Introduction to Computer Architecture — Lab 2
A 4-bit incrementor

This assignment is due Thursday, Sep-18, 11:59 pm.

For this week, we will perform a slightly different kind of arithmetic operation—similar to the addition we have discussed during lectures, but a bit specialized and thus simplified. This one will later be used, in Lab 3, to build a fundamentally different kind of circuit.

1 New toys

Don't do anything yet! For this lab, we are going to introduce the components for making *physical logic circuits*. We will spend a few minutes going over the various chips, boards, and other devices that you'll need to use for this and other labs. Here's a list of the devices you'll be using, and some key information about them:

- **Breadboards and the ETS-7000:** These big units have a number of parts, some of which we'll never use. Their key feature is the *breadboard*—white boards with lots of little holes in them. These will allow us to structure our circuits, as we'll have to plug all of the chips and wires into them to make them work. Each breadboard has **power and ground channels** that provide the digital zeros (0 *volts*, *ground*) and ones (+5 *volts*, *power*) that we will use as inputs into gates. More on these below. The breadboard also has **wells** that chips straddle, with independent rows of connected holes that allow you to connect a wire to a chip pin by putting that wire in the same row.

  Note that the ETS-7000 also contain a number of devices around the periphery for input and output. For now, we are interested in the eight **switches** at the bottom that allow us to easily select power and ground inputs; we are also going to use the eight **LEDs** in the upper-right corner, allowing us to see the value flowing out of our circuits.

- **Power channels:** There are several power channels on each board, marked by red or blue/black lines. The colors respectively mean **power** and **ground**. There should be wires from the posts to two of the power channels. Each power channel is electrically connected inside the board, meaning that once a channel is connected to a source (in the upper left corner of the ETS-7000), power is available at each post in the channel. There should be wires connecting all of the red channels together and all of the blue/black channels together. If these wires are not already on your board, you can add them as you go.

- **Chips:** We'll use a few types of chips today: 7404 (NOT gates), 7408 (AND gates), 7432 (OR gates), and 7486 (XOR gates). *Data sheets* describing the operation of these chips are posted on the class web pages, under the Documents section. Some important notes on the chips and their use:

  - **Orientation:** Each chip has a mark, either a small hole or a small cutout, to indicate the top end. The top pin on the left is pin 1. The pin numbers go down the left side and up the right side. Most of our chips have 14 pins, but some will have more.

  - **Power and ground pins:** Two pins on each chip must be connected to power channels. The pin marked V_{cc} on the data sheet should be connected to the red channel. The pin marked GND should be connected to the black/blue channel. *Don't get them backwards, and don't install the chip upside down.*

  - **Installing chips:** Chips must be laid on the board with the right end up and with the pins straddling the groove. Each row of five pins is electrically connected within the board. By placing the chip so it straddles the groove, you are ensuring that there are separate sets of holes for each pin of the chip. Be sure to press each chip in gently and evenly, without letting one end or the other twist up or down. This will help you avoid breaking pins.

  - **Removing chips**: Remove chips carefully and evenly, by **using a chip extractor** and pulling straight up. Do not try to remove the chips with your fingers, as you'll probably bend or break the pins in the process. Return each chip to the place you got it.

- **Wires:** There are bins of wires available for your use, as well as kits that contain pre-cut, pre-bent wires that are color-coded by length. When you make a connection on the board, try to do it neatly and try to avoid using wires that are too long for the purpose. Your work will be far easier to test and correct if the wires are short, well organized, and labeled. When you need a wire of a certain length, you can either look for one or you can make one from a longer wire, using wire strippers to cut and remove insulation. You may even want to devise for yourself a wire-color scheme, such that each color implies something about the purpose to which the wire is being put.

- **Logic probes**: Logic probes are great debugging tools. If you connect them to power you can insert the probe tip into holes to determine if there is a positive voltage (a red light and a high-pitched sound), a ground connection (a green light and a low-pitched sound), or an open connection (no light or sound). *Probes don't always work in locations that are connected to LEDs.* As an alternative, you can always use a wire connected to one of the ETS-7000's LEDs as an ad-hoc logic probe.

2 The project: an *incrementor*

You will design and implement a *4-bit binary incrementor*. There are 16 possible integers that can be formed with 4 bits, from 0 to 15 (or, in binary, from 0000 to 1111). Given that the incrementor should add 1 to each of these possible input values, we can make a table that shows each possible input value and its corresponding output value:

(original) input value	**(incremented) output value**
0	1
1	2
2	3
3	4
4	5
5	6
6	7
7	8
8	9
9	10
10	11
11	12
12	13
13	14
14	15
15	0

Notice that when the input is at its maximum possible value (15), the output "wraps around" to the minimum possible value (0).

3 A suggested approach

Here is a set of suggested steps that may help you both solve this problem and implement your solution as a circuit:

1. **Determine the output functions:** The output of your circuit should be a 4-bit number. Therefore, you have four output bits, each of whose value is determined by some Boolean logic function composed of the four inputs. Write out a truth table for the four input bits and their corresponding output bits, and then use the table to write the four output functions in disjunctive normal form.

2. **Simplify the output functions:** The output functions determined in the previous step are helpful, but likely more complex than necessary. Use Boolean algebraic transformations to simplify those functions.

3. **Draw the circuit:** Draw a circuit that computes the four simplified output functions that you developed in the previous step. You may have to draw the circuit a few times to come up with a clean layout that is easy to read.

4. **Build the circuit:** Use the switches, LEDs, chips, and wires to implement the circuit you've drawn. Be sure to leave time for debugging!

4 Submitting your work

Submitting your completed work: For this lab, demonstrate your working incrementor *on every possible input value*:

1. **Take a video:** Caputure a video of your incrementor on *all sixteen possible input patterns*. Move through the inputs in order, clearly showing the setting of the input switches and the outputs shown on the LED's for each possible input combination.

2. **Share the video:** Upload your video to your *college Google Drive account*. Then, **share the video** with me (`sfkaplan@amherst.edu`) and your lab's head TA (either `twstephens26@amherst.edu` for Section 01 or `eleroy27@amherst.edu` for Section 02).