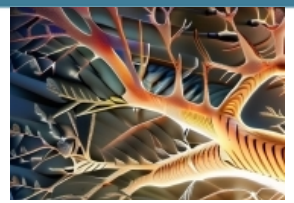
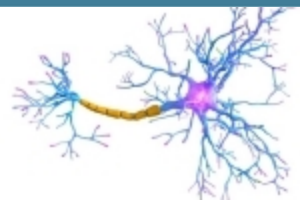
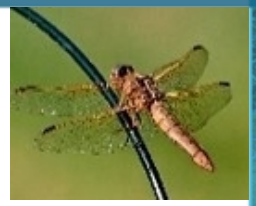
SAND2023-07386C

Sandia National Laboratories

Dendritic Computation for Neuromorphic Applications







Suma George Cardwell and Frances S. Chance

Cognitive and Emerging Computing

Sandia National Laboratories

International Conference on Neuromorphic Systems (ICONS)

August 3rd, 2023

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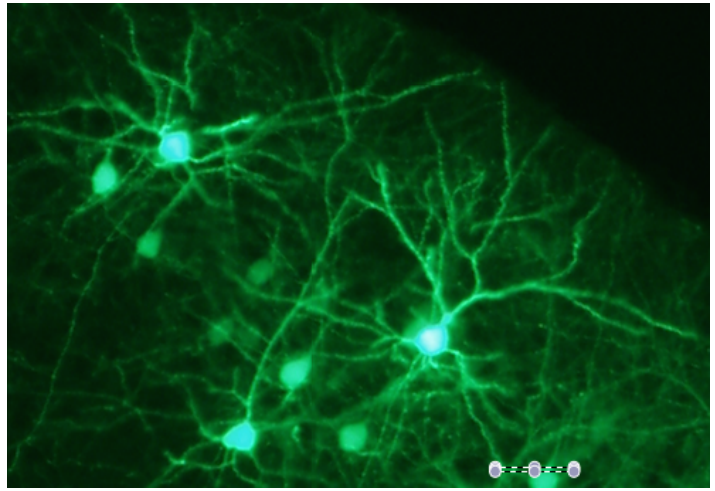
DENDRITIC TOOLKIT FOR COMPUTATION

Dendrites are tree-like structures that connect neurons synapses to its soma.

Dendrites are not *just* wires!

They can perform interesting computation like:

- Coincidence Detection
- Current Summation
- Directional selectivity
- Non-linear filtering
- Amplification of Synaptic inputs

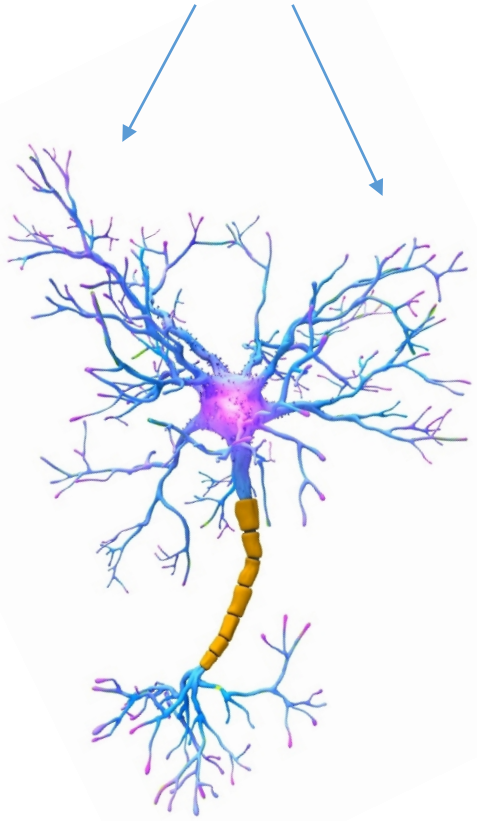


London 2005, Poirazi 2020

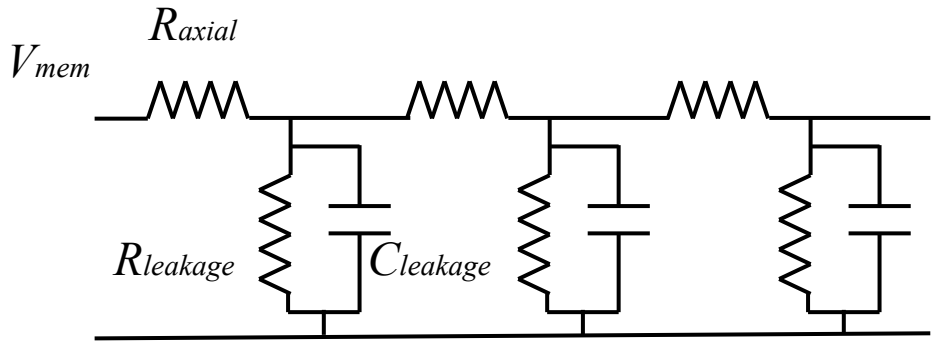
Increased Connectivity and Computation

DENDRITE MODELING

DENDRITES

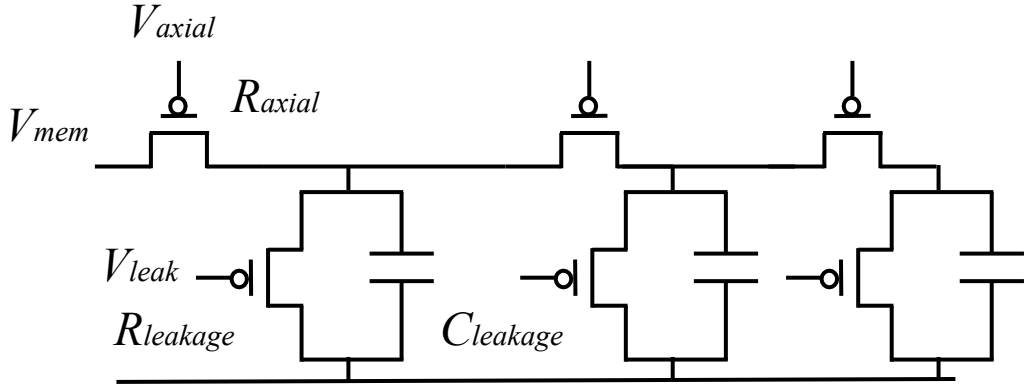


Resistor-Capacitor Circuit



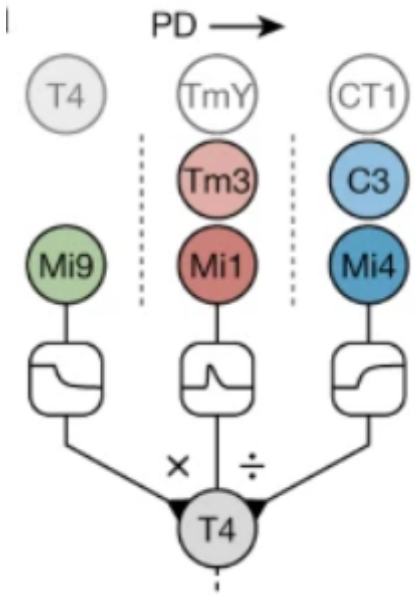
Rall's Cable Model

CMOS-transistor based Dendrite



Nease et al. 2011

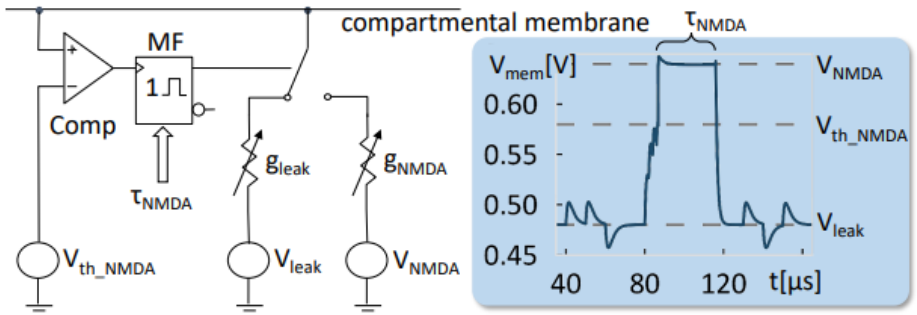
SINGLE NEURON MULTIPLICATION



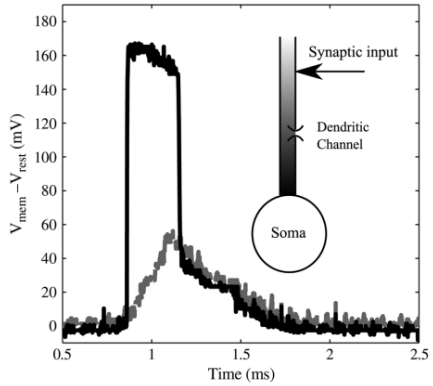
Groschner et al., Nature 2022

Leveraging Inhibition

Shunting Inhibition/ Leveraging Leakage Conductance

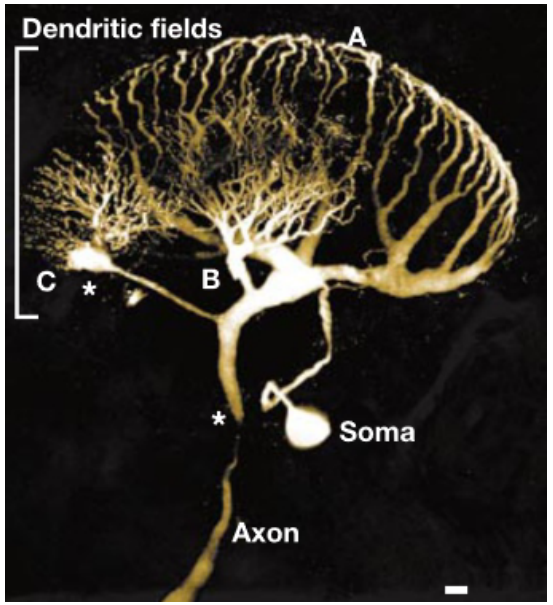


Schemmel, Johannes, et al. , IEEE IJCNN, 2017.



Dendrites with Active Channel, Ramakrishnan et al., IEEE TBIOCAS, 2013.

NMDA /Ca



Lobula giant movement detector (LGMD) of locusts Gabbiani et al., Nature 2002

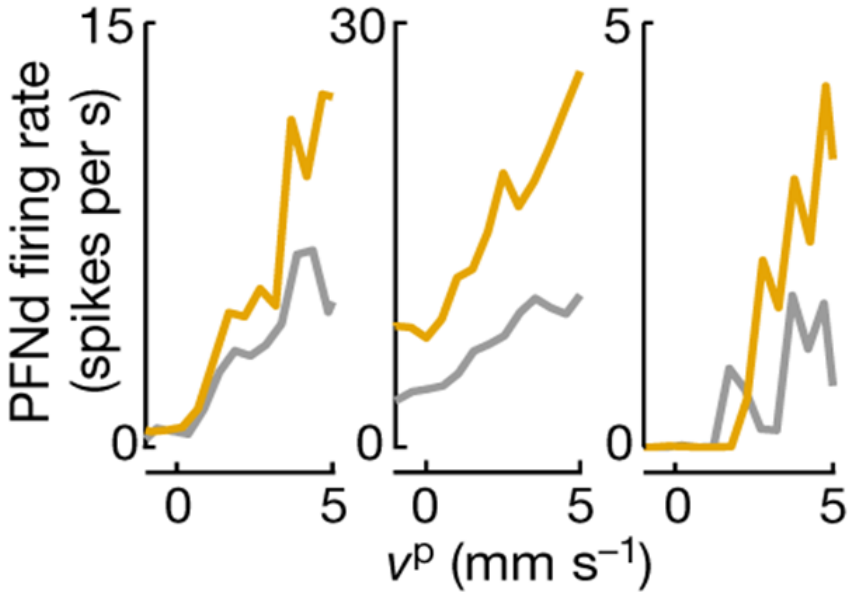
Multiplication based on dendritic subtraction of two converging inputs encoded logarithmically, followed by exponentiation through active membrane conductances.

SINGLE NEURON MULTIPLICATION

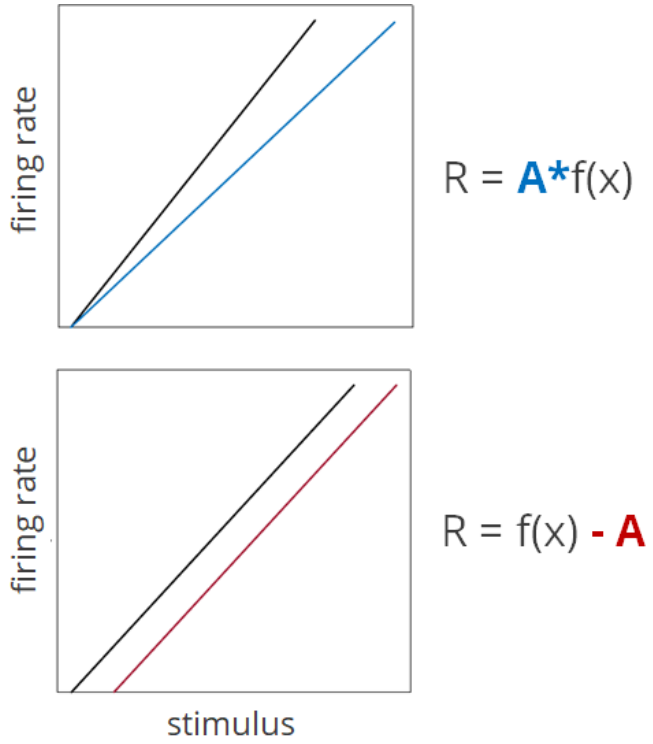


Algorithms *Devices & Circuits* *Physics of Computing*

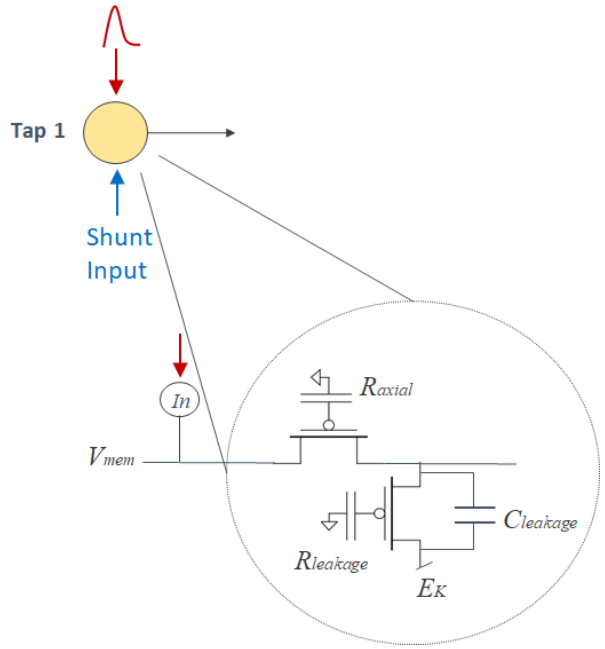
from fan-shaped body of *Drosophila* brain



Lu et al. 2020



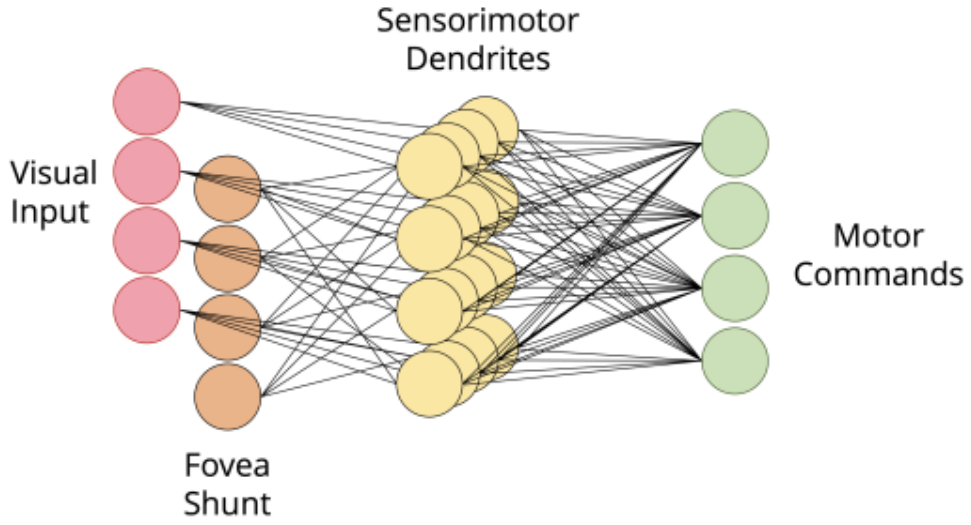
Chance & Cardwell
NICE 2023

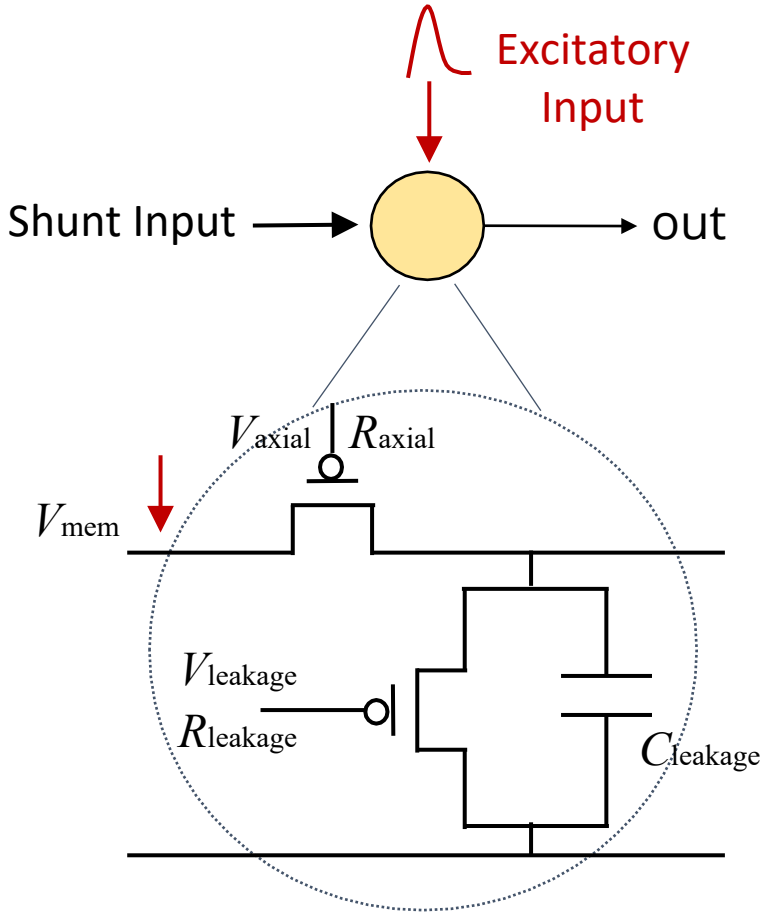


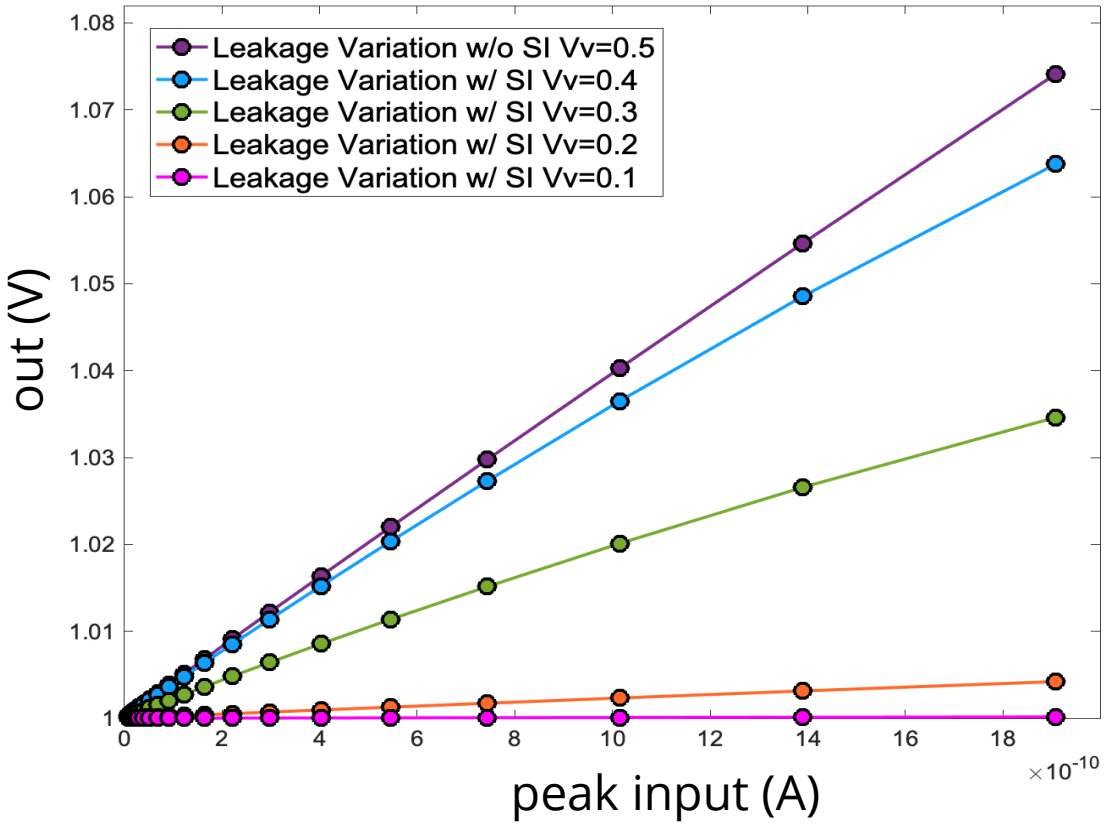
Shunting Inhibition in Neuromorphic Dendrite

Collaborators: University of Texas at Austin, Intel Neuromorphic Research Community

DRAGONFLY WITH DENDRITES







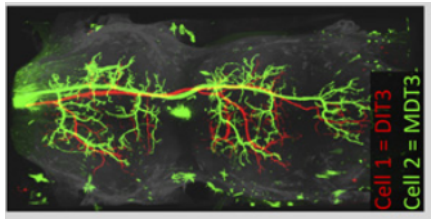
NEUROMORPHIC CODESIGN

Algorithms *Devices & Circuits* *Physics of Computing*

Coordinate transformations from Dragonflies to Neuromorphic Hardware

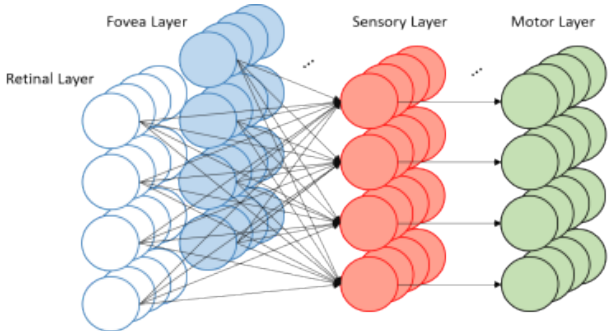
Lead PI: Frances Chance, SNL

October 2021

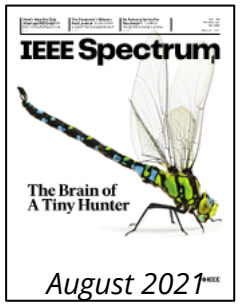


Gonzalez-Bellido, UMN

DRAGONFLY EXPERIMENTS



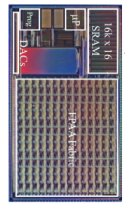
Chance 2020



August 2021

COMPUTATIONAL MODEL

GT FPAA



George Cardwell 2016

Intel's Loihi

Davies 2018

SNL, Baylor

NEUROMORPHIC IMPLEMENTATION

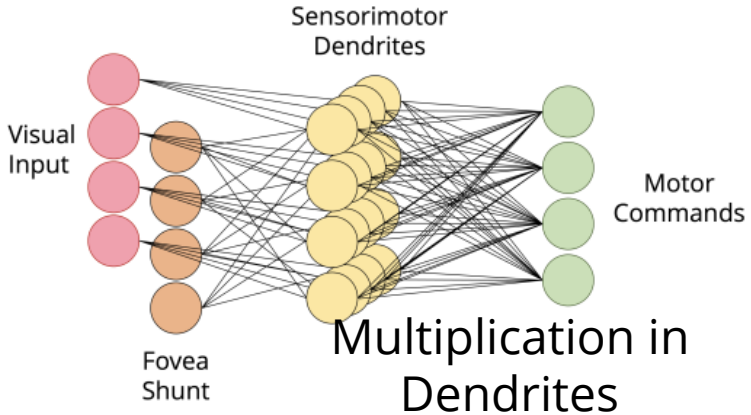
U.S. DEPARTMENT OF ENERGY | Office of Science

DOE ASCR (FY21-24)

Department of Energy
Advanced Scientific Computing Research

Increased collaboration between neuroscience and neuromorphic engineering will facilitate development of novel neural-inspired architectures.

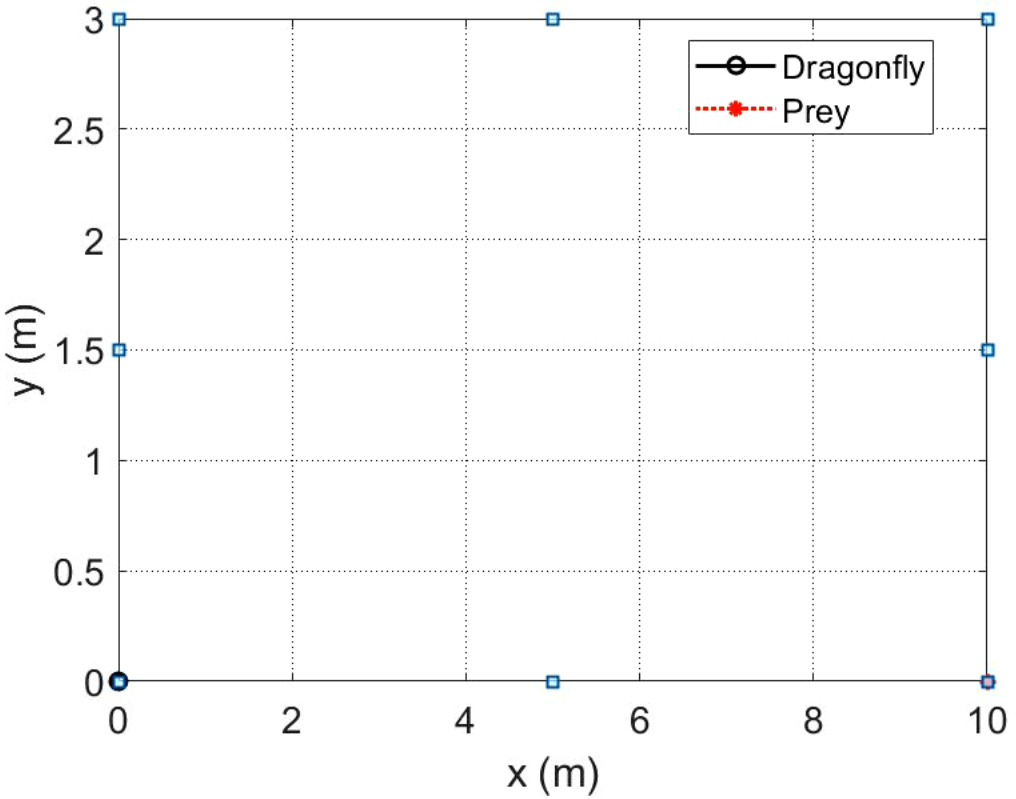
DRAGONFLY INTERCEPTION WITH DENDRITES

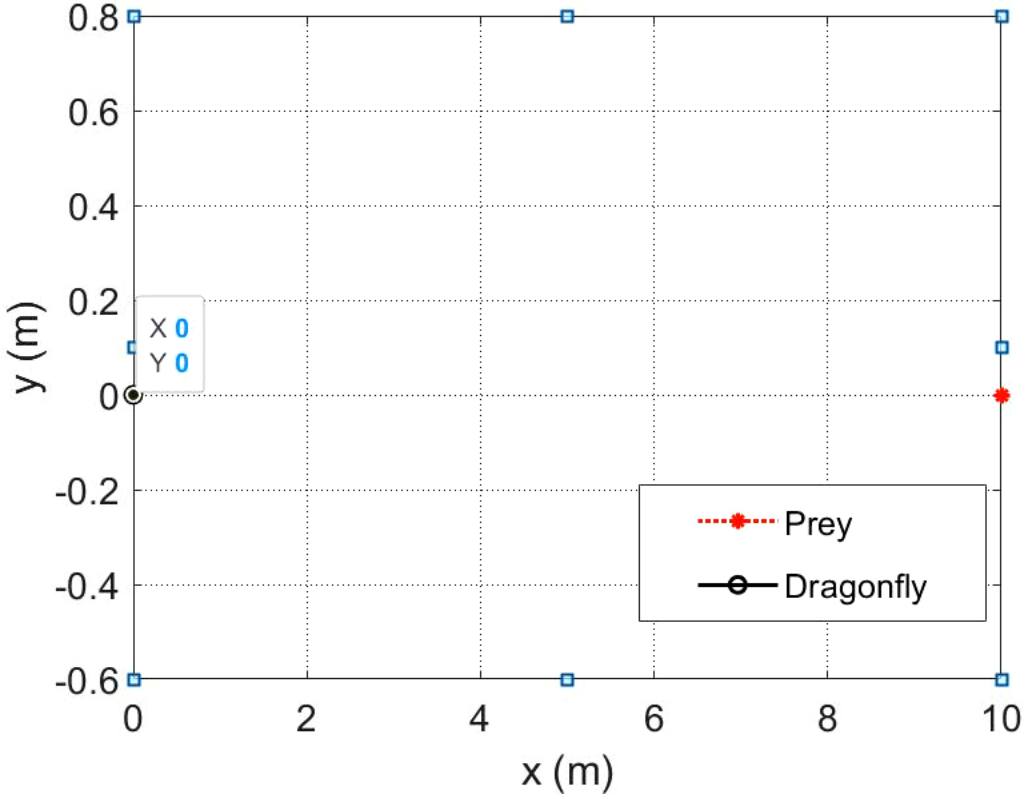


Multiplication in Dendrites

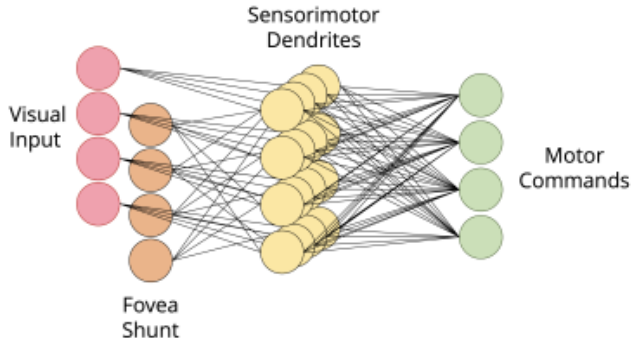
Sensorimotor Dendrites Response

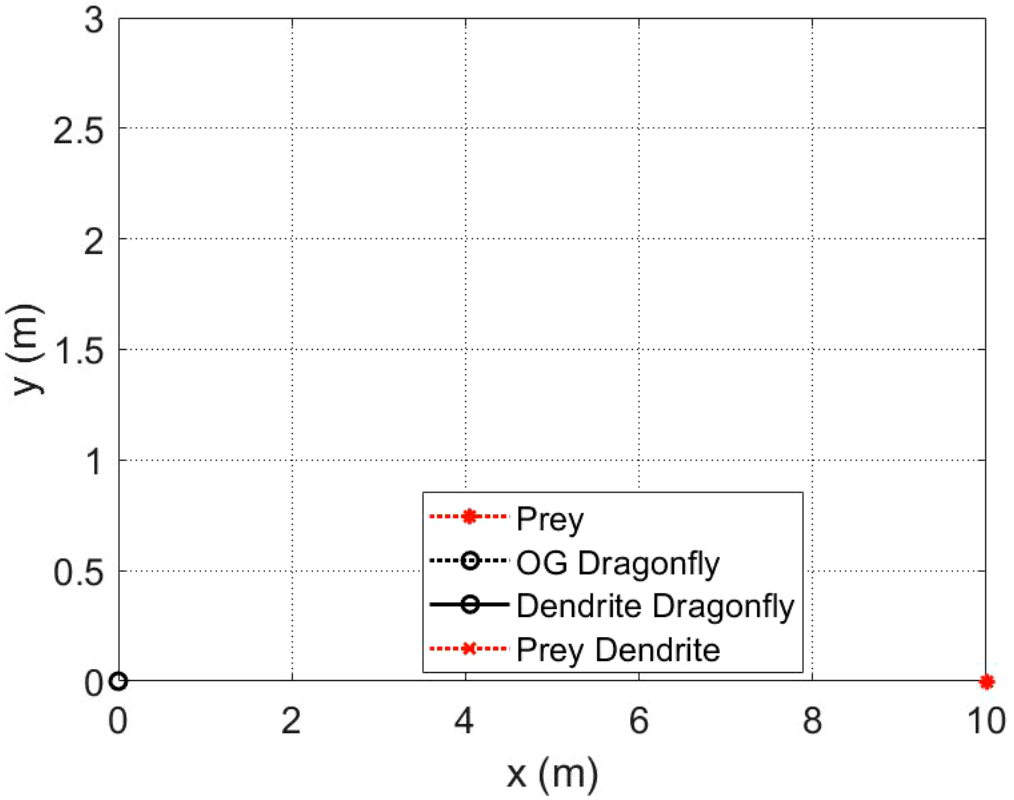
$$S_{ij} = f_i(x)g_j(y)$$

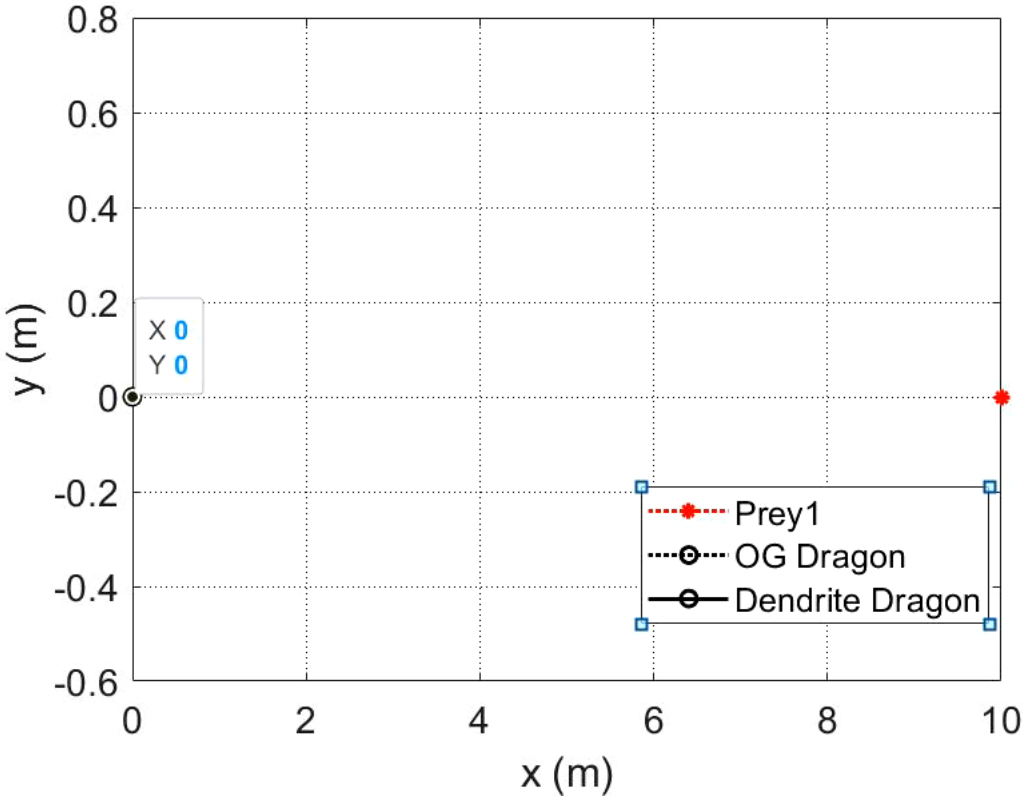




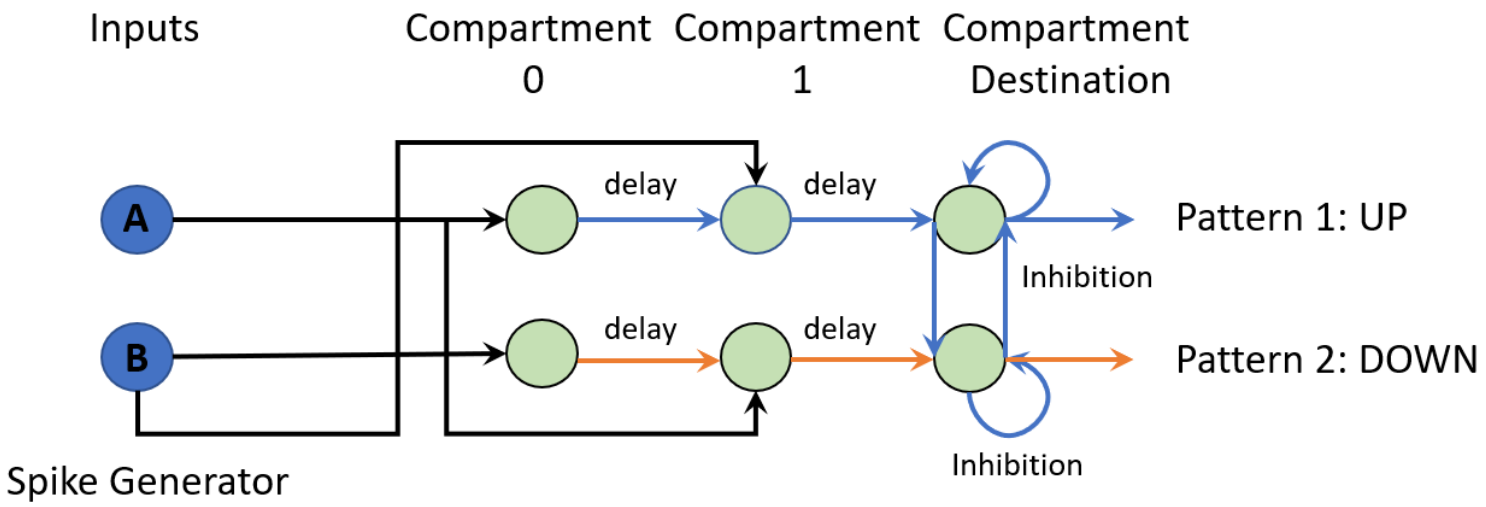
DRAGONFLY INTERCEPTION WITH DENDRITES COMPARISON

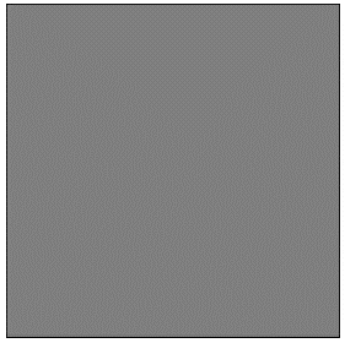




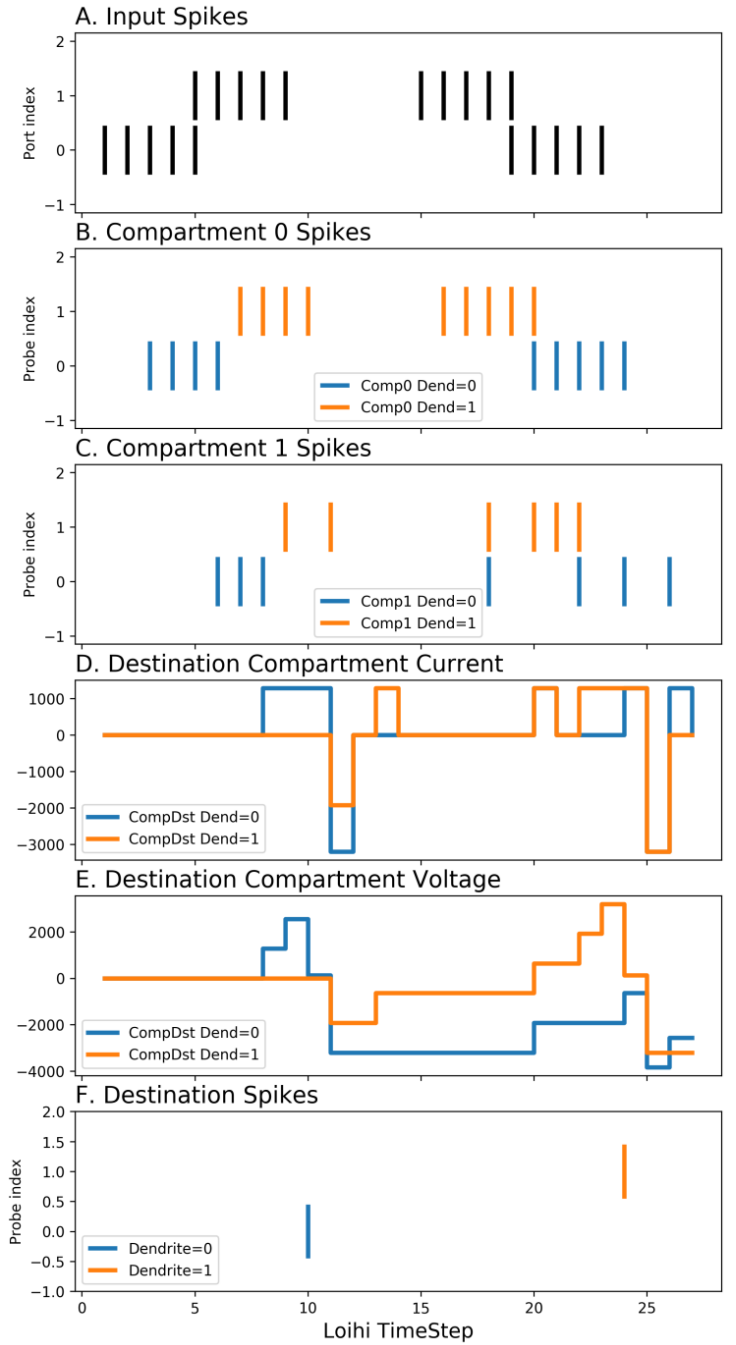


DIRECTION-SELECTIVE DENDRITES

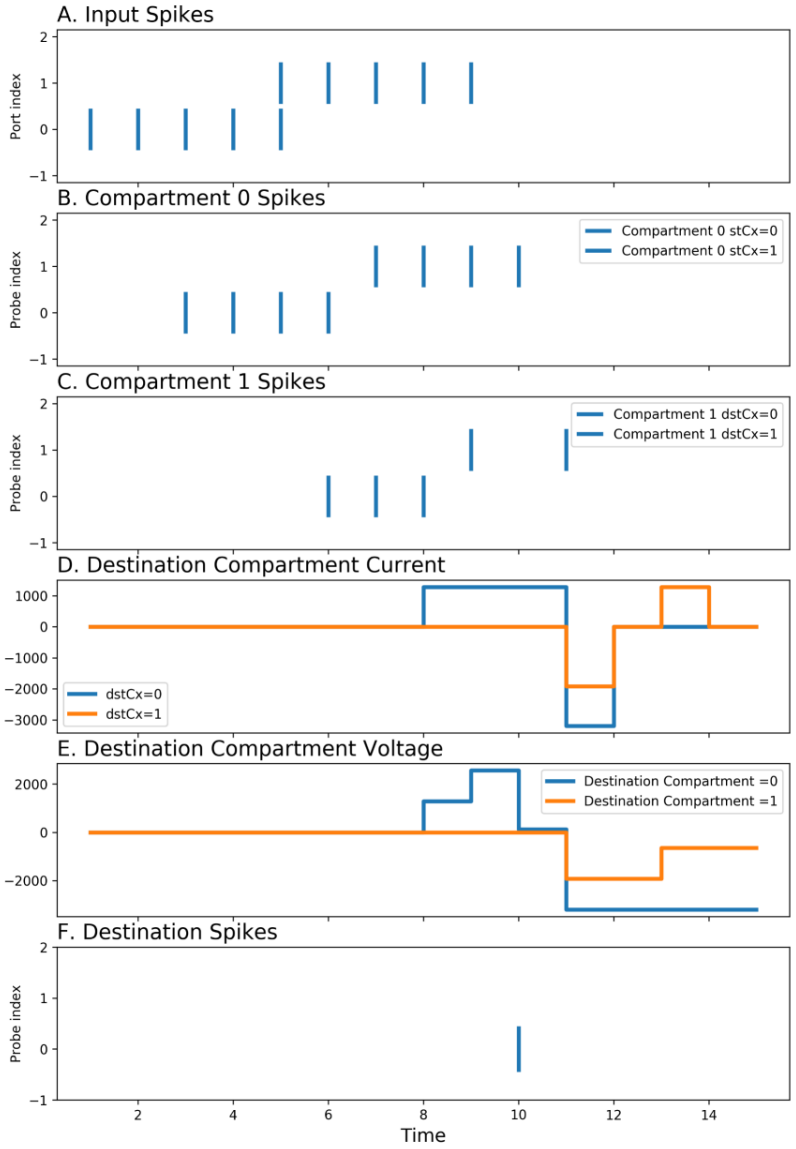


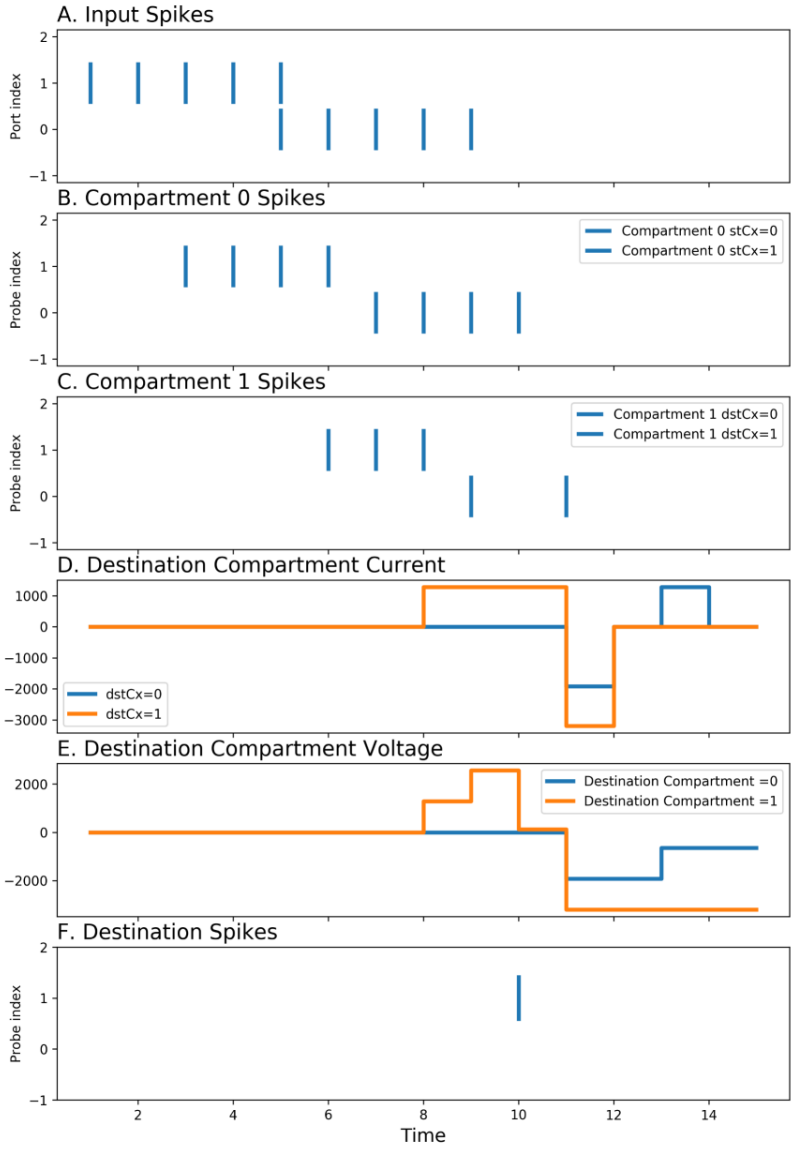


Nahuku (Loihi Chips)
Davies 2018

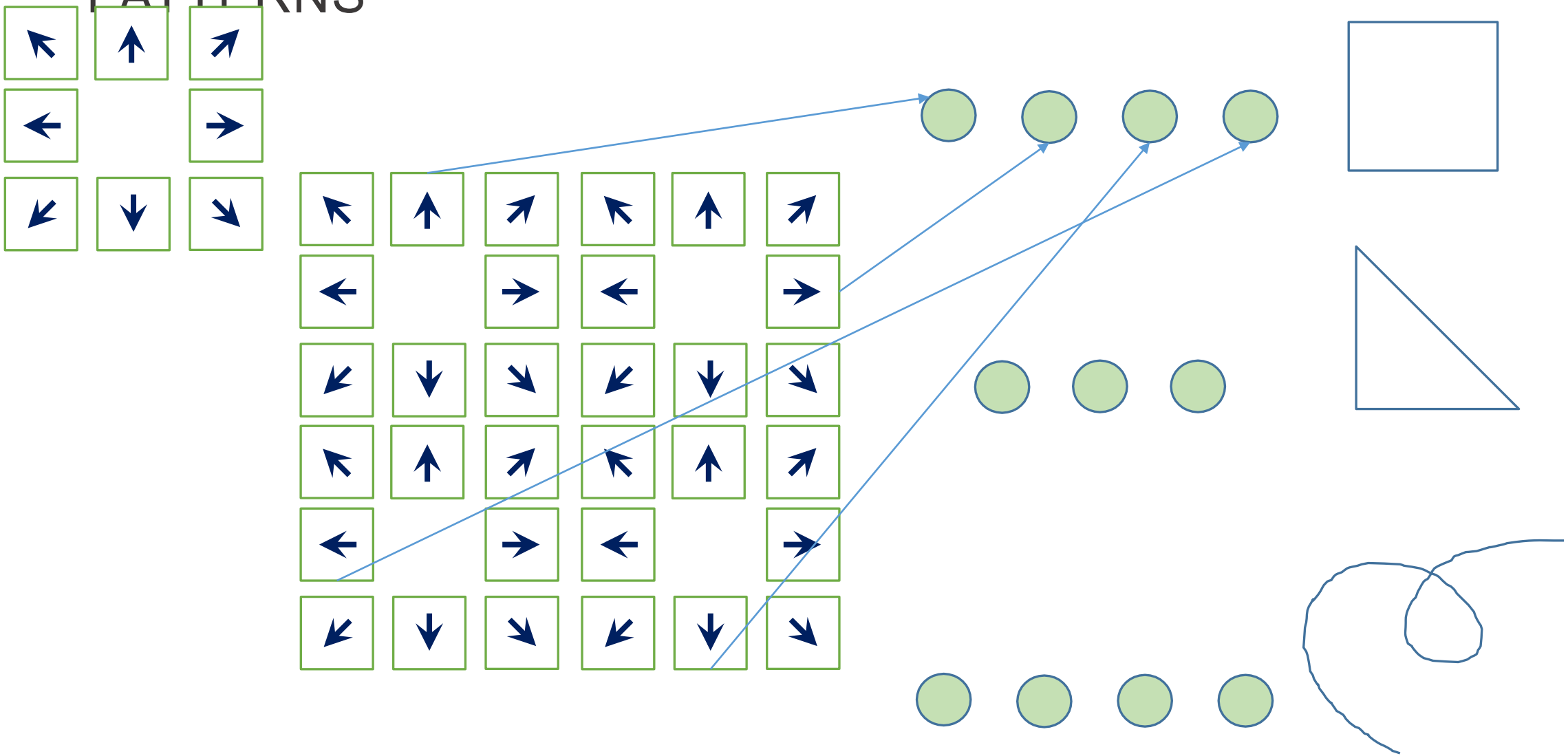


DIRECTION SELECTIVE CIRCUITS

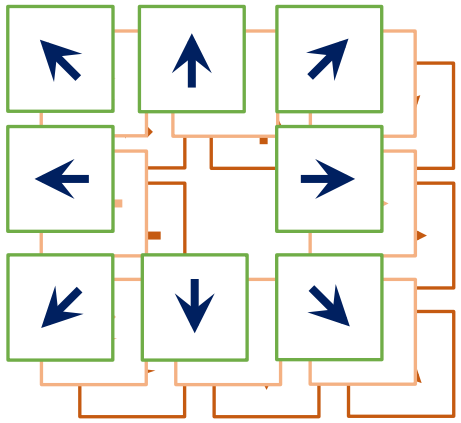




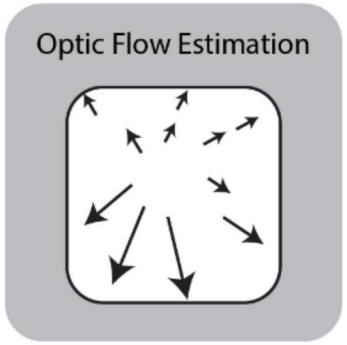
DIRECTION-SELECTIVE CELLS FOR COMPLEX PATTERNS



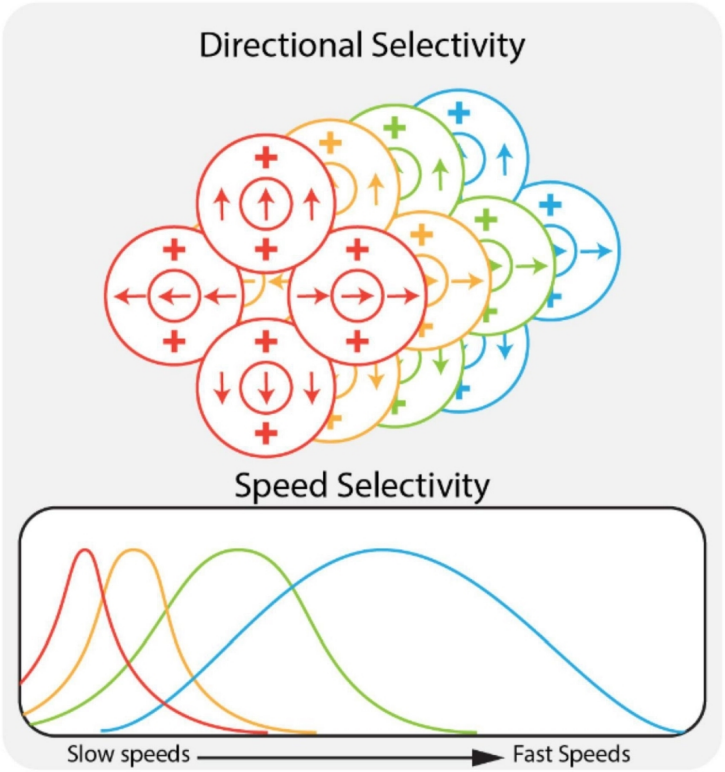
DIRECTION-SELECTIVE CELLS FOR COMPLEX PATTERNS



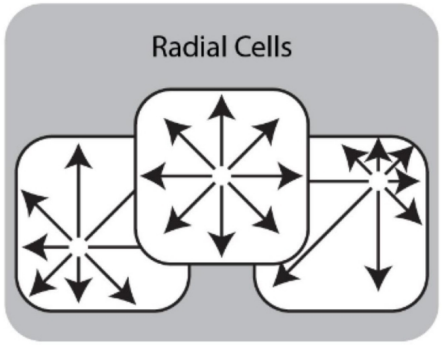
V1



MT+

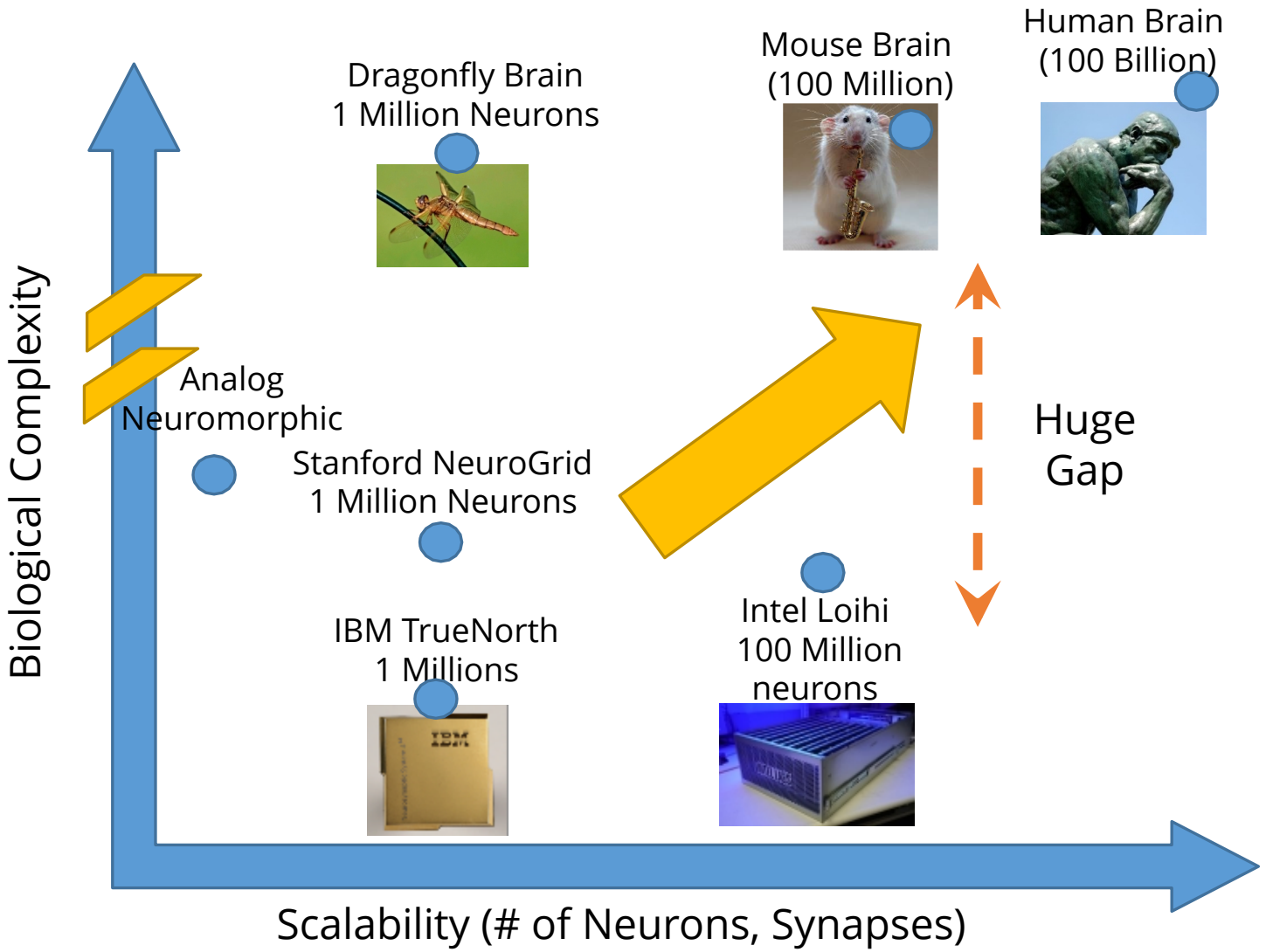


MSTd



Steinmetz et al. 2022

NEUROMORPHIC COMPUTING CHALLENGE: SCALABILITY VS. COMPLEXITY



However, to achieve brain-like complexity we need both scaling and rich dynamics.

- Solving ill-structured problems
- Online learning
- Transfer learning

Understanding fundamental mechanisms in neuroscience, translated to algorithms and models will influence next-generation devices, architectures and intelligent computing systems

THANK YOU!!

Neural Exploration and Research Lab

WE ARE HIRING!

Careers

careers.sandia.gov

https://neuroscience.sandia.gov/

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Frances S. Chance fschanc@sandia.gov