Course ~~Over~~Review

15-213: Introduction to Computer Systems
26th Lecture, August 2, 2016

Instructor:

Brian Railing

The course that gives CMU its "Zip"!


WELCOME
TO
15-213
18-213
15-513

Overview

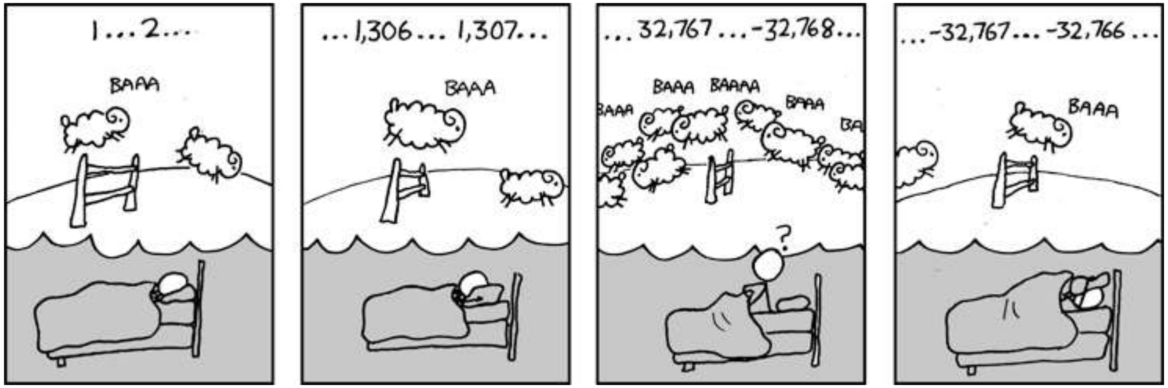
- Course theme
- Five realities
- How the course fits into the CS/ECE curriculum
- Academic integrity

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 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

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

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

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!

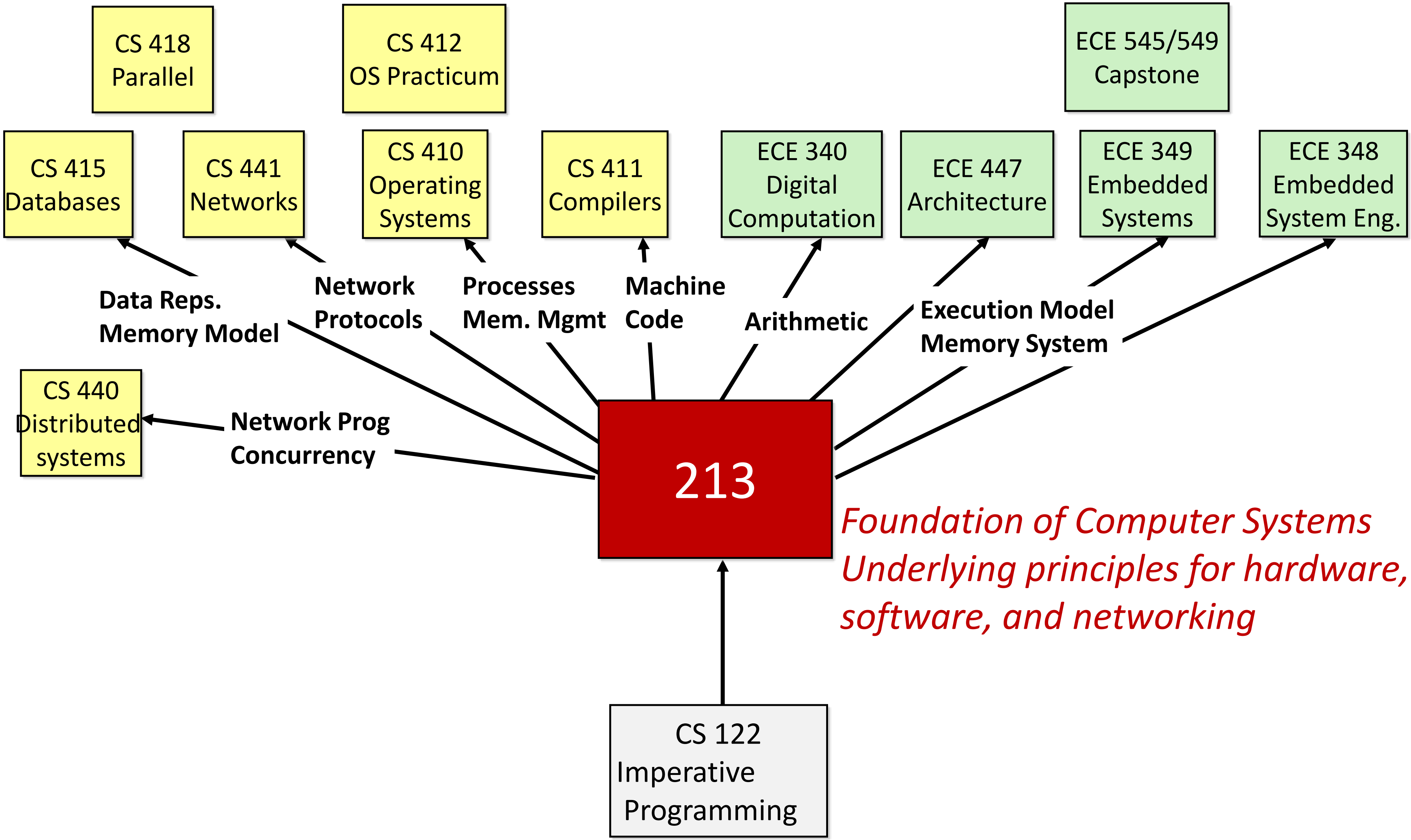
Course Perspective

- **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**
  - 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!**

Role within CS/ECE Curriculum



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

Cheating: Consequences

- **Penalty for cheating:**
  - Removal from course with failing grade (no exceptions!)
  - Permanent mark on your record
  - Your instructors’ personal contempt
  - If you do cheat – come clean asap!

- **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

FCEs

Semester: Summer 2016

Course: 15213

Section: A

Course Title: INTR CMPUTER SYSTEMS

Instructor(s): BRIAN RAILING

In the case of multiple instructors, you will be asked to evaluate each instructor separately.

Instructor: BRIAN RAILING (PREVIEW MODE NOTE: The answers to these questions are viewable only by RAILING)

	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25+
1. On average, how many hours per week have you spent on this class, including attending classes, doing readings, reviewing notes, writing papers and any other course related work?	○	○	○	○	○	○	○	○	○

	Excellent (5)	Above Average (4)	Average (3)	Below Average (2)	Poor (1)
2. Does the faculty member display an interest in students' learning?	○	○	○	○	○
3. Does the faculty member provide a clear explanation of the course requirements?	○	○	○	○	○
4. Does the faculty member provide a clear explanation of the learning objectives or goals of the course?	○	○	○	○	○

Final Exam

- **August 5th**
  - Pittsburgh 11am – Close
  - Silicon Valley
  - Qatar

- **The focus is on the second half of the course**
  - IO
  - Signals
  - Processes
  - Virtual Memory
  - Malloc
  - Threads
  - Thread Synchronization
  - Other

IO

In the following code, a parent opens a file twice, then the child reads a character:

```
char c;
int fd1 = open("foo.txt", O_RDONLY);
int fd2 = open("foo.txt", O_RDONLY);
if (!fork()) { read(fd1, &c, 1); }
```

Clearly, in the child, fd1 now points to the second character of foo.txt. Which of the following is now true in the parent?

(a) **fd1 and fd2 both point to the first character.**

(b) **fd1 and fd2 both point to the second character.**

(c) **fd1 points to the first character while fd2 points to the second character.**

(d) **fd2 points to the first character while fd1 points to the second character**

Signals

```
void sigint_handler(int sig)
{
    pid_t pid = fgpid(job_list); /* Masking signals */
    sigset_t mask, prev_mask;
    Sigfillset(&mask);
    Sigprocmask(SIG_BLOCK,&mask,&prev_mask);
    if (pid!=0)
    {
        /* Sending a SIGINT signal for the process group.
         * Deleting the job. */
        int jid = pid2jid(pid);
        kill(-pid, SIGINT);
        deletejob(job_list, pid);
    }
    /* Unblocking the masked signals */
    Sigprocmask(SIG_SETMASK,&prev_mask,NULL);
    return;
}
```

Name three bugs in this code

Processes

What strings are possible? Is “15213”?

```
int main(int argc, char** argv)
{
    if (fork() == 0) { printf(“3”); return 0;}
    else {printf(“5”);}
    if (fork() == 0) {printf(“2”);}
    printf(“1”);
    return 0;
}
```

Virtual Memory

- Virtual addresses are 20 bits wide
- Physical addresses are 18 bits wide
- Page size is 1024 bytes
- TLB is 2-way set associative with 16 total entries

- Label each bit of a virtual address (Virtual Page offset, Virtual page number, TLB index, TLB tag):

- Given virtual address 0x04AA4, what happens?

TLB			
Index	Tag	PPN	Valid
0	03	C3	1
	01	71	0
1	00	28	1
	01	35	1
2	02	68	1
	3A	F1	0
3	03	12	1
	02	30	1

Malloc

- **For an implicit allocator, with 16-byte alignment, 8-byte headers / footers, and prologue / epilogue.**

  Malloc(3)

  Malloc(11)

  Malloc(40)

  Free (40)

  Malloc(10)

- **Draw the state of the heap in 8 byte units, label as header / footer (size, alloc or free), payload:**

- **What is the utilization for this allocator, versus 54 bytes?**
- **How much space would be saved by removing footers?**

Threads

- What is the range of value(s) that main will print?
- A programmer proposes removing i from thread and just directly accessing count. Does the answer change?

```
volatile int count = 0;

void* thread(void* v)
{
    int i = count;
    i = i + 1;
    count = i;
}
```

```
int main(int argc, char** argv)
{
    pthread_t tid[2];
    for(int i = 0; i < 2; i++)
        pthread_create(&tid[i],
NULL, thread, NULL);
    for (int i = 0; i < 2; i++)
        pthread_join(tid[i]);
    printf("%d\n", count);
    return 0;
}
```

Thread Synchronization

- **Make FIFO -> LIFO**

```
void sbuf_init(sbuf_t *sp, int n)
{
    sp->buf = Calloc(n, sizeof(int));
    sp->n = n;
    sp->front = sp->rear = 0;
    Sem_init(&sp->mutex, 0, 1);
    Sem_init(&sp->slots, 0, n);
    Sem_init(&sp->items, 0, 0);
}
```

```
void sbuf_insert(sbuf_t *sp, int item)
{
    P(&sp->slots);
    P(&sp->mutex);
    sp->buf[(++sp->rear)%(sp->n)] = item;
    V(&sp->mutex);
    V(&sp->items);
}
```

```
int sbuf_remove(sbuf_t *sp)
{
    int item;
    P(&sp->items);
    P(&sp->mutex);
    item = sp->buf[(++sp->front)%(sp->n)];
    V(&sp->mutex);
    V(&sp->slots);
    return item;
}
```