ESE370: Circuit-Level Modeling, Design, and Optimization for Digital Systems

Day 1: August 26, 2015
Introduction and Overview
Where I come from

- Analog VLSI Circuit Design
- Convex Optimization
  - System Hierarchical Optimization
- Biomedical Electronics
- Biometric Data Acquisition
  - Compressive Sampling
- ADC Design
- Low Energy Circuits
  - Adiabatic Charging
MicroImplant: An Electronic Platform for Minimally Invasive Sensory Monitors

Signal Sensing and Processing

Energy Management

Data Collection and Transmission

Penn ESE370 Fall 2015 – Khanna
Outline

- Motivating questions
- What this course is about
- Learning objectives
- What you need to know
- Course Structure
- Course Policies
- Course Content
Motivating Questions

- How fast can my computer run?
  - What limits this speed?
  - What can I do to make it run faster?

- How can I extend the battery life on my gadget?
  - How much energy must my computation take?

- How small can I make a memory?
  - Why does DRAM need to be refreshed?
Motivating Questions (con’t)

- How many bits/second can I send over a link?
  - What limits this?
  - How do I maximize?

- How does technology scaling change these answers?
  - What can I rely on technology to deliver?
Sample Problems

- What does this circuit do? How fast does it operate?
Sample Problems (con’t)

- What’s wrong here? How do we fix it?
Limits?

- Consider a 22nm technology
- Typical gate with $W=3$, 2-input NOR
- Use chip in cell phone
- What prevents us from running 1 billion transistor chip at 10GHz?
Impact of Voltage?

- If have a chip running at 1GHz with a 1V power supply dissipating 1W.
- What happens if we cut the power supply to 500mV?
  - Speed?
  - Power?
Course Deconstruction

- Circuit-Level Modeling, Design, and Optimization for Digital Systems

  - Look below the gates
    - ...transistors, resistance, capacitance, inductance...
  - Abstract and predict
  - Create
  - Make efficient (fast, low energy, small)
  - Compute, store, transmit binary values (0s, 1s)
What this course is about

- Modeling and abstraction
  - Predict circuit behavior
  - Well enough to know our design will work
  - …with given specs
    - Performance, speed, energy, ….
  - Well enough to reason about design and optimization
    - What knob can I turn to make faster?
    - How much faster can I expect to make it?
What this course is about (con’t)

- Modeling and abstraction
  - Back-of-the-envelope
    - Simple enough to reason about
      - …without a calculator…
  - Sensitive to phenomenology
    - Able to think through the details
  - With computer assistance
    - …understanding even that is a simplified approximation
We are here.

CIS120

CIS380

CIS240

CIS371, ESE534

ESE170

We are here.

ESE205/215, ESE319

ESE218

Phys151
Learning Objectives

- Disciplines for robust digital logic and signaling
  - (e.g., regeneration, clocking)
- Where delay, energy, area, and noise arise in gates, memory, and interconnect
- Modeling these physical effects
  - back-of-the-envelope design
    - (e.g. RC and Elmore delay)
  - detailed simulation (e.g. SPICE)
Learning Objectives (con’t)

- Tradeoffs in performance specs
  - Among delay, energy, area, noise

- How to design and optimize
  - Logic, memory, and interconnect structures
  - At the gate, transistor, and wire level

- How technology scales
  - Impact on digital circuits and computer systems
What you need to know

- See pages linked from course page
- CIS 170
  - Gates, Boolean logic, DeMorgan’s, optimization
- ESE 215
  - RLC circuit analysis
  - Diagnostic Quiz on Canvas
    - Not graded, weighted as a homework assignment
    - Complete by Monday class time
Review Session Poll

Will work?
- Thursday 5pm?
- Thursday 6pm?
- Thursday or Friday 7pm?
- Thursday or Friday 8pm?
Course Structure

- MWF Lecture
- Readings from text
- 4 lecture periods ➔ Detkin Lab
- Class cancelled for Pope visit
- Office hours
  - Khanna – Monday 3-4:30 pm and by appointment
  - Giesen – Tuesday 6-8 pm
Course Structure - Lectures

- Better if interactive, everyone engaged
  - Asking and answering questions
  - Actively thinking about material
- Two things
  - Preclass exercises
    - Work during ~5 minutes before lecture starts
    - Prime for topic of the day
  - Ask questions of individuals
Course Structure - SPICE

- Simulation Program with Integrated Circuit Emphasis
  - Industry standard analog circuit simulator
  - Non-linear, differential equation solver specialized for circuits
- Integrated circuits – simply impractical to build to debug
  - Must simulate to optimize/validate design
Course Structure - Assignments/Exams

- Homework – week long (8 total) [25%]
  - Due Wednesdays at start of class (12pm)
- Projects – two weeks long (2 total) [30%]
  - Design oriented
  - On two main topics
    - Computation
    - Storage
- Two midterms [20%]
- Final [25%]
Course Structure - Admin

- Use course calendar
  - Lectures online before class
    - (most of the time)
    - Reserve the right to change them
  - Homeworks linked
    - Homework 1 out now
  - Diagnostic quiz available now
  - Reading for whole term specified

- Take notes!
Course Policies

See web page for full details

- Turn homework in class
  - Anything handwritten/drawn must be clearly legible
  - Submit CAD generated figures, graphs, results when specified
  - NO LATE HOMEWORKS!

- Individual work (HW & Project)
  - CAD drawings, simulations, analysis, writeups
  - May discuss strategies, but acknowledge help
Course Content

- Logic (Computation) [8 weeks]
  - Combinational
  - Sequential
- Memory/Storage [2 weeks]
- Communication/Interconnect [3 weeks]
Course Content (con’t)

- Logic
  - Transistors → Gates
  - **In Lab:** build gate, measure delay
  - Regeneration
  - Delay
  - Area (no layout → ESE570)
  - Energy
  - Synchronous (flip-flops, clocking, dynamic)
  - **Project 1:** fast ripple-carry adder
Course Content (con’t)

- Memory/Storage
  - No Lab component
  - RAM Organization
  - Driving Large Capacitances
  - Signal amplification/regeneration
  - Project 2: design a SRAM Register File
Course Content (con’t)

- Communication/Interconnect
  - In Lab
    - Measure inductive ground bounce, crosstalk
    - Experiment with transmissions lines, termination
  - Noise
    - Crosstalk
    - Inductive
    - Ionizing particles, shot
  - Transmission Lines
Advice

- Course is hard (but valuable)
- Should be thinking about this material every day
- MUST READ TEXT!
- Learning is spread over all components
  - Lecture, reading, homeworks, projects, exams
- Must be able to get quantitative answers to get an A (maybe even for B)
Wrap up

- Admin
  - Find web, get text, assigned reading…
  - http://www.seas.upenn.edu/~ese370
  - https://piazza.com/upenn/fall2014/ese370/home
  - https://canvas.upenn.edu/courses/1294989

- Big Ideas/takeaway
  - Model (a.k.a. analysis and simulation) to enable real-life design

- Diagnostic Quiz in Canvas
  - Review as needed

- Remaining Questions?