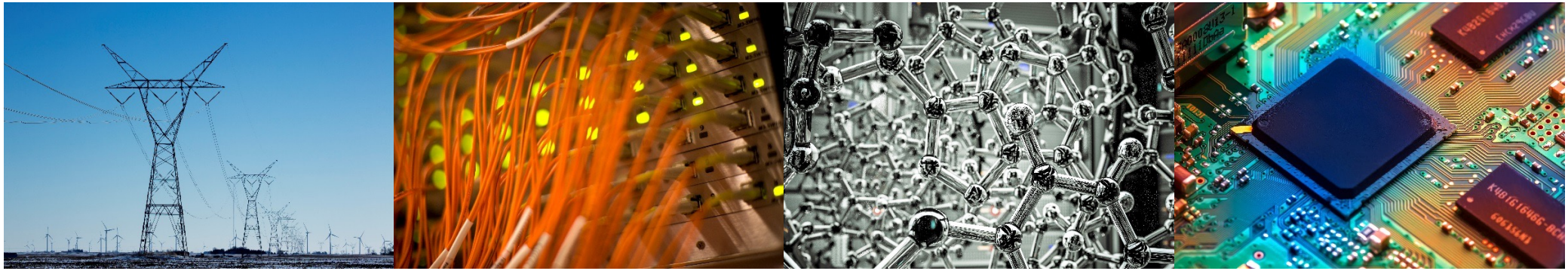
Energy-Accuracy-Security Trade-offs in Resistive In-memory Computing Architectures



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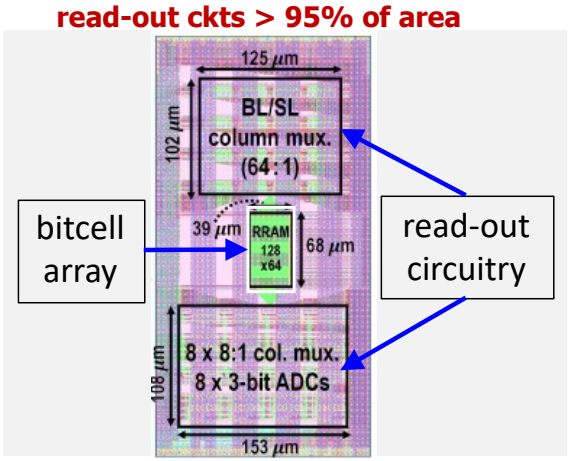
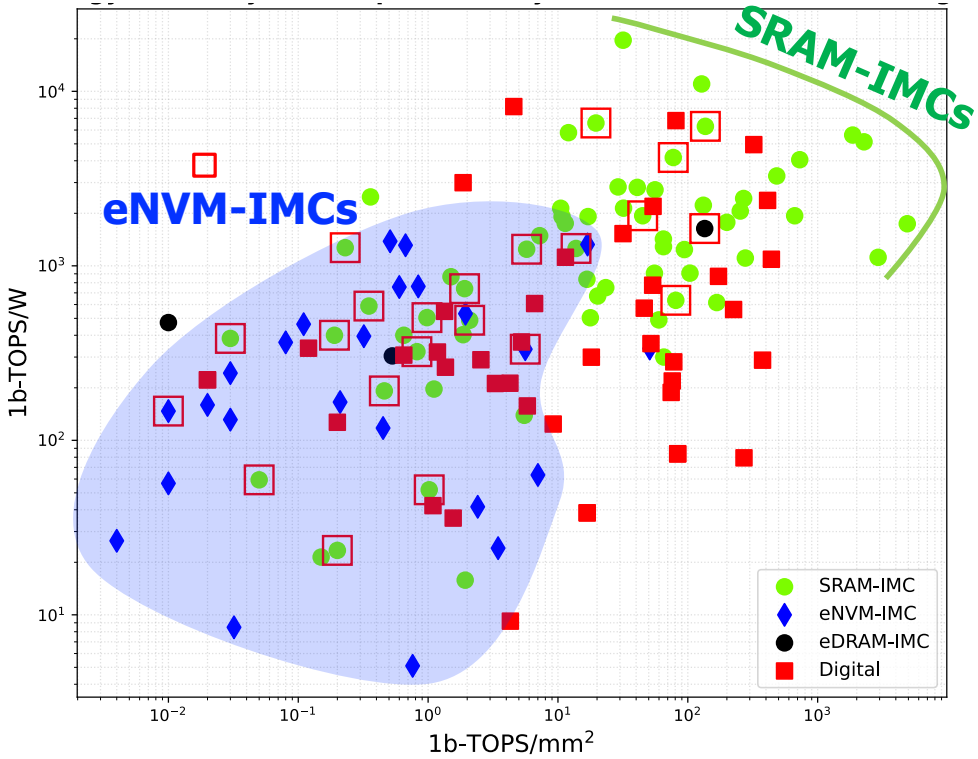
Resistive IMCs in the Landscape of AI Accelerators

- eNVM-based IMCs lagging in energy efficiency & compute density (why?)
- Reason - low array-level compute accuracy



[Yin et al., TED'20]

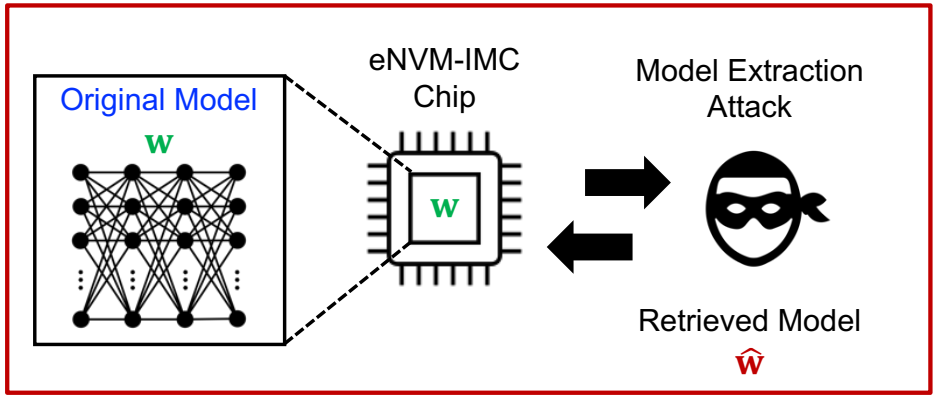


https://github.com/UIUC-IMC/UIUC-IMC-benchmarking

Are eNVM-based IMCs Secure?

Low compute SNDR (Bug) → potential resilience to security attacks (Feature)?

Model Extraction Attacks (MEAs)



leakage of private training data
&
adversarial attacks

Security vulnerability of eNVM IMCs unknown?

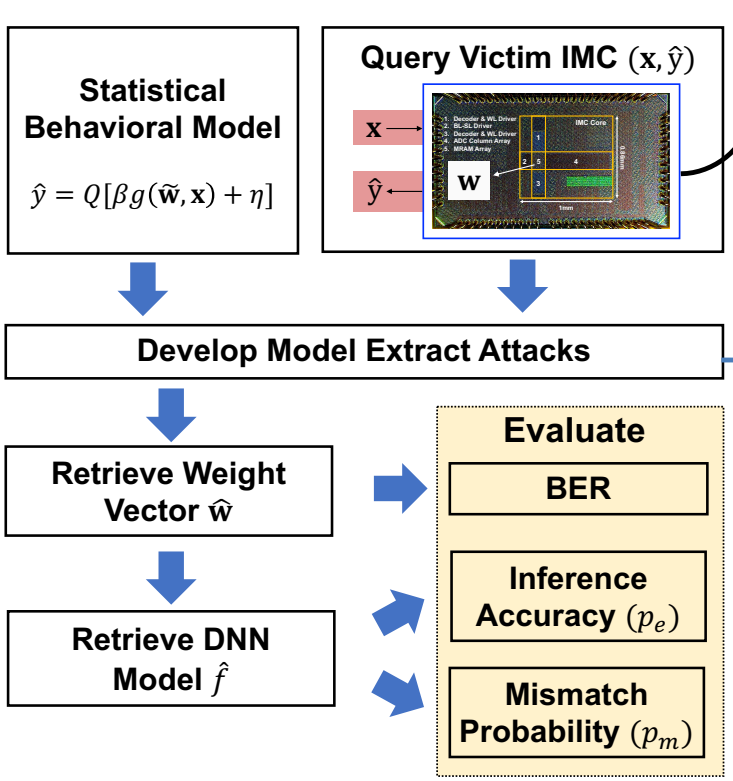
[Roy & Shanbhag, "On the Security Vulnerabilities of MRAM-based In-Memory Computing Architectures against Model Extraction Attacks," *ICCAD,* 2024]
[Roy & Shanbhag, "Energy-Accuracy-Security Trade-off in Resistive In-memory Architectures," *IEEE IEDM,* 2024]

Proposed MEA Construction Framework

statistical model

$$\hat{y} = Q[\beta g(\tilde{\mathbf{w}}, \mathbf{x}) + \eta]$$

- Conductance Variations
- Parasitics Conductance
- Mirroring Mismatch
- ADC Thermal Noise
- ADC Quantization

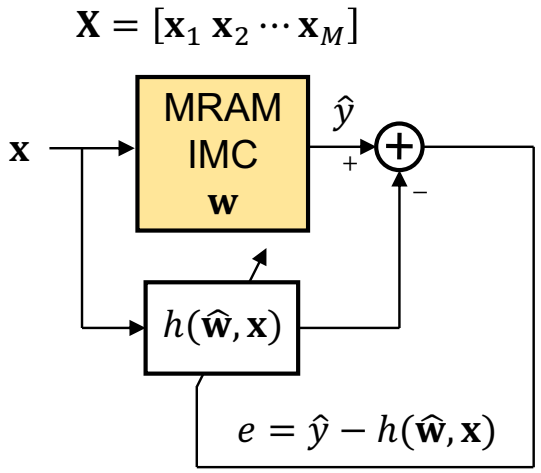


MRAM IMC Prototype
(22nm FD-SOI)
[Roy et al., JSSC'24] with UIUC, Princeton, GF and Raytheon

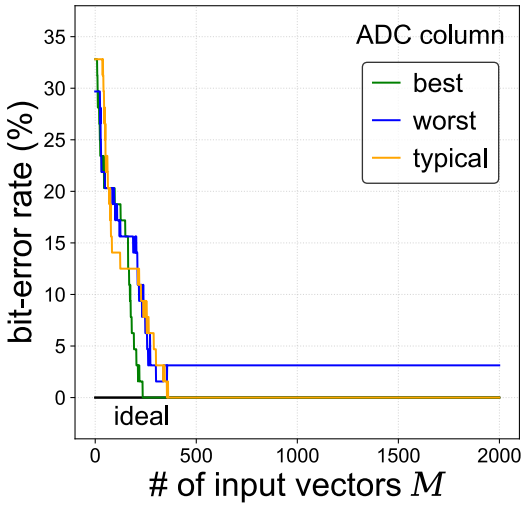
- Linear attacks:
  - basis vectors
  - least squares
- Non-linear SGD attack

Proposed SGD Attack for MEA

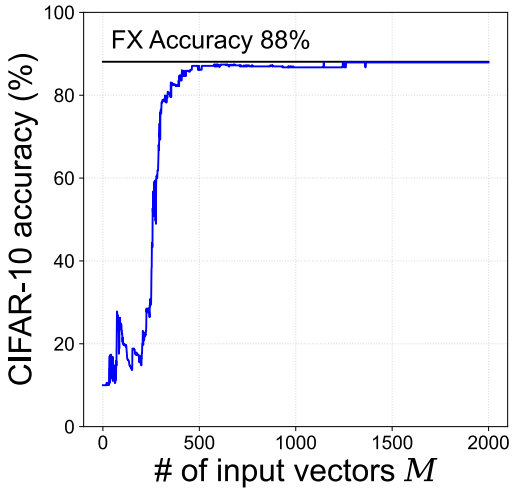
SGD Attack



Bit-error rate (BER)



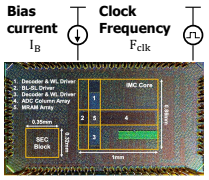
Inference accuracy



Apply MEAs to retrieve weights of ResNet-20 last layer from MRAM-IMC chip

SGD attack requires least number of queries at **high SNDR** to achieve **lowest BER for all ADC columns → inference accuracy within < 0.1% of FX**

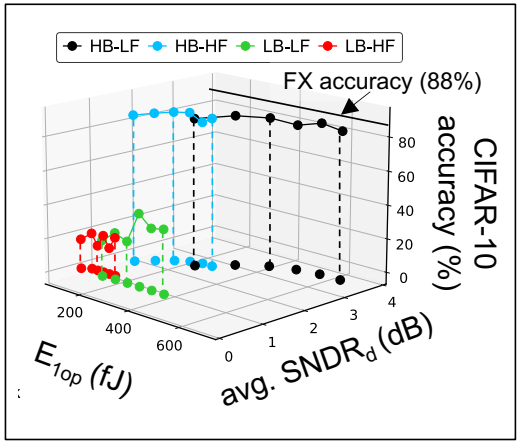
Measured Energy-Accuracy-Security Trade-offs



Previous attacks were performed at high SNDR

What happens at low SNDR?

	High bias (HB) ($I_B = 92\ \mu A$)	Low bias (LB) ($I_B = 67\ \mu A$)
Low frequency (LF) ($F_{clk} = 8.3$ MHz)	**HB-LF (highest SNDR)**	**LB-LF**
High frequency (HF) ($F_{clk} = 16.6$ MHz)	**HB-HF**	**LB-HF (lowest SNDR)**



Strongest attack fails at low-SNDR

Resistive IMCs are vulnerable to model extraction attacks

Low-SNDR settings resilient to MEAs, with need for algorithmic methods to boost inference accuracy under benign scenarios

Thank You!

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