An Inexpensive Laboratory for Teaching Digital Logic and Microcomputer System Design

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Outline

- The Problem
- The Solution
- The Hardware
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- The Experiments
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The Challenge

In 1998/99 UBC ECE added two new 3rd-year courses which required new lab facilities: ELEC 379 and ELEC 353. ELEC 379 covers two areas:

- Microcomputer system design
  - buses, memory systems, I/O interfaces, interrupts, DMA, . . .
- Digital logic design
  - combination & sequential logic
  - VHDL synthesis and simulation
  - RTL level design

The Problem

- too many students ($>$100)
- too little money ($<$\$100k for all u/g lab equipment)

The Solution

Have students design, connect to a computer bus, and test various peripherals implemented with programmable logic.

- simultaneously teaches logic and microcomputer system design
- each application motivates the other
- labs: five progressively more complex peripherals
- students use VHDL synthesis for all logic design
- enough equipment so each student works individually

The Hardware

The labs use low-cost equipment ($30k for 12 stations). Each workstation includes:

- Low-end PC ($1300)
- Single-Board Computer (SBC) ($250)
- Altera FPGA Demo Board ($0)
- PC-based Logic Analyzer ($500)
- Interconnect Board ($150)
- PC power supply ($0)

Hardware - PC

- for logic design and software development
- hosts logic analyzer
- low end: 166 MHz Pentium, 32 MB RAM, 15” monitor
- ethernet for printing, web downloads
- CD-ROM for [re-]loading software

Hardware - PC-based logic analyzer

- used for debugging
  - can monitor data, address, and control bus
  - students apply knowledge of bus cycles
- 24 channels (e.g. 10 address, 8 data, 4 control)
- 50 MHz sampling, 32k samples
- external clock, complex triggering (rarely used)
- awkward DOS-based software

Hardware - Single-Board Computer (SBC)

- Intel 386EX CPU
- PC-104 (ISA) bus
- 2 MB DRAM
- 1 MB EEPROM disk emulator
- download `.COM` files via serial port (xmodem)
- about US $180

Hardware - Altera FPGA Demo Board

- 10K20 FPGA RAM-based (240 pin)
- 2 7-segment LEDs
- 25 MHz oscillator
- 2 pushbutton switches (not debounced!)
- donated by Altera

Hardware - Interconnect Board

- two solderless breadboards
- all PC 104 signals available
- about 60 FPGA pins available
- protection features:
  - current-limiting resistors
  - PTC resetable fuses, power status LEDs
- logic analyzer can monitor any PC-104 or FPGA signal
- other components (switches, LEDs, level-shift ICs) easily hooked up

Hardware - Power Supply

- removed from discarded PCs
- free!

Lab Software

- Free software:
  - Altera MaxPlus+II FPGA VHDL Synthesis
  - 8086 assembler/linker
- most design and testing can be done before lab
  - both can be installed on students' home PCs
  - also available on departments' PC network

Software - Altera MaxPlus+II

- student edition, free for student use
- logic synthesis from VHDL
- waveform editor
- post-layout timing simulation
- device programmer (via PC’s parallel port)
- poor diagnostics

Software - 8086 Assembler

- freeware Microsoft-compatible assembler
- limited to real mode
- adequate for simple programs ($<$100 lines)
- assembled on PC and downloaded to SBC

The Labs

Five experiments, each to be completed in 3 lab hours. All labs must be completed to pass the course.

1. 3-bit counter and LED display driver
2. LED display peripheral
3. timer peripheral
4. interrupt-generating timer
5. serial interface (UART) transmitter

Details at `http://casas.ee.ubc.ca/379/labs`

Lab 1 : 3-bit counter and LED display driver

- introduces the FPGA board
- 3 concurrent VHDL statements
- doesn’t use computer bus

Lab 2 : LED display peripheral

- introduces SBC
- address bus decoder
- latched output port
- re-uses LED decoder

Lab 3 : timer peripheral

- introduces input ports and tri-state buffers
- read-only timer counter register
- includes clock divider (25 MHz to 1 Hz)

Lab 4 : interrupt-generating timer

- simple counter generates periodic interrupts
- students write interrupt handler software
- familiarization with the PC (8259) interrupt controller

Lab 5 : serial interface (UART) transmitter

- design of a complex peripheral
- bit sequencer state machine
- baud rate generator
- status input register
- data output register
- simple device driver
- serial output monitored on PC

Advantages

- Develops problem-solving skills
  - labs are a rich source of problems to solve
  - students work individually
- Motivates lecture material
  - designing computer peripherals demonstrates a practical application of logic design
  - combines hardware and software design/implementation/testing
- Introduces good practices
  - pre-lab exercises demonstrate importance of simulation
  - limited time rewards careful and methodical approach

Disadvantages

It's labour-intensive!

- suitable TAs are hard to find
  - requires combination of VHDL synthesis, 80x86 assembler and microcomputer system design expertise
  - more difficult task than marking
- limited student access to labs
  - lab cannot be left unattended (unlike “terminal” rooms)
  - lab only available during scheduled times (3 hours/2 weeks)
- wide variation in students' problem-solving skills:
  - most can follow instructions

- few can develop a useful hypothesis and test it
- most students require a TA's help to finish the lab

- need to periodically reload system software
  - students
  - modify system settings
  - install/remove/re-configure software
  - leave solutions on disks
  - use "ghost" software to reload disk images in about 10 minutes per machine

- need to test hardware during labs
  - TA uses known-good FPGA configuration and software to test hardware

Planned Improvements

- expanded hours using undergraduate TAs
  - more lab time for slower students
  - reduce pressure on graduate TAs

Summary

- it's possible to assemble a microcomputer and logic design lab for about $2500 per station using:
- low-cost hardware: PC-104 bus SBC, FPGA demo board, PC-based logic analyzer
- free software: FPGA synthesis software, 8086 assembler
- our labs involve implementing computer peripherals using FPGAs
- provides intensive practice in problem-solving
- supervising these labs is labour-intensive