Lecture 13:
New Computing Paradigms

Notes

- Lab 3 grades posted, will post the breakdown very soon
- Second project meeting on this Thursday and Friday
  - Please sign up if you have not.
- Final Presentation
  - 5/13/2025 (9am-4pm, 2MTC, Rm 907)
  - 5/14/2025 (9am-4pm, RH Rm 202)
  - Will send all the information and signup sheet tonight
- Please participate the final course evaluation:
  - https://coursefeedback.nyu.edu/nyu/

Recap

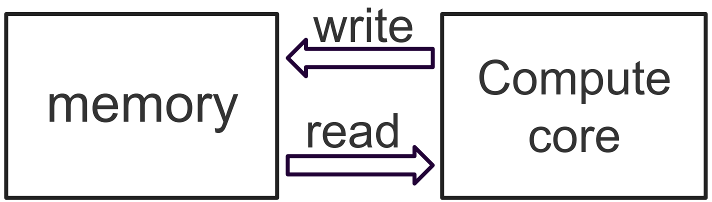
- FovealNet: Advancing AI-Driven Gaze Tracking Solutions for Efficient Foveated Rendering in Virtual Reality
- FovealSeg: Efficient Gaze-driven Instance Segmentation for Augmented Reality

Topics

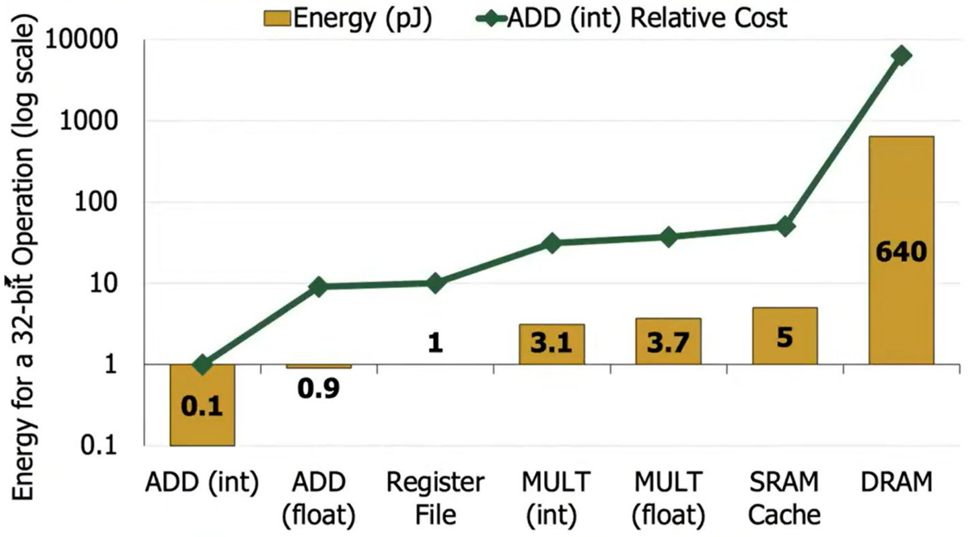
- In-memory computing
- Stochastic computing

NYU SAI LAB

Data Movement Cost vs. Computation Cost



- Retrieving a single element from memory is more costly than computing it.

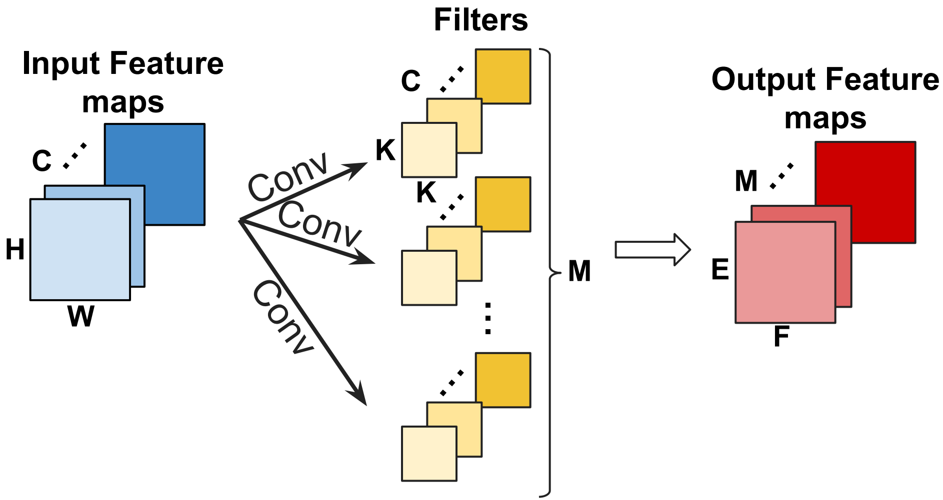


Onur Mutlu, "ISCA 2023 Tutorial: Real-world Processing-in-Memory Systems for Modern Workloads."

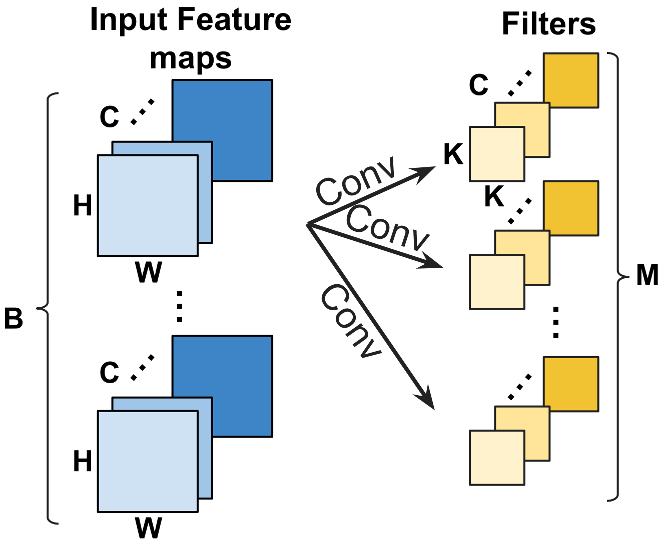
Data Movement Cost vs. Computation Cost

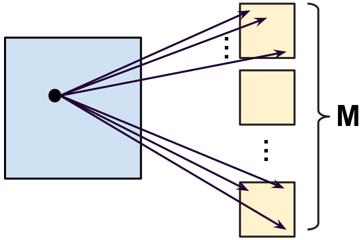
- **Arithmetic intensity**: the ratio of total floating-point operations to total data movement (bytes)

$$\frac{\text{Total FLOPs}}{\text{Total data movement}}$$



Data Movement Cost vs. Computation Cost

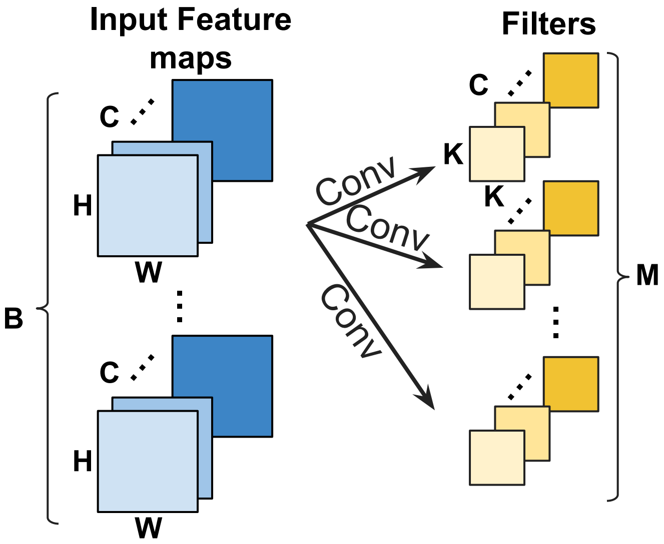


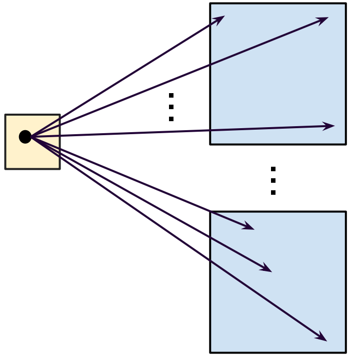


- For each single element within the input feature maps, the maximum amount of reuse = K^2M.

NYU SAI LAB

Data Movement Cost vs. Computation Cost

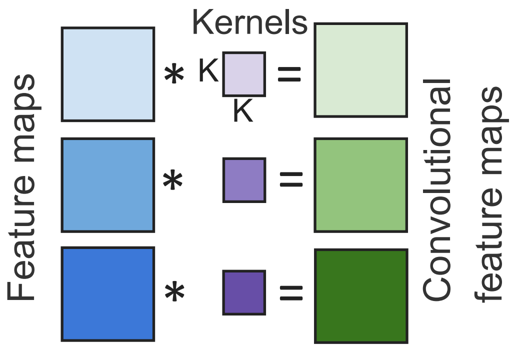




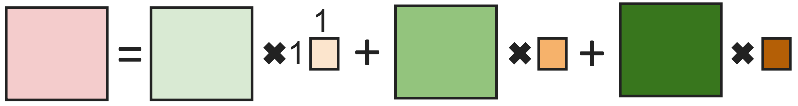
- For each single element within the weight kernel, the maximum amount of reuse = BHW.
- For standard convolution, the arithmetic intensity is high.

NYU SAI LAB

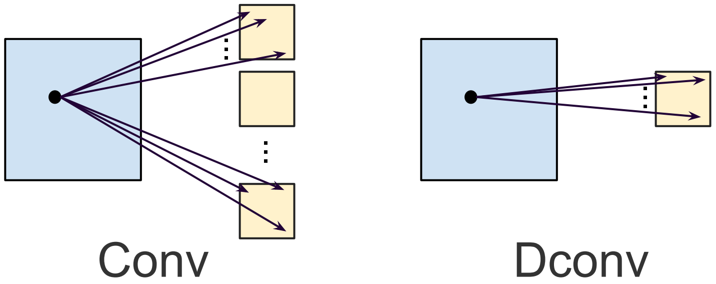
Data Movement Cost vs. Computation Cost



Step 1 Depthwise Convolution



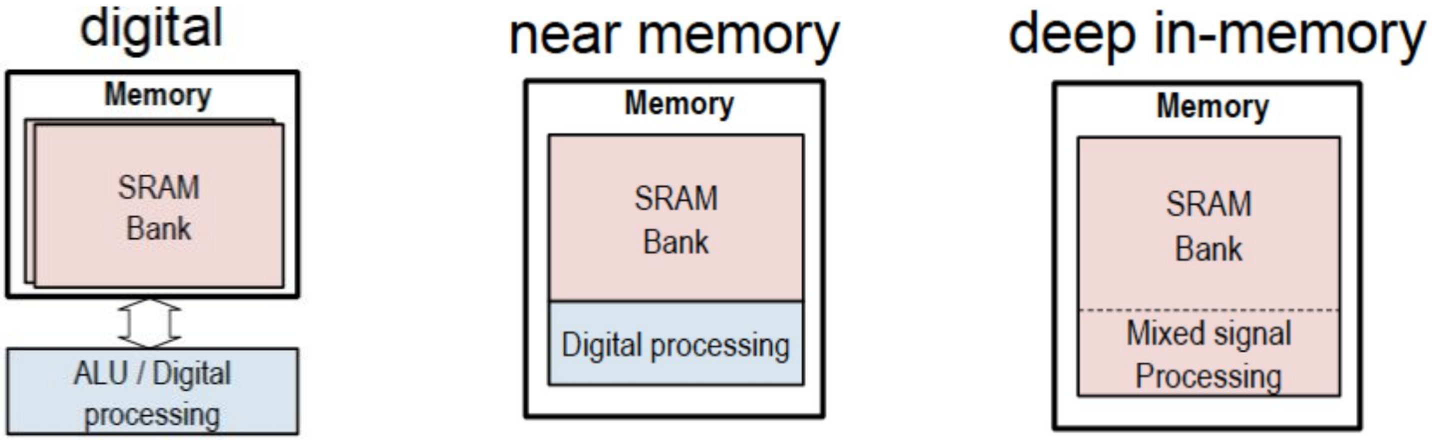
Step 2 Pointwise Convolution



- For each single element within the input activation, the maximum amount of reuse = K^2 for Dconv.

NYU SAI LAB

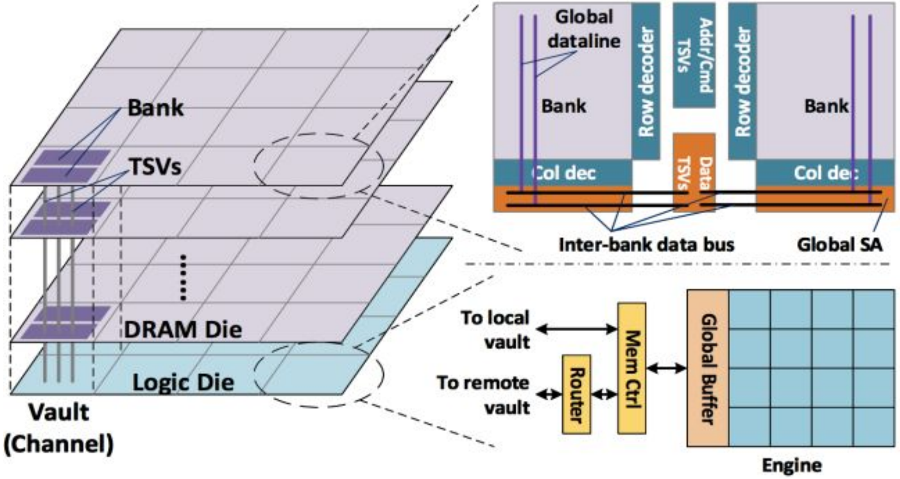
Near/In-Memory Processing



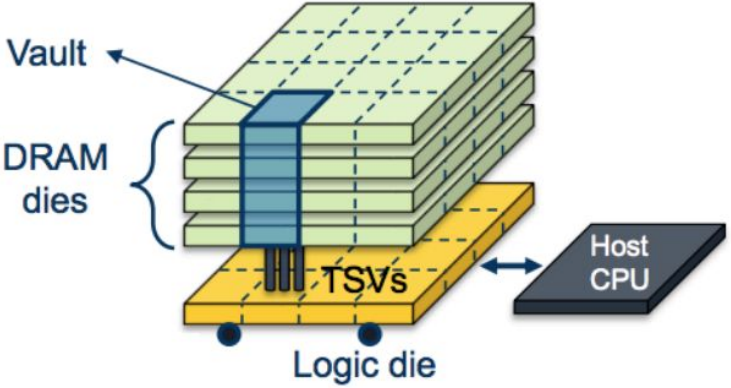
- Near memory computing has a higher BW, and analog in-memory computing integrate the computation with the memory access.
- Analog PIM brings compute closer to the memory.

NYU SAI LAB

Near Memory Processing



Eyeriss design

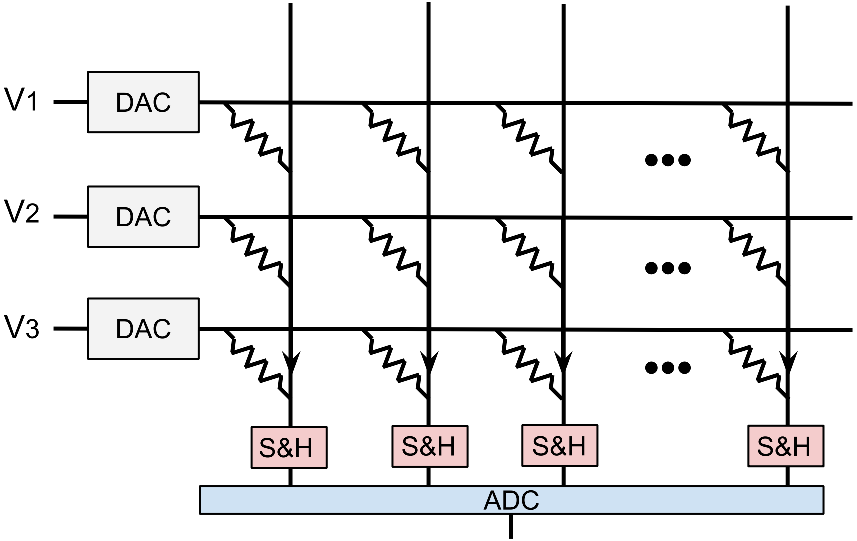


Tetris **NeuroCube**

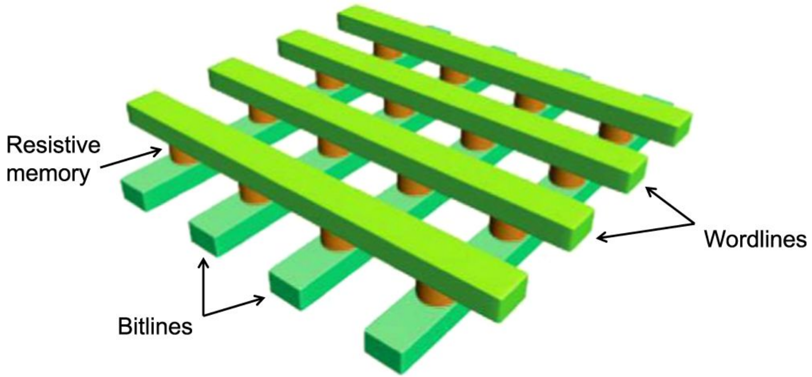
NYU SAI LAB

Gao, Mingyu, et al. "Tetris: Scalable and efficient neural network acceleration with 3d memory." *Proceedings of the Twenty-Second International Conference on Architectural Support for Programming Languages and Operating Systems*. 2017.

Resistive Memory



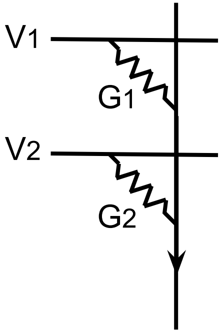
- Resistive RAM (ReRAM or RRAM) is a type of non-volatile RAM that works by changing the resistance across a dielectric solid-state material, often referred to as a memristor.

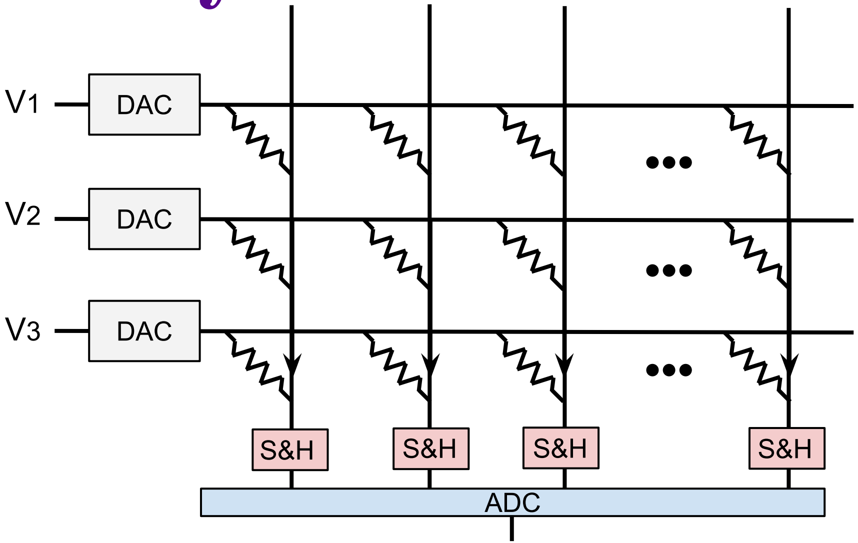


NYU SAI LAB

Processing In Memory

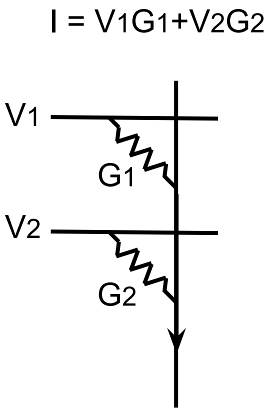
$I = V_1G_1+V_2G_2$

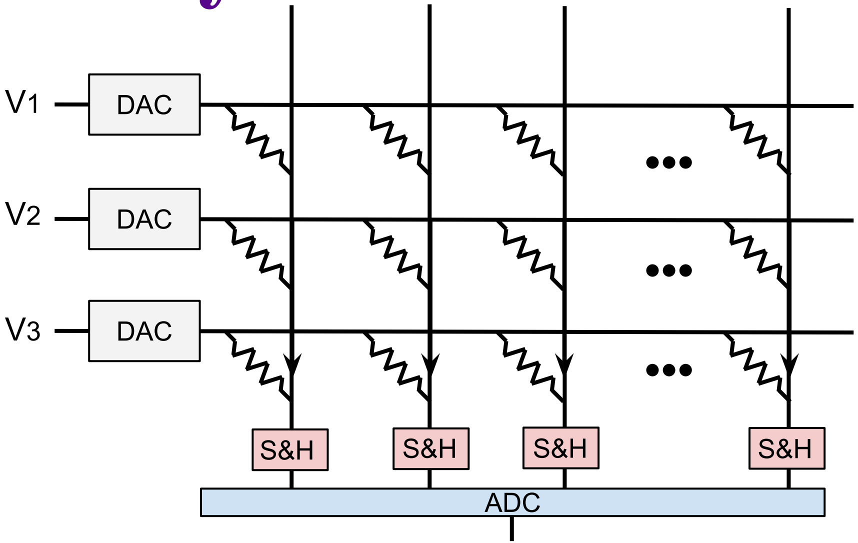




- The digital input are first passed to the DAC and converted to the analog input voltages.
- The voltages are applied to each of the rows in the crossbar array.

Processing In Memory

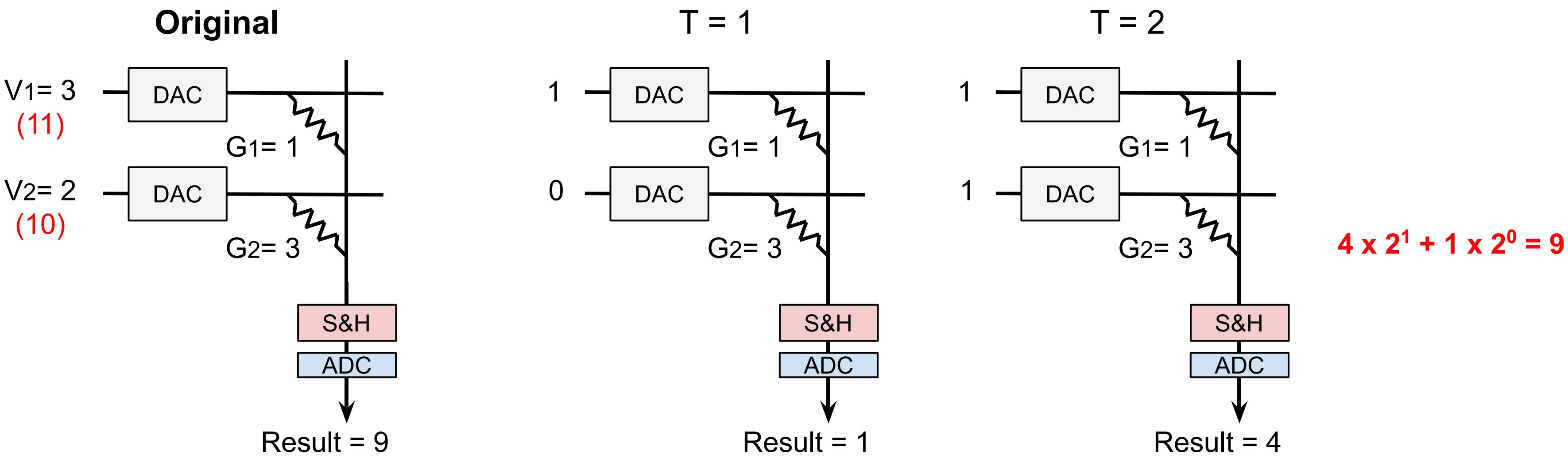




- The output current accumulated at the bottom of each column is the dot product between the voltages and the conductances across the rows.
- A sample-and-hold (S&H) circuit receives the bitline current and feeds it to a shared ADC unit

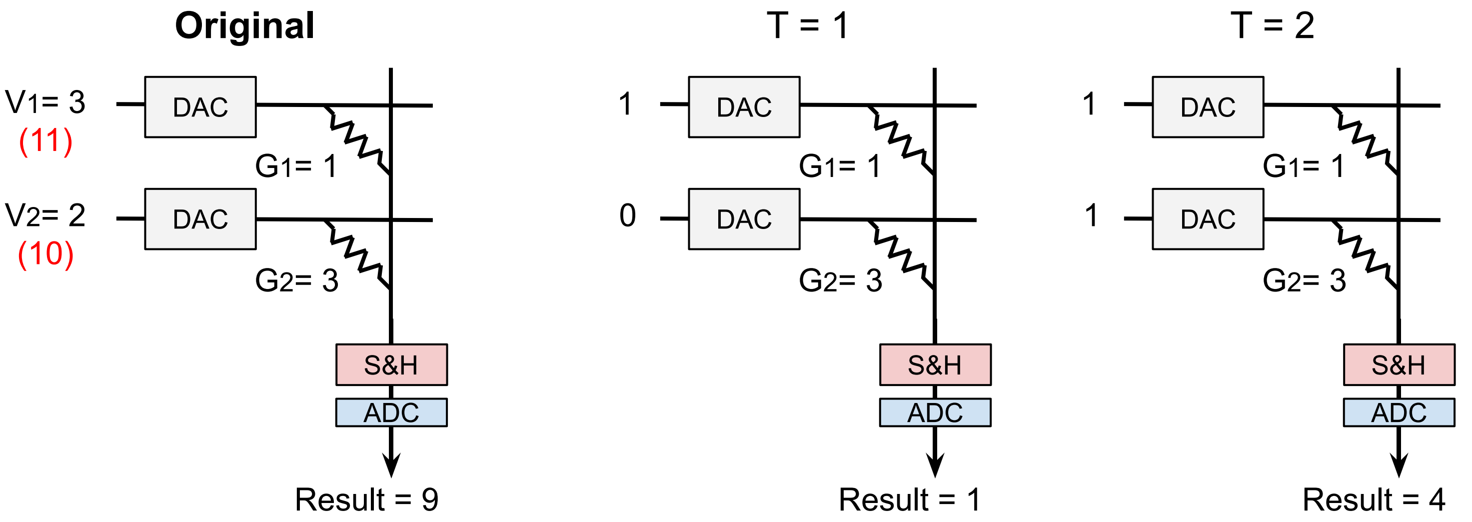
NYU SAI LAB

Processing In Memory



- Assume both inputs and weights are 16 bits, we need a 16-bit DAC to provide input voltage, 2^{16} resistance levels in each cell, and an ADC which can handle over 16 bits, which leads to a significant overhead.

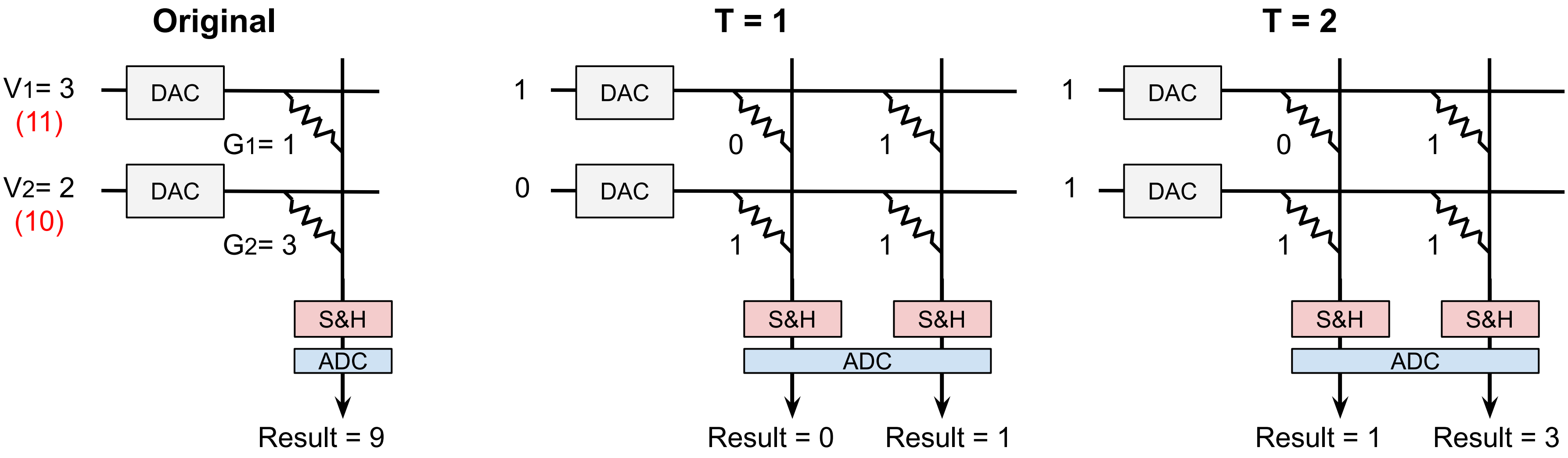
Processing In Memory



$4 \times 2^1 + 1 \times 2^0 = 9$

- Instead, the digital input enters the crossbar in a bit-serial manner, the intermediate results are buffered in the register. Shift-Add operation is them performed after all the input bits entering the crossbar.

Processing In Memory



$1 \times 2^0 + 0 \times 2^1 + 1 \times 2^1 + 3 \times 2^1 = 9$

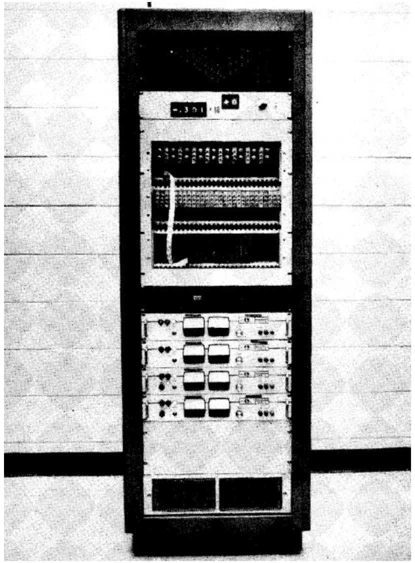
Topics

- Processing in memory
- Stochastic Computing

NYU SAI LAB

Stochastic Computing

- Stochastic computing is a computational approach that utilizes random bit streams to perform numerical calculations, offering benefits in power efficiency and hardware simplicity, particularly for error-tolerant applications.
- Introduced by John von Neumann in 1953.

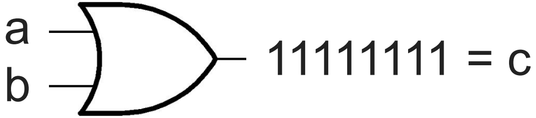


The RASCEL stochastic computer, circa 1969

NYU SAI LAB

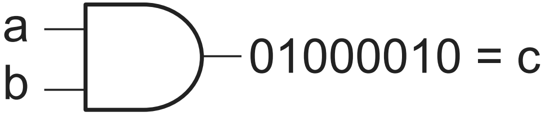
Stochastic Computing

- a = 0.5, b = 0.5
  - a = 00111100 $p_a(1) = 0.5$
  - b = 11000011 $p_b(1) = 0.5$



$p_c(1) = 1$

- a = 0.5, b = 0.5
  - a = 11001010 $p_a(1) = 0.5$
  - b = 01010011 $p_b(1) = 0.5$

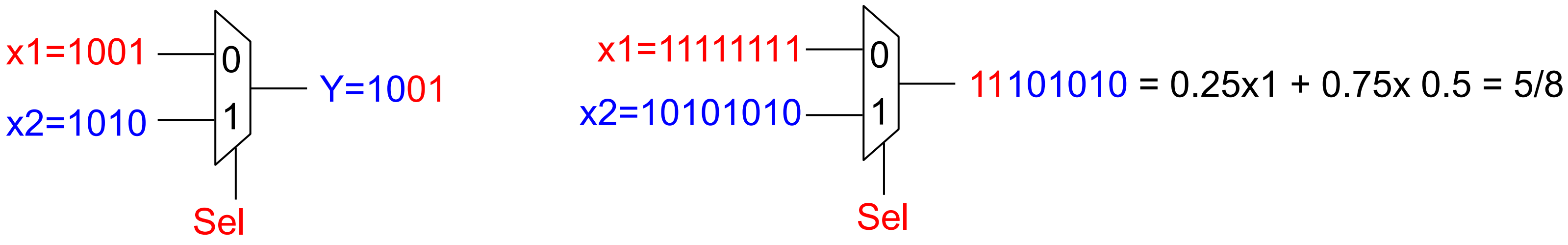


$p_c(1) = 0.25$

- As the input stream lengthens, the multiplication process will become more accurate.

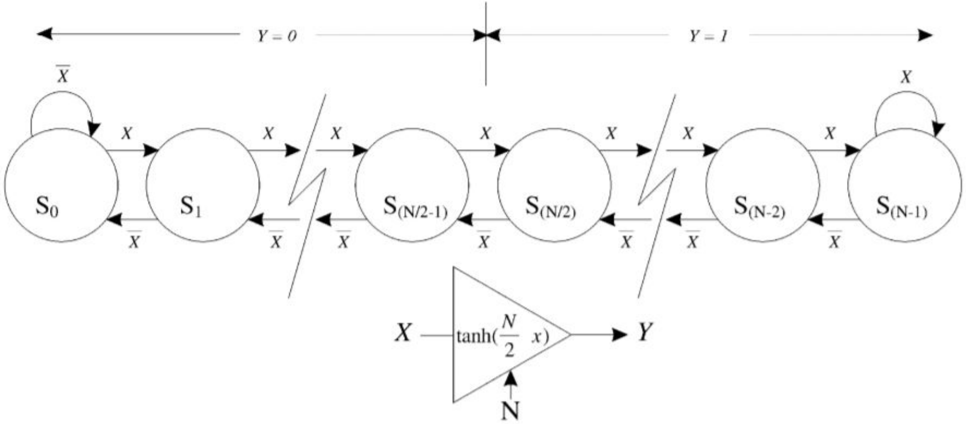
Addition with Stochastic Computing

- MUX implementation
  - By adjusting Sel over time, the output of the multiplexer will equal to the weighted sum of the input bit streams.
  - The accuracy gets worse when the number of inputs to the MUX is large.



Nonlinear Operation with Stochastic Computing

- The tanh function is highly suitable for SC-based implementations because i) it can be easily implemented with a K-state finite state machine (FSM) in the SC domain.



- The major advantage of stochastic computing is the significantly lower hardware cost for a large category of arithmetic calculations.

Presentations

- ISAAC: CNN Accelerator with In-Situ Analog Arithmetic in Crossbars (Dhairya, Rohan)

- Sc-dcnn: Highly-scalable deep convolutional neural network using stochastic computing (Yinqi, Jeet)