CPSC 121: Models of Computation
Lab #2: Black Box Testing

Objectives

In this lab, you will get more experience with physical logic circuits using *The Magic Box*. You will also get your first exposure to Logisim, a tool for simulating circuits.

About marking

The labs in CPSC 121 have a standard marking scheme. All labs are out of 10. Two of the marks are for the pre-lab, which you are required to complete before coming to lab. Five marks are for the items marked "**TODO:** " – so, if you complete the pre-lab and the basic lab activities, you will get 70%. To get 90%, there is a "further analysis" question, denoted with "**TODO (further analysis)**" and a survey to complete at the end of the lab. The final mark is for returning the Magic Box in proper conditions. For the labs where the Magic Box is not used, the further analysis question will be worth 20% of the lab.

For full credit on **further analysis** questions, you are required to give a thoughtful, detailed response to your TAs. If you are having difficulty coming up with the correct response, ask your TAs for guidance. You can additionally get a bonus mark for the Challenge Problem. **Be sure to show each TODO item to your TAs as you complete them.**

Pre-lab

There are three pre-lab questions to prepare you for the upcoming lab. In this lab, your TA will provide you with two ICs. An integrated circuit (IC) is a manufactured electronic circuit and in the 121 labs, this will refer to the black chips that you have already seen in lab 1. The labels on both ICs will be covered, but the notch is visible (so you know the orientation to place them on your breadboard!). One of these chips is a hex inverter, a chip with six inverters. The other is one of: a quad 2-input NAND gate, a quad 2-input AND gate, a quad 2-input OR gate, or a quad 2-input XOR gate. Your job is to identify these two chips.

The probe: Using the probe will simplify this task, and help you to debug your circuits in the future. The probe input pin is in line with, and to the left of the clock outputs, and is connected to the red LED directly above it. The probe is on when the top half of the leftmost switch is down. An unused probe will blink. It will also blink if connected to an input that is not connected to anything. *This is a common error, and the probe will help you quickly identify it.* The probe will otherwise output the value of any input or output that it connects to. (The probe is detailed in Appendix B and Section 2.1 in The Magic Box User's Manual).

1. **TODO (pre-lab):** *Using the probe*, how will you determine which of the two chips is the hex inverter?
   (a) Sketch your wiring plan. Provide enough details so that your TAs could implement the plan just by looking at your diagram.

   (b) Write down the steps you'll take. Carefully explain what happens if it is a quad chip and what happens if it is a hex inverter.

2. **TODO (pre-lab):** Once you've done that, how will you determine which "quad" chip you have? Again, sketch your wiring plan with sufficient details and write down your steps.

3. **TODO (pre-lab):** Why *didn't* we include the quad 2-input NOR gate as one of the possible "quad" chips?

Experimenting with an Unknown Chip

As you know from the pre-lab, your TAs will be giving you the two mystery chips. **These two chips are NOT from inside The Magic Box and their labels should be covered**. Using your plan, wire up the mystery chips to determine which one of the two is the hex inverter. Then, wire up your quad chip to determine which of the quads (AND, NAND, OR, or XOR) you have. You have room to keep both circuits on your breadboard at the same time; so, keep them both to demonstrate to your TA as you finish. *Remember to use appropriate power and ground connections, or you may damage the ICs!*

TODO: Which one was the hex inverter? How did you figure it out?

TODO: Which quad chip did you have? How did you figure it out?

Practicing Debugging with *The Magic Box*

During this term, you will be building more and more complicated circuits. Debugging is an important skill in doing this, one you will find vital with more complex wiring. **An important way to avoid a lot of debugging is to test incrementally: rather than build everything at once and then test, build a portion, test it, move on to the next portion, test it, and so on**.

But even when you are testing a smaller component, debugging will still be necessary. Some common issues are:

- improperly powering or grounding an IC
- using the wrong type of IC
- a broken pin on an IC
- placing a wire in the wrong hole of the breadboard, or putting the IC in the wrong spot

For this section, you and your partner are to find another pair with a Magic Box.
Plan to wire $(A \lor B) \land (C \lor D)$ – but don't do it exactly. (An example of doing this is in Appendix B)

Intentionally make two errors in the circuit, like the ones discussed above. **Warning: Do NOT intentionally destroy any of the lab equipment. Do not fry chips by powering the ground pins, nor break any of the pins on the ICs!**

When both groups are done, swap Magic Boxes. **TODO: Debug each other's circuits. What were the two errors in it?**
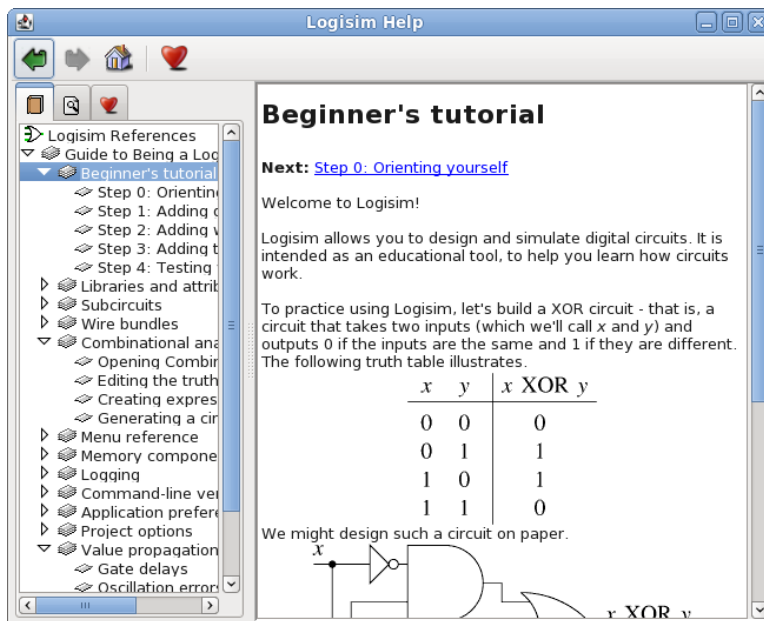
Logisim

Your first simulation

Log in to the Linux server using a computer in the lab. Open up the main menu and find and click on the Logisim entry. This should run the program Logisim, which is the circuit simulator we will be using in this class. If this doesn't work, log out of the Linux server and in to Windows. Go to the start menu, find and click on the Logisim executable file and click "run" when the Security Warning dialog box appears.

Once you have Logisim open, click on the "Help" menu and select "Tutorial" (as seen in the image below).
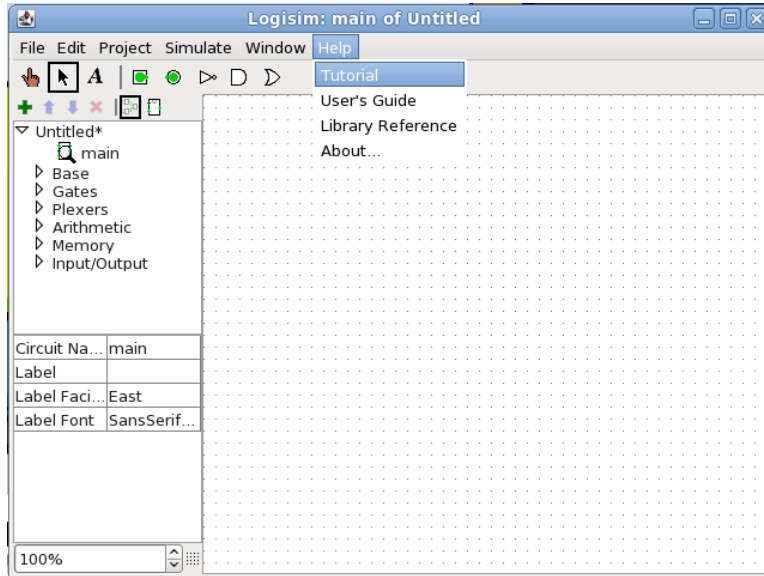

You will now get a screen with the tutorial. It begins like this:

TODO: Follow and complete Steps 0 to 4 of the Logisim Tutorial. By the end, you will have completed an XOR circuit. Show it to your TA when you are done. Be sure *both* you and your partner are comfortable with using Logisim.

A Mystery Circuit

It is standard practice with electronics to show common circuits as "black boxes"; the most common circuits will have their own distinctive shapes. Download the file mux.circ from the CPSC 121 website (right click and select save) and load it in Logisim. It should look like this:
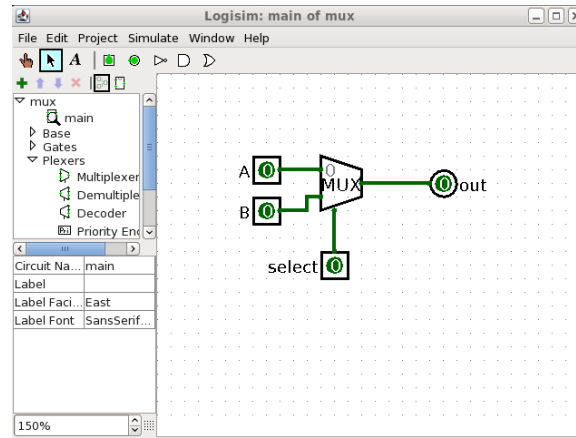
In computer science, when we want to test a black box – like we did earlier this lab with the mystery chip – we do so by looking at the different possible inputs and outputs – which for a logic circuit would be its truth table. Logisim features a useful tool for this: in the upper menu, select "Project" then "Analyze Circuit". A pop-up will tell you that Logisim will calculate the truth table for you, and you will get this:

TODO: Examine the truth table of this circuit – what does it do? Tell your TA a description in English.

Further Analysis

TODO (further analysis): Consider the black box you just examined – can you think of a basic statement in programming that is similar to it? How are the two similar, and how are they different?

End of Lab Survey

TODO: To help us improve these labs both this term and for future offerings, complete the survey at http://www.tinyurl.com/cs121labs.

Magic Box Cleanup

TODO: Before leaving the lab, show your Magic Box to your TA

Challenge Problem

TODO (challenge): In the Logisim tutorial, you made a circuit that outputs an XOR value. That circuit was made using OR, AND and NOT gates. Now make a circuit that outputs an XOR value using only NOR gates.You have to use more than 6 NOR gates in order to get the bonus mark.

Marking Scheme

All labs are out of ten marks, with two marks for pre-labs, and eight marks for in-lab work. In more detail:

- Two marks - Pre-lab questions.
- Five marks - In-lab questions. Two marks are for Section 2. One is for Section 3. Two are for Section 4.
- One mark - Further analysis.
- One mark - End of lab survey.
- One mark - Magic Box cleanup

TAs may at their discretion award one bonus mark, such as for completing the challenge problem. It is expected that most students will achieve a 6-8. If you feel like you're heading towards a 0-5, **get immediate help from the TAs!**

Wiring Diagram for a Sample Circuit

Imagine we were designing a circuit to compute $(A \lor B) \land (C \lor D)$, we might use a 74LS32 IC (two OR gates, using pins 1–3 and 11–13) and a 74LS08 IC (one AND gate, using pins 1–3). To prepare for wiring the physical circuit, we could mark up a diagram as in Figure 1.
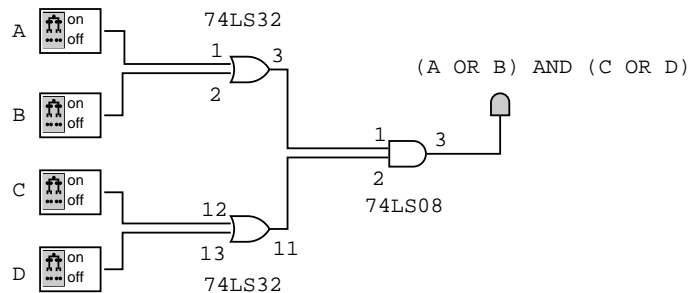

Figure 1: A circuit computing $(A \lor B) \land (C \lor D)$, labeled with IC part and pin numbers.

As we wire the circuit, our first wired gate might look like Figure 2. In the figure, we have wired up the OR gate for $C \lor D$ according to Figure 1: a 74LS32 IC wired (1) to power with a red wire (pin 14 in the upper-right, using the colour reserved for power); (2) to ground with a black wire (pin 7 in the lower-left, using the colour reserved for ground); and (3) to the inputs and output with green and yellow wires (pins 11–13 in the upper right, using arbitrary colours that distinguish inputs from outputs). This demonstrates the kind of careful circuit building methods that can make your work with hardware smoother.
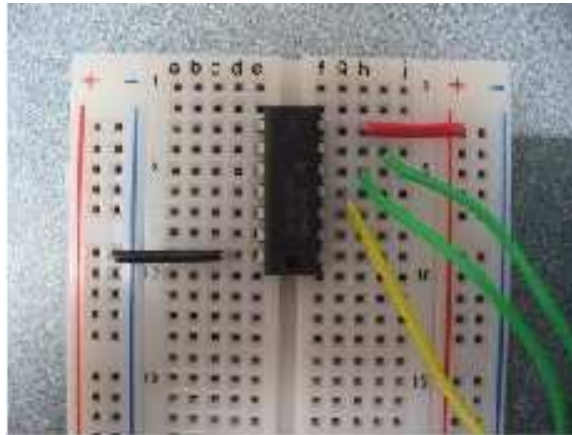

Figure 2: A breadboard with the $C \lor D$ gate of $(A \lor B) \land (C \lor D)$ wired according to Figure 1.