CPSC 121: Models of Computation
The Magic Box Debugging Guide

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OK, so you have wired up your circuit and it did not do what you expected. Do not worry. Everyone will have this experience many times during the semester. It is just a natural part of learning. In other words, even if everything works the first time for Lab 1, you will probably want to keep this guide around for later labs.

This section provides a step-by-step guide that should let you track down most bugs. As you get experience, you will find that often you have a pretty good guess of where the bug is, and you will skip over many of the steps to get to the ones you need. This guide is divided into ten sections. The first three describe how to get started with debugging, setting the inputs to create the error and checking that you have got power on the breadboard, and tracing the cause of the error. These are the main steps that you will use for finding most problems. The last seven sections give more details about how to track down particular kinds of problems.

1 Getting Started with Debugging

1. **Is your *Magic Box* turned on?**
   If no LEDs are glowing and there is nothing displayed on the 7-segment displays, then check the on-off switch[1] and the connections to the AC power adapter. Even if all of the inputs to the LEDs are low, the 7-segment displays will display 0s.

   If your *Magic Box* has no LEDs or 7-segment displays glowing, you are sure that the AC power adapter is plugged into the wall outlet and the board, and the on-off switch of *The Magic Box* is in the "on" position, there might be a short-circuit between power and ground on your breadboard. Go to section 7.

2. **Switch your *Magic Box* into "debug" mode.**
   To do this, set the leftmost switch of the four "clock-control" switches to "on." This is the switch labeled "Blink" that you encountered at the beginning of lab 1. When you set the switch to "on", any LEDs on your *Magic Box* that are not connected to anything will start blinking. Here is why.

   As you know, a logical "true" value is represented by a voltage near 5 volts. A logical "false" value is represented by a voltage near 0 volts. An input that is not connected to anything does not mean "0" (i.e. "false"). It means an undefined voltage. Thus, a gate with an unconnected input can do anything. Most of the gates in our kits will treat an unconnected input as a high level, but they are not guaranteed to do this consistently.

   When *The Magic Box* is in debug mode (i.e. blinking), the LED input circuitry checks for unconnected inputs. If there is not anything driving the input, the LED will flash. This makes it easy to check for unconnected inputs, a common error.

[1] The first batch of Magic Boxes did not (and still does not) have an on-off switch.

3. **Plug a long wire into the connection for an LED.**
   The other end of this wire will be your logic probe. Now, you are ready to test.

2 Create the Error

1. **Elicit the error.**
   Since you have a bug, you must be able to set the input switches to some combination such that one or more of the outputs from your circuit is wrong. Set the input switches to a combination that elicits an output error.

2. **Check for power.**
   Touch your logic probe wire to the power pin of the chip that produces the output that shows the error. The LED for your probe should stop blinking and become steady. If it continues to blink, or turns off, then the power connection for the chip is wrong. Go to section 4 to continue debugging.

If you make it through this test OK, then you know that you have power properly connected to the board; your logic probe is set-up for further debugging; and you have a set of inputs that triggers the error that you want to fix. Continue to the next section.

3 Tracing Back the Error

The main idea in this section is that each gate's output is determined simply by the values of its inputs. We start with a gate that we know is producing a different value than we want. We will look at its inputs to determine the cause of the error. This may lead us back to the gate that produced one of these inputs and we will continue our search for the error from there until we find the error.

1. **Probe the output pin.**
   Touch the tip of the probe wire to the pin of the chip that is producing the erroneous output. This is to make sure that the connections from this gate to the next one or to *The Magic Box* is correct. If you see the same wrong value that you had noted before, then go on to the next step 2.

   Otherwise, the value on the pin is different from the value that you saw at the next gate or at *The Magic Box*. This indicates that there is some kind of wiring error.

   (a) **Insert the tip of the logic probe wire into a breadboard hole in the row for this pin.**
   Do you see the same value that you just saw at the pin? If so, then there is an incorrect connection between this breadboard row and the input to the next chip or to *The Magic Box*. Check the wiring. Otherwise, the pin is not making a proper connection to the breadboard row. Go to section 6.

   (b) **Still having problems?**
   This means that you have found a wire between two rows of the breadboard where the

logic probe shows different values on each end of the wire. Look at the wire to see if you can find a loose connection. If so, fix it. Otherwise, remove the wire and insert it again. If this does not fix the problem, remove the wire, and try with a different wire. Occasionally, the copper conductor inside the wire can crack if the wire has been bent back and forth many times (but this is rare).

If after doing this you still have not found the problem, ask a TA for help.

2. **Check the inputs to the gate**
   Determine what values you should have at each input to the gate that is producing the erroneous output. This may be simple and obvious. For some circuits, you may go back to your TKGate simulation to find out what values you expect. See section 10 for suggestions on how to use TKGate while debugging circuits on the breadboard.

   Touch the tip of the probe wire to each input pin for the gate that produces the erroneous output. Does some pin have a different value than you expected? If so, go to step 3. Otherwise, continue with this step.

   OK, the output of the gate is wrong, but all of the inputs are correct. Remove all connections to this output. Typically, this will involve removing one or two wires from the breadboard.

   (a) **Is the output still wrong?** Either you have the chip connected improperly, or you misunderstand the operation of this chip, or the chip is bad. Sections 8 and 9 describe how to check for incorrect connections to the chip. You can check the truth-tables for the chip at the end of *The Magic Box User's Manual*. What does the truth table say that your gate should do for the inputs that are applied?

   Compare the operation of the gate with your simulation from TKGate. See section 10 for suggestions on how to use TKGate while debugging your breadboard.

   If this fixes the problem, remember to reinsert the wires that you removed above, and retest the circuit.

   If you still have a problem, ask a TA for help.

   (b) **The output is correct after you removed the wires.**
   This means that the output was connected to another output, or to power or ground. Reinsert the wires that connect this output to other gates one at a time. When you reproduce the output error, check to make sure that what you connected to really is an input pin. Also, check anything that that input is connected to. If you find an input pin where adding a connection to that (and nothing else) causes the output to go to the wrong value, then check the pin-out for the chip with that input pin – see section 8. If this does not fix the problem, you might have a bad chip. Ask a TA for help.

3. **Bad value at input pin.**
   OK, you have found a pin that has a different value than you expected. This is excellent progress.

   (a) Insert the tip of the probe wire into an empty hole in a row for that pin.

Do you get the same result? If not, then there is a bad connection between the chip and the breadboard – go to section 6. Otherwise, continue with step 3b.

(b) Is this signal driven by another gate or by *The Magic Box*?

If this is driven by another gate, continue by going back to the beginning of this section (section 3) working with the output of the gate that drives this signal.

If this signal is driven by *The Magic Box*, check the connection between *The Magic Box* and the breadboard. If it looks good, disconnect the wire from the breadboard and plug it in to one of the LED inputs for your *Magic Box*. Is the switch working properly? If so, reconnect the wire to the board and test again. If you still can not find the problem, ask a TA for help.

4 No Power at a Chip

OK, you have checked the power pin on some chip and found that it was not a high signal. Here are some likely causes:

1. **The 5-volt wire is not properly connected to *The Magic Box* or the breadboard.**
   Probe the power column of your breadboard that the chip gets its power from. If it shows a steady high level, then go to the next step.

   OK, you do not have power on the power column. Here are three things to check:

   (a) Is the plug from the red/black power/ground wires inserted all the way into the jack on *The Magic Box*?

   (b) Are the red/black power/ground wires plugged correctly into the breadboard?

   (c) Is the wire between the left and right power columns on the breadboard inserted correctly?

   If this does not solve your problem, ask a TA for help.

2. **The power column from the breadboard is not connected to the breadboard row with the chip's power pin.**

   Plug the tip of the probe wire into an empty hole in the power pin's row. If it shows a steady high level, then go to section 6

   OK, you are not getting power to the row. Take a look at the wire that connects the power column to this row. If you see a loose connection, fix it and try again. Otherwise, remove the wire and reinsert it. Then, try with another wire – there is a slight chance that the copper conductor inside the wire has cracked after being bent back and forth many times. If none of these solve your problem, ask a TA for help.

5 No Ground at a Chip

OK, you have checked the ground pin on some chip and found that it was not a low signal. This is similar to the "No Power" problem addressed above. Here some likely causes:

1. **The 5-volt wire is not properly connected to *The Magic Box* or the breadboard.**
   Probe the ground column of your breadboard that the chip gets its ground from. If it shows a steady low level, then go to the next step.

   OK, you do not have ground on the ground column. Here are three things to check:

   (a) Is the plug from the red/black power/ground wires inserted all the way into the jack on *The Magic Box*?
   (b) Are the red/black power/ground wires plugged correctly into the breadboard?
   (c) Is the wire between the left and right ground columns on the breadboard inserted correctly?

   If this does not solve your problem, ask a TA for help.

2. **The ground column from the breadboard is not connected to the breadboard row with the chip's ground pin.**

   Plug the tip of the probe wire into an empty hole in the ground pin's row. If it shows a steady low level, then go to section 6

   OK, you are not getting ground to the row. Take a look at the wire that connects the ground column to this row. If you see a loose connection, fix it and try again. Otherwise, remove the wire and reinsert it. Then, try with another wire – there is a slight chance that the copper conductor inside the wire has cracked after being bent back and forth many times. If none of these solve your problem, ask a TA for help.

6 A Bad Connection Between a Breadboard Row and a Chip Pin

You have confirmed that the correct signal level is present in the breadboard row for some pin of the chip, but you do not see that level on the pin.

1. **Make sure that you are checking the right row for the pin.**
   Sometimes, you can be off by one row in your wiring. Take a close look at the board and make sure that you have got the right row for the pin. If you spot a mistake, fix it. Otherwise, go on to the next step.

2. **Make sure that the chip is inserted into the breadboard all the way.**
   When you press the chip into the breadboard, it should snap into place and be flat against the breadboard. If necessary, press the chip firmly but gently into the breadboard. If it snaps down, then it had not been properly inserted. Check the level at the pin again. If it is still incorrect, go to the next step.

3. **Check for a bent pin.**
   Pins occasionally buckle under the chip package and they look almost the same as a pin that is properly inserted into the board. Remove the chip from the board, and check to see if any pins are bent. If so, get a pair of pliers from the TA and straighten any bent pins. Re-insert the chip into the board and try again. Sometimes, a pin will break off when you try to straighten it. If so, ask the TA for a replacement.

4. **Ask for help.**
   If you still are not getting the same signal level at the chip pin as in the breadboard row, ask a TA for help.

7 A Short-Circuit Between Power and Ground

OK, the AC power adapter is properly plugged into the wall outlet and into *The Magic Box*. The on-off switch on *The Magic Box* is in the on position, but nothing lights up. You may have a short-circuit between power and ground on your breadboard. This is not dangerous because the voltage regulator in *The Magic Box* detects the short-circuit and shuts down *The Magic Box*. However, it will make sure that nothing else works.

1. **Disconnect the 5-volt wire from the breadboard.**
   Now, the seven-segment displays should light up on *The Magic Box*. If not, ask a TA for help. Otherwise, continue with the next step.

2. **Determine which column causes the short-circuit.**
   Remove the jumper between the left and right power columns and the jumper between the left and right ground columns.

   (a) **Check the left power and ground columns**
   Turn off *The Magic Box*. Connect the red/black power/ground wires to the left power and ground columns. Turn on *The Magic Box*. If nothing lights up, the short-circuit involves the left power and ground columns, and you can go to step 3. Otherwise, continue with step 2.b.

   (b) **Check the right power and ground columns**
   Turn off *The Magic Box*. Connect the red/black power/ground wires to the right power and ground columns. Turn on *The Magic Box*. If nothing lights up, the short-circuit involves the right power and ground columns, and you can go to step 3. Otherwise, continue with step 2.c.

   (c) **Check the left power and right ground**
   Turn off *The Magic Box*. Connect the red 5V-wire to the left power column and the black wire to the right ground column. Turn on *The Magic Box*. If nothing lights up, the short-circuit involves this power/ground combination, and you can go to step 3. Otherwise, continue with step 2.d.

(d) **Check the right power and left ground**
As above, with the one remaining combination. It this combinations has the short-circuit, go to step 3. Otherwise, continue with step 2.d.

(e) **Try the whole thing one more time.**
Turn off *The Magic Box*. Re-insert the black jumper between the left and right ground columns and the red jumper between the left and right power columns. Connect the 5V red-wire to one of the power columns and the 5V black-wire to one of the ground columns. Turn on *The Magic Box*. If *The Magic Box* lights up, you had an error in the jumpers that you fixed by removing them and wiring them anew. If the *The Magic Box* does not light up, ask a TA for help.

3. **Track down the short-circuit.**
You now know which power column and ground column are included in the short-circuit.

(a) **Look at the wires connected to those two columns.**
If you find the wrong connection, turn off *The Magic Box*; fix the wiring; and try again. Otherwise, continue to step 3.b.

(b) **Find the offending connection.**
Turn on *The Magic Box* (if you turned it off earlier). Remove wires that connect to the power column one at a time. At some point, *The Magic Box* should light up when you remove a wire. Look at what it was connected to, and see if you can find the wire or wires that lead to the ground column. If you find it, fix the error and replace the wires that you removed earlier in this step.

If you can not see why there is a short-circuit, or if you remove all of the wires connected to the power column and still have a short-circuit, as a TA for help.

8 Checking the Chip Pin-out

If you have made it here, then your chip is not doing what you expected it to. An output may be acting like an input, or it did not calculate the values that you would expect given the input values. Here, we will figure out what the problem is.

1. **Check the orientation of the chip.**
It should be plugged into the breadboard so that it is straddling the gutter with the chip's notch at the top. If this is not the case, turn off the power to *The Magic Box* immediately. Plugging a chip in backwards will in most cases reverse power and ground to the chip. This can damage the chip.

Remove the chip from the breadboard and plug it in correctly. Continue debugging. Remember that the chip may have been damaged if it had power and/or ground connected wrong. If you get to a step that says you may have a bad chip and that you should talk to a TA, let your TA know that the chip may have been damaged.

2. **Make sure the connection is correct.**
   A common error is being off by one row in making a connection. Check that you have the right row and the right pin for your measurements.

3. **Check the pin-out.**
   Check the chip pin-out diagrams at the end of *The Magic Box User's Manual*. Make sure that each pin is wired up in agreement with those diagrams.

4. **Make sure that you have the right chip.**
   Check the part number on the chip and make sure that you got the right one. Some of the chips are marked rather faintly. Using a bright reading lamp can help.

5. **Ask a TA for help.**
   If you still have not found the problem, ask a TA for help.

9 Checking Power and Ground Connections

If you have made it here, then you have a gate that has the right inputs but is producing the wrong output.

1. **Check the power pin.**
   Touch the power pin of the chip with the tip of the probe wire. The probe's LED should go on without blinking. If it goes off or continues to blink, then power is not connected properly to your chip. Go to section 4.

2. **Check the ground pin.**
   Touch the ground pin of the chip with the tip of the probe wire. The probe's LED should go off and not blink. If it goes on or continues to blink, then ground is not connected properly to your chip. Go to section 5.

10 Using TKGate While Debugging the Breadboard

The TKGate simulator can be handy while debugging circuits on your breadboard. Load your circuit in TKGate, start the simulator, and set the switches to provide the same input values to your circuit as you are using on your breadboard.

1. **Does TKGate show the same output value as you are getting from the circuit on your breadboard?**

   If TKGate shows the correct output, but you are getting a wrong value from the circuit on your breadboard, go to step 2. If TKGate and the circuit on your breadboard produce the same error, you can use this error case to help figure out how to correct your design.

(a) **Simulate your corrected design.**
Once you have fixed your design, use TKGate to simulate the corrected design. Make sure that it now works properly, both for the inputs that caused the error in the first place, and for other input values as well to make sure that there are not any new errors in the design.

(b) **Revise your breadboard implementation.**
Change the wiring on your breadboard so that it matches your corrected design. Typically, only a few changes are needed and they can be made fairly easily and quickly. If you made lots of changes to your design, you may decided that it will be easier and less error prone to remove all of the signal wires from your breadboard; remove chips that you do not need any more; add new chips that you now need; and wire again. Or you may be able to keep portions of the wiring where nothing has changed and just change the wires for a section of the design.

(c) **Test your revised implementation.**
If it works correctly, congratulations – you are done!! If it still has problems, this debugging guide should help you.

2. **Take a closer look at a gate that is producing a wrong value.**
You got directed to this section because a gate produced a different value than you thought is should. The TKGate simulation will show you what values you were expecting to get at the inputs and output of that gate. Compare the values from TKGate with those you observe using your logic probe.

(a) **An input of the gate has a different value on the breadboard than in TKGate.**
You continue tracing back the error from that input (see section 3).

(b) **All of the inputs agree, but the output is different.**
Make sure that you have the right chip plugged in – see section 8. Make sure that the output is not connected to another output or to power or ground (see section 3 step 2).