MASSACHVSETTS INSTITVTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science
6.081—Introduction to EECS I
Spring Semester, 2007

Assignment for Week 7

- Software Lab for March 20th
- Prelab exercises due Thursday March 22th before lab
- Lab on designing and using a virtual oscilloscope.
- Post-lab due Tuesday April 3rd in Lecture.

The constraints view of circuits

In this problem set you will learn about resistor networks both as constraint systems and from a more intuitive perspective. The former is more useful when writing programs to determine the behavior of circuits, the latter is more helpful during design. You will get a chance to use your understanding of resistor networks to design a virtual oscilloscope, and then use that oscilloscope to investigate the behavior of a lego motor.

This problem set has four parts:

1. Post-Lecture lab on using a constraint resolver to solve circuit problems.
2. Tutor problems on analyzing resistor networks.
3. Lab on designing and using a virtual oscilloscope.
4. Post-lab problem on generating constraints for a neuron model.

Note, we are still having some issues with the software for Thursday's lab, so we will post the final version of Thursday's lab Wednesday evening. We will also bring paper copies to Thursday's lab.

Tuesday Post-lecture Software Lab

You will be downloading and using *resolve_constraints.py*, which contains programs for creating lists of constraints and their associated variables, and then once the list of constraints and variables has been generated, determining values for the variables so that the constraints are satisfied. In particular, a user must first create an instance of the class *constraint_list*. Then the user invokes *constraint_list*'s function *add_constraint* multiple times, once for each of the constraints. The function *add_constraint* appends a constraint and the constraint's associated variables to the instance. By calling the instance's function *resolve_constraints*, values are determined for the variables so that the constraints are satisfied. The values of the variables can be printed by calling *constraint_list*'s function *display*.

There are two arguments to the function *add_constraint*. The first is a procedure whose input is a tuple of variable values, and the second is a lists of strings which are the labels for the variables used in the constraint. The order of the strings should match the order of the variables in the tuple. The procedure that is passed to *add_constraint* should return zero when the input tuple satisfies the

constraint, and if the tuple does not satisfy the constraint, the procedure should return a floating point number which indicates how far the tuple is from satisfying the constraint.

As an example, consider the problem of finding values for x and y which satisfy the two constraints

$$5 * x - 2 * y = 3$$

and

$$3 * x + 4 * y = 33.$$

Of course, $x = 3$ and $y = 6$ satisfy the above two constraints.

To use the constraint class and the function *resolve_constraints* to find the constraint-satisfying values of x and y, first define functions which generate the two constraint procedures:

```
def firstEqn():
    # Enforces 5*x - 2*y = 3, assumes [x,y]
    return lambda x : 5.0*x[0] - 2.0*x[1] - 3.0

def secondEqn():
    # Enforces 3*x + 4*y = 33.0, assumes [x,y]
    return lambda x : 3.0*x[0] + 4.0*x[1] - 33.0
```

Second, create an instance of *constraint_list* and add the two constraints, being careful to provide variable labels in the same order as used in the constraint procedures:

```
linSys = constraint_list()
linSys.add_constraint(firstEqn(),['x', 'y'])
linSys.add_constraint(secondEqn(),['x', 'y'])
```

Finally, call *resolve_constraints* and display the solution:

```
solution = resolve_constraints(linSys())
linSys.display(solution)
```

In order to use *resolve_constraints* for circuit problems, one needs an organized approach for generating the variables and constraints for a circuit. In class we discussed the nodal approach for accomplishing this task. The steps in the nodal approach were

1. Label all the circuit node voltages and element currents (noting direction), and select a reference node.
2. For each element, write constitutive equations that relate element currents to the voltages at the element's terminals.
3. For each circuit node, except the reference node, write a conservation law. That is, insist that the sum of currents entering a node should be equal to the sum of currents leaving a node.

In order to use the constraint resolver to solve circuit problems, it is helpful to have functions which return constraint procedures associated with a circuit's constitutive equations and conservation laws. In the file *circuit_constraints.py*, there are functions to generate procedures that implement circuit related constraints. The *resistor* and *vsrc* functions return procedures which implement the constitutive relations associated with a resistor and a voltage source, the *kcl* function returns a procedure which implements the constraint that the signed sum of currents must equal zero, and the *set_ground* returns a procedure which implements a constraint forcing a value to zero (typically used to force the reference node voltage to be zero).

Download and test the constraint System

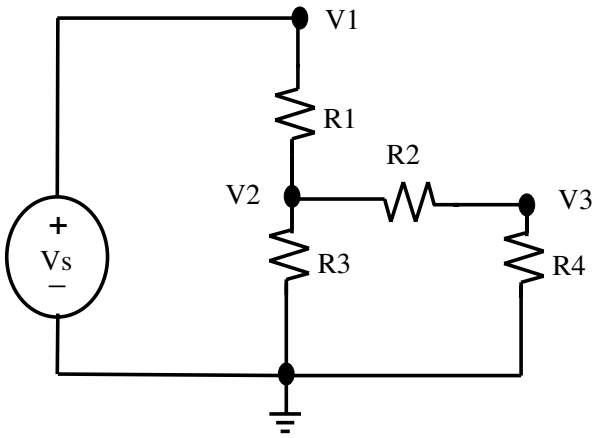
The software for this prelab is at the 6.081 web site. Download and unzip constraint resolver software, and note that there are four python files: *resolve_constraints.py* and *circuit_constraints.py* described above, as well as two example circuit files, *circuit.py* and *circuit2.py*. Try running the two example circuit files, and notice the second example generates an error. Fix the error in the second example circuit file (the reference node voltage has not been set), then draw the resistor and voltage source circuit diagrams associated with the two examples.

Checkpoint: 4:00 PM

- Show your LA your circuit diagrams, and demonstrate that you have fixed the problem in the circuit file.

Use the constraint resolver

Use the constraint resolver to find the node voltages in the following circuit, assuming $Vs = 5.0$ and $R1 = R2 = R3 = R4$.



Checkpoint: 4:30 PM

- Show your LA your input file for the constraint resolver and demonstrate that the resolver generates the correct result.

Add the non-ideal voltage source

The voltage source is an idealized model of a battery. All real batteries have some internal resistance, and this resistance restricts the current that can be provided by the battery. We can model a real battery by creating a more complicated circuit in which we add a resistor in series with an ideal voltage source, but one can also generate a single non-ideal voltage source constraint. Try adding such a constraint to the file *circuit_constraints.py*, and then use your new non-ideal voltage source to reduce the total number of constraints in the *circuit2.py* file. Notice that you will eliminate a node voltage as an explicit variable and should also eliminate its conservation law, but you should still compute the same source current.

Checkpoint: 5:00 PM

- Demonstrate your program with the non-ideal source to your LA.

ONLY FOR FUN

You might try adding a nonlinear resistor constraint to the system (one in which the current is a nonlinear function of the voltage). One example nonlinear resistor has a current-voltage constraint given by

$$R_0 i_R - (v_{n_1} - v_{n_2}) - \beta (v_{n_1} - v_{n_2})^3 = 0.$$

where β is typically less than one, and larger values of β correspond to more nonlinear resistors. Can you find an interesting circuit using such a resistor?

To hand in

You do not need to hand in anything for this software lab, but please make sure you get checked off.

Pre-lab problems due Thursday before lab

The tutor has circuit examples, one of which is too annoying to analyze by hand. Use a combination of your understanding of circuits and the constraint resolver to solve the tutorial problems.

Thursday Lab - Designing and using a virtual oscilloscope

In this lab you will design a resistor network that will allow you to measure voltages over a wide range. Then you will write a python program that will create a graph of a sequence of voltage samples taken at regular time intervals, effectively creating a virtual oscilloscope. Finally, you will use your virtual oscilloscope to measure the relationship between voltage and current for a LEGO motor, and use your knowledge of circuits to develop a circuit model for the motor.

For this lab you will not need the robot, but you will need a laptop and:

- National Instruments (NI) Interface Box, USB cable, and screwdriver.
- A number of resistors.
- A Lego motor with connector.
- A protoboard with built-in power supply.

We will be using the NI box in a number of labs to interface to circuits, sensors and motors. The NI box can be used to measure voltages and convert those voltages to numbers that can be accessed using python. We have provided a python program which will read numbers generated by the NI box, specifically the numbers that are related to the voltage at the NI box terminal labeled *AI0*. Note that for the NI box, the voltages are measured with respect to the voltage at the terminal labeled *GND*.

You will also be using a protoboard to connect components together. A protoboard is used for making easily modifed electrical connections between wires and circuit elements. If you look at your protoboard, you will notice many rows of holes, where each row has five holes. These holes are electrically connected, so if you plug two wires in to two holes in the same row, the wires will be connected electrically. Resistor leads can also be plugged directly in to the protoboard holes. Also, each protoboard has several long columns of holes which are used for nodes in a circuit that have a large number of connections. These columns are often used for ground and power. If you have never used a protoboard, have one of the staff members demonstrate the board's use.

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