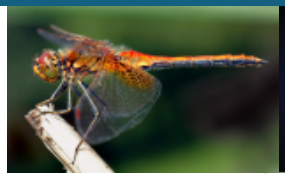
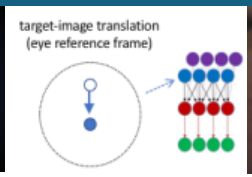
SAND2022-1733C

Sandia National Laboratories

Neuroscience-Inspired Approaches to Low-Power Computing





Frances S. Chance, Suma George Cardwell, Paloma T. Gonzalez-Bellido and Scott Koziol

Energy Consequences of Information Workshop
February 17, 2022

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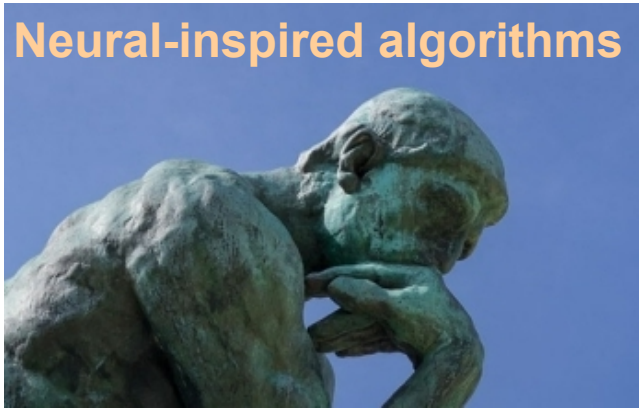
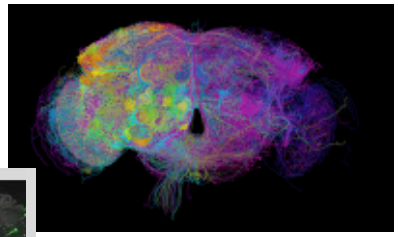
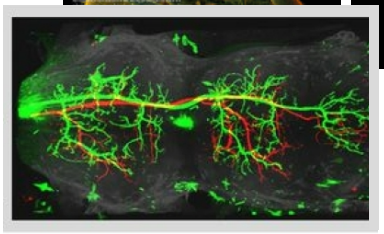
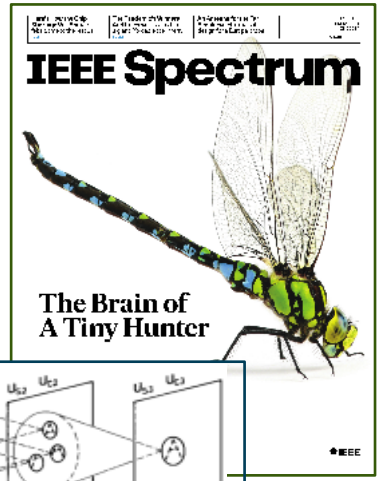
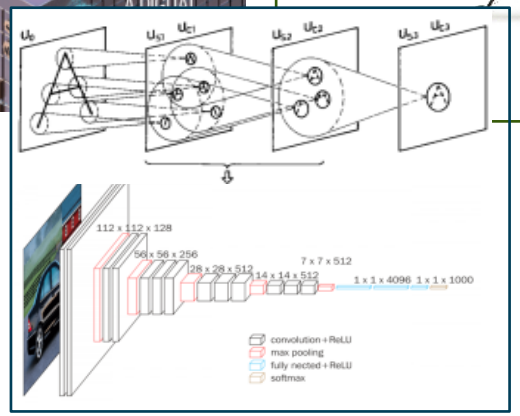
Neuroscience inspiration for next-generation computing



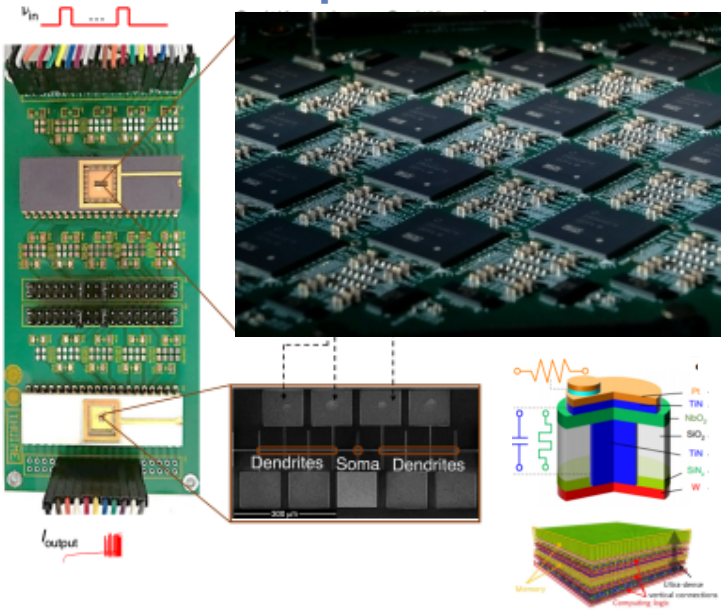






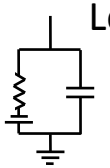


Neuromorphic hardware



The path to next-generation neuromorphic computers

Increasing numbers of neurons



Leaky integrate-and-fire (LIF) model neurons

- Relatively easy to scale
- Single passive compartment
- Spiking

IBM TrueNorth:
1 million neurons

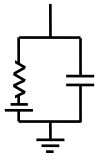
Intel Poihiki Springs:
100 million neurons

human brain:
86 billion neurons

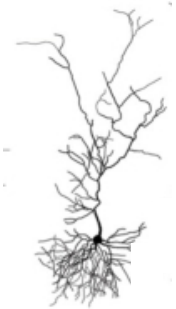
The path to next-generation neuromorphic computers

BIOLOGICAL COMPLEXITY

Increasing numbers of neurons



LIF neuron



IBM TrueNorth:
1 million neurons

dragonfly brain:
1 million neurons

How do we bridge this gap?

mouse brain:
71 million neurons

Intel Poihiki Springs:
100 million neurons

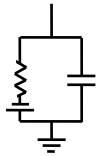
human cognition:
86 billion complex neurons

human brain:
86 billion neurons

The path to next-generation neuromorphic computers

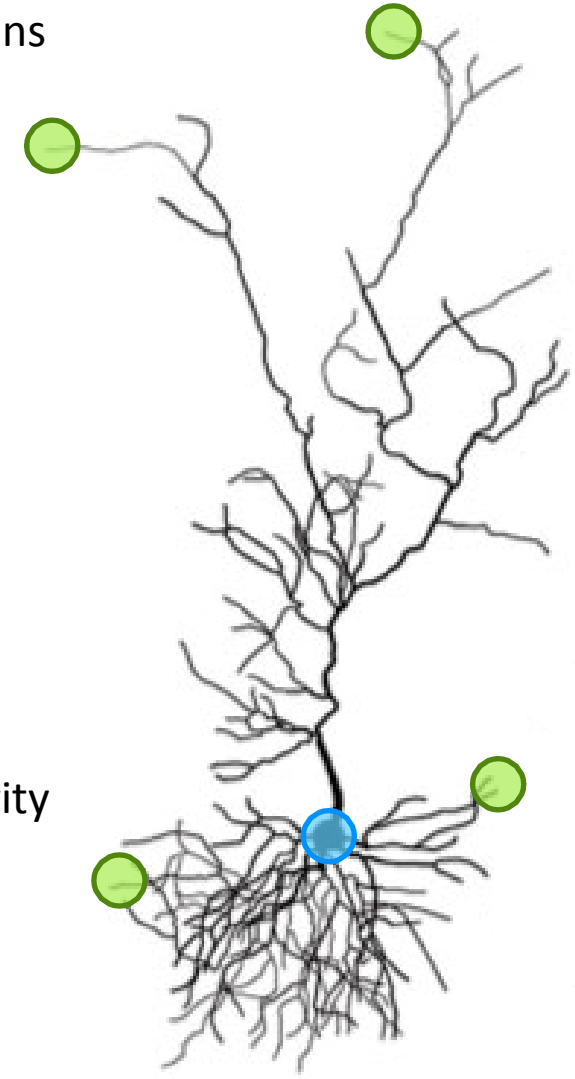
BIOLOGICAL COMPLEXITY

Compact scalable models for brain-like numbers of neurons

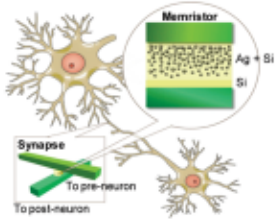


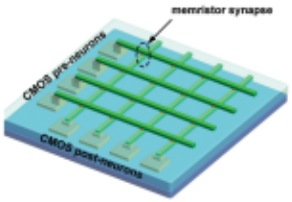
IBM TrueNorth
Merolla et al 2014

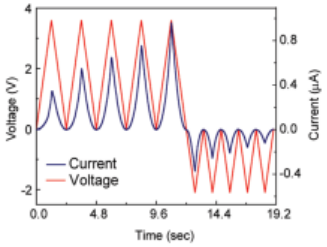
Intel Loihi
Davies et al 2018



In-memory computing devices mimic biological synapses

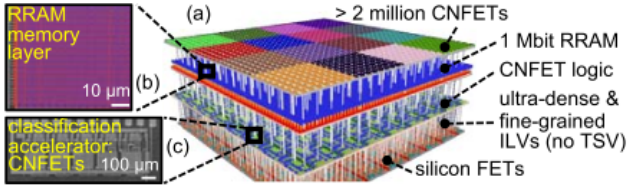






from Jo et al 2010

3D architecture approaches for more brain-like connectivity



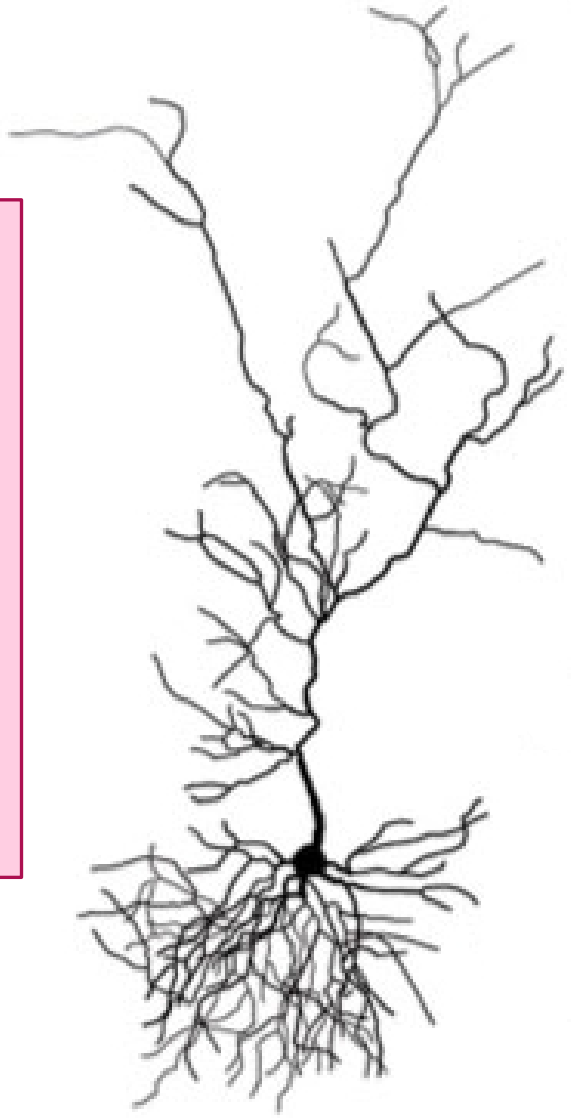
from Aly et al 2018

The path to next-generation neuromorphic computers

Biological dendrites offer computational power that has yet to be realized in silicon

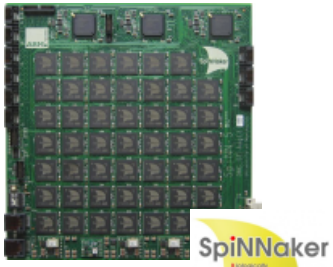
- local and active processing
- subthreshold regime
- “computing on the wires”

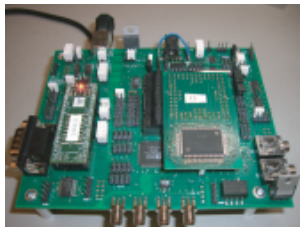
Examples: coincidence detection, direction selectivity, gated learning, nonlinear summation and multiplicative integration



The path to next-generation neuromorphic computers

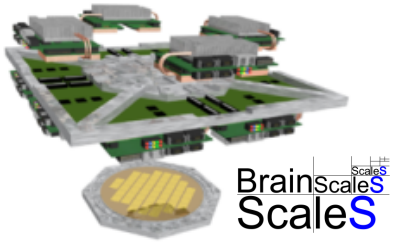
Configurable approaches

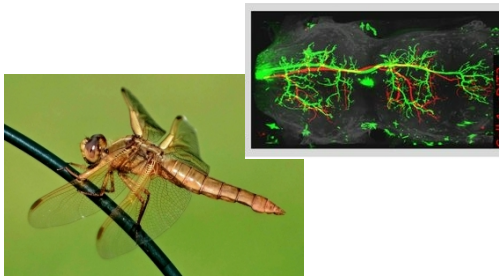




Ingestion of biological data

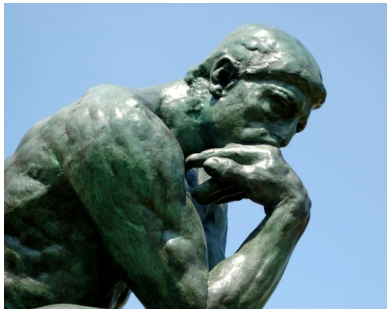
Human Brain Project





Dragonflies for next-generation neuromorphic computers

Why dragonflies?



dragonfly nervous system is “light”

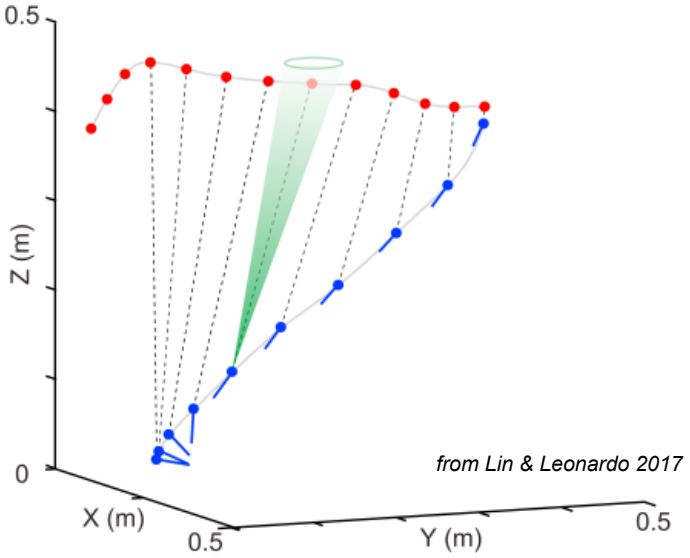
identifiable neural circuits and neurons

(and if we can identify it we can study it)

dragonfly is a successful and highly-specialized predator

Dragonflies for next-generation neuromorphic computers

Why dragonflies?



dragonfly nervous system is “light”

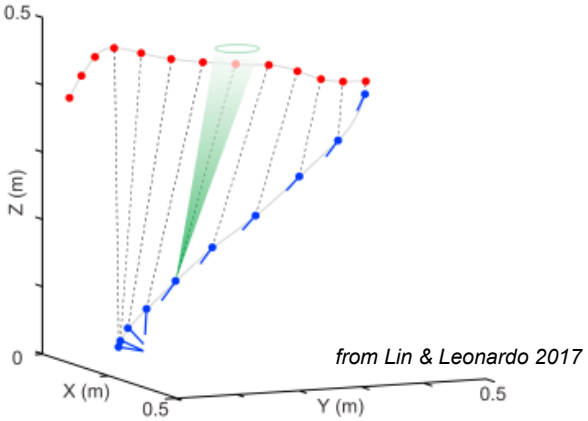
identifiable neural circuits and neurons

(and if we can identify it we can study it)

dragonfly is a successful and highly-specialized predator

dragonflies are fast

Dragonflies for next-generation neuromorphic computers

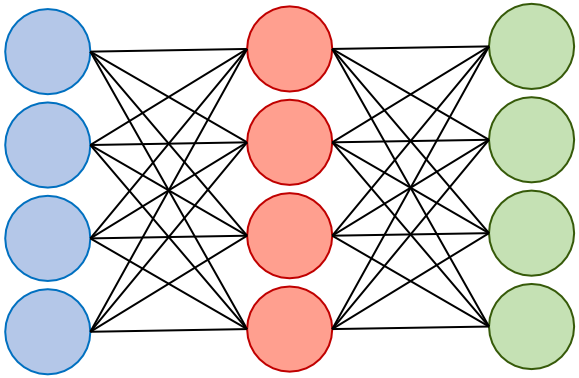


dragonfly latency: 50 ms

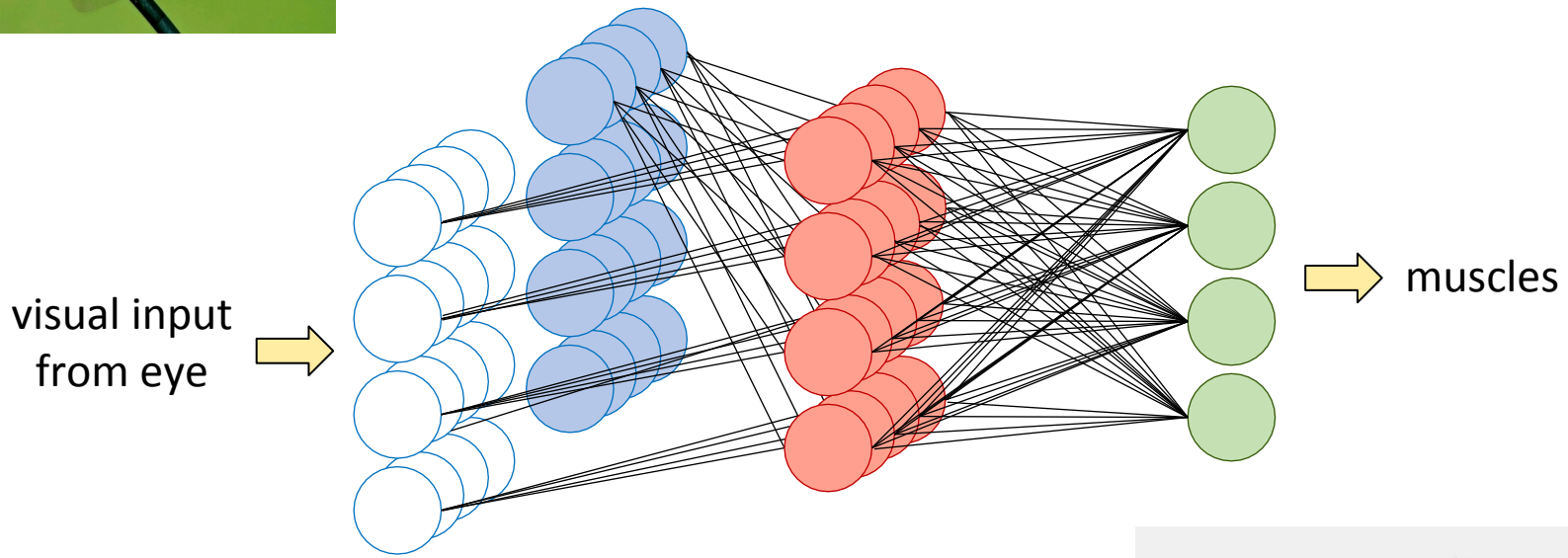
synaptic transmission: 1-5 ms

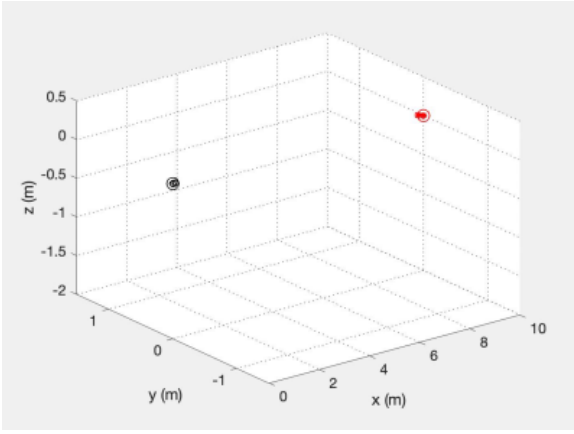
muscle response: ~5 ms

neuron membrane time constant: 10-50 ms



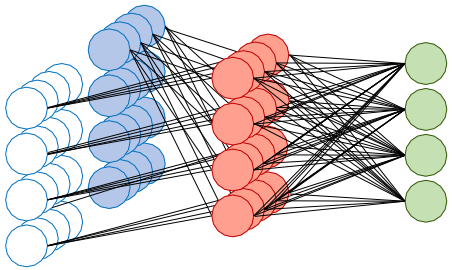
Dragonflies for next-generation neuromorphic computers





see Chance, International Conference on Neuromorphic Systems (ICONS) 2020

Biological complexity of dragonfly interception neurons



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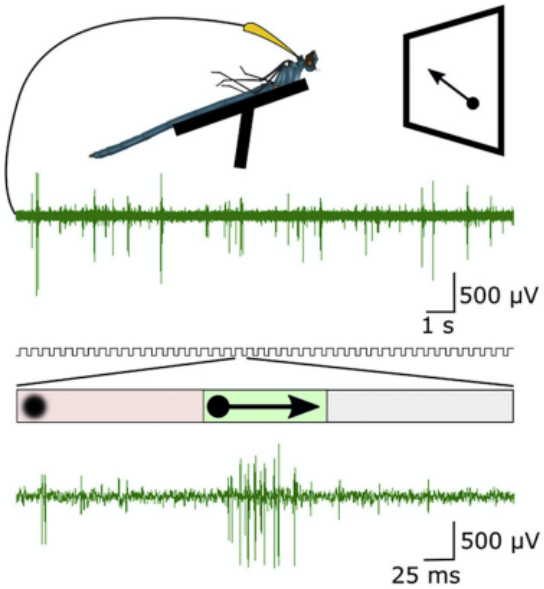
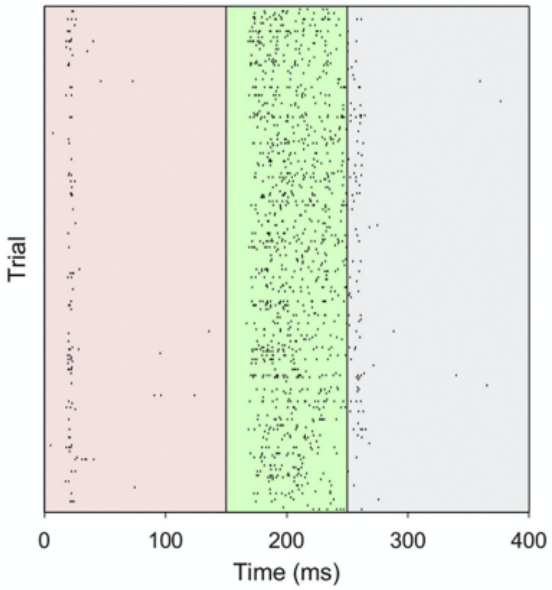
University of Minnesota

David Munkvold
University of Minnesota





identify site of coordinate transformation in the dragonfly nervous system

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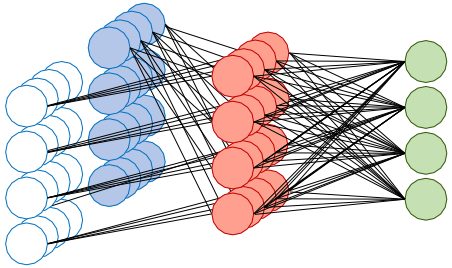
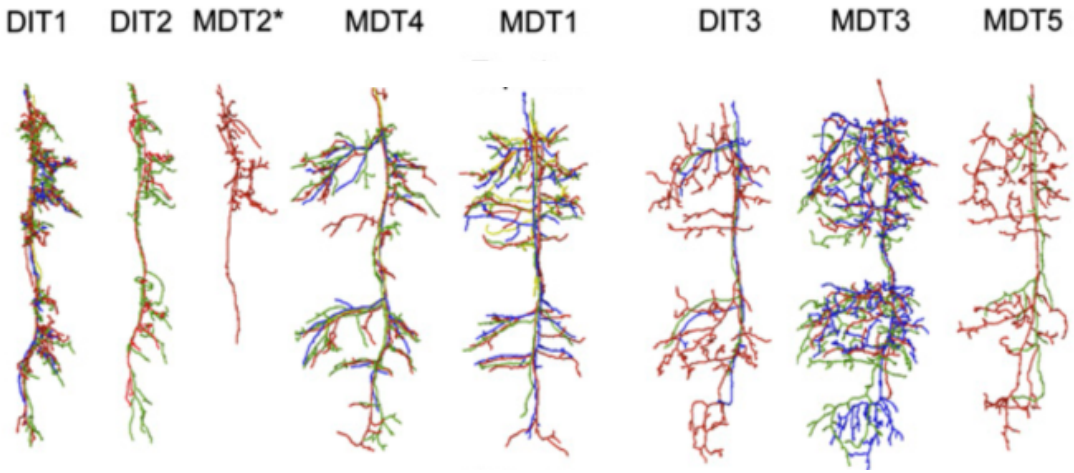
Biological complexity of dragonfly interception neurons



Dr. Paloma Gonzalez-Bellido
University of Minnesota

David Munkvold
University of Minnesota

Target-selective descending neurons (TSDNs)



identify site of coordinate transformation in the dragonfly nervous system

reveal biophysical and circuit properties that underlie dragonfly interception behavior

from Gonzalez-Bellido et al (2013) PNAS 110: 696

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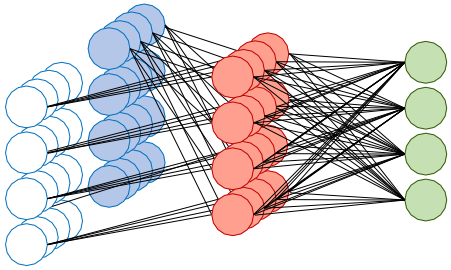
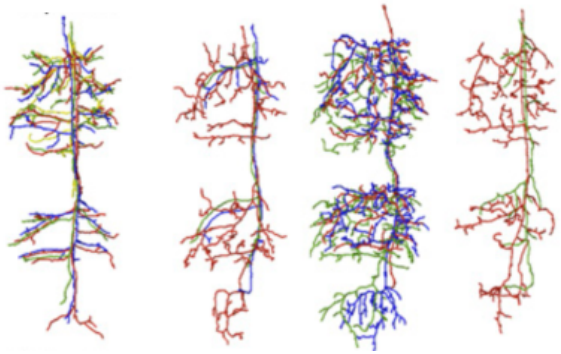
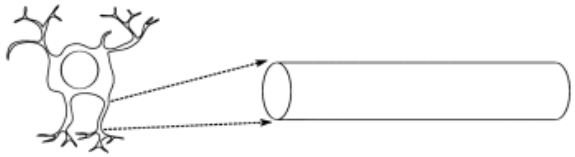
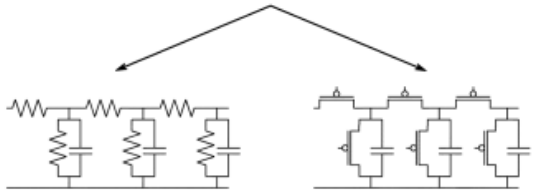
Biological complexity in novel neuromorphic architectures









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Dr. Scott Koziol

Baylor University

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Develop and prototype neuromorphic dendrite models inspired and constrained by biological data

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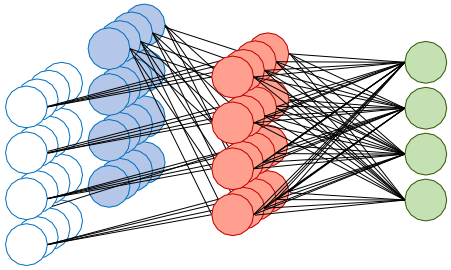
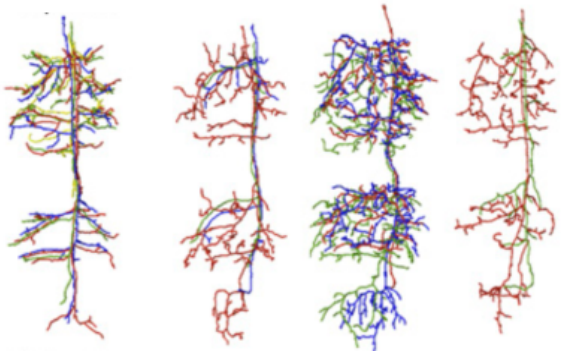
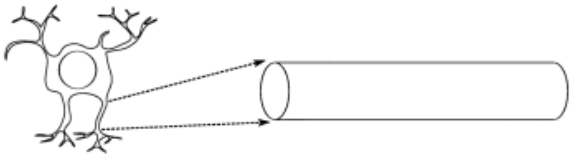
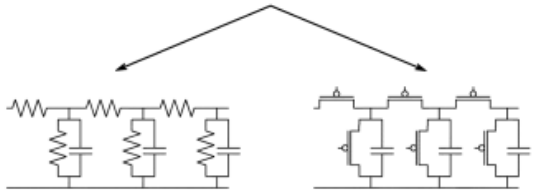
Biological complexity in novel neuromorphic architectures









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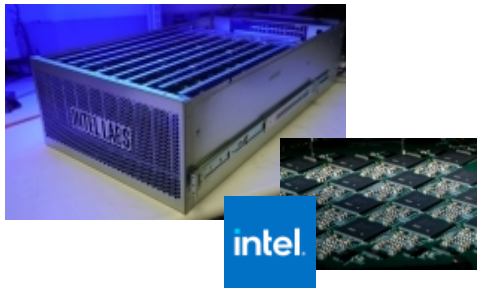
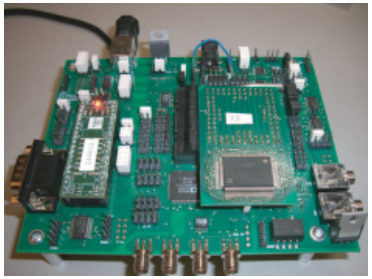
Develop and prototype neuromorphic dendrite models inspired and constrained by biological data

Demonstrate the compute power of the more complex neuron



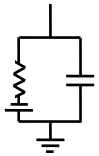


Georgia Tech

The path to next-generation neuromorphic computers

BIOLOGICAL COMPLEXITY

Increasing numbers of neurons



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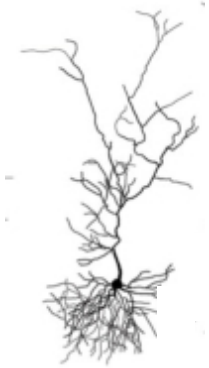
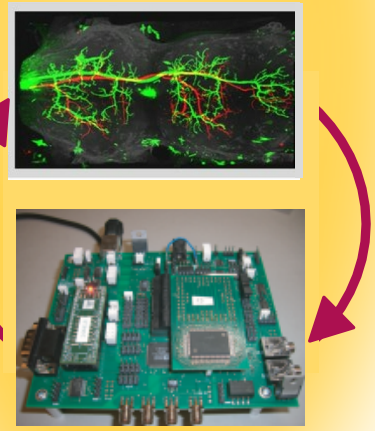


Next-generation neurons:
- **more complex and powerful**
- **less scalable**

IBM TrueNorth:
1 million neurons

dragonfly brain:
1 million neurons

Intel Poihiki Springs:
100 million neurons



mouse brain:
71 million neurons

human cognition:
86 billion complex neurons

The End

Questions? Email fschanc@sandia.gov

Dr. Frances Chance
Sandia National Laboratories