Memristors and Beyond:
Recent Advances in Analog Computing

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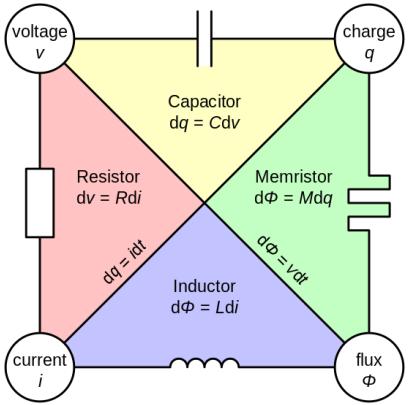
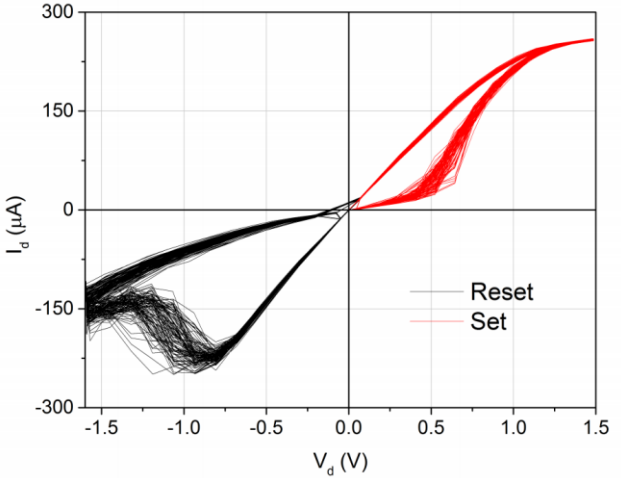
What is a Memristor

- Theorized by Leon Chua in 1971
- 4th basic circuit element
- Contraction of Memory Resistor
- Can have its resistance altered
- “Remembers” resistance without current
- Completely Theoretical for 37 years*



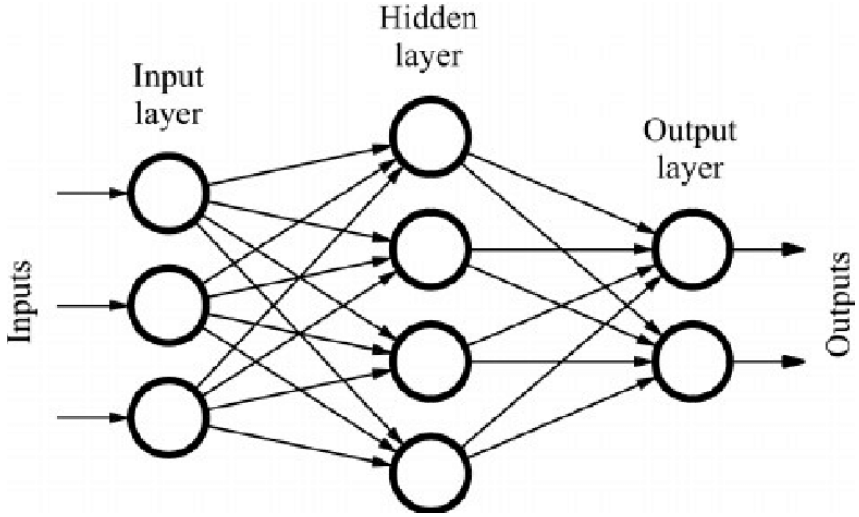
Discovery of Memristors

- 2008 Stan Williams led team to make memristor
- Titanium Dioxide film with Pt and Ti electrodes
- Many different types developed since
  - Halfnium Oxide IV pictured right
- Some Proposed Uses:
  - Ultra-dense memory
  - Neuromorphic Computing



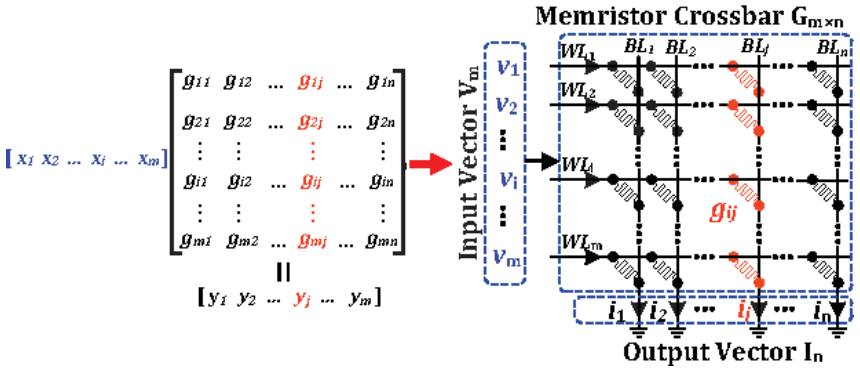
Feed-forward Neural Network

- Popular machine learning technique
- Power hungry and time consuming
- Lots of matrix multiplication
- GPU accelerators help



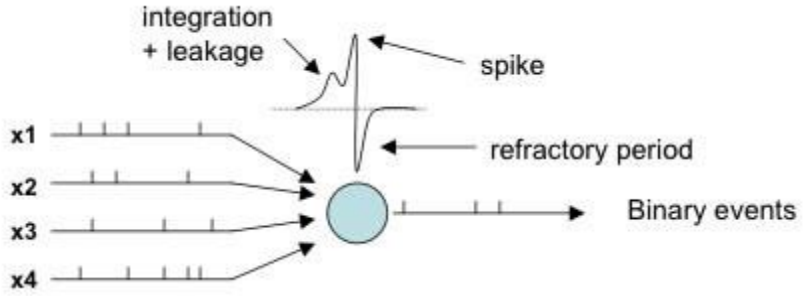
Memristor Crossbar

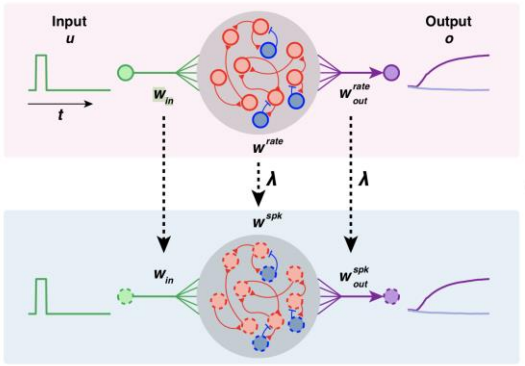
- Array of Memristors
- Single pass programmable matrix multiplication
- Memristors <= 3nm
- Dense and low power



Spiking Neural Networks

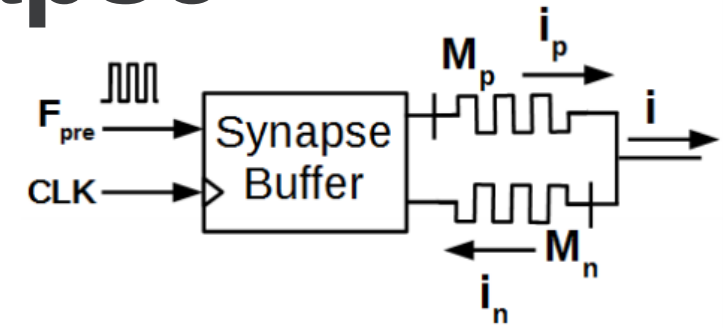
- Cumulative Threshold
- Leak
- Delay
- Time-based inputs
- Usually non-feed-forward
  - Difficult to train

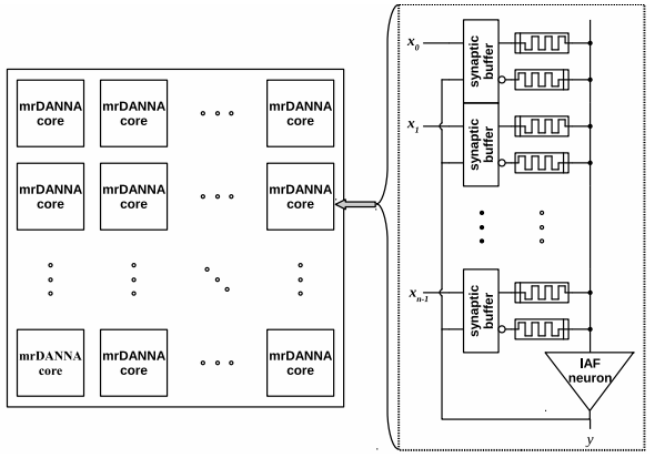




Memristive Synapse

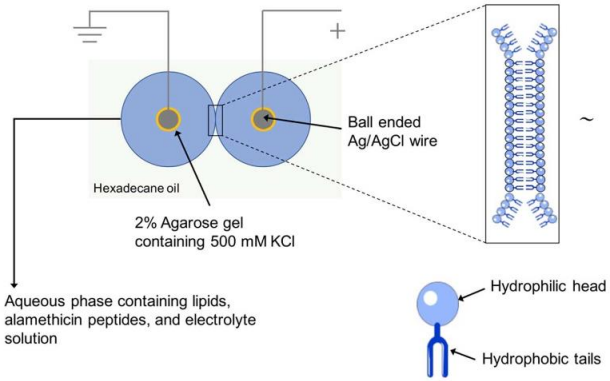
- 1+ memristors as synapse value
- Great parallelism
- Analog or mixed signal designs
- Can do feedback learning in analog
  - STDP
- Feed-forward spiking networks as crossbars

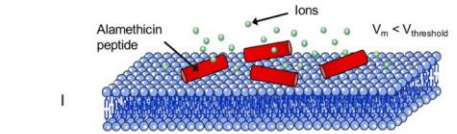




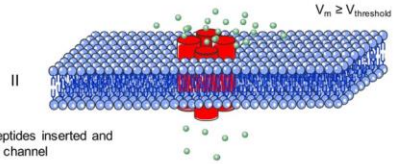
Lipid Biomembrane

- A pair of water droplets suspended in oil
- Water has Antibiotics and electrolytes
- Alamethicin / Monozamiacin:
  - Hydrophobic and Hydrophyllic ends
  - Used to break hostile bacteria apart
- Applying current causes peptides to form channels
- Longer current both more and larger channels
- Easier travel, higher conductance





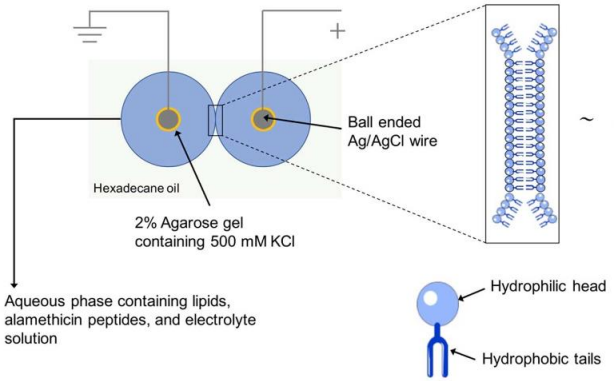
Alamethicin peptides before insertion
sitting at the surface of the bilayer

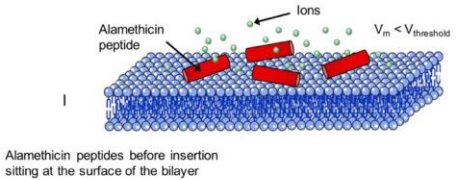


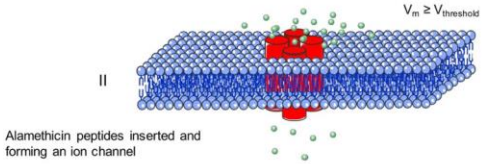
Alamethicin peptides inserted and
forming an ion channel

Lipid Biomembrane

- Parameterizable analog sigmoid
- Without current quickly falls back to normal
  - Not instantaneous
- Short pulses with very short gap allows for more linear growth

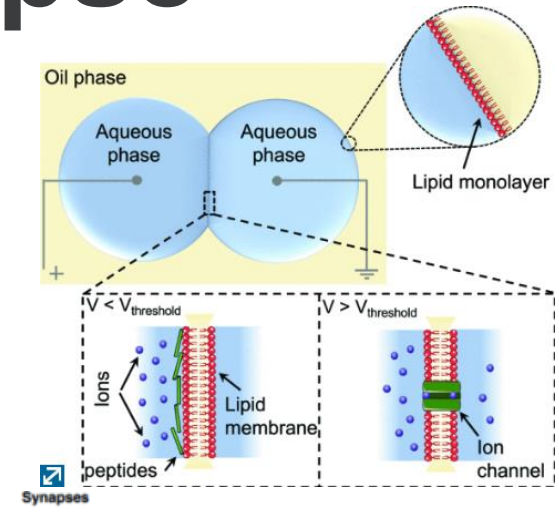


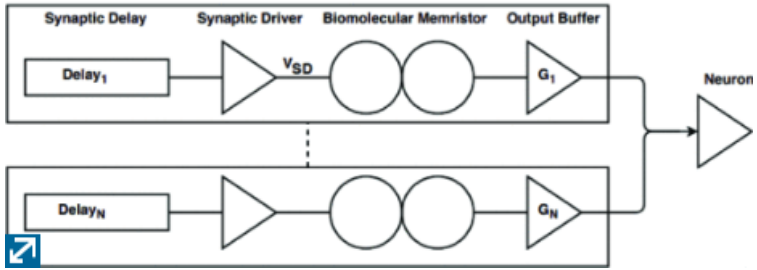




Biomembrane Synapse

- Volatile Memristor
  - Loses state over time
- Spike Rate Dependent Plasticity (SRDP)
- Small scale networks generated
- Not large-scale viable
  - Droplets made by hand-pipette
  - Antenna effect – Faraday Cage
  - Sound/vibration sensitive
  - Large – mm scale elements
  - Evaporates





Sources

- L. Chua, "Memristor-The missing circuit element," in *IEEE Transactions on Circuit Theory*, vol. 18, no. 5, pp. 507-519, September 1971. doi: 10.1109/TCT.1971.1083337
- Strukov, D., Snider, G., Stewart, D. *et al.* The missing memristor found. *Nature* **453,** 80–83 (2008) doi:10.1038/nature06932
- Brotzer, J & Gorro, Ken. (2019). Predicting emotion in music through audio pattern analysis. IOP Conference Series: Materials Science and Engineering. 482. 012021. 10.1088/1757-899X/482/1/012021.
- Liu, C., Yang, Q., Yan, B., Yang, J., Du, X., Zhu, W., Jiang, H., Wu, Q., Barnell, M., & Li, H. (2016). A Memristor Crossbar Based Computing Engine Optimized for High Speed and Accuracy. *2016 IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 110-115.
- Sayyaparaju, S., Chakma, G., Amer, S., Rose, G., “Circuit Techniques for Online Learning of Memristive Synapses in CMOS-Memristor Neuromorphic Systems”. GLSVLSI '17 Proceedings of the on Great Lakes Symposium on VLSI 2017, Pages 479-482
- S. Amer and S. Sayyaparaju and G. S. Rose and K. Beckmann and N. C. Cady, “A Practical Hafnium-Oxide Memristor Model Suitable for Circuit Design and Simulation”, ISCAS: International Symposium on Circuits and Systems May 2017, Baltimore, MD
- M. S. Hasan *et al*., "Biomimetic, Soft-Material Synapse for Neuromorphic Computing: from Device to Network," *2018 IEEE 13th Dallas Circuits and Systems Conference (DCAS)*, Dallas, TX, 2018, pp. 1-6. doi: 10.1109/DCAS.2018.8620187
- M. S. Hasan *et al*., "Response of a Memristive Biomembrane and Demonstration of Potential Use in Online Learning," *2018 IEEE 13th Nanotechnology Materials and Devices Conference (NMDC)*, Portland, OR, 2018, pp. 1-4. doi: 10.1109/NMDC.2018.8605829

Questions?

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