CS 3410: Computer System Organization and Programming

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The slides are the product of many rounds of teaching CS 3410 by Professors Weatherspoon, Bala, Bracy, and Sirer.
The Analytical Engine

- Designed by Charles Babbage from 1834 – 1871
- Considered to be the first digital computer
- Built from mechanical gears, where each gear represented a discrete value (0-9)
- Babbage died before it was finished

http://history-computer.com
http://wikimedia.com
Turing Machine
1936

Alan Turing

= abstract model for CPU that can simulate any algorithm

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1936

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= abstract model for CPU that can simulate any algorithm
The Bombe used by the Allies to break the German Enigma machine during World War II
ENIAC
Electronic Numerical Integrator And Computer

1946
John Mauchly
J. Presper Eckert
Who are you?

“Sometimes it is the people that no one imagines anything of who do the things that no one can imagine.” – Alan Turing

• Turing Award Winners?
• Eckert Mauchly Award Winners?
Course Objective

• Understand the HW / SW interface software
  ▪ How a processor works
  ▪ How a computer is organized

• Establish a foundation for building applications
  ▪ How to write a good program
    • Good = correct, fast, and secure
  ▪ How to understand where the world is going

• Understand technology (past, present, future)
What is this?

#include <stdio.h>

int main() {
    printf("Hello world!\n");
    return 0;
}

How does it work?
I’m glad you asked...

15 weeks later and you’ll know!
“l know Kung Fu.”
Compilers & Assemblers

C

\[
\begin{align*}
\text{int } x &= 10; \\
x &= 2 \times x + 15;
\end{align*}
\]

\[
\text{r0} = 0
\]

MIPS

assembly

language

\[
\begin{align*}
\text{addi } r5, r0, 10 & \quad \text{r5} = \text{r0} + 10 \\
\text{muli } r5, r5, 2 & \quad \text{r5} = \text{r5} \times 2 \\
\text{addi } r5, r5, 15 & \quad \text{r5} = \text{r5} + 15
\end{align*}
\]

Everything is a number!
How to Design a Simple Processor

- Memory
- Instruction (inst)
- Register File
- ALU
- Control
- New PC Calculation

Instructions:
- 00: addi r5, r0, 10
- 04: muli r5, r5, 2
- 08: addi r5, r5, 15
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
Overview

Instruction Set Architecture

Datapath & Control
Digital Design
Circuit Design

Memory system
Instr. Set Proc.
I/O system

Compiler
Firmware

Operating System

Application
 Covered in this course

Instruction Set Architecture

Application

Operating System

Compiler Firmware

Memory system

CPU

I/O system

Datapath & Control

Digital Design

Circuit Design

Compiler

Firmware

I/O system

CPU

Application

Operating System

Compiler Firmware

Memory system

CPU

I/O system

Datapath & Control

Digital Design

Circuit Design
Where did it begin?

- Electrical Switch
  - On/Off
  - Binary

- Transistor

The first transistor on a workbench at AT&T Bell Labs in 1947
Moore’s Law

• 1965
  ▪ # of transistors integrated on a die doubles every 18-24 months (*i.e.*, grows exponentially with time)

• Amazingly visionary
  ▪ 2300 transistors, 1 MHz clock (Intel 4004) - 1971
  ▪ 16 Million transistors (Ultra Sparc III)
  ▪ 42 Million transistors, 2 GHz clock (Intel Xeon) – 2001
  ▪ 55 Million transistors, 3 GHz, 130nm technology, 250mm² die (Intel Pentium 4) – 2004
  ▪ 290+ Million transistors, 3 GHz (Intel Core 2 Duo) – 2007
  ▪ 721 Million transistors, 2 GHz (Nehalem) - 2009
  ▪ 1.4 Billion transistors, 3.4 GHz Intel Haswell (Quad core) – 2013
  ▪ 7.2 Billion transistors, 3-3.9 GHz Intel Broadwell (22-core) – 2016
Microprocessor Transistor Counts 1971-2011 & Moore’s Law

The curve shows transistor count doubling every two years.
Processor Performance Increase

- SUN-4/260
- MIPS M/120
- MIPS M2000
- IBM RS6000
- HP 9000/750
- DEC AXP/500
- DEC Alpha 5/300
- DEC Alpha 4/266
- IBM POWER
- DEC Alpha 5/300
- DEC Alpha 21264/600
- DEC Alpha 5/500
- DEC Alpha 5/300
- Intel Xeon/2000
- Intel Pentium 4/3000
Then and Now

• The first transistor
  • One workbench at AT&T Bell Labs
  • 1947
  • Bardeen, Brattain, and Shockley

• Intel Haswell
  • 1.4 billion transistors, 22nm
  • 177 square millimeters
  • Four processing cores

What are we doing with all these transistors?

https://en.wikipedia.org/wiki/Transistor_count
Then and Now

• The first transistor
  • One workbench at AT&T Bell Labs
  • 1947
  • Bardeen, Brattain, and Shockley

• Intel Broadwell
  • 7.2 billion transistors, 14nm
  • 456 square millimeters
  • Up to 22 processing cores

What are we doing with all these transistors?

https://en.wikipedia.org/wiki/Transistor_count
Then and Now

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

- Galaxy Note 8
  - 8 processing cores
  - Exynos 9 Octa 8895 processor

What are we doing with all these transistors?

https://en.wikipedia.org/wiki/Exynos
What are we doing with all these transistors?

- Everything these days!
  - Phones, cars, televisions, games, computers,...
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

*The Mysteries of Computing will be revealed!*