EE 156/ CS 140: Advanced Topics in Computer Architecture
Spring 2023

Instructors

Prof. Mark Hempstead
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CLIC (574 Boston) 318J
Office Hours:
Mondays 1:30 pm – 3 pm
(Virtual and in-person)
Wednesdays 11:45 am – 1:00pm
(in-person walk from class)

Course Resources

Meeting Time:
Mon/Wednesday 10:30-11:45am
Lane Hall 100A
Website: Tufts Canvas
Piazza lined through Canvas

Teaching Assistants and Office Hours

Parnian Mokri Parnian.Mokri@tufts.edu
Thurdays XXXXX CLIC Room 310, 574 Boston Ave

Robert Costa Robert_J.Costa@tufts.edu
Fridays 4-5pm on Zoom

Bharat Kesari Bharat.Kesari@tufts.edu
Tuesdays 2-3 on Zoom

Note: The course staff will only use Piazza, Canvas, and Tufts email addresses for communication

All zoom links are on the Zoom tab in Canvas and you must be authenticated through Tufts

Course Description: Modern computer architecture, starting from caches and memory systems, basic 5-stage pipelines and progressing to out-of-order superscalar processors, multicore processors, and heterogeneous processors. Techniques to maximize single-thread performance within the constraints of memory technology, power consumption, and the inherent instruction-level parallelism of applications. Current and future challenges faced by computer architects and computer-system designers. Discussion of research papers.

Prerequisite Courses:
Recommendations: EE 126/COMP 146 or EE 25/CS 46.
Required: CS 40 or EE14 or Graduate Standing

This course has two distinct phases: a standard lecture based course designed to teach advanced computer architecture concepts; a research seminar where research papers are discussed and students complete an independent research project.

Expected Course Outcomes

Students will:

- Develop an understanding of cache design trade-offs and the impact of the memory hierarchy on system performance
- Develop an understanding of the quantitative evaluation of microprocessors and metrics for measuring and estimating performance
- Develop an understanding of pipelined processor design
- Develop an understanding of dynamic instruction scheduling and multiple-issue
- Become comfortable with reading and analyzing current research papers in the computer architecture field.
- Learn to convey the results of their research efforts through effective written and oral communication.
- Develop an understanding of the current research challenges and impediments to performance improvement in the computer architecture field.

Recommended Textbook: "Computer Architecture: A Quantitative Approach," **Sixth** Edition,
John L. Hennessy and David A. Patterson, ISBN: 978-0128119051

This is the newest version of the textbook (6th Ed) of the but is not yet available as an ebook. The library has older editions available as ebooks. The concepts are the same but they use MIPS, another ISA, though it is similar to RISC-V.

Additional Online References:
Topics will be taken from the Synthesis Lectures on Computer Architecture. Free from Tish Library http://www.morganclaypool.com/toc/cac/1/1

Prerequisites and Additional References: This course assumes that every student has taken an undergraduate-level introduction to computer organization/architecture including: computer arithmetic, assembly programming, and memory systems (cache or virtual memory). EE126, EE25 or CS 40.

Approximate Course Schedule:
The course is divided into mini units designed to review the relevant background material, teach current commercial approaches, and review some of the current research in the area.

Unit 1: The Memory Hierarchy (3-4 weeks)

- Introduction and Performance Metrics [Chapter 1]
- Review of Basic Caches and Set Associativity [Appendix B]
- Advanced Cache Optimization Techniques and Replacement policies [Appendix B, Ch 2]
- Prefetching [SLCA: Falsafi and Wenisch]
- Memory consistency and Cache coherence [Chapter 5]
- Software interfaces and memory consistency [Chapter 5]
- Transactional memory
- Review of Virtual Memory and TLBs [Appendix B]

- Advanced Virtual Memory [SLCA: Bhattacharjee and Lustig]
- New Non-Volatile Memory (NVM) technologies

Unit 2: Microarchitecture and the Pipeline (3 weeks)

- Instructions Introducing the RISC-V ISA [Appendix A]
- Basic Pipelining Review [Appendices A, C and K]
- Hardware instruction-level parallelism (ILP) and Tomosulo's algorithm [Ch 3]
- Advanced Branch Prediction [Chapter 3]

Unit 3: Security from the Hardware/Systems Perspective (2 weeks)

- Security Principles [SLCA: R. Lee]
- Principles of Secure Processor Architecture Design [SLCA: J. Szefer]
- Side-Channels and Examples
- Hardware Security and Side-Channel Attacks (Spectre and Meldown)

Unit 4: Multicore and Heterogeneous Systems (2 weeks)

- Impact of Technology Scaling on Design [Chapter 1]
- Dark Silicon and the End of Technology Scaling
- Data-level Parallelism, SIMD and Vector Architectures [Chapter 4 and G]
- GPU Architectures [Chapter 4]
- Heterogeneous Systems and Many Accelerator Architectures [Chapter 7]
- Deep Learning for Computer Architects [SLCA: B. Reagen]

Unit 5: Power and Energy (1 week)

- Power Modeling [SLCA: Kaxiras, Martonosi: 2010-Chapters1/2, 2014-Chapter 1]
- Introduction to DVFS [SLCA: Kaxiras, Martonosi: 2010-Chapters 2/3, 2014-Chapter 2]

Other Potential Mini Units Depending on Student Interest

- Hardware Reliability: Process Variations and Process Variability
- Storage and Interconnection Networks [Appendices D and F]
- Workload characterization
- Industry workloads and machine learning

Grade Formula

- Programming Simulation Assignments – 20%
- Quizzes – 20%
- Project – 40 %
- Paper Review Assignments – 10%
- Participation in Paper Discussions – 10 %

Quizzes:

After each major unit there will be a comprehensive take-home quiz taken through Canvas. Each student must complete this quiz individually without collaborating with

others. Students will sign an honor statement at the top of the quiz. No extensions will be given except for a documented illness or family emergency.

Simulation and Programming Assignments:
The complexity of modern processor designs makes it all but impossible to do a comprehensive pen and paper evaluation of a design. Consequently, most working computer architects run benchmarks on cycle accurate simulators. In a series of assignments students will write small models of processors and caches and then conduct experiments the complete sniper simulation environment. Students are expected to be proficient in C++ programming and Linux. More details will be posted.

Late Assignments:
Each student will be allocated five late days per semester that can be used for the programming and simulation assignments, but not for other assignments. Please make a note on the top of the assignment report if you would like to use a late day. After the allocated late days have been exhausted, the grade on a late assignment will be penalized by 10% per day.

Paper Review Assignments and Class Discussion:
Every student will write a brief review a paper assigned for class.
Reviews will include 1) a brief summary of the paper; 2) strengths of the paper; 3) weaknesses of the paper; 4) general comments See the "paper review assignment" handout for more specifics. Because these assignments prepare the students for class discussion, all assignments must be completed before the start of class. Late paper review assignments will receive a zero.

Each paper will be discussed in class and all students will be graded on their participation on a 0-3 point scale each class. The lowest two participation grades will be dropped.

Project:
The course culminates in a significant research project in the area of computer architecture, which students will complete in groups of 2-4. Each group, in consultation with the instructor, will select a topic for themselves. Half of the project grade will reflect an evaluation of the content and quality of the research project. The other half of the grade is determined by the quality of the written assignments (project proposal and final report), the final presentation, and completion of tasks along the way. See the "final project guidelines" handout for details.

The final project paper will be due during the Final Exam Block Monday

Hybrid-Virtual Course, Office Hours and Extra Help: The course staff is here to help and we have posted office hours. Please take a moment to attend office hours and introduce yourself to the instructors. In addition, we will hold extra help sessions around the due dates of the lab assignments.

In addition, because of the pandemic and need to isolate, many students will be attending class online and in-person. All class sessions will available on zoom as well as in-person. However, because of the paper discussion component, it is important to attend class synchronously.

Official University Policies

Collaboration Rules and Academic Integrity:
You may consult other students in the class while you are working on the programming assignments but the code must be your own and not a group effort. As a rule, do not share code with any student in any class unless explicitly permitted by the instructor. The course staff may use automated plagiarism detection tools such as Stanford's *Moss* to detect similarities between assignments, but a human instructor will make the final determination.

Academic Integrity Policy: Tufts holds its students strictly accountable for adherence to academic integrity. The consequences for violations can be severe. It is critical that you understand the requirements of ethical behavior and academic work as described in Tufts' Academic Integrity handbook. If you ever have a question about the expectations concerning a particular assignment or project in this course, be sure to ask me for clarification. The Faculty of the School of Arts and Sciences and the School of Engineering are required to report suspected cases of academic integrity violations to the Dean of Student Affairs Office. If I suspect that you have cheated or plagiarized in this class, I must report the situation to the dean.

Religious Accommodations: Tufts University faculty, staff, and administration highly value and acknowledge the religious diversity of its student body. Students seeking religious accommodations related to their holy days are encouraged to collaborate with faculty to make arrangements during the first week of each semester. The religious holy days calendar, including the holy days policy from the Faculty Handbook, is available here for your reference. Students seeking additional support may refer to the University Religious Accommodations Policy, available here. The University Chaplaincy is also available to respond to questions on religious observances; their contact information is available here.

Accommodations for Students with Disabilities: Tufts is committed to providing equal access and support to all qualified students through the provision of reasonable accommodations. If you have a disability that requires reasonable accommodations, contact the StAAR Center at StaarCenter@tufts.edu or 617-627-4539. Please be aware that accommodations cannot be enacted retroactively, making timeliness a critical aspect for their provision.

Academic Support at the StAAR Center: The StAAR Center offers a variety of FREE resources to all students. Students may make an appointment to work on any writing-related project or assignment, attend subject tutoring in a variety of disciplines, or meet

with an academic coach to hone skills like time management and navigating procrastination. Students can make an appointment for any of these services by visiting https://students.tufts.edu/staar-center.

Student Support, including Mental Health: As a student, there may be times when personal stressors or difficulties interfere with your academic performance or well-being. The Dean of Student Affairs Office offers support and care to undergraduates and graduate students who are experiencing difficulties, and can also aid faculty in their work with students. In addition, through Tufts' Counseling and Mental Health Service (CMHS) students can access mental health support 24/7, and they can provide information on additional resources. CMHS also provides confidential consultation, brief counseling, and urgent care at no cost for all Tufts undergraduates as well as for graduate students who have paid the student health fee. To make an appointment, call 617-627-3360. Please visit the CMHS website: http://go.tufts.edu/Counseling to learn more about their services and resources.

Policy on sharing. This course is designed for everyone to feel comfortable participating in discussion, asking questions, learning, and facilitating the learning of others. In order for that atmosphere to be maintained, the recordings of our conversations will only be shared with the enrolled students in the class (not posted publicly) and it is prohibited for any of us who have access to the video to share it outside the course. Similarly, I have specifically designed the syllabus, exams, handouts, and lectures for the people who are enrolled in the course this term and those may not be shared outside this course. It is against Tufts policy for anyone to share any content made available in this course including course syllabi, reading materials, problems sets, videos, handouts, and exams, with anyone outside of the course without the express permission of the instructor. This especially includes any posting or sharing of videos or other recordings on publicly accessible websites or forums. Any such sharing or posting could violate copyright law or law that protects the privacy of student educational records.