CS 351: Computer Architecture, Fall 2016

Instructor  
Dr. Suzanne Rivoire

Meeting times  
Section 1: MoWe 2:00–3:50 PM, Darwin 29  
Section 2: MoWe 6:00–7:50 PM, Ives 35

Drop-in office hours  
Mo 12:30–1:45 PM  
We 4:00–5:00 PM  
Th 10:15–11:45 AM  
Office hours are in Darwin 116F. Please knock if the door to 116 is closed.

Textbook  
This is a different edition from past semesters, and it matters!

Prerequisites  
Grades of C- or better in CS 215 and CS 252, or consent of instructor.

Catalog description

(4 units) Lecture, 4 hours. Instruction set design; stages of instruction execution, data and control path design; CISC, RISC, stack architectures; pipelining; program optimization techniques, memory hierarchy: cache models and design issues, virtual memory and secondary storage; I/O interfacing; advanced topics to include some of the following: parallel architectures, DSP or other special purpose architecture, FPGA, reconfigurable architecture, asynchronous circuit design.

Course Goals

The major goals of this course are for you to

1. Understand the mechanics of how hardware and system software execute the programs that you write.

2. Understand software and hardware’s contributions to the performance, reliability, and energy efficiency of your programs and systems.

For a list of detailed objectives that will be used to assess whether or not you have met these goals, visit http://rivoire.cs.sonoma.edu/cs351/objectives.html. You can also use that list as an exam study guide.

Prerequisites

Grade of C- or better in both CS 215 and 252.

Students who do not meet these prerequisites will need instructor consent to remain in the course.

Consolidated Syllabus

You may download the course description, objectives, syllabus, and schedule in a consolidated pdf: http://rivoire.cs.sonoma.edu/cs351/syllabus_consolidated.pdf

Exam dates
Exam 1: Oct. 5 (Wed.) In lecture
Exam 2: Nov. 2 (Wed.) In lecture
Exam 3 (final): Dec. 12 (Mon.) Section 1: 2:00–3:50 PM
Section 2: 5:00–6:50 PM

Students who have scheduling conflicts on these dates should contact the instructor at the beginning of the semester.

Coursework and Grading

Course Activities

Lecture and Reading

The tentative course schedule shows the topics to be covered. Students are expected to attend all lectures and to get the notes from another student if absent. Students are also expected to skim the assigned reading material before each lecture and read more fully after the lecture.

In-class Activities

In-class activities, including quizzes, will be given almost every lecture. Students' lowest 3 scores on these activities will be dropped from the grade calculation. These activities cannot be made up.

Homework problem sets

Approximately 6 homework problem sets will be assigned. You may work in groups of up to three students and submit a single solution set for the group.

Projects

In addition to the problem sets, students will complete projects to further explore the topics covered in class. You may work in groups of up to three students on the projects.

You are not required to work with the same group for the entire semester. You are permitted to do each homework set/project with a different group. However, you are strongly encouraged to work with at least one other student on each assignment.

Exams

Three exams will be given, with the third during the scheduled final exam time. The exams cover the material from lecture, homework, projects, and the textbook. Exams will emphasize recent material, although you are responsible for knowing previous material as well. You may bring one 8.5 by 11-inch handwritten sheet of notes to all exams.

Makeup exams will be given only in extraordinary circumstances.

Grading Policies

Grade breakdown

Exams 45%
Homework problem sets  30%
Projects            15%
Class activities    10%

Your final semester grade will be rounded to the nearest integer.

_Cutoffs for letter grades (after rounding)_

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<thead>
<tr>
<th>Grade</th>
<th>Cutoff</th>
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<tbody>
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<td>B+</td>
<td>87</td>
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<td>B</td>
<td>83</td>
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<td>B-</td>
<td>80</td>
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<td>C+</td>
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<td>C</td>
<td>73</td>
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<td>D-</td>
<td>60</td>
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<td>0</td>
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</table>

CS majors must take this course for a letter grade.

Up to 3% may be added to your final grade at the instructor's discretion for constructive participation in the class. Constructive participation includes in-class participation; asking good questions via email or during office hours; and doing outstanding or extra work on assignments. No other adjustments of borderline grades will be considered.

_Late policy_

_Late homework problem sets:_ No late problem sets will be accepted. This policy allows solutions to be distributed in time for you to study for exams.

_Late projects:_ If you miss a project due date, you may submit the project by the beginning of the next class session with no penalty. This is the only extension that will be given for minor emergencies.

_Regrade policy_

Regrade requests will be accepted up to 7 days after an assignment or exam is returned. The reason for the regrade request must be explained _in writing_ and submitted as a hard copy along with the assignment or exam to be regraded. Note that all regrade requests, except for those pointing out mistakes in the totaling of points, will cause the _entire_ assignment or exam to be regraded. The adjusted grade may therefore be higher or lower than the initial grade.

_Attendance Policy_

Your attendance is highly encouraged, and absence from class can affect your grade in the following ways:

- You may miss valuable material in lecture and will need to get notes from another student.
- You may miss graded activities or exams, which can only be made up under extraordinary circumstances.
- A pattern of poor attendance will make it difficult to earn the constructive participation bonus on your final semester grade.

_Collaboration Policies_

_Special note for group work_

Your work is the collective responsibility of your group: you will all get the same grade for the assignment, and you will all be held responsible for any violation of the course collaboration policy in the work you submit.
If you start working with a group on a particular assignment but are no longer comfortable sharing this credit or responsibility with one or more of your groupmates, please let me know as soon as possible.

**Project and Homework Assignment Collaboration Policy**

Academic misconduct is taken very seriously in this course. For each homework assignment or class project, you must work with at most *one group* of up to 3 students.

The work you turn in must be the sole work of your group members. You may discuss ideas and approaches with other students and the instructor, but you should work out all details and write up all solutions with your group.

The following actions will be penalized as academic dishonesty:

- Copying part or all of another group's assignment
- Copying old or published solutions
- Looking at another group’s work or discussing another group's work in great detail. You will be penalized if your solution matches another group's solution too closely.
- Showing your group's work or describing your work in great detail to anyone other than your group members or the instructor.

**Exam Collaboration Policy**

Exams must be your own work. You are allowed to consult only your own brain, your 8.5x11” handwritten cheat sheet, and other materials specifically permitted by the instructor. Quiz policies will vary and will be announced when the quiz is given. On both exams and quizzes, giving or receiving unpermitted aid will be penalized as academic dishonesty.

**Penalties for Academic Dishonesty**

Academic dishonesty will be severely penalized; at a *minimum*, you will receive a grade of 0 on the assignment. For more information, see SSU's cheating and plagiarism policy (http://www.sonoma.edu/UAffairs/policies/cheating_plagiarism.htm) and the Dispute Resolution Board website (http://www.sonoma.edu/senate/committees/drb/drb.html).

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**Course and University Resources**

**Online Resources**

**Website**

- The course homepage is [http://rivoire.cs.sonoma.edu/cs351/](http://rivoire.cs.sonoma.edu/cs351/).
- The schedule page ([http://rivoire.cs.sonoma.edu/cs351/schedule.html](http://rivoire.cs.sonoma.edu/cs351/schedule.html)) will be regularly updated with links to assignments.
- The resources page ([http://rivoire.cs.sonoma.edu/cs351/resources.html](http://rivoire.cs.sonoma.edu/cs351/resources.html)) will be updated with links to software tools and helpful resources.

**Moodle Gradebook**

The course gradebook will be kept on Moodle ([http://moodle.sonoma.edu](http://moodle.sonoma.edu)) so that you can check your grades and compute your average at any time. Grades will be posted to Moodle shortly after assignments are returned.
Email List

Course announcements will be sent to your SSU email address, so you should check your email frequently.

University Resources

Disability Accommodations

If you are a student with a disability and you think you may require accommodations, please register with the campus office of Disability Services for Students (DSS), located in Salazar Hall - Room 1049, Phone: (707) 664-2677, TTY/TDD: (707) 664-2958. DSS will provide you with written confirmation of your verified disability and authorize recommended accommodations. This authorization must be presented to the instructor before any accommodations can be made. Visit http://www.sonoma.edu/dss for more information.

University Policies

There are important University policies that you should be aware of, such as the add/drop policy, cheating and plagiarism policy, grade appeal procedures, accommodations for students with disabilities, and the diversity vision statement. Go to this URL to find them: http://www.sonoma.edu/uaffairs/policies/studentinfo.shtml.
CS 351 Learning Objectives

Note: this course's goals and objectives are based on the Association for Computing Machinery (ACM)'s Computing Curricula 2013, mostly in the knowledge area of Architecture and Organization.

Exam 1: Introduction; Metrics; MIPS assembly

Introduction (Sec. 1.1–1.5)
- Identify the major domains of computing (embedded, desktop, server, etc.).
- Based on the requirements of each of these domains, analyze the appropriateness of different hardware and technologies for each domain.
- Define and explain vocabulary related to program translation and execution, such as compiler, assembler, assembly language, and machine language.
- Define vocabulary related to data storage, such as bit, byte, KB, MB, GB, and TB.
- Explain (at a high level) the interactions among I/O devices, the processor, and memory.
- Classify specific devices as I/O, processor, or memory.

Metrics (Sec. 1.6–1.10)

Metrics: Processor-specific metrics
- Apply the classic (single-core) processor performance formula.
- Apply the classic processor power and energy consumption formulas.
- Explain the implications of the "power wall" in terms of further processor performance improvements and the drive towards harnessing parallelism.

Metrics: Evaluation
- Evaluate performance in terms of latency and throughput/bandwidth, and determine which metrics are appropriate for different uses.
- Express relative performance in terms of speedup.
- Explain the circumstances in which a given system performance metric is useful.
- Explain the inadequacies of benchmarks as a measure of system performance.
- Assess systems' performance, power, and cost in a given situation.
- Critically examine claims about systems' performance, power, and cost.

MIPS Assembly (Ch. 2.1–2.9, 2.12–2.14)
- Summarize how instructions are represented at both the machine level and in the context of a symbolic assembler.
- Show how fundamental high-level programming constructs are implemented at the machine-language level.
- Explain different instruction formats, such as addresses per instruction and variable-length vs. fixed-length formats.
- Explain how subroutine calls are handled at the assembly level.
- Write simple assembly language program segments in the MIPS programming language using...
  - arithmetic operations
  - logical operations
  - memory operations
  - conditional operations
  - functions and the call stack
  - string processing and manipulation

Exam 2: Processor implementation (basic and pipelined); AMAT and locality

Basic Processor Implementation (Ch. 4.1–4.4)
- Explain the organization of the classical von Neumann machine and its major functional units.
- Describe how an instruction is executed in a classical von Neumann machine.
- Trace the execution of MIPS instructions and programs on the simple processor implementation.
- Modify the simple processor implementation to accommodate additional instructions.
- Compare alternative implementations of datapaths.

Pipelined Processors (Ch. 4.5–4.9)
- Trace the execution of MIPS instructions and programs on pipelined processor implementations.
- Quantitatively compare the performance of programs on pipelined and non-pipelined processors.
- Explain basic instruction level parallelism using pipelining and the major hazards that may occur.
- Explain the concept of branch prediction and its utility.
Quantitatively evaluate the performance of programs on systems that use mechanisms like forwarding and branch prediction to mitigate these hazards.

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Exam 3: Memory hierarchy and virtual memory; I/O; parallelism

Caches (Ch. 5.1–5.4)
- Describe how the use of memory hierarchy is used to reduce the effective memory latency.
- Analyze the spatial and temporal locality of different programs.
- Compute Average Memory Access Time under a variety of cache and memory configurations and mixes of instruction and data references.
  Quantitatively and qualitatively reason about the effects of cache block size, mapping scheme, replacement policy, and write policy on the performance and complexity of the hardware.
- Trace the cache state, including the mapping of memory addresses to cache blocks, for a pattern of memory references.

Virtual Memory (Ch. 5.6–5.8)
- Explain the workings of a system with virtual memory management.
- Trace the state of the page table and TLB, including the mapping of virtual to physical addresses, for a pattern of memory references.
- Calculate the required size of the page table for a given set of design decisions.
- Trace the steps in handling a page fault.
- Explain how VM allows protection and isolation.

I/O and Reliability (Ch. 4.9, 5.2, 5.5, 5.11, online readings)
- Evaluate I/O throughput and latency.
- Apply the classic MTTF equation.
- Describe data access from a magnetic disk drive.
- Apply the classic equation for magnetic disk performance.
- Explain (at a high level) how flash memory works.
- Compare the pros and cons of different storage types, and evaluate which is better for a given purpose.
- Explain how interrupts are used to implement I/O control and data transfers.
- Define interrupts and polling, compare their pros and cons, and evaluate which is better in a given situation.
- Define DMA and explain how it works.
- Quantitatively compare the performance and fault-tolerance of different approaches to RAID for different I/O access patterns.

Parallel Hardware and Software (Ch. 4.10, 5.10, 6)
- Define speedup and efficiency, and explain the notion of an algorithm's scalability in this regard.
- Describe the relevance of scalability to performance.
- Apply Amdahl's Law and Gustafson's Law and analyze their limitations and implications.
- Explain the need for cache coherence and trace a simple cache coherence protocol.
- Explain (at a high level) how GPUs work and what types of problems they are good at.
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<th>Week</th>
<th>Monday</th>
<th>Wednesday</th>
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<tr>
<td>1</td>
<td>Aug 22–Aug 26</td>
<td>Intro and syllabus CS 252 review &quot;quiz&quot;</td>
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<td>2</td>
<td>Aug 29–Sep 02</td>
<td>Domains of computing Performance metrics Project 1 assigned</td>
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<td>Performance metrics Amdahl's Law CPU performance HW 1 assigned</td>
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<td>Reading: Ch. 1.1-1.4</td>
<td>Reading: Ch. 1.6, 1.10</td>
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<td>3</td>
<td>Sep 05–Sep 09</td>
<td>Labor Day holiday</td>
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<td>Power and energy metrics Reading: Ch. 1.7, 1.8</td>
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<td>4</td>
<td>Sep 12–Sep 16</td>
<td>LEGv8 ISA intro Arithmetic operations Machine code</td>
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<td>Machine code, continued Logical operations Conditionals</td>
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<td>Reading: Ch. 2.1-2.3; data representation notes; Ch. 2.5</td>
<td>Reading: Ch. 2.5, 2.6, 2.7</td>
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<td>Conditional operations Memory operands and the stack</td>
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<td>Functions HW 1 due; HW 2 assigned</td>
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<td>Reading: Ch. 2.3, 2.7, 2.9; Optional: 2.14</td>
<td>Reading: Ch. 2.8</td>
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<td>Processor implementation intro Project 1 due</td>
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<td>The datapath</td>
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<td>Reading: Ch. 4.1-4.2; Skim: 4.3</td>
<td>Reading: Ch. 4.3</td>
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<td>7</td>
<td>Oct 03–Oct 07</td>
<td>The control path HW 2 due</td>
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<td>8</td>
<td>Oct 10–Oct 14</td>
<td>Review of single-cycle implementation HW 3 assigned</td>
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<td>Pipelining intro</td>
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<td>Oct 17–Oct 21</td>
<td>Pipelined implementation Data hazards and forwarding</td>
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<td>Control hazards and branch prediction HW 3 due; HW 4 assigned</td>
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<td>Reading: Ch. 4.7</td>
<td>Reading: Ch. 4.8</td>
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<td>Processor implementation review Memory hierarchy intro</td>
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<td>Cache mapping schemes Project 2 assigned</td>
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<td>Reading: Ch. 5.1-5.2; pp. 412-416</td>
<td>Reading: Ch. 5.3</td>
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<td>Cache block sizing HW 4 due</td>
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<td>Cache write policies; review Project 2 statement of interest due; HW 5 assigned</td>
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<td>Virtual memory intro</td>
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<td>Reading: Write policy notes</td>
<td>Reading: Ch. 5.7; Virtual memory notes</td>
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<td>13</td>
<td>Nov 14–Nov 18</td>
<td>Virtual memory</td>
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<td>Memory hierarchy catchup</td>
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<td>Reading: Ch. 5.7</td>
<td>Reading: Ch. 5.8</td>
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<td>14</td>
<td>Nov 21–Nov 25</td>
<td>Reliability I/O: disks and flash</td>
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<td>Reading: Ch. 5.5; 5.2</td>
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<td>Nov 28–Dec 02</td>
<td>RAID HW 5 due; HW 6 assigned</td>
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<td>Parallelism: introduction and metrics</td>
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<tr>
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<td>Reading: Ch. 6.1-6.2</td>
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<td>16</td>
<td>Dec 05–Dec 09</td>
<td>Data-level parallelism and GPUs Thread-level parallelism Project 2 due</td>
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<td>Cache coherence HW 6 due</td>
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<td>Reading: Ch. 6.3, 6.6</td>
<td>Reading: Ch. 5.10</td>
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<td>Finals</td>
<td>Dec 12–Dec 16</td>
<td>EXAM 3</td>
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<td>Section 1: Monday 2:00 AM–3:50 PM, Darwin 29 Section 2: Monday 5:00 AM–6:50 PM, Ives 35</td>
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