Advanced Operating Systems (CS 523)

Introduction

Tianyin Xu

The easiest, the hardest, and the best course.

Metadata

- Instructor: **Tianyin Xu**
- TA: **Jinghao Jia**
- Website: https://cs523-uiuc.github.io/fall21/
  - Add yourself on Piazza if you are not there.
- **Format**
  - Synchronous ***online*** discussion
    - W/F 12:30—13:45pm
  - Open Studio ***(in person)***
    - Friday 2-4pm
  - Office hours
    - By appointment (online or in person)

Why is your course hybrid?

- … because systems people like to make things complicated
  - Well, because workloads are complicated.

- **Principles**
  - Accommodate different needs and preferences
  - The course can be taken in a purely online manner
  - Provide venues for in-person discussion

$ Whoami

- Ass prof @ CS
- Working on software and system reliability
- Played with Facebook data centers
  - happy to chat about industry versus academia
- Grad school at UC San Diego.
  - I thought nobody would come here from SD
- Applied twice for grad school.
  - I failed the first time.
  - persistence >> genius
  - understanding / experience >> wild ideas
  - doers >> talkers

Our TA: Jinghao Jia

- PhD student working on OS Security
- Graduated from UCSD in 2020
- Hobby: hiking
  - I went to Marin Headlands every week when doing my internship in San Francisco

What is this course about?

- **It's all about ~~Operating~~ Systems Research**
  - Develop a systematic understanding of *systems research*
  - Grasp the basic knowledge of *systems research*
  - Discuss the seminal *systems research* papers
  - Get feet wet in *systems research* (mini research project)

- **This is a course about:**

  "discussing systems research"
  + "doing systems research"

This course does NOT teach:

- Basic concepts of operating systems
- The skills of hacking an operating system kernel
  - Kernel hacking experience is not required for 523.
  - Systems research is much broader than OS kernel.
- **CS 423 / ECE 391** is the choice if you want to learn the above.
- There is a prerequisite quiz on the course website.

You are expected to:

- **Read research papers (before the class):**
  - 2 papers for each class
  - Do not come to class if you don't read ☺
- **Discuss the reading (in class, online)**
  - You will either be embarrassed if you don't read, or pretend you were not there (and lose points)
- **Conduct a semester-long mini-research project**
  - The best way to learn is to do it!
  - The real deal of the course -- **90% of your final grade**

No MP, homework, midterm or final exam!

Who are the target students?

- Students who are actively doing systems research.
  - Review classic, seminal papers
  - Explore and discuss new ideas
  - Try out new, wild ideas
- Students who are interested in systems research.
  - Evaluate if systems research is something for you.
- If you are neither of the above, you may reconsider.

Paper Reading

- **Reading papers is one of the most important skill sets in grad school.**
  - You need to learn how to **efficiently** and **effectively** read research papers
  - You will be slow in the beginning and be faster and faster
  - If you don't practice reading, you never know how.

- **We will read a lot of classic papers.**
  - Those are the must-to-read papers for systems research.
  - Some of them will appear in the SysNet qual exam.
  - It's hard to innovate if you don't know the literature well.

Rule #1:

Do NOT worship any paper or author.

- **A paper is *not* a "truth" but an "opinion"**
  - You should have your own judgement
- **Critical thinking is a must in grad school**
  - Papers are arguments based on the authors' work.
  - You are welcome to reject the arguments, criticize the approaches, and question the results.
  - You will need to back up your criticisms and rejections.
- **Plenty of horrible papers published in top venues.**
  - But you need a legit reason to "attack."

How to read a research paper? (Griswold's version)

1. What are the **motivations** for this work?
2. What is the proposed **solution**?
3. What is the work's **evaluation** of the proposed solution?
4. What is your analysis of the identified problem, idea and evaluation?
5. What are the **contributions**?
6. What are **future directions** for this research?
7. What questions are you left with?
8. What is your take-away message from this paper?

W. Griswold, How to Read an Engineering Research Paper, https://cseweb.ucsd.edu/~wgg/CSE210/howtoread.html

How to read a research paper? (Xu's version)

1. What **problem** is the paper solving?
   - Is it a real problem or a fake/imaginary problem?
   - Is it an important problem?
     - What's the consequence if the problem is not solved?
   - How many people can benefit from a solution?
2. Is the proposed solution **useful** and **practically**?
   - How much it *actually* solves?
   - How to use the solution?
   - Do you want to use the proposed tool/system?
3. What do you **learn** from the paper?

Topics we will be discussing

- Historical Perspectives
- Unix and Plan 9 (and MINIX and Linux)
- Microkernel
- Library OS
- Synchronization
- Scheduling
- Memory Management
- Virtualization
- Storage and File Systems
- Communication
- Distribution
- Protection
- Reliability

Class Discussion

- **There will be no "lecture".**
  - Classes are for questions and discussions.
  - This is a 500-level course.
- **We will discuss questions by cold calls.**
  - I will prepare the questions;
  - You can also ask questions.
- **You can volunteer or you will be asked to discuss questions in class.**
  - If you do not read the paper, you will be embarrassed.

Course Project

- **A research project fitting in the broad definition of "computer systems."**
  - In a group of **1** or **2**.
  - If you have strong reasons to do a **large** project in a team of more than 2, talk to us first.
    - Exceptions are never problems, as long as they make sense.
- **Please form groups before the end of next week.**
  - Send us an email by the end of next week identifying who is in your group

We take a very broad and inclusive view of systems research.

- It is well connected to areas like architecture, PL, SE, HPC, networking, and embedded/mobile.
- Security and reliability are essential aspects of system design and implementation.
- Everyone is talking about Sys4ML and ML4Sys.
- It can be even broader, e.g.,
  - Visualizing large-scale system data (e.g., logs/traces)
  - Human factors in system operations
  - OS Education
  - Cryto for OS

Project Timeline (12 Weeks in Total)

- **End of Week 3: Submit project proposal**
  - A well-defined research problem and feasible solutions.
  - Show the feasibility by concrete examples, datasets, and tools for system building.
  - **You can try me the idea before deciding on the project.**
- **End of Week 7: Submit Checkpoint 1 report**
  - Show your system/tool prototype and preliminary results.
  - Your prototypes should be able to work with your motivating examples.
- **End of Week 11: Submit Checkpoint 2 report**
  - (At this point, you are expected to build your system/tool and start evaluation)
  - Describe the detailed evaluation plan in your report.
- **Final project demo (15 min)**
- **Submit final project report (6 pages)**

Open Studio (Friday 2-4pm)

- Discuss and debate your research ideas and proposals
- See what other teams are working on
- Brainstorming and getting feedback

This's the easiest course!

- **No homework, no MPs, no exams!**
  - "I hate them!"
- **You are supposed to do research as a grad student**
  - So, you earn credits by doing what you're supposed to do.
- **You are supposed to read those papers.**
  - Qual exams
  - Those are the papers every system student needs to read.

This's the hardest course!

- **You are expected to be a *senior* PhD student.**
  - **You are expected to come up with your own ideas.**
    - We will release some candidate idea list.
  - **You are expected to design and implement your ideas.**
    - All we will do is to push you.
  - **You are expected to evaluate your system.**
- **There is no lecture but discussion.**
  - You are expected to understand the basic of the paper;
  - The class is mainly for discussion and QA.

FAQ

- **I have no interested in research. Do you have some pure engineering projects?**
  - **No.** // We tried before, and it didn't work well.
- **I don't want to come to lectures. Can I skip?**
  - Yes, but you will lose the 10% class discussion points.
- **I don't want to come to open studio. Can I skip?**
  - Yes.
- **Can I simply *reuse* my own research projects?**
  - Unfortunately, yes
- **Then, I don't need to do anything in your course?**
  - Yes, if that's really your plan.

Most projects fall into the following categories:

- **Study**: qualitatively or quantitatively analyze an important aspect of a type of systems.
- **Measurement**: measure/characterize an important aspect of a type of systems through experiments.
- **Tooling**: design and implement a new tool that can address an important problem in modern systems
- **System**: design and implement a novel system with new capabilities or properties

Examples

- **Study**
  - Chou et al., An Empirical Study of Operating Systems Errors, SOSP 2001.
- **Measurement**
  - Pillai et al., All File Systems Are Not Created Equal: On the Complexity of Crafting Crash-Consistent Applications, OSDI 2014.
- **Tooling**
  - Li et al., CP-Miner: A Tool for Finding Copy-paste and Related Bugs in Operating System Code, OSDI 2004.
- **System**
  - Rosenblum et al., The Design and Implementation of a Log-Structured File System, SOSP 1991.

Evaluation of Research Projects

- **It will be evaluated using the same criteria as SOSP/OSDI submissions.**
  - **Overall merit**
  - Importance of the topic
  - Originality and insightfulness
  - Validation and thoroughness
  - Presentation and clarify

- **Dream bar**: CP-miner, Veriflow
- **High bar**: Sufficiently interesting to be a real paper
- **Low bar**: Something you can brag about

Project Grading

- **A to A+:** significant results and publishable work;
- **A- to A:** strong results and a clear roadmap towards publishable work;
- **B+ to A-:** interesting results but quite far from being significant;
- **B to B+:** a good exploration but leads to nothing;
- **B- to B**: some efforts of exploration; no conclusion.

(You should have the courage to explore and fail)

Best Project Award

- **Sponsored by Facebook**

Tips

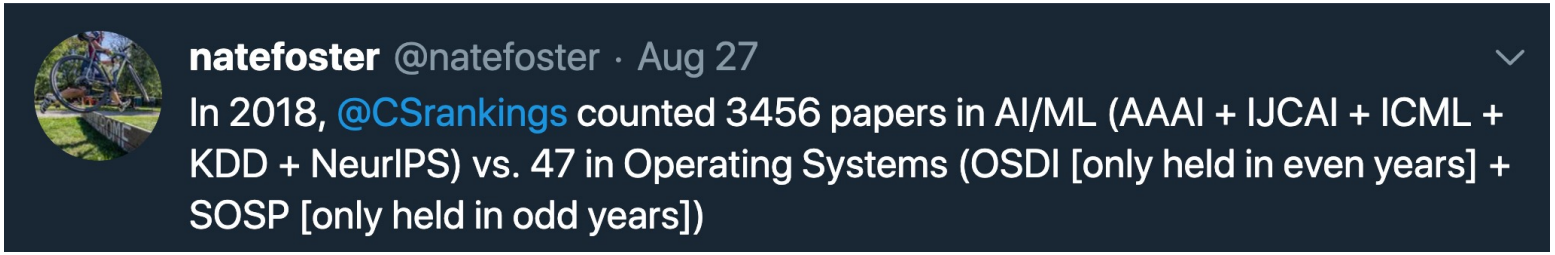
- **Pick a good problem**
  - Why is this problem interesting?
  - What is the impact of solving this problem?
  - Look at what others are doing:
    - Academic conferences: OSDI/SOSP, NSDI, EuroSys, ATC , etc.
    - Engineering blogs and postmortems
- **Pick a problem that is achievable.**
  - Start from small (you only have one semester)
  - What resources would you need to investigate the problem? (ask if you're serious)
- **Think about how to evaluate your work.**

Systems Research Conferences

- SOSP/OSDI (one conference with two names)
- ASPLOS (arch + PL + OS)
- NSDI (networked systems)
- FAST (file and storage systems)
- EuroSys (European)
- MobiSys (mobile systems)
- USENIX ATC (everything)

Systems Research Conferences

- The research cycle is long;
  so as the publication cycle.



- There not many papers to read, but you are expected to read the small number of published work.

Questions about the project?

- We are always here to help (use us well; but don't abuse us)
  - Open Studio
  - Appointment
  - Email

Finding Teammates NOW!

- **Piazza (the "Search for Teammates!" section)**
  - I'm Tianyin Xu, a 9th year grad student
  - I'm interested in reliability – I enjoy watching failures.
  - I have an idea on configuration management [2000 words]

- **We will give you 5-minute to pitch ideas at the beginning of each class.**
  - Send me or TA an email if you want to do it.

Exploring your project NOW!

- **Project proposals due in 3 weeks (one page)**
  - What do you plan to do?
  - Why is it interesting?
  - How you'll do it (feasibility)?
    - What is the basic idea?
  - What's your plan and schedule?
  - What you're not sure about?
  - What resources you need?
    - We can provide VMs

Problem Statement

How to find good (research) ideas?

Marinov 4-way method:

- Talking
- Reading
- Hacking
- Dreaming

Marinov method, the bad way

- **Talking**
  - ”Hey, you are the advisor – tell me a damn OSDI idea.”
- **Reading**
  - Find ideas by reading the Limitation section
- **Hacking**
  - Let me read Linux kernel before doing research.
  - Let me take CS 423 before doing research.
- **Dreaming**
  - Sleep → Apple → Gravity

Marinov method, the good way

- **Talking**
  - Articulate the problem you want to solve
    - Why it's important and why it hasn't been addressed?
  - Pitch your idea with concrete examples or data points
    - Why your idea can solve the problem in a better way?
- **Reading**
  - Seek for inspiration, but I don't find it too useful.
- **Hacking**
  - Look at the design and implementation of existing systems
  - Hack those systems to see if only a hack is needed
- **Dreaming**
  - What's your wish list?

Tips that may be useful (I)

- **Understanding the problem first!**
  - Innovation without understanding leads to BS.
  - **Understanding itself could be a huge contribution.**
  - Empirical studies and measurements are great ways to develop understanding.
    - E.g., Goto statement considered harmful
  - If you have a topic/direction/problem but don't have a crisp idea, work on a study or a measurement.
    - Ask yourself questions – let your curiosity guide you.

Examples of Studies

- Chou et al., An Empirical Study of Operating Systems Errors, SOSP 2001.
  - Study bugs in the OS kernels
- Lu et al., Learning from Mistakes — A Comprehensive Study on Real World Concurrency Bug Characteristics, ASPLOS 2008.
  - Study concurrency bugs
- Lu et al., A Study of Linux File System Evolution, FAST 2013.
  - Study code changes in file systems
- Simple Testing Can Prevent Most Critical Failures: An Analysis of Production Failures in Distributed Data-intensive Systems, OSDI 2014.
  - Study catastrophic failures in data systems

Examples of Measurement

- Ren et al., An Analysis of Performance Evolution of Linux's Core Operations, SOSP 2019.
  - Measuring system call performance
- Ganesan et al., Redundancy Does Not Imply Fault Tolerance: Analysis of Distributed Storage Reactions to Single Errors and Corruptions, FAST 2017.
  - Measuring fault tolerance by fault injection testing
- Li et al., Tales of the Tail: Hardware, OS, and Application-level Sources of Tail Latency, SOCC 2014.
  - Measuring and analyzing tail latency

Tips that may be useful (II)

- **Build on top of your experience**
  - Systems work is mostly about experiences.
  - You need to know the systems well, before doing research (or development).
  - Don't attack a type of systems that you have no experience in your project.
    - If you never hacked the Linux kernel, don't do a kernel project (taking 423 first).
  - Scratching your own itch
    - The dreaming idea – what do you wish to have?

Tips that may be useful (III)

- **What system properties you want to improve?**
  - **Performance** – making systems run fast
  - **Reliability** – dealing with failures
  - **Security** – dealing with attacks
  - **Usability** – easy to use / less error-prone
  - **Manageability** – systems need to be managed
  - **Compatibility / Portability**
  - **Scalability** – making systems run at large scale
  - **Energy-efficient / environment-friendly**
- *Pick one; don't try to do everything*

Tips that may be useful (IV)

- **What are driving forces for new system research?**
  - **Hardware** (multiprocessor, big memory)
  - **Network** (distributed systems, P2P)
  - **Scale** (datacenters, edge)
  - **Application** (GFS, MapReduce, Haystack)
  - **Computing model** (cloud, serverless)
  - **Operation** (DevOps, microservices)

Tips that may be useful (V)

- **Ideas are pipedreams without execution.**
  - **No system can be done in one day.**
  - **Manage your time well.**
    - Surprisingly, this is often what makes the difference.
  - **Insights often come from doing things.**
    - Get your hands dirty
  - **Think about evaluation at the design phase**
    - How will you evaluate?

"Can you post the projects that have been done in the past?" (I)

- Understanding Configuration Dependencies in Cloud Systems
  - A comprehensive study of configuration dependencies of cloud systems (including Hadoop, HBase, Spark, etc)
    - Published at FSE'20 (a top Software Engineering conference)
- Cozart: Automatic disaggregation for off-the-shelf OS kernels
  - A `kconfig`-based OS kernel debloating tool
    - Published at Sigmetrics'20
    - Selected as a research highlight by CACM
- Characterizing Reliability Issues in a Large Deployment of Lustre Distributed File System
  - A comprehensive analysis of storage failures of a distributed file system deployed in the Blue Water supercomputer
    - Published at SC'20 (a top Supercomputing conference)
    - Nominated for both Best Paper and Best Student Paper

"Can you post the projects that have been done in the past?" (II)

- Forensic Analysis of Configuration-oriented Cyber Attacks
  - Built a forensic analysis infrastructure for configuration-change tracking and integrate it with provenance-based forensic analysis
    - Will appear at NDSS'21 (a top Security conference)
- Leyenda: An Adaptive, Hybrid, Radix Sorting Algorithm for Large-scale Data
  - Sorting 60GB data in 290 seconds
    - Runner-up at SIGMOD'19 Sorting Contest.
- Toller: Improving Android UI testing infrastructure
  - Optimize the perf. of 3 key operations in Android UI testing framework
    - Published at ISSTA'21 (a top Software Engineering conference)

What's the secret of publishing my 523 project at top conferences?

- I have no magic – good problem + good execution
- It takes longer than a semester.
  - Unless you are working on some ML/DM stuff.
- The successful ones are typically connected to the student's own interests and/or research
  - Leo Chen (SRE and configuration management)
  - Austin Kuo (OS kernel specialization and debloating)
  - Wajih Ul Hassan (provenance and forensic analysis)
- Time management and hard work