submit. No extra credit is awarded for avoiding the use of slip days. However, it is in your best interest to avoid turning in lab assignments late, as the next assignment is often released slightly afterwards.

Slip days are applied individually, so for partner assignments be careful to communicate about plans to use slip days. It is possible for an assignment submitted one day late to have no penalty for one student (due to spending a slip day) and a one day late penalty for their partner with no slip days remaining.

Example slip day usage:

- Use two slip days to receive no penalty on a lab assignment submitted two days late.
- Use two slip days to receive no penalty on two separate lab assignments each submitted one day late.
- Use three slip days to receive just a one-day late penalty on a lab assignment submitted four days late.

Slip days are meant to automatically handle minor issues. If you are having a major issue, please contact the instructor as soon as possible, and we will work together on a solution. Particularly for issues outside of the student's control, such as major injury, sickness, or family emergency, deadlines can be shifted without penalty if you contact the instructor.

Academic Integrity

Students in this course are required to comply with the policies found in the booklet, "Academic Integrity at Northwestern University: A Basic Guide". All papers submitted for credit in this course must be submitted electronically unless otherwise instructed by the professor. Your written work may be tested for plagiarized content. For details regarding academic integrity at Northwestern or to download the guide, visit:

<https://www.northwestern.edu/provost/policies/academic-integrity/index.html>

Collaboration is a really good thing, and we encourage it. On the other hand, cheating is a very serious offense, which carries serious consequences. It is OK to meet with colleagues, form study groups, discuss assignments with them, compare alternative approaches, go over examples from textbooks or other sources. **But it is never ok to share code or homework solutions, or even to see each other's code or solutions.**

What you turn in must be your own work. Copying (or even studying) code, solution sets, etc., from anywhere (e.g., other people, web, GitHub) is strictly prohibited. Be aware that we use a number of tools to detect and discover integrity violations. If you discuss your work with other people, please acknowledge them by listing their names in your submission. It is also forbidden to share, post, or otherwise publicize course materials. This includes (but is not limited to) homeworks, exams, solutions, or your own submissions. This extends even after the quarter ends; course material remains private information which you may not share or reproduce.

It is the responsibility of every student in this class to be familiar with and to adhere to the [Academic Integrity Policies](#) of Northwestern University and the McCormick School of Engineering. Any suspicion of violation of these policies will be reported immediately to the Associate Dean for Undergraduate Studies. If you are in doubt whether your actions constitute a violation of the above policies, ask the instructor (preferably before doing what you are unsure about).

Accessibility

Northwestern University is committed to providing the most accessible learning environment as possible for students with disabilities. Should you anticipate or experience disability-related barriers, please contact AccessibleNU to move forward with the university's established accommodation process (accessiblenu@northwestern.edu; 847-467-5530). If you already have established accommodations with AccessibleNU, please let me know as soon as possible, preferably within the first two weeks of the term, so we can work together to implement your disability accommodations. Disability information, including academic accommodations, is confidential under the Family Educational Rights and Privacy Act.

Should you need them, additional campus resources are available, including, but not limited to:

- Accessible NU: www.northwestern.edu/accessiblenu/
- CAPS: www.northwestern.edu/counseling/index.html
- Student Enrichment Services: www.northwestern.edu/enrichment/

I believe in providing reasonable accommodations that allow for full access to learning for all. Please contact me if there is anything that we should be aware of that might have an impact on your participation in this course (documented disability, language challenges, absences for religious observations, etc.).

Diversity and Inclusion

I consider this classroom to be a place where you will be treated with respect, and we welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, ability—and other visible and nonvisible differences. All members of this class are expected to contribute to a respectful, welcoming, and inclusive environment for every other member of the class.

This course will also include a mix of undergraduates and graduate students with differing backgrounds in computer science. Do not feel discouraged by this. Each student will bring a different aspect of their knowledge to discussions, and we'll all be contributing towards increasing each other's understanding of operating systems.

Support for Wellness and Mental Health

Northwestern University is committed to supporting the wellness of our students. Student Affairs has multiple resources to support student wellness and mental health. If you are feeling distressed or overwhelmed, please reach out for help. Students can access confidential resources through the Counseling and Psychological Services (CAPS), Religious and Spiritual Life (RSL) and the Center for Awareness, Response and Education (CARE). Additional information on all of the resources mentioned above can be found here:

- <https://www.northwestern.edu/counseling/>
- <https://www.northwestern.edu/religious-life/>
- <https://www.northwestern.edu/care/>

COVID-19 Compliance

Students, faculty, and staff must comply with University expectations regarding appropriate classroom behavior, including those outlined below and in the COVID-19 Code of Conduct. With respect to classroom procedures, this includes:

- Policies regarding masking and social distancing evolve as the public health situation changes. Students are responsible for understanding and complying with current masking, testing, Symptom Tracking, and social distancing requirements.
- In some classes, masking and/or social distancing may be required as a result of an Americans with Disabilities Act (ADA) accommodation for the instructor or a student in the class even when not generally required on campus. In such cases, the instructor will notify the class.

If a student fails to comply with the [COVID-19 Code of Conduct](#) or other University expectations related to COVID-19, the instructor may ask the student to leave the class. The instructor is asked to report the incident to the Office of Community Standards for additional follow-up.

To protect the health of our community, Northwestern University requires unvaccinated students who are in on-campus programs to be tested for COVID-19 twice per week.

Students who fail to comply with current or future COVID-19 testing protocols will be referred to the Office of Community standards to face disciplinary action, including escalation up to restriction from campus and suspension.

Some (hopefully most) class sessions for this course will occur in person. Individual students will not be granted permission to attend remotely except as the result of an Americans with Disabilities Act (ADA) accommodation as determined by AccessibleNU.

Maintaining the health of the community remains our priority. If you are experiencing any symptoms of COVID do not attend class and update your Symptom Tracker application right away to connect with Northwestern's Case Management Team for guidance on next steps. Also contact the instructor as soon as possible to arrange to complete coursework.

Students who experience a personal emergency should contact the instructor as soon as possible to arrange to complete coursework.

Should public health recommendations prevent in person class from being held on a given day, the instructor or the university will notify students.

Class Recordings

This class or portions of this class will be recorded by the instructor for educational purposes and available to the class during the quarter. Your instructor will communicate how you can access the recordings. Portions of the course that contain images, questions or commentary/discussion by students will be edited out of any recordings that are saved beyond the current term.

Unauthorized student recording of classroom or other academic activities (including advising sessions or office hours) is prohibited. Unauthorized recording is unethical and may also be a violation of University policy and state law. Students requesting the use of assistive technology as an accommodation should contact [AccessibleNU](#). Unauthorized use of classroom recordings – including distributing or posting them – is also prohibited. Under the University's [Copyright Policy](#), faculty own the copyright to instructional materials – including those resources created specifically for the purposes of instruction, such as syllabi, lectures and lecture notes, and presentations. Students cannot copy, reproduce, display, or distribute these materials. Students who engage in unauthorized recording, unauthorized use of a recording, or unauthorized distribution of instructional materials will be referred to the appropriate University office for follow-up.