CS 250: FOUNDATION OF COMPUTER SYSTEMS

[Introduction]

The Systems Arsenal
Looking to solve a problem?
   Let systems thinking come to the fore
Get to different vantage points
   And gain a holistic problem view
Know where you need to be
   Before you set off on your voyage

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Topics covered in this lecture

- Introduction
- Course overview and expectations
- Communications
Commonly argued that enlightened people of the twenty-first century ought to familiarize themselves with the key ideas underlying BANG

- Bits, Atoms, Neurons, and Genes (BANG)

Although science has been remarkably successful in uncovering their basic operating systems, it is quite possible that we will never fully grasp how atoms, neurons, and genes actually work

- A consoling exception?
  - Bits and computing systems at large
Gaining a gestalt understanding of how the machine works

- At least one field in this BANG quartet can be fully laid bare to human comprehension
- The interactions between hardware and software were simple and transparent enough to produce a coherent picture
- Alas, as digital technologies have become increasingly more complex, this clarity is all but lost
  - Hidden under many layers of obscure interfaces and proprietary implementations

Inevitable consequence of this complexity?

- Specialization
  - Pursuit of many niche courses, each covering a single aspect of the field
  - Many computer science students are missing the forest for the trees
    - Marshaled through a series of courses in programming, theory, and engineering
      - Without pausing to appreciate the beauty of the picture at large
  - We will strive to do this
    - Allowing you to view problems (and devise solutions) from multiple vantage points
About me

- I do research in this area
- My research has been funded by agencies in the United States and the United Kingdom
  - These include the National Science Foundation, the Department of Homeland Security (including the Long Range program), the Environmental Protection Agency, Department of Agriculture, National Institute of Food & Agriculture, and the U.K’s e-Science program
  - Recipient of the National Science Foundation’s CAREER Award
  - I direct the Center for eXascale Spatial Data Analytics and Computing (XSD) @ CSU [https://spatial.colostate.edu]
Areas that I have worked or actively work in include:

- Cloud computing and analytics
- Internet-of-Things (IoT)
- Big Data
- Content dissemination and streaming systems
- Grid computing
- P2P systems
- Object Request Brokers

My research has been deployed in

- Urban sustainability
- Epidemic modeling
- Agriculture
- Commercial internet conferencing systems
- Defense applications
- Earthquake sciences
- Environmental monitoring
- Healthcare informatics
- High energy physics
- Visualizations
COURSE LOGISTICS, EXPECTATIONS, AND SUCH

Course webpage

- All course materials will be on the course webpage http://www.cs.colostate.edu/~cs250
  - Schedule
  - Lectures
  - Assignments
  - Syllabus
- Grades will be posted on Canvas; assignment submissions will be via Canvas
- The course website, MS Teams Channel, and Canvas are all live now
Office Hours

- **Professor: Shrideep Pallickara**
  - Office Hours: 9:00 – 10:00 AM Friday (in CSB-364 and via Zoom)

- **TA: Office hours will be in CSB-120 and via MS Teams**
  - **Kassidy Barram** (Graduate Teaching Assistant)
    - Office Hours in CSB 120: 2:00-4:00 pm Monday and 5:00-7:00 pm Wednesday
  - **Zach Fuchs** (Undergraduate Teaching Assistant)
    - Office Hours in CSB 120: 3:00-5:00 pm Tuesday and 3:00-5:00 pm Thursday

- Please send all e-mails to: **compsci_cs455@colostate.edu**

Communications

- Please DO NOT use Canvas messages for communications
  - Please send communications to **compsci_cs250@colostate.edu**

- The e-mail account is checked by the entire team and allows us to respond to communications in a timely fashion

- Send e-mails from accounts that match your name
  - **No pseudonyms please**

- Do not post code on the MS Teams Channel
Recitations: Will be in the CS Building

- **Labs/Recitations** will be in CSB-325
  - R1: 3:00-3:50 pm on Wednesdays
  - R2: 4:00-4:50 pm on Wednesdays

- Recitations will be helpful to prepare you for the assignments
- Recitation grading is based on attendance and completion scores

Course textbook

- This class has three optional textbooks
When I make slides …

- I usually refer to, and build them, from several texts
  - And technical papers and articles (with URLs)
- I always list my references at the end of every slide set

Textbooks that I will refer to during the course include … (1/2)

Textbooks that I will refer to during the course include … (2/2)


On the Course schedule page
http://www.cs.colostate.edu/~cs250/schedule.html

- You will see the topics that will be covered and the order in which I will cover them
- The readings section will list the books (and the chapters therein) that form the basis for the materials
- You will also see the complete schedule for when the assignments are posted and when they are due
Infospaces (https://infospaces.cs.colostate.edu)

- New knowledge repository that we are building to enhance learning
- All videos are designed to be less than 2 minutes
- Improving Infospaces
  - Let us know what you would like to see
  - If you’d like to contribute to this repository let us know!

**Grading**
Grading breakdown

- Assignments: 30%
  - HW1: 7.5%; HW2: 7.5%; HW3: 7.5%, and HW4: 7.5%
- Recitations {attendance + completion}: 10%
- Quizzes (10 best): 10%
- Mid Term I: 15%
- Mid Term II: 15%
- Comprehensive final exam: 20%

Grading Policy [1/4]

- Letter grades will be based on the following standard breakpoints:
  - >= 90 is an A, >= 88 is an A-,
  - >= 86 is a B+, >=80 is a B, >=78 is a B-
  - >= 76 is a C+, >=70 is a C,
  - >= 60 is a D, and <60 is an F
- I will not cut higher than this, but I may cut lower.
Grading Policy [2/4]

- There will be no make-up exams or quizzes
  - On-campus section: All exams (including quizzes) are in-class, in-person
  - Online section (801): Canvas will be used to administer these
- On-campus students: If you need University SDC accommodations so that your mid-terms and final are administered at a University Testing Center
  - SDC needs to submit an official letter on your behalf
  - They will cc you on this note to me; so please ensure that this happens

Grading Policy [3/4]

- Every assignment will be posted at least 2 weeks before the due date.
- Every assignment will include information about:
  - How much it will count towards the course grade
  - How it will be graded
- Late submission penalty: 7.5% per-day for the first 2 days
  - Submissions after the late submission period will have an automatic ZERO
  - If you submit the wrong files? 30% deduction
  - Detailed submission instructions posted on the course website.
  - Assignments will be graded within 1 week of submission
Grading Policy

- If you have problems with the grading
  - Talk to the TAs first
  - Complaints must be lodged via an e-mail to compsci_cs250@colostate.edu within 10 days of the grade being posted on Canvas
    - Briefly describe why you feel aggrieved
- The GTA and UTA will strive to ensure that the grading is consistent across the board

Quizzes, mid term, and final

- I will only ask questions about what I teach
  - If I didn’t teach it, I won’t ask from that portion
- If the concepts were covered in my slides
  - You should be be able to answer the questions
Quizzes

- There will be 12-13 quizzes
- We will take your 10 highest scores
- If you have an interview or need to miss class for some reason, you do not need to let me know and there will be NO makeup for quizzes (please don’t ask to do this!)

ASSIGNMENTS
Assignments will target the following elements...

- Number representations and computing
- Memory
- Networking
- Storage systems

Assignments: Logistics

- Assignments will be due at 5:00 pm MT on Tuesdays
- You are allowed to submit up to 2 days late
  - There is a 7.5% deduction for each day that you are late
- All assignments are individual assignments
- Assignments should be submitted via Canvas
Expectations

- You will attend all classes
- You will focus on the discussions, and not on ...
  - Other assignments
  - Social networking updates
- Assignments have to be done **individually**

**WHAT IT TAKES TO SUCCEED**
What it takes to succeed

[1/3]

- You are required to work at least **12 hours** per-week outside of class
  - Coding and reviewing material from class

- If you miss a lecture
  - Add about 3 hours per missed lecture

What it takes to succeed

[2/3]

- Work on the assignments **every day**
  - There is no such thing as waiting for inspiration to strike!

- **Reflect** about how you could have done things differently for better performance
  - Even after you have submitted an assignment
  - It will improve the choices you make in the next assignment
What it takes to succeed

- Work in bigger-sized chunks
  - Too many short bursts = Too many context switches
  - You will be busy doing nothing
- Document your code

How to fail this course?

- Believing that you can learn via osmosis
- Missing lectures
  - If you don’t have the discipline to show up, you will most likely not have the discipline to catch up
- Procrastinating
  - The assignments cannot be done in a week
  - Organize your schedule so that you can succeed
- Not attacking the problem and working on the fringes
  - Spend your time wisely on critical paths
Use of laptops, cell phones, tablets, and other electronic devices

- If you must use a laptop or tablet you will have to
  - Turn off wireless
  - And use it only for taking notes
- Authorized laptop/tablet users
  - Pledge forms on table
  - Will sit in the back row starting at the corners
- When the class is in session, put away your cell-phones!

Why attend lectures if all the slides are posted?

- Slides are only part of the story
  - They anchor the discussion
- Any field has a **language** associated with it
- People who have worked in an area for a long time speak the language
  - Sitting in classes helps you learn how to frame questions and responses
- Often there are surprising questions
  - Some of these may be asked by interviewers
Lecture recordings are **ONLY** for distance students

- The on-campus course is the on-campus course
  - Who wants to lecture in an empty room!
- Students in the on-campus section will not be given the recording links
  - So please don’t ask even if you have an interview
- Distance students should not post (or share) the Echo360 links or videos of the recorded lectures on any forum

An incentive to attend in-class sessions

- Pop quizzes (in-class)
- We will have **extra credit** (up to an extra 2% towards your cumulative course grade) based on attendance
  - Note: this incentive is only for lectures and not recitations
- You will be marked present ONLY if you have not been more than 5 minutes late and do not leave class more than 5 minutes early
- For the remainder of the semester:
  - If you attend &ge; 60% of the lectures you will have a +1
  - If you attend &ge; 70% of the lectures you will have a +1.5
  - If you attend &ge; 80% of the lectures you will have a +2
Late arrivals and quizzes

- Tardiness is not professional behavior
- Late arrivals will be penalized
- 20% deduction on the quiz score for every 15-minute increment that you are late
  - E.g., $30 <\text{tardy} < 45 \Rightarrow 40\%$ deduction
  - There will be no negative scores ... scores will bottom out at zero

Emergencies

- We will account for personal emergencies (please write)
- University regulations regulation require that students submit documentation
- Video lectures will be made available to the impacted student
  - Attendance requirements will be calibrated to exclude dates encompassing the emergency
  - Please do not redistribute the lecture videos or post them
Help me help you

- We will have surveys at the end of every class
- You will provide a list of
  - 3 concepts you followed clearly
  - 3 concepts you had problems keeping up with
- Problem areas for the majority of the class will be addressed in the next class

Interactions

- You can have discussions with me, the TAs, and your peers
- There are two constraints to these discussions
  1. No code can be exchanged under any circumstances
  2. No one takes over someone else’s keyboard
- Bumps are to be expected along the way
  - But you should get over this yourself
  - It will help you with the next problem you encounter
Fairy tales are more than true: not because they tell us that dragons exist, but because they tell us that dragons can be beaten.

G.K. Chesterton by way of Neil Gaiman, Coraline

**Topics covered in CS250**

**Part I: The von Neumann Architecture**
The von Neumann Architecture

- Processors, cores and hyperthreading
  - Mapping threads to execution pipelines
- Number representations
  - Boolean Algebra, Boolean Logic
- Memory hierarchy and its impact on performance
  - Cache organization: L1, L2 and L3 caches
  - Main Memory: CPU RAM

CPU meet the GPU (TPU, etc.)

- GPU: Design, operations, and concurrency
- The right tool for the right job
  - How the GPU waxed while the CPU waned
  - GPU Limitations: general purpose computations and memory management
PART II
NETWORKED
COMPUTER SYSTEMS

Networking

- IPv4 and IPv6
  - Encapsulation, packet header formats, fragmentation, and extension headers
- TCP
  - Sliding window, buffering, reliable and ordered delivery
- BGP
- DNS
PART III: STORAGE SYSTEMS

Storage Systems

- File systems and databases
  - File control blocks and indexing schemes
- Pitfalls of using in-memory data structures for storage systems
- B-tree and variants
Large scale computing systems

- Characterizing compute-bound and I/O bound workloads
- Parallel computing and distributed systems
  - Key architectural design considerations
Future Computing Systems

- The von Neumann bottleneck
- Where to from here?
CONNECTIONS TO 300-LEVEL COURSES

CS280A1/CS250: Downstream analysis and impact

- **CS314: Software Engineering**
  - Holistic view of software development with diverse processors, memory hierarchy, networks, and storage

- **CS320: Algorithms Theory & Practice**
  - Benefit from seeing another perspective on complexity besides time

- **CS335: Data Mining at Scale**
  - Benefit from the connections between computing, networking, storage, and scalable systems

- **CS345: Machine Learning Foundations and Practice**
  - Understanding of co-processors and scalable systems

- **CS356: Systems Security**
  - Build on knowledge of basic networking concepts and memory buffers

- **CS370: Operating Systems**
  - Benefit from the von Neumann architecture and basic storage systems concepts
What about CS270?

- CS280A1/CS250 is meant to be a drop-in replacement for CS270 in the Computer Science prerequisite chain.

- CS270 Core areas
  - C, LC3, and assembly language
Algorithm

- Sequence of steps to accomplish desired objectives
  - E.g., sorting numbers, factorizing numbers, processing graphs, etc

- Humans can carry out algorithms, but we are much slower than machines
  - Modern computers are a trillion times faster!

Computations and computers

- Computations are complex series of numerical calculations

- Computers are agents that carry out operations within a computation
A (Very) Brief History of Computers

- Napier invented the logarithm, which became the principle of the slide rule (invented circa 1620)
  - Could not add or subtract

- Blaise Pascal designed and built an arithmetic machine in 1642 to add and subtract
A Brief History of Computers: Part II

- In 1819, Babbage designed a machine of gears, shafts, and wheels that could calculate tables of arithmetic numbers such as logarithms.

- 1890 US census, Hollerith's punched card machines tabulated large amounts of data.
  - Jacquard’s loom (1801) was the first place where punched cards were used.

Modern computer systems design

- Has it origins dating back to 1947 as part of work on ENIAC.

- Breaks up a computing machine into three main subsystems:
  - The central processing unit (CPU) for performing arithmetic operations.
  - The memory for storage of instructions and data.
  - The input-output (I/O) unit for communicating with the external world.

- This way of organizing a machine became known as the “von Neumann architecture.”
Modern computers: The secret sauce?

- At its core modern computers harnesses the **movement of electrons** in circuits to carry out computations
- Computer circuits deal only with voltages, currents, switches, and malleable materials
  - Internally the computer does not process numbers and symbols

No information without representation

- To be processable, data must be represented as
  - Signals in the machine or
  - As measurable disturbances in the structure of storage media
Computations & Complexity

Computation complexity

- Measured in terms of time, space, and (increasingly energy)
- Impacts responsiveness and how you can scale
- Other implications
  - Cryptocurrency: Systems like Bitcoin, where the currency represents a solution to a problem and reflects the amount of computational work that needs to (and has been) performed
Perils of wishful thinking

- Most common wish is that we can get computers to do any job we can conceive of.
- Many jobs are impossible for computers.
  - No algorithm that will inspect another algorithm and tell us whether it terminates or loops forever.
  - It was logically impossible in 1936 when Alan Turing proved it so, and it is still impossible today.

A problem for you to solve

- UPS truck driver must deliver packages to 10 cities.
  - Wants to travel the least distance, but visit each city exactly once.
Perils of wishful thinking

- Even if we stick to logically possible jobs, there are many that cannot be done in a reasonable time — they are **intractable**

- Example: Shortest tour of a set of cities that visits each city just once
  - The simplest way to find the shortest tour is to enumerate all possible tours and select the shortest

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Intractability and Heuristics

- For a small set of 100 cities, this would take $10^{130}$ years on the world’s fastest supercomputer
  - The age of the universe is $10^{10}$ years
  - Even the “simplest way” can be impossible!

- The picture gets even more confusing because in most cases there are fast algorithms to find an **approximate** answer
  - They are called **heuristics**
Wishful thinking is also when you believe the computer is smart

- If you are not precise in translating the algorithm into program steps, your computation will contain errors
- The computer amplifies your intelligence but has none of its own!

The contents of this slide-set are based on the following references