A HARDWARE LAB FOR THE COMPUTER ORGANIZATION COURSE AT SMALL COLLEGES

Lubomir Ivanov
Computer Science
Iona College
New Rochelle, NY 10801
Tel.: 914-633-2342
Email: livanov@iona.edu

ABSTRACT

This paper deals with the issues of adding a hardware lab component to a typical undergraduate Computer Organization course at a small college. We present a sequence of lab exercises, linked to the material presented during lectures, and discuss the advantages, challenges and pitfalls of implementing such a lab as a part of a liberal-arts Computer Science program.

1. INTRODUCTION

Most small, liberal-arts colleges include one or two "computer hardware" courses as part of their Computer Science curriculum. In fact, Computer Organization and Architecture is often a part of the Computer Science core, and is an essential component of the effort to provide students with a well rounded view of our discipline.[1] However, due to a multitude of factors [1], Computer Organization and Architecture is often the only course dealing with computer hardware in any detail in the Computer Science curriculum at small colleges. As a result, the instructor is faced with a difficult choice between a broad but very superficial treatment of the material or a relatively detailed presentation limited to a few key topics, which are not sufficient for students to understand and appreciate the overall design and implementation strategies in computer organization.

The Computer Organization course is often accompanied by an assembly language laboratory, during which students learn to write trivial assembly programs, that, outside the classroom, no one would ever consider writing in assembly.

[1] The ABET accreditation requirements (section IV.6 of the ABET Evaluation Criteria) explicitly specifies that computer science "core materials must provide basic coverage of computer organization and architecture".

No mention is ever made of the types of programs, which assembly language programming is suited for – device drivers, speed/space critical applications, etc. Among the reasons for this failure is the fact that students have no hands-on experience with actual hardware systems, since there is usually no hardware lab associated with the Computer Organization course.

Recognizing these facts, and in an effort to provide our students with a more complete educational experience, our department has added a new 1-credit hardware lab to the 4-credit Computer Organization and Architecture course and the associated software lab. The goal of this paper is to describe the integration of the hardware lab with the Computer Organization course and into the Computer Science curriculum, and to inform the readers of the challenges and obstacles we had to face, and their resolution.

2. THE NEED FOR A HARDWARE LAB

The need for the hardware lab stems from a number of issues. For years, the Computer Science curriculum of our department has been quite unbalanced in favor of programming courses, with Computer Organization being the only hardware course offered. During the past two years I developed and taught a new course – Advanced Computer Architecture, but, being an elective, it does not provide the opportunity to enhance the hardware knowledge and experience of all undergraduate Computer Science students. Without sufficiently emphasizing hardware issues, students gain a one-sided view of Computer Science, never reaching a solid understanding of all the issues involved in hardware-software interaction, and the intimate interdependency between computer organization, operating systems, and programming languages. Thus, enhancing the Computer Science curriculum by adding a hardware lab brings a better balance in our students' education.

Another need for the hardware lab is dictated by the insufficient amount of class time needed to cover the multitude of topics in Computer Organization. Since our students do not have the benefit of course on Digital Design as a prerequisite, all relevant material, including number systems, combinational and sequential circuit analysis and design, etc. has to be taught during the first few weeks of the Computer Organization course, taking away time from the real focus of the course – the design and organization of a modern computer system. The availability of a hardware lab shifts the coverage of some of these topics from lectures to the lab, thus providing the instructor with more time to concentrate on other parts of the course.

A third reason for adding a hardware lab is to provide students with a hands-on experience in designing and implementing real circuits using hardware components such as integrated circuits, LEDs, switch banks, resistors, etc. This experience is quite novel to most students, different from all the other labs they have taken, and they welcome it quite enthusiastically. The hardware lab assignments not only reinforce the material covered in class, but present the abstract, theoretical notions from lectures in a much more accessible, real-world form that most students can relate to, and find challenging, but fascinating.

Finally, the addition of the hardware lab component to the Computer Organization course will probably be beneficial to the department's current ABET accreditation efforts by bringing our Computer Science curriculum in accord with the stringent ABET requirements.

3. ESTABLISHING THE LAB

Setting up the hardware lab did not require major financial resources and expense. Since the class size is limited to 25 students working in pairs during lab, only 13 powered breadboards needed to be purchased at about $100 each [7].

Fig. 1 Powered Breadboard

The breadboards are fairly small, and can therefore be stored in a cabinet, and taken out before the beginning of each lab. The lab exercises can be conducted in a regular classroom. Thus, the issue of finding a separate room for the lab equipment and for conducting the actual labs was avoided. In addition to the breadboards, a selection of integrated circuits, resistors, capacitors, LEDs, wiring sets, chip extractors, etc. were ordered. The overall cost of all lab equipment was less than $3000.

4. TEACHING THE LAB

The lab involves a sequence of progressively more complex exercises, intended to familiarize students with various aspects of combinational and sequential circuit analysis and design. Each lab assignment is handed out a few days in advance of the lab, and requires that the students prepare for the lab by designing a specific digital circuit from specifications, and drawing a wiring diagram of the circuit. The instructor evaluates and corrects the students' designs, and, based on the correct wiring diagram, the students implement the circuit during the lab period on a breadboard.

The first lab is introductory in nature, and is intended to familiarize the students with the equipment, basic concepts of electrical/computer engineering, and safety issues (not many of those since we are dealing with low-power electronics). The students are introduced to the powered breadboards they will use during all subsequent lab exercises. The layout of the board is explained along with proper procedures for chip insertion and extraction. Furthermore, basic concepts such as voltages and currents are discussed along with the need for using resistors and capacitors, the operation of LEDs, identification of pins on integrated circuits, searching for and understanding technical specifications of various digital components, etc.

The second lab is synchronized with the introductory lecture material on logic gates. During this lab, students experiment with a several integrated circuits – 74LS08 (AND), 74LS32 (OR), 74LS06 (Inverters), 74LS86 (XOR) – by connecting the inputs to a switch bank, the outputs to LEDs, and verifying the truth table of each logic gate [2]. This lab, although simple, teaches students the basics of digital circuit implementation and debugging, and builds their confidence for the next assignments.

In lab 3 the students are asked to design and implement a simple 3-input combinational circuit based on specifications provided as a truth table [3]. This goal of this lab is to reinforce the lecture material on converting truth tables to Boolean equations and logic diagrams, and then to wiring diagrams. Although the circuit is not as large or complex as some of the circuits the students have been asked to design as homework, it allows them to experiment with a combinational design involving more than one integrated circuit.

Labs 4 and 5 are dedicated to the design of a full adder and 4-bit binary adder/subtractor [4, 5]. The diagrams are more challenging, and for first time some students require close guidance and help. However, with support from the instructor, each of the two labs can be completed within the allocated 50 minute lab period. The timing of the lab coincides with the coverage of ALU design during lectures, where the binary adder/subtractor is one of the topics discussed. Thus, once again, the lab exercise is used to reinforce lecture material, and to bring realism into a relatively abstract classroom discussion.

Lab 6 revolves around a single chip – the 74LS181 (4-bit ALU). Students familiarize themselves with the pin-out diagram of the chip and its operation table, as well as with its electrical and timing characteristics from the specification sheets distributed to them a few days before the lab. In the course of the laboratory exercise, students examine, through experimentation, the various functions of the chip, and verify the ALU's correct operation as specified in the operation table.

The next two lab periods are used as a tutorial introduction to the analysis and design of synchronous sequential circuits. By this time sequential circuits, mainly flip-flops, registers, and counters, have been used extensively during lectures, but, in the interest of leaving more lecture time for advanced organization and architecture questions, the formal discussion of analysis and design of sequential circuits has been left for the lab. Based on the material presented during these lab sessions, and backed up with homework assignments, the students are prepared to design and implement sequential on their own, which is required of them during the following lab.

Lab 9 is dedicated to the design of a simple 2-bit binary up-counter [6]. This time, the problem is specified only by a word description. Students are asked to provide a state diagram, a state table, state equations, a logic diagram, and a wiring diagram of the counter. In this exercise, the degree of autonomy is quite high, but, by then, the students have acquired enough experience to deal with the problem with minimal help from the instructor, whose main responsibility is checking the student designs and ensuring that the wiring diagram have been correctly drawn. The subsequent implementation based on these wiring diagrams is accomplished during the next 50 minute lab period.

The remaining two labs are dedicated to the study of the organization of a modern computer system. During the first lab, students observe as the instructor disassembles a personal computer, explaining the function of each of the components, discussing possible substitutions and new components available in place of the ones being demonstrated in a brand new PC. For example, while removing the SDRAM DIMMs from their sockets, the instructor may discuss new types of memories available such as RDRAM and DDRRAM, their differences, advantages, and disadvantages. While removing the CPU from its socket the instructor may comment on the differences between the CPU at hand and the latest CPUs available at present. This is the perfect time to discuss all the latest developments in hardware available to those interested in building their own computer[2]. During the last lab period, the students are given the opportunity to disassemble and re-assemble a PC themselves – either individually or in groups.

5. DECISIONS, OBSTACLES, CHALLENGES

The decision to add a hardware lab to the Computer Organization course was not taken lightly. Indeed, despite the many advantages that such a lab offers, there were some serious questions to be resolved and obstacles to be overcome.

A major part of the consideration was the addition of one new credit to a 4-credit course. Some members of the department argued that this puts too much weight on the Computer Organization course since no other course in the Computer Science curriculum is assigned 5 credits. However, considering that Computer Organization is our only core Computer Science course dealing with hardware, and in light of the ABET accreditation guidelines for Computer Science programs mandating substantial coverage of organization and architecture topics, the majority of the faculty agreed that adding one more credit of hardware lab work to Computer Organization and Architecture is justified.

The additional credit also meant increasing the number of credits in the major. This issue meant restructuring parts of the program to accommodate the extra credit. Fortunately, since several other courses were being re-organized at the same time, fitting the additional credit into the curriculum did not prove to be a significant problem. However, adding the extra hardware lab credit would have been justified even if it meant increasing by one the overall number of credits required for graduation, since the benefits of the hands-on experience students gain are significant.

The financial issues – initial cost and yearly maintenance – were also seriously considered. Since the initial investment did not prove to be a significant figure (less than $3000), this issue was easily resolved. The funds required for yearly maintenance and upgrade of equipment are minimal since, if properly supervised, students do not inflict significant damage on the equipment requiring a yearly replacement or update. In fact, during the entire semester, not one integrated circuit or any other component has been burnt during lab exercises, and none of the breadboards have been damaged.

---

[2] In fact, after the lab, I helped a number of students to select appropriate components and put together compete computer systems.

One other issue that was considered carefully by the department was the suggestion to invest in hardware simulation software. The initial investment was similar to the above stated figure, but license renewal and upgrade would have incurred significantly larger costs than the minimal upkeep needed for the actual hardware equipment. In addition, it was argued that a hardware lab, in which students work with real circuits, and see the results of their design efforts realized directly, would bring realism to the educational experience, which even limited to the small sized circuits actually designed and implemented on breadboards far outweighs the relatively abstract nature of working with a simulation package.

6. PRELIMINARY ASSESSMENT AND CONCLUSIONS

All indications are that the introduction of the hardware lab was a resounding success. Students have expressed unbridled enthusiasm for the lab exercises to the point of establishing a section of the Computer Science Club dealing with advanced topics of hardware design. The topics covered in the lab seem to have reinforced the lecture material since test questions pertaining to the material covered in the lab and during lecture are answered far better than the questions on the lecture material only. The hardware lab has freed lecture time to pursue more advanced issues of Computer Organization and Architecture such as pipelining, super-scaling, and out-of-order execution. And perhaps most significantly, the lab has reinforced the bond between theory and practice, between abstract design concepts and real-world circuits, helping achieve a better, more-balanced Computer Science curriculum at our college.

7. REFERENCES

[1] L.Ivanov, "*Hardware Courses and the Undergraduate Computer Science Curriculum at Small Colleges*", presented at CCSC-East, 10/02

[2] http://www.iona.edu/faculty/livanov/cs311/cs311_lab2_wiring_diagram.jpg

[3] http://www.iona.edu/faculty/livanov/cs311/cs311_lab3_prep_pg1.jpg

[4] http://www.iona.edu/faculty/livanov/cs311/cs311_lab4_prep_pg1.jpg

[5] http://www.iona.edu/faculty/livanov/cs311/cs311_lab5_prep_pg1.jpg

[6] http://www.iona.edu/faculty/livanov/cs311/cs311_lab8.jpg

[7] http://www.jameco.com/cgi-bin/ncommerce3/ProductDisplay?prmenbr=91&prrfnbr=3613&cgrfnbr=876&ctgys=505;560;876