Teaching the First EDA MOOC: Reflections on the Experience, and Opportunities for the Discipline

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From March – May 2013, I did the first-ever MOOC on how we build EDA tools for chip design, on Coursera.

In contrast to lots of MOOCS, explicitly a “grad level” course.
More Context

- I spent 25 years on faculty in ECE at Carnegie Mellon

- And I taught this class...
  - About 15 times over the years
  - To about 700-750 students over these years
  - Class called: VLSI CAD: Logic to Layout
    - I “came of age” in Mead&Conway era, so it’s “VLSI” and “CAD” for me...
    - ...even tho in course I explained “yeah, it’s really EDA”
What Does the “Regular” Class Teach?

**Classical ASIC Flow**
- Some models
- Some synthesis
- Some verification
- Some logic, some layout
- Some timing

**Topics**
- Computational Boolean Alg
- Logic verification: BDDs, SAT
- FSM verification (no model check)
- Logic synthesis: 2-level, multi-level
- Technology mapping
- Timing analysis: static + electrical
- Placement (Iterative, mincut, analytical)
- Routing: maze
- Geometric data structures
- Extras: eg, Litho simulation
Physical On-Campus Class → MOOC

- My physical class is
  - 15 weeks
  - 948 PPT slides
  - 20 separate slide decks
  - Delivered as roughly 14*3 hours (est) = 52 hours of lecs

- But, typical MOOC not same length & intensity as a standard semester
Designing Coverage for my MOOC

- Walking thru each lec slide by slide, and chunking into individual essential topics, was for me a very useful exercise
  - I have ~102 separate topics, with per-topic slides counts below
Closeup on Topical Coverage

- Example of 2 topics, up close, PPT lecture slide counts

### Computational Boolean Algebra
- cofactors
- bol diff
- quantif defs
- network repair
- compu strategies URP

### BDDs
- BDD basic defs ROBDD
- Building, Var order, Simple SAT
- Multi root, GC
- Neg arc
- Ops, Retrict & ITE
- ITE implementation, hash tables
Result: From Regular Course to MOOC

Regular class:
- 20 Lectures
- 948 PPT slides

69 Short Video Lectures
Average length: 15 minutes

615 total PPT slides
17 total lecture hours / 10 weeks

> 50-60% of regular course, in about 1/3 of the time
MOOC Video Content: Minutes/Lecture, by Week

1. Comp Bool Alg
2. BDDs & SAT
3. Logic Synth I
4. Logic Synth II
5. Placement
6. Tech Map
7. Routing
8. Timing

Tool Tutorials
Why Many Short Video Segments?

- **Pedagogy**
  - Better retention with short bursts of focused instruction
  - Emphasize one (or few) core topics

- **Bandwidth**
  - In much of planet, cannot download 2-hour video as 1 chunk
  - So– keep vids short. Don’t stream “live”. Download, view later
  - Critical to respect infrastructure realities for successful MOOC
What’s In A Video Lecture?

- Start with “talking Rob head” intro of lecture topic
What’s In A Video Lecture?

- Most content is me writing-on-the-slides of lec + voiceover

Multiple-Cube Extraction: # Literals Saved

<table>
<thead>
<tr>
<th>Row weights</th>
<th>Column weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>P a 1</td>
<td>c 3</td>
</tr>
<tr>
<td>P b 2</td>
<td>d e 4</td>
</tr>
<tr>
<td>P c 5</td>
<td>e f 5</td>
</tr>
<tr>
<td>P d 3</td>
<td>f g 6</td>
</tr>
<tr>
<td>P e 1</td>
<td>g 7</td>
</tr>
<tr>
<td>Q a 7</td>
<td>h 8</td>
</tr>
<tr>
<td>Q b 8</td>
<td>i 9</td>
</tr>
<tr>
<td>Q c 9</td>
<td>j 10</td>
</tr>
<tr>
<td>R de 11</td>
<td>k 11</td>
</tr>
</tbody>
</table>

Values:

- \( P = ab + cf + ag + cg + ade + bde + cde \)
- \( Q = af + bf + ace + bce \)
- \( R = ade + cde \)

\[ \sum \text{element values} = 20 \]
\[ \sum \text{row weights} = 10 \]
\[ \sum \text{column weights} = 2 \]

Change in # literals = 33 - 25 = 8!
MOOC Assignments

- 8 weekly homeworks, aka, Problem Sets
  - True/False
  - Multiple Choice
  - Type a number in a box, etc

- What’s *different* than in-class versions?
  - Can’t do math derivations
  - Must “over supply” sub-problems, and randomize (cheating)
  - Partition big problems into smaller, step-by-step parts

- Took about 3 HW sets to “get this right”, style-wise
Example: One HW Problem Spec

Q1. Single-cube extraction from multi-level logic.

Consider this Boolean logic network with variables \( a, b, c, d, e, f \).

\[ R = abf + abcd + abce + cdf \]

\[ S = acd + cdef + abce \]

\[ T = cdef + af \]

Build the \textit{cube-literal matrix} associated with this set of functions. Look at what prime rectangles are possible in this matrix. Which are the following are correct statements about extractions using this matrix?

- **OPTION GROUP 1: SELECT 2 randomize (These are all correct statements)**
  - Single cube divisor can be extracted as a prime rectangle. It has 2 columns and 4 rows. Extracting this divisor saves 3 literals.
  - Single cube divisor can be extracted as a prime rectangle. It has 3 columns and 2 rows. Extracting this divisor saves 3 literals.
  - Single cube divisor can be extracted as a prime rectangle. It has 2 columns and 2 rows (green). Extracting this divisor saves 0 literals - i.e., no fewer literals in this new factored network.

- **OPTION GROUP 2: SELECT 1 randomize (These are all correct statements)**
  - This is a correct extraction associated with a prime rectangle in this matrix.
  - This is a correct extraction associated with a prime rectangle in this matrix.
  - This is a correct extraction associated with a prime rectangle in this matrix.

Randomize selection from this 1\textsuperscript{st} group of sub-questions

Randomize selection from this 2\textsuperscript{nd} group of sub-questions

Etc...
MOOC Assignments

- Lots of criticism of MOOCs being “dumbed down”
  - Yes, they are a bit simpler. No, not a lot “dumber”
  - Mostly, burden on instructor to **design smart assignments**
  - Ex: this is the “macro answer” to one factoring HW problem
MOOC Assignments: 2 Paths Thru Class

Grading: Certificate & 2 Badge Options

Two options for a *Statement of Accomplishment* Certificate

- **Achievement Badge**
  - 8 Problem Sets = 75%
  - Single submission; late submission allowed after deadline for 50% of credit
  - 1 Final exam = 25%
  - Single submission.
  - Idea: Do this if you don’t have time to do all the code

- **Mastery Badge**
  - 8 Problem Sets = 40%
  - Same single submit policy
  - 4 Program Assignments = 40%
  - Multiple submissions ok; late submission allowed after deadline for 50% of credit
  - 1 Final exam = 20%
  - Same single submission
  - Idea: Do this for *deepest* understanding of course
EDA MOOC: Some Philosophy

I don’t believe you can teach a serious EDA course without:
- Experimenting with some existing EDA tools
- Designing software to build some EDA tools

How to do this at scale? To 10,000 students?
- CDNS, SNPS, etc, are not going to give us free stuff
- Lots of IP, Licensing, etc, landmines: you get to know your university’s top lawyers on a first name basis, in your MOOC

Answers
- Carefully select open source software
- Write everything else yourself
VLSI CAD MOOC: Software Ecosystem

Tool Portals for Student Use
- kbdd
- miniSAT
- espresso
- SIS
- Ax=b

Input: Text file
Output: Webpage

Auto-Graders
- Prog1
- Prog2
- Prog3
- Prog4

Input: Text file
Output: Webpage
Aside: Building this Software Ecosystem

kbdd  miniSAT  espresso  SIS  Ax=b

Rob – what is this stuff? Is this K&R C or what??

Ohhhh....

Yes.
VLSI CAD MOOC: Software Ecosystem

kbdd

Tool output ➔ Private webpage

kbdd

txt

kbdd

fan out to:

- txt
- Private webpage

Diagram showing the integration of kbdd with Coursera and Amazon Web Services to provide tool output and access to a private webpage.
VLSI CAD MOOC: 4 Software Projects

1. Boolean Data Structures & Computation (URP, PCN)

2. BDD-based Logic Network Repair

3. Quadratic Placement

4. Maze Routing
About MOOC Software Projects

- We provide the spec and input data; we grade output file

- Too hard to compile/run other people’s code
  - Too many platform issues; too many language issues
  - ASCII textfile in; ASCII textfile out

- Architect like a real “regression test suite”
  - Several benchmarks, from tiny to big
  - Partial credit for each part (as much as possible)
  - Lots of feedback in the webpage portal about how it went
Concrete Example: Regression-Like Benchmarks

- Can you route a 2-point wire in 1 layer?? Horizontal? Vertical? Around obstacle? Straight line? With a bend? etc
Software Project Examples: Layout

Recursive Quadratic Placer

2-Layer ASIC-style Maze Router
New Problem: How Can Students See Layout?

- Can’t control what platform they use!
- Answer: custom HTML5 geometry web-based environment
  - If they have a modern browser, they can drag/drop text file

(HTML5 design and pic by Nicholas Chen)
The Elephant In The (MOOC) Room...

LOTS of people start...

NOT so many people finish
VLSI CAD MOOC: The Participant Landscape

- 17,500 participants at peak
- 7,000 people watched a video
- 1,300 people did a homework
- 400 people tried a software assignment
- 500 people took the Final Exam
- 386 Statement of Accomplishment Cert's

DEMOGRAPHICS

- Average age: 30
- Min: 15
- Max: 75
- Have a Bachelors: 30%
- Have MS/PhD: 29%
- Male: 88%
- Female 12%
University of Illinois Coursera Students: VLSI CAD Percent of Students by Country

VLSI CAD Student Percent

- 0%
- 0.01 - 1%
- 1.01 - 2.5%
- 2.51 - 5%
- 5.01 - 10%
- 10.01 - 29.69%

ATLAS Statistics Group
University of Illinois
Data gathered between Fall 2012 and Spring 2013
Details: Views Across All My MOOC Videos

- Roughly number of employees in SYNOPSYS, world’s largest EDA company
- Roughly attendance at DAC’13
- Roughly equivalent to 40 years of students for this course

Many ways to deliver educational value in a MOOC; it’s not all about how many people take the Final...
Things One Learns in MOOC-Land..

My handwriting *unreadable* for a planetary audience

Creativity to make homeworks in multiple-choice format

MOOCers crave *interaction* with instructors, 24x7!

Be sensitive to *diversity of IT resources of participants*

**"* when 2 or more individual variables in the main loop "For (each variable x in F) yield the same solution for F/x, we just draw them pointing to the same child box in our diagram of the progress of the algorithm."**
My MOOCers: Want More EDA...

Word-cloud from Final Exam question: what else would you like us to cover
Why Did I Do This...?

Because every vibrant discipline needs a solid on-ramp, and teaching of core-EDA was vanishing, rapidly...
Reflections...

- If we want to energize a new generation of EDA
  - Moving EDA into other areas or kinds of systems
  - Moving EDA into new technology platforms (eg, post-Moore)
  - Translating EDA “sideways” into adjacent opportunity areas

- If we want to do any of these things, somebody has to be teaching the foundational topics
  - Maybe it is the case that planet can only support a handful of these large, global-scale courses on EDA foundations
  - Maybe this is only way to reach broadest, global audience
  - OK – so be it. Here’s my shot at “regenerating the excitement”
Me: Personally Positive on MOOC Potential

Version 002 of my EDA MOOC goes live MARCH 3, 2014
Me: Personally Positive on MOOC Potential

Me, March-May 2013

INABIF, Villa El Salvador, Peru

Me, Aug 2013
Summary

- I taught the first-ever EDA MOOC last year
  - Why? Because somebody has teach this stuff at scale.
  - Why? Because the material is important & beautiful.
  - Why? Because need excitement for vibrancy of discipline.

- I’m doing it again this year (in about 2 weeks)
  - Ask me at DAC how Round #2 goes....