Memristors:
The key to Neuromorphic Circuits

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Agenda/Overview

1. Background
2. Technical Description
3. Future Applications
4. Conclusion

Introduction

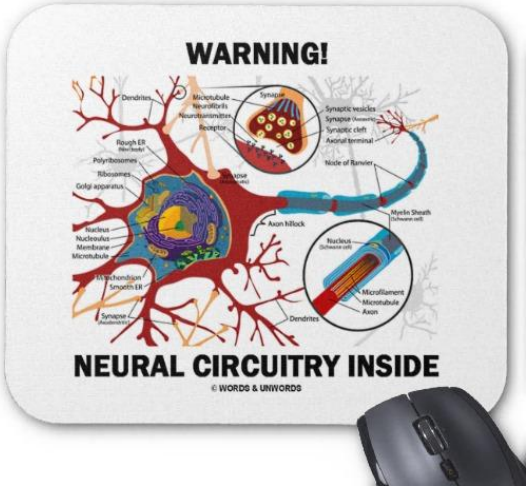
- Memristor
  - A 4th circuit element to complement RLC
  - Proposed in 1971 by Leon Chua
- Neuromorphic circuit
  - Use hardware to emulate brain functions
  - First proposed by Carver Mead in late 1980s

Why?

- Brains have several desirable features
  - Low power consumption
  - Fault tolerance
  - Learning
  - Particularly fast/useful for certain tasks
- Medical Reasons
  - Better understanding of brain functions

So how does it work?

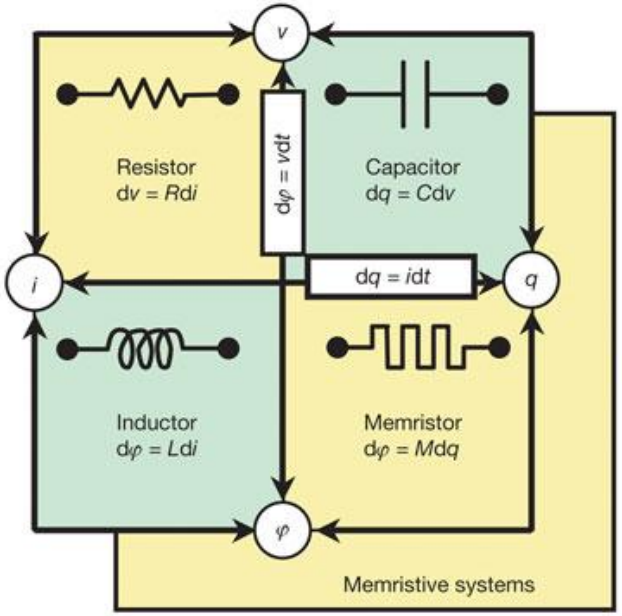
- Neurons work by sending electrical signals from nerve to nerve.
- At the interval between neurons (synapses), the signal is transmitted via the release of chemicals.
- Need electronic components to simulate neurons



Memristor

- The Resistance of the device depends on the direction of the current.

$$M(q(t)) = \frac{\mathrm{d}\Phi_m/\mathrm{d}t}{\mathrm{d}q/\mathrm{d}t} = \frac{V(t)}{I(t)}$$

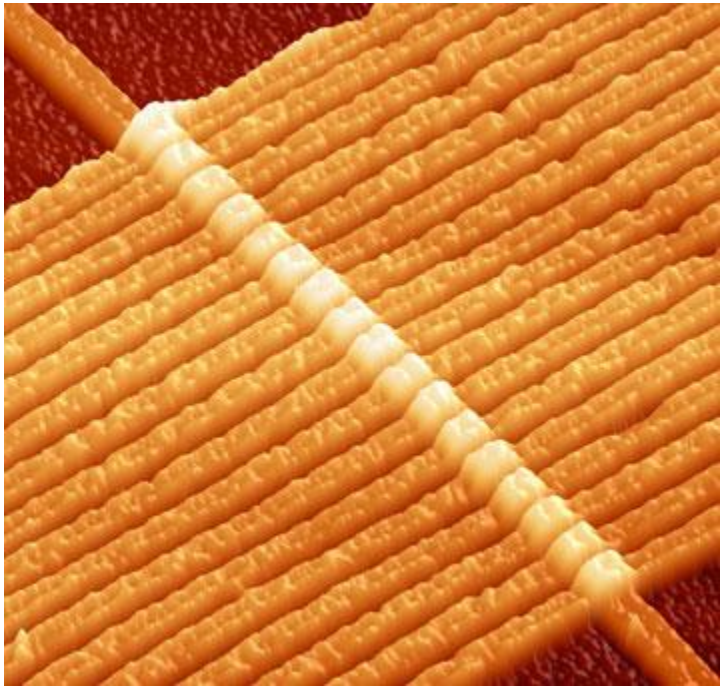


Memristor - the missing 4th circuit element

Research at HP Labs

- Electric current shifts the oxygen vacancies, causing a gradual and persistent change in electrical resistance
- HP prototyped a crossbar latch memory that can fit 100 gigabits in $1cm^2$

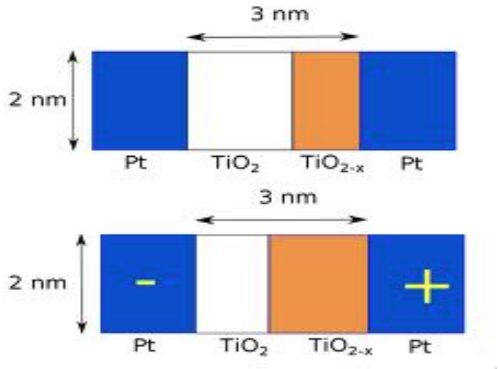
$$M(q) = \mathcal{R}_{\mathrm{OFF}}\left(1 - \frac{\mu_V \mathcal{R}_{\mathrm{ON}}}{D^2} q(t)\right)$$

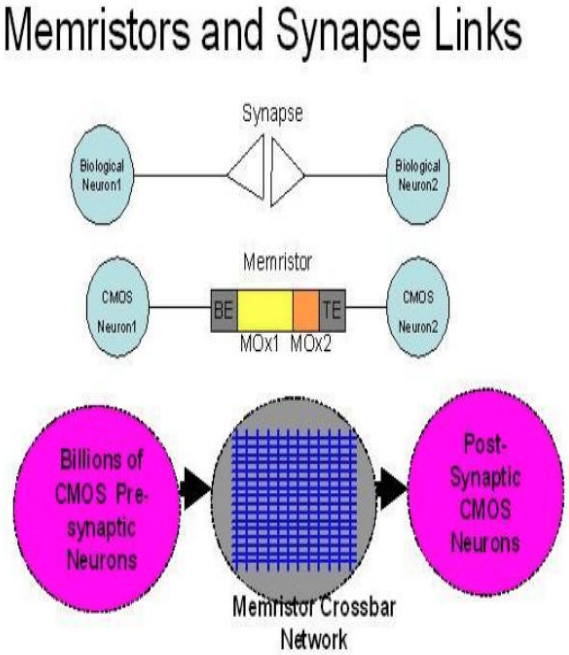


An array of 17 purpose-built oxygen depleted titanium dioxide memristors. The wires are about 50 nm, or 150 atoms, wide.

Better than CMOS-based chips?

- One memristor equivalent to approximately 15 transistors and other passive elements
- Can be layed out in crossbars (3D)
- Able to program and erase information rapidly
- Store information with electrical resistance





Research Projects

- Human Brain Project

  A 10 year project attempting to simulate complete human brain

  Intent is to understand the brain and its diseases

  Knowledge gained will help build new computing technology

- BRAIN Initiative

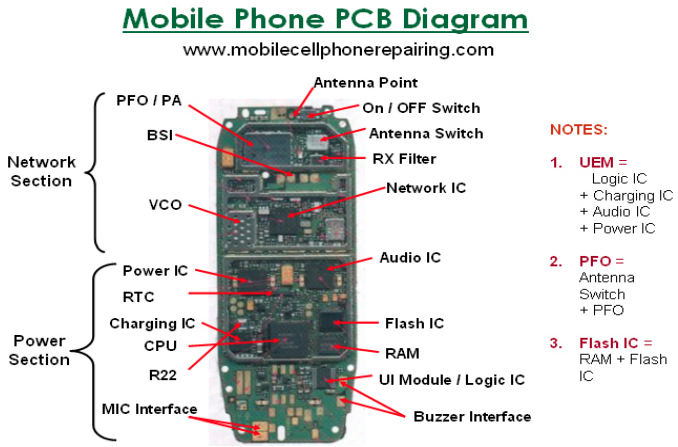
  Brain Research through Advancing Innovative Nanotechnologies

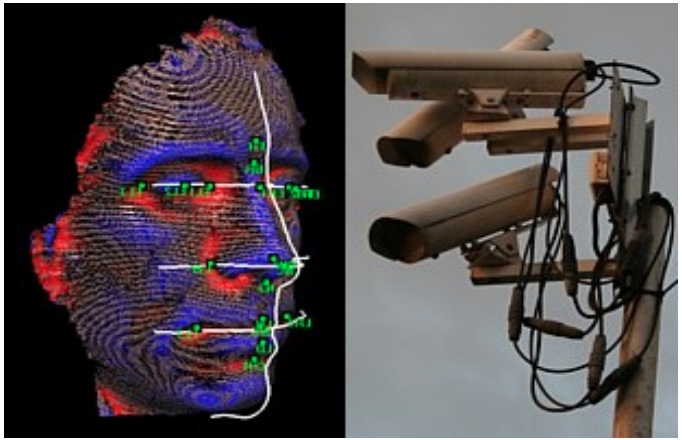
  Goal is to map activity of every neuron in the human brain

  Noninvasive, wireless methods of neuronal activity detection

Electronics

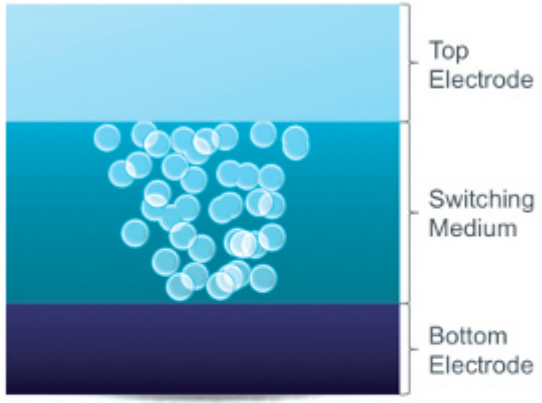
- Flash memory chips are found in almost all modern electronic products
- Cell phones, computers, video games, and flat panel televisions
- Complex biometric recognition systems (facial recognition technology)

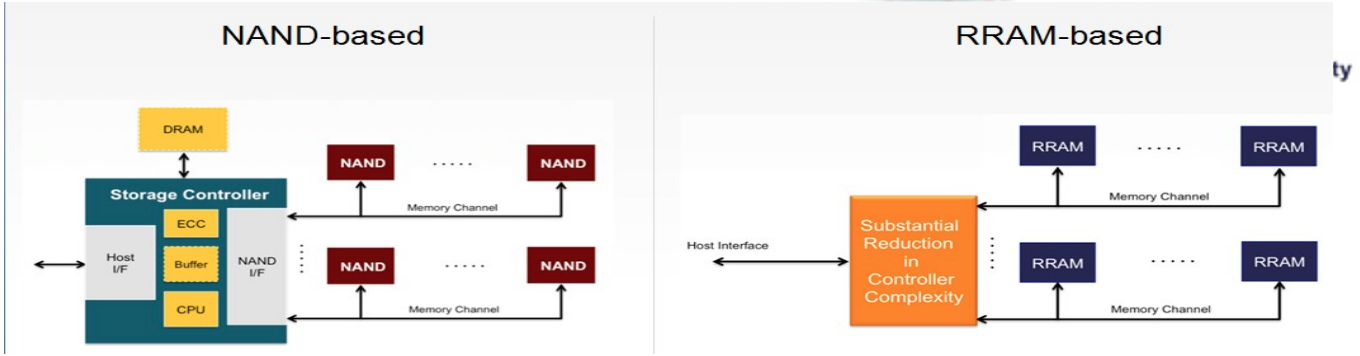




ReRAM (or RRAM)

- Smaller 2D process geometries for NAND flash not the long-term answer
- Resistance only changes when driving voltage fluctuates
- Implementation based on switching material and memory cell organization





ReRAM (or RRAM)

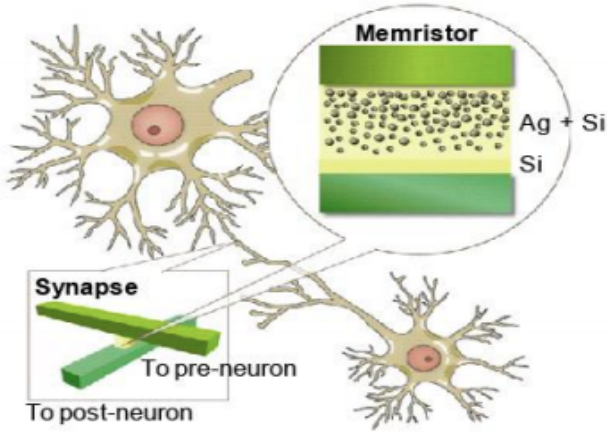
How Does it Stand Up as a Memory?

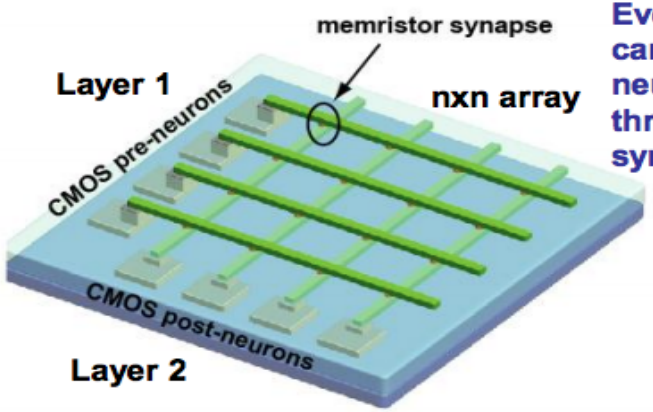
	Memristor	PCM	STTRAM	DRAM	Flash	HDD
Density (F^2)	<4	8–16	37–64	6–8	4–6	2/3
Energy per bit† (pJ)	0.1–3	2–27	0.1	2	10000	1–10x10^9
Read time (ns)	10-100(?)	20–70	10–30	10–50	25000	5–8x10^6
Write time (ns)	~10	50–500	13–95	10–50	200000	5–8x10^6
Retention	years	years	weeks?	<<second	years	years
Endurance (cycles)	>10^{12}	10^7	10^{15}	10^{15}	10^6	10^4

What needs to happen

- Need to agree on type of material
- Cost is too high, people more willing to sacrifice performance for cost
- Find efficient way of incorporating memristors with CMOS technology

CMOS/Memristor Neuromorphic Circuits

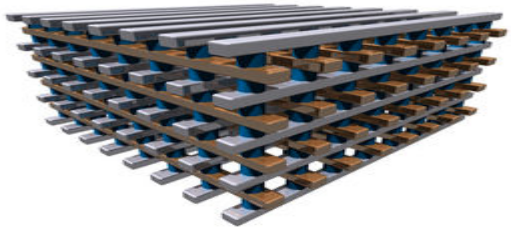




Every neuron in lay 1 can be connected to *n* neurons in layer 2 through n memristor synapses

Conclusion

- CMOS alone cannot improve computing to level of human brain behavior
- Memristor resistance fluctuates due to applied voltage and current direction
- Switching layer material and 3D layering can optimize performance
- Research projects implemented to simulate neuron activity for entire brain
- ReRAM is the replacement for DRAM, SRAM

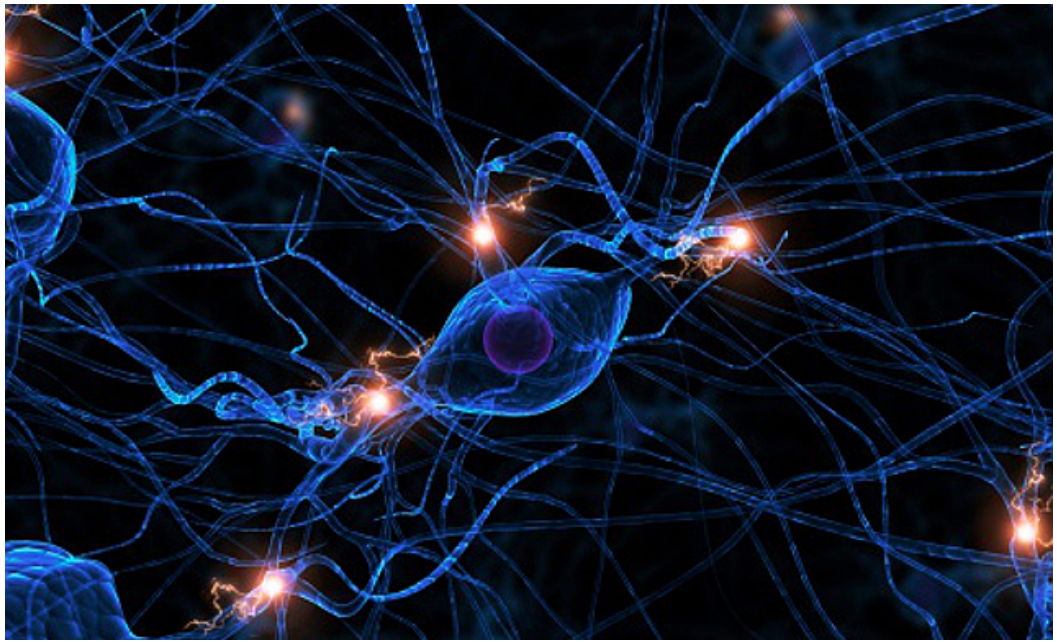


Crossbar RRAM Technology
CMOS Compatible for Easy Integration

Crossbar's simple and very scalable memory cell structure enables an entirely new class of 3D RRAM which can be easily incorporated into the back end of line of any standard IOS manufacturing fab.

Questions

Any questions?



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