CMOS-Free Magnetic Domain Wall Leaky Integrate-and-Fire Neurons with Intrinsic Lateral Inhibition

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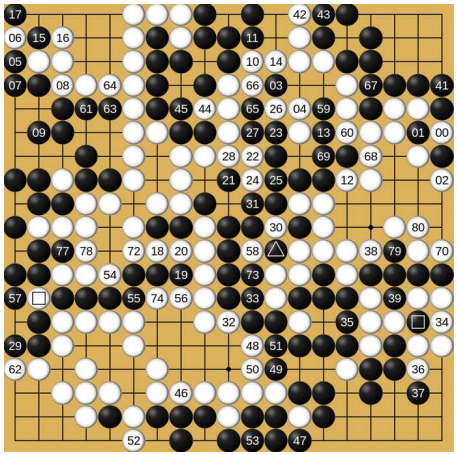
Automated Cognitive Reasoning

1 - 4



AlphaGo

Brain

~ 20 W

~ 10^{-3} m^3

Cluster

> 10^5 W

> 1 m^3

Credit: A. F. Vincent, IMS Bordeaux

Presentation Overview

I. Background

II. LIF Neurons

III. Lateral Inhibition

IV. Fabrication Analysis

V. Conclusions

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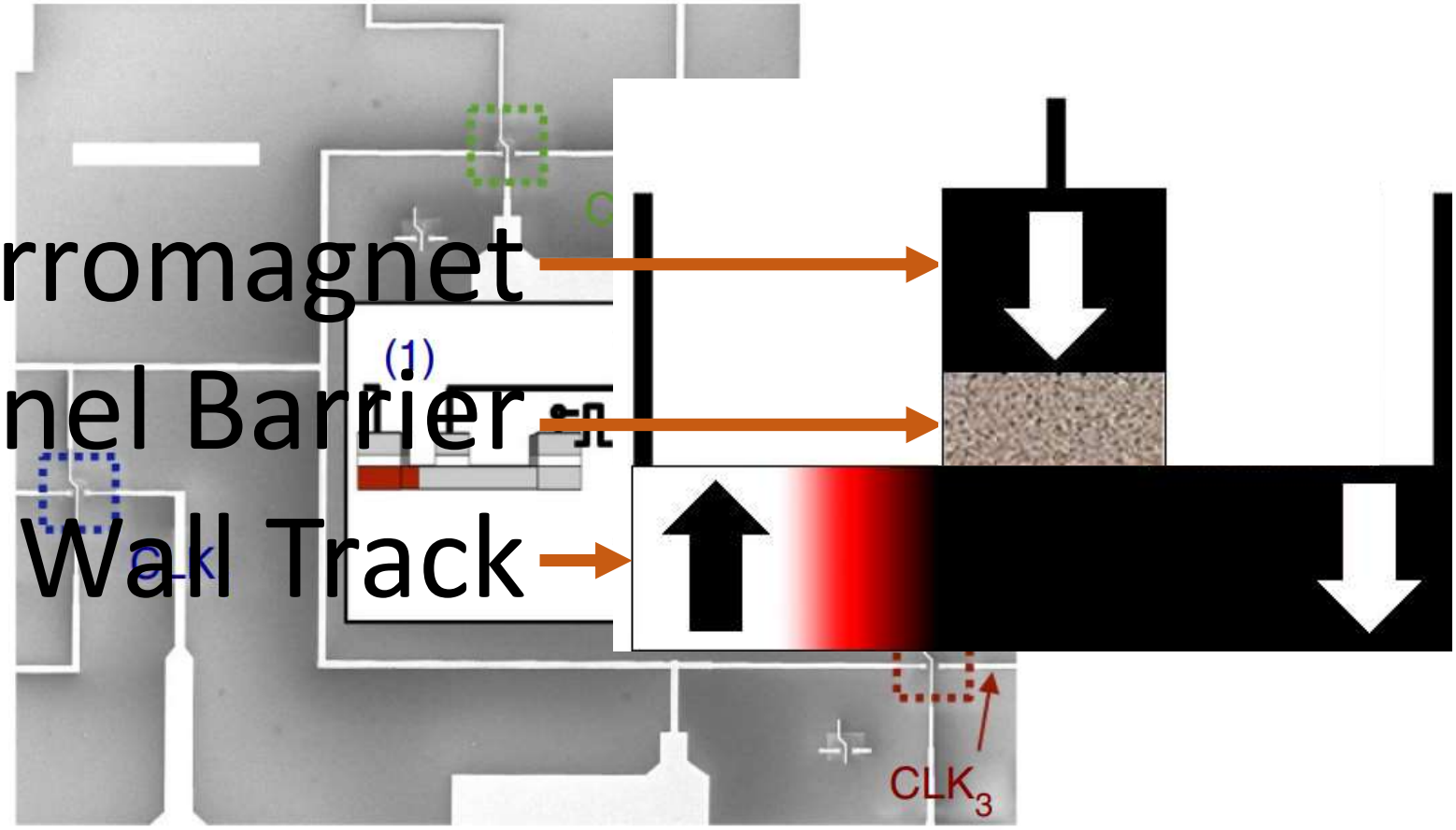
Background: DW-MTJ Logic

Fixed Ferromagnet

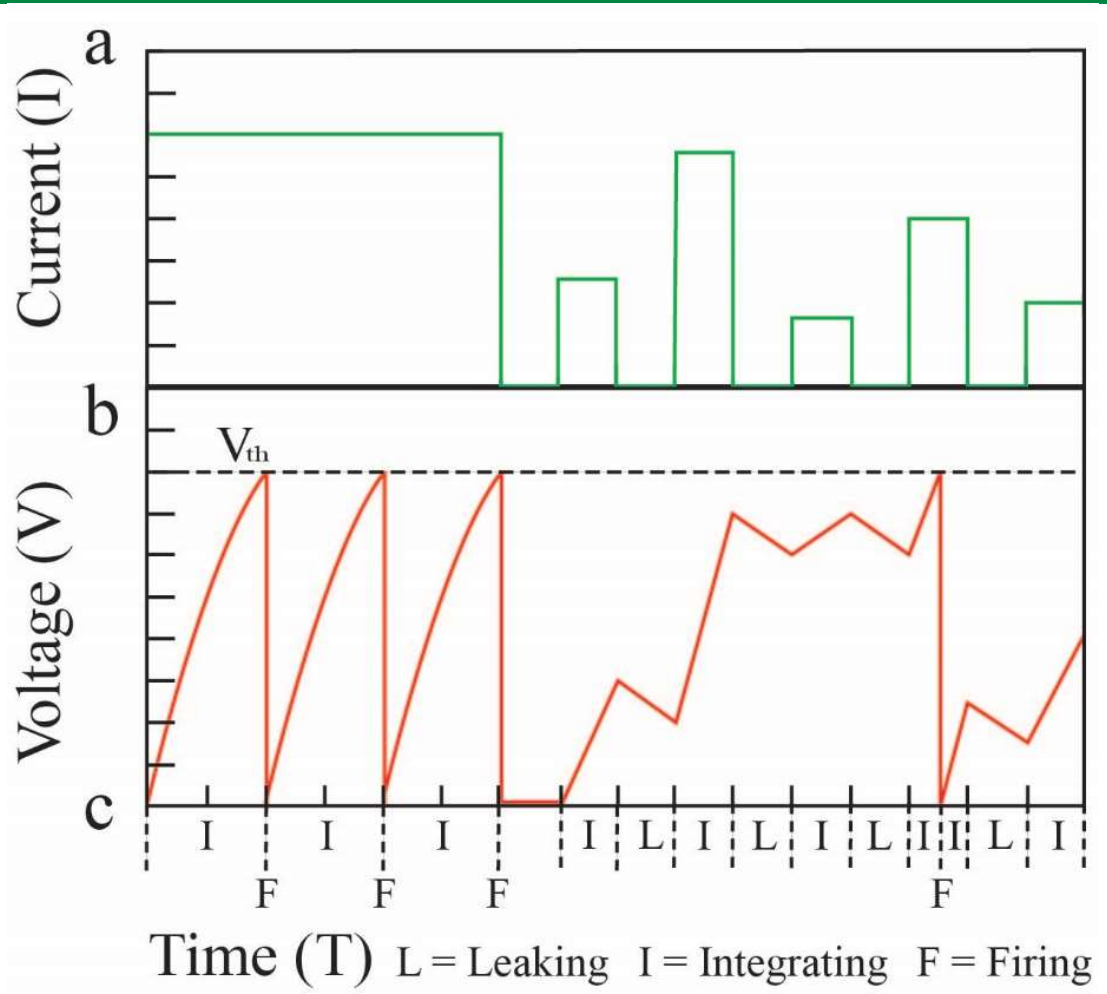
Tunnel Barrier

Domain Wall Track

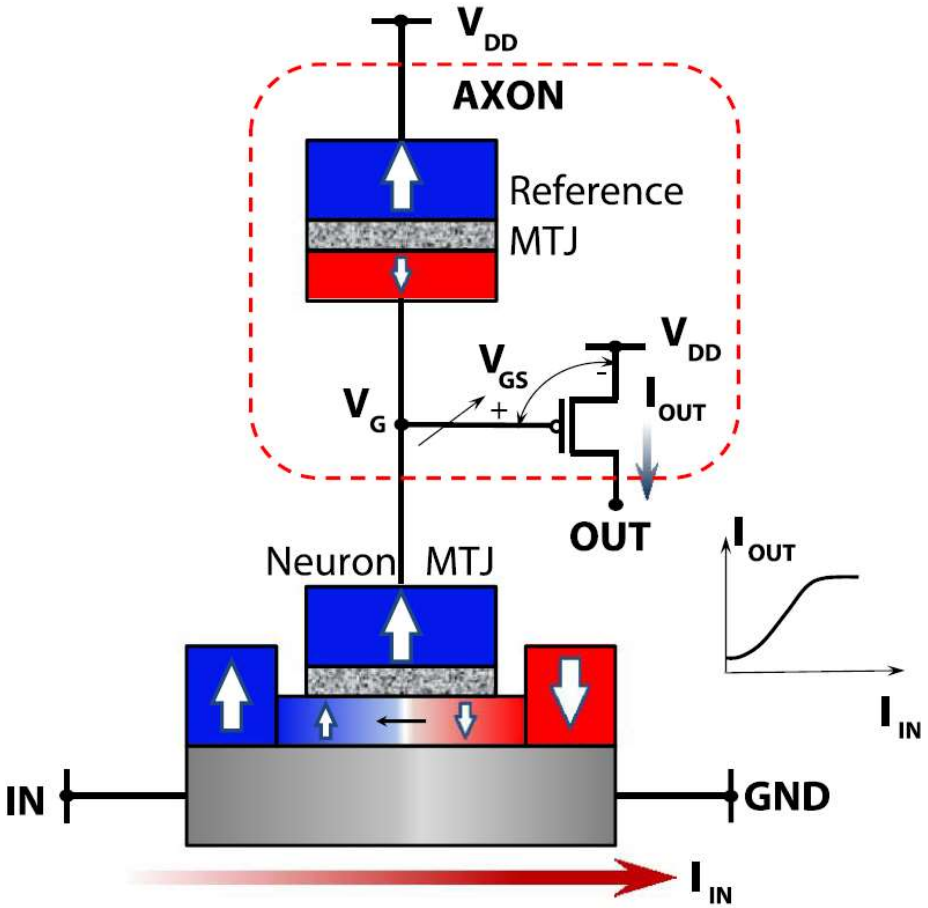


J. A. C. Incorvia, S. Siddiqui, S. Dutta, E. R. Evarts, J. Zhang, D. Bono, C. A. Ross, M. A. Baldo, *Nature Communications*, 2016

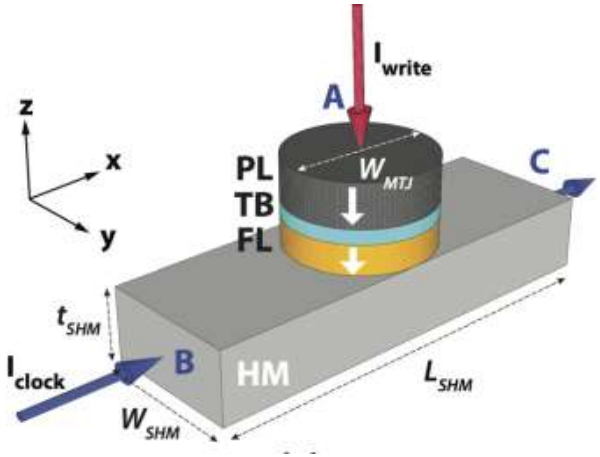
Background: Leaky-Integrate & Fire Neuron



Background: Previous Neuron Proposals



A. Sengupta, Y. Shim, K. Roy, *IEEE TBioCAS*, 2016



A. Sengupta, S. H. Choday, Y. Kim, and K. Roy, *Applied physics letters*, 2015

- Requires external circuitry for leaking and firing
- Extra layer for inhibition

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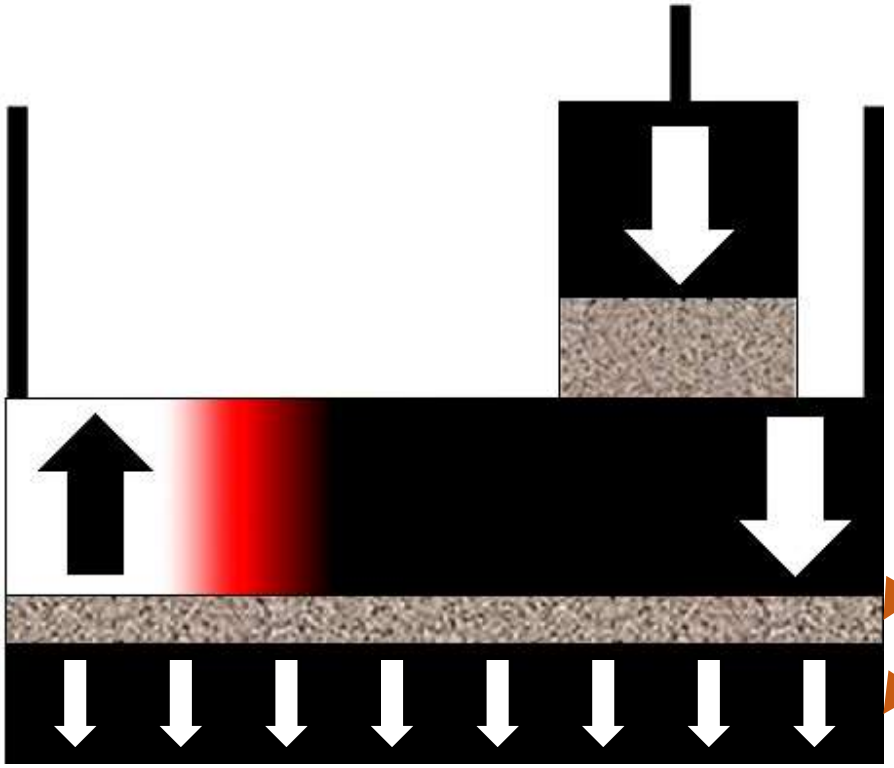
Dipolar Coupling Field Neuron: Structure

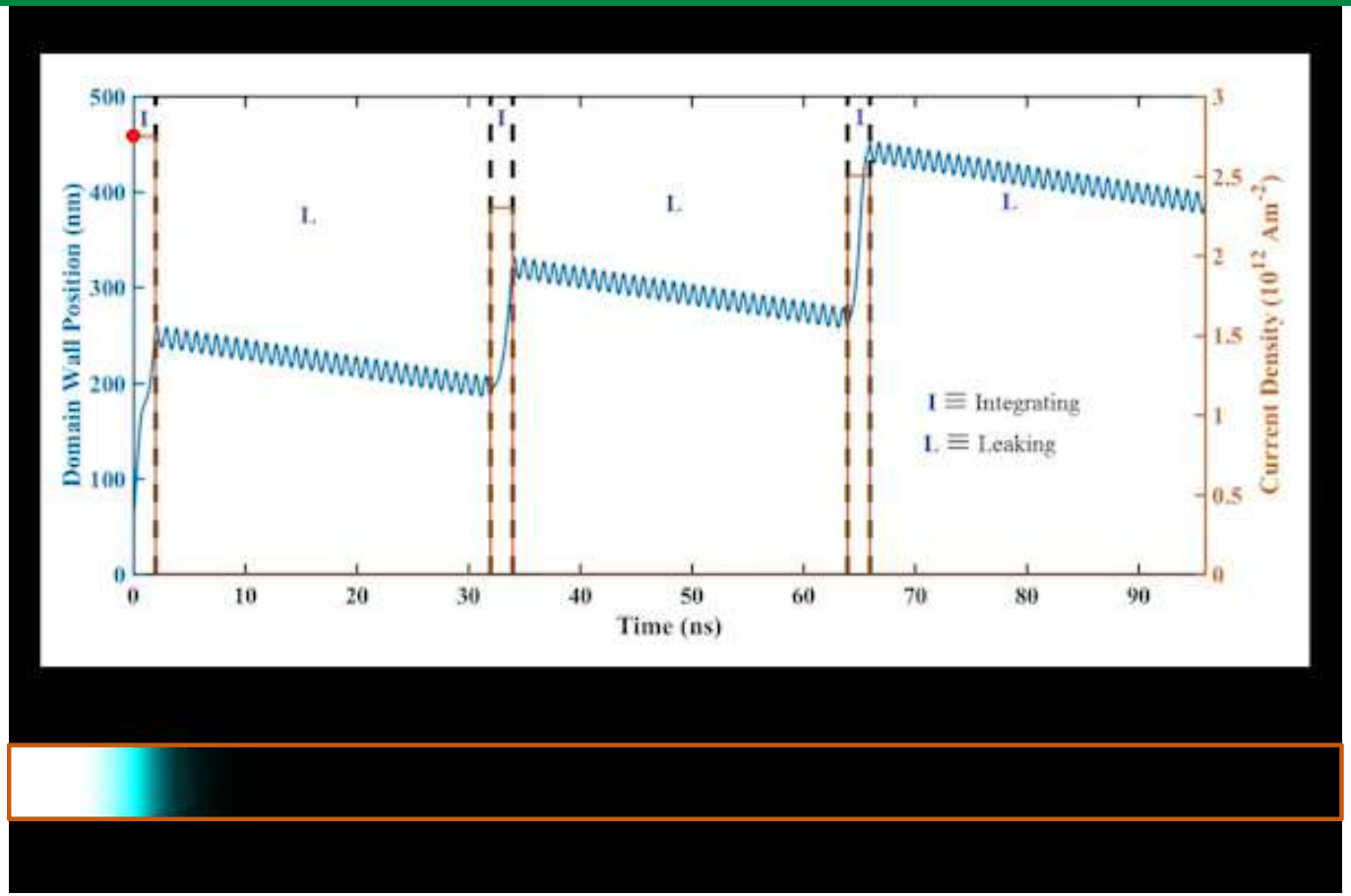


Insulator

Coupled Ferromagnet

N. Hassan*, X. Hu*, L. Jiang-Wei, W. H. Brigner, O. G. Akinola, F. Garcia-Sanchez, M. Pasquale, C. H. Bennett, J. A. C. Incorvia, J. S. Friedman, *Journal of Applied Physics*, 2018

Dipolar Coupling Field: Leaking & Integrating



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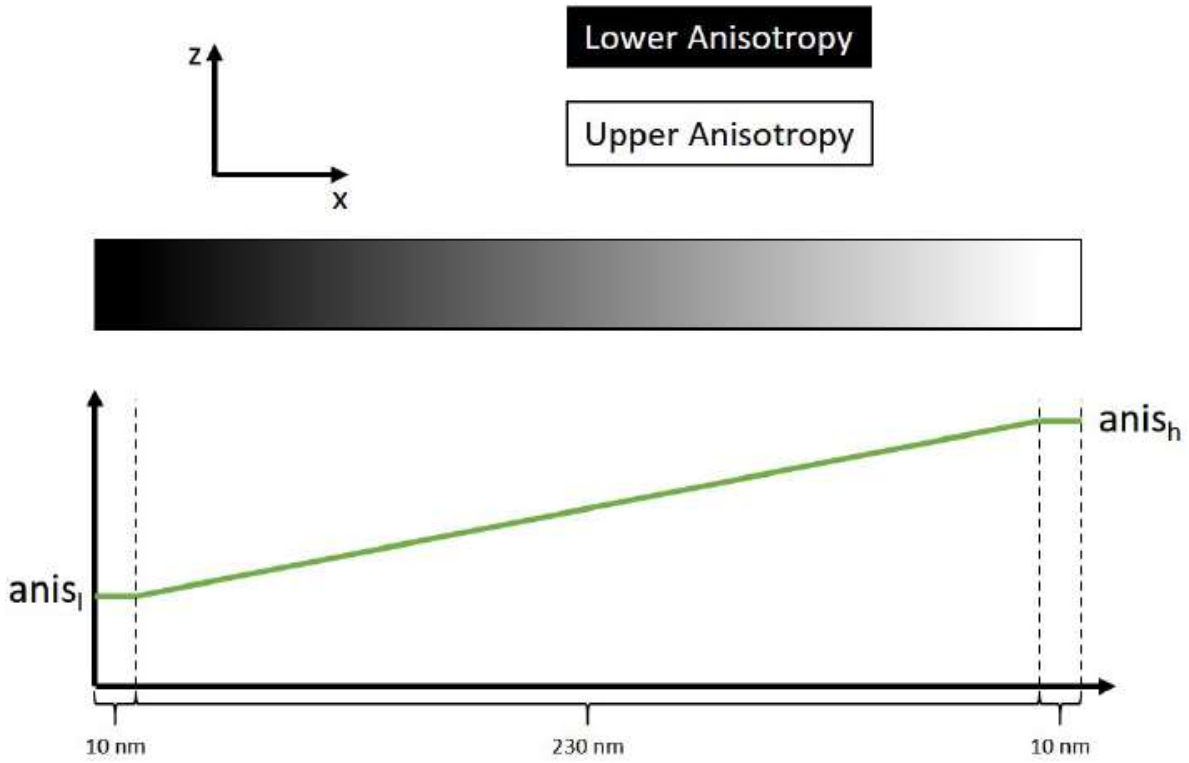
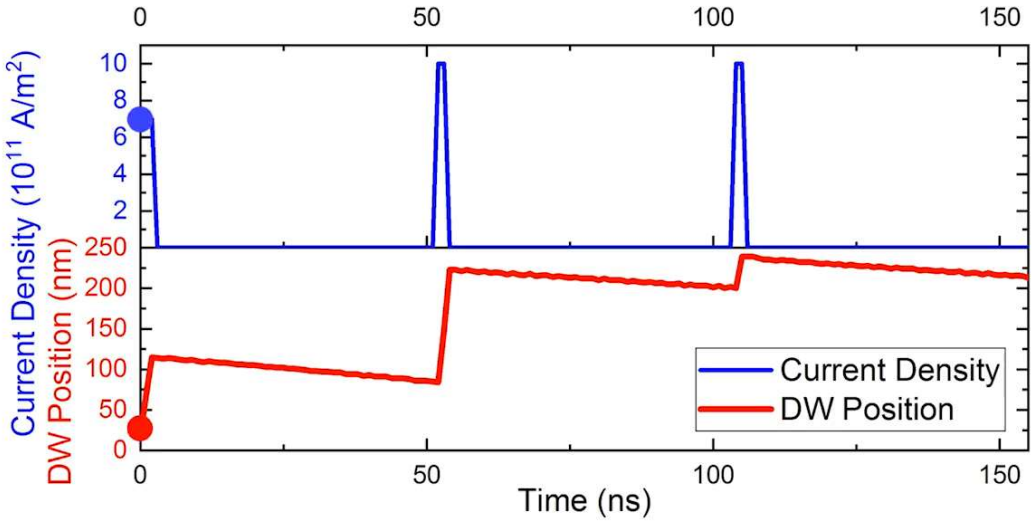
Anisotropy Gradient Neuron: Structure



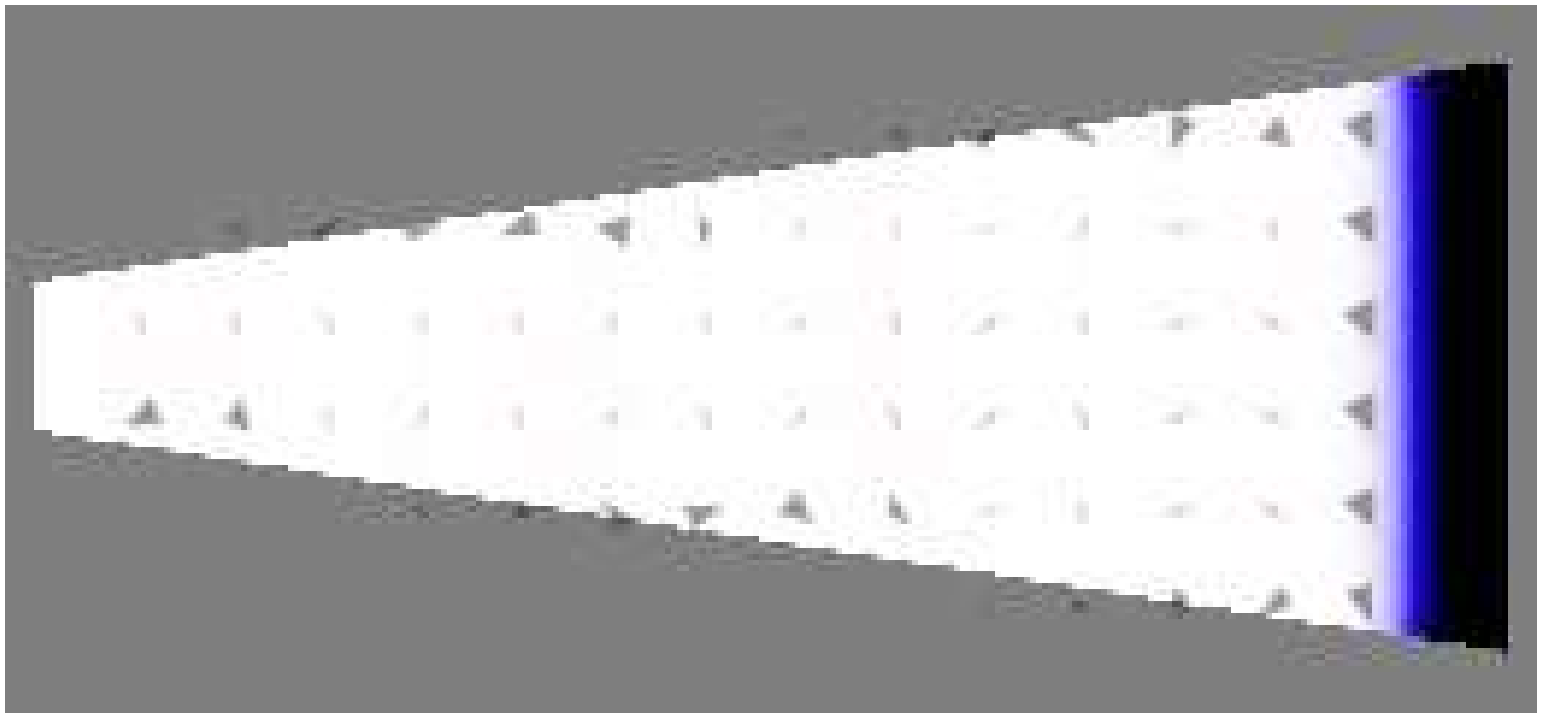
W. H. Brigner, X. Hu, N. Hassan, C. H. Bennett, J. A. C. Incorvia, F. Garcia-Sanchez, J. S. Friedman, *IEEE JxCDC*, 2019

Anisotropy Gradient: Leaking & Integrating



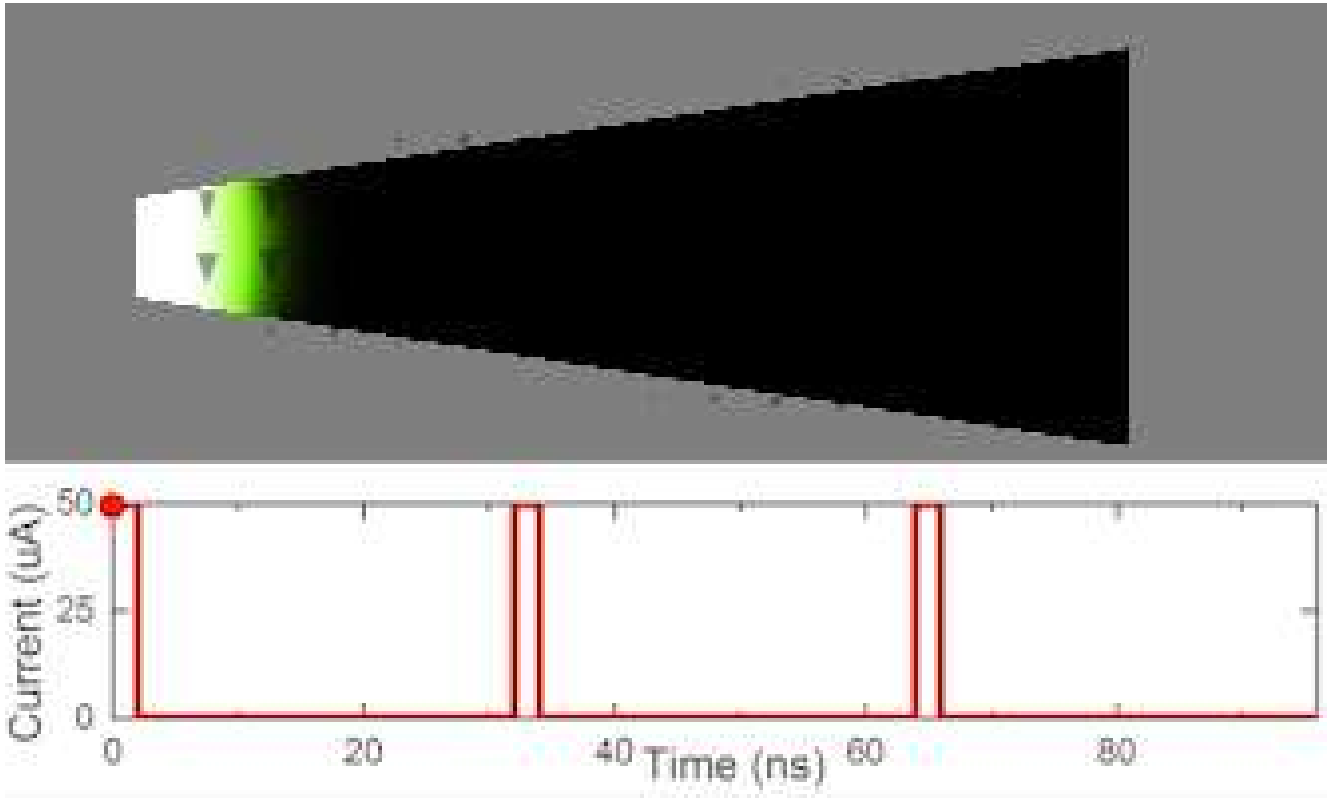
W. H. Brigner, X. Hu, N. Hassan, C. H. Bennett, J. A. C. Incorvia, F. Garcia-Sanchez, J. S. Friedman, *IEEE JxCDC*, 2019

Shape Gradient: Leaking



W. H. Brigner, N. Hassan, L. Jiang-Wei, X. Hu, D. Saha, C. H. Bennett, M. J. Marinella, J. A. C. Incorvia, F. Garcia-Sanchez, J. S. Friedman, *IEEE Trans. Electron Devices* **66**:6, 2817-2821 (2019).

Shape Gradient: Leaking & Integrating



W. H. Brigner, N. Hassan, L. Jiang-Wei, X. Hu, D. Saha, C. H. Bennett, M. J. Marinella, J. A. C. Incorvia, F. Garcia-Sanchez, J. S. Friedman, *IEEE Trans. Electron Devices* **66**:6, 2817-2821 (2019).

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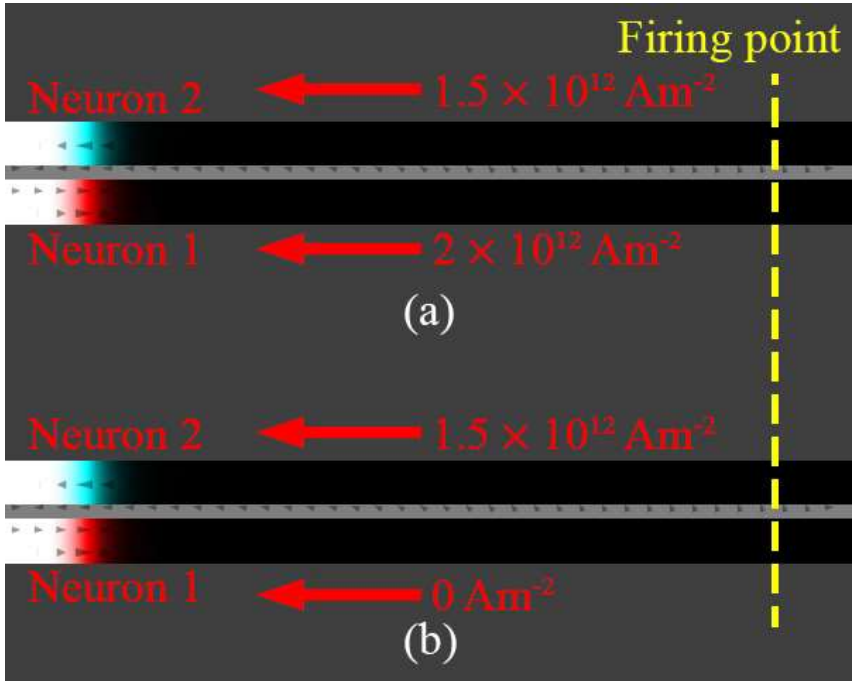
Lateral Inhibition

- DW tracks produce B-fields
  - Can therefore interact with nearby DW tracks
- Integration in one track produces effective leaking force in nearby tracks
  - More advanced integration results in larger effective leaking force



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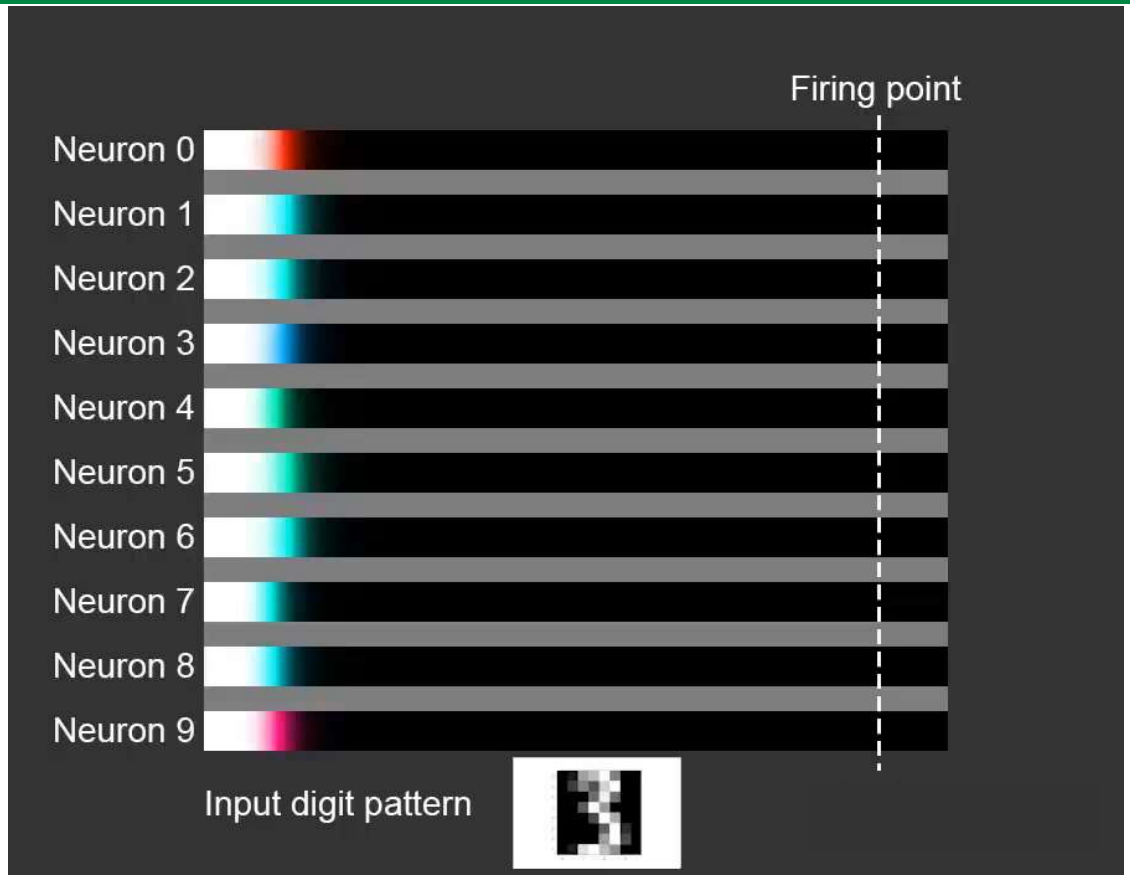
Output Layer with Digit Recognition



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Comparison of Fabrication Approaches

	Dipolar Field
Fabrication Approach	Additional ferromagnet provides dipolar coupling field
Pros	Simple fabrication of each layer
Cons	Requires additional material layers

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Conclusions

- Demonstrated first spintronic neuron capable of leaking and integrating without any external circuitry
- Intrinsic lateral inhibition capabilities allow for improved biomimicry
- Use of spintronics will significantly reduce power consumption
- New devices will markedly decrease area overhead, which will, in turn, decrease fabrication complexity

Thank You


Xuan Hu


Naimul Hassan


Joseph Friedman

CCF Awards
1910800
1910997

Graduate Research Fellowship Program (GRFP)
Award No. 1746053

McDermott Graduate Fellows
Award No. 202001


Jean Anne Incorvia


Otitoaleke Akinola


Christopher Bennett


Matthew Marinella


Felipe Garcia-Sanchez