CS110: Principles of Computer Systems

Autumn 2021
Jerry Cain
PDF

Welcome to CS110: Principles of Computer Systems

- I'm Jerry Cain (jerry@cs.stanford.edu)
  - Chemistry undergrad MIT, originally chemistry Ph.D. student here, defected to CS
  - Senior Lecturer in CS, teaching CS106AX, CS106X, CS107, CS109, and CS110
  - Taught CS110 for the first time in Spring 2013, and I absolutely love teaching it!
    - Leveraged much of Mendel Rosenblum's CS110 materials from prior offerings
    - Introduced my own materials since then, and will introduce even more this time
    - CS110 is still an evolving system—particularly given the upheaval that was the 2020-2021 school year—but hopefully you don't notice one bit
  - Started working at Facebook in 2008, still with them in an emeritus role
    - Learned web programming, PHP, CSS, JavaScript. Old CS107 student of mine (class of 2004) is my manager
    - Have grown to understand and appreciate large systems much better as a result of working there

Welcome to CS110: Principles of Computer Systems

- Staff and Students
  - 164 students as of September 19th at 5:30 pm (only expected 100, cause 8:30am)
    - 7 graduate student CA's at the moment
    - Sophie, Patrick, Ayelet, Julia, Victor, Swayam, Joel
    - We’re working on getting at least one more CA. We can never have enough!
- Soft Prerequisites
  - Each of you should know C and C++ reasonably well so that you can...
    - write moderately complex programs
    - read and understand portions of large code bases
    - trace memory diagrams and always win!
  - Each of you should be fluent with **Unix**, **gcc**, **valgrind**, and make to the extent they're covered in CS107 or its equivalent.

CS110 Class Resources

- Course Web Site: https://cs110.stanford.edu
  - Very simple, optimized to surface exactly what you need and nothing else
  - Check the website for information about upcoming lectures, assignment handouts, discussion sections, and links to slide decks like those you're working through right now
- Online Student Support
  - Edstem (for the questions that require staff response)
  - I'm likely to set up a Slack channel as well, but if I do, it'll be set up to foster chatty silliness
- Office Hours
  - I'll be holding in-person office hours on Wednesdays in a location TBD. I'll also pop online for some of the online office hours we'll be providing as well.
  - CA's will soon provide a full matrix of office hours. Some will be in person, and others will be virtual.
  - Office hours are not for debugging your assignments, and the CA's have been instructed to never look at code, except for Assignment 1, which is designed to get everyone from varying backgrounds up to speed so that Assignments 2 through 6 all go brilliantly.

CS110 Class Resources

- Two Textbooks
  - First textbook is other half of CS107 textbook
    - "Computer Systems: A Programmer's Perspective", by Bryant and O'Hallaron
    - Stanford Bookstore stocks custom version of just the four chapters needed for CS110, and that custom version can be purchased online from the Bookstore, and they'll ship it right to you.
  - Second textbook is more about systems-in-the-large, less about implementation details
    - "Principles of Computer System Design: An Introduction", by Jerome H. Saltzer and M. Frans Kaashoek
    - Provided free-of-charge online, chapter by chapter. Not stocked at Stanford Bookstore by design. You can buy a copy of it from Amazon if you want.
    - Very few reading assignments from this one, so there's no advantage of owning your own copy.

CS110 Class Resources

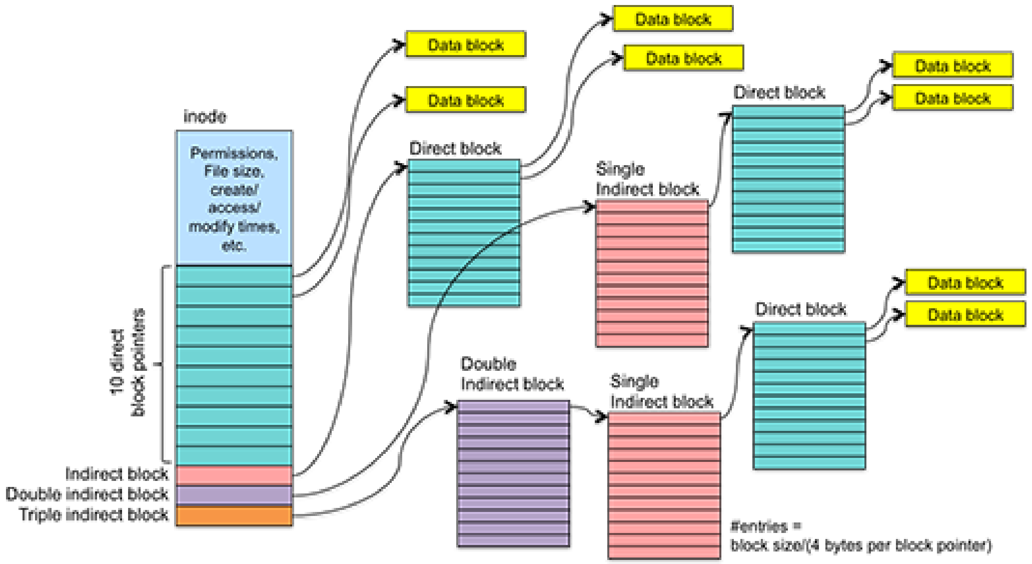
- Lectures and Lecture Examples
  - We will meet every Monday, Wednesday, and Friday from 8:30am to 9:30am.
  - Lectures are generally driven by coding examples, and all coding examples can be copied/cloned into local space so you can play and confirm they work properly
  - Code examples are developed and tested on the myth machines, which is where you'll complete all of your CS110 assignments
  - The accumulation of all lecture examples will be housed in a git repository at **/usr/class/cs110/lecture-examples**, which you can initially **git clone**, and then subsequently **git pull** to get the newer examples as I check them in
- Lecture Slides
  - We rely on slides like these when we need to press through lots of information not driven by coding examples
    - All lectures will have them. They'll be organic, in that we'll inject updates and clarifications (and be clear we added stuff when it really impacts you).

CS110 Class Resources

- CS110A: Problem Solving Lab for CS110
    - CS110A is a one-unit supplementary discussion section designed to foster additional community and establish a bedrock foundation in systems programming.
        - CS110A is relatively new and is based on one of the School of Engineering's Equity and Inclusion Initiatives.
        - CS110A meets once a week, on Sundays at 2:00pm for two hours.
    - We limit enrollment—that limit is currently 20—so that CS110A students can more readily interact with a supportive and empathetic cohort and more easily access the time and attention of the course staff (particularly me and the CS110A CA, Amrita Kaur).
    - We're particularly eager to accept students who have not had as much priori exposure to CS and who may question their ability to do well in CS110 unless they have this added support.
    - Students interested in taking CS110A must submit an application by Friday, September 24th, and CS110A formally begins on Sunday, September 26th. You'll know by Sunday morning whether you've been accepted and offered a spot under the CS110A wing.

Course Syllabus

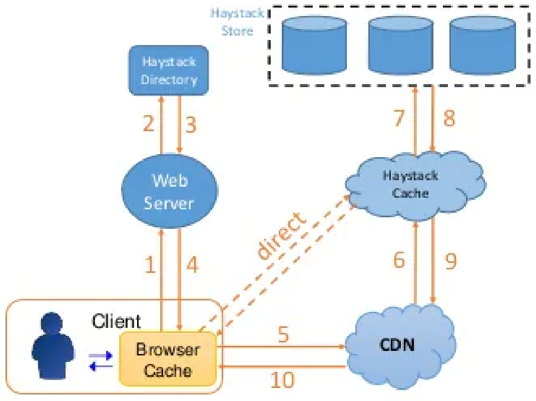
- Overview of Linux Filesystems
  - Linux and C libraries for file manipulation: **stat**, **struct stat**, **open**, **close**, **read**, **write**, **readdir**, **struct dirent**, file descriptors, regular files, directories, soft and hard links, programmatic manipulation of them, implementation of **ls**, **cp**, **find**, and other core Unix utilities you probably never realized were plain old C programs
  - Naming, abstraction and layering concepts in systems as a means for managing complexity, blocks, inodes, inode pointer structure, inode as abstraction over blocks, direct blocks, indirect blocks, doubly indirect blocks, design and implementation of a file system



Unix Filesystem Inode Design [source]

Course Syllabus

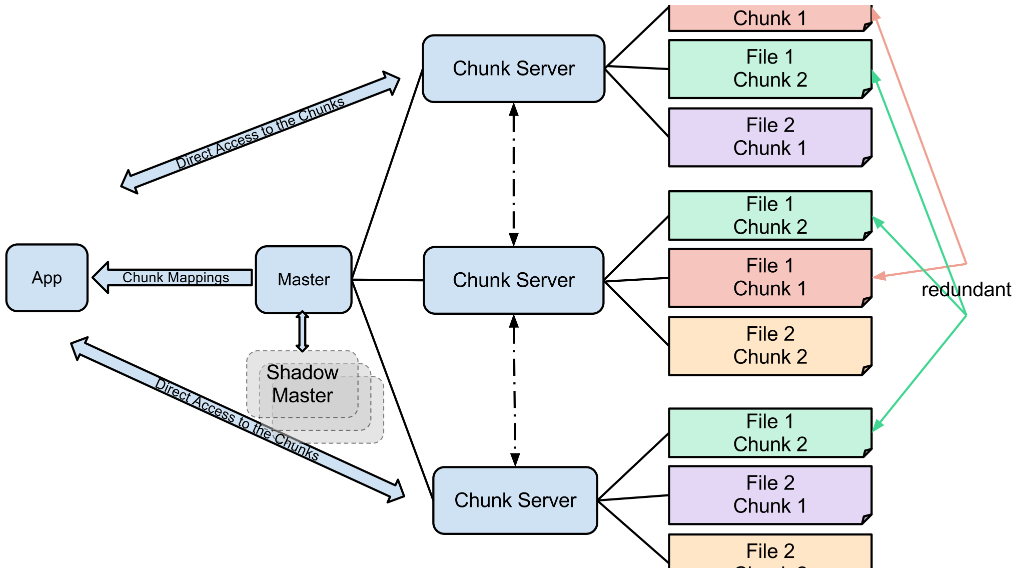
Haystack Architecture



Three core components:

- Haystack Store
- Haystack Directory
- Haystack Cache: functions as an internal CDN
  - Browser can be directed to either the CDN or the Cache
  - **Not confirmed**, but this “*Haystack Cache*” may be referring to Facebook’s many “*Edge Cache*” located at Internet Points of Presence (PoPs).

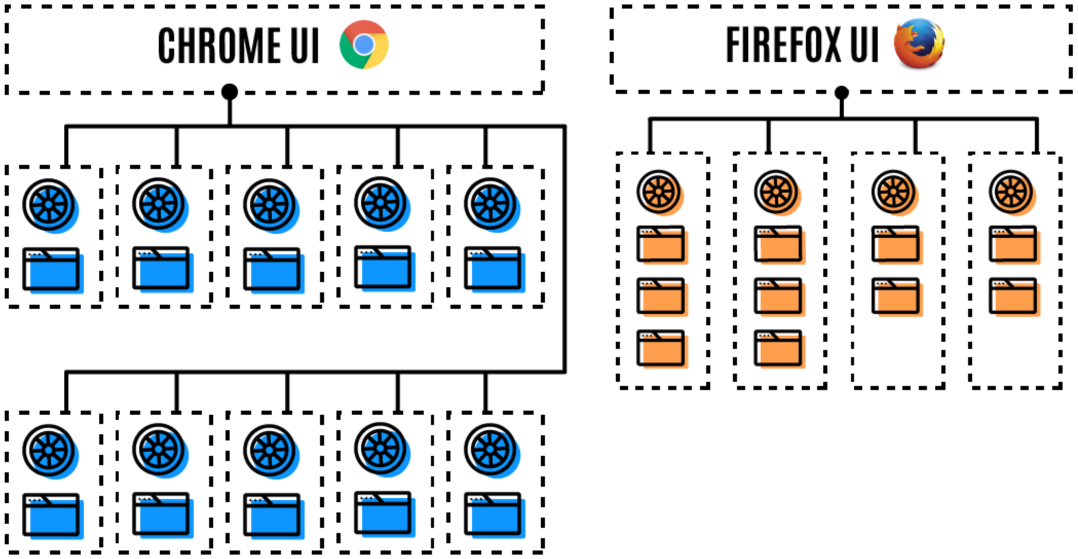
Facebook's First Generation Haystack [source]



Google File System [source]

Course Syllabus

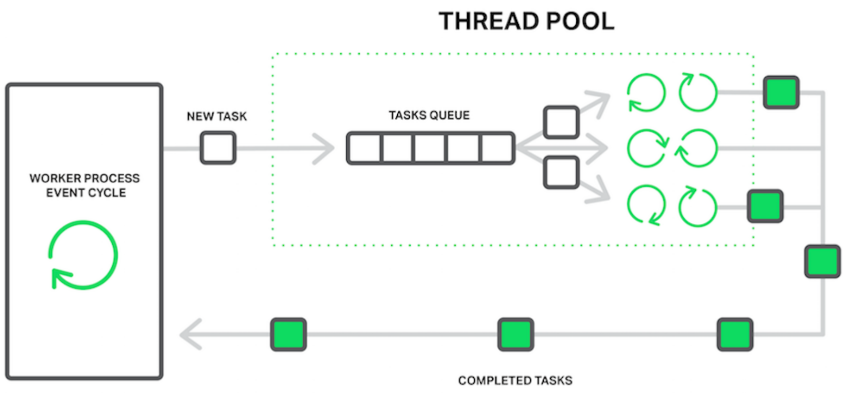
- Multiprocessing and Exceptional Control Flow
  - Introduction to multiprocessing, **fork**, **waitpid**, **execvp**, process ids, interprocess communication, context switches, user versus kernel mode, system calls and how their calling convention differs from those of normal functions
  - Protected address spaces, virtual memory, virtual to physical address mapping, scheduling
  - Concurrency versus parallelism, multiple cores versus multiple processors, concurrency issues with multiprocessing, signal masks



Browser Architecture [source]

Course Syllabus

- Threading and Concurrency
  - Sequential programming, desire to emulate the real world within a single process using parallel threads, free-of-charge exploitation of multiple cores (8 per **myth** machine, 12 - 16 per **wheat** machine, 16 per **oat** machine), pros and cons of threading versus forking
  - C++ threads, **thread** construction using function pointers, blocks, functors, **join**, **detach**, race conditions, mutex, IA32 implementation of **lock** and **unlock**, spinlock, busy waiting, preemptive versus cooperative multithreading, **yield**, **sleep_for**
  - Condition variables, **condition_variable_any**, rendezvous and thread communication, **wait**, **notify_one**, **notify_all**, deadlock, thread starvation
  - Semaphore concept and **semaphore** implementation, generalized counters, pros and cons of **semaphore** versus exposed **condition_variable_any**, thread pools, cost of threads versus processes

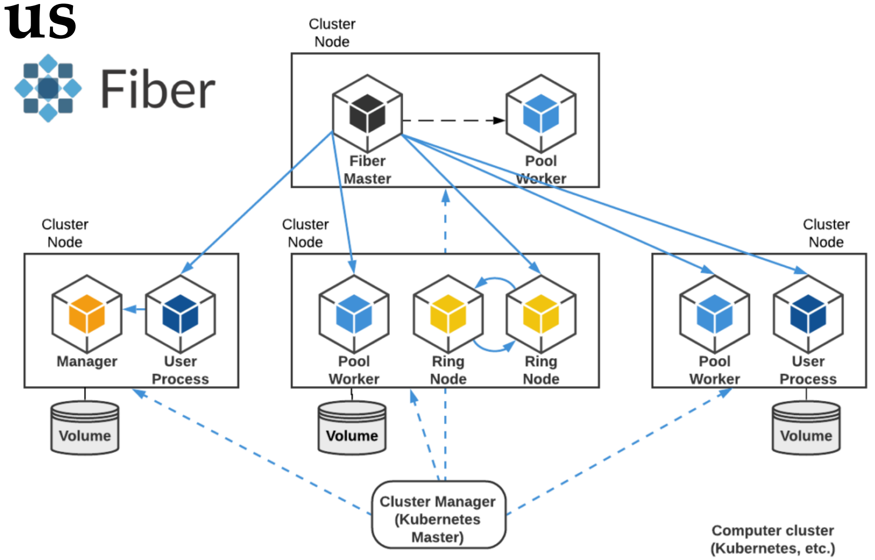


Nginx and Thread Pools [source]

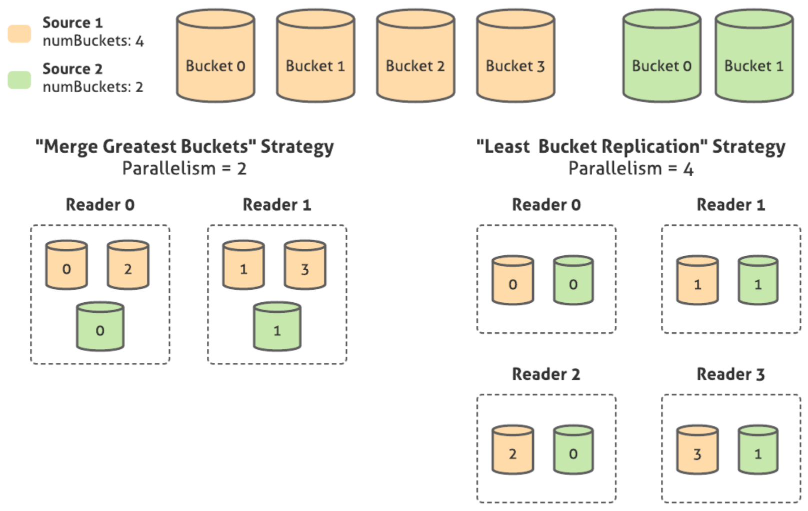
Course Syllabus

- Networking and Distributed Systems
  - Client-server model, peer-to-peer model, **telnet**, protocols, request, response, stateless versus keep-alive connections, latency and throughput issues, **gethostbyname**, **gethostbyaddr**, IPv4 versus IPv6, **struct sockaddr** hierarchy of records
  - Ports, sockets, socket descriptors, **socket**, **connect**, **bind**, **accept**, **read**, simple echo server, time server, concurrency issues, spawning threads to isolate and manage single conversations
  - C++ layer over raw C I/O file descriptors, introduction to **sockbuf** and **sockstream** C++ classes (via **socket++** open source project)
  - HTTP 1.0 and 1.1, header fields, **GET**, **HEAD**, **POST**, response codes, caching
- Additional Topics
  - MapReduce programming model, implementation strategies using multiple threads and multiprocessing
  - Nonblocking I/O, where normally slow system calls like **accept**, **read**, and **write** return immediately instead of blocking
  - **select**, **epoll**, and **libev** libraries all provide nonblocking I/O alternatives to maximize CPU time using a single thread of execution within a single process

Course Syllabus



Uber's Fiber: Distributed AI Computation [source]



Spotify's Dataflow for Wrapped 2020 [source]

CS110: Intersection of Systems Design and Art

WORDS THAT WILL NEVER BE THE SAME AFTER CS110
fork
thread
child
farm
shell
lock
kill
permit
zombie
pipe
workers
-Ecy

Illustration courtesy of Ecy King, CS110 Champion, Spring 2021

Course Expectations

- Discussion Sections: 5%
  - Everyone is expected to sign up for a weekly, 80-minute discussion section
  - We introduced the CS110 discussion section for the first time some 3.5 years ago, and the general consensus is that they substantially improved the course
  - Section will be a mix of theoretical work, coding exercises, and advanced software engineering etudes using **gdb** and **valgrind**
  - Discussion section preference forms will go live later this week, and we'll do our best to ensure that you get placed in a discussion section that works for you.
  - Section attendance is required. We're offering an array of times—all on Thursday, with in person and online options—that will hopefully work for everyone.
  - Your total discussion section grade is 100%. However, every time you miss a section, your discussion section grade counts a little less and your assessment average counts a little more. See the Course Information Handout for details.
- Concept Checks: 5%
  - You're to submit answers to a collection of questions posted after each lecture.
  - Concept checks are posted by 5pm on Monday, Wednesday, and Friday, and you have a week to complete them. The late penalty is trivial, so be sure to submit all of them, even if you absentmindedly miss a deadline.
  - All concept checks count equally, and you can submit as often as needed until you get everything correct.

Course Expectations

- Programming Assignments: 60%
  - Expect six assignments.
  - For Assignments 3, 4, and 5, you may pair up with one other CS110 student and jointly arrive at a single solution that you submit once on behalf of both of you.
  - Some assignments are a single file, others are significant code bases you'll extend and update.
  - Regardless of your overall average, you must get 70% of the points on each of the six assignments in order to pass the class. See resubmission policy below!
- Late policy is different than it is for many other CS classes.
  - If you submit on time, you can get 100% of the points. How's that for fair?
  - If you can't meet the deadline, you can still submit up to 24 hours later, but your overall score is capped at 95%.
  - If you need more than 24 additional hours to submit, you can submit up to 48 hours later, but overall score is capped at 90%.
  - If you need to submit more than 48 hours late, you can, but you need to message Jerry saying so. Your overall score will be capped at a 85%.
- Anyone who gets fewer than 85% of the functionality points on an assignment will be permitted to re-submit that assignment to recover all of the lost points, up to 85%.

Course Expectations

- Self-Assessments: 30%
    - There are no traditional exams at all this quarter
        - The university cancelled traditional finals for all of last, citing a distaste for anything high-stakes that might cause undue stress for those who are geographically and situationally disadvantaged.
        - I'm not wholly convinced this quarter will be even close to normal, so I'm not quite ready to bring the in-classroom exam back yet.
        - I'm sticking with low-stakes assessments as opportunities to gauge how well you understand the accumulation of topics taught so far.
            - We'll have three of them, and they'll go the Fridays of Week 3, 6, and 8.
            - Each self-assessment will be timed: once you download it, you'll have three hours to complete and submit it.
            - We will, however, give you a 72-hour stretch of time during which you choose what three-hour block works best for you.
            - The self-assessments will be graded using a square-rooting scheme I describe in the Course Information Handout.

Honor Code

- Please take it seriously, because the CS Department does
    - The following are clear no-no's for CS110 assignments
        - Looking at another person’s CS110 code
        - Showing another student your code
        - Discussing assignments in such detail that you duplicate a portion of someone else's code in your own program
        - Uploading your code to a public repository (e.g. github) so others can find it
        - If you'd like to upload your code to a private repository, you can do so on github or some other hosting service that provides free private hosting
- Self-assessments are open book, open notes, open WWW, though you may not actively collaborate with others in person or online. In general, you can only rely on materials that are discoverable by all students via search engines.