A HARDWARE COURSE FOR A SOFTWARE CURRICULUM

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Abstract

The computer science program at Central Michigan University is a predominantly software oriented program with approximately 400 undergraduate majors and minors. One "hardware" course, which is described in this paper, is required of all majors. One hundred ten students were enrolled in the course during the Fall 1979 Semester. Concepts covered include logic circuit design, arithmetic and logic unit design/operation, and the architecture of various computers.

A logic demonstration board has been developed as a teaching aid for the course, as no laboratory is currently available. Five other architecture/design courses are available in the department, although they are taken primarily by graduate students.

Introduction

Most undergraduate majors at CMU take only one "hardware" course in their program. CPS 360-Logic Circuit Design covers sufficient material to enable students to begin their professional careers with some knowledge of logic, design, architecture, and internal operation of digital computers. Additionally the course prepares students for additional architecture/design courses available at the undergraduate and graduate levels.

CPS 560-Digital Computer Design, for which CPS 360 is the prerequisite, has been extensively documented in previous SIGCSE Bulletins [4,5]. In CPS 560, students have previously designed the control and arithmetic/logic units for a small computer. Due to personnel considerations CPS 560 was not offered during the 1979-1980 academic year. In the future CPS 560 may possibly evolve into a microprogramming course utilizing the department's Burroughs 1830 computer. Additional hardware/architecture courses offered at the graduate level include CPS 620-Switching Theory, CPS 635-Automata Theory, and CPS 660-Advanced Computer Organization. The graduate students have an increased interest in design/architecture courses compared to previous years.

Subsequent sections of this paper deal with the goals, objectives, and contents of CPS 360. The use of a logic demonstration board in class is also discussed.

Goals and Objectives

The goal of CPS 360 is to provide sufficient hardware background to computer science majors who will take only one hardware course before beginning their professional careers or entering graduate school. An ancillary goal is to show, whenever possible, the interdependence of hardware and software and the effects of design and architecture on software.

Objectives of the course are to convey a number of specific concepts to the students to meet the stated goals. An understanding of binary, octal, BCD, and hexadecimal number systems is fundamental to the course. Although these concepts are covered in the prerequisite course, CPS 210-Assembly Language Programming, most students do not thoroughly understand the need for or use of these number systems prior to taking this course. Characteristics of fundamental digital devices such as gates and flip flops as well as digital design techniques used to simplify digital circuits are described. The Karnaugah map is the principal tool used to simplify logical expressions. Counter designs using various flip flops are the main vehicle for students to apply the design techniques. Approximately seven to eight weeks are spent on these concepts followed by a two hour exam.

In the remaining half of the course, concepts of the arithmetic/logic unit, the control unit, and various architectures are developed. Both the operation and the design of the ALU are covered. Hard wired control units are explained by studying the control sequences for several instructions of a simple computer. The important concepts of microprogramming and microprogrammable control units are covered by examining the microprograms for several machine language instructions. The architecture of several micro, mini, and large scale computers is discussed to complete the course. A two hour exam on the last half of the course is followed by a two hour final exam covering the entire course. While other hardware concepts come to mind which are not covered above, the objectives given are sufficient to implement the goals of the course given the constraint of a 15 week, three credit course.

Specific Course Content

A topic outline of the course shows the specific topics discussed to meet the objectives of the course.

I. Preliminary Concepts (2 hours)

   A. Basic Computer Components
   B. Assembly Language Examples

II. Number Systems (2 hours)

   A. Binary Numbers
   B. Binary Arithmetic
   C. Conversion to/from Binary
   D. Sign Magnitude and Complement Representation of Negative Numbers
   E. BCD Numbers
   F. Excess Three Code
   G. Octal Numbers
   H. Hexadecimal Numbers

III. Design Fundamentals (6 hours)

   A. Or Gates, And Gates
   B. Inverters
   C. Logical Expressions/Boolean Algebra
   D. Perfect Induction
   E. Duality
   F. POS, SOP Forms
   G. Nand Gates, Nor Gates
   H. Karnaugh Map Simplification
   I. Redundancies

IV. Design Applications (6 hours)

   A. Flip Flop Characteristics
      1. D Flip Flops
      2. R-S Flip Flops
      3. J-K Flip Flops
      4. T Flip Flops

   B. Transfer (Gating) Circuit
   C. Shift Registers
   D. Binary Counters
   E. BCD Counters
   F. State Diagrams
   G. State Tables/Design of Counters

V. Review, Two Hour Exam on I-IV, Discussion of Exam (6 hours)

VI. Arithmetic/Logic Unit (4 hours)

A. Half Adder
B. Full Adder
C. Parallel Binary Adder
D. Compliment Adder/Subtracter
E. BCD Adder
F. Binary Multiplier
G. Floating Point Representation/Operations

VII. Control Unit (6 hours)

A. I Cycle, E Cycle
B. Hard Wired Control Units
C. Microprogrammable Control Units
D. Microprogramming

VIII. Organization and Architecture (6 hours)

A. Architectural Design Considerations
B. Instruction Words Formats
C. Addressing
D. Indexing
E. Paging
F. Indirect Addressing
G. Channels, Peripheral Processing Units
H. Motorola 6800 Microprocessor
I. DEC PDP-8 Minicomputer
J. Intel 8080 Microprocessor
K. IBM 360/370

IX. Review, Two Hour Exam on VI-VIII, Discussion of Exam (6 hours)

X. Review for Final Exam (2 hours)

XI. Final Exam (2 hours)

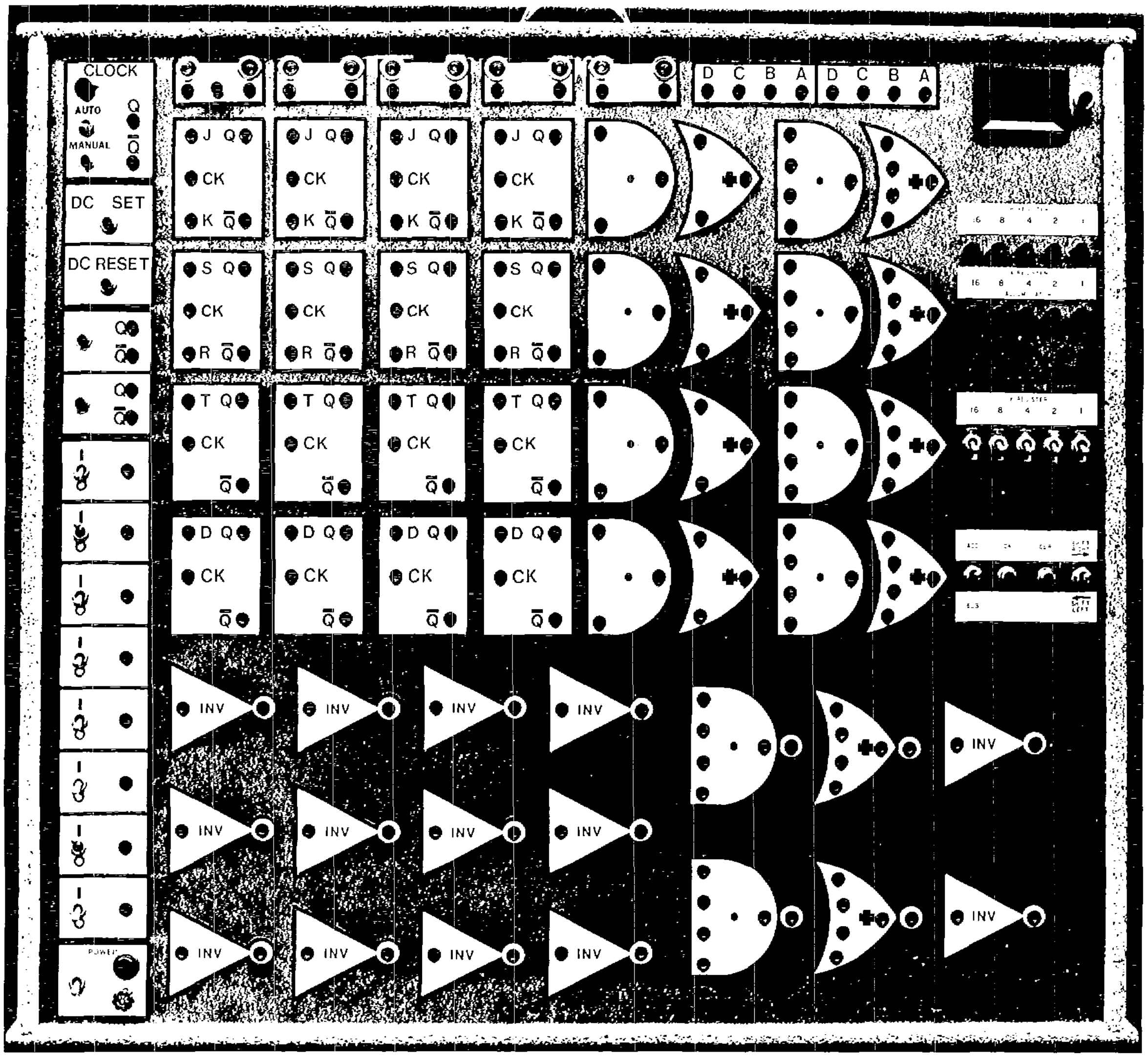
A major component of the course as outlined above is a copious amount of assigned homework. As this is an entirely different type of course compared to other courses taken by our undergraduates, I feel that this amount of outside effort is absolutely necessary. To compensate for the somewhat excessive amount of homework, it is counted as 1/3 of the total grade.

A major failing of the present course is the absence of a digital logic laboratory for the course. The design problems and the operation of the Arithmetic/Logic Unit and control unit could be made much more understandable to the student if such a laboratory were available [3]. Efforts are currently under way to establish such a laboratory.

Logic Demonstration Board

To supplant the nonexistent logic laboratory and to give the students "proof" that the design techniques used in class actually work, a logic demonstration board has been built. The demonstration board differs markedly from the usual logic lab station that the students would use if we had a logic lab. Since it is a classroom demonstration device, the demonstration board is large--about 32 x 36 inches. The front of the board has large (3 x 4 inch) symbols for each logic device, which are visible from "the back of the room".

The picture that follows shows the logic demonstration board. Logical devices on the board were chosen so that virtually every circuit discussed in the course can be implemented. A word of caution, of course, is that these circuits should not be wired up in class with 40 to 70 students watching; but before class with as small an audience as possible. Wiring the board in class can prove even more embarrassing than executing programs written in class that don't work.



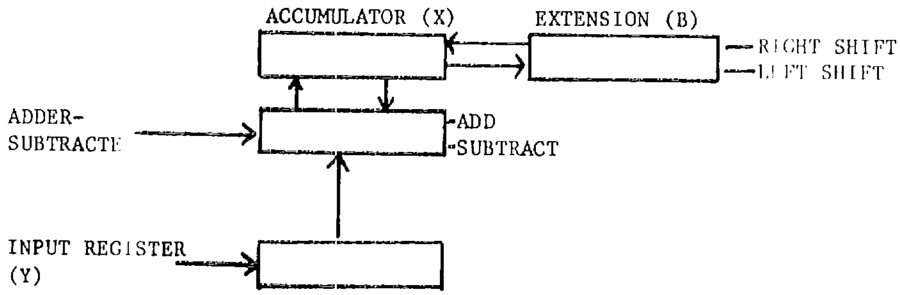
LOGIC DEMONSTRATION BOARD

As may be seen from the picture, the logic demonstration board contains the following devices:

4 J-K Flip Flops
4 R-S Flip Flops
4 T Flip Flops
4 D Flip Flops
1 Variable Frequency Clock
DC Set/Reset for the Flip Flops
4 Two Input AND Gates
4 Two Input OR Gated
4 Four Input AND Gates
4 Four Input OR Gates
2 Four Input AND/NAND Gates
10 Lights
14 Inverters
2 Push Button (0,1)
8 Toggle Switches (0,1)

With these components, counters with up to 16 states, shift registers, gating circuits and so on can be easily demonstrated. After discussing a design in class or doing one for homework, the students are encouraged to see the design actually work. This type of demonstration tends to make the course less abstract, as well as to provide occasional comic relief when circuits suddenly don't work. Even when the circuits do work, the use of the board provides a change of pace from the normal lecture-discussion format.

Those of you with good vision may have noticed additional devices on the board that have not been discussed so far. A complete arithmetic unit for a five bit computer along with two decimal read out devices is present on the right side of the logic demonstration board. This arithmetic unit consists of an input register (Y), an adder-subtracter, an accumulator (X) and an accumulator extension (B).



The operation of the arithmetic unit is:

$$X \leftarrow (X) \pm (Y)$$

where () denotes content of. Control unit logic signals for the arithmetic unit are entered through toggle switches, so the student can gain a better understanding of the function and operation of both the arithmetic and control of units of a simple computer. Addition, subtraction, and multiplication can all be demonstrated. Multiplication using the "add and right shift or right shift" algorithm [2] needs to be demonstrated for the student to understand it. The next version of the logic demonstration board will include hexadecimal instead of decimal read out and logic input to the arithmetic unit, so that simple control unit functions can be patched in for "hands off" operation. The 14 inverters will also be omitted.

Summary/Conclusions

By omitting some of the topics usually found in introductory logic design courses, the goal of CPS 360 can be attained--to provide a single three credit hour course which contains sufficient hardware background for computer science majors who are to pursue software careers. To supplant a digital logic laboratory, a logic demonstration board was developed for use in class. The board makes the course significantly less abstract for many students. Possibly some of the students who think they are interested only in software may someday work with firmware, so the microprogrammable control unit and microprogramming are emphasized more than hard wired control units.

The intersection of this course and ACM Curriculum '78 course CS4 appears to be at least 80%. As the course is required for majors, the student reaction is somewhat mixed, but generally quite favorable. Most students are curious as to what goes on "inside the machine" and this course more than satisfies their curiosity. Textbooks taking this approach are rare but available. The best text that I have found to date is Bartee's Digital Computer Fundamentals [2]. With few additions (mostly state diagrams, state table, and a more systematic approach to designing counters with flip flops) and, unfortunately, many deletions (memory elements and I/O devices) due to time limitations, this excellent book serves well as a text for a course with this approach.

References

1. Austing, R.H., et al., "Curriculum '78: Recommendations for the Undergraduate Program in Computer Science," Communications of the ACM, Vol. 22, No. 3, March, 1979.

2. Bartee, T. C., Digital Computer Fundamentals--Fourth Edition, McGraw-Hill (1977).

3. Hobson, R.F., "Computing Science Hardware Laboratories and the LSI Revolution", SIGCSE Bulletin, Vol. 10, No. 1, February, 1978.

4. Vishnubotla, S.T., "A Logical Approach to Teaching Digital Computer Design" SIGCSE Bulletin, Vol. 9, No. 1, February, 1977.

5. Vishnubotla, S.T., "A Project to Teach Microprogrammed Asynchronous System Design", SIGCSE Bulletin, Vol. 10, No. 1, February, 1978.