Course Overview

15-213: Introduction to Computer Systems
1st Lecture, Sep. 1, 2015

Instructors:

Randal E. Bryant and David R. O'Hallaron

The course that gives CMU its "Zip"!

Overview

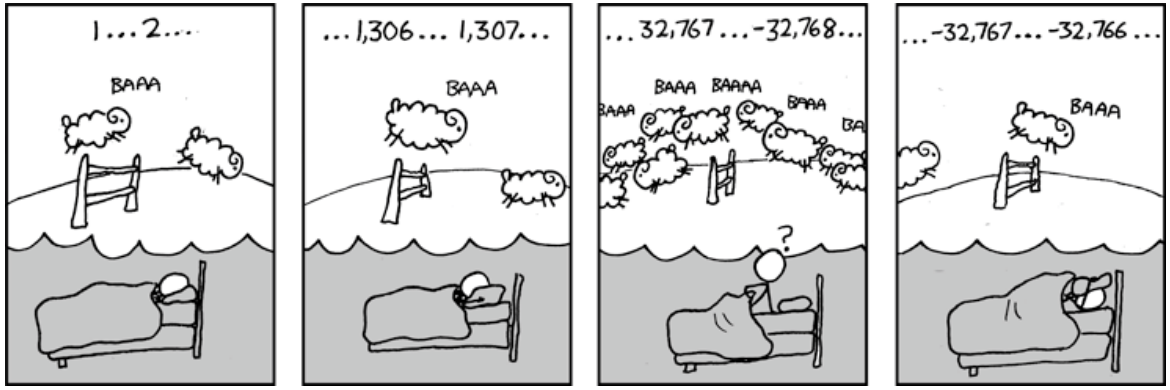
- Course theme
- Five realities
- How the course fits into the CS/ECE curriculum
- Academic integrity

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 --> ??



- **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(6)  ↝  Segmentation fault
```

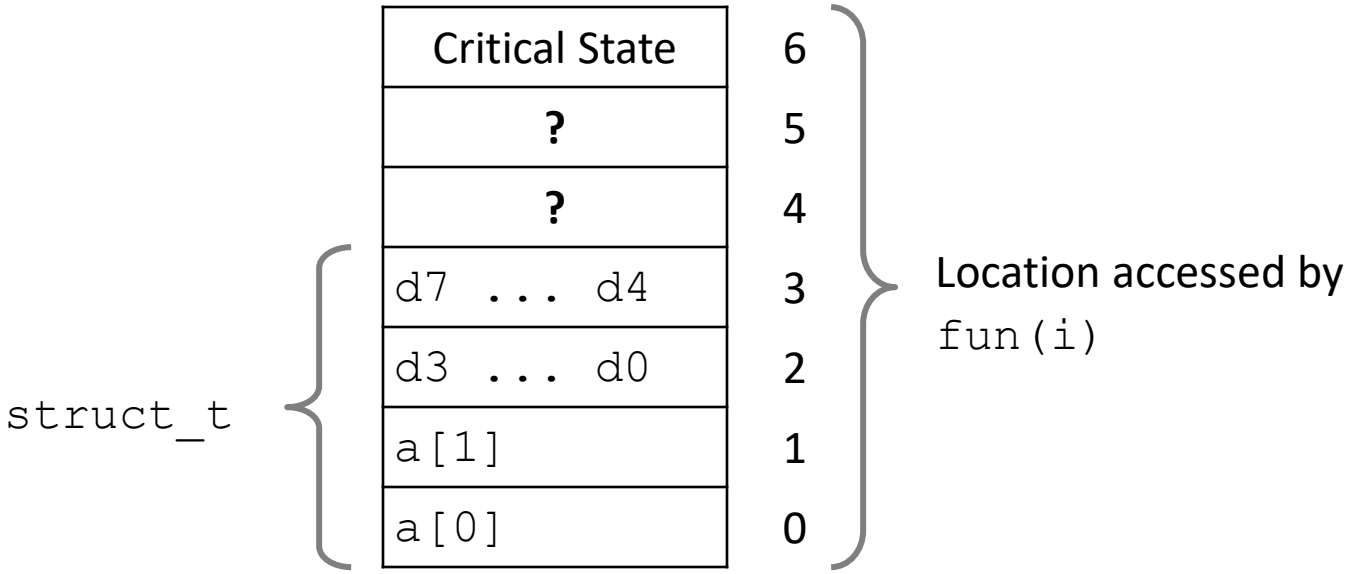
- Result is system specific

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)  ↝  2.0000061035156
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

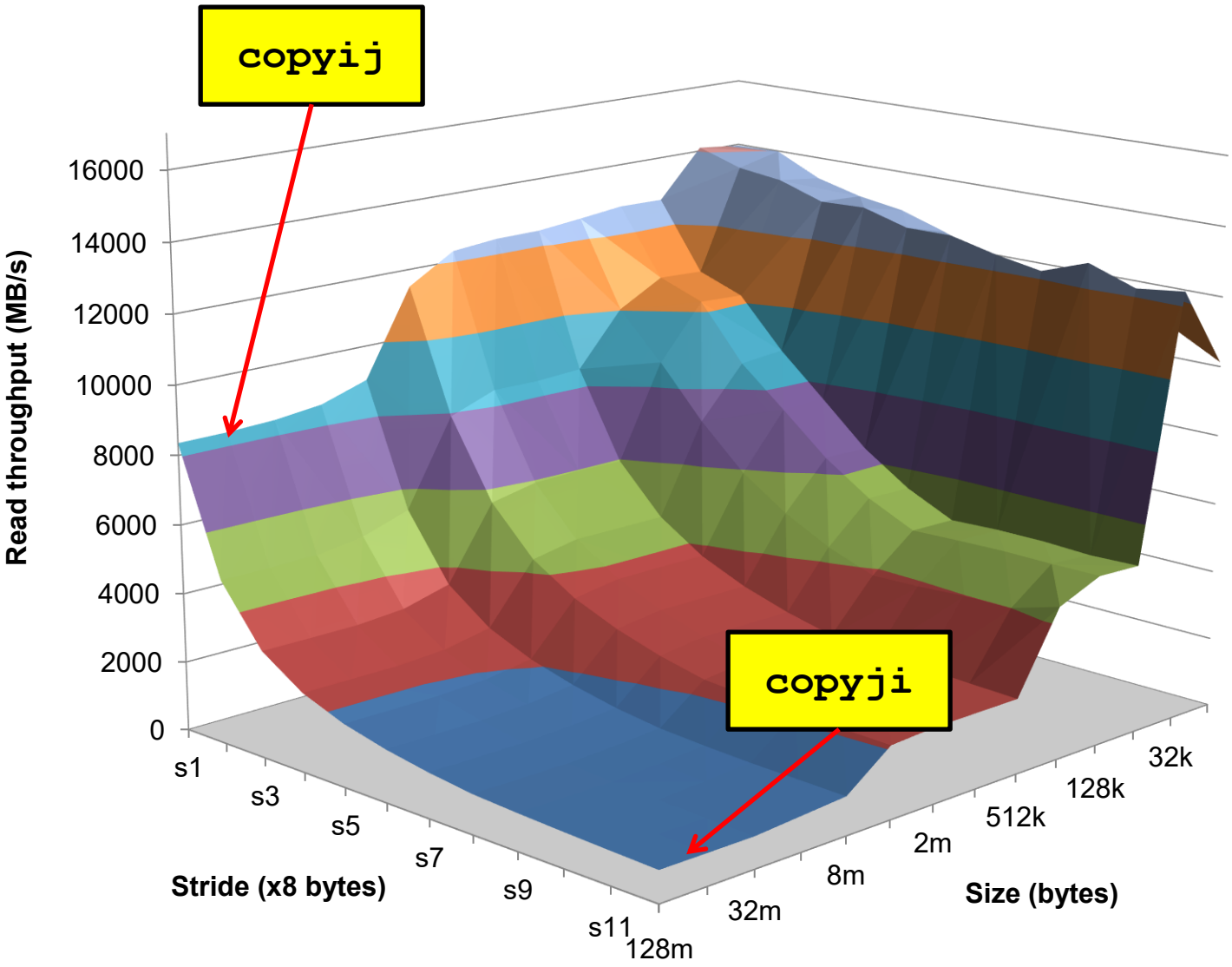
```
void copyij(int src[2048][2048],
            int dst[2048][2048])
{
  int i,j;
  for (i = 0; i < 2048; i++)
    for (j = 0; j < 2048; j++)
      dst[i][j] = src[i][j];
}
```

```
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 **2.0 GHz Intel Core i7 Haswell** **81.8ms**

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

Why The Performance Differs

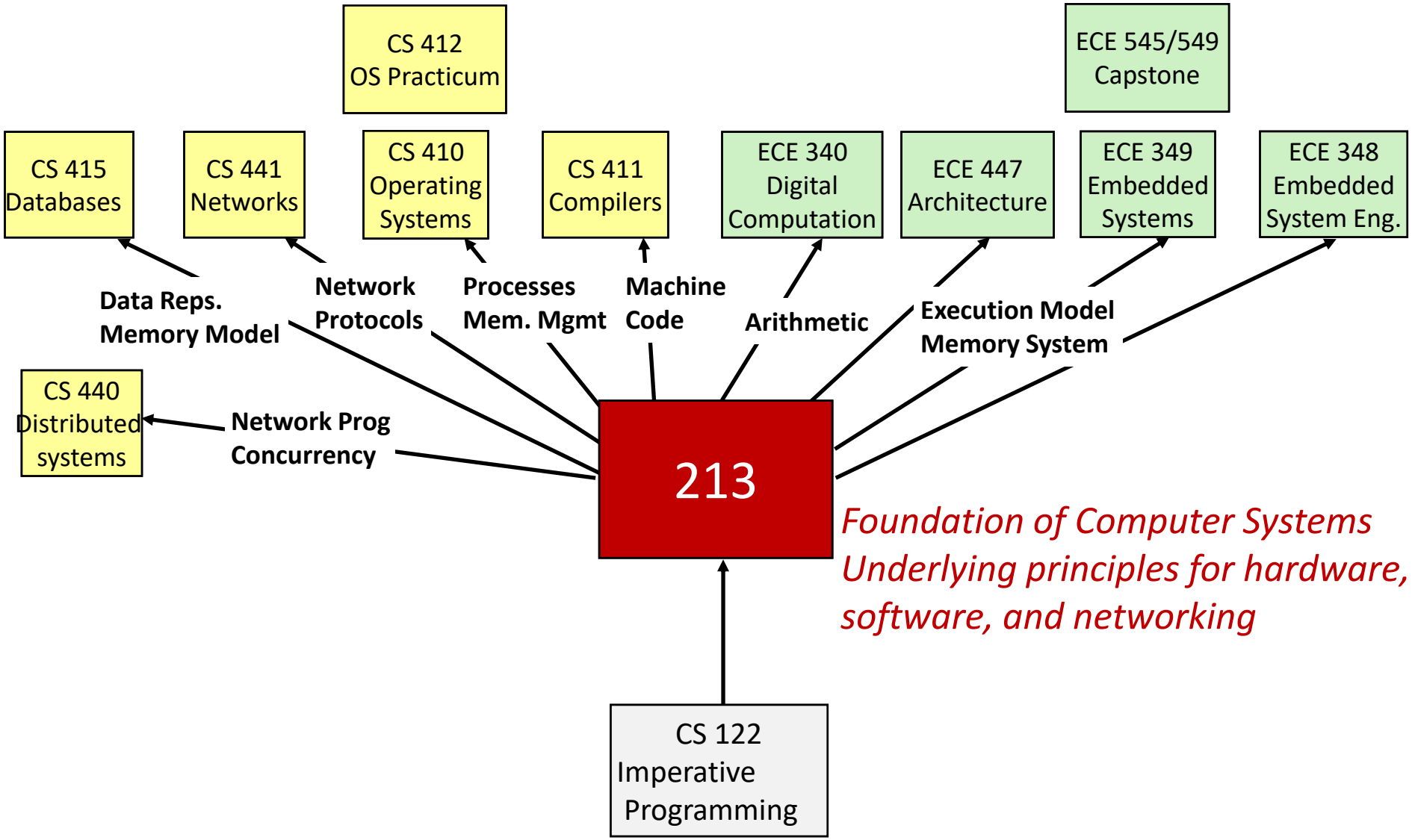


Great Reality #5: Computers do more than execute programs

- **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

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 sample portions of operating system
  - Compilers
    - Write compiler for simple language
  - Networking
    - Implement and simulate network protocols

Instructors

Randy Bryant

Dave O'Hallaron

Cheating: Description

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

- **What is cheating?**
  - Sharing code: by copying, retyping, **looking at**, or supplying a file
  - Describing: verbal description of code from one person to another.
  - Coaching: helping your friend to write a lab, line by line
  - Searching the Web for solutions
  - Copying code from a previous course or online solution
    - You are only allowed to use code we supply, or from the CS:APP website
- **What is NOT cheating?**
  - Explaining how to use systems or tools
  - Helping others with high-level design issues

- **See the course syllabus for details.**
  - Ignorance is not an excuse

Cheating: Consequences

- **Penalty for cheating:**
  - Removal from course with failing grade (no exceptions!)
  - Permanent mark on your record
  - Your instructors' personal contempt

- **Detection of cheating:**
  - We have sophisticated tools for detecting code plagiarism
  - Last Fall, 20 students were caught cheating and failed the course.
  - Some were expelled from the University

- **Don't do it!**
  - Start early
  - Ask the staff for help when you get stuck

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

- **Brian Kernighan and Dennis Ritchie,**
  - *The C Programming Language*, Second Edition, Prentice Hall, 1988
  - Still the best book about C, from the originators

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

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 and Piazza**
  - We won't be using Blackboard or Piazza for the 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 Tue Sept 3):**
  - SMTWR, 5:30-7:30pm, WeH 5207

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

Policies: Labs And Exams

- **Work groups**
  - You must work alone on all lab assignments
- **Handins**
  - Labs due at 11:59pm on Tues or Thurs
  - Electronic handins using **Autolab** (no exceptions!)
- **Exams**
  - Exams will be online in network-isolated clusters
  - Held over multiple days. Self-scheduled; just sign up!
- **Appealing grades**
  - In **writing** to Prof O'Hallaron within 7 days of completion of grading
  - Follow formal procedure described in syllabus

Facilities

- **Labs will use the Intel Computer Systems Cluster**
  - 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 semester**
  - **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

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 straight scale.

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 (attacklab): The basics of code injection attacks

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 Autolab scoreboard for glory!

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

- **Labs are provided by the CMU Autolab system**
  - Project page: http://autolab.cs.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 10am on Mon, Aug 26 have Autolab 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

- **For those who are waiting to add in, the first lab (datalab) will be available on the Schedule page of the course Web site.**

Waitlist questions

- 15-213: Catherine Fichtner (cathyf@cs.cmu.edu)
- 18-213: Zara Collier (zcollier@andrew.cmu.edu)
- 15-513: Catherine Fichtner (cathyf@cs.cmu.edu)

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

Welcome
and Enjoy!