Teaching Computer Organization/Architecture by Building a Computer

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Abstract

This paper describes a series of exercises and assignments suggested for an introductory computer organization or computer architecture course. The primary objective of these exercises is to engage a class of students by introducing the practical, hands-on application of assembling a computer by selecting or purchasing individual components. While the ideal implementation involves the purchasing and assembling of components, various alternatives will be presented that do not require any additional funds to be secured.

Categories and Subject Descriptors

K.3.2 [Computers and Education]: Computer and Information Science Education – *Computer Science Education*

Keywords

Computer Science Education, Computer Architecture, Hardware

1. Introduction

A course in computer architecture or computer organization offers a unique opportunity to study the principles of modern computer design. From embedded systems to pipelining to virtual memory, this course often covers the components of a modern computer in a fundamental, theoretical manner. While computers are becoming increasingly complicated, teaching the basics of hardware design requires not only explanation of theoretic principles, but also their practical relevance.

As a means to motivate students and generate a more complete understanding of the underlying theoretical components of computer organization/architecture, this paper proposes a practical exercise of assembling a modern machine from components. This exercise involves students researching the current state of the art of computer components and ultimately assembling a machine. It also provides an opportunity for students to engage in a debate regarding the advantages and disadvantages of the various components and communication paradigms.

2. Motivation

Traditional computer architecture or computer organization textbooks often include an introductory chapter on the components of a computer [3, 6, 7]. These chapters will traditionally include pictures of motherboards or CPUs and explain the basic functionality of the components that constitute a modern computer. A student only subjected to this cursory introduction may be able to identify the components of a computer, but his or her impressions would be limited to abstract concepts. By physically dissecting and assembling a computer, students obtain an understanding of the size and scale of the components. Furthermore, students can directly associate the theoretical function of the objects with a physical object. Hands-on experiences have been shown to be effective tools for increasing learning comprehension [1, 2]. As technology trends are constantly changing, exercises such as these help students to develop skills to gather and critically analyze information.

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This type of project encourages students to develop skills necessary to keep abreast of the current state of computing. Considering the continual rapid advances of advanced technology, specific details taught in the classroom will likely be obsolete by the time a student graduates. Encouraging students to gather and critically analyze information found in periodicals, books, or on the internet will help them develop the skills needed to maintain a current understanding of modern computing – not just what was taught in the classroom.

3. Related Work

There are several techniques that are typically used to make a computer architecture course applicable to modern computing. These techniques enrich a theoretical course that would otherwise involve only paper and pencil exercises. Courses involving lab sessions often use breadboards or other hardware to offer an effective hands-on approach to teaching concepts introduced in a course on computer hardware [4, 5]. The exercises presented in this paper would be suitable for a lab course, or could be implemented by utilizing a few class periods in a traditional course.

Another educational technique often introduced in homework assignments in a computer architecture or computer organization course is the use of simulators [8]. Simulators are effective tools designed to familiarize students with embedded systems and microprocessors. A simulator can be used for a number of programming tasks involved in the computing pipeline (e.g. CPU simulators, microcode simulators, assembly language simulators). Learning the design languages and syntax of these simulators, however, can become a task that is largely akin to learning an additional programming language. Students may learn the language to satisfy requirements, but without careful explanation, the practicality of these exercises can result in a purely theoretical, not practical, knowledge of computer hardware.

4. Exercises

The goal of the exercises presented is to give students a hands-on experience while developing real-world computing knowledge that can be used immediately to identify the functionality of computer components, understand and use the associated jargon, and ultimately assemble a machine on their own. As a result of these exercises, students will be able to construct machines at a fraction of the cost of a similar machine purchased at a retail store.

The experience is organized into three separate exercises. The first is an in-class exercise designed to introduce the components of the machine on the first day of the course. In the second exercise, students are asked to research various components and report their findings to the class. Students are then asked to design an appropriate machine according to assigned hypothetical profiles. The third exercise involves students debating which components should be included in order to purchase the most cost-effective machine.

4.1. Exercise One: Identifying Components

The first day of class is an excellent opportunity to demonstrate to students that studying computer organization can be an exciting, hands-on experience. Several computers should be transported to the classroom or lab; students are put in groups and encouraged to dissect a working computer – identifying components as they are dismantled. A professor with experienced students could use working lab machines if he or she has the confidence they can be correctly reassembled. A more conservative approach would be to use machines that could simply be recycled after the exercise.

Many of the concepts that will be covered in the course can be introduced throughout the first exercise. For example, memory hierarchy, processor design, component connections, and magnetic disks can all be explained in a manner that will be consistent with how they will be covered during the course. Given the proper time, tools, and care, these individual components can also be dissected. By introducing the components as tangible objects, students are given the initial impression that the course covers practical concepts that are actually implemented outside academia.

4.2. Exercise Two: Planning to Build a Computer from Components

After students have had the hands-on experience of dissecting a working computer, a discussion of the practical components is easy to facilitate. The first portion of the next exercise is to familiarize students with the fundamental components of a computer: motherboard, case, optical drive, hard drive, graphics card, sound card, power supply, and RAM. A lecture can be devoted to explaining the purpose of each component and the considerations that must be made when selecting a combination of these components. The following are a few examples of topics that should be considered before purchasing components for a machine: the motherboard and processor type must be in agreement, the power supply must provide enough wattage to support the graphics card, the differences between parallel ATA (Advanced Technology Attachment) and serial ATA for connecting a hard drive with the motherboard, and the difference between buying a component by means of retail or OEM (Original Equipment Manufacturer).

The students are each assigned one of the computer components to research and instructed to focus on covering a wide range of possibilities including expense and performance. After doing the research, the students are expected to be relative "experts" in their component – knowing prices, brands, and performance considerations. The course website can refer students to several resources for each of the various components outlining the performance and cost scenarios. Several good sources for this kind of information include: cnet.com, tomshardware.com, anandtech.com, and slashdot.org. Comparison shopping guides are typically easy to find for each of the components. The next class period consists of a "round table" discussion where each student shares with the class the considerations for purchasing their specialized component.

Students are also assigned a situation that is associated with the particular computer component (see figure 1). Each profile is also assigned a budget. The different profiles and budgets are designed to give the student guidance as to how to purchase the various components in order to assemble a machine that satisfies the needs of the profile they have been assigned while meeting the budget. It also demonstrates to the class the numerous options available when selecting components to build a machine. The students are asked to find the prices for the components at various online computer stores (e.g. newegg.com), online auctions (e.g. ebay.com), or retail stores (e.g. Best Buy). Specifically, the student is asked to comprise a list of price quotes for all of the components necessary to assemble a computer given the assigned profile and budget. In addition to the list of price quotes for the components, the student is required to write a paper that details the decision making process, including the rationale for selecting each of the components.

Profile: You are an 82-year old grandparent. Your computer will used primarily to email your children and grandchildren. Budget: Build a computer for as little money as possible.
Profile: You are a 32-year old successful business professional. You want a computer to play the latest video games, download movies, and keep up-to-date with the latest gadgets. Budget: Money is not an object.
Profile: You are a working college student. You need a computer so you can write papers, write programming assignments, and maybe if you have some time, play a video game or two. You are looking for an all-purpose machine. Budget: $1200
Profile: You are a high school music teacher. You desire a new computer to start your own music studio so you can stop teaching and start your own recording career. You are interested in a computer with a high storage capacity and a state-of-the-art sound card. Budget: $2200
Profile: You are an aspiring film director. You are buying a computer to store all of your home movies in hopes of compiling them into the next blockbuster feature-length film. Your machine needs to have a large amount of storage space. Budget: $1600
Profile: You work as a low-level employee for high-profile software company. You have been assigned to experiment with the next operating system that will require a large amount of RAM. Your company has given you $1600 to invest in a machine that will exploit the current state-of-the-art RAM capabilities. Budget: $1600
Profile: You are a NASA scientist working from home. You need the fastest, most solid number-crunching machine you can buy for $2000. Budget: $2000
Profile: You are a professional video game player. While not a lucrative career, your constant "practicing" while in college is finally paying off! You want the best game-playing machine available within a budget of $2500. Budget: $2500
Profile: You are the wealthiest person in the world. Build the most ridiculously expensive machine possible. Budget: Money is not an object

Figure 1: Profiles and budgets for a writing assignment designed to help students make informed selections of individual computer components.

4.3. Exercise Three: Building a Computer from Components

In an effort to mimic a real-world engineering experience in which design decisions must be made by a team while considering a limited budget, the next exercise calls for the class to collaborate in assembling a single machine with a budget of $1000.00. Note that the monetary amount is somewhat arbitrary as a viable machine can be constructed for as little as a few hundred dollars. Ideally, an educational funding organization (either external or internal to the university) will support the purchase of the components for the construction of the machine. If such an opportunity does not exist, the exercise can still be completed without the purchase of the machine.

Students are asked to write a paper detailing a general-purpose machine that can be purchased, component-by-component, for under $1000.00. In order to ensure the students are making informed decisions, it is important that the components selected are supported by research articles read and cited. The bibliography in the paper should have a minimum number of sources that the student has used to help make the decision of the components to select. Students should also consider that the goal is to construct a machine that is well-rounded, efficient, and powerful – maximizing the performance of each of the components while considering the imposed budget. The purpose of this paper is to encourage students to form an idea of a machine that meets the budget and to have a detailed and broad understanding of the various components, not only a detailed understanding of a specific component researched for the first paper.

The following class period consists of a student-led debate as to which components to purchase in order to maximize the performance of a machine that can be purchased with a budget of $1000. These discussions allow for students to discuss the advantages and disadvantages of the components of the machines. For example, what kind processor to buy (AMD vs. Intel) or which graphics card manufacturer is superior are excellent topics for debate. Once the class agrees on the components (or the professor declares the winner of the debate), the components can be purchased and assembled as a class at a later time.

5. Results

The series of exercises described in this paper was used in CS 172 Digital Computer Organization during the spring semester of 2007 at Drake University. Students enrolled in the course have taken an assembly language course as a prerequisite. The exercises took approximately two weeks during a sixteen week semester. At the end of the exercises, each student expressed that he or she would be comfortable assembling a machine from components for their own personal use. One anonymous student commented, “The computer assembling was great. This forced students to understand how the components fit together and worked with each other. This provided real world aspects to what most professors only talked in theory about.”

Figure 2 lists the components purchased as a part of the course in 2007 for a total of $926.56. As the grant that supported the purchase of components stipulated that the assembled machine would support ongoing research in computer graphics, the class was instructed to design an all-purpose machine with a specified video card. A comparable machine quoted at a retail store was priced at approximately $1830.00. As an incentive for students to enroll in this course, a flier posted in the computer science building during the course enrollment timeframe correctly stated “taking this course can save you hundreds of dollars on the purchase of your next computer.”

Item	General Description	Cost
Case	ATX Mid Tower	$24.99
PSU	GOODPOWER 500W	$51.99
Motherboard	ATX AMD Motherboard	$88.99
CPU	AMD 2.4GHz Socket AM2	$189.00
Memory	(2 x 1GB) DDR2	$184.99
Video Card	Quadro FX560	$269.99
Hard Drive	160GB 7200RPM SATA	$52.99
Optical Drive	Sony 18X DVR+R	$29.99
	Shipping	$33.63
	Total	$926.56

Figure 2: Components of the machine built by the students enrolled in CS 172 at Drake University. The components were purchased in February 2007.

This project was initially intended to be a hands-on activity in a small class consisting of nine students. The exercises will likely be most effective with small classes typically found at liberal arts or engineering technology colleges. In lectures with a large number of students, the number of available computers for dissection or the cost of the assembly portion of the exercise may be prohibitive. In this case, various components of the exercises could be demonstrated or encouraged as exercises outside of class.

6. Conclusion

This paper outlines a hands-on project that involves a class of students assembling a computer from components. The hands-on approach allows students to experience the intricacies of computer hardware, physically identify components, and develop the confidence to construct their own personal computers in the future – saving hundreds of dollars on the purchases of future computers. The project requires the students to work together, mimicking a real-world engineering experience in which design decisions must be made by a group while considering a limited budget.

7. Acknowledgements

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