CSCI-UA.0201

Computer Systems Organization

Overview

Mohamed Zahran (aka Z)
mzahran@cs.nyu.edu
http://www.mzahran.com
Who Am I?

- Mohamed Zahran (aka Z)
- Research interest: Computer architecture/OS/Compilers Interaction
- http://www.mzhahran.com
- Office hours: Wed/Th 2:00-3:00 pm
- If you want to meet outside these office hours, please email me first.
- My office: WWH 320
Formal Goals of This Course

• What happens under the hood when you boot your computer and start running applications?
• How do software and hardware interact?
• This course is programmer-centric
  – Understanding of underlying system makes you a more effective programmer and helps you find hidden bugs!
  – Bring out the hidden hacker in everyone
  – Be way more efficient debugger
  – Tune your programs for performance
Informal Goals of This Course

• To learn computer systems and enjoy it
• To use what you have learned in MANY different contexts
• To start your research project if you want
• To know the big picture of the whole computing stack.
• To enjoy the course!
Textbook

Randy Bryant

Dave O’Hallaron
Course Components

• Lectures
  – Higher level concepts
  – slides + reading material from the textbook
• Programming labs (3 of them → 35%)
  – 1-2 weeks each
  – Provide in-depth understanding of some aspect of systems
• Homework assignments (3 of them →10%)
  – Labs do not cover all the material we will study!
  – For theoretical knowledge
• One midterm exam (20%)
  – You don’t want the final exam to be your first exam, do you?
• One final exam (35%)
Exams

- Closed books & notes
- No electronic devices allowed
- Cheat sheet:
  - A single sheet of letter-sized paper for midterm
  - Two cheat sheets for the final
  - Feel free to write anything on it (front and back), before the exam.
  - You are allowed to take it to the exam.
Main Topics

• Basic C
• Representation of program and data
• Memory hierarchy and systems hardware
• Dynamic memory allocation
• Virtual Memory
• Concurrency & Processes
Policies: Assignments (Labs)

• You must work alone on all assignments
  – Post all questions on the forums
  – You are encouraged to answer others’ questions, but refrain from explicitly giving away solutions.

• Hand-ins
  – Labs due at 11:59pm on the due date
  – Homework assignments due at the end of the lecture of the due date
Integrity and Collaboration

• What is cheating?
  – Sharing code: by copying, retyping, looking at, or supplying a file
  – Describing code: 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

• Ignorance is not an excuse

We have sophisticated tools for detecting code plagiarism
Facilities

• Lab environments:
  – Use official class VM image
    • Download (free) virtualbox for Windows/Linux/Mac
    • Download VM appliance from course web page
Web Presence

• Course webpage:
  – sec 1: http://cs.nyu.edu/courses/fall16/CSCI-UA.0201-001/
  – sec 3: http://cs.nyu.edu/courses/fall16/CSCI-UA.0201-003/

• Mailing List

• NYU Classes
Course Theme:
Abstraction Is Good But Don’t Forget Reality

• Most CS courses emphasize abstraction
  – e.g. data types
• Abstracts are good but have limitations
  – Especially in the presence of bugs!
• This class:
  – Helps you peek under-the-hood
  – Become more effective programmers
    • Debug problems
    • Tune performance
  – Prepare for later courses in CS
    • Compilers, Operating Systems, Computer Architecture, Distributed Systems, parallel computing, ...
Reality #1:
Ints are not Integers
Floats are not Reals

- $x^2 \geq 0$? Overflow!!
- $(x + y) + z = x + (y + z)$? $1e20+(-1e20+3.14)! = 3.14$

Source: xkcd.com/571
Reality #2: You’ve Got to Know Assembly

- No need to program in assembly
- Knowledge of assembly helps one understand machine-level execution
  - Debugging
  - Performance tuning
  - Writing system software (e.g. compilers, OS)
  - Creating / fighting malware
    - x86 assembly is the language of choice!
Reality #3: Memory Matters

• Memory is not unbounded
  – It must be allocated and managed

• Memory referencing bugs especially wicked

• Memory performance is not uniform
  – Cache and virtual memory effects can greatly affect performance
Memory Referencing Errors

• C/C++ let programmers make memory errors
  – Out of bounds array references
  – Invalid pointer values
  – Double free, use after free
• Errors can lead to nasty bugs
  – Corrupt program objects
  – Effect of bug observed long after the corruption
double fun(int i) {
    int a[2];
    double d[1] = {3.14};
    a[i] = 1073741824; /* Possibly out of bounds */
    return d[0];
}

fun(0) = 3.14
fun(1) = 3.14
fun(2) = ?
fun(3) = ?
fun(4) = ?
• Similar to code found in FreeBSD
• There are legions of smart people trying to find vulnerabilities in programs
Typical Usage

/* Kernel memory region holding user-accessible data */
#define KSIZE 1024
char kbuf[KSIZE];

/* Copy at most maxlen bytes from kernel region to user buffer */
int copy_from_kernel(void *user_dest, int maxlen) {
    /* Byte count len is minimum of buffer size and maxlen */
    int len = KSIZE < maxlen ? KSIZE : maxlen;
    memcpy(user_dest, kbuf, len);
    return len;
}

#define MSIZE 528

void getstuff() {
    char mybuf[MSIZE];
    copy_from_kernel(mybuf, MSIZE);
    printf("%s\n", mybuf);
}
#define MSIZE 528
void getstuff() {
    char mybuf[MSIZE];
    copy_from_kernel(mybuf, -MSIZE);
    . . .
}

/* Kernel memory region holding user-accessible data */
#define KSIZE 1024
char kbuf[KSIZE];

/* Copy at most maxlen bytes from kernel region to user buffer */
int copy_from_kernel(void *user_dest, int maxlen) {
    /* Byte count len is minimum of buffer size and maxlen */
    int len = KSIZE < maxlen ? KSIZE : maxlen;
    memcpy(user_dest, kbuf, len);
    return len;
}
Reality #4: Asymptotic performance is not always sufficient

- Factors like memory access, communication, etc. matter
- Even operation count might not predict performance
- Must understand system to optimize performance
  - How are programs compiled and executed?
  - How to measure performance and identify bottlenecks?
  - How to improve performance without destroying code modularity and generality?
Memory System Performance Example

formance depends on access patterns

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];
}

21 times slower
(Pentium 4)
Example Matrix Multiplication

Matrix-Matrix Multiplication (MMM) on 2 x Core 2 Duo 3 GHz (double precision)

Gflop/s

- Standard desktop computer and compiler
- Both implementations have **exactly** the same operations count \((2n^3)\)
Matrix-Matrix Multiplication (MMM) on 2 x Core 2 Duo 3 GHz

Gflop/s

- Multiple threads: 4x
- Vector instructions: 4x
- Memory hierarchy and other optimizations: 20x

Reason for 20x: Blocking or tiling, loop unrolling, array scalarization

Effect: fewer register spills, L1/L2 cache misses, and TLB misses
Reality #5: Computer is more than the CPU

- They need to do I/O (get data in and out)
- They communicate with each other over networks
  - Concurrent operations by autonomous processes
  - Coping with unreliable media
  - Cross platform compatibility
  - Complex performance issues
A Little Bit of History

Eckert and Mauchly

- 1st working electronic computer (1946)
- 18,000 Vacuum tubes
- 1,800 instructions/sec
- 3,000 ft$^3$
A Little Bit of History

• Maurice Wilkes

EDSAC 1 (1949)

http://www.cl.cam.ac.uk/UoCCL/misc/EDSAC99/

1\textsuperscript{st} stored program computer
650 instructions/sec
1,400 ft\textsuperscript{3}
A Little Bit of History

- 1954 IBM developed 704
- All programming done in assembly
- Software costs exceed hardware costs!
A Little Bit of History

- Fortran I (project 1954-57)
- The main idea is to translate high level language to assembly
- Many thought this was impossible!
- In 1958 more than 50% of software in assembly!
- Development time halved!

John Backus
(December 3, 1924 – March 17, 2007)
Problem → Algorithm Development → Programmer

High Level Language → Compiler (translator)

Assembly Language → Assembler (translator)

Machine Language → Control Unit (Interpreter)

Microarchitecture → Microsequencer (Interpreter)

Logic Level

Device Level → Semiconductors → Quantum
Source Code to Execution

C source → Compiler → Assembly → Assembler → Object File

Object File → Library → Linker → Executable

Loader

DLL
Conclusions

• This first lecture was just an overview. More fun is yet to come!

• Computer system can be viewed as layers of abstractions → knowing these layers helps us see the big picture

Welcome ... And Enjoy 😊