Contemporary Methods of Digital Design Fundamentals Education

Hana Kubátová, Martin Novotný

Department of Computer Science and Engineering, Czech Technical University,
Karlovo nám. 13, 121 35 Prague 2, Czech Republic
e-mail:{kubatova, novotnym}@fel.cvut.cz

Abstract. This paper presents practical experience with teaching of the basic course of digital design using laboratory kits based on modern programmable circuits. The course is characterized by early semester (third), number of students in course (350) and practical use of EDA tools. The course structure and utilization of professional design tools (Digilent XCRP design kit and Xilinx EDA tools) are presented in this paper.

I. Introduction

Most students and mainly technical university students are not interested in learning pure theory without practical examples. A lot of students cannot understand the theory if it is presented in a simple manner by showing mathematical definitions, formulas, laws etc. But the real exactness and precision is achieved by strict usage of mathematical language. Lecturers could have the opportunity to translate the theory into the practice and seminars should be the key element depicting various real-world situations of theoretical aspects. However, the reality is somewhat different. Due to a large number of students, vastness of knowledge covered by one course, and numerous time constraints inflicted upon classes and curriculum in general, it is not possible to demonstrate all basic examples of theory appliance in specified time of curriculum, let alone more complex examples.

Moreover, students nowadays have more and more time constraints of their own, and thus, cannot devote adequate amount of time for better understanding of examined problems. Because of that, their comprehension of the knowledge is constantly getting weaker. Contradictory, demands of industrial practice have been increasing.

However, it is possible to address described problems with a different approach. Rapid development of computer and information technology and mainly its massive wide-spreading into the whole population has enabled development of new, technology-driven learning processes in education, thus facilitating the learning process (in sense of faster and better comprehension of presented knowledge), making it more attractive and less time consuming.

The appropriate combination of the theoretical methods, practical experiments and information technology support has been searched at our department. Our experience with the first run of the "Logic Circuits" course is presented in this paper. This course runs in the third semester of our bachelor study program of the Computer Science branch. When creating the content of the course we were mainly inspired by MIT course "Introductory Digital Systems Laboratory" [2]. But, the actual load of our course is 350 students whereas only 40 students enroll in the MIT course. That represents extreme effort addressed to the course content, to the quality and number of teachers, to the lab capacity and to the support, including materials, web pages, hardware kits, EDA tools, etc.

The paper is structured as follows: the principles, global structure and content of the desired knowledge are given in Chapter II. Chapter III describes our teaching methods. The hardware, software and web support are stated in Chapter IV. Chapter V contains the experience based on the first run of the course in a winter semester 2004/2005 and Chapter VI brings some concluding remarks.

II. Course Content and Structure

The course runs in one semester. It consists of one lecture and one seminar or lab (each of 90 minutes duration) in a week. The exam evaluation consists of up to 50 points from semester and up to 50 points from exam test. Semester points can be given for tests, for successful implementation of several combinational and sequential circuits and for project.

The desired goal is to get knowledge about basic principles of the digital design methods. Their practical applications represent foundations for following courses, mainly in areas of:

- Combinational circuits, their description and representation.
- Logic minimization methods.
- Sequential circuits, FSM and its specification and properties. State diagram, next-state and output tables, internal states minimization and coding.
- Technology mapping using gates, flip-flops, multiplexers, memory and programmable circuits.
- Typical blocks used in processors (adders, multiplexers, decoders, registers, counters).
- Analysis – static and dynamic hazards, maximum frequency estimation.
- Introduction to the digital testing methods.

III. Teaching Methods

The course consists of lectures, seminars, and labs. We have decided (mainly due to our lab capacity) to apply the system of two weeks blocks – one seminar and one lab in the same time – that means 7 weeks of seminars and 7 weeks of labs with interleaving. This leads to the organization of lectures strictly subordinated to the lab and seminar subject. Practically the lectures are more intended to the example solving and visualization of the results. All materials can be downloaded from the web page.

A. Former Teaching Methods of Digital Design Fundamentals

Previously, fundamentals of digital design were taught in the fifth semester for 200 students. During the semester students attended 14 lectures, 12 seminars and 2 labs. In labs students realized logic circuits on solderless breadboards with TTL integrated circuits and wires. For simulation the schematic was drawn and then simulated in OrCAD. Students were taught relatively large theory but without necessary practice that strengthens acquired knowledge.

B. Current Digital Design Education

Currently, fundamentals of digital design are taught one year earlier, in third semester within a scope of bachelor study program. The number of students has increased to 350. As bachelor students are claimed to have practical knowledge, the amount of theory was reduced. For example, Quine-McCluskey minimization method is presented at lectures only and the internal states coding method of Dolotta-McCluskey has been completely omitted. Students attend 7 seminars and 7 labs.

- *Seminars*. Seven seminars have two main aims: to explain and review the examples suggested in lectures and importantly to prepare students for the following labs.
- *Labs.* As mentioned above, students realized their circuits on breadboards in past. Such circuits were untransparent and unreliable mainly due to the complicated wiring. The construction of the circuit spent a plenty of time. Moreover, if the simulation was necessary, the circuit had to be redrawn into the simulation system. These reasons led to our decision to employ programmable devices in the education of digital design fundamentals. Currently, students "construct" their circuits in schematic editor that is the part of EDA tool. When finished, they translate the circuit

into the bitstream and download the circuit into the design kit equipped with programmable device. The circuit in a schematic form is transparent. If students make some mistake, correction is simple and fast. Moreover, if simulation is needed, the scheme (together with stimuli) is used as an input to the embedded simulator.

- *Project.* Each student has his individual project – a sequential circuit described by next-state and output tables with redundant internal states. The description, available at web pages, is generated by our original project generator. Functionality of the project must be verified by its simulation and by its hardware implementation.

IV. Hardware, Software, and Web Support

Xilinx and Altera are two most significant companies in the market of programmable devices. Their products, including circuits, design kits and development systems, are comparable. As Xilinx provides better university support, we have decided to use Xilinx products. ISE 5.2i is the development system in which students design their circuits. ModelSim simulator, linked with ISE, is used for the simulation. The circuit is downloaded into the design kit Digilent XCRP [3] (see Fig. 1), equipped with Xilinx CoolRunner XCR3064 [4].

The proposed complex course content would not be achieved neither by our bachelor students nor by teachers without detailed and well structured web. Information at web pages is divided into the part for students and the private part for teachers, where teachers may discuss and share student's evaluation statistics. Students can download lecture presentations, directions for labs and the actual content of every seminar with the precise specification of test dates and the desired knowledge.

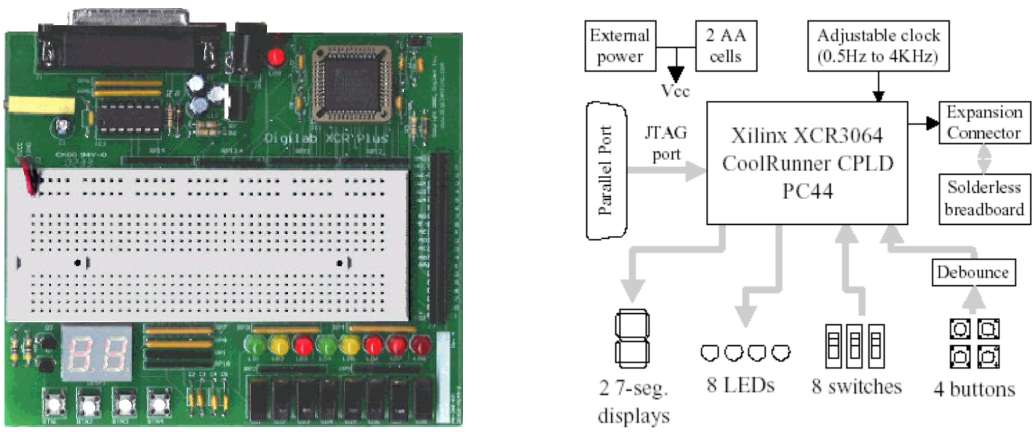

Fig. 1 Digilent XCRP design kit

V. First Run Experience

The productivity has increased about 4 times in comparison with former education when logic circuits were realized on solderless breadboards. In past, during one lab students were able to realize maximally two functions of 4 input variables. Currently, typical tasks solved during one lab are:

- Two-bit adder a) constructed from two one-bit full adders, then b) realized as three 5-input functions (see Fig. 2); both versions are also simulated.
- Electronic code-lock realized as both Mealy and Moore FSM. This helps students to better understand the difference between these two basic types of FSMs (in past, students designed FSMs "on paper" only). Both versions are also simulated.

All circuits are designed, simulated and then downloaded into design kits. Note that the complexity of logic circuits is increasing proportionally to the student's experience. Some blocks, realized in earlier labs, can be and *are* reused in further labs, similarly to software construction methods where the final design is typically composed from previously debugged blocks.

Students may download limited versions of design tools (ISE WebPACK and ModelSim XE Starter) from Internet [4]. Therefore, students may prepare their labs and projects at home. Experience with design tools is reused in further courses, e.g. Computer Units and Computer Architecture.

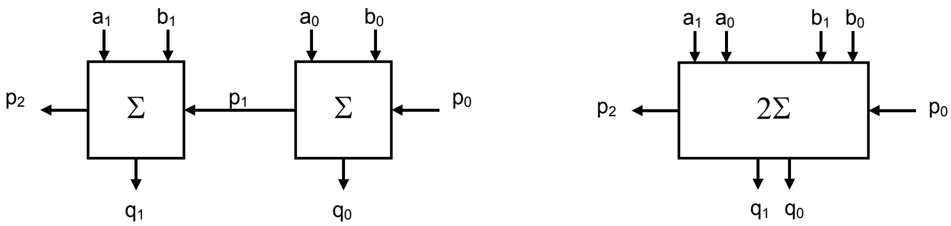

Fig. 2: Two variants of 2-bit adder realized during 1 lab. Both variants are simulated and then downloaded into design kit.

VI. Final Remarks

The relatively great amount of students has been taught the fundamentals of the digital design using contemporary design tools. Two main effects have been achieved: used technology allows performing more experiments and the experiments can be more complicated. Moreover, as students use state-of-the-art design tools, circuits and design methods, they are better prepared for nowadays demands of industrial practice.

Acknowledgements

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