Course Overview

Introduction to Computer Systems
1st Lecture, Feb. 22, 2019

Instructor:

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Overview

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

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

- **Most CS 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 this course**
  - 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
    - Compilers, Operating Systems, Networks, Computer Architecture, Embedded Systems, Storage Systems, etc.

16级同学课程学习心得

可以让人对计算机体系有了一个总体的了解，这门课程不仅让后续课程的学习变得轻松了许多(其他班的同学学体系结构时看见汇编都被吓了大跳)，也让人学习了很多实际中有用的东西。比如说实验就要求安装Linux来使用。

感觉对具体实现有个初步概念，然后一步一步很有成就感，解开谜团的感觉。对将来的电脑学习充满了兴趣。

计算机系统基础是让我开始觉得计算机真的有意思的课程。做labs虽然耗费精力但是好玩。对计算机组成原理的过渡效果非常好，计组学习基本没有太大压力。尤其是优化程序性能的那一部分，对编程帮助也蛮大的。

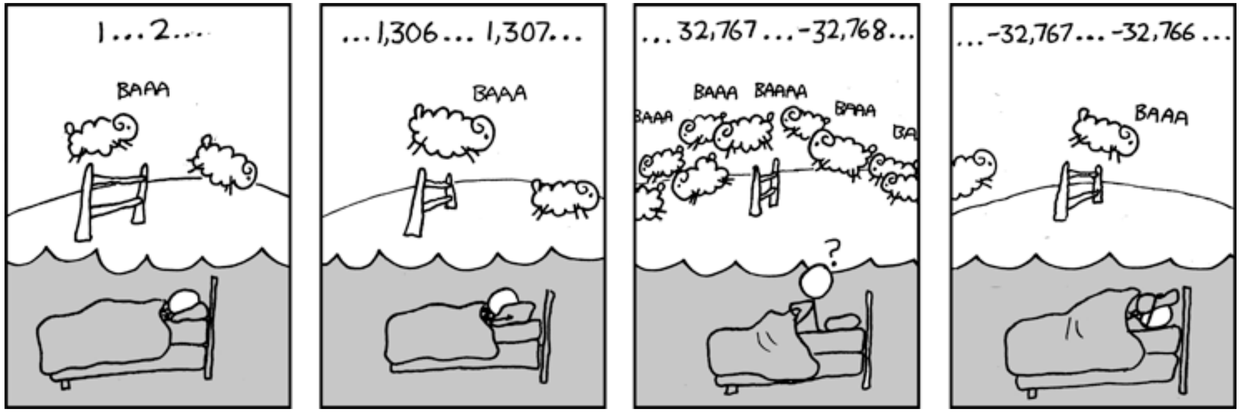
计算机系统基础是CMU的镇校神课当然要上

17级同学学习心得

别整虚的（比如相信书光看就能看懂，大佬除外），多动手做课后题和lab

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
```

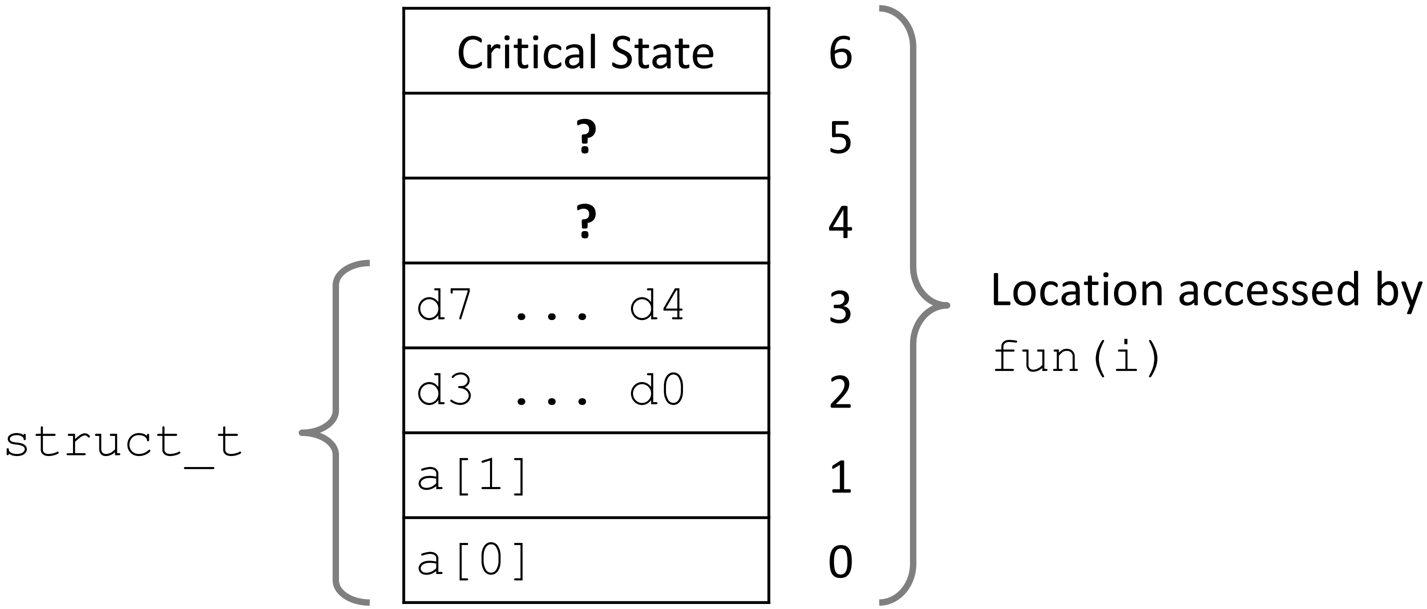
- Result is system specific

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)  ➙  2.00000061035156
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

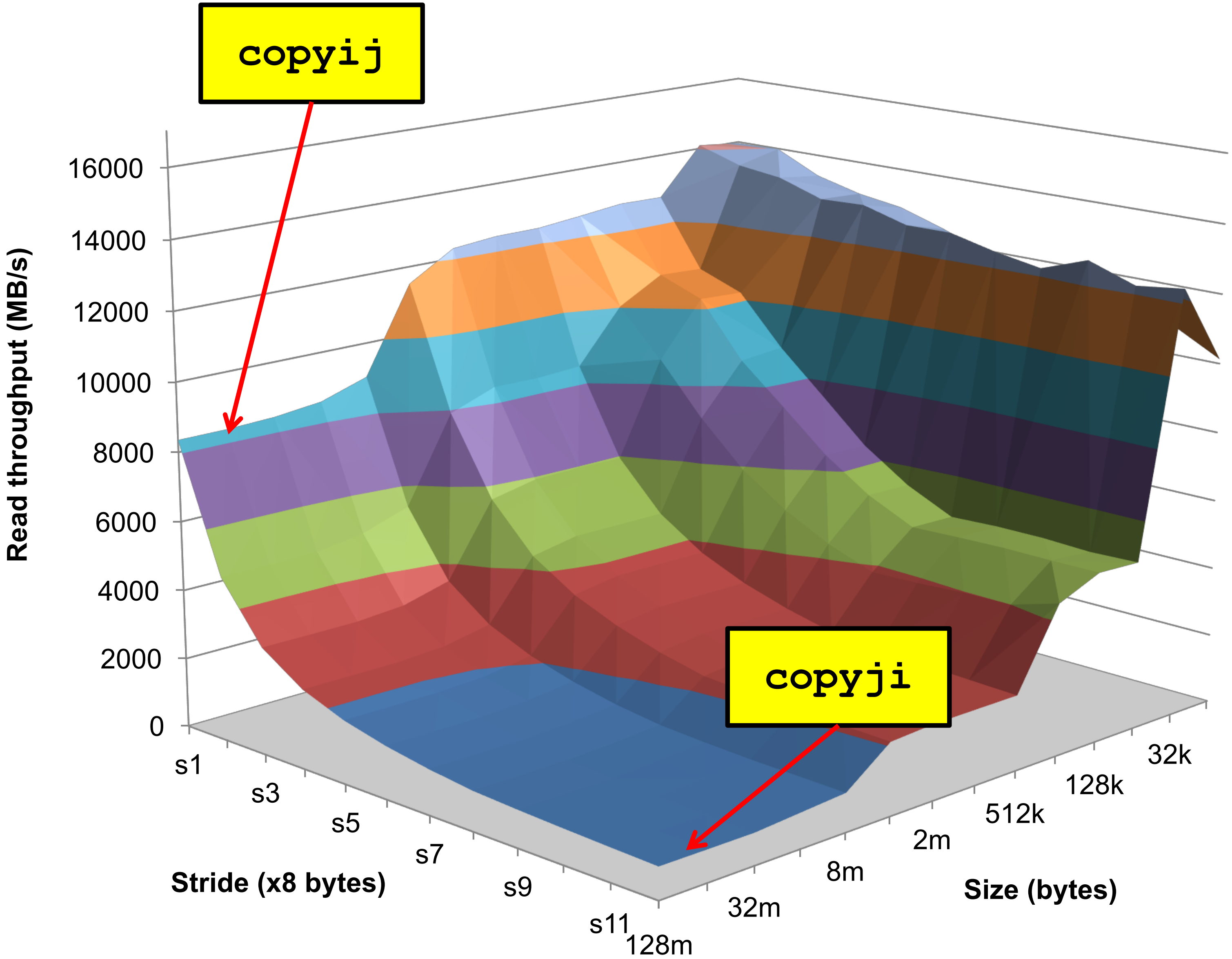
```c
void copyij(int src[2048][2048],
            int dst[2048][2048])
{
  int i,j;
  for (i = 0; i < 2048; i++)
    for (j = 0; j < 2048; j++)
      dst[i][j] = src[i][j];
}
```

```c
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

Course Perspective

- **Most Systems Courses are Builder-Centric**
  - Computer Organization and 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!**

Cheating: Description

- **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
- **What is NOT cheating?**
  - Explaining how to use systems or tools
  - Helping others with high-level design issues

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
  - Personal interview for grading

- **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
  - 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
- **Labs (4-5)**
  - The heart of the course
  - 1-3 weeks each
  - Provide in-depth understanding of an aspect of systems
  - Programming and measurement
- **Final Exam**
  - Test your understanding of concepts & mathematical principles

Getting Help

- Email: yiligong@whu.edu.cn
- QQ群
- TAs? Sorry ……

Other Rules of the Lecture Hall

- **Laptops: permitted**

- **Electronic communications:** ***forbidden***
  - No email, instant messaging, cell phone calls, etc

- **Presence in lectures: voluntary, recommended by me, while requested by the school**

Policies: Grading

- **Exams (50%)**
- **Labs (40%): weighted according to effort**
- **Homework (10%)**
- **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**
  - L0 (clab): Basic C programming skills
  - L1 (datalab): Manipulating bits
  - L2 (bomblab): Defusing a binary bomb
  - L3 (attacklab): The basics of code injection attacks
  - L4 (shelllab): Writing your own Unix shell

The Memory Hierarchy

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

Exceptional Control Flow

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

Virtual Memory

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

I/O

- **Topics**
  - Unix low-level I/O Unix I/O
  - RIO (robust I/O) package
  - Metadata, sharing, and redirection
  - Standard I/O
  - Includes aspects of OS, and architecture

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!

Welcome and Enjoy!