A New Method for the Creation of MOOC-ready Database of Test Questions

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Keywords: Formative Assessment, Massive Open Online Course (MOOC), Engineering Education, Distance Learning, e-Learning, Training, Digital Circuit Design, Combinational Logic.

Abstract: Recently, there has been a wide interest in the massive open online courses (MOOCs) that are freely available to the students from all over the world. Due to the large scale of MOOCs, the instructors (even with their teams of graders) cannot assess all the examinations and quizzes themselves. Peer grading eases the assessment burden but has its shortcomings. Ideally, the assessments should be fully automated and should also allow partial grading. Additionally, a sizeable database of questions is needed so that an individual student or a group of students are not able to see all the questions by repeatedly attempting the quizzes. In this paper, we present a Matlab-based method for automatically generating a large number of questions and their (intermediate and final) answers for a MOOC or a traditional classroom-based course on digital circuit design. The method that enables formative assessment is also applicable to other courses in engineering and sciences.

1 INTRODUCTION

Different methods of distance learning have existed for many years. Short video tutorials were popularized by Khan Academy (Anon, 2014f) that was founded in 2006, while fully online courses have been offered by some universities since 2008 (Koller, 2013). One of the first *massive open online courses* (MOOCs) offered by the University of Illinois, Springfield, was attended by more than 2500 students, in 2011 (Anon 2011). TED and iTunesU (Anon ,2014e) also came about in the same timeframe.

MOOCs became very well-known after more than 100,000 students signed up for a Stanford University course. A large number of full-length courses are now available through different sources for millions of students enrolled from all over the globe (Frank, 2012; Mitros et al., 2013).

The popularity of MOOCs is driven by the no-cost availability of the course content. Unlike traditional courses, there are no enrolment limits for the students and there are relatively low requirements on faculty facilitation after a course has been *developed* (Briggs, 2013).

Currently, Coursera (Anon, 2014c), Udacity (Anon, 2014h), and EdX (Anon, 2014d) are three major sources of MOOCs albeit with different missions, strategies, and tactics. Coursera's offerings mainly come from a few select universities inside and outside the US. Their upper-level courses are somewhat specialized. Udacity has used rather elaborate production methods in the course preparation and delivery; the courses are for lower-level maths and science, and are relatively few in numbers. EdX's offerings fall somewhere in between Coursera's and Udacity's.

The popular learning management systems such as Blackboard (Anon, 2014a) and Canvas (Anon, 2014b) have also jumped the MOOC bandwagon.

While MOOCs *democratize* the learning, they tend to deviate from traditional in-class courses in many respects. Due to the sheer number of course enrolees, they present a set of challenges never encountered before. The challenges lie in the areas of course design, delivery and assessment (Daradoumis et al., 2013).

One of main challenges for MOOCs has been the impracticability of human review of individual student learning progress and the assessments (Fournier, 2013). So the student work, including quizzes, have been either computer-graded or assessed by the peers. Automatic grading, understandably, has so far been limited and

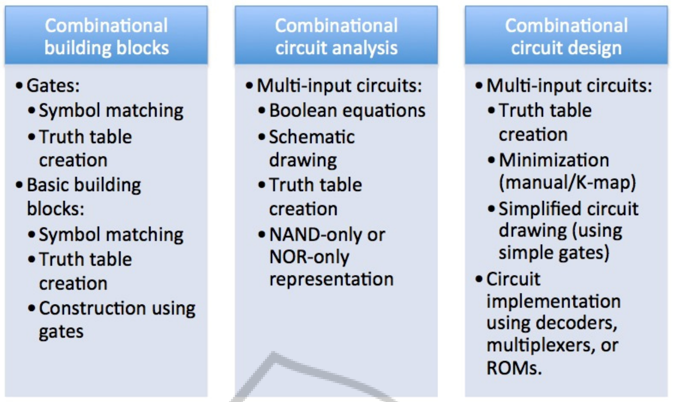

Combinational building blocks
• Gates:
• Symbol matching
• Truth table creation
• Basic building blocks:
• Symbol matching
• Truth table creation
• Construction using gates
Combinational circuit analysis
• Multi-input circuits:
• Boolean equations
• Schematic drawing
• Truth table creation
• NAND-only or NOR-only representation
Combinational circuit design
• Multi-input circuits:
• Truth table creation
• Minimization (manual/K-map)
• Simplified circuit drawing (using simple gates)
• Circuit implementation using decoders, multiplexers, or ROMs.

Figure 1: Combinational logic topics and the mechanisms for assessing them.

insufficient in nature. For student assignments that involve mathematical proofs, detailed designs, and essays, evaluation and proper feedback still remain the stumbling blocks. These lacunas in the assessment process are some of the hurdles in MOOCs being accepted as *for-credit* courses (Briggs, 2013; Miranda et al., 2013).

Many MOOCs have, to some degree, relied on peer-grading as an assessment tool. However, such grading is fraught with issues, such as the grader's bias due to his/her own performance, and possibly large differences in the graders' and the gradees' cultural and lingual backgrounds. How much time a grader spends on grading also comes into play (Piech, 2013). Providing rubrics to the graders helps achieve some degree of uniformity (Sandeen, 2013).

In this paper, we provide a mechanism for making the online assessment more effective while retaining automation. This is done by creation of a large number of test questions that are suitable for formative assessment. This set of questions can be utilized for a very large number of cohorts. The questions also allow checking of intermediate as well as final answers. Although our method is applicable to many courses in science and engineering, we will cover examples mainly from a course in electrical/computer engineering.

2 TACKLING THE ASSESSMENT CHALLENGE

Having an effective assessment is crucial for the ultimate acceptance of MOOC as a replacement of a traditional in-class course. Georgia Institute of Technology's recently proposed MOOC-based Master of Science (MOOMS) faces "a potential threat" from their evaluation system that would not fully assess, and would therefore "lead to an ineffective program" (Briggs, 2013).

Although having the students take proctored examinations is an option, it would incur some cost (vs. the completely free option) to the student.

Traditional test-banks accompanying the textbooks are mostly limited in size. Someone signing in with multiple accounts could repeat a quiz until he is able to get a perfect score. Therefore, the test-banks are not suitable for MOOCs' *class-sizes*.

Our proposed approach involves the use of Matlab (Anon, 2014g) for generating a very large number of questions and answers so that repeated attempts by a single person or by a group has little chances of seeing the same questions. We employ Perl CGI scripts to generate the webpages that display the problems and grade them automatically.

2.1 Assessment of a Course on Digital Circuit Design

In this section, we present the topics from a course that we have taught for several years, "Digital Design and Computer Organization."

One of the course *outcomes* is that the students are able to "analyze and design combinational circuits." The course topics related to the outcome are: logic gates, combinational building blocks, the analysis of combinational circuits, and the design of combinational circuits (see Figure 1). The last topic is the most complex of all, and entails a longer multi-step process. Obviously, for such as question, the grading based on a single, final answer is insufficient to provide effective feedback to a student. So partial grading should be done. Assessing the design problem conventionally requires step-by-step checking by a human grader.

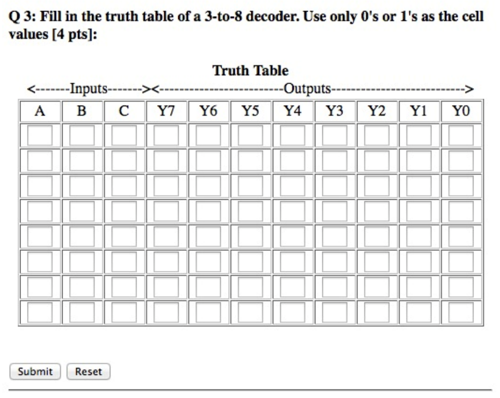
2.1.1 Assessing Topic 1: Logic Gates and Combinational Building Blocks

The students are expected to learn about the symbols of different logic gates and combinational building blocks.

Examples of logic gates are INV, AND, NAND, OR, NOR, and XOR, mostly with 2 or more inputs. Assessing the knowledge of the gates involves matching the symbols with their names (not too complex of a task but essential in nature). The second type of questions require filling in of *truth tables* of gates with multiple inputs.

The combinational building blocks include decoders, encoders, multiplexers, etc. Besides many inputs, some of these blocks have multiple outputs. The assessment questions include building of the blocks with individual gates using a schematic entry module. The other type of questions includes completion of the truth tables for different blocks. See an example in Figure 2.

As one can see, by using the truth table entries and the schematic module, it is possible to both perform the partial grading and the checking of the detailed answers.



Q 3: Fill in the truth table of a 3-to-8 decoder. Use only 0's or 1's as the cell values [4 pts]:

Truth Table

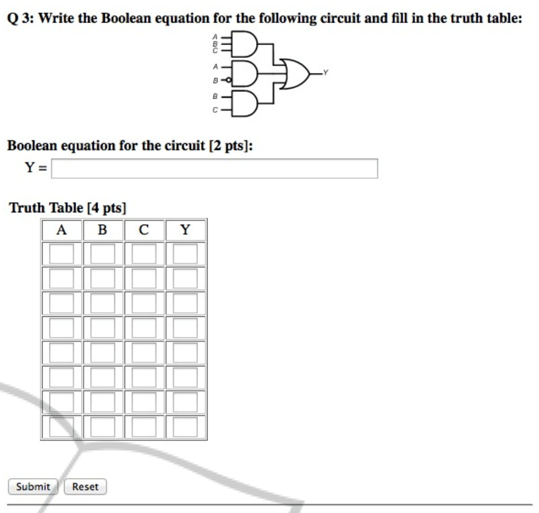
<-------Inputs-------><-------------------------Outputs-------------------------->

A	B	C	Y7	Y6	Y5	Y4	Y3	Y2	Y1	Y0

Figure 2: A sample problem for Topic 1: Filling in the truth table for a combinational block (3-to-8 decoder).

2.1.2 Assessing Topic 2: Analysis of Combinational Circuits

The learning expectations are met if the students are able to: (1) draw a simple schematic for a given Boolean function; (2) write the Boolean equation for a given circuit; (3) create a properly-sized truth table (i.e., dependent upon the number of inputs and output/s), and fill in the binary values; and (4) transform a circuit into the one that uses only the NAND or the NOR gates. A sample question generated with Matlab and presented (in online format) with a Perl script is shown in Figure 3.



Q 3: Write the Boolean equation for the following circuit and fill in the truth table:

Boolean equation for the circuit [2 pts]:

Y =

Truth Table [4 pts]

A	B	C	Y

Figure 3: A sample problem for Topic 2: Combinational circuit analysis by writing the Boolean equation and completing the truth table.

2.1.3 Assessing Topic 3: Design of Combinational Circuits

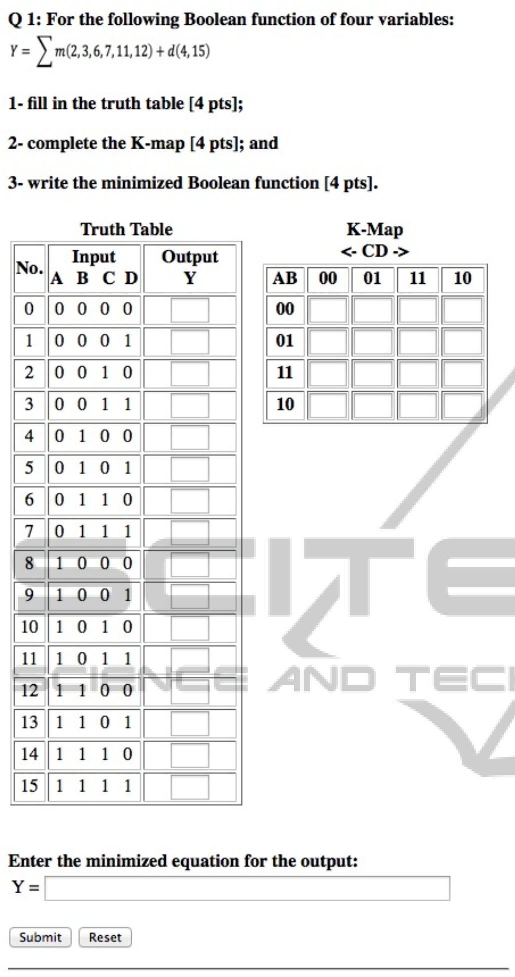
The students taking this course should be able to design combinational circuits by: (1) creating a truth table that lists all combinations of inputs and output(s), (2) creating minimized Boolean functions using Karnaugh maps (K-maps), and (3) drawing the final circuit-schematic. The problems can also be descriptive in nature, but such questions would be limited in number, and hence not suitable for MOOCs. One of the solutions is to present problems that require minimization of a *sum-of-products* (SOP or sum-of-*minterms*) or *product-of-sums* (POS or *product-of-maxterms*). Using Matlab, we have created a very large number of problems (see the code in Appendix A), i.e., several thousand for three inputs, and a few million for four inputs.

A design example based on the *sum-of-minterms* and the *sum-of-don't cares* is shown in Figure 4. The students exhibit their knowledge of design by filling in the two tables and by typing in the final equation.

2.2 Evaluation of Question Database

We have seen signs of success with some initial use of the automatically generated tests. In the coming academic year, we are planning to fully utilize the question database in the Digital Design and Computer Organization in our university. The questions will be loaded in (the currently-used) BlackBoard learning management system.

Traditionally, during a given semester, we give



Q 1: For the following Boolean function of four variables:

$Y = \sum m(2,3,6,7,11,12) + d(4,15)$

1- fill in the truth table [4 pts];

2- complete the K-map [4 pts]; and

3- write the minimized Boolean function [4 pts].

Truth Table

No.	Input A B C D	Output Y
0	0 0 0 0	
1	0 0 0 1	
2	0 0 1 0	
3	0 0 1 1	
4	0 1 0 0	
5	0 1 0 1	
6	0 1 1 0	
7	0 1 1 1	
8	1 0 0 0	
9	1 0 0 1	
10	1 0 1 0	
11	1 0 1 1	
12	1 1 0 0	
13	1 1 0 1	
14	1 1 1 0	
15	1 1 1 1	

K-Map
<- CD ->

AB	00	01	11	10
00				
01				
11				
10				

Enter the minimized equation for the output:

Y =

Submit Reset

Figure 4: A sample problem for Topic 3: Design of a combinational circuit by (a) filling in the truth table, (b) using the K-map, and (c) writing the final minimized equation.

one quiz to the students on every topic of digital design. Due to the limited number of questions in our current test-bank, we have limited the test-attempts to one. With the availability of a much larger number of quiz questions, we will be able to offer the students some questions only for practice; no grades will be assigned for these questions. The number of quizzes would also increase; for each topic, the students may be allowed two attempts without exposing them to all the questions.

We will evaluate the effectiveness of our new database of questions by (1) comparing the upcoming semester's test-scores with the scores of the last four semesters', and (2) by conducting a student survey about the usefulness of the practice-quizzes in improving their understanding of different topics.

3 CONCLUSIONS

A new and powerful mechanism for creating assessment questions for a digital design course's combinational logic problems. Future applications of the method include question-generation for other topics in other courses taught at other institutions, in the traditional and the MOOC formats. Microelectronics, analog circuit design, and computer architecture are some of the courses in which the presented technique can be utilized.

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APPENDIX

The Matlab code for generating an exhaustive list of sum-of-minterms and sum-of-don't-cares for a given number of input variables is given in Figure 5a.

For three variables/inputs, a total of 3,248 different questions are generated, some of which are shown in Figure 5b.

```
nVar = 3;        % number of input-variables

N    = -1+2^nVar % maximum possible minterms
arrN = 0:N;      % array containing all minterms

% arbitrarily, between 50% and 80% of the values are "trues"
for sel = ceil(0.5*N):ceil(0.8*N)

   % select 'sel' terms from the arrN array
   minterms = combnk(arrN, sel);
   [rwMT tmp] = size(minterms);

   % for each set of minterms, vary "don't cares"
   for i = 1:rwMT

      % arbitrarily, up to 50% of 1's can become "don't cares"
      for doNotCareCount = 0:ceil(0.5*sel)
         mintermRow = sum_m(i,:);

         % use all combinations of "don't cares"
         arrDoNotCares = combnk(mintermRow, doNotCareCount);
         [rwDNC tmp] = size(arrDoNotCares);
         for j = 1:rwDNC

            % array of don't-care terms
            dontCareRow = arrDoNotCares(j,:);

            % final array of minterms
            finalMinTermRow = setdiff(mintermRow, dontCareRow);
        end
     end
  end
end
```

(a)

```
                              …
3202: y = sum_m (1, 3, 6) + sum_d (0, 2, 4)
3203: y = sum_m (1, 4, 6) + sum_d (0, 2, 3)
3204: y = sum_m (2, 3, 4) + sum_d (0, 1, 6)
3205: y = sum_m (2, 3, 6) + sum_d (0, 1, 4)
3206: y = sum_m (2, 4, 6) + sum_d (0, 1, 3)
3207: y = sum_m (3, 4, 6) + sum_d (0, 1, 2)
3208: y = sum_m (1, 2, 3, 4, 5) + sum_d (0)
3209: y = sum_m (0, 2, 3, 4, 5) + sum_d (1)
3210: y = sum_m (0, 1, 3, 4, 5) + sum_d (2)
                              …
```

(b)

Figure 5: (a) The Matlab script for generating an exhaustive set of sum-of-product equations, and (b) a sample set of 3-variable sum-of-product equations created by the script.