Learning in biological and artificial neural networks

for understanding the brain and developing energy-efficient hardware implementations

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Motivation

- Brain
  - Seat of human intelligence and very **energy efficient**
  - Computations performed by interconnected neurons
    - **Asynchronous** communication through brief electrical pulses (“spikes”)
    - Connection strengths adjustable — basis for **learning**

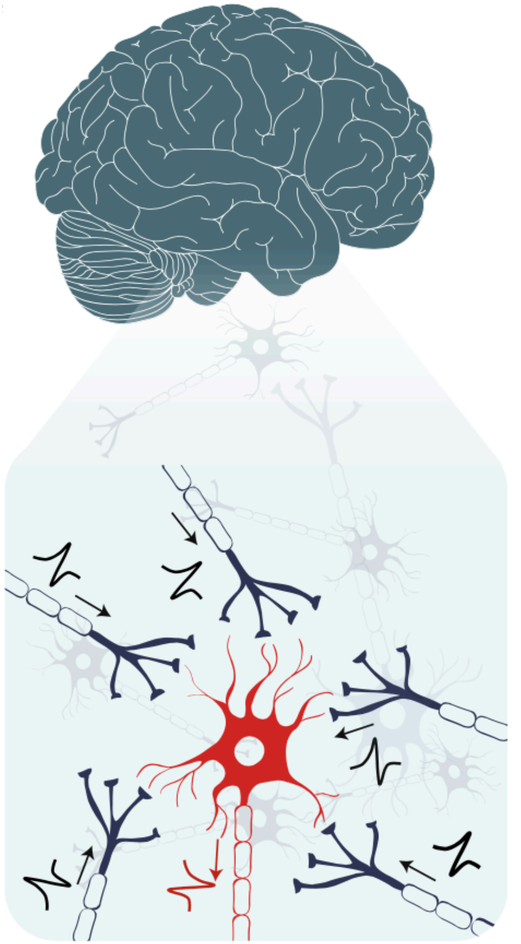

Image source:
Zhang, Wenqiang, et al. "Neuro-inspired computing chips." *Nature electronics* 3.7 (2020): 371-382.

My research directions

Research statements:

- Brain mechanisms are poorly understood.
- Neural networks are good at learning patterns, but have difficulties manipulating symbols.
- Neuro-inspired (brain-like) computing hardware is emerging.

Goals:

- Understand mechanisms of the brain
- Develop more intelligent models with cognitive abilities
- Develop learning algorithms suitable for use in neuromorphic silicon hardware (e.g., robust, operating under constraints)

Spiking Neural Networks and Memristors

- Spiking neuron
- Learning: iterative change in w such that a measurable cost J is minimized (e.g., distance between desired and observed firing rates is minimal)
- Memristors:
  - Hardware implementation of connections w
  - State variable $G[S]$ (conductance)
  - Programmable and able to “remember”
  - Noisy and unreliable

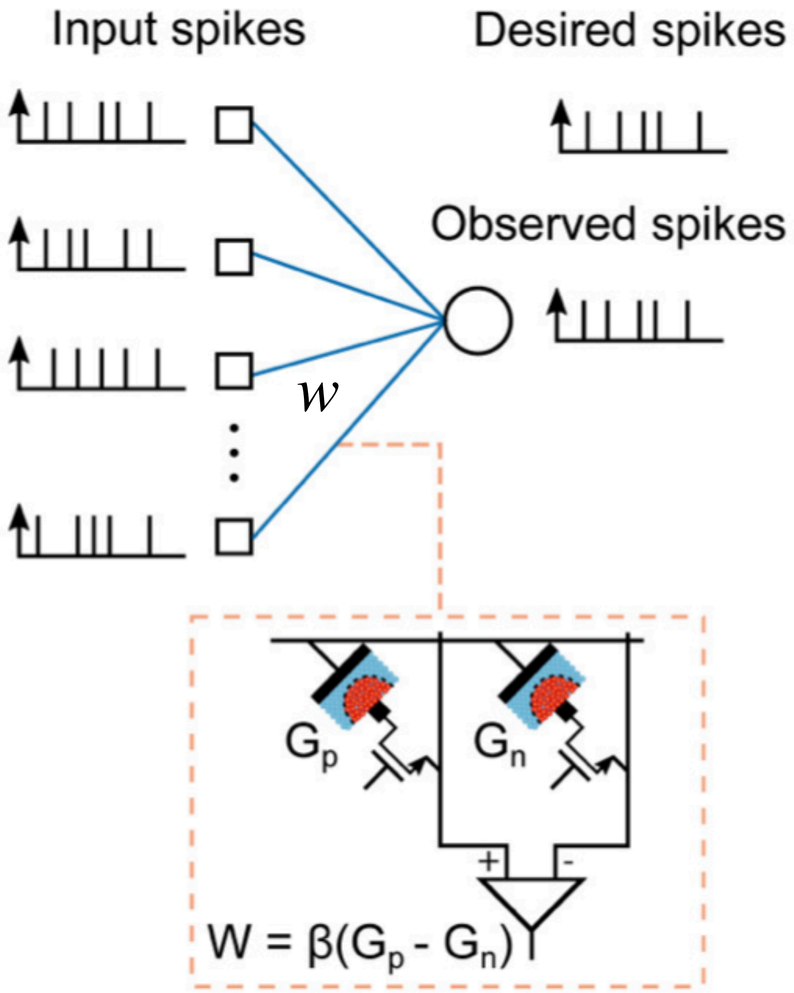

Image source:
Nandakumar, S. R., et al. "A phase-change memory model for neuromorphic computing." *Journal of Applied Physics* 124.15 (2018): 152135.

Future of energy-efficient hardware for artificial intelligence

- Overcoming the “von Neumann architecture bottleneck” (a)
  - Neuro-inspired computing paradigm (c)
  - Neural Networks learn directly in hardware (d)

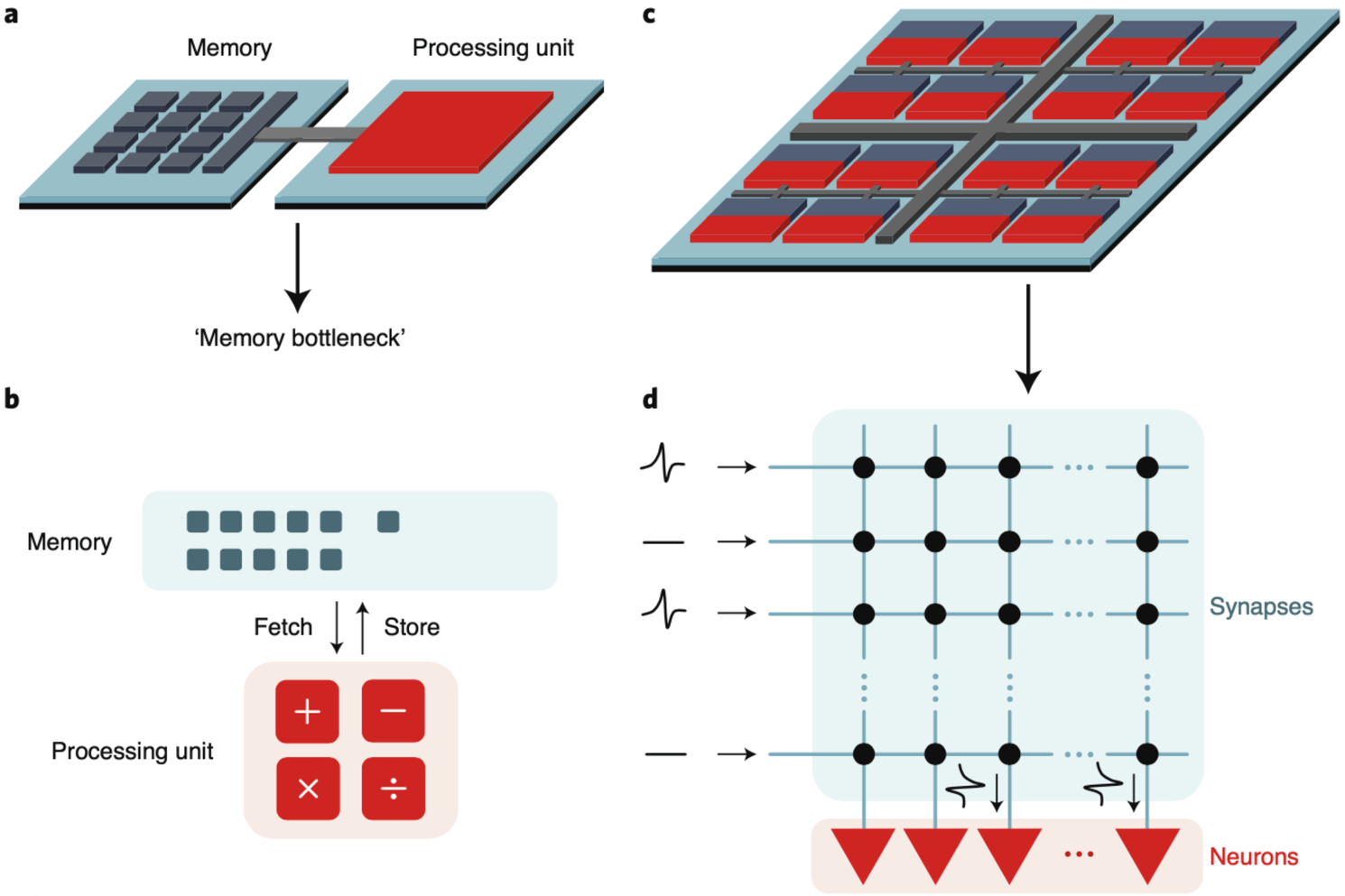

Image source:
Zhang, Wenqiang, et al. "Neuro-inspired computing chips." *Nature electronics* 3.7 (2020): 371-382.

Thanks for attention!

Questions?

About my publications

- “Fault pruning: Robust training of neural networks with memristive synapses”
  - **Contribution:** Method for detection of faulty memristive behavior during training.
- “Spike-based symbolic computations on bit strings and numbers”
  - **Contribution:** Novel examples of spiking neural networks performing cognitive tasks on sequences of symbols.
- “Spike frequency adaptation supports network computations on temporally dispersed information”
  - **Contribution:** Memory enhancement capabilities of spiking neural networks; Statistical analysis of spiking activity shows what neurons specialize for, i.e., their preferred stimulus.