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Compact Model of Resistive Memory Devices for Pulsed Analog and Neuromorphic Applications

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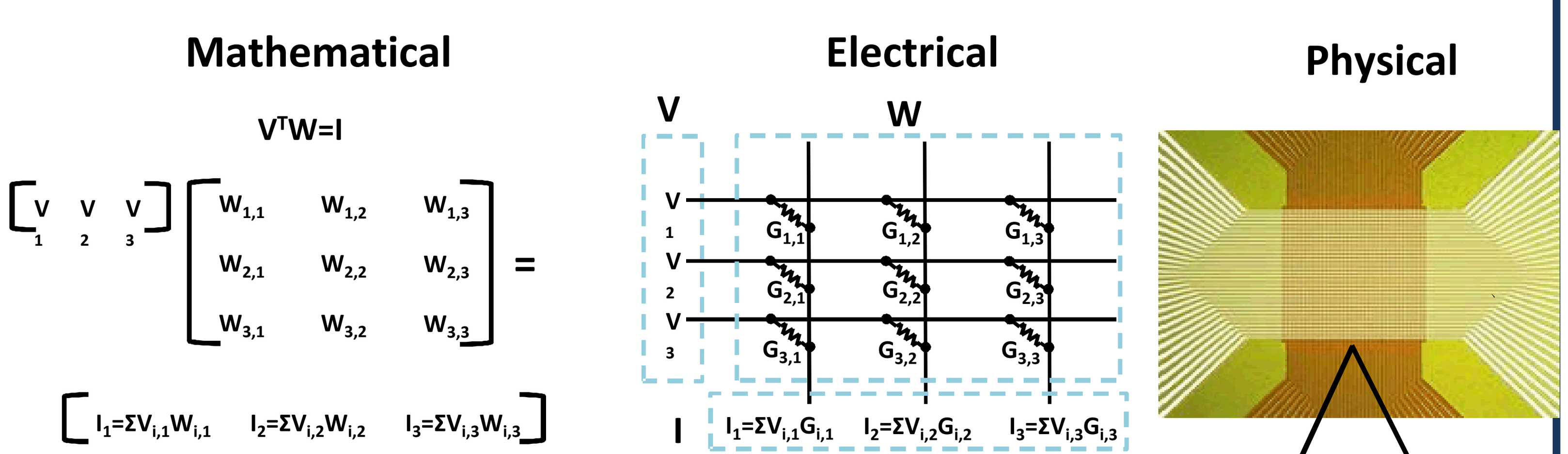
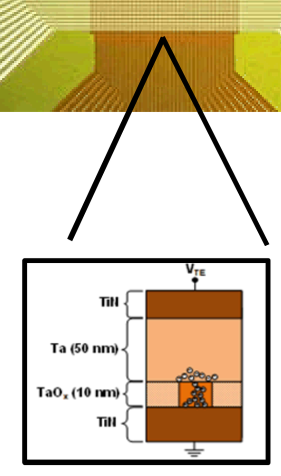
Abstract

Resistive switching devices are promising candidates for next generation computer hardware, with the ever increasing need for more efficient, faster computation. These devices show particular promise for use in a neuromorphic accelerator as they can be tuned to multiple resistance states which can be a hardware equivalent to the weights in neuromorphic algorithms. Modeling a ReRAM-based neuromorphic accelerator requires a compact model capable of correctly simulating the small weight update behavior associated with neuromorphic training. Here, we propose an empirically derived general purpose state-conductance model that can accurately capture the nonlinearity of an arbitrary two terminal device to match pulse measurements important for neuromorphic applications.

Hardware Based Deep Learning Overview





- Deep Learning provides solutions but currently requires MWs of power.
- Analog accelerators may offer ~10^5 times less power
- Matrix vector multiplication is most computationally expensive process

"Let physics do the computation"

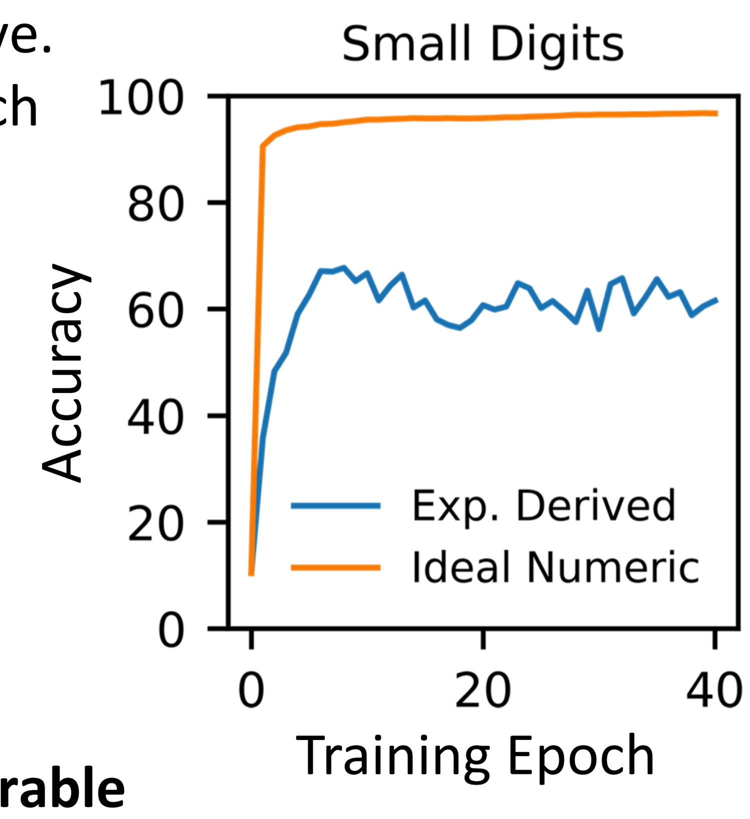
Compact Model Basics

- **However we need to be able to model devices for circuit design and simulation**
- Model must be accurate, fast, and intuitive.
- Standard state variable modeling approach

$$I = G(x) \times h(V)$$

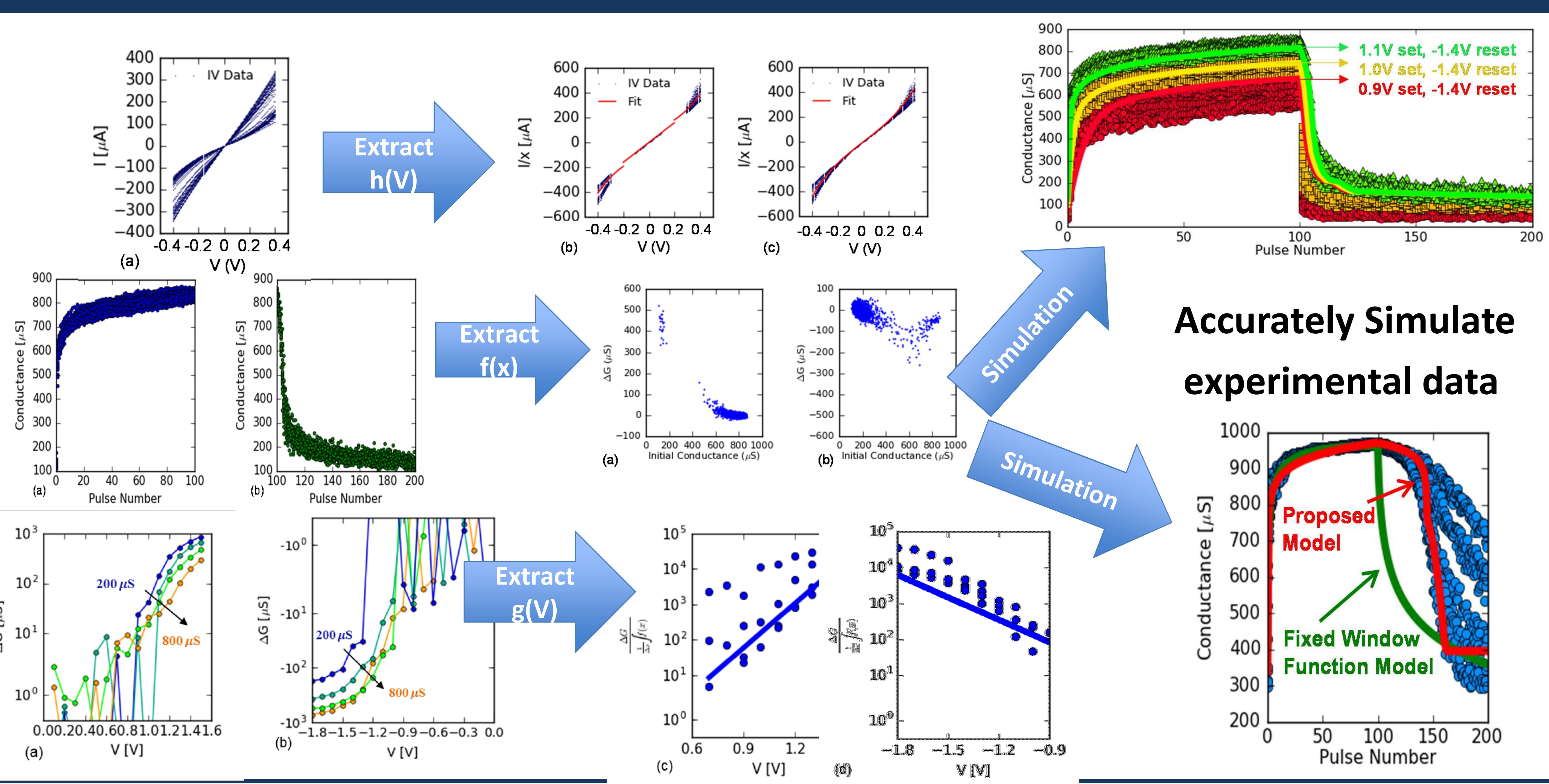
$$\frac{dx}{dt} = C \times f(x) \times g(V)$$

- Where **G(x) =** $x = \frac{G}{G_{max}}$ **is normalized conductance**
- This allows us to experimentally obtain $f(x)$ and $g(V)$
- $f(x) \times g(V) = \frac{dx}{dt} \approx \frac{\Delta x}{\Delta t} = \frac{\frac{\Delta G}{G_{max}}}{\Delta t}$ ← **measurable**



Parameter Extraction and Model Validation

- Measure static I-V at multiple states, achieved through pulses
- Measure conductance changes through pulse train sequence with fixed voltage pulse height
- Measure conductance change at fixed conductance by varying voltage pulse heights



Conclusion

A compact model that accurately simulates the pulsed conductance changes in a two terminal resistive switching device has been presented. The key improvement of this compared to prior models is the capability to model arbitrary ΔG-G behavior, which is a requirement for correctly modelling training in a neuromorphic accelerator. This model is compatible with any two terminal resistance switching device that has separable static and dynamic equations and is operated in the regime controlled by a single state variable. Parameter extraction on a Sandia Ta/TaO_x ReRAM demonstrates the capability of this model to correctly predict conductance-pulse behavior.

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