

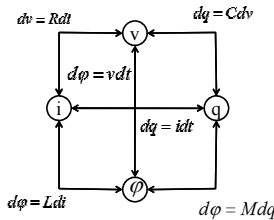


# Memristors: Hardware Implemented Learning Circuits



## Project Description

- The memristor was proposed in 1971 by Leon Chua [1] on the basis of symmetry using the classical relationships describing resistance, capacitance, inductance, charge, current, voltage, and magnetic flux.
- Strukov et al. [2] reported the first physical realization of a memristor and a simple model accounting for its behavior.
- Since this report, several applications of memristors have been described including light emitting memristors [5], memristor logic boards [4] and a circuit for modeling learning in primitive organisms [3].
- The modeling of a memristive learning circuit is of particular interest due to the potential creation of hardware-based artificial intelligence.



Symmetry argument for the existence of a memristor as a basic circuit element. Modeled after [2]



Hybrid memristor/transistor logic board as shown in [4].

## Scientific Challenges

- Altering the model in [3] to include a physically relevant memristor can expand the study of learning circuits implemented in hardware.
- Test the circuit for uses beyond biological modeling such as programmable, analog filters.

## Potential Applications

- Use of multiple circuits in parallel would allow for simultaneous learning and advanced signal processing.
- Potential to forward the field of neural networking by modeling the learning process triggered by stimuli.
- Artificial intelligence implemented by various hardware elements instead of elaborate software systems.

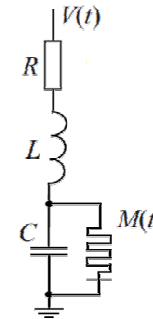


*P. polycephalum* navigating the Tower of Hanoi at initial time (left) and after nine hours (right). The amoeba is capable of determining the most efficient route.

## Team Members:

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Theoretical circuit used for emulating learning responses in *P. polycephalum*. The inductor and capacitor simulate biological oscillations, the resistor attenuates the response and the memristor alters the reaction from the RLC circuit. The input and output voltages represent the stimuli and the response respectively. Taken from [3].



## Methodology

- The above circuit was modeled assuming an ideal voltage source as described by [3]. The output voltage was measured across the capacitor and memristor. Note memristance is a function of voltage resulting in an inherently nonlinear equation.
- Kirchhoff's voltage and current laws are used to determine the following relationships:

$$V_C + LI + IR = V(t)$$

$$C\dot{V}_C + \frac{V_C}{M} = I$$

Where:

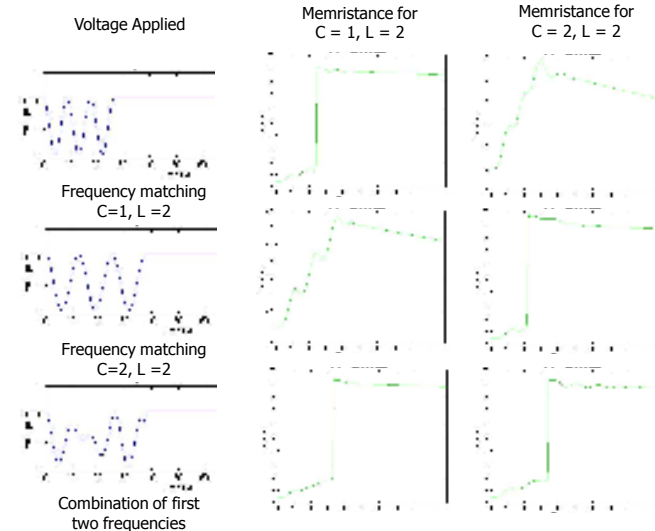
- $M$ , a function of voltage, is the memristance of the memristor described in [3]
- $V_C$  is the voltage across the capacitor
- $L$  is the inductance on the inductor
- $I$  is the current through the circuit
- $R$  is the resistance on the resistor
- $V(t)$  is the applied voltage
- $C$  is the capacitance on the capacitor

- The system of differential equations were solved numerically in MATLAB.

## Acknowledgments

This project was mentored by Jefferson Taft, whose help is acknowledged with great appreciation.

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The above figures demonstrate the training of two memory circuits in parallel using sine wave voltages with LC resonant frequencies. This shows the circuit can respond selectively to a precise frequency which alters the capacitor's effect.

## Results

- The learning circuits are selective for their LC resonant frequencies.
- These circuits isolate their respective frequencies from superimposed signals. Further research could focus on constructing programmable, analog filters in greater detail.
- Further study could extend the simulation with more realistic values of inductance and capacitance and the use of the physically relevant memristor presented in [2].

## References

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