# Design Lab 7   6.01 – Fall 2011

For Your Eyes Only

> **Goals:** The ultimate goal of the next few labs is to build a robot "head" with eyes to detect a light and a neck that can turn to track the light. Today's task is to (1) simulate and experiment with basic circuits, (2) explore voltage dividers and potentiometers, and (3) use a pair of photoresistors to construct a light sensor circuit ("eyes") for the robot head.

Resources: This lab should be done with a partner. Each partnership should have a **robot** and lab **laptop** or a personal laptop that reliably runs soar. In addition, you will need:
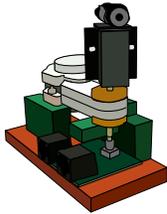
Robot head	Robot	Two eight-pin connectors	Two clip leads
Multimeter	Resistors, as needed	Silver lamp	Wire kit

Proto board   Red cable

Do `athrun 6.01 getFiles` to get the following files (in `Desktop/6.01/designLab07`):

- `CMax.py`: used to start the CMax layout tool.
- `lightTest.py`: Input signal for the CMax simulation.
- `eyeDataBrain.py`: A brain that rotates the robot a fixed amount; used for data collection.

1   Circuit Prototyping Tools

Objective: Get familiar with a **prototyping platform** for electrical circuits:

- Setup a proto board
- Configure and measure the output of a $+10V$ power supply

Resources: Obtain some **aligator clips** and wires, and three pieces of equipment:

- A **multimeter**, for measuring voltages and resistances
- A **power supply box**
- A "proto board" like the one shown below:
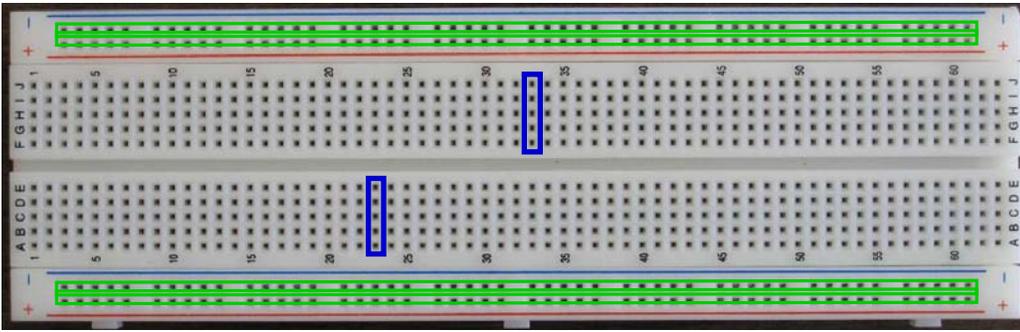
*Use a **single, separate, proto board** as shown above for building your circuits. Do not use the proto boards that are attached to the power supply!!!*

Detailed guidance:

Proto boards (also known as "breadboards") are basic tools used in prototyping simple electrical components. They provide an array of holes into which wires and leads from components can be inserted. Certain rows and columns of the holes are electrically connected, providing a convenient way to connect components together.

Specifically, each column of 5 holes in the center areas is connected internally, as indicated by two representative vertical boxes (above). In other words, if you insert one end of one component into one of the holes in a column of 5, and then insert one end of a separate component into a second hole in the same column of 5, these two components are now connected by an internal wire that connects the 5 holes together. Holes in the top row (marked here with a red line, but sometimes indicated with blue instead) are connected internally (as are those in the second row, bottom row and next-to-bottom row), as indicated by the long horizontal boxes (above). These rows are convenient for distributing power (we typically use $+10\,\text{V}$) and ground.

It is conventional to use the top rail (which can be either red or blue) for positive supply voltages and the next rail (which can be either red or blue) for ground. Notice that the highest numbered column is on the right and the lowest is on the left.

Step 1.

- Connect the power supply terminals labeled +15V and **GND** to the power rails of your separate proto board using alligator clip leads. Connect the alligator clip to the proto board through short (less than 1") wires (from a wire kit); connect it to the terminal on the power supply by just sticking one 'jaw' of the alligator clip into the center of the terminal. **Don't unscrew the power-supply terminals.**
- Set the multimeter to measure voltage, and connect its probes to the power rails of the proto board using alligator clip leads, through short wires from a wire kit.
- Now, turn on the power supply and measure the power supply voltage with your multimeter. Adjust the positive supply to +10V. This step ensures that your setup will be delivering an appropriate amount of voltage to your protoboard.

2 CMax to the Rescue

Objective: Simulate, build, and test a basic electric circuit: a voltage divider; also explore how such dividers can be realized using a potentiometer.

- Setup a simple model circuit in CMax
- Model and build a voltage divider circuit using two **resistors**
- Model and characterize a **potentiometer**

Resources:

- Four 1KΩ resistors, one 100Ω resistor, and one 10KΩ resistor
- Wires (from a shared wire kit)
- A blue 5KΩ potentiometer
- CMax: **On any machine, you can start** `idle`, **open the** `CMax.py` **file and then do** `Run Module`**. On Linux and Mac, you can run CMax by using the terminal to navigate to the directory containing the file** `CMax.py` **and running** `python CMax.py`.
- `mystery.cmax`: Example CMax circuit
- `lightTest.py`: Input signal for the CMax simulation

Detailed guidance:

We use a simple layout and simulation tool, called *Circuits Maximus*, or "CMax" to its friends, to design and test circuits before constructing them. The following figure shows a screen-shot of CMax:
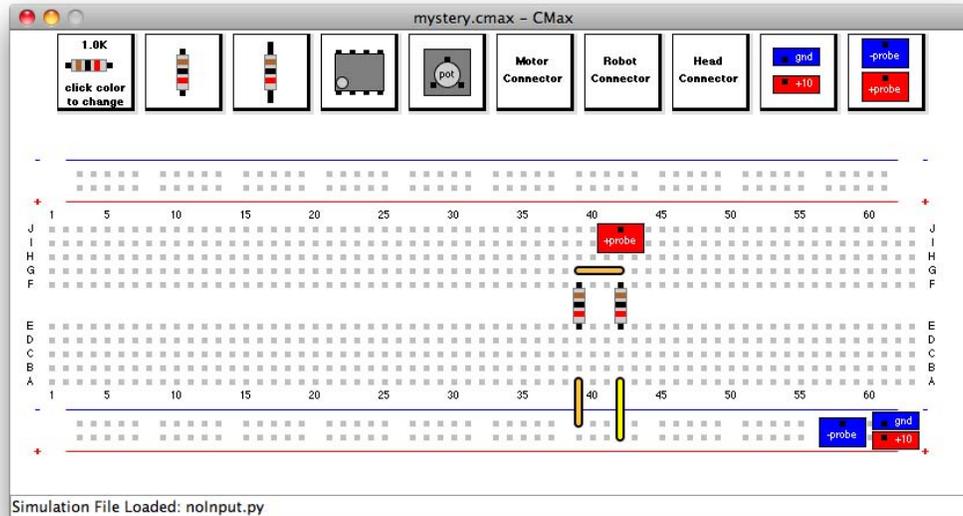
Step 2. Once CMax is running, **double check that you have the correct version**. Type ctl+a (hold Ctl key and type a). You should see a window pop-up that shows it's CMax version 1.5.2. If no window pops up or a different version is indicated, please re-reread the instructions for starting CMax and try again.

Step 3. Now, select **File > Open** from the menu to open the file mystery.cmax.

Step 4. Draw a schematic diagram for the circuit shown in the CMax window.
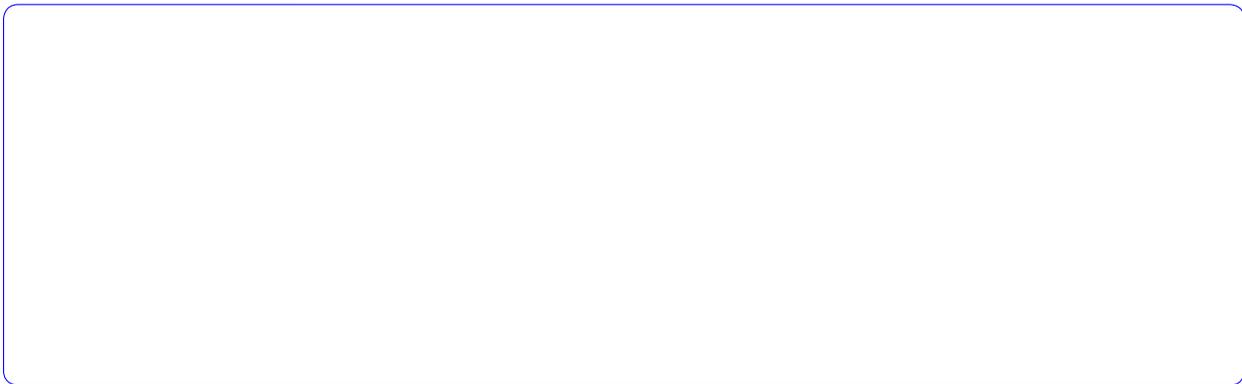
Step 5. Note the meter 'probes', attached to the ground rail and to location J42. Predict the voltage that will be measured across those two nodes in the circuit.

Step 6. Choose **Sim > Run Simulation** to make the simulator calculate the voltage across the probes. The result will be printed in a pop-up window. Do your calculations match the simulation?

3 Voltage Dividers

A voltage divider is a circuit that uses resistors to generate an output voltage that is a fixed fraction of the input voltage. The following figure illustrates a voltage divider as well as the resulting relation between its input voltage V_i and output voltage V_o:

$$V_o = \frac{R_2}{R_1 + R_2} V_i$$
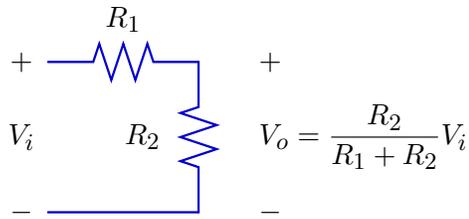
If $R_1 = R_2$, then $V_o = \frac{V_i}{2}$.

Can we cascade two divide-by-two circuits to produce a divide-by-four circuit? Consider the following design, where all of the resistors have $1\,\text{k}\Omega$ resistance.
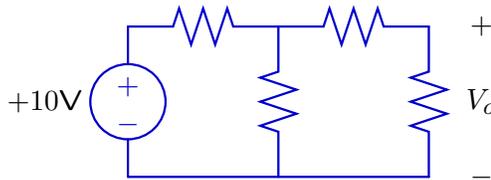
Step 7. Lay out this circuit using CMax. Documentation for CMax is available from the "Reference Material" page of the course web site.

Try to make your layout simple and clear. Use short wires oriented horizontally or vertically where possible. Try to avoid crossing wires, and do not run wires across other components! You will be using your layout as a guide to constructing a physical circuit. Jumbled wires are more difficult to construct correctly, and they are extremely difficult to debug!

Connect the "probes" so that they measure V_o. Choose **Sim > Run Simulation** to measure V_o. The value of V_o will be in the pop-up window.

Check Yourself 1. What is the simulated value of V_o?

$$V_o = $$

Check Yourself 2. Calculate V_o using circuit theory.

$$V_o = $$

Compare your result to that of the simulation.

Step 8. Lay out your circuit with physical parts. Make your physical layout look **exactly** like the CMax version. Trim the resistor leads so that the resistors lay flat against the proto board. (This step makes it easier to debug your circuit, by presenting a clean view of your components and their layout.)

Check Yourself 3.   Measure V_o with your multimeter. Do you get the same voltage V_o? Exactly?

Checkoff 1.   **Wk.7.1.1**: A voltage divider with equal resistors produces an output voltage that is half the value of the input voltage. However, two voltage dividers connected in cascade do not produce an output that is one quarter of the input voltage. Explain why.
Show that your circuit looks **exactly** like the layout in CMax. Show the results from your circuit and simulation.

4 Potentiometer

A potentiometer (or pot) is a three-terminal device whose electrical properties depend on the angle of its mechanical shaft. The following figure shows a picture of the pot that we will use in lab (left), the electrical symbol used for a pot (center), and an equivalent circuit (right). The quantity α is in the range $[0, 1]$; Θ is the maximum turn angle of the pot, for example, $270°$, and $\theta = \alpha\Theta$ is the actual turn angle of the pot's input shaft.
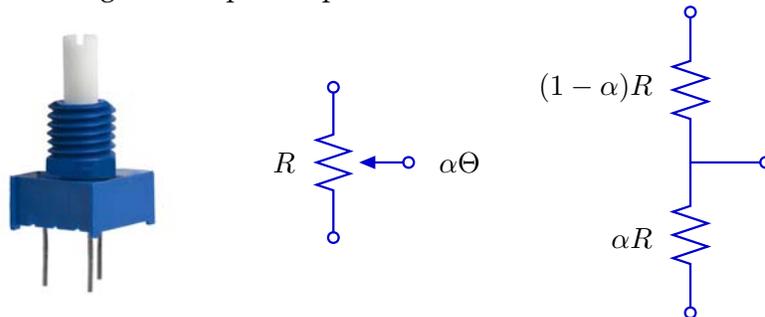
As the angle θ of the input shaft increases, the resistance between the bottom and middle terminals increases and the resistance between the middle and top terminal decreases. These changes in resistance occur such that the sum of the top and bottom resistors is constant. If you are interested in the internal construction of a potentiometer, look it up on a source such as Wikipedia. For our purposes, we will treat a potentiometer as a primitive element, which behaves as we just described.

By connecting a pot as a voltage divider (top terminal to a voltage source and bottom terminal to ground), the voltage at the middle terminal is made proportional to the angle of the shaft.

The pots we handed out in lab today have a total resistance of $5K\Omega$.

Step 9. On your protoboard, wire a potentiometer to a $10\,V$ supply and ground. Notice that the leads are arranged in a triangle, with the base of the triangle parallel to one of the straight sides of the pot and the apex of the triangle near the middle of the opposite side. Connect power and ground to the two leads on the base of the triangle.

What are the min and max voltages at the middle terminal of the potentiometer?

> [ ]

Step 10. Adjust the potentiometer (the one you just put on your protoboard, **not** the knob on the power supply) so that the voltage on the middle terminal is 2.0V.

To what value of α does this correspond?

> [ ]

Step 11. Leaving the pot adjusted as it was in step 10, attach a 100Ω resistor between the middle terminal of the potentiometer and ground. Measure the voltage V_o at the middle terminal.

> [ ]

Step 12. Use circuit theory to compute the ideal value of V_o in this circuit.

> [ ]

Step 13. Leaving the pot adjusted as it was in step 9, remove the 100Ω resistor and attach a $10K\Omega$ resistor between the middle terminal of the potentiometer and ground. Now what is the voltage V_o at the middle terminal?

> [ ]

Step 14. Use circuit theory to compute the ideal value of V_o in this circuit.

> [ ]

> **Wk.7.1.2**   Complete this tutor problem based on your computations above.

5 Seeing the light

> **Objective:**   Use a pair of photoresistors to construct a light sensor circuit ("eyes") for the robot head:
>
> - Characterize **photoresistors** (two-terminal devices whose electrical resistance depends on the intensity of light incident on its surface)
> - Design and simulate a circuit to generate a voltage proportional to light intensity
> - Build and characterize a circuit with two photoresistors, suitable for locating the angular position of incident light

> Resources:
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>
>
> - A robot head: with two photoresistors:
> - A lamp
> - A red cable
> - Two **8-pin connectors** (**head and robot connectors**)
> - A robot (and lab laptop running `soar`)
> - `eyeDataBrain.py` – a brain which collects and plots voltages measured at the robot's inputs as the robot is rotated

The robot head (which should be familiar from Homework 2) is an assembly custom crafted for this class, which has two photoresistors positioned on the shaft of a motor. **Position the photoresistors so they are roughly 90° apart, for this lab**. Mounted above the photoresistors is a simple laser pointer, which use useful for clearly indicating what the eyes are pointed toward. At the base of the robot head are two connectors; in this lab you will use the 8-pin connector only; it provides access to the wires of the photoresistors, as explained below. More information about the robot head can be found in the *Infrastructure Guide* .


Detailed guidance:

Step 15. We use photoresistors to measure light intesity for the robot head. We start by measuring the resistance of the photoresistors (right figure) in different lighting conditions. The photoresistors are already mounted on the robot head. Plug an 8-pin connector into an otherwise empty protoboard.
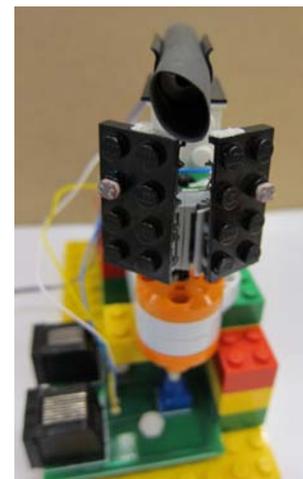
The head's two photoresistors are wired to the head connector (described in the Infrastructure Guide, as shown in the following figure.

Measure the resistance of **each photoresistor** as follows. Switch your meter to measure resistance (the scale is marked Ω) and connect it to pins 4 and 5 (for left photoresistor) or pins 6 and 5 (for right photoresistor) of the head connector. For stable readings, you should insert short wires so that they connect to the pins 4, 5, and 6, and then connect the meter probes to those wires using clip leads. Be sure you understand the meter's scales (you can always measure a known resistor to help figure out the scale). Repeat your measurements using a silver lamp as illumination. **The lamp gets very hot — turn it off when not in use.** Record your results in the following table.
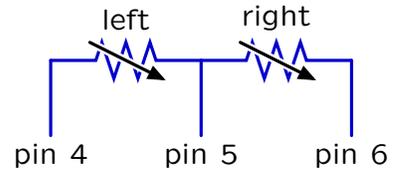
	Left	Right
ambient light		
one foot in front of lamp		
three feet in front of lamp		

Step 16. Design a circuit that uses one photoresistor (plus one or more additional resistors) to generate a voltage that is large under bright conditions and small under dark conditions. Assume a 10 V power supply. Design your circuit so that the output voltage (relative to ground) changes at least 3 V when the light is turned on and off at a distance of one foot. Sketch your circuit below.

Hint: think about how a change in resistance maps to a change in voltage.

What voltage do you expect for the following lighting conditions?

	Left	Right
ambient light		
one foot in front of lamp		
three feet in front of lamp		

Check Yourself 4. Explain how your circuit generates a low voltage under ambient conditions and a higher voltage under bright conditions.

Draw a schematic for two photoresistor circuits, one to generate the voltage V_L from the left photoresistor and one to generate the voltage V_R from the right photoresistor, using pins 4, 5, and 6 on the head connector.
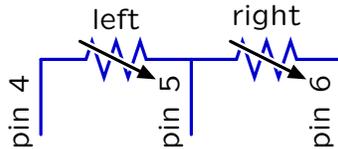
Step 17. Start CMax by running `designLab07/CMax.py`. Add a **Robot Connector** and a **Head Connector** to your layout. The robot connector will accept the yellow cable from the robot, which provides power and ground for your circuit through pins 2 and 4, respectively. **You should use the robot connector to provide power and ground to your circuit; do not use a separate power supply.** The head connector will connect to the head via a red cable, and provides connections to the photoresistors through pins 4, 5, and 6, as shown in the diagram above.

Use CMax to lay out the circuit you designed in the previous step.

Load the simulation file `lightTest.py`, which simulates moving a light from left to right in front of the robot at a constant distance. Run this simulation three times: once using a voltage probe to measure V_L, once to measure V_R, and once to measure $V_L - V_R$.

You can ignore the warnings: "Motor is not connected" and "Head potentiometer is not connected". These are accurate but not relevant here.

Check Yourself 5. How should each of the measured voltages change as the light moves from left to right? Make sure your plots reflect this.
Save each of your plots as a screenshot.

Step 18. Plug a second 8-pin connector into your proto board; we call this the **robot connector**. You can connect your circuit to a robot via the yellow 8-pin cable that is coming out of the robot **(don't do it yet though; that would make it awkward to work on your board)**. This connector is exactly the same as the head connector; to help keep this distinct from the red cable connecting your board to the head, remember: 'red' — 'head'.

As in your CMax layout, connect power and ground on your board to the corresponding pins (pins 2 and 4, respectively) on the robot connector.

Build the circuits you designed. Here is how the whole system should be configured:
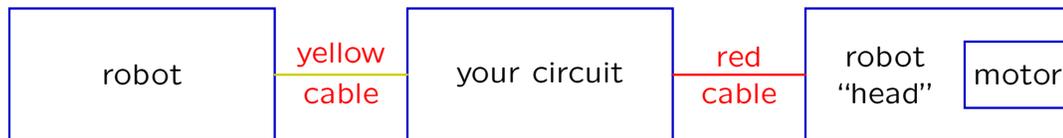
Attach the head to the lego plate on the front of the robot (sometimes putting a couple of lego bricks in between will make this easier), connect the yellow robot cable to your board, and **turn on the robot**. Use your multimeter to make sure that you are getting reasonable values for V_R and V_L. You can use your finger to obscure each of the sensors in turn and see that the voltages behave as expected.

Step 19. Connect V_L to analog input #2 (pin 3) on the **robot** connector and connect V_R to analog input #3 (pin 5). These pins connect to **A-to-D (analog to digital) converters** within the robot; for more information on how these work, see the *Infrastructure Guide*.

You can think of your circuit as an added component of the robot. In addition to its built-in sonar sensors, the robot now has a light sensor as well.

Step 20.

- Find one of the standing lamps and place it near the robot (or move the robot to near one of the lamps).
- Make sure the head/circuit is connected to the robot and turn the robot on.
- Start soar and select the `eyeDataBrain.py` brain.
- Line up the robot in front of the lamp, so that the head is pointing at the lamp and the robot is about a meter from the lamp. Now manually turn the robot **clockwise** by 90 degrees.
- Click Start in soar. This will turn the robot through 180 degrees.
- Click Stop when the robot has fully turned.

Three plots should appear when you click Stop: the brightness on the left and right eyes as well as the difference between them. Note that if you want to run your robot through this rotation again, you will need to reload the brain file in soar.

Check Yourself 6.   Do your measured plots match the ones created by CMax? Should they?
Save your plots as a screenshot.

Step 21.   Determine a strategy for making the robot turn toward the light regardless of the initial angle between the robot and light. Think about how angle affects the light on each photoresistor. Your strategy should build on your plots of V_L and V_R as a function of angle.
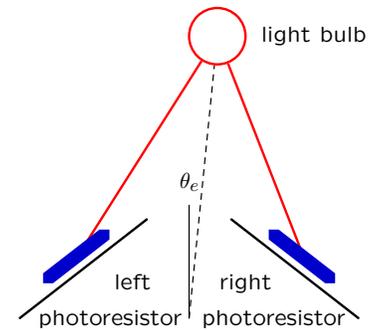
Checkoff 2.   **Wk.7.1.3**: **Part a.** Explain your plots to a staff member.
Part b. Explain your approach to pointing at the light.

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