
WELCOME
TO
15-213
14-513
18-213
18-613
15-513

Course Overview

18-213/18-613: Computer Systems

1st Lecture, Spring 2023

Overview

- Introductions
- Big Picture
  - Course theme
  - Five realities
  - How the course fits into the CS/ECE/INI curriculum
- Academic integrity
- Logistics and Policies

Instructors

Swarun Kumar

18-213

Greg Kesden

18-613

Lectures & course content coordinated with
15-213, 14-513 & 15-513 teams

The Big Picture

Course Theme: (Systems) Knowledge is Power!

- **Systems Knowledge**
  - How hardware (processors, memories, disk drives, network infrastructure) plus software (operating systems, compilers, libraries, network protocols) combine to support the execution of application programs
  - How you as a programmer can best use these resources
- **Useful outcomes from taking 213/613**
  - Become more effective programmers
    - Able to find and eliminate bugs efficiently
    - Able to understand and tune for program performance
  - Prepare for later “systems” classes across departments ...
    - Compilers, Operating Systems, Networks, Computer Architecture, Embedded Systems, Storage Systems, Computer Security, etc.

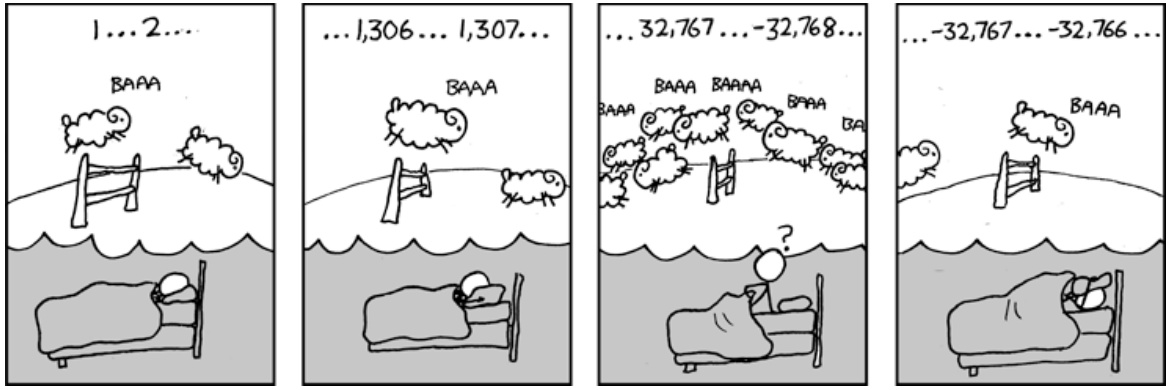
It's Important to Understand How Things Work

- **Why do I need to know this stuff?**
  - Abstraction is good, but don't forget reality
- **Most CS courses emphasize abstraction**
  - **(CE courses less so)**
  - Abstract data types
  - Asymptotic analysis
- **These abstractions have limits**
  - Especially in the presence of bugs
  - Need to understand details of underlying implementations
  - Sometimes the abstract interfaces don't provide the level of control or performance you need

Great Reality #1:

Ints are not Integers, Floats are not Reals

- **Example 1: Is $x^2 \geq 0$?**
  - Float's: Yes!
  - Int's:
    - 40000 * 40000 --> 1600000000
    - 50000 * 50000 --> ?



- **Example 2: Is (x + y) + z = x + (y + z)?**
  - Unsigned & Signed Int's: Yes!
  - Float's:
    - (1e20 + -1e20) + 3.14 --> 3.14
    - 1e20 + (-1e20 + 3.14) --> ??

Source: xkcd.com/571

Computer Arithmetic

- **Does not generate random values**
  - Arithmetic operations have important mathematical properties
- **Cannot assume all "usual" mathematical properties**
  - Due to finiteness of representations
  - Integer operations satisfy "ring" properties
    - Commutativity, associativity, distributivity
  - Floating point operations satisfy "ordering" properties
    - Monotonicity, values of signs
- **Observation**
  - Need to understand which abstractions apply in which contexts
  - Important issues for compiler writers and serious application programmers

Great Reality #2:
You've Got to Know Assembly

- **Chances are, you'll never write programs in assembly**
  - Compilers are much better & more patient than you are
- **But: Understanding assembly is key to machine-level execution model**
  - Behavior of programs in presence of bugs
    - High-level language models break down
  - Tuning program performance
    - Understand optimizations done / not done by the compiler
    - Understanding sources of program inefficiency
  - Implementing system software
    - Compiler has machine code as target
    - Operating systems must manage process state
  - Creating / fighting malware
    - x86 assembly is the language of choice!

Great Reality #3: Memory Matters

Random Access Memory Is an Unphysical Abstraction

- **Memory is not unbounded**
  - It must be allocated and managed
  - Many applications are memory dominated
- **Memory referencing bugs especially pernicious**
  - Effects are distant in both time and space
- **Memory performance is not uniform**
  - Cache and virtual memory effects can greatly affect program performance
  - Adapting program to characteristics of memory system can lead to major speed improvements

Memory Referencing Bug Example

```
typedef struct {
  int a[2];
  double d;
} struct_t;

double fun(int i) {
  volatile struct_t s;
  s.d = 3.14;
  s.a[i] = 1073741824; /* Possibly out of bounds */
  return s.d;
}
```

```
fun(0) -->     3.14
fun(1) -->     3.14
fun(2) -->     3.1399998664856
fun(3) -->     2.00000061035156
fun(4) -->     3.14
fun(5) -->     Segmentation fault
```

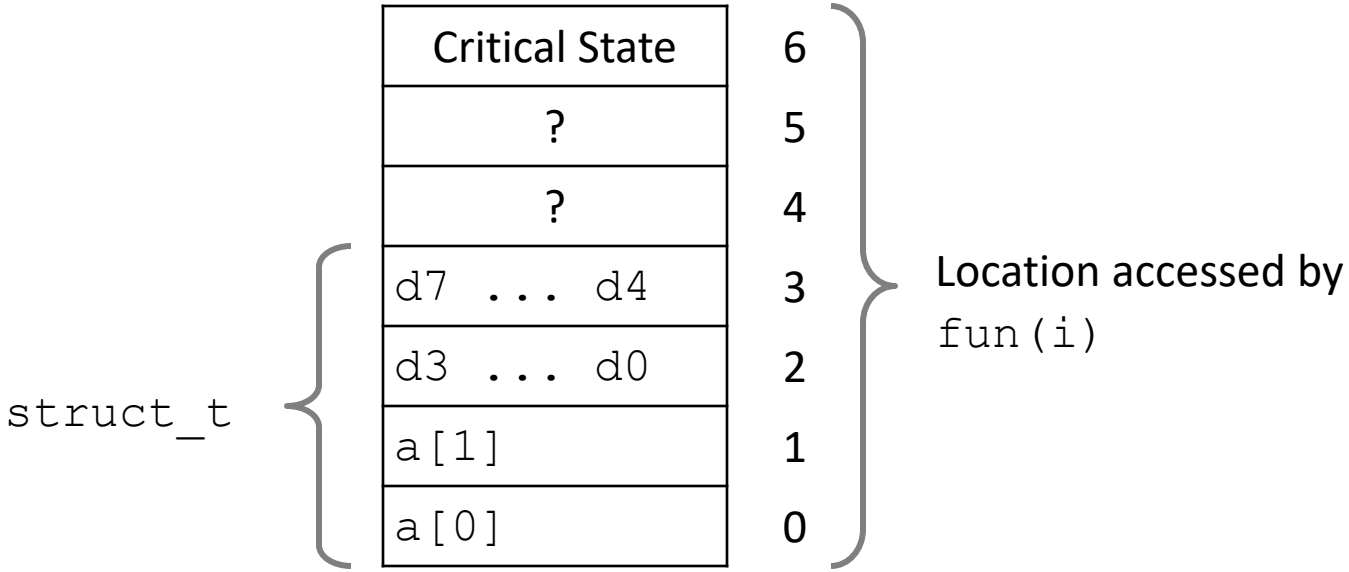
- Result is system specific

Memory Referencing Bug Example

```
typedef struct {
  int a[2];
  double d;
} struct_t;
```

```
fun(0) -->     3.14
fun(1) -->     3.14
fun(2) -->     3.1399998664856
fun(3) -->     2.00000061035156
fun(4) -->     3.14
fun(6) -->     Segmentation fault
```

Explanation:



Memory Referencing Errors

- **C and C++ do not provide any memory protection**
  - Out of bounds array references
  - Invalid pointer values
  - Abuses of malloc/free
- **Can lead to nasty bugs**
  - Whether or not bug has any effect depends on system and compiler
  - Action at a distance
    - Corrupted object logically unrelated to one being accessed
    - Effect of bug may be first observed long after it is generated
- **How can I deal with this?**
  - Program in Java, Ruby, Python, ML, …
  - Understand what possible interactions may occur
  - Use or develop tools to detect referencing errors (e.g. Valgrind)

Great Reality #4: There's more to performance than asymptotic complexity

- **Constant factors matter too!**
- **And even exact op count does not predict performance**
  - Easily see 10:1 performance range depending on how code written
  - Must optimize at multiple levels: algorithm, data representations, procedures, and loops
- **Must understand system to optimize performance**
  - How programs compiled and executed
  - How to measure program performance and identify bottlenecks
  - How to improve performance without destroying code modularity and generality

Memory System Performance Example

```
void copyij(int src[2048][2048],
            int dst[2048][2048])
{
  int i,j;
  for (i = 0; i < 2048; i++)
    for (j = 0; j < 2048; j++)
      dst[i][j] = src[i][j];
}
```

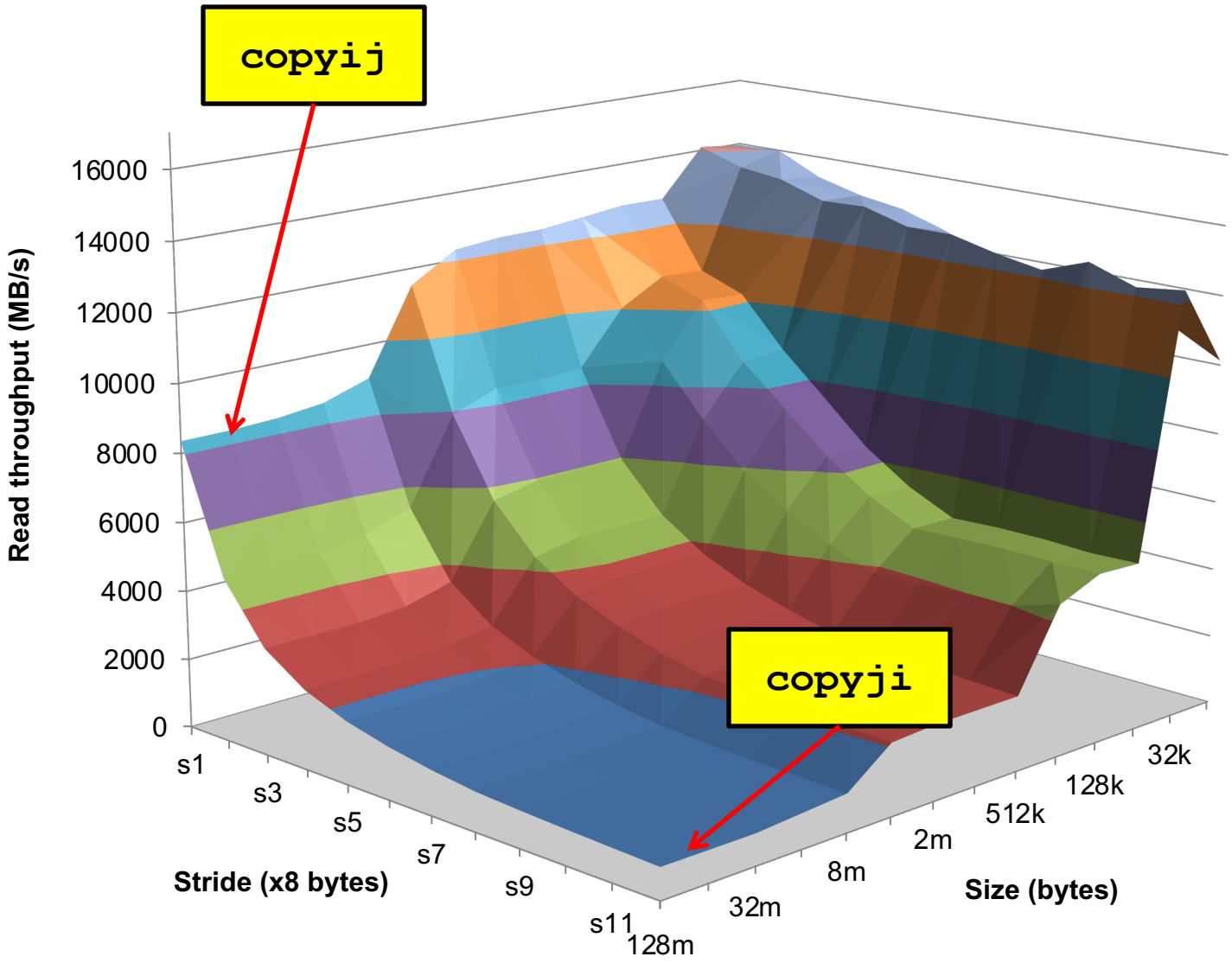
```
void copyji(int src[2048][2048],
            int dst[2048][2048])
{
  int i,j;
  for (j = 0; j < 2048; j++)
    for (i = 0; i < 2048; i++)
      dst[i][j] = src[i][j];
}
```

4.3ms 81.8ms

2.0 GHz Intel Core i7 Haswell

- Hierarchical memory organization
- Performance depends on access patterns
  - Including how step through multi-dimensional array

Why The Performance Differs



Great Reality #5:
Computers do more than execute programs

- **They need to get data in and out**
  - I/O system critical to program reliability and performance

- **They communicate with each other over networks**
  - Many system-level issues arise in presence of network
    - Concurrent operations by autonomous processes
    - Coping with unreliable media
    - Cross platform compatibility
    - Complex performance issues

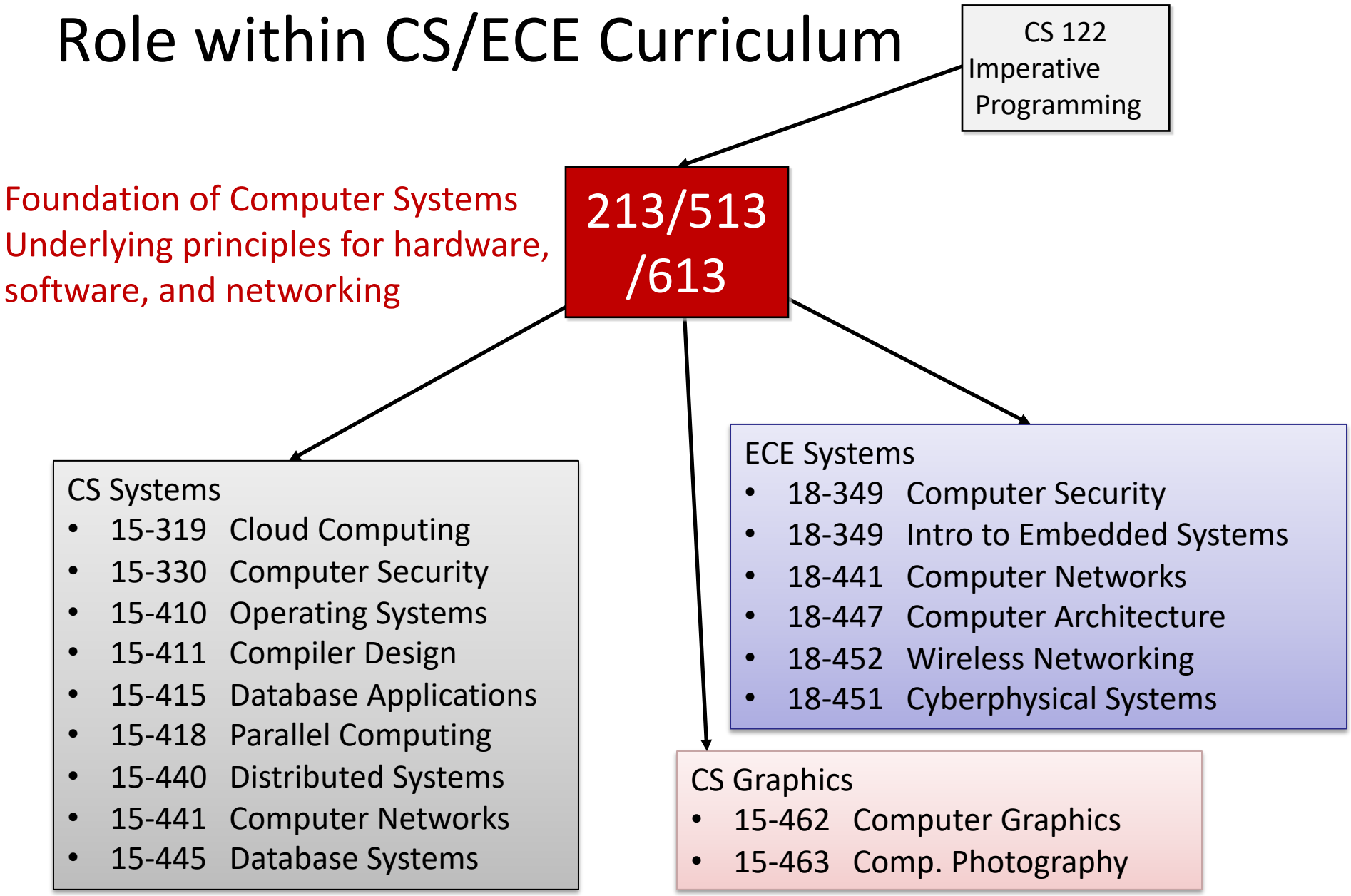
Course Perspective

- **Most Systems Courses are Builder-Centric**
  - Computer Architecture
    - Design pipelined processor in Verilog
  - Operating Systems
    - Implement sample portions of operating system
  - Compilers
    - Write compiler for simple language
  - Networking
    - Implement and simulate network protocols

Course Perspective (Cont.)

- **Our Course is Programmer-Centric**
  - By knowing more about the underlying system, you can be more effective as a programmer
  - Enable you to
    - Write programs that are more reliable and efficient
    - Incorporate features that require hooks into OS
      - E.g., concurrency, signal handlers
  - Cover material in this course that you won't see elsewhere
  - Not just a course for dedicated hackers
    - **We bring out the hidden hacker in everyone!**

Role within CS/ECE Curriculum



Academic Integrity

Please pay close attention, especially if this is your first semester at CMU

Carefully review policy:

http://www.cs.cmu.edu/~18213/academicintegrity.html

Cheating/Plagiarism: Description

- Unauthorized use of information
  - Borrowing code: by copying, retyping, **looking at** a file
  - Describing: verbal description of code from one person to another.
  - Searching the Web for solutions
  - Copying code from a previous course or online solution
  - Reusing your code from a previous semester (here or elsewhere)
    - Arrange meeting with instructor before reusing your old solutions

Cheating/Plagiarism: Description (cont.)

- Unauthorized supplying of information
  - Providing copy: Giving a copy of a file to someone
  - Providing access:
    - Putting material in unprotected directory
    - Putting material in unprotected code repository (e.g., Github)
      - Or, letting protections expire
  - Applies to this term and the future
    - There is no statute of limitations for academic integrity violations
- Collaborations beyond high-level, strategic advice
  - Anything more than block diagram or a few words
  - Code / pseudo-code is NOT high level
  - Coaching, arranging blocks of allowed code is NOT high level
  - Code-level debugging is NOT high level

Cheating/Plagiarism: Description

- What is NOT cheating?
  - Explaining how to use systems or tools
  - Helping others with *high-level* design issues
    - High means very high
  - Using code supplied by us
    - Starter code, class examples
  - Using code from the CS:APP web site
- Attribution Requirements
  - Starter code: No
  - Other allowed code (course, CS:APP): Yes
  - Indicate source, beginning and end

Cheating: Consequences

- Penalty for cheating:
  - Best case: -100% for assignment
    - You would be better off to turn in nothing
  - Worst case: Removal from course with failing grade
    - This is the default
  - Permanent mark on your record
  - Loss of respect by you, the instructors and your colleagues
  - If you do cheat – come clean asap!

- Detection of cheating:
  - We have sophisticated tools for detecting code plagiarism
  - In Fall 2015, 20 students were caught cheating and failed the course.
    - Some were **expelled** from the University
  - In January 2016, 11 students were penalized for cheating violations that occurred as far back as Spring 2014.
  - In May 2019, we gave an AIV to a student who took the course in Fall 2018 for unauthorized coaching of a Spring 2019 student. His grade was changed retroactively.

- Don't do it!
  - Manage your time carefully
  - Ask the staff for help when you get stuck

Some Concrete Examples:

- This is Cheating:
  - Searching the internet with the phrase 15-213, 15213, 213, 18213, malloclab, etc.
    - That's right, just entering it in a search engine
  - Looking at someone's code on the computer next to yours
  - Giving your code to someone else, now or in the future
  - Posting your code in a publicly accessible place on the Internet, now or in the future
  - Hacking the course infrastructure
- This is OK (and encouraged):
  - Googling a man page for fputs
  - Asking a friend for help with gdb (but not with your code)
  - Asking a TA or course instructor for help, showing them your code, …
  - Using code examples from book (with attribution)
  - Talking about a (high-level) approach to the lab with a classmate

How it Feels: Student and Instructor

- Fred is desperate. He can't get his code to work and the deadline is drawing near. In panic and frustration, he searches the web and finds a solution posted by a student at U. Oklahoma on Github. He carefully strips out the comments and inserts his own. He changes the names of the variables and functions. Phew! Got it done!
- The course staff run checking tools that compare all submitted solutions to the solutions from this and other semesters, along with ones that are on the Web.
  - Remember: We are as good at web searching as you are
- Meanwhile, Fred has had an uneasy feeling: Will I get away with it? Why does my conscience bother me?
- Fred gets email from an instructor: "Please see me tomorrow at 9:30 am."
  - Fred does not sleep well that night

How it Feels: Student and Instructor (cont.)

- The instructor feels frustrated. His job is to help students learn, not to be police. Every hour he spends looking at code for cheating is time that he cannot spend providing help to students. But, these cases can't be overlooked
- At the meeting:
  - Instructor: "Explain why your code looks so much like the code on Github."
  - Fred: "Gee, I don't know. I guess all solutions look pretty much alike."
  - Instructor: "I don't believe you. I am going to file an academic integrity violation."
    - Fred will have the right to appeal, but the instructor does not need him to admit his guilt in order to penalize him.
- Consequences
  - Fred may (most likely) will be given a failing grade for the course
  - Fred will be reported to the university
  - A second AIV will lead to a disciplinary hearing
  - Fred will go through the rest of his life carrying a burden of shame
  - The instructor will experience a combination of betrayal and distress

Why It's a Big Deal

- This material is best learned by doing
  - Even though that can, at times, be difficult and frustrating
  - Starting with a copy of a program and then tweaking it is very different from writing from scratch
    - Planning, designing, organizing a program are important skills
- We are the gateway to other system courses
  - Want to make sure everyone completing the course has mastered the material
- Industry appreciates the value of this course
  - We want to make sure anyone claiming to have taken the course is prepared for the real world
- Working in teams and collaboration is an important skill
  - But only if team members have solid foundations
  - This course is about foundations, not teamwork

Version Control: Your Good Friend

- We will be using Github Education
  - Assignment distribution
  - Your workspace
    - Use your course account, rather than a personal Github account
- Use as you should a version server
  - Commit early and often
  - Document your commits
  - Missing GIT history can count against you
- How we use it
  - If we suspect academic integrity issues, we can see if commit history looks reasonable.
    - Steady, consistent, and sustained work
    - It can serve as your character witness

How to Avoid AIVs

- Start early
- Don’t rely on marathon programming sessions
  - Your brain works better in small bursts of activity
  - Ideas / solutions will come to mind while you’re doing other things
- Plan for stumbling blocks
  - Assignment is harder than you expected
  - Code doesn’t work
  - Bugs hard to track down
  - Life gets in the way
    - Minor health issues
    - Unanticipated events

Logistics

15-213, 14-513, 15-513, 18-213, 18-613

- 15-213
  - CS Undergraduates and other Undergraduates
- 14-513
  - INI Masters students
- 15-513
  - CS Masters and other Masters students

15-cohort
(for TAs, office hours, etc)

- **18-213**
  - **ECE Undergraduates**
  - **In-class lectures in DH A302**
- **18-613**
  - **ECE Masters students**
  - **In-class lectures in HOA 160 / B23 110**

18-cohort
(for TAs, office hours, etc)

- **Same material & labs for all the courses**
- **Only go to 18-cohort TAs and OHs**

Textbooks

- Randal E. Bryant and David R. O'Hallaron,
  - *Computer Systems: A Programmer's Perspective*, **Third Edition** (CS:APP3e), Pearson, 2016
  - http://csapp.cs.cmu.edu
  - This book really matters for the course!
    - How to solve labs
    - Practice problems typical of exam problems
  - Electronic editions available (*Don't get paperback version*!)
  - On reserve in Sorrells Library
- Brian Kernighan and Dennis Ritchie,
  - *The C Programming Language*, Second Edition, Prentice Hall, 1988
  - Still the best book about C, from the originators
  - Even though it does not cover more recent extensions of C
  - On reserve in Sorrells Library

Course Components

- Lectures
  - Higher level concepts
  - In-class quizzes could tilt you to a higher grade if borderline
- Labs (8)
  - 1-2+ weeks each
  - Provide in-depth understanding of an aspect of systems
  - Programming and measurement
- Weekly Assignments (best 10 of 12)
  - Reinforce concepts
- Final Exam
  - Test your understanding of concepts & mathematical principles
  - Covers content from the whole semester
- Small student groups (weekly)

Programs and Data

- Topics
  - Bit operations, arithmetic, assembly language programs
  - Representation of C control and data structures
  - Includes aspects of architecture and compilers

- Labs
  - L0 (C programming Lab): Test/refresh your C programming abilities
  - L1 (datalab): Manipulating bits
  - L2 (bomblab): Defusing a binary bomb
  - L3 (attacklab): The basics of code injection attacks

The Memory Hierarchy

- Topics
  - Memory technology, memory hierarchy, caches, disks, locality
  - Includes aspects of architecture and OS

- Labs
  - L4 (cachelab): Building a cache simulator and optimizing for locality.
    - Learn how to exploit locality in your programs.

Virtual Memory

- Topics
  - Virtual memory, address translation, dynamic storage allocation
  - Includes aspects of architecture and OS

- Labs
  - L5 (malloclab): Writing your own malloc package
    - Get a real feel for systems-level programming

Exceptional Control Flow

- Topics
  - Hardware exceptions, processes, process control, Unix signals, nonlocal jumps
  - Includes aspects of compilers, OS, and architecture

- Labs
  - L6 (tshlab): Writing your own Unix shell.
    - A first introduction to concurrency

Networking, and Concurrency

- Topics
  - High level and low-level I/O, network programming
  - Internet services, Web servers
  - concurrency, concurrent server design, threads
  - I/O multiplexing with select
  - Includes aspects of networking, OS, and architecture

- Labs
  - L7 (proxylab): Writing your own Web proxy
    - Learn network programming and more about concurrency and synchronization.

Lab Rationale

- Each lab has a well-defined goal such as solving a puzzle or winning a contest
- Doing the lab should result in new skills and concepts
- We try to use competition in a fun and healthy way
  - Set a reasonable threshold for full credit
  - Post intermediate results (anonymized) on Autolab scoreboard for glory!

Policies: Lab

- Work groups
  - You must work **alone** on all lab assignments
  - Instructors and TAs are here to help!

- Handins
  - Labs due at 11:59pm ET
  - Electronic handins using **Autolab** (no exceptions!)

Timeliness

- Grace days
  - **5 grace days** for the semester
  - Limit of **0, 1, or 2 grace days** per lab used **automatically**
  - Covers scheduling crunch, out-of-town trips, illnesses, minor setbacks
- Lateness penalties
  - Once grace day(s) used up, get penalized **15% per day**
  - No handins later than **3 days after due date**
- Catastrophic events
  - Major illness, death in family, …
  - Formulate a plan (with your academic advisor) to get back on track
- Advice
  - Once you start running late, it's really hard to catch up
  - Try to save your grace days until the last few labs

Facilities

- Labs will use the Intel Computer Systems Cluster
  - A subset of the “shark machines”, e.g.
  - `linux> ssh angelshark.ics.cs.cmu.edu`

  - Total set: 21 servers donated by Intel for 213/513/613
    - 10 student machines (for student logins)
    - 1 head node (for instructor logins)
    - 10 grading machines (for autograding)
  - Each server: Intel Core i7: 8 Nehalem cores, 32 GB DRAM, RHEL 6.1
  - Rack-mounted in Gates machine room

  - Login using your Andrew ID and password

Autolab (https://autolab.andrew.cmu.edu)

- Labs are provided by the CMU Autolab system
  - Project page: http://autolab.andrew.cmu.edu
  - Developed by CMU faculty and students
  - Key ideas: Autograding and Scoreboards
    - **Autograding:** Providing you with instant feedback.
    - **Scoreboards:** Real-time, rank-ordered, and anonymous summary.
  - Used by over 3,000 students each semester
- With Autolab you can use your Web browser to:
  - Download the lab materials
  - Handin your code for autograding by the Autolab server
  - View the class scoreboard
  - View the complete history of your code handins, autograded results, instructor's evaluations, and gradebook.
  - View the TA annotations of your code for Style points.

Autolab accounts

- Students enrolled on Monday, August 29 have Autolab accounts
- You must be enrolled to get an account
  - Autolab is not tied into the Hub's rosters
  - If you add in, sign up with Google form (check on Piazza)
  - We will update the autolab accounts once a day, so check back in 24 hours.
- For those who are waiting to add in, the first lab (C Programming Lab) is available on the Schedule page of the course Web site.

Weekly Assignments

- 12 weekly assignments starting this week
- Released on Tuesdays, due 9 days later at 11:59 pm ET
  - Exception: Assignment #5/6 (released Mon 10/10, due Fri 10/14)
  - No grace days (15% penalty/day for up to 3 days)
  - Last turn-in date is 3 days after due date
- Released and collected on Canvas
  - Upload solutions & put final answers into a quiz
- Drop 2 lowest out of 12
  - Remaining 10 are each worth 2% of your grade
- Reinforce concepts
  - Typically, concepts from that week's lectures

Small Student Groups

- Replaces recitation
- Meet Mondays at scheduled time
  - Your TA may contact you to schedule an introductory zoom meeting to discuss lab-0
- Goal: Descale the course, making it more personal and personally supportive
  - Also taming office hours, which could get crazy at times in the past.
- Groups of 5 students + 1 TA facilitator
  - Meet for 1 hour each week (Mandatory)
  - Maintain a group chat (Slack, GroupMe, Hangouts, WeChat, whatever)
  - Try to develop a good social bond, like 5 friends going through class
    - And a TA who really knows you and how to support you
  - TAs have time reserved for helping their group members, hopefully reducing dependency upon global office hours

Policies: Grading

- Labs (50%): weighted according to effort
- Final Exam (25%)
- Written Assignments (20%): drop lowest 2 out of 12
- Small group participation (5%)
- Final grades based on a straight scale (90/80/70/60) with a small amount of curving
  - Only upward

Getting Help

- Class Web pages:

  http://www.cs.cmu.edu/~18213 for 18-213/18-613

  - Complete schedule of lectures, exams, and assignments
  - Copies of lectures, assignments, exams, solutions
  - FAQ
- Piazza
  - Best place for questions about assignments
  - We will fill the FAQ and Piazza with answers to common questions
  - Be careful about public posts: Remember the AIV policy
- Canvas
  - Recorded lectures
  - In-class quizzes
  - Written assignments

Getting Help

- Email
  - Send email to individual instructors or TAs only to schedule appointments
    - (Kesden is the exception, and you can feel free to email or call, he is sometimes hard to reach otherwise)
- TA Office Hours (starting today)
  - Sundays - Thursdays, 6-8pm ET, Ansys A050 or via Zoom
  - Sundays - Thursdays, 8-10pm ET, Zoom-Only
  - CMU SV Only: Tuesdays, 3:30pm PT - 6:00pm PT, B23:211
  - CMU SV Only: Wednesdays, 3:00pm PT - 5:30pm PT, B23:211
- Walk-in Tutoring
  - Details TBA. Will put information on class webpage.
- 1:1 Appointments
  - You can schedule 1:1 appointments with any of the teaching staff

Instructor Office Hours

- Swarun Kumar, CIC 4113,
  3:30-4:30 pm Tuesdays

- Greg Kesden, HH A205,
  https://www.cs.cmu.edu/~gkesden/schedule.html

Bootcamps

- Bootcamp #1
  - Linux & the Command Line
  - TBA
- Bootcamp #2
  - GCC & Build Automation (makefiles)
  - TBA
- Bootcamp #3
  - Debugging Fundamentals & GDB
  - TBA

- More bootcamps to be announced for specific labs later

Waitlist questions

- ECE Academic services (ece-asc@andrew.cmu.edu)

- Please don't contact the instructors with waitlist questions.

Welcome and Enjoy!