Logic circuits laboratory for an undergraduate course in Discrete Mathematics

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Abstract :

The purpose of this talk is to share a new laboratory experience for an undergraduate Discrete Mathematics course for mathematics and computer science majors. In the laboratory, students were given homemade electronic truth tables made from LED's, NAND gates, and switches. They were also given circuit diagrams but were not told which diagrams matched each device. In the class, they formed groups and learned about reverse engineering. The devices and worksheets will be available at the talk for the audience to handle.

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1. Introduction

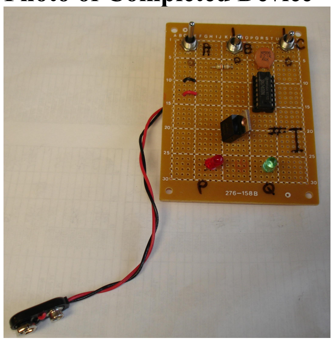
Modern computers are primarily made of microscopic parts, so students studying Mathematics and/or Computer Science often do not have the opportunity to see how computers are built (that is, from very basic building blocks). In Discrete Mathematics, Logic is often covered, often with discussion of truth tables and circuit diagrams, but students are not usually given the chance to see how these could be useful. To fill this gap, I created a simple but useful Laboratory device which uses only NAND gates, as a way of linking up the concepts of circuit diagrams and truth tables. This is a very basic exercise in reverse engineering. After testing the original laboratory on some advanced students, I settled on this simplified laboratory which only takes one class-period to complete. It could certainly be expanded, but in order for a mixed group of students (Mathematics majors as well as Computer Science majors) to complete the exercise in a 50-minute period, the objectives had to be limited.

2. Assembling the Device

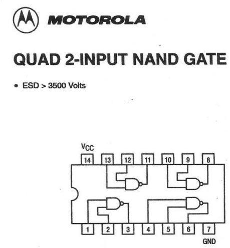
The parts for three devices can be purchased for under $60 at Radio Shack or online at various websites such as Mouser Electronics, Jameco, or Digikey, for those who do not happen to have these parts readily available. (The price of parts is relatively expensive when purchased individually, primarily due to the cost of individual packaging. The $60 estimate uses this assumption.) If your college or university has a basic Electrical Engineering course, most or all of these parts could probably be donated by a colleague, as they are all rather cheap and common parts. You will need wire cutters and a soldering iron in addition to the parts listed below. The wiring diagram as given will give you the generic device. Additional wiring should be added as desired, by following your own whims, or by using the circuits given in the attached lab.

For example, in the wiring diagram below, there are three 'unattached' wires coming off switches which are labeled as A, B, and C. Likewise, there is another A-B-C trio going into part 74LS00. LED's P and Q are also similarly labeled. So, to wire example circuit 2, one possible combination is to connect A to Pin 1, C to Pin 2, Pin 3 to Pin 4, and Pin 3 to Pin 5. Pin 6 is then connected to LED P. This leaves 2 NAND gates and one LED untouched so example circuit 3 could be placed on the same device with little effort. Certainly a NAND gate can be used for more than one circuit diagram so long as it takes the same inputs.

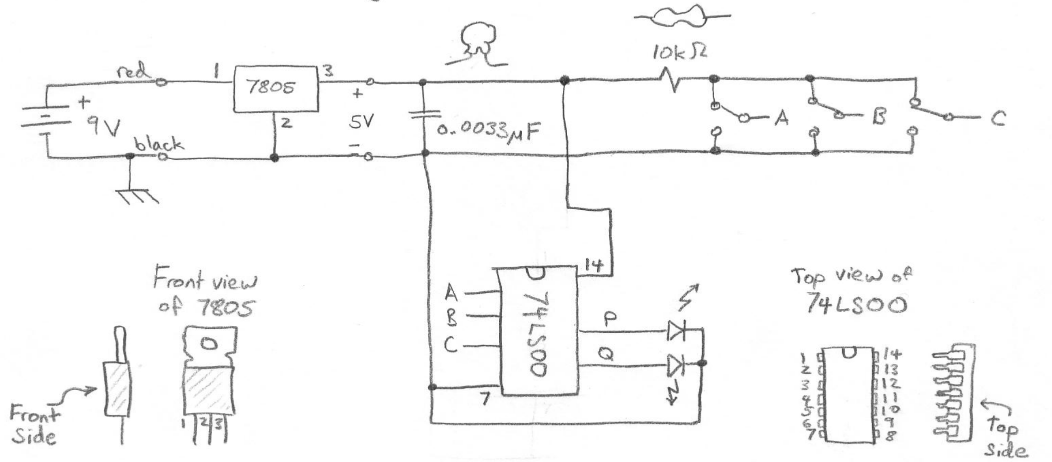
Photo of Completed Device



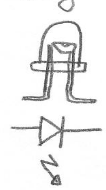
Schematic of the part 74LS00



Logic Lab Generic Wiring

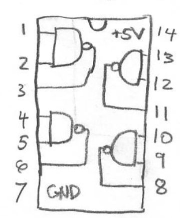


(Typical) Wiring of LED



(if this doesn't cause LED to light, try opposite polarity)

Internal wiring of 74LS00



Do not install 74LS00 backwards! You can burn it out!

Parts List

Qty	Number	Description
1		circuit board
1		9V socket
1	7805	5V linear regulator
1		0.0033μF mica capacitor (value not critical, can substitute for nearly any other disc-shaped capacitor)
1		10kΩ resistor (brown black orange) (a 1kΩ resistor (brown black red) is OK too)
3		Single pole double throw switch (SPDT)
2		Light emitting diodes (LED)
1	74LS00	Quad 2-input NAND gate
1		14 pin socket
		30 gauge wire, and solder

For the devices I have made, example circuits were paired as examples 2 and 5 on device I, examples 3 and 6 on device II, and examples 1 and 4 on device III.

3. Laboratory Procedure

I handed out the laboratory assignment, which is attached at the back of this paper. The final page of the laboratory serves only to hold their final answers, and in reality was mostly attendance verification as I was using it. (I gave them full credit for one quiz for completing this lab.) I placed the students in groups so that there were six groups in the class. I had previously introduced logic circuit diagrams and truth tables to these students. I handed out devices to half of the groups and explained that they should begin recording in their labs what the functional outputs of these devices were so that they could match the 6 functions (two per device) to the 6 logic circuit diagrams. Those groups who did not have devices were prompted to begin work on the truth tables for the same ultimate goal.

The results were that the groups generally relinquished the devices, thinking that they understood the assignment, but then requested them back several minutes later. This worked nicely, because by that time, another group had finished with one of the devices. After a bit of thinking, talking to me, and discussing with their team members, most of the students came away with a better understanding of how logic circuits and truth tables can represent physical computing devices.

4. Conclusions

This laboratory was completed in one class hour with some assistance from me. Most students understood either the logic circuit (the Computer Science majors) or the truth tables (the Mathematics majors) fairly solidly, but were weaker in the other area. It was good to have mixed groups containing both Mathematics majors and Computer Science majors. If some student in the group understood one aspect of the lab quite well, it seemed to work best to let that student explain to his/her peers what the laboratory was requesting, but if the entire group was stuck or confused, it took relatively little instruction from me to assist them in progressing.

The unfortunate down-side of this laboratory was that it was not possible to assess individual learning with the laboratory write-up, since they were collaborating. This assessment had to be left to the examination or another quiz. However, since the devices are small and inexpensive, it was easy to allow students who had missed that class period (or who wanted more time to absorb it) to simply borrow the devices from my office and work alone on the laboratory.

I found it easiest to present this laboratory to my own students, because I was able to prepare them for it by having them practice computing truth tables (and circuit diagrams) comprised entirely of NAND gates in the class period leading up to the laboratory. So, although the lab itself only required one class-period, I would estimate that it also required an additional half-period of preparation beyond what would be typically covered in a Discrete Math course.

Useful websites and other information

Basic instructions on how to solder are at
http://ourworld.compuserve.com/homepages/G_knott/elect3.htm

Instructions on how to read resistor color codes are at
http://xtronics.com/kits/rcode.htm

Mouser Electronics (http://www.mouser.com) can supply the needed parts. Search under "74LS00" for various manufacturer's NAND gates.

Most parts can be purchased at local Radio Shack stores. There is much flexibility in what will work, but for example: catalog numbers: 276-158 (board), 276-1999 (14-pin socket), 270-324 (9-V socket), 276-1770 (Voltage Regulator), 272-801 (multi-pack of capacitors), 271-308 (resistors), 275-409 (2 SPDT switches), 276-026, 276-022 (LEDs), 278-503 (wire), 64-013 (solder) or 64-035 (non-lead-based solder).

64-2055 (Cheap soldering iron) Lead-based solder is usually easier to work with than silver solder, but if you are concerned about lead-safety (for example, if you are planning to use the device around minors), use the silver. If you are using lead-based solder, wash hands after use.

http://www.amtechsolder.com/pdf/SolderPowderMSDSJan07.pdf (Material Safety Data Sheet for Solder)

Acknowledgements

I would like to thank Michael Robinson (my husband) for creating the Generic Wiring diagrams and instructions, and for helping me with soldering techniques. I would also like to thank Zachary Heiland for test-driving the first version of the lab, and Premalatha Junius for allowing me to bring this exercise into her course.

Discrete Mathematics: Logic Circuits Lab Name:_________________________

The purpose of this lab is to allow hands-on experience with real (although simple) logic circuits, and to match up the diagrams with actual devices.

There are 3 circuit boards each with 3 logic inputs and 2 logic outputs, for a total of 6 switch-operated functions. The attached 6 circuit diagrams need to be matched to the 6 switch-operated functions.

For this lab, you will get into groups and create 9 truth tables, one for each of the 6 circuit diagrams and one for each of the 3 switch-operated devices (each having two functions). Then, match them up!

Some hints along the way:
* The switches need to be all the way up or all the way down. Don't use output created with switches "halfway".
* For circuits with only two inputs, don't be afraid to still list all three inputs in your truth table.

Use the attached grids.
Devices will be shared between the groups, but you each have a copy of the circuit diagrams, so you can begin to work even if your group does not yet have a device.

Device I				
switch A	switch B	switch C	LED P	LED Q

Device II				
switch A	switch B	switch C	LED P	LED Q

Device III				
switch A	switch B	switch C	LED P	LED Q

Circuit Diagram #1									
A	B	C							

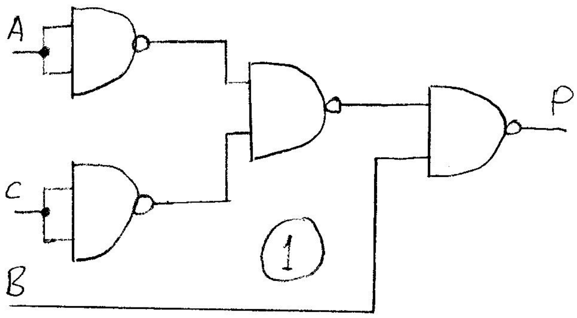
Circuit Diagram #2									
A	B	C							

Circuit Diagram #3									
A	B	C							

Circuit Diagram #4									
A	B	C							

Circuit Diagram #5									
A	B	C							

Circuit Diagram #6									
A	B	C							



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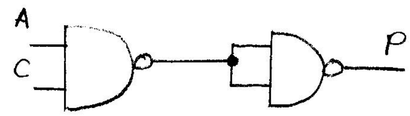

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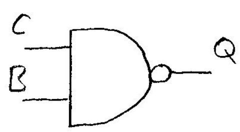

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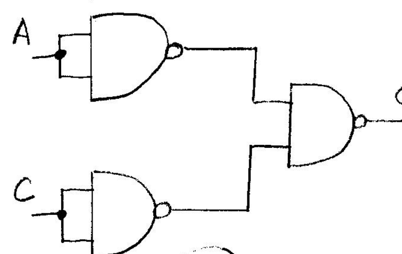

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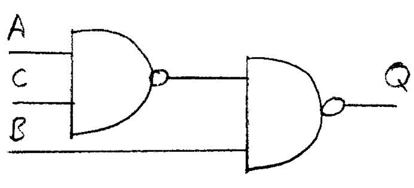

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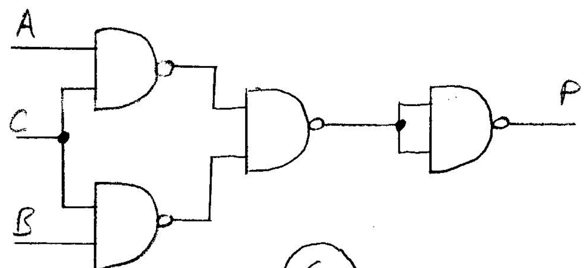

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Logic Lab Writeup

Name:________________________________

Names of my group members:

Switch-operated logic function #1 is on BOARD ___________ and is LED _______

Switch-operated logic function #2 is on BOARD ___________ and is LED _______

Switch-operated logic function #3 is on BOARD ___________ and is LED _______

Switch-operated logic function #4 is on BOARD ___________ and is LED _______

Switch-operated logic function #5 is on BOARD ___________ and is LED _______

Switch-operated logic function #6 is on BOARD ___________ and is LED _______