# 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

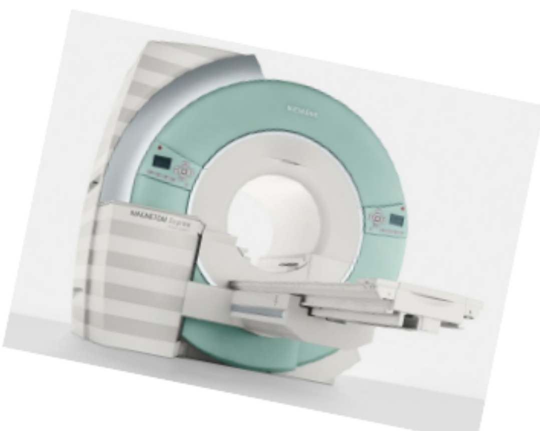
- Pique your interest to learn more on your own
  - introduce some cutting-edge research topics

# 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?

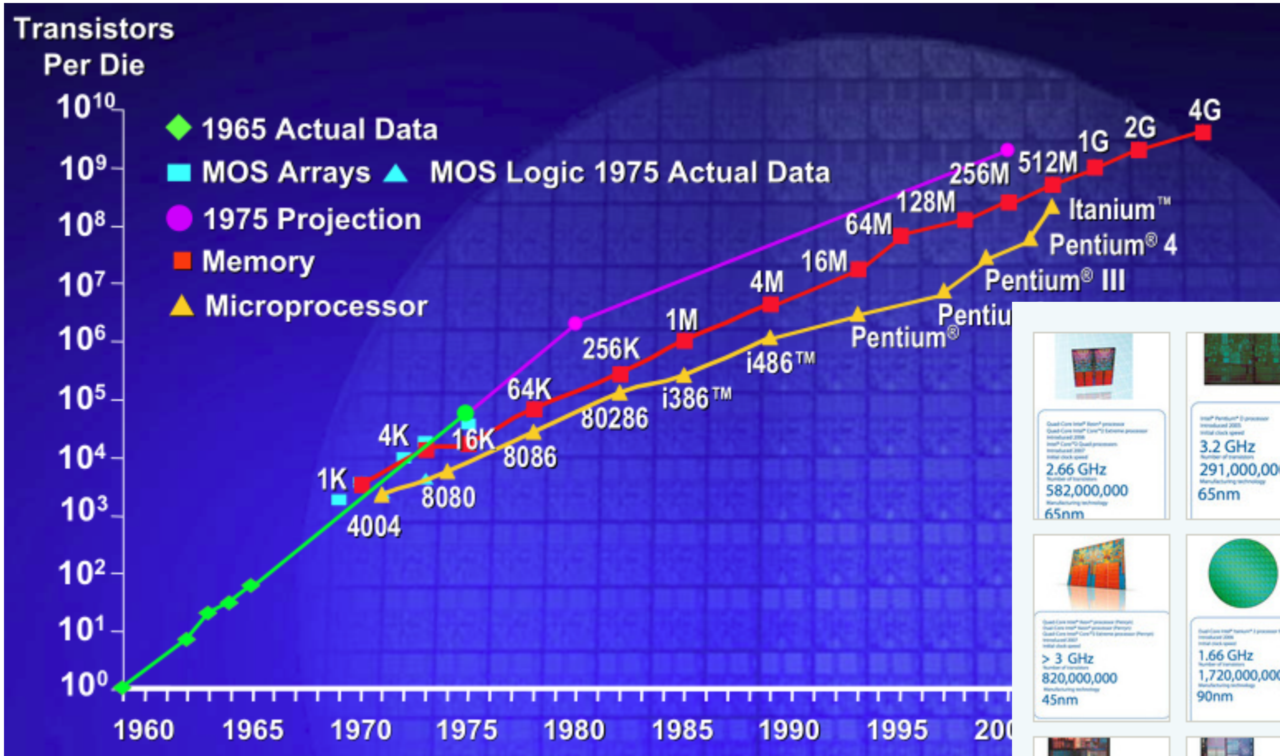
# Intelligence, everywhere

eZ430-Chronos
Wireless Development Tool

Texas Instruments
MSP430

# Moore's Law



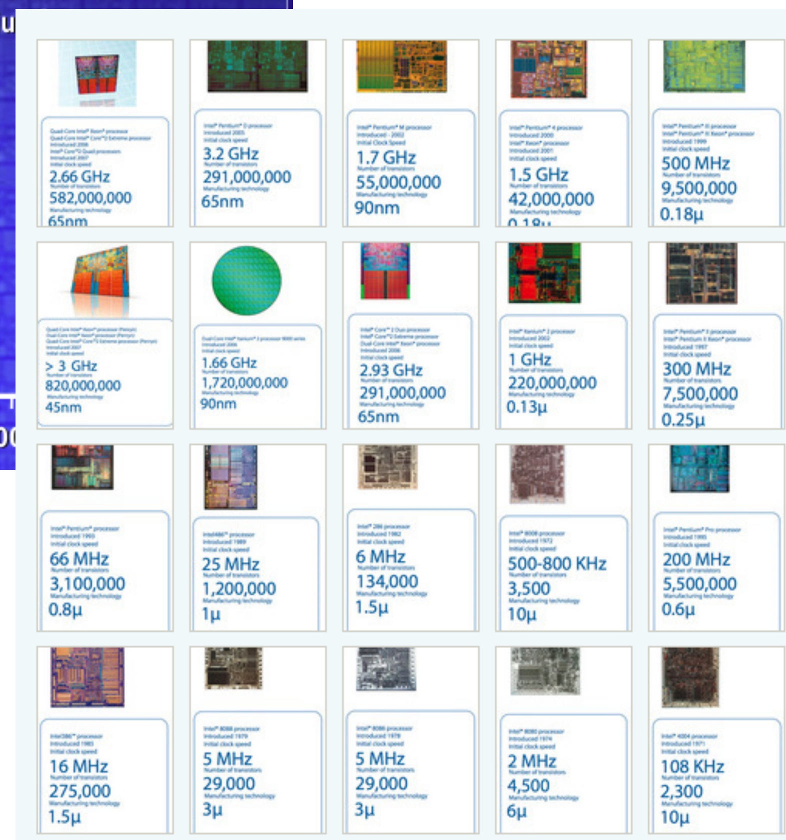
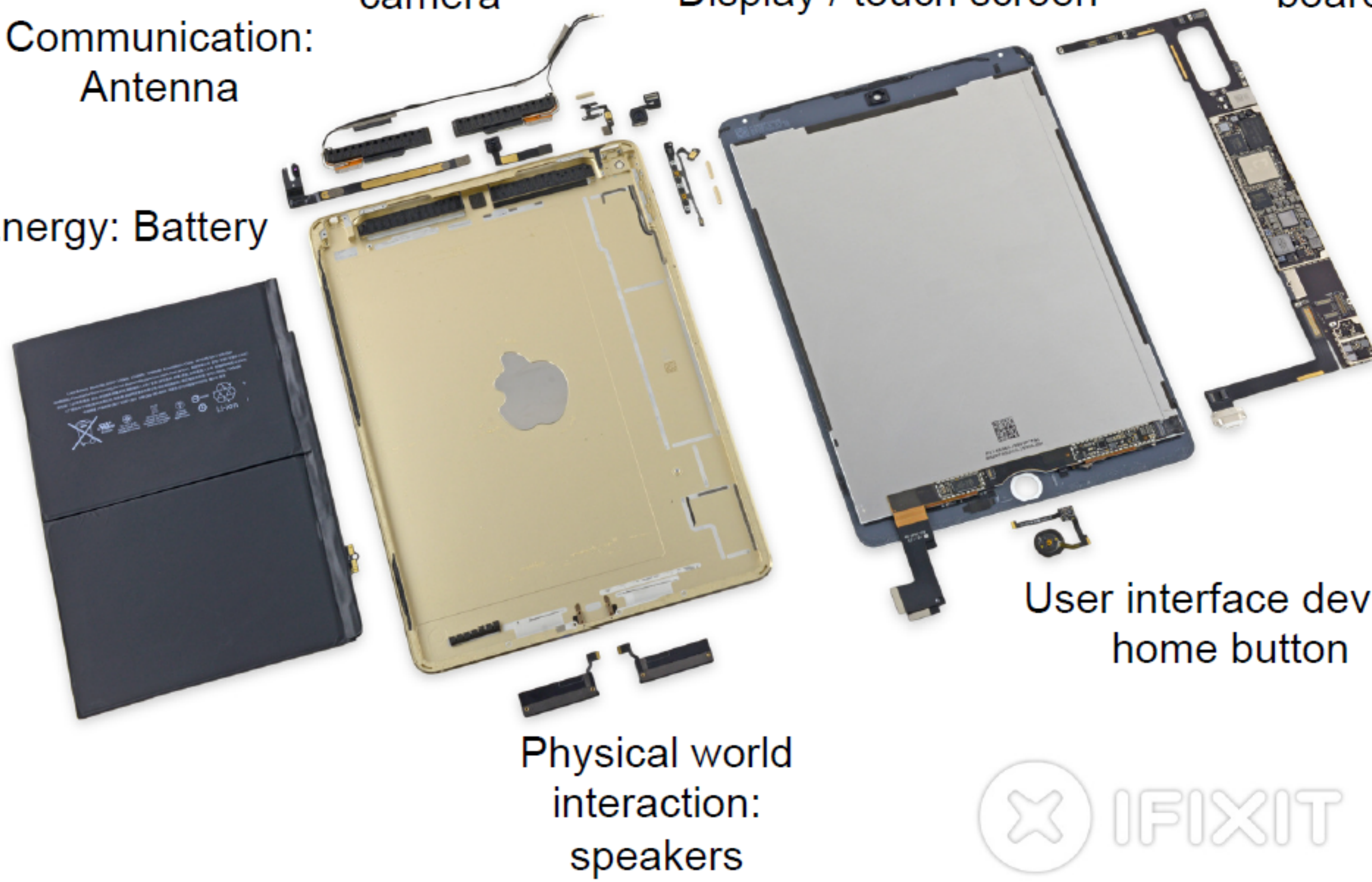
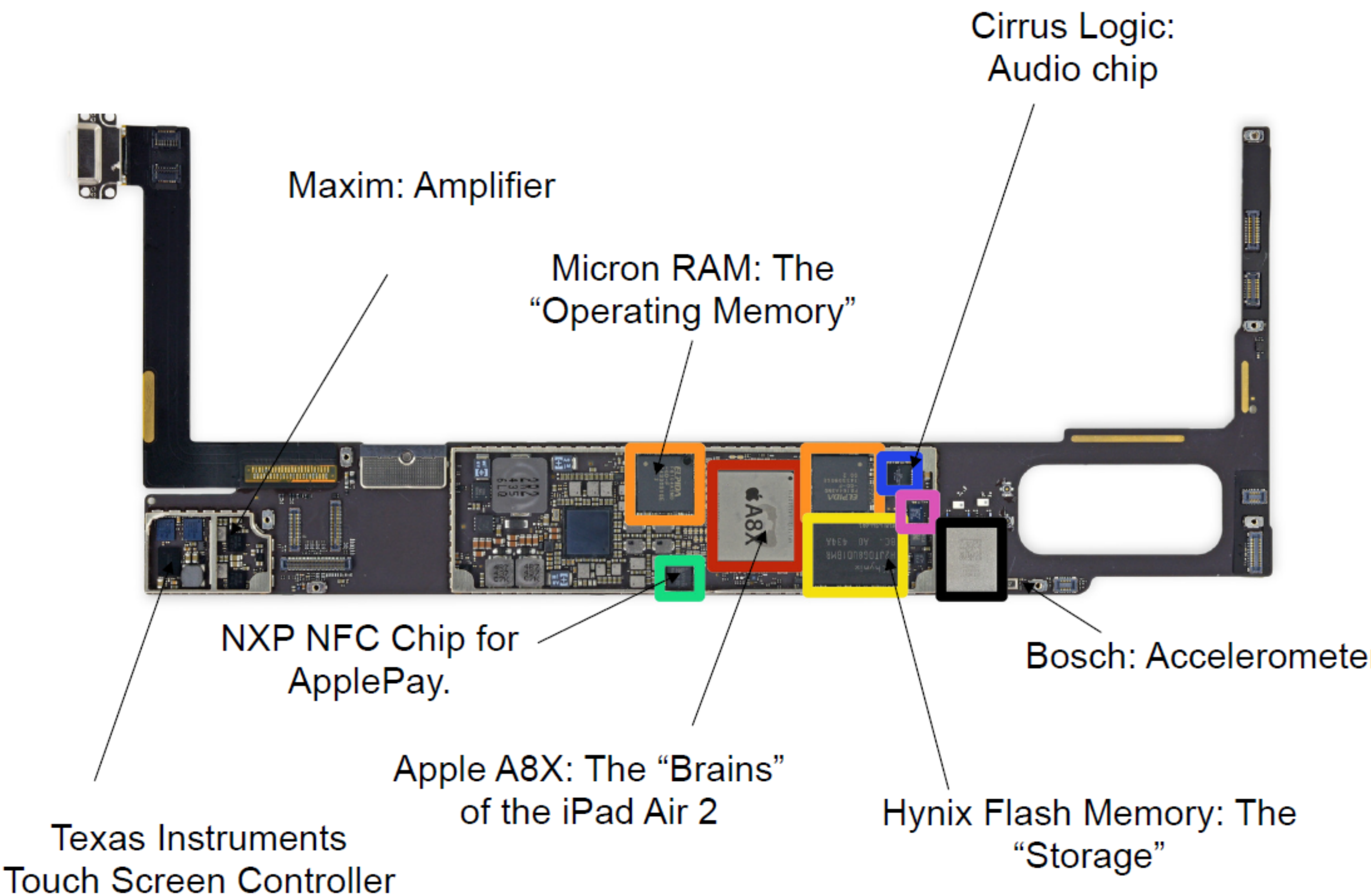




Photo Credit: Intel

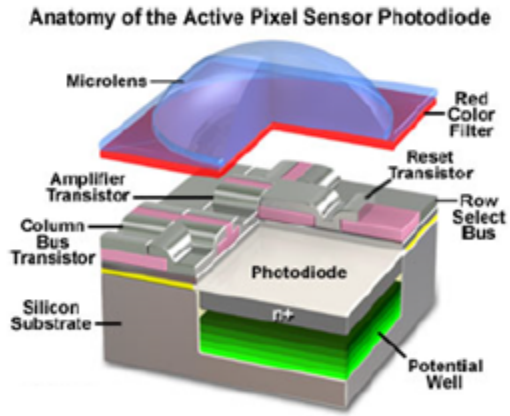
# Inside an iPad Air 2

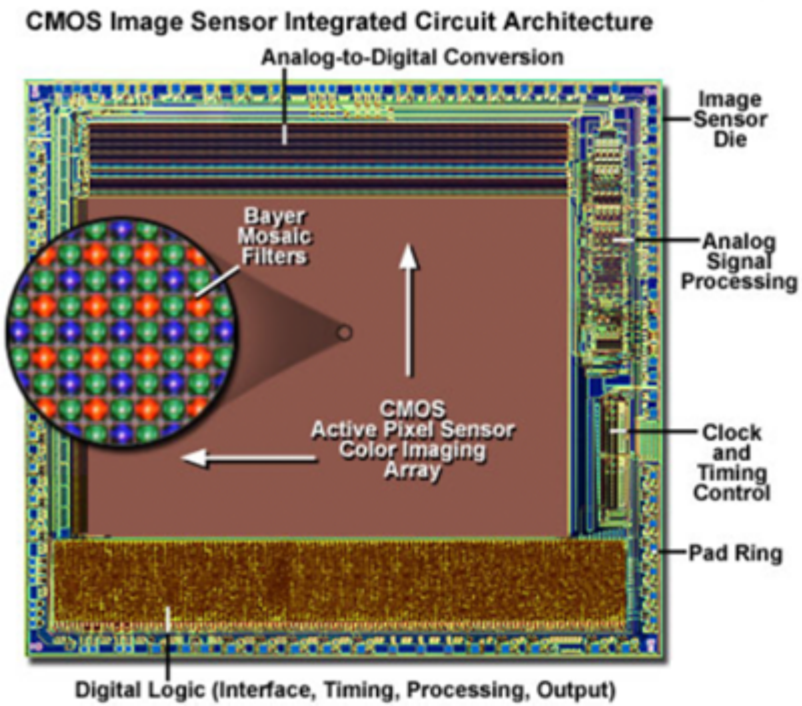


# iPad Main Board



# Interface to the Physical World: The camera

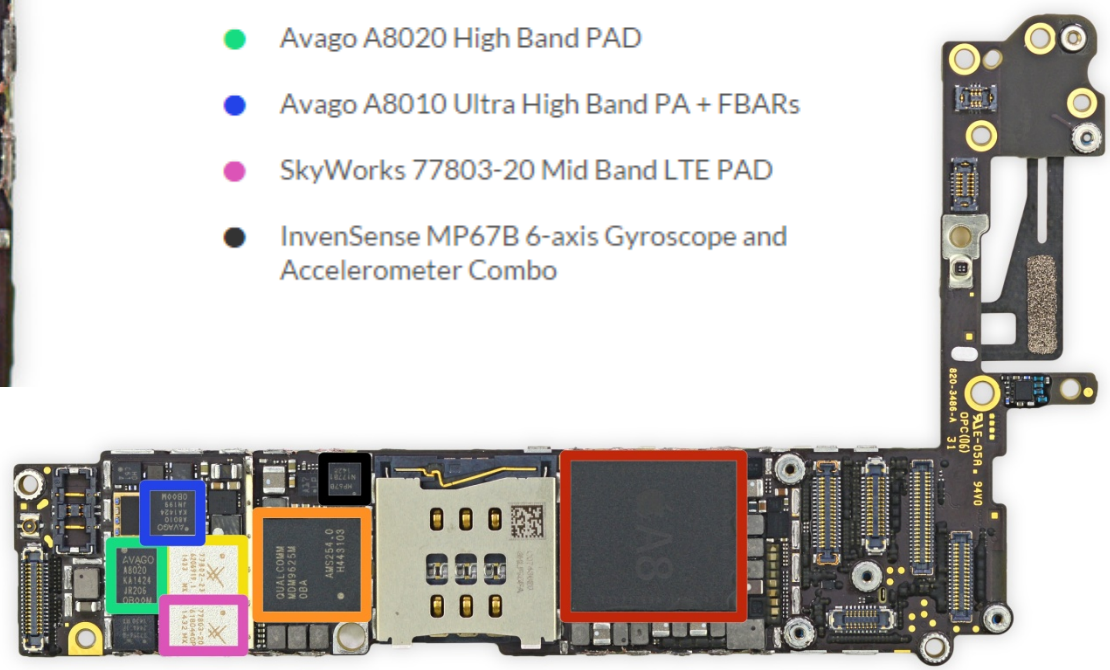




- Focus/Exposure Control
- Pre-processing
- White-balancing
- Demosaic
- Color Transform
- Post-processing
- Compression

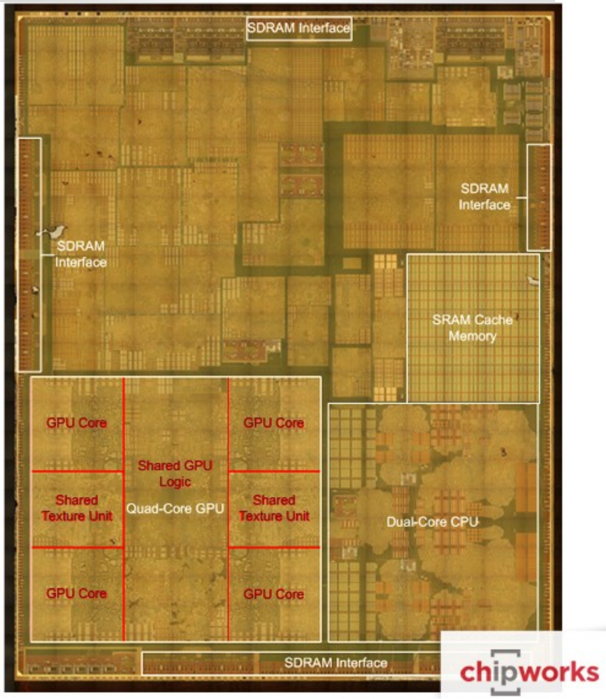
# Apple iPhone: The quintessential smart system


- Apple A8 APL1011 SoC + SK Hynix RAM as denoted by the markings H9CKNNN8KTMRWR-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

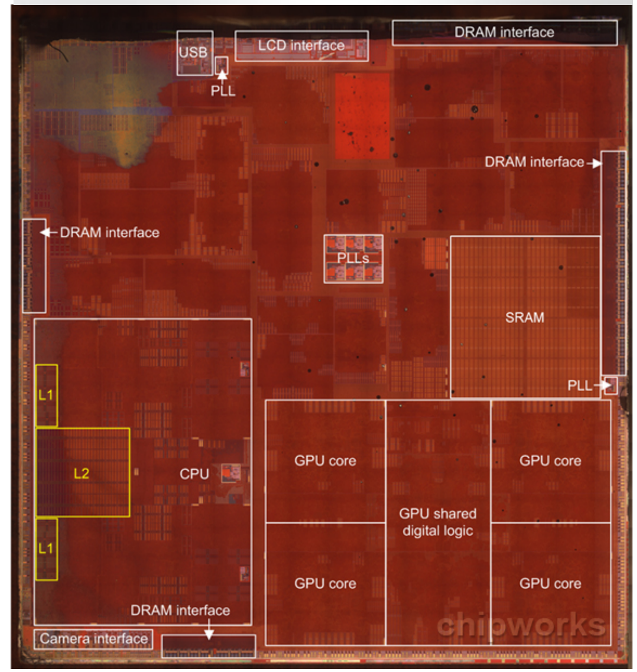


source: ifixit.com

**A8**
8.47 x 10.50 mm




**A7**
9.83 x 10.45 mm

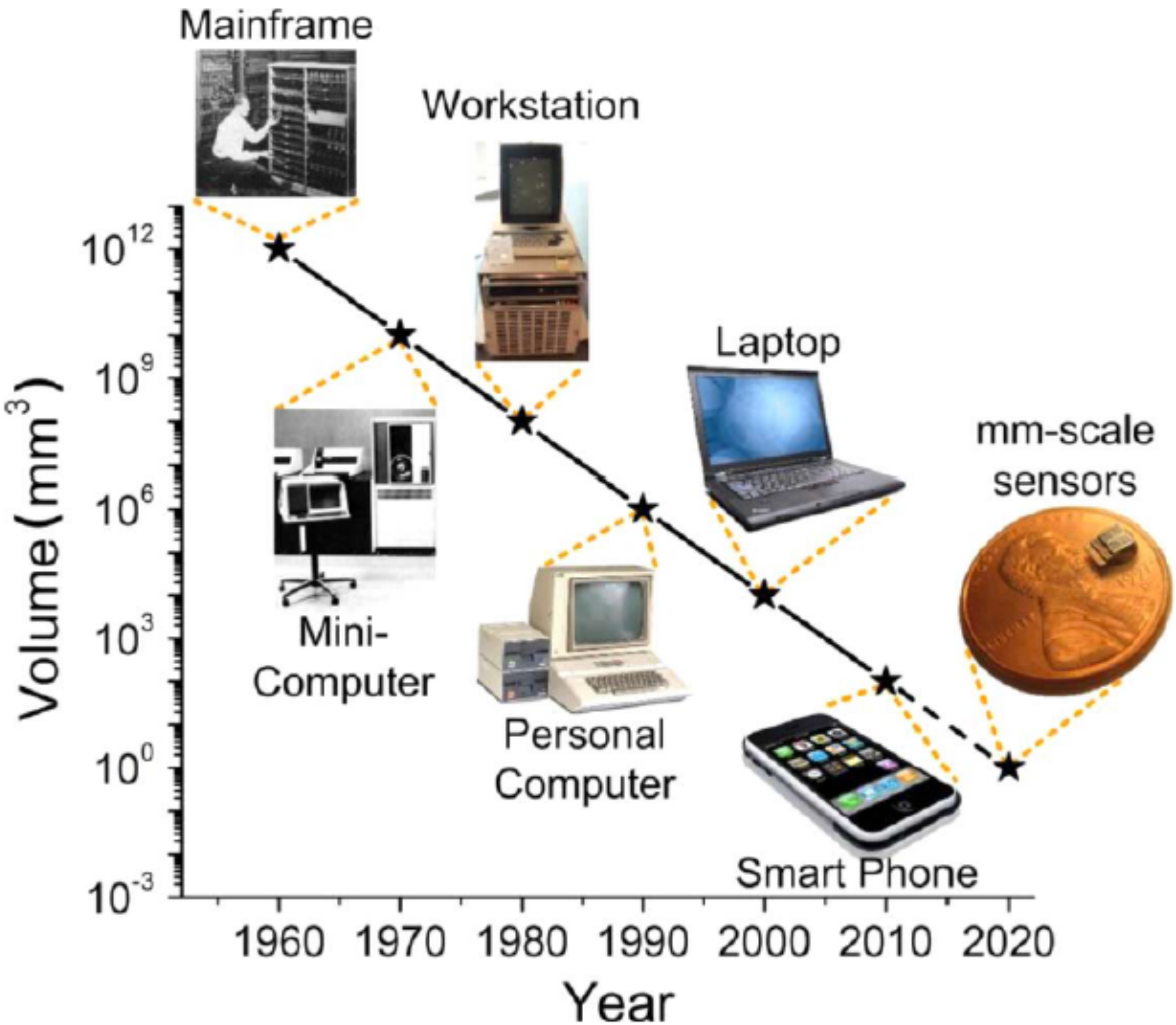



| Apple A8 vs A7 SoCs | | |
|---|---|---|
| | Apple A8 (2014) | Apple A7 (2013) |
| **Manufacturing Process** | TSMC 20nm HKMG | Samsung 28nm HKMG |
| **Die Size** | 89mm$^2$ | 104mm$^2$ |
| **Transistor Count** | ~2B | "Over 1B" |
| **CPU** | 2 x Apple Enhanced Cyclone ARMv8 64-bit cores | 2 x Apple Cyclone ARMv8 64-bit cores |
| **GPU** | IMG PowerVR GX6450 | IMG PowerVR G6430 |

source: anandtech.com

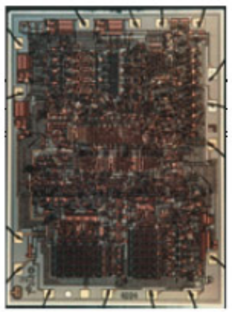
Why should we care now?

# 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."*

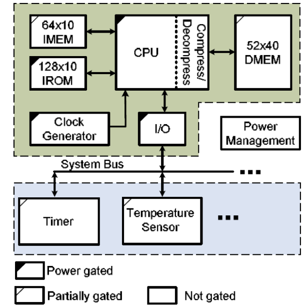
– Adapted from D. Culler

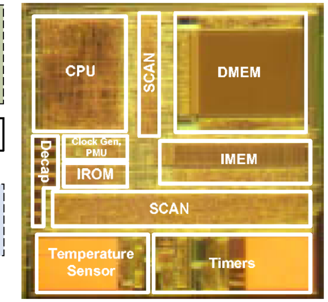


Intel® 4004 processor
Introduced 1971
Initial clock speed
108 KHz
Number of transistors
2,300
Manufacturing technology
10µ

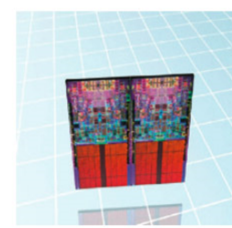
source: Intel, U. Michigan

**15x size decrease**
**40x transistors**
**55x smaller λ**



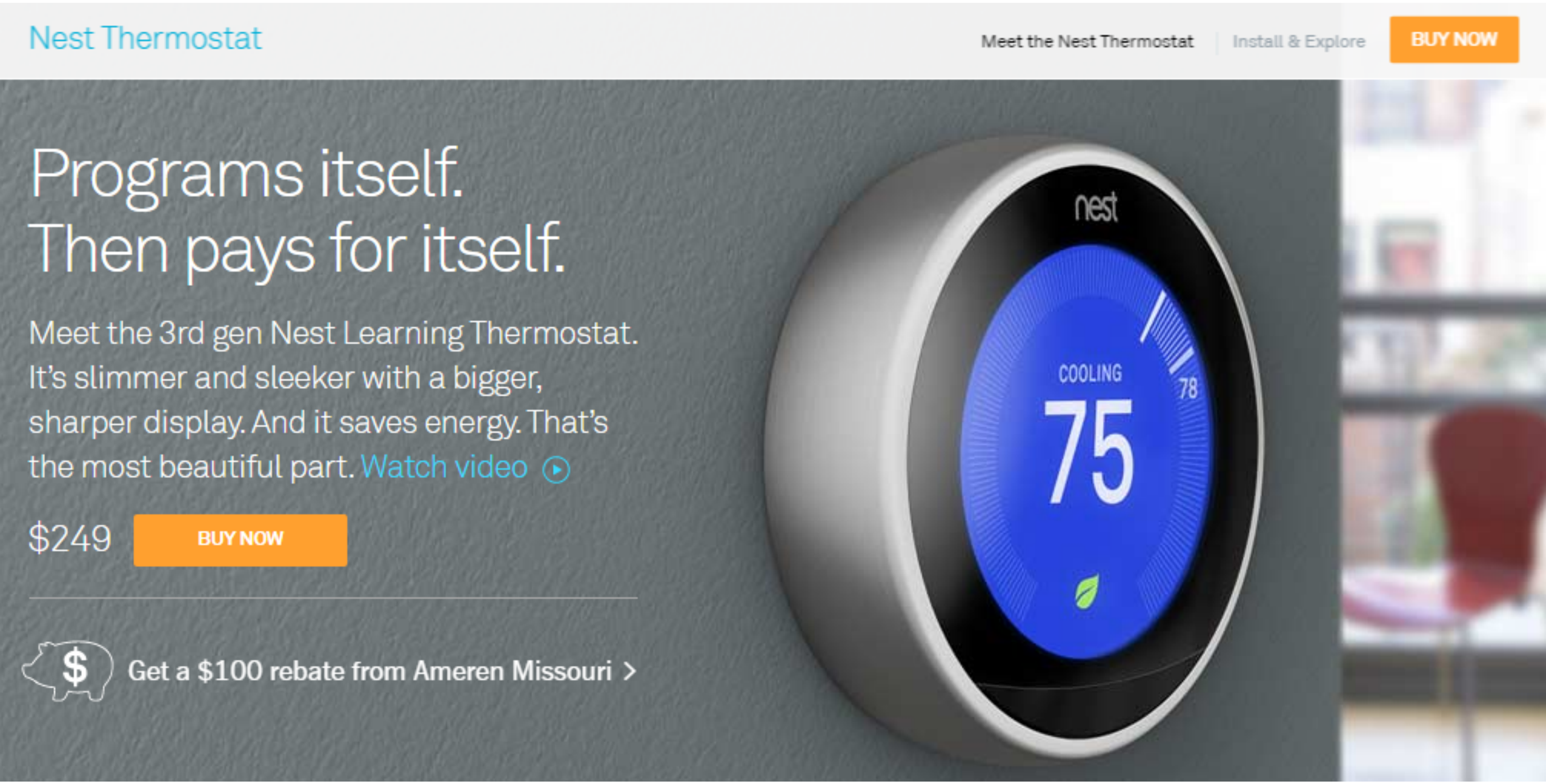




UMich Phoenix Processor
Introduced 2008
Initial clock speed
106 kHz @ 0.5V Vdd
Number of transistors
92,499
Manufacturing technology
0.18 µ

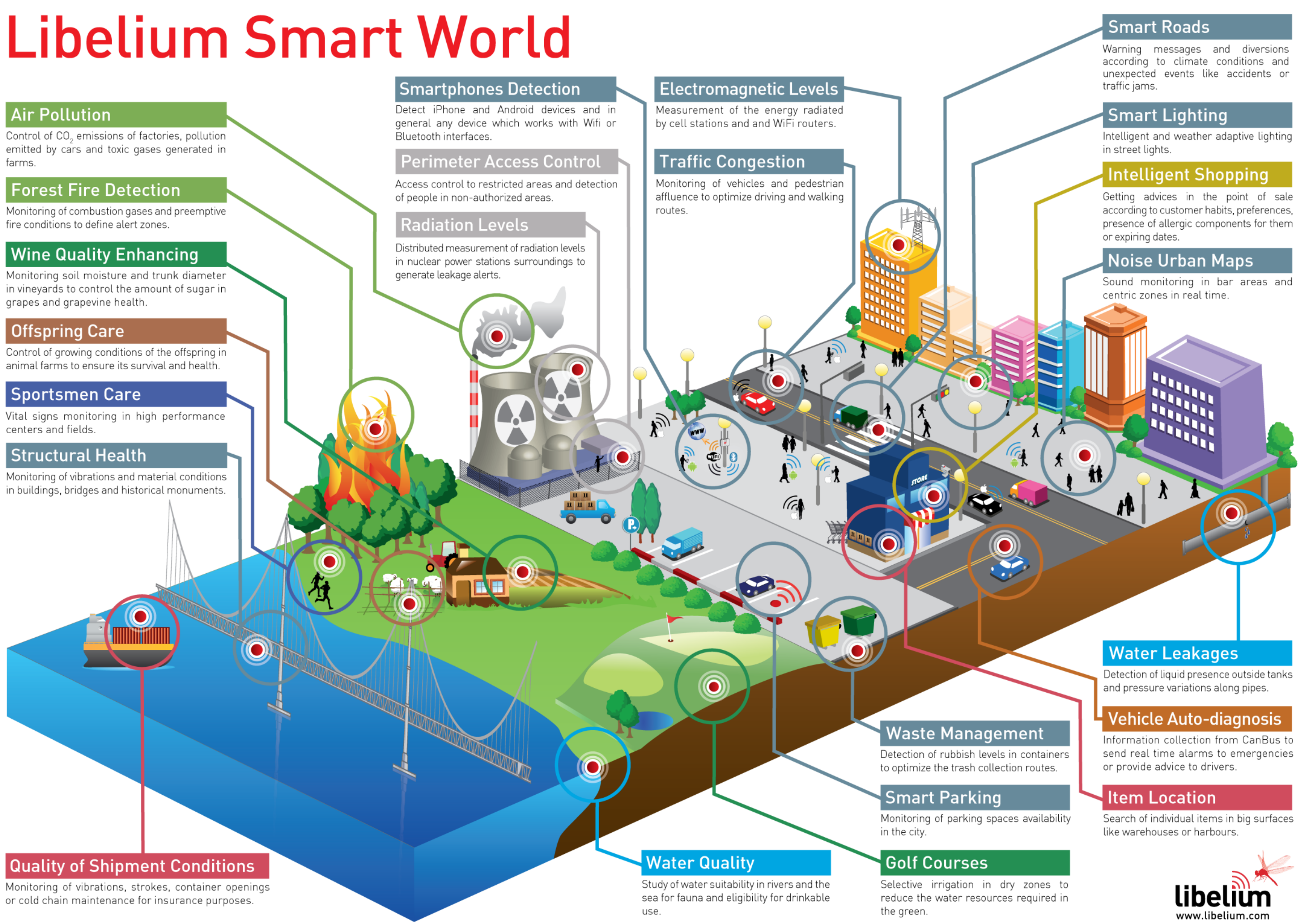


Quad-Core Intel® Xeon® processor
Quad-Core Intel® Core™2 Extreme processor
Introduced 2006
Intel® Core™2 Quad processors
Introduced 2007
Initial clock speed
2.66 GHz
Number of transistors
582,000,000
Manufacturing technology
65nm

# Case Study: Internet-of-Things (IoT)

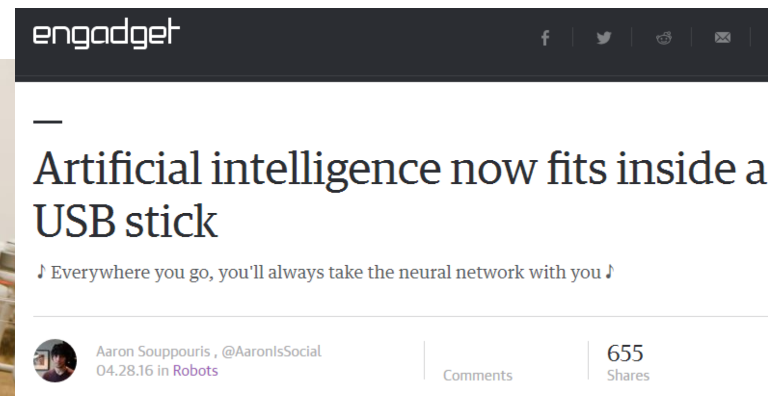


# Case Study: Internet-of-Things (IoT)


Libelium Smart World
Air Pollution
Control of $CO_2$ emissions of 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 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 advices in the point of sale according to customer habits, preferences, presence of allergic 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.
Vehicle Auto-diagnosis
Information collection from CanBus to send real time alarms to emergencies or provide advice to drivers.
Item Location
Search of individual items in big surfaces like warehouses or harbours.
Waste Management
Detection of rubbish levels in containers to optimize the trash collection routes.
Smart Parking
Monitoring of parking spaces availability in the city.
Golf Courses
Selective irrigation in dry zones to reduce the water resources required in the green.
Water Quality
Study of water suitability in rivers and the sea for fauna and eligibility for drinkable use.
Quality of Shipment Conditions
Monitoring of vibrations, strokes, container openings or cold chain maintenance for insurance purposes.
STORE
libelium
www.libelium.com

# 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)


engadget

Artificial intelligence now fits inside a USB stick

♪ Everywhere you go, you'll always take the neural network with you ♪

Aaron Souppouris , @AaronIsSocial
04.28.16 in Robots

Comments

655
Shares

# Case Study: Deep Learning Hardware

Movidius

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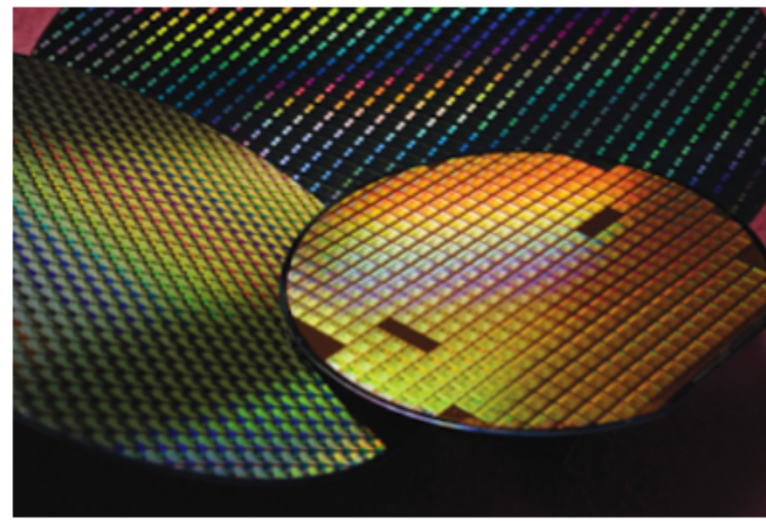
## Nervana Engine delivers deep learning at ludicrous speed!



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

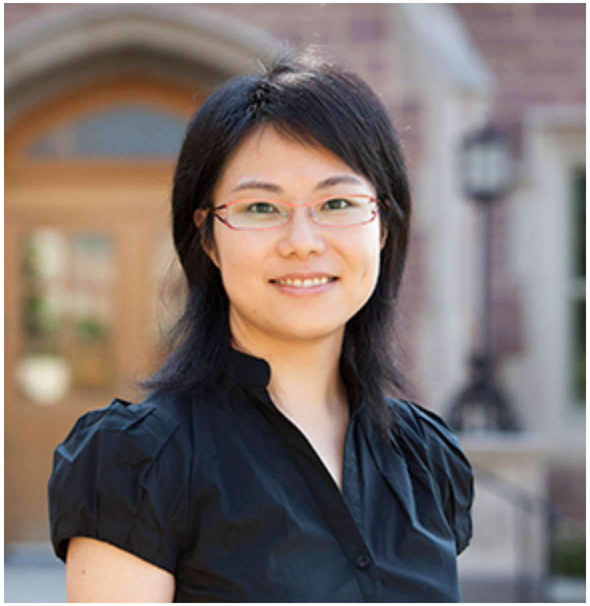
# Outline

Course Objectives

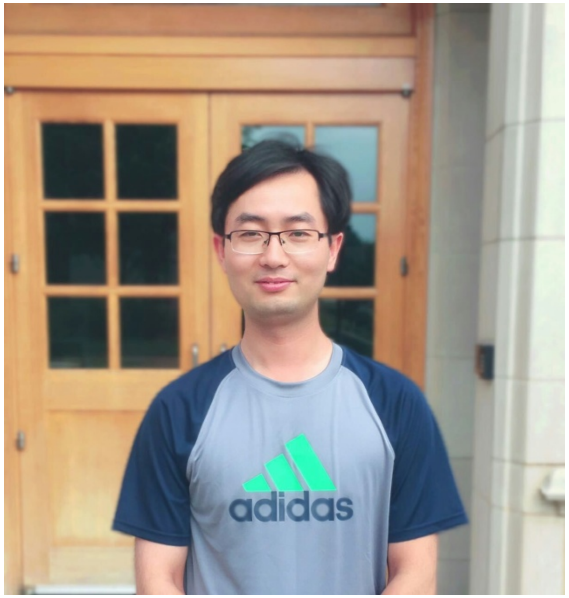
Motivations

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
  - http://www10.edacafe.com/book/ASIC/ASICs.php

# Make and Hack

- Open Source Resources

- Community

- Explore and Have Fun

Questions?

Comments?

Discussion?