Appendix 1

Lab Exercises For A Computer Architecture Course

A1.1 Introduction

This Appendix presents a set of lab exercises for an undergraduate computer architecture course. The labs are designed for students whose primary educational goal is learning how to build software, not hardware. Consequently, after a few weeks of introduction to digital circuits, the labs shift emphasis to programming.

The facilities required for the lab are minimal: a small amount of hardware is needed for the early weeks, and access to computers running a version of the Unix operating system (e.g., Linux) is needed for later labs. A RISC architecture works best for the assembly language labs because instructors find that CISC architectures absorb arbitrary amounts of class time on assembly language details.

One lab asks students to write a C program that detects whether an architecture is big endian or little endian. Few additional resources are needed, however, because most of the coding and debugging can be performed on one of the two architectures, with only a trivial amount of time required to port and test the program on the other.

A1.2 Digital Hardware For A Lab

The hardware labs covered in the first few weeks of lab require each student to have the following:

- Solderless breadboard
- Wiring kit used with breadboard (22-gauge wire)
- Five-volt power supply
- Light-Emitting Diode (used to measure output)
- NAND and NOR logic gates

None of the hardware is expensive. To handle a class of 70 students, for example, Purdue University spent less than $1000 on hardware. Smaller classes or sharing in the lab can reduce the cost further. As an alternative, it is possible to institute a lab fee or require students to purchase their own copy of the hardware.

A1.3 Solderless Breadboard

A *solderless breadboard* is used to rapidly construct an electronic circuit without requiring connections to be soldered. Physically, a breadboard consists of a block of plastic (typically three inches by seven inches) with an array of small holes covering the surface.

The holes are arranged in rows with a small gap running down the center and extra holes around the outside. Each hole on the breadboard is a socket that is just large enough for a copper wire — when a wire is inserted in the hole, metal contacts in the socket make electrical contact with the metal wire. The size and spacing of the sockets on a breadboard are arranged to match the size and spacing of pins on a standard integrated circuit (IC), and the gap on the breadboard matches the spacing across the pins, which means that one or more integrated circuits can be plugged into the breadboard. The pins on an IC plug directly into the sockets.

The back of a breadboard contains metal strips that interconnect various sockets. For example, the sockets on each side of the center in a given row are interconnected. Figure A1.1 illustrates sockets on a breadboard and the electrical connections among the sockets.

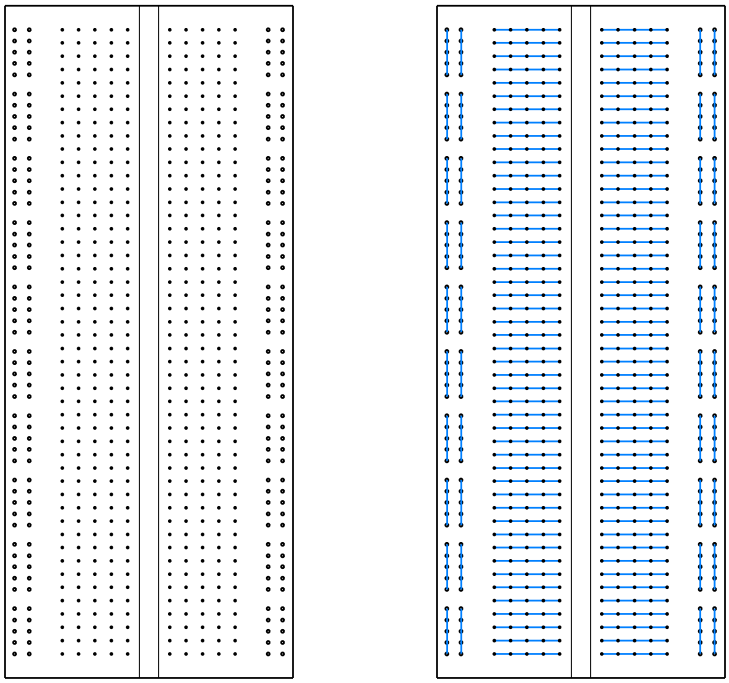

Figure A1.1 (a) Illustration of a breadboard with sockets into which wires can be inserted, and (b) blue lines showing the electrical connections among the sockets.

A1.4 Using A Solderless Breadboard

To use a breadboard, an experimenter plugs integrated circuits onto the breadboard along the center, and then uses short wires to make connections among the ICs. A wire plugged into a hole in a row connects to the corresponding pin on the IC that is plugged into the row. To make the connections, an experimenter uses a set of pre-cut wires known as a *wiring kit*. Each individual wire in the wiring kit has bare ends that plug into the breadboard, but is otherwise insulated. Thus, many wires can be added to a breadboard because the insulated area on a wire can rub against the insulation of other wires without making electrical contact.

Figure A1.2 illustrates part of a breadboard that contains a 7400 IC, with wires connecting some of the gates on the IC.

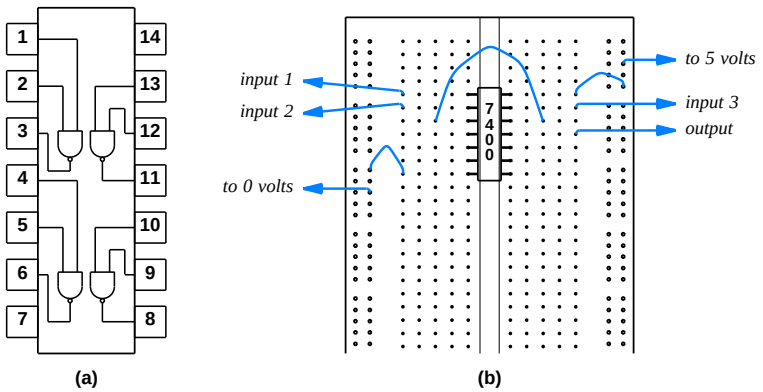

Figure A1.2 Illustrations of (a) the internal connections on a 7400 chip, and (b) part of a breadboard with blue lines indicating wires connecting a 7400 chip. Using a set of sockets to connect power and ground wires allows additional connections to be added.

A1.5 Testing

Beginners often find it easiest to construct a circuit in stages, and test each part of the circuit as building proceeds. For example, after connecting power and ground to a chip, a gate on the chip can be tested to verify that the chip is working. Similarly, after a particular gate has been connected, the input(s) and output(s) of the gate can be measured to determine whether the connections are working.

An easy and inexpensive way to test digital logic consists of using a *Light Emitting Diode* (*LED*). The LED glows when its input wire connects to logical one (i.e., five volts), and is off when its input wire connects to logical zero (i.e., zero volts). For example, to test the circuit in Figure A1.2, an LED can be connected between the output (pin 11 of the integrated circuit) and ground (zero volts)†.

A1.6 Power And Ground Connections

When multiple chips are plugged into a breadboard, each chip must have connections to *power* and *ground* (i.e., five volts and zero volts). To ensure that the power and ground connections are convenient and to keep the wires short, many experimenters choose to devote the outer sets of sockets on both sides of the breadboard to power and ground. To do so, jumper wires are added that interconnect the outer columns. Figure A1.3 illustrates the wiring.

The wires used to connect power and ground are semi-permanent in the sense that they can be reused for many experiments. Thus, experimenters often use the color of a

†Note: the LED must have electrical characteristics that are appropriate for the circuit — an arbitrary LED can draw so much electrical power that it will cause a 7400-series integrated circuit to burn out.

wire to indicate its purpose, and choose colors for power and ground that are not used for other connections. For example, red wires can be used for all power connections, black wires can be used for all ground connections, and blue wires can be used for other connections. Of course, the wires themselves do not differ — the color of the insulation merely helps a human understand the purpose of the wire. When disassembling a breadboard after an experiment is finished, the experimenter can leave the power and ground connections for a later experiment.

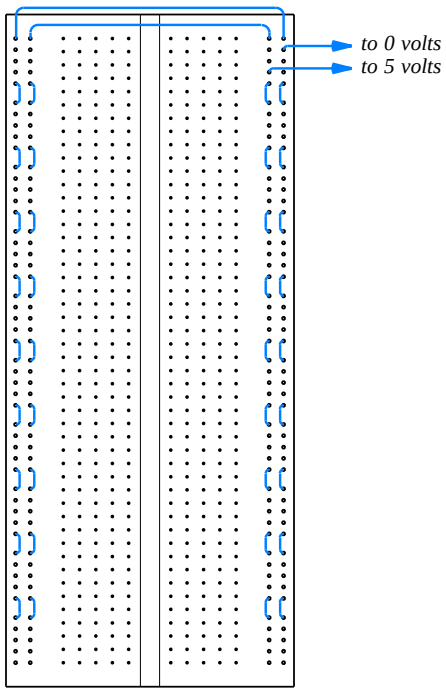

Figure A1.3 A breadboard with semipermanent jumper wires added to connect the outer two rows of sockets on each side of the board to power and ground. The outer row of sockets connects to ground (zero volts), and the next row of sockets connects to five volts.

A1.7 Lab Exercises

The next pages contain a series of lab exercises. Although each writeup specifies the steps to be taken in lab, additional details that pertain to the local environment or computer system must be supplied by the lab instructor. For example, the first lab asks students to establish their computer account, including environment variables. Because the set of directories to be included on the path depend on the local computer system, the set of actual paths must be supplied for each environment.