ESE535: Electronic Design Automation

Day 1: January 14, 2015
Introduction

Complete questionnaire

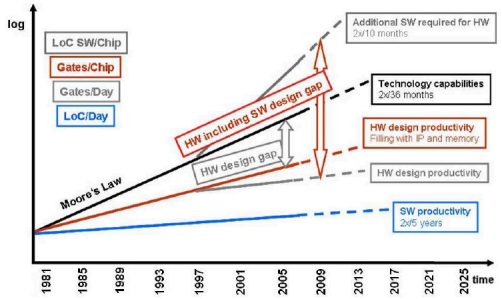
Warmup Poll

- How many of you have:
  - Drawn geometry for transistors and wires
  - Sized transistors
  - Placed logic and/or memory cells
  - Selected the individual gates
  - Specified the bit encoding for an FSM
  - Designed a bit-slice for an Adder or ALU
  - Written RTL Verilog or VHDL
  - Written Behavioral Verilog, VHDL, etc. and compiled to hardware?
  - Written SystemC or Bluespec System Verilog?
  - Compiled C to gates?

Modern Design Challenge

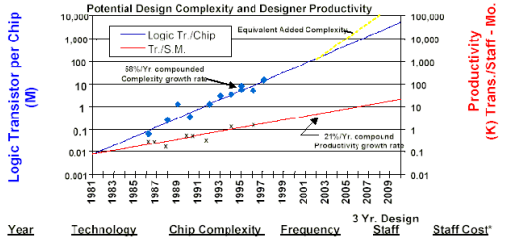
- How do we design modern computational systems?
  - billions of devices
  - used in everything
  - billion dollar businesses
  - rapidly advancing technology
  - more "effects" to address
  - rapidly developing applications and uses
  - short product cycles
  - extreme time-to-market pressures

Productivity Gap



Source: ITRS2009, 2011 Design Chapter

The Productivity Gap



Year	Technology	Chip Complexity	Frequency	Staff	Staff Cost*
1997	250 nm	13 M Tr.	400	210	90 M
1998	250 nm	20 M Tr.	500	270	120 M
1999	180 nm	32 M Tr.	600	360	160 M
2002	130 nm	130 M Tr.	800	800	360 M

* @ $150K / Staff Yr. (In 1997 Dollars)

Source: Newton (UCB/GSRC)

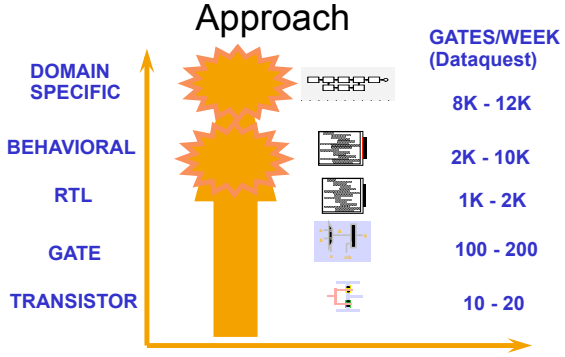
Bottleneck

- Human brain power is the **bottleneck**
  - to producing new designs
  - to creating new things
    - (applications of technology)
  - to making money

Avoiding the Bottleneck

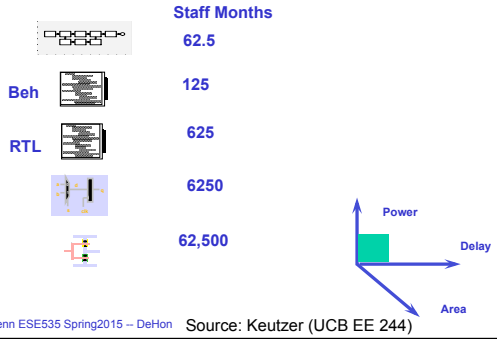
- How do we unburden the human?
  - Take details away from him/her
    - raise the level of abstraction at which human specifies computation
  - Pick up the slack
    - machine take over the details

Design Productivity by Approach



 Source: Keutzer (UCB EE 244)

To Design, Implement, Verify 10M transistors



 Source: Keutzer (UCB EE 244)

Central Questions

- How do we make the machine fill in the details (elaborate the design)?
- How **well** can it solve this problem?
- How **fast** can it solve this problem?

Outline

- Intro/Setup
- Instructor
- The Problem
- Decomposition
- Costs
- Not Solved
- This Class

Instructor

- VLSI/CAD user + Novel Tech. consumer
  - Architect, Computer Designer
  - Spatial designs: FPGAs, Reconfigurable
  - Hybrid: Multicontext FPGAs, P+FPGA
  - Nanoscale: CNT, NW-based, NEMS
  - Avoid tedium (impatient)
- Analyze Architectures
  - necessary to explore
  - costs different (esp. in new technologies)
- Mapping as part of runtime?
  - Variation, wear, reliability, changing dataset??
- Requirements of Computation

Problem

- Map from a problem specification down to an efficient implementation on a particular computational substrate.
- What is
  - a specification
  - a substrate
  - have to do during mapping

Problem: Specification

- Recall: basic tenant of CS theory
  - we can specify computations precisely
  - Universal languages/building blocks exist
    - Turing machines
    - nand gates
- EEs:
  - Can build any function out of nand gates
  - Any FSM out of gates + registers
    - FSM = Finite State Machine

Specifications

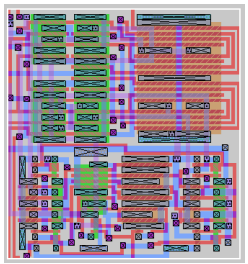
- netlist
- logic gates
- Finite-State Machine (FSM)
- programming language
  - C, C++, Lisp, Java, block diagram
- DSL (domain specific)
  - MATLAB, Snort
- RTL
  - Register Transfer Level
  - (*e.g.* subsets of Verilog, VHDL)
- behavioral
- dataflow graph
- layout
- SPICE netlist

Substrate

- "full" custom VLSI
- Standard cell
- metal-only gate-array
- FPGA
- Processor (scalar, VLIW, Vector)
- Array of Processors (SoC, {multi,many}core)
- billiard balls
- Nanowire PLA
- molecules
- DNA

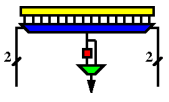
Full Custom

- Get to define all layers
- Use any geometry you like
- Only rules are process design rules
- ESE570

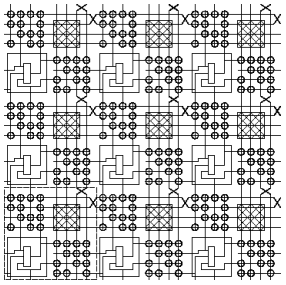


FPGA

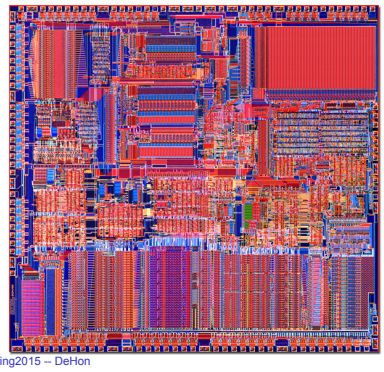
K-LUT (typical k=4)
Compute block
w/ optional
output Flip-Flop



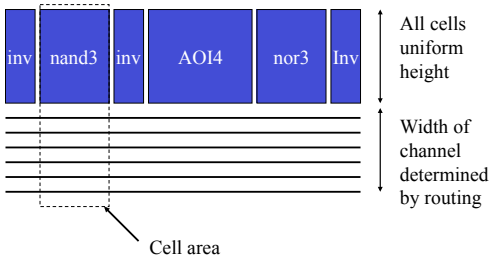
ESE171, CIS371



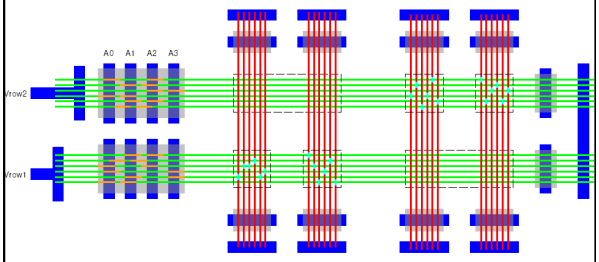
Standard Cell



Standard Cell Area



Nanowire PLA



What are we throwing away? (what does mapping have to recover?)

- layout
- TR level circuits
- logic gates / netlist
- FSM
- Allocation of functional units and assignment
- Cycle-by-cycle timing
- Operation sequencing
- How task implemented

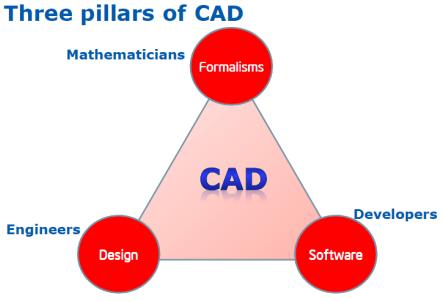
DSL: MATLAB

Specification not Optimal

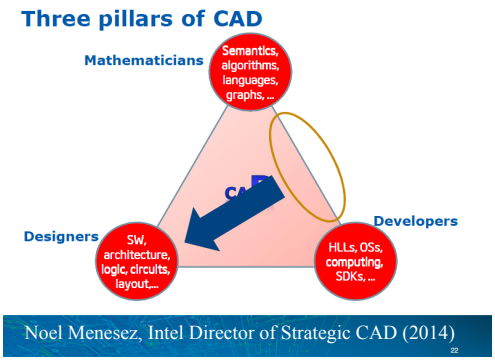
- Y = a*b*c + a*b*/c + /a*b*c
- Multiple representations with the same semantics (computational meaning)
- Only have to implement the semantics, not the "unimportant" detail
- Exploit **freedom** to make

smaller/faster/cooler

Three pillars of CAD



Noel Menezez, Intel Director of Strategic CAD (2014)



Problem Revisited

- Map from some "higher" level down to substrate
- Fill in details:
  - device sizing, placement, wiring, circuits, gate or functional-unit mapping, timing, encoding, data movement, scheduling, resource sharing

Decomposition

- Conventionally, decompose into phases:
  - Arch. select, scheduling, assignment -> RTL
  - sequential opt. -> logic equations
  - logic opt., covering -> gates
  - retiming -> gates and registers
  - placement-> placed gates
  - routing->mapped design
- Good abstraction, manage complexity

Behavioral
(C, MATLAB, …)
↓ Arch. Select Schedule
RTL
↓ FSM assign, Two-level, Multilevel opt. Covering Retiming
Gate Netlist
↓ Placement Routing
Layout
↓
Masks

Easy once decomposed?

- All steps are (in general) NP-hard.
  - routing
  - placement
  - partitioning
  - covering
  - logic optimization
  - scheduling

NP-hard:
Can verify solution in polytime
N, N^2, N^{100}
Do not know how to find in polytime
only known e^N
if there were a polytime solution
then P=NP

- What do we do about NP-hard problems?
  - Return to this problem in a few slides…

Decomposition

+ Easier to solve
  - only worry about one problem at a time
+ Less computational work
  - smaller problem size
- Abstraction hides important objectives
  - solving 2 problems optimally in sequence often not give optimal result of simultaneous solution

Mapping and Decomposition

- Two important things to get back to
  - disentangling problems
  - coping with NP-hardness

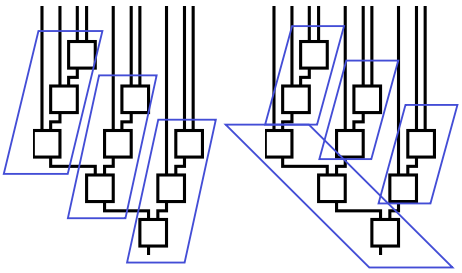
Costs

- Once get (preserve) semantics, trying to minimize the cost of the implementation.
  - Otherwise this would be trivial
  - (none of the problems would be NP-hard)
- What costs?
- Typically: EDA [:-)]
  - Energy
  - Delay (worst-case, expected….)
  - Area
- Future
  - Yield
  - Reliability
  - Operational Lifetime

Costs

- Different cost critera (e.g. E,D,A)
  - behave differently under transformations
  - lead to tradeoffs among them
    - [LUT cover example next slide]
  - even have different optimality/hardness
    - *e.g.* optimally solve delay covering in poly time, but not area mapping
      - E.g. covering

Costs: Area vs. Delay



Example of exploiting freedom of mapping choice.

Costs

- Cannot, generally, solve a problem independent of costs
  - costs define what is “optimal”
  - e.g.
    - (A+B)+C vs. A+(B+C)
    - [cost=pob. Gate output is high]
    - A,B,C independent
    - P(A)=P(B)=0.5, P(C)=0.01
    - P(A)=0.1, P(B)=P(C)=0.5

Costs may also simplify problem

- Often one cost dominates
  - Allow/supports decomposition
  - Solve dominant problem/effect first (optimally)
  - Cost of other affects negligible
    - total solution can’t be far from optimal
  - e.g.
    - Delay in gates,
    - Delay in wires
  - Require: formulate problem around relative costs
- Simplify problem at cost of generality

Coping with NP-hard Problems

How do we cope with?

- simpler sub-problem based on dominant cost or special problem structure
- problems exhibit structure
  - optimal solutions found in reasonable time in practice
- approximation algorithms
  - Can get within some bound of optimum
- heuristic solutions
- high density of good/reasonable solutions?
  - Try many … filter for good ones
- …makes it a highly experimental discipline

Not a solved problem

Why need to study – not just buy tool from C, M, or S?

- NP-hard problems
  - almost always solved in suboptimal manner
  - or for particular special cases
- decomposed in suboptimal ways
- quality of solution changes as dominant costs change
  - …and relative costs are changing!
- new effects and mapping problems crop up with new architectures, substrates

Big Challenge

- Rich, challenging, exciting space
- Great value
  - practical
  - theoretical
- Worth vigorous study
  - fundamental/academic
  - pragmatic/commercial

This Class: Student Outcomes

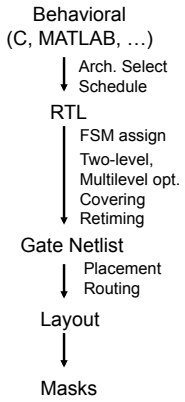
- You will learn:
  - Freedom exists in design mappings and how to exploit
  - Formulate & abstract optimization problems
  - How to decompose large problems
  - Techniques for attacking these problems
  - Traditional design objectives (e.g. E,D,A, map time.)
  - Canonical representations for problems
  - Evaluate the quality of a design mapping
  - Implement design automation *algorithms*

This Class: Technique Toolkit

- Dynamic Programming
- Linear Programming (LP, ILP)
- Graph Algorithms
- Greedy Algorithms
- Randomization
- Search
- Heuristics
- Approximation Algorithms
- SAT

This Class: Decomposition

- Provisioning
- Scheduling
- Logic Optimization
- Covering/gate-mapping
- Partitioning
- Placement
- Routing



Student Requirements

- Reading
- Class
- Projects
  - Will involve programming algorithms
  - Roughly weekly
  - Cumulative build toward an overall mapping goal
  - Choose what you do for final piece
    - Last month
  - Must do assign/project to pass course
- Final Exam

Graduate Class

- Assume you are here to learn
  - Motivated
  - Mature
  - Not just doing minimal to get by and get a grade
- Not plug-in-numbers and get solution
- Things may be underspecified
  - Reason
  - Ask questions
  - State assumptions

Materials

- Reading
  - Online
    - several on canvas
    - Rest on Xplore, ACM DL, web
      - Linked from syllabus page
  - If online, linked to reading page on web; I assume you will download/print/read.
  - Possible reference texts (on web)
- Lecture slides
  - I'll try to link to web page by 10am
    - you can print

Today's Big Ideas

- Human time limiter
- Leverage: raise abstraction+fill in details
- Problems complex (human, machine)
- Decomposition necessary evil (?)
- Implement semantics
  - Exploit freedom to xform to reduce costs
- Dominating effects
- Problem structure
- Optimal solution depend on cost (objective)

Questions?

Administrivia

- Next Lecture W 1/21 (Monday MLK)
  - Reading on canvas
- Return Info sheets
- Feedback – every lecture – return@end
- Web page
  - http://www.seas.upenn.edu/~ese535/
  - Policies on web page
    - READ THIS (you are responsible for knowing)
  - Syllabus linked off page (reading, assign)
  - Note Piazza group