Course Overview

15-213 /18-213: Introduction to Computer Systems
1^{st} Lecture, Jan. 14, 2014

Instructors:

Seth Copen Goldstein, Anthony Rowe, Greg Kesden

The course that gives CMU its "Zip"!

Overview

- Course theme
- Five realities
- How the course fits into the CS/ECE curriculum
- Logistics

Course Theme:
Abstraction Is Good But Don't Forget Reality

- **Most CS and CE courses emphasize abstraction**
  - Abstract data types
  - Asymptotic analysis
- **These abstractions have limits**
  - Especially in the presence of bugs
  - Need to understand details of underlying implementations
- **Useful outcomes from taking 213**
  - Become more effective programmers
    - Able to find and eliminate bugs efficiently
    - Able to understand and tune for program performance
  - Prepare for later "systems" classes in CS & ECE
    - Compilers, Operating Systems, Networks, Computer Architecture, Embedded Systems, Storage Systems, etc.

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 → ??

Source: xkcd.com/571

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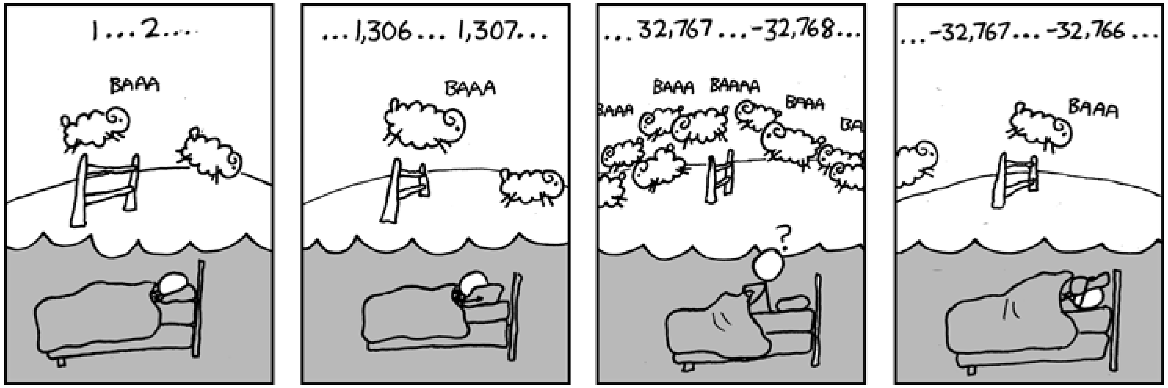

  - Int's:
    - 40000 * 40000 → 1600000000
    - 50000 * 50000 → ??

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

```
double fun(int i)
{
  volatile double d[1] = {3.14};
  volatile long int a[2];
  a[i] = 1073741824; /* Possibly out of bounds */
  return d[0];
}
```

```
fun(0)  →   3.14
fun(1)  →   3.14
fun(2)  →   5.30499e-315
fun(3)  →   3.14
fun(4)  →   segmentation fault
```

- **Result is architecture, compiler, and OS specific**

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```

Explanation:

Saved State	3
d[0]	2
a[1]	1
a[0]	0

Location accessed by `fun(i)`

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 or 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];
}
```

Same instructions, but different order → 21x slower! (Pentium 4)

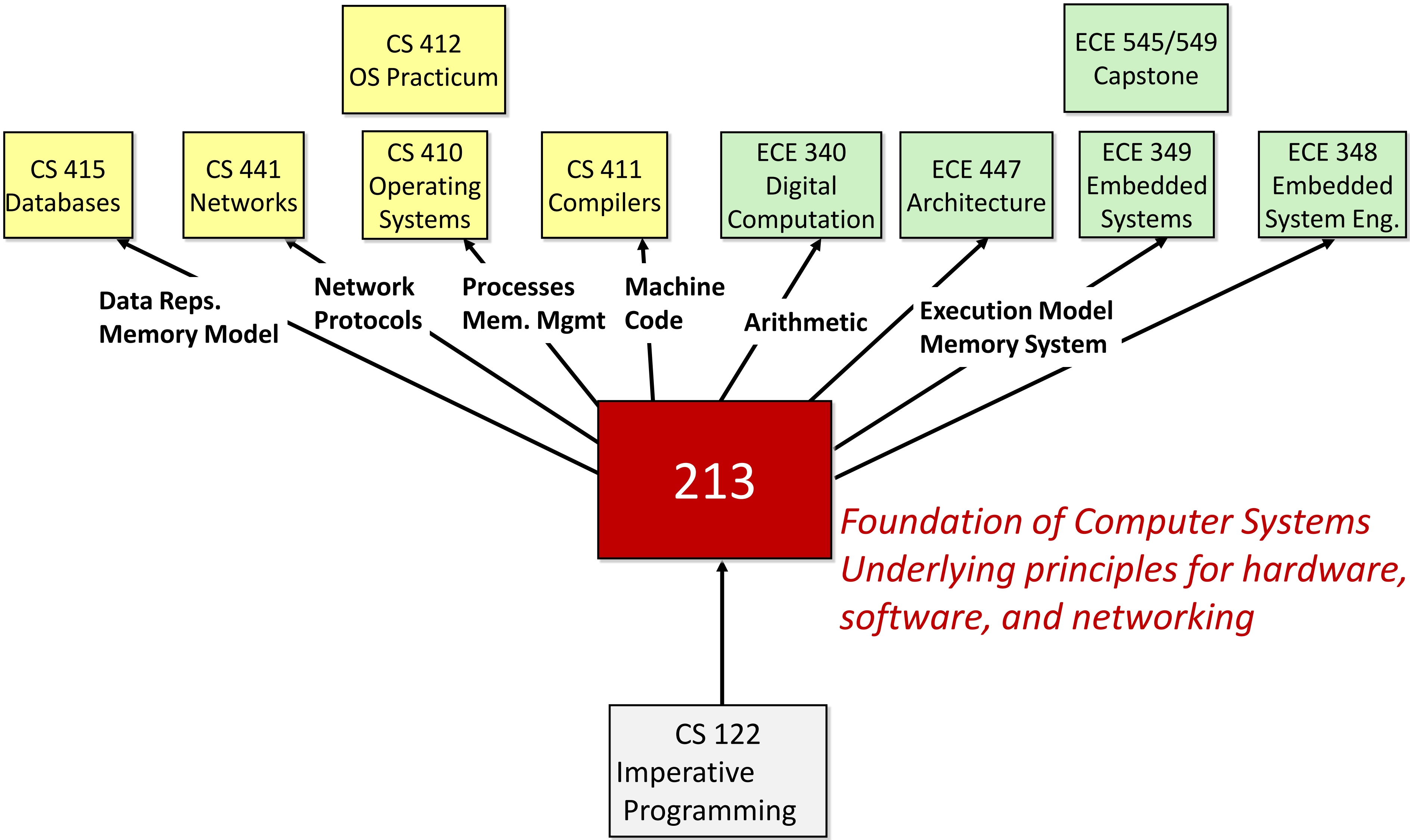
- **Hierarchical memory organization**
- **Performance depends on access patterns**
  - Including how step through multi-dimensional array

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

Role within CS/ECE Curriculum



Foundation of Computer Systems
Underlying principles for hardware, software, and networking

Course Perspective

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

Course Perspective (Cont.)

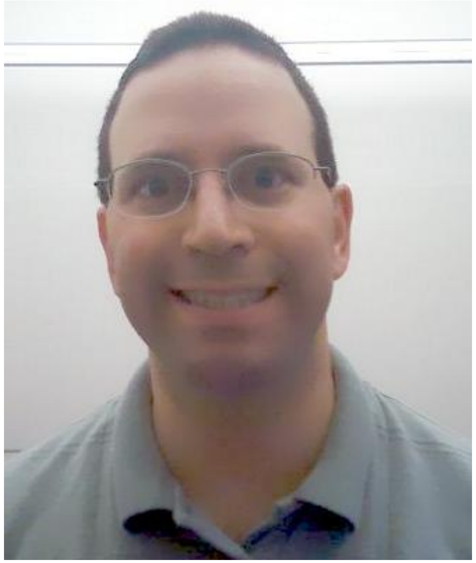
- **Our Course is Programmer-Centric**
  - Purpose is to show that by knowing more about the underlying system, one can be more effective as a programmer
  - Enable you to
    - Write programs that are more reliable and efficient
    - Incorporate features that require hooks into OS
      - E.g., concurrency, 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!**

Power Programmers

- **Manage the flow of data**
  - Inside the computer (memory hierarchy)
  - Between computers and devices (I/O)
- **Manage concurrency**
  - Inside the computer (multiple cores, threads, vectors, events, …)
  - Between computers (web servers, distributed apps, …)

Teaching staff

Seth Copen Goldstein



Greg Kesden

Anthony Rowe

Textbooks

- **Randal E. Bryant and David R. O'Hallaron,**
  - "Computer Systems: A Programmer's Perspective, Second Edition" (CS:APP2e), Prentice Hall, 2011
  - http://csapp.cs.cmu.edu
  - This book really matters for the course!
    - How to solve labs
    - Practice problems typical of exam problems

- **Brian Kernighan and Dennis Ritchie,**
  - "The C Programming Language, Second Edition", Prentice Hall, 1988

Course Components

- **Lectures**
  - Higher level concepts
- **Recitations**
  - Applied concepts, important tools and skills for labs, clarification of lectures, exam coverage
- **Labs (7)**
  - The heart of the course
  - 1-2 weeks each
  - Provide in-depth understanding of an aspect of systems
  - Programming and measurement
- **Exams (midterm + final)**
  - Test your understanding of concepts & mathematical principles
  - Online this semester

Getting Help

- **Class Web page: http://www.cs.cmu.edu/~213**
  - Complete schedule of lectures, exams, and assignments
  - Copies of lectures, assignments, exams, solutions
  - Clarifications to assignments

- **Blackboard**
  - We won’t be using Blackboard for the course

- **Piazza**
  - We won’t be using Piazza for this course

Getting Help

- **Staff mailing list: 15-213-staff@cs.cmu.edu**
  - Use this for all communication with the teaching staff
  - Always CC staff mailing list during email exchanges
  - Send email to individual instructors only to schedule appointments

- **Office hours (starting Sunday Jan 19th):**
  - SMTWR, 6:00-8:00pm, WeH 5207

- **1:1 Appointments**
  - You can schedule 1:1 appointments with any of the teaching staff

Policies: Assignments (Labs) And Exams

- **Work groups**
  - You must work alone on all assignments
- **Handins**
  - Assignments due at 11:59pm on Tues or Thurs evening (except L7, which is due on a Sunday)
  - Electronic handins using **Autolab** (no exceptions!)
- **Conflict exams, other irreducible conflicts**
  - OK, but must make PRIOR arrangements with Professors
  - Notifying us well ahead of time shows maturity and makes us like you more (and thus to work harder to help you out of *your* problem)
- **Appealing grades**
  - In **writing** within 7 days of completion of grading
  - Follow formal procedure described in syllabus

Facilities

- **Labs will use the Intel Computer Systems Cluster (aka "the shark machines")**
  - `linux> ssh shark.ics.cs.cmu.edu`

  - 21 servers donated by Intel for 213
    - 10 student machines (for student logins)
    - 1 head node (for Autolab server and instructor logins)
    - 10 grading machines (for autograding)
  - Each server: iCore 7: 8 Nehalem cores, 32 GB DRAM, RHEL 6.1
  - Rack mounted in Gates machine room
  - Login using your Andrew ID and password
- **Getting help with the cluster machines:**
  - Please direct questions to staff mailing list

Timeliness

- **Grace days**
  - **5 grace days for the course (none for L7)**
  - **Limit of 2 grace days per lab used automatically**
  - Covers scheduling crunch, out-of-town trips, illnesses, minor setbacks
  - Save them until late in the term!
- **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

Cheating

- **What is cheating?**
  - Sharing code: by copying, retyping, **looking at**, or supplying a file
  - Coaching: helping your friend to write a lab, line-by-line
  - Copying code from previous course or from elsewhere on WWW
    - Only allowed to use code we supply, or from CS:APP website
- **What is NOT cheating?**
  - Explaining how to use systems or tools
  - Helping others with high-level design issues
- **Penalty for cheating:**
  - Removal from course with failing grade
  - Permanent mark on your record
- **Detection of cheating:**
  - Our tools for doing this are much better than most cheaters think!
  - Last Fall, 12 students were caught cheating and failed the course.

Other Rules of the Lecture Hall

- **Laptops: permitted**
- **Electronic communications:** *forbidden*
  - No email, instant messaging, cell phone calls, etc
- **Presence in lectures, recitations: voluntary, recommended**
- **No recordings of ANY KIND**

Policies: Grading

- Exams (50%): midterm (20%), final (30%)
- Labs (50%): weighted according to effort
- Final grades based on a combination of straight scale and *possibly* a tiny amount of curving.

Programs and Data

- **Topics**
  - Bits operations, arithmetic, assembly language programs
  - Representation of C control and data structures
  - Includes aspects of architecture and compilers
- **Assignments**
  - L1 (datalab): Manipulating bits
  - L2 (bomblab): Defusing a binary bomb
  - L3 (buflab): Hacking a buffer bomb

The Memory Hierarchy

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

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

Exceptional Control Flow

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

- **Assignments**
  - L5 (tshlab): Writing your own Unix shell.
    - A first introduction to concurrency

Virtual Memory

- **Topics**
  - Virtual memory, address translation, dynamic storage allocation
  - Includes aspects of architecture and OS
- **Assignments**
  - L6 (malloclab): Writing your own malloc package
    - Get a real feel for systems-level programming

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

- **Assignments**
  - 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 Web page for glory!

autolab.cs.cmu.edu

- **Labs are provided by the CMU Autolab system**
  - Developed by CMU faculty and students
  - Key ideas: Autograding and Scoreboards
    - **Autograding**: Using VMs on-demand to evaluate untrusted code.
    - **Scoreboards**: Real-time, rank-ordered, and anonymous summary.
  - Used by 2,500+ students each semester, since Fall, 2010

- **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 result, instructor's evaluations, and gradebook.

Autolab accounts

- **Students enrolled as of 10am on Mon, Jan 14th have accounts**

- **You must be enrolled to get an account**
  - Autolab is not tied in to the Hub's rosters
  - If you add in, contact 15-213-staff@cs.cmu.edu for an account
  - Put "**waitlist add**" in the email subject

Waitlist questions

- **15-213: Catherine Fichtner (cathyf@cs.cmu.edu)**
- **18-213: Jennifer Loughran (jackson1@andrew.cmu.edu)**

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

Welcome
and Enjoy!