

Flipping Lectures in a Junior-level Course in Digital Design Using VHDL

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Abstract - A junior-level course in digital design using VHDL has been taught at Oakland University for many years. In this course, students design digital systems using VHDL, and implement the designs on a Xilinx FPGA. In such a course, it is important to have students work on designs that require the capabilities of an FPGA, and can not be implemented easier using a simple microprocessor. In order to do so, many topics ranging from basic digital design principles to timing to the design of significant hardware such as a VGA controller must be covered. It is, therefore, very important to find ways to make the most efficient use of class time to provide a quality learning experience to the range of students in the course. To this end, using the video modules available on YouTube™ developed to accompany the book with over 75 design examples, we "flipped" the course where students watch some of the lecture topics on video before coming to class and in class lecture is focused more specifically on student questions and interactive discussions about the current topic instead of introducing and teaching the topic for the first time. This method provides for additional class time to discuss and present more in-depth topics specifically relevant to student questions. We found that the role of the instructor is key to reaping the expected benefits and the results of this experience were positive.

Index Terms – Digital Design, FPGA, VHDL, VGA, Flipping.

INTRODUCTION

Traditional hardware design courses focus on topics spanning Boolean algebra, the design of basic combinational and sequential elements, and sometimes the design of significant special purpose processors or a microcontroller. In these three- or four-credit courses, there is little time to dwell on any one of these topics, plus most courses strive to have their students create significant hardware in the lab or for an end-of-course project. In a junior-level course at Oakland University, where students learn hardware design using VHDL, we have found that "flipping" the lecture style where students are assigned short videos to watch that introduce them to the topics to be covered in upcoming lectures has been effective to improve student engagement in the classroom and more efficiently use class time to emphasize more complex aspects such as design rather than introduction.

In this course, we ultimately teach students to design, implement, and expand upon a VGA controller that incorporates most hardware design concepts into a single topic, which also saves time and provides a continuous example for students to follow over multiple lectures. This topic alone results in a significant boost for students to transition from basic hardware design skills to more advanced skills, which enables them to create impressive, elaborate projects during the last two to three weeks of the course. [1]

COMPUTER HARDWARE DESIGN COURSE STRUCTURE

All of the material used in this course is covered in a textbook [2] that is available to all students. A Verilog version of this textbook is also available [3]. These books assume prior knowledge of VHDL or Verilog. For those with no prior knowledge of VHDL or Verilog, Digilent is now bundling books [4] [5] with both the BASYS2, Nexys2, and Nexys3 boards, which provide over 75 examples of VHDL or Verilog programs, including VGA examples that can run on any of these boards. These books do not include the examples covered in [2] and [3] using the external RAM and flash memory, which are available only on the Nexys2 and Nexys3 boards. The University loans a copy of the book to each student to use for the semester and return and the students purchase the Digilent Nexys2 board. The board along with the free student edition of the Active-HDL simulator and Xilinx ISE WebPACK software for synthesis to the FPGA enable students to work on homework and lab assignments from their home computers or laptops.

Computer Hardware Design is a four credit course at Oakland University. Students attend two one hour and forty-seven minute lectures and a three hour lab each week for thirteen weeks. There are eight lab assignments that change some from semester to semester. A list of the typical lab assignments are listed below in Listing 1. For all labs, students design, simulate, synthesize, implement, and download their designs onto the board for physical testing.

LISTING 1: LABORATORY LEARNING EXERCISES

1. *Introduction to Simulating and Synthesizing* – a tutorial that walks students through using the design tools to implement, simulate, and synthesize a generic multiplexer (Appendix A of the book).
2. *Majority Circuit and G4FET* – students derive the logic equations for a majority circuit and G4FET universal element.
3. *11-bit Binary-to-BCD Converter* – students expand upon a smaller binary-to-BCD converter from the book. They create a top-level including the 7-segment display component that time-multiplexes the four displays on the Nexys2 board.
4. *16-bit Function Unit* – students design a 16-bit function unit that performs 16 arithmetic/logic functions.
5. *A Single-Cycle Calculator* – in this lab, students use the function unit from lab 4 in a small stack-based calculator with program memory and program counter. The calculator schematic is given. Students must implement all of the components, port map them together, derive the micro-coding for each instruction, and write a small program for their calculator. This is shown in Figure 1.
6. *A Code Detector* – students design and implement a code detector including a state diagram and state machine.
7. *Datapaths and State Machines: Square Root* – in this lab, students implement the special-purpose processor for computing the integer square root of an input. They also perform a timing simulation, write a test bench, and witness glitches.
8. *VGA Controller and Group Photos* – this lab is performed in groups of 2 or 3. Students implement the VGA Controller design introduced in class and described in the book. They modify the controller to display a photo of each member in their group in a different place on the screen.

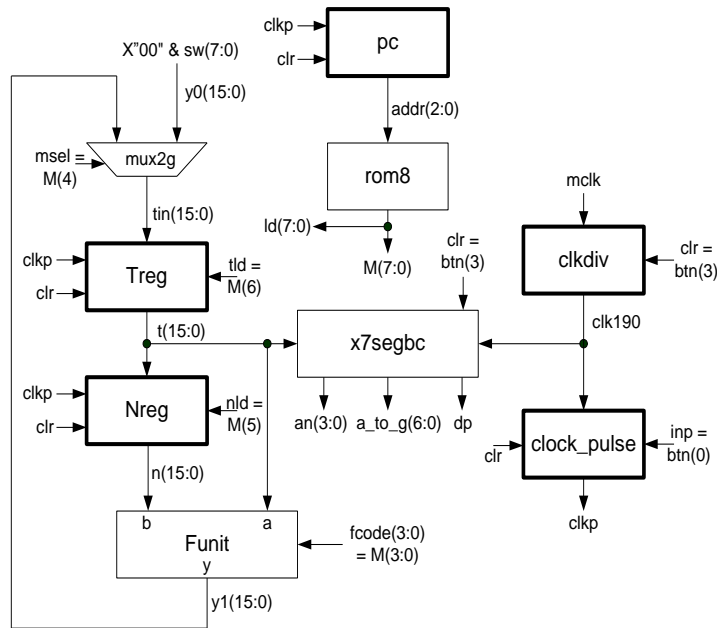


FIGURE 1: SINGLE-CYCLE CALCULATOR

The labs are given in increasing complexity. In the last lab, students implement and modify the VGA controller that they use for their projects. During lecture, the VGA controller provides for a visual way to teach developing special-purpose hardware for performing interesting, non-trivial tasks with graphics in video memory such as generating stripes and checker boards, animating objects, resizing sprites, rotating sprites, character fonts, resizing fonts, multiple characters with images, and slide shows [6]. Other designs presented in detail in class include clearing the screen plotting a dot, plotting a line, and plotting a circle. The course continues by designing a PS/2 Keyboard interface, PS/2 Mouse interface, and basic UART. These are used to design hardware for controlling a sprite using the keyboard, controlling a sprite using the mouse, using the SPI joystick interface and controlling a sprite using the joystick, and sending characters to the video screen from the PC using the UART.

"FLIPPING" THE CLASS: CHALLENGES AND SOLUTIONS

During the Fall 2012 semester, LBE Books created modular videos for each of the examples and topics in the book. There are 112 short videos ranging from 3 to 15 minutes with an average length of approximately 7 minutes. These videos show the upcoming PowerPoint lectures that match the book with voice-over explanations from the authors. All of the videos are made available by LBE Books on YouTube™ so all students had access to any video at any time.

This course covers quite a bit of material. Some students thrive on the faster pace while others would like a more in-depth explanation. The best way to accomplish this is to make more efficient use of class time. To do so, the videos were assigned to students to watch *before* coming to class during the lecture in which the topics were covered. This is referred to as "flipping" the course since lectures focus on material already familiar to the students via video instead of continuously introducing new topics during the lecture [7, 8, 9]. Not all 112 videos were assigned. To be reasonable about the workload, approximately 15-25 minutes of videos were assigned before each lecture. For lecture topics in which pre-class videos were not assigned but students wished to review the material, see it again, or study for tests, students could watch any video at their discretion.

Short homework assignments were typically assigned to students on the information shown in the videos. In class, students were randomly picked to come to the front of class and show their solutions for a particular homework problem and discuss the solution briefly with the class. By doing so, they earned a scored credit that counted towards their homework grade assigned by the instructor during lecture based on their solution and discussion with the class.

Since the students were more prepared having watched the videos, the lectures reviewed the information shown in the videos and discussions focused specifically on student questions instead of the traditional start-to-finish lecture style where the instructor decides what to emphasize given the time. We implemented this "flipping" technique in this computer hardware design course for the first time during the Fall 2012 term. The students appreciated the extra resources.

A crucial part of reaping the expected benefits of "flipping" the class requires the instructor to be fully committed to the new philosophy. Some of the challenges that occurred during this first term were mostly on behalf of the instructor; it was difficult to get used to not covering material that was already covered in the pre-class videos. That is, working with more prepared students than usual. During this initial term, the instructor re-covered a fair amount of the material from the videos. This has two negative repercussions: the obvious one is that class time that could have been more efficiently used was spent on covering basics again and more notably, students caught on to the fact that the material would be covered in class anyway and would watch the videos only to the extent that they needed to complete or partially complete the homework. Recognizing these factors, during Winter 2013, the instructor executed the "flipping" fully and did not re-cover material presented in the video. The response has been excellent; most all students watch the videos and a fair amount more class time is spent doing design examples together with the class interactively. The difference is very visible, during the Fall 2012 semester with the instructor half-implementing "flipping", the students were semi-prepared while during the Winter 2013 semester with the instructor fully-implementing "flipping", the students have been significantly more prepared for class.

The videos provided by LBE Books along with their almost 100 examples between the two books used in this course are modular. This allows for flexibility in teaching topics, skipping topics, or easily selecting any order in which topics are taught. For example, during the Winter 2013 semester, we are teaching the course using a problem-based approach in which students are taught to design components based on problem statements and circuits designed in class. This means that components are taught as-needed, therefore, combinational and sequential components are taught concurrently. This way, students can get to meaningful design earlier in the course.

THREE-WEEK STUDENT DESIGN PROJECTS

After engaging students in these more advanced hardware design topics, students are prepared to create end-of-course projects in groups of three or four that are quite impressive and elaborate given the short period of time in a "first course" in hardware design. Many students choose to create games that use the VGA monitor interactively with video game controllers ranging from home-made controllers to Nintendo joysticks that they wire into the board, and create a controller based on the joysticks timing diagram.

The figures in this section demonstrate some of the typical projects that students have done in this course during Fall 2012, when the course was first "flipped". Figure 2 shows the game "Nuts" that was implemented by a group of 4 students. This game is a fairly complex card game for 4 players. The students implemented the cards, game engine, VGA controller, and four PS/2 mouse components. Four

mice were attached to the Nexys2 board including three through PMOD PS/2 ports from Digilent. Each player uses their own mouse to play concurrently on their own and each other's card piles.

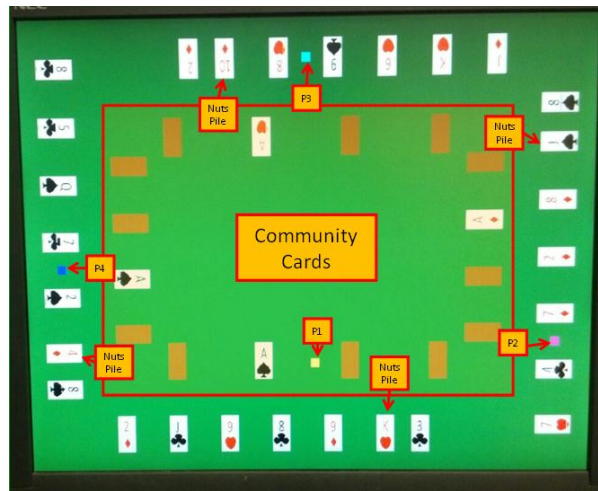


FIGURE 2: THE GAME OF NUTS

Figure 3 shows the classic game of checkers. The students created the board, checker sprites for the two teams, other icons, and a PS/2 mouse controller. Pieces can be dragged and dropped for moving the checker pieces and the game will only allow valid moves.

Another group created an audio equalizer where audio is captured through an audio jack PMOD from Digilent, a Fourier transform is computed, the strengths of the different frequencies are used to form an equalizer-looking image on the VGA screen using the VGA controller, and the audio is output through another PMOD audio-out jack. Figure 4 shows the block diagram for this design. The students completed approximately 75% of their idea; it was certainly ambitious for a three-week project.

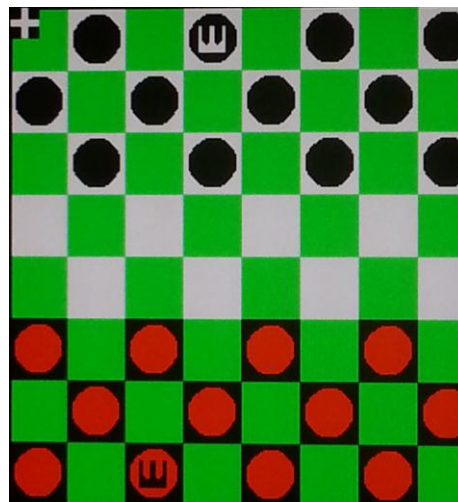


FIGURE 3: CHECKERS

Figure 5 shows Piano Hero. This is similar to the arcade game Guitar Hero™. Musical notes for a song scroll across the screen and the player must press the correct key sequence on the piano to play the song. The player gains points by hitting the correct key at the right time. Figure 5(a) shows the video

from the VGA controller for the game. Figure 5(b) shows the piano that the students purchased at a toy store and rewired into their Nexys2 board via a breadboard to the PMOD ports on the board.

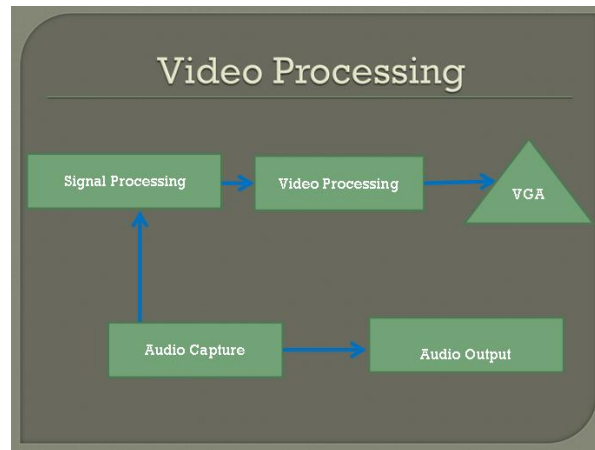
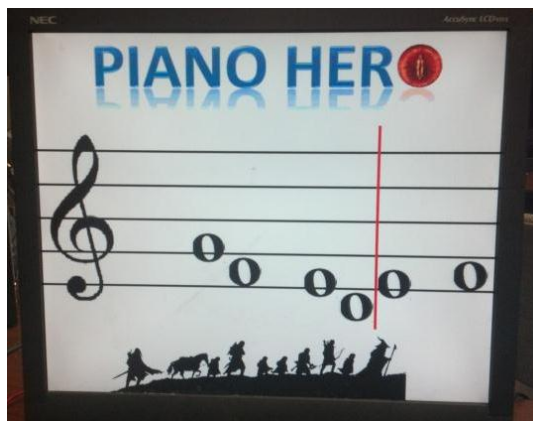
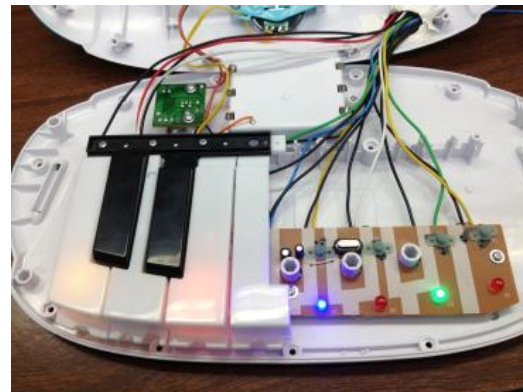


FIGURE 4: AUDIO EQUALIZER

Figure 6 shows Typing Mania created by another group. In this project, they created two different fonts, one for play and the other for the instructions screen and logo. The player plays with the keyboard that is interfaced to the Nexys2 board through the PS/2 port.



(a)



(b)

FIGURE 5: PIANO HERO

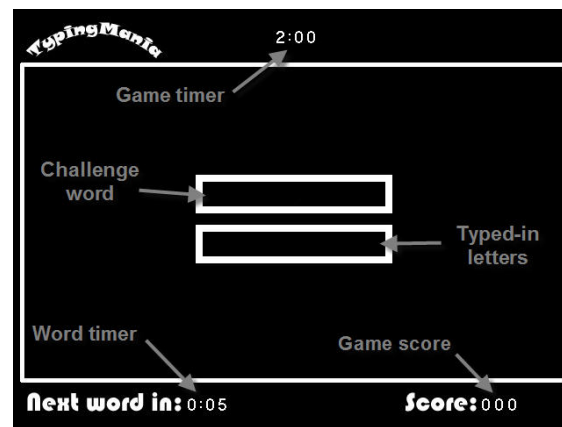


FIGURE 6: TYPING MANIA

CONCLUSION

Using videos that accompany the book for a junior-level computer hardware design course, the course can be "flipped" by assigning pre-class videos for students to watch that introduce them to new topics. Class time can be focused on specific questions from class and results in more time to provide more examples and answer specific question. Further, students presented homework solutions and discussed them in class interactively. The instructor's role in fully executing "flipping" is critical to realizing these benefits. The students appreciate and utilize the additional video resources for reviewing lectures a second time and for studying for tests. Students were able to apply their knowledge to produce custom hardware for projects that were impressive given the short three-week timeframe in their first hardware design course.

ACKNOWLEDGEMENTS

The authors would like to thank the outstanding lab teaching assistants for this course, Bryant Jones and Lincoln Lorenz, and the students who worked very hard on the projects shown in this paper in ECE/CSE 378 Fall 2012.

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