ESE 461
Design Automation for Integrated Circuit Systems

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http://classes.engineering.wustl.edu/ese461/
You are in the wrong class if you

- Have never taken a digital logic class (like CSE 260) before;
- Have never heard of MOSFET or CMOS or transistors before;
- Think writing and debugging programs are excruciatingly painful;
- Don’t like reasoning about automation algorithms for repetitive tasks;
- Are not interested in designing your very own integrated circuit chips.
Course Objectives

- Understand the design flow of modern IC
  - Very-large-scale integration (VLSI)
  - language: Verilog
  - tools: Synopsys, Cadence
  - process: design, simulation, synthesis, verification, test
  - principles: performance, power, other considerations

- Understand the basics of design automation
  - study the basic algorithms used in VLSI design
  - learn the automation techniques used in the tools

- Pique your interest to learn more on your own
  - introduce some cutting-edge research topics
Tentative Syllabus

- W1: Intro. Review combinational logic.
- W2: Labor day. Review sequential logic.
- W3: Review quiz, Linux and VCS tutorial.
- W3-W4: Verilog. Intro of design flow.
- W5: Logic synthesis.
- W6: Timing analysis.
- W7: Physical design.
- W8: Fall break. Class project intro.
- W9: I/O design and RC extraction.
- W10: Power optimization.
- W11: Hardware acceleration. HLS.
- W12: Reliability and security.
- W13: Conclusion. Thanksgiving.
- W14: Project presentation.
What is the big deal about IC?
Intelligence, everywhere
Moore’s Law
Inside an iPad Air 2

- Physical world interaction: camera
- Display / touch screen
- “Brains”: the main board
- Communication: Antenna
- Energy: Battery
- User interface device: home button
- Physical world interaction: speakers
iPad Main Board

- Maxim: Amplifier
- Micron RAM: The "Operating Memory"
- NXP NFC Chip for Apple Pay
- Texas Instruments: Touch Screen Controller
- Apple A8X: The "Brains" of the iPad Air 2
- Bosch: Accelerometer
- Cirrus Logic: Audio chip
- Hynix Flash Memory: The "Storage"
Interface to the Physical World: The camera

- Focus/Exposure Control
- Pre-processing
- White-balancing
- Demosaic
- Color Transform
- Post-processing
- Compression
Apple iPhone: The quintessential smart system

- Apple A8 APL1011 SoC + SK Hynix RAM as denoted by the markings H9CKNNN8KTMWR-NTH (we presume it is 1 GB LPDDR3 RAM, the same as in the iPhone 6 Plus)
- Qualcomm MDM9625M LTE Modem
- Skyworks 77802-23 Low Band LTE PAD
- Avago A8020 High Band PAD
- Avago A8010 Ultra High Band PA + FBARs
- SkyWorks 77803-20 Mid Band LTE PAD
- InvenSense MP67B 6-axis Gyroscope and Accelerometer Combo

source: ifixit.com
## Apple A8 vs A7 SoCs

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Manufacturing Process</td>
<td>TSMC 20nm HKMG</td>
<td>Samsung 20nm HKMG</td>
</tr>
<tr>
<td>Die Size</td>
<td>89mm(^2)</td>
<td>104mm(^2)</td>
</tr>
<tr>
<td>Transistor Count</td>
<td>~2B</td>
<td>&quot;Over 1B&quot;</td>
</tr>
<tr>
<td>CPU</td>
<td>2 x Apple Enhanced Cyclone ARMv8 64-bit cores</td>
<td>2 x Apple Cyclone ARMv6 64-bit cores</td>
</tr>
<tr>
<td>GPU</td>
<td>IMG PowerVR GX6450</td>
<td>IMG PowerVR G6430</td>
</tr>
</tbody>
</table>

*source: anandtech.com*
Why should we care now?
Bell’s Law of Computer Classes:
A new computing class roughly every decade

“Roughly every decade a new, lower priced computer class forms based on a new programming platform, network, and interface resulting in new usage and the establishment of a new industry.”

- Adapted from D. Culler
Intel® 4004 processor
Introduced 1971
Initial clock speed
108 KHz
Number of transistors
2,300
Manufacturing technology
10μ

UMich Phoenix Processor
Introduced 2008
Initial clock speed
106 kHz @ 0.5V Vdd
Number of transistors
92,499
Manufacturing technology
0.18 μ

source: Intel, U. Michigan
Case Study: Internet-of-Things (IoT)

Programs itself. Then pays for itself.

Meet the 3rd gen Nest Learning Thermostat. It's slimmer and sleeker with a bigger, sharper display. And it saves energy. That's the most beautiful part. Watch video

$249

BUY NOW

Get a $100 rebate from Ameren Missouri
Case Study: Internet-of-Things (IoT)

A Simple Explanation Of 'The Internet Of Things'
Libelium Smart World

Case Study: Internet-of-Things (IoT)

- **Air Pollution**
  - Control of CO₂ emissions from factories, pollution emitted by cars and toxic gases generated in farms.

- **Forest Fire Detection**
  - Monitoring of combustion gases and preemptive fire conditions to define alert zones.

- **Wine Quality Enhancing**
  - Monitoring soil moisture and trunk diameter in vineyards to control the amount of sugar in grapes and grapevine health.

- **Offspring Care**
  - Control of growing conditions of the offspring in animal farms to ensure its survival and health.

- **Sportsmen Care**
  - Vital signs monitoring in high performance centers and fields.

- **Structural Health**
  - Monitoring of vibrations and material conditions in buildings, bridges and historical monuments.

- **Smartphones Detection**
  - Detect iPhone and Android devices and in general any device which works with WiFi or Bluetooth interfaces.

- **Perimeter Access Control**
  - Access control to restricted areas and detection of people in non-authorized areas.

- **Radiation Levels**
  - Distributed measurement of radiation levels in nuclear power stations surroundings to generate leakage alerts.

- **Electromagnetic Levels**
  - Measurement of the energy radiated by cell stations and WiFi routers.

- **Traffic Congestion**
  - Monitoring of vehicles and pedestrian affluence to optimize driving and walking routes.

- **Smart Roads**
  - Warning messages and diversions according to climate conditions and unexpected events like accidents or traffic jams.

- **Smart Lighting**
  - Intelligent and weather adaptive lighting in street lights.

- **Intelligent Shopping**
  - Getting advice in the point of sale according to customer habits, preferences, presence of allergenic components for them or expiring dates.

- **Noise Urban Maps**
  - Sound monitoring in bar areas and centric zones in real-time.

- **Water Leakages**
  - Detection of liquid presence outside tanks and pressure variations along pipes.

- **Waste Management**
  - Detection of rubbish levels in containers to optimize the trash collection routes.

- **Vehicle Auto-diagnosis**
  - Information collection from CANbus to send real time alarms to emergencies or provide advice to drivers.

- **Smart Parking**
  - Monitoring of parking spaces availability in the city.

- **Item Location**
  - Search of individual items in big surfaces like warehouses or harbours.

- **Water Quality**
  - Study of water suitability in rivers and the sea for fauna and eligibility for drinkable use.

- **Golf Courses**
  - Selective irrigation in dry zones to reduce the water resources required in the green.
Case Study: Deep Learning Hardware

- **Artificial Intelligence (AI)**
- **Machine Learning**
  - a branch of machine learning
  - deep neural networks (DNN)
  - convolutional neural networks (CNN)
  - recurrent neural networks (RNN)
Nervana Engine delivers deep learning at ludicrous speed!

Nervana is currently developing the Nervana Engine, an application specific integrated circuit (ASIC) that is custom-designed and optimized for deep learning.

Training a deep neural network involves many compute-intensive operations, including matrix multiplication of tensors and convolution. Graphics processing units (GPUs) are more well-suited to these operations than CPUs since GPUs were originally designed for video games in which the movement of on-screen objects is governed by vectors and linear algebra. As a result, GPUs have become the go-to computing platform for deep learning. But there is much room for improvement — because the numeric precision, control logic, caches, and other architectural elements of GPUs were optimized for video games, not deep learning.
Case Study: Deep Learning Hardware

- Study group planned
  - meet once a week (Sunday afternoon)
  - faculty-moderated, students-led
  - read classic foundational papers in depth
  - discuss and criticize current research
  - envision emerging technology direction

- Objective
  - participate and lead the change
  - cultivate the habit of research
  - curate a community with shared interest, understanding and language, but diverse ideas
Outline

Course Objectives

Motivations

Course Administrivia
Instructional Staff
(see homepage for contact info, office hours)

Xuan ‘Silvia’ Zhang
(Tue 4-5pm)

Dengxue Yan
(Thur 3:30-5pm)
Prerequisites

- ESE 232: Introduction to Electronic Circuits
  - analysis and design of transistors
  - semiconductor memory devices

- ESE 260: Introduction to Digital Logic and Computer Design
  - combinational and sequential logic
  - logic minimization, propagation delays, timing

- Plus but not required
  - basic computer architecture
  - basic hardware description language (Verilog, VHDL)
  - basic Linux commands
Course Overview

• Course homepage:
  - http://classes.engineering.wustl.edu/ese461/

• Distribution
  - 30%: reading and learning
  - 70%: programming, debugging, design iteration

• Workload
  - no mid or final exams
  - in-class review quiz
  - homework
  - labs
  - one group final project

• Philosophy
  - learner-directed instruction
Final Project

• **Goal:** *learn by doing*
  - Work in teams of 2
  - Choose from a few suggested projects
  - Release around Week 8
  - Optimize design to meet/exceed performance goals
  - A custom designed IC chip as the end result

• **Evaluation**
  - Completion of the design flow
  - Performance achieved
  - Techniques applied
  - Presentation
  - Report
Grading

- Engagement  5%
- Review Quiz  10%
- Homework  10%
- Labs  40%
- Final Project  35%

Policy:
- 90% or above  A
- 80% - 89%  B
- 65% - 79%  C
- 45% - 64%  D
- 44% or below  F
Policies

• Submission
  - quiz, labs, homework due in class
  - 2-day grace period, then 50% penalty
  - no credits after 1 week, no exception

• Discussion & Collaboration
  - learning through discussion
  - help classmates to understand concepts
  - sharing code or schematics not-allowed

• Plagiarism
  - zero tolerance
  - specify sources to avoid confusion
Textbook

- Lecture Slides and Notes
- Tutorials
- Documentations

- Recommended Textbook
  - Application-Specific Integrated Circuits (ASICs... the book), by Michael John Sebastian Smith
  - online at EDACafe
Make and Hack

- Open Source Resources
- Community
- Explore and Have Fun
Questions?

Comments?

Discussion?