EECS251B : Advanced Digital Circuits and Systems

Lecture 1 – Introduction

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Tuesdays and Thursdays 9:30-11am
Cory 540AB

Class Goals and Expected Outcomes
Practical Information

- **Instructors:**
  - Borivoje Nikolić
    - Physical location (some day): Cory Courtyard, 3-9297, bora@eecs
    - Office hours: Th 11am-12pm, or by appointment
  - Vladimir Stojanović
    - Office hours: TBD
  - Sophia Shao (ysshao@berkeley.edu)
    - Office hours: Tu 2pm-3pm, or by appointment

- **GSI:**
  - Erik Anderson  
  - erik.f.anderson@berkeley

Class Discussion
http://piazza.com/berkeley/spring2022/eecs251b
Sign up for Piazza!

Class Web page
  inst.eecs.berkeley.edu/~eecs251b

Class Topics

- **This course aims to convey a knowledge of advanced concepts of digital circuit and system design in state-of-the-art technologies.**
  - Emphasis is on the circuit and system design and optimization for both energy efficiency and high performance for use in a broad range of applications, from edge computing to datacenters. Special attention will be devoted to the most important challenges facing digital circuit designers in the coming decade. The course is accompanied with practical laboratory exercises that introduce students to modern tool flows.

- We will use qualitative analysis when practical

- Many case studies will be used to highlight the enabling design techniques
EECS251A vs. EE251B

- **EECS 251A:**
  - Emphasis on digital logic design
  - (Very) basic transistor and circuit models
  - Basic circuit design styles
  - First experiences with design – creating a solution given a set of specifications
  - A complete pass through the design process

- **EECS 251B:**
  - Understanding of technology possibilities and limitations
  - Transistor models of varying accuracy
  - Design under constraints: power-constrained, flexible, robust, ...
  - Learning more advanced techniques
  - Study the challenges facing design in the coming years
  - Creating new solutions to challenging design problems, design exploration

Special Focus in Spring 2021

- SoC systems and components
- Current technology issues
- Process variations
- Robust design
- Memory
- Energy efficiency
- Power management
Class Topics

• Module 1: Fundamentals – SoC design template, languages (1.5 weeks)
• Module 2: Current technologies (1 wk)
• Module 2: Models – From devices to gates, logic and systems (2 wks)
• Module 3: Design for performance (1.5 wks)
• Module 4: Memory, SRAM, variability, scaling options (2.5 wks)
• Module 5: Energy-efficient design (3 wks)
• Module 6: Clock and power distribution (1 week)
• Project presentations, final exam (1 week)

Class Organization

• 5 (+/-) assignments, with embedded labs (20%)
• 4 quizzes (10%)
• 1 term-long design project (40%)
  • Phase 1: Topic selection (Feb 24, after ISSCC)
  • Phase 2: Study (report by March 18, before Spring break)
  • Phase 3: Design (report in RRR week)
  • Presentations, May 2, afternoon
• Final exam (30%) (Thursday, April 28, in-class)
Class Material

  - Available at link.springer.com
- Other reference books:
  - “CMOS VLSI Design,” 4th ed, by N. Weste, D. Harris

Class Material

- List of background material available on website
- Selected papers will be made available on website
  - Linked from IEEE Xplore and other resources
  - Need to be on campus to access, or use library proxy, library VPN (check http://library.berkeley.edu)
- Class notes on website
Reading Assignments

• Three types of readings:
  • Assigned reading, that should be read before the class
  • Recommended reading that covers the key points covered in lecture in greater detail
  • Occasionally, background material will be listed as well

Reading Sources

• IEEE Journal of Solid-State Circuits (JSSC)
• IEEE International Solid-State Circuits Conference (ISSCC)
  • Symposium on VLSI Technology and Circuits (VLSI)
  • Other conferences and journals
Project Topics

- Focus this semester: Memories, power management, clocking
- Project teams: 2+ members, proportional to the size of the project
  - Can also do a bigger project merging with 290C or 252 classes
  - More details in Week 2

Tools

- 7nm predictive model (ASAP7), with (mostly) complete design kit
  - Or Intel 16 process if enrolled in 290C as well
- Cadence, Synopsys, available on instructional servers
- Berkeley’s open-source flows and tools
  - Chipyard, Hammer
- Other open-source models
Zoom

- Will post recordings. But focus on interactive lectures
  - May pre-record some modules in advance
- Course notes available in advance.
  - Be engaged in the discussions. You are part of the learning process.

Trends and Challenges in Digital Integrated Circuit Design
Reading (Lectures 1 & 2)

- **Assigned**
  - Rabaey, LPDE, Ch 1 (Introduction)
  - G.E. Moore, No exponential is forever: but “Forever” can be delayed! Proc. ISSCC’03, Feb 2003.

- **Recommended**
  - Chandrakasan, Bowhill, Fox, Chapter 1 - Impact of physical technology on architecture (J.H. Edmonds),

- **Background:** Rabaey et al, DIC Chapter 3.

The contributions to this lecture by a number of people (J. Rabaey, S. Borkar, etc) are greatly appreciated.

Class in a Nutshell

- Design decisions needed to make a modern SoC
  - CPUs
  - SoC Components
  - Interconnect
  - Clocking
  - Memory
  - Power management

https://www.techinsights.com/blog/two-new-apple-socs-two-market-events-apple-a14-and-m1

Current State of Semiconductor Industry

Worldwide semiconductor market size, 1987-2022


Current gross world product (GWP) ~ 88,000 billion (Wikipedia)
Moore’s Law

- In 1965, Gordon Moore noted that the number of transistors on a chip doubled every 12 months.
- He made a prediction that semiconductor technology will double its effectiveness every 12 months.

“*The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term, this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000.”*

Gordon Moore, Cramming more Components onto Integrated Circuits, (1965).
Moore’s Law – 1965

“Reduced cost is one of the big attractions of integrated electronics, and the cost advantage continues to increase as the technology evolves toward the production of larger and larger circuit functions on a single semiconductor substrate.”

Electronics, Volume 38, Number 8, April 19, 1965

Moore’s Law – 2005

Graph from S. Chou, ISSCC’2005

Source: Intel
Moore’s Law - 2020

Moore’s Law: The number of transistors on microchips doubles every two years. Moore’s Law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

Transistor count:

- 50,000,000
- 100,000,000
- 1,000,000,000
- 2,000,000,000
- 10,000,000,000
- 50,000,000,000
- 100,000,000,000
- 1,000,000,000,000
- 2,000,000,000,000
- 5,000,000,000,000
- 10,000,000,000,000
- 25,000,000,000,000
- 50,000,000,000,000


Moore’s Law and Cost

Transistor Price

- Ten
- One
- One Tenth
- One Hundredth
- One Thousandth
- One Ten Thousandth
- One Hundred Thousandth
- One Millionth
- One Ten Millionth

Moore’s Law: Starts 1965

Transistor Price in US Dollars

- One
- One Tenth
- One Hundredth
- One Thousandth
- One Ten Thousandth
- One Hundred Thousandth
- One Millionth
- One Ten Millionth
Progress in Nano-Technology

Spintronic Storage
Molecular Electronics
Silicon Nanowires
Carbon Nanotubes
Nanomechanics

T.C. Chen, Where Si-CMOS is going: Trendy Hype vs. Real Technology, ISSCC'06

Technology Strategy / Roadmap

Plan A: Extending Si CMOS
Plan B: Subsytem Integration
Plan C: Post Si CMOS Options
Plan Q: Quantum Computing

T.C. Chen, Where Si-CMOS is going: Trendy Hype vs. Real Technology, ISSCC'06
Printed vs. Physical Gate

Source: Intel, IEDM presentations

Transistors are Changing

- From bulk to finFET and FDSOI

Bulk
SiO₂/SiN
Strain
FinFET
HK/MG
Strain

TSMC
Samsung

Intel, IEDM'07
IEDM'09

Intel, IEDM'12
VLSI'14

Intel, IEDM'17

ST,
VLSI'12

TSMC 7nm
(hexus.net)
Varying Flavors in Each Node

• 32nm (and 28nm): Various flavors - Intel

<table>
<thead>
<tr>
<th>Logic Transistor (HP or SP)</th>
<th>Low Power Transistor (LP)</th>
<th>HV I/O Transistor (1.8 V or 3.3 V)</th>
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<tbody>
<tr>
<td>Lg = 30/34nm</td>
<td>Lg = 46nm</td>
<td>Lg &gt; 140nm</td>
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C.-H. Jan, IEDM’09, P. VanDerVoorn, VLSI Tech’10

5nm Flavors

Fig. 3 The 5nm also offers a set of critical HPC features. Extremely LVT (eLVT) for 25% faster peak speed over 7nm, and HPC 3-fin standard cell for additional 10% performance.

TSMC, IEDM’19
Putting Scaling in Perspective

Performance gains over the past decade

Lisa Su, HotChips’19 keynote

Power and Performance Trends

• What do we do next?
Cost Of Developing New Products

- These are non-recurring (NRE) costs, need to be amortized over the lifetime of a product
- We will attempt to dismantle this...

Major Roadblocks

1. Managing complexity
   How to design a 10 billion (100 billion) transistor chip?
   And what to use all these transistors for?

2. Cost of integrated circuits is increasing
   It takes >>$10M to design a chip
   Mask costs are many $M in 16nm technology
   Wafer costs are increasing

3. Power as a limiting factor
   End of frequency scaling
   Dealing with power, leakages

4. Robustness issues
   Variations, SRAM, memory, soft errors, signal integrity

5. The interconnect problem
Next Lecture

- Chipyard as an SoC template