CS 3410: Computer System Organization and Programming

Hakim Weatherspoon
Spring 2012
Computer Science
Cornell University
Computer System Organization

- The most amazing and likely to be most long-lived invention of the 1800’s was…
Computer Organization

• The most amazing and likely to be most long-lived invention of the 1800’s was…
  – (a) The steam engine?
  – (b) The lightning rod?
  – (c) The carbonated beverage?
  – (d) All of the above
  – (e) None
Computer Organization

• The most amazing and likely to be most long-lived invention of the 1800’s was…

THE ELECTRIC SWITCH
Basic Building Blocks: A switch

• A switch is a simple device that can act as a conductor or isolator

• Can be used for amazing things…
In what language do computers think?

• (a) Java
• (b) C/C++
• (c) Matlab
• (c) Python
• (d) Binary Digits
Basic Building Blocks: Switches

- Either (OR)
- Both (AND)
- But requires mechanical force

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Basic Building Blocks: Transistors

- Solid-state switch
  - The most amazing invention of the 1900s

- PNP and NPN
Basic Building Blocks: NPN Transistors

- Semi-conductor

- Connect E to C when base = 1
P and N Transistors

- PNP Transistor
  - Connect E to C when base = 0

- NPN Transistor
  - Connect E to C when base = 1
**Inverter**

- **Function:** NOT
- **Called an inverter**
- **Symbol:**
  - ![Inverter Symbol]

**Truth table**

<table>
<thead>
<tr>
<th>In</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Useful for taking the inverse of an input**
  - CMOS: complementary-symmetry metal–oxide–semiconductor
NAND Gate

- Function: NAND
- Symbol:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>out</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
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<tr>
<td>1</td>
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<tr>
<td>1</td>
<td>1</td>
<td>0</td>
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</tbody>
</table>
NOR Gate

- Function: NOR
- Symbol:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>out</th>
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</thead>
<tbody>
<tr>
<td>0</td>
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<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

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Building Functions

- **NOT:**
- **AND:**
- **OR:**
- **NAND and NOR are universal**
  - Can implement any function with NAND or just NOR gates
  - useful for manufacturing
Then and Now

- The first transistor
  - on a workbench at AT&T Bell Labs in 1947
  - Bardeen, Brattain, and Shockley

- An Intel Westmere
  - 1.17 billion transistors
  - 240 square millimeters
  - Six processing cores

http://www.theregister.co.uk/2010/02/03/intel_westmere_ep_preview/
Moore's Law

The number of transistors integrated on a single die will double every 24 months...
– Gordon Moore, Intel co-founder, 1965

Amazingly Visionary

1971 – 2300 transistors – 1MHz – 4004
1990 – 1M transistors – 50MHz – i486
2001 – 42M transistors – 2GHz – Xeon
2004 – 55M transistors – 3GHz – P4
2007 – 290M transistors – 3GHz – Core 2 Duo
2009 – 731M transistors – 2GHz – Nehalem
Course Objective

• Bridge the gap between hardware and software
  – How a processor works
  – How a computer is organized

• Establish a foundation for building higher-level applications
  – How to understand program performance
  – How to understand where the world is going
Announcements: How class organized

• Instructor: Hakim Weatherspoon
  (hweather@cs.cornell.edu)

• Lecture:
  – Tu/Th 1:25-2:40
  – Hollister B14

• Lab Sections:
  – Carpenter 235 (Red Room)
Who am I?

- Prof. Hakim Weatherspoon
  - (Hakim means Doctor, wise, or prof. in Arabic)
  - Background in Education
    - Undergraduate University of Washington
      - Played Varsity Football
        - Some teammates collectively make $100’s of millions
        - I teach!!!
    - Graduate University of California, Berkeley
      - Some classmates collectively make $100’s of millions
      - I teach!!!
  - Background in Operating Systems
    - Peer-to-Peer Storage
      - Antiquity project - Secure wide-area distributed system
      - OceanStore project – Store your data for 1000 years
    - Network overlays
      - Bamboo and Tapestry – Find your data around globe
    - Tiny OS
      - Early adopter in 1999, but ultimately chose P2P direction
Who am I?

- Cloud computing/storage
  - Optimizing a global network of data centers
  - Cornell National λ-Rail Rings testbed
  - Software Defined Network Adapter
  - Energy: KyotoFS/SMFS
- Antiquity: built a global-scale storage system
Course Staff

- cs3410-staff-l@cs.cornell.edu

- **Lecture/Homwork TA’s**
  - Colin Ponce (cponce@cs.cornell.edu) (lead)
  - Anish Ghulati (ag795@cornell.edu)
  - Ming Pan (mp492@cornell.edu)

- **Lab TAs**
  - Han Wang (hwang@cs.cornell.edu) (lead)
  - Zhefu Jiang (zj46@cs.cornell.edu)

- **Lab Undergraduate consultants**
  - Doo San Baik (db478@cornell.edu)
  - Erluo Li (el378@cornell.edu)
  - Jason Zhao (jlz27@cornell.edu)
  - Peter Tseng (pht24@cornell.edu) (lead)
  - Roman Averbukh (raa89@cornell.edu)
  - Scott Franklin (sdf47@cornell.edu)

**Administrative Assistant:**
- Randy Hess (rbhess@cs.cornell.edu)
Course Staff

Doo San Baik  Roman Averbukh  Peter Tseng
Book

- Computer Organization and Design
  - The Hardware/Software Interface

- David Patterson, John Hennessy
  - Get the 4th Edition Revised

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Pre-requisites and scheduling

• CS 2110 is required
  – Must have satisfactorily completed CS 2110
  – *Cannot take CS 2110 concurrently with CS 3410*

• CS 3420 (ECE 3140)
  – Take either CS 3410 *or* CS 3420
    ▪ both satisfy CS and ECE requirements
  – *However, Need ENGRD 2300 to take CS 3420*

• CS 3110
  – Not advised to take CS 3110 and 3410 together
Grading

• Lab (45-50%)
  – 4-5 Individual Labs (15-20%)
  – 4 Group Projects (30-35%)

• Lecture (45-50%)
  – 3 Prelims (35-40%)
  – Homework (10%)

• Participation/Discretionary (5%)

Prelims
- Tu Feb 28
- Th Mar 29
- Th Apr 26
Grading

• Regrade policy
  – Submit written request to lead TA, and lead TA will pick a different grader
  – Submit another written request, lead TA will regrade directly
  – Submit yet another written request for professor to regrade.

• Late Policy
  – Each person has a total of four “slip days”
  – Max of two slip days for any individual assignment
  – For projects, slip days are deducted from all partners
  – 20% deducted per day late after slip days are exhausted

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Administrivia

- http://www.cs.cornell.edu/courses/cs3410/2012sp
  - Office Hours / Consulting Hours
  - Lecture slides & schedule
  - Logisim
  - CSUG lab access (esp. second half of course)

- Lab Sections (start today)
  - Labs are separate than lecture and homework
  - Bring laptop to Labs (optional)
Administrivia

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- **Lab Sections (start *today*)**
  
<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>2:55 – 4:10pm</td>
<td>Carpenter Hall 235 (Red Room)</td>
</tr>
<tr>
<td>W</td>
<td>3:35 – 4:50pm</td>
<td>Carpenter Hall 235 (Red Room)</td>
</tr>
<tr>
<td>W</td>
<td>7:30—8:45pm</td>
<td>Carpenter Hall 235 (Red Room)</td>
</tr>
<tr>
<td>R</td>
<td>11:40 – 12:55pm</td>
<td>Carpenter Hall 235 (Red Room)</td>
</tr>
<tr>
<td>R</td>
<td>2:55 – 4:10pm</td>
<td>Carpenter Hall 235 (Red Room)</td>
</tr>
<tr>
<td>F</td>
<td>2:55 – 4:10pm</td>
<td>Carpenter Hall 235 (Red Room)</td>
</tr>
</tbody>
</table>

- Labs are separate than lecture and homework
- Bring laptop to Labs
- *This* week: intro to logisim and building an adder
Communication

• Email
  – cs3410-staff-l@cs.cornell.edu
  – The email alias goes to me and the TAs, not to whole class

• Assignments
  – CMS: http://cms.csuglab.cornell.edu

• Newsgroup
  – For students

• iClicker
  – http://atcsupport.cit.cornell.edu/pollsrvc/
Lab Sections & Projects

• Lab Sections start this week
  – Intro to logisim and building an adder

• Labs Assignments
  – Individual
  – One week to finish (usually Monday to Monday)

• Projects
  – two-person teams
  – Find partner in same section
Academic Integrity

• All submitted work must be your own
  – OK to study together, but do not share soln’s
  – Cite your sources

• Project groups submit joint work
  – Same rules apply to projects at the group level
  – Cannot use of someone else’s soln

• Closed-book exams, no calculators

• Stressed? Tempted? Lost?
  • Come see me before due date!

Plagiarism in any form will not be tolerated
Why do CS Students Need Transistors?
Why do CS Students Need Transistors?

- **Functionality and Performance**
Why do CS Students Need Transistors?

• To be better Computer Scientists and Engineers
  – Abstraction: simplifying complexity
  – How is a computer system organized? How do I build it?
  – How do I program it? How do I change it?
  – How does its design/organization effect performance?
Computer System Organization
Computer System Organization

Computer System = ?

Input +
Output +
Memory +
Datapath +
Control

Registers

CPU

Video

Network

USB

Keyboard

Mouse

Serial

Memory

Disk

Audio

CPU

Memory

Network

USB

Serial

Keyboard

Mouse

Audio
Compilers & Assemblers

C

```
int x = 10;
x = 2 * x + 15;
```

MIPS

```
addi r5, r0, 10
muli r5, r5, 2
addi r5, r5, 15
```

MIPS machine language

```
001000000000010100000000000001010
0000000000000101001010010000100000
001000001010010100000000000001111
```

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Instruction Set Architecture

- ISA
  - abstract interface between hardware and the lowest level software
  - user portion of the instruction set plus the operating system interfaces used by application programmers
Basic Computer System

• A processor executes instructions
  – Processor has some internal state in storage elements (registers)
• A memory holds instructions and data
  – von Neumann architecture: combined inst and data
• A bus connects the two
How to Design a Simple Processor

```
new pc calculation

00: addi   r5, r0, 10
04: multi  r5, r5, 2
08: addi   r5, r5, 15
```
Inside the Processor

- AMD Barcelona: 4 processor cores

Figure from Patterson & Hennessy, Computer Organization and Design, 4th Edition
How to Program the Processor: MIPS R3000 ISA

- Instruction Categories
  - Load/Store
  - Computational
  - Jump and Branch
  - Floating Point
    - coprocessor
  - Memory Management

<table>
<thead>
<tr>
<th>Registers</th>
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<tbody>
<tr>
<td>R0 - R31</td>
</tr>
<tr>
<td>PC</td>
</tr>
<tr>
<td>HI</td>
</tr>
<tr>
<td>LO</td>
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</table>

<table>
<thead>
<tr>
<th>OP</th>
<th>rs</th>
<th>rt</th>
<th>rd</th>
<th>sa</th>
<th>funct</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP</td>
<td>rs</td>
<td>rt</td>
<td></td>
<td></td>
<td>Immediate</td>
</tr>
<tr>
<td>OP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Jump Target</td>
</tr>
</tbody>
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Overview

Instruction Set Architecture

Memory system

Datapath & Control

Digital Design

Circuit Design

Instr. Set Proc.

I/O system

Compiler

Firmware

Operating System

Application
Applications

• Everything these days!
  – Phones, cars, televisions, games, computers,…
Example 3: New Devices

- Xilinx FPGA
- NVidia GPU
- Berkeley mote

Bar chart showing sales of cell phones, PCs, and TVs from 1997 to 2007.
Covered in this course

- Instruction Set
- Processor
- Operating System
- Firmware
- Compiler
- Application
- Memory system
- Datapath & Control
- Digital Design
- Circuit Design
- I/O system

Instruction Set Architecture
Reflect

Why take this course?

- Basic knowledge needed for *all* other areas of CS:
  operating systems, compilers, ...
- Levels are not independent
  hardware design ↔ software design ↔ performance
- Crossing boundaries is hard but important
  device drivers
- Good design techniques
  abstraction, layering, pipelining, parallel vs. serial, ...
- Understand where the world is going