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A Simulation based learning for Computer Organization Education

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Abstract: Computer Organization is a course for undergraduate computer science students that comprises of aspects of functional units of a computer. In this course, students learn designing the CPU, ALU, RAM, Pipelining, ARM and MIPS programmingusing Open Source tools and also they simulate the working of Single data path bus and Intercommunication between the CPU and Memory and the working of ARM instruction in ARM Processor using Open Source Tools. In this paper, we investigated Simulation based learning for Computer Organization through Open Source Tools.

Keywords: Computer Organization, Open source tools, ARMSim, MarieSim, Logisim, QTSpim, CPU-OS Sim

1. Introduction

The computer organization deals with the structure and behavior of digital computers (Petterson, Hennessy 2010). The main objective of this subject to understand the overall principles of computer organization, including its hardware structure and communication among the functional units (Hamacher,Vranesic, Zaky, 2011).Like any other systems, a computer system also consists of an inter-related set of components known as functional units.

Depending upon the organization of these functional units i.e the way in which they are interconnected and how they function as a individual component, the system can be characterized as a best system. In this subject we are simulating each functional unit including the working of a processor, using open source tools like MarieSim, ARMSim andLogisim. The paper is further organized as follows. Section 2 discusses about a brief introduction to the different functional units of a computer that we simulated. Section 3 describes about course overview, tasks carried out in each week and the tools used, section 4 discusses about survey conducted for the curriculum and its results based on the course outcomes of the introduction of a Simulation based teaching Computer Organization using open source tools and section 5 focus on conclusion.

Simulation based learning (SA notes 2013) helps in linking theory with the practice of teaching. It is an effective means of teaching/demonstrating concepts to the students. In our curriculum, we have used different simulators to simulate the working of different functional units of a computer and also allow the designer to study the problem at different levels of abstraction. We have used simulators to design ALU, CPU and Memory system which are very difficult to represent it in theory, so it has helped us to examine and confirm theoretical models which may be too difficult to grasp from a purely conceptual level.

2. Functional Units of a Computer

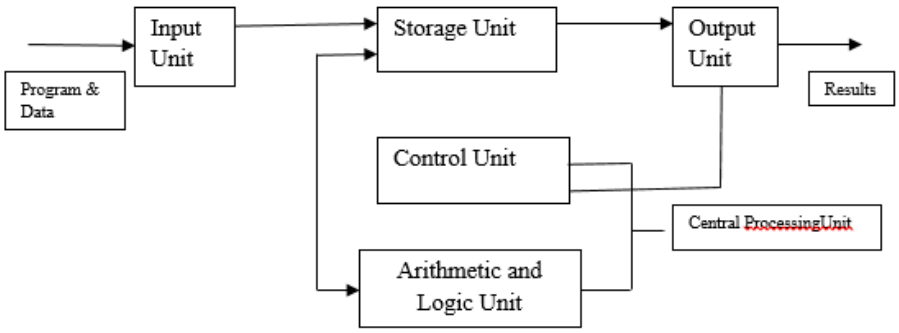

Figure1. Functional units of Computer

Figure 1: represents the functional units of Computer, they are as follows:

1. Input Unit
2. Output Unit
3. Central Processing Unit

The simulations have been done for the following concepts to teach the Computer organization and Architecture in a better way.

- In Central Processing Unit, the basic functions of an Arithmetic and Logical Unit.
- The working of Memory system in executing the data transfer instructions.
- Execution of the ARM instructions.
- Execution of an instruction using single data path bus architecture for the 8086 instructions.
- The advantages of using Pipelining technique.
- Execution of MIPS Instructions.

3. Course Overview

MarieSim(Linda, Julia 2016) is a computer architecture simulator based on the MARIE architecture and it is mainly used to teach the execution phases of an instruction to the beginners of computer organization and architecture effectively. It provides users with interactive tools and simulations to help them to expand their understanding of the operation of a simple computer. During the execution of assembly language instructions, students can see the execution datapath by observing the changes in CPU's registers and system'smemory. Java Swing is used to design the GUI of MarieSim.

Figure1 represents some of the samples the students they have worked out to understand the interaction between the CPU and the Memory and the single datapath Simulation.

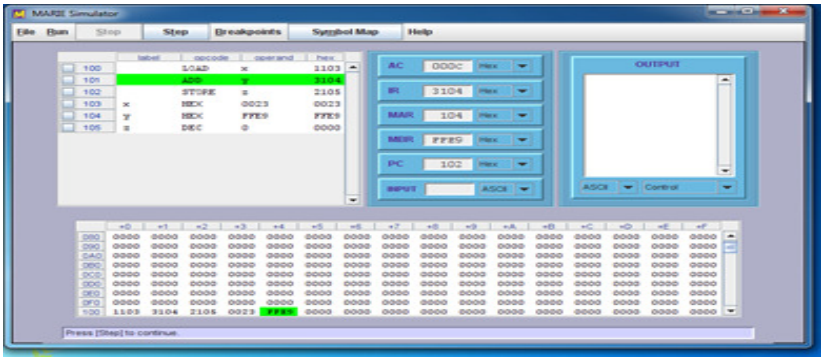

Figure1: The content of MAR, MDR, PC, IR and Accumulatorwith respect to the code got executed.

Logisim (Sourceforge.net 2016) is a simulation tool developed for educational purpose.It helps the instructor to teach thelogical circuit subject effectively showing the designing and simulation of digital logic circuits. With its trouble free and rich set of logical entities available ina self explanatorytoolbar, a student can easily build the required circuits, it is simple enough to facilitate the students to learn the most basic concepts related to logic circuits. Using those logic circuits, we are able to build the ALU and SRAM. Figure 2 represents the design of ALU using different gates to perform Arithmetic and Logical operations(IITKGP, 2010).

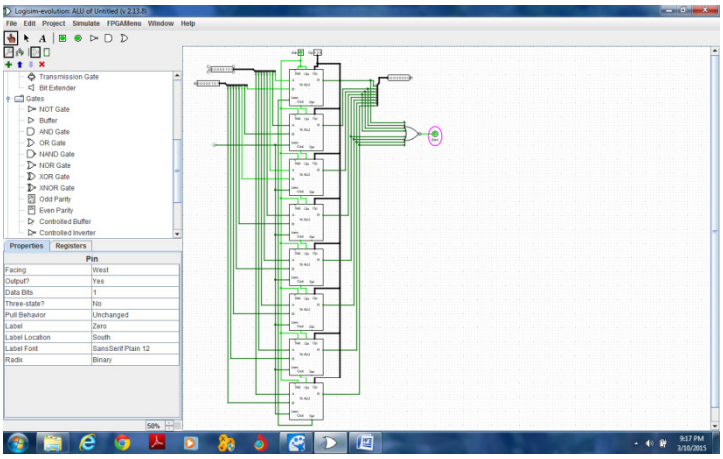

Figure 2: Design of Complete ALU Operations

Figure 3 represents the design of RAM (IITKGP, 2010) using different gates to perform Reading and Writing of data on to the memory.

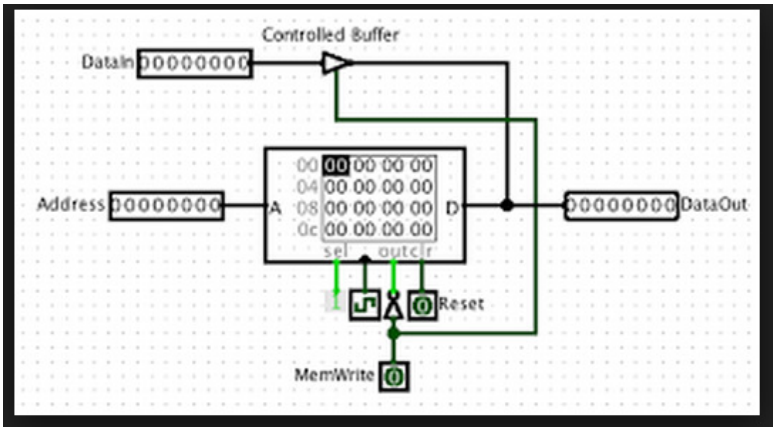

Figure 3: RAM Operations

ARMSim(University of Victoria) is an open source desktop application running on a Windows environment. It allows users to enter an ARM program (simple basic programs to lightly complex programs including loops and subroutines). Once the program is run, students can clearly observe the contents of registers and memory locations after the execution of each instruction.With the help of this simulator students can also understand different ARM addressing modes. Figure 4 represents the ARMSim editor for the program execution and with the register contents and memory location.

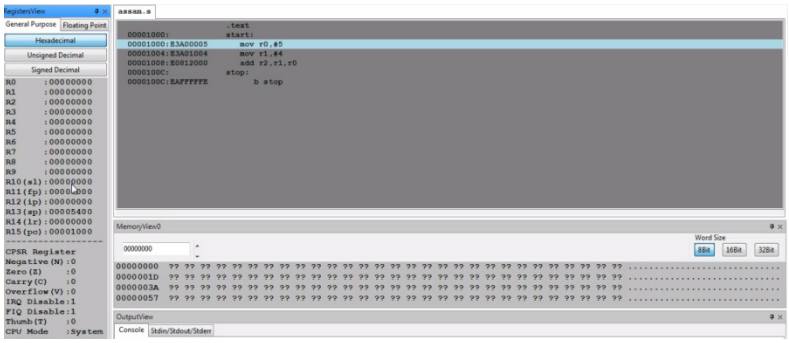

Figure 4. ARMSim editor for a simple program

One of the key important and advanced topic in Computer Organization is pipeline technique which affects the CPU performance. We have used CPU-OS Simulator(Informer Technologies, 2016) to demonstrate advantages of using pipelining over sequential execution. The students in addition can also analyze the causes of different pipeline hazards likeData hazard, Control hazard and Branch hazard.

Figure 5 represents the Pipelinined stages for a simple program of adding 2 numbers with the data hazard (highlighted in Red). It will even demonstrate the number of clock cycles required and the runtime for that program in 3 different stages

1. Instruction execution without pipelining

2. Instruction execution without pipelining

3. Instruction execution by inserting bubble(delay)

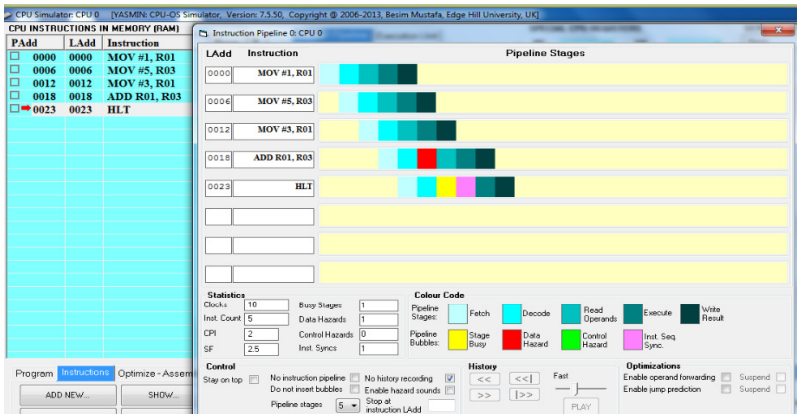

Figure 5. Pipelining with data Hazard

In this tool we will demonstrate

1. The data hazard and how it can handled after inserting the bubble, and

2. The Control hazard and how it can handled after inserting the bubble

MIPS(Microprocessor without Interlocked Pipeline Stages) programs can be better demonstrated by QtSpim(Jorgensen 2016) software that will help the students to simulate the execution of MIPS assembly programs. Just like ARMSim students upload their MIPS program. Once they run, they can see the execution of each MIPS instruction by observing the changes in register set and memory locations.

Figure 6 represents a snapshot of QTSpim editor with the string reverse function and its output on the console

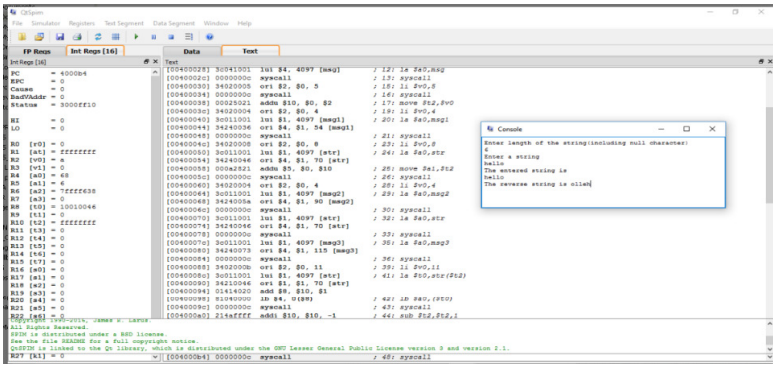

Figure 6. MIPS Program Execution and its output using QTSpim

In this course, the students are able to work with many open source tools for simulating different functional units of computer. The below table1 represents the simulation, tools used and corresponding information

Table 1: Free and open source tools used for simulation for understanding Computer organization concepts

Simulation conducted	**Free and Open Source Tools used**	**Information**
Simulate the execution stages of an instruction. **Students are able to understand theinterconnection between processor and memory and the data path.**	Mariesim	The usage of the tool and the conduction is been demonstrated in the college website https://sites.google.com/a/msrit.edu/computer-organization/simulation4
Simulating the design of SRAM using counter, controlled buffer, clock, Random generator and tty **to write and read the data onto the memory.**	Logisim	https://sites.google.com/a/msrit.edu/computer-organization/simulation-5
Simulating the design of ALU and its working using AND, OR, X-OR gates to perform **Arithmetic and Logical Operations.**	Logisim	https://sites.google.com/a/msrit.edu/computer-organization/simulation1
Simulating the execution of an Assembly instructions. Comparing the performance of the CPU without and with pipelining. **Students are able to identify the Data Hazard.**	CPU-OS simulator	https://sites.google.com/a/msrit.edu/computer-organization/simulation-6
Simulation of execution of Assembly instructions without and with pipelining and inserting bubble and also **students can demonstrate the Control Hazard.**	CPU-OS simulator	https://sites.google.com/a/msrit.edu/computer-organization/simulation-7
Simulation of ARM Instruction Execution. **Students can understand the ARM Architecture** through simulation.	ARMSim	https://sites.google.com/a/msrit.edu/computer-organization/simulation-8
Simulation of MIPS Instruction execution. **Students can understand the MIPS Architecture** through simulation.	QTSpim	https://sites.google.com/a/msrit.edu/computer-organization/simulation-3

3. Course Surveys and Results

In this course of Computer Organization, we conducted surveys by designing course outcomes that can be satisfied by the students after learning this course. The main aim of these surveys is to improve the curriculum of Computer Organization course using the feedback from the students. The analysis and the results are as shown in the table 2 and table 3. Table 2 lists the course outcomes and their results. Table 3 lists the survey questions formed and its results. From these survey results and feedback from the students we infer the following results.

- Ability to design a CPU using the Basic gates and to verify the proper working of CPU.
- Ability to design ALU using the basic gates and verify all the Arithmetic and Logical Operations.
- Ability to design RAM using basic gates and simulate the movement of data in memory.
- Analyzing the working of Processor, Memory and Single Datapath.
- Analyze the working of ARM Processor.
- Analyzing the working of MIPS Instruction using QTSpim
- Demonstration of Pipelining and different hazards using CPU-OS Simulator

We have taken a survey on Computer organization course outcomes and we are appreciable for the attainment of all 5 CO's. Totally 114 responses we got from the students. Here we are representing that attainment of CO's graphically. Around 50% of the students have rated the attainment of CO's are very good.

Table 2: Course outcomes and its attainment

No	Course Outcome	Results of Survey(Attainment Level)	
1	Understand the operations & operands of the computer, representing instruction and ARM addressing modes.	Rating Criteria Excellent Very good Good Satisfactory	Percentage of Attainment 26% 51% 22% 3%
2	Implement different algorithms used to perform fast multiplication and division also represent the floating-point number in IEEE format	Rating Criteria Excellent Very good Good Satisfactory	Percentage of Attainment 26% 45% 24% 4%
3	Analyze the logic design convention, datapath elements and understand the importance of pipelining	Rating Criteria Excellent Very good Good Satisfactory	Percentage of Attainment 26% 46% 26% 4%
4	Learn how to measure and improve the cache memory performance and also recognize the advantages of using virtual memory technique	Rating Criteria Excellent Very good Good Satisfactory	Percentage of Attainment 25% 44% 27% 5%
5	Evaluate I/O system also demonstrate the connection and interfacing of I/O devices with the system.	Rating Criteria Excellent Very good Good Satisfactory	Percentage of Attainment 26% 37% 33% 3%

We have also taken the survey of simulation tools whatever the students explored in the lab. In that survey 85% of students felt that the simulation has helped the students in understanding the basic concepts of functional units of a computer. Around 50% of the students have felt very good in the attainment level of Logisim in designing the ALU and RAM. The survey on attainment level of MarieSim and ARMSim are appreciable. Where they rated Excellent in understanding the interactions between the processor and the Memory and Working of ARM Instructions in ARM processor.

Table 3: Attainment level of each simulation tool in the lab

Sl.no	Survey questions	Results
1	Use of Simulation and practical approach to understand the Computer Organization and Design	**Was the Simulation helpful in understanding the concepts of functional units of a Computer** Yes 84% No 15% **Attainment Level of tools explored in the LAB** Excellent 33% Very Good 36% Good 25% Satisfactory 6%
2	Design of ALU and RAM using Logisim	**Attainment Level of Logisim tool for designing CPU, ALU, RAM** Excellent 28% Very Good 43% Good 24% Satisfactory 4%
3	Understanding the concepts of Single data path Bus and Communication between Processor and Memory	**Attainment Level of MarieSim tool for Understanding of Interconnection between Processor and Memory** Excellent 28% Very Good 43% Good 24% Satisfactory 4%
4	Understanding the working of ARM processor in the execution of ARM instructions	**Attainment Level of ARMSim tool for Understanding of ARM Instruction and the Architecture** Excellent 29% Very Good 34% Good 26% Satisfactory 7%
5	Understanding the working of MIPS processor in the execution of MIPS instructions	**Attainment Level of QTSpim tool for Understanding of MIPS Instruction and the Architecture** Excellent 26% Very Good 37% Good 26% Satisfactory 7%

5. Conclusion

Computer Organization education plays a key role for the students to understand functional units of a Computer and also to design the functional units. The Simulation using open source tools based approach for Computer Organization helps the students to understand practically the processor and its operation. The approach we have introduced in the course is in par with virtual labs introduced in. The mapping of categories of the experiments followed in the virtual labs is same as the different tasks carried out in our approach. Initially, the course was designed with only lectures based on the contents in the syllabus. Based on the student's opinion to improve the course content through a practical approach, the course was modified with new syllabi and lab. The proposed Simulation based approach for Computer Organization made students aware of the course contents and the principles and techniques of the course.

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