Expanding the Silicon Brain: Exploring Neurons-Dendrites' Connectivity in the MICrONS Dataset

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Introduction

- Matching the brain's energy-scaling would make artificial intelligence more accessible and sustainable [1].
- Spatial-temporal spike sequences can encode rich information. Thus, understanding how a dendrite could decode a spatiotemporally ordered spiking sequence would allow AI hardware to transcend 3-D thermal constraints [1].
- This project explores neurons-dendrites' connectivity in the the Machine Intelligence from Cortical Networks (MICrONS) Cortical mm^3 dataset [2][3][4] that spans all 6 layers of mouse primary visual cortex and 3 higher visual areas (LM, AL, RL) within 1 mm^3.

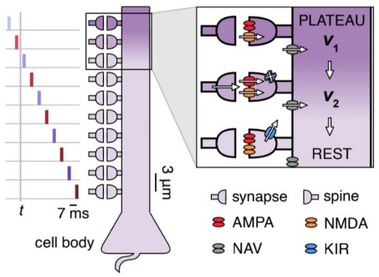

Fig 1: A stretch of dendrite seems capable of detecting a sequence of spikes if it arrives on synapses whose spatial ordering matches the sequence's temporal ordering [1].

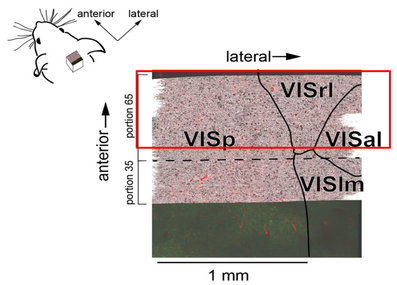

Fig 2: The MICrONS Cortical mm^3 dataset spans a 1.4mm x 0.87mm x 0.84 mm volume of cortex in a P87 mouse [2].

Methodology

query the MICrONS Cortical mm^3 proofread dataset from the cloud storage and filter out the non pyramidal cells

cloudstorage

construct a bipartite graph that encodes information of the presynaptic neuron-synapse-postsypnaptic neuron connectivity

transform the voxel coordinates of the synapses into xyz coordinates then apply "KD tree" to each synapse to group its neighboring synapses within a 10-µm diameter balls.

identify candidate sequences of presypnaptic neurons for which all of them connect to a common postsypnatic neuron

analyze the candidate sequences to obtain information regarding the scaling between number of candidate sequences and the number of axons traced

visualize the candidate sequences in Neuroglancer and select the desired sequences

google/ neuroglancer
WebGL-based viewer for volumetric data

Abstract

- This project aims to provide insights that would allow AI hardware to transcend 3-D thermal constraints.
- The project first finds synapses clustered on a stretch of dendrite in the MICrONS dataset and trace their axons. Then a KD tree is applied to the synapses to query groups of synapses within 10-µm diameter balls. We then filter each group for synapses with the same postsynaptic target and we infer these synapses' spatial ordering from their relative distances
- The power-law scaling in our preliminary findings supports the potential for a combinatorially-large spike-sequence code.

Results and Analysis

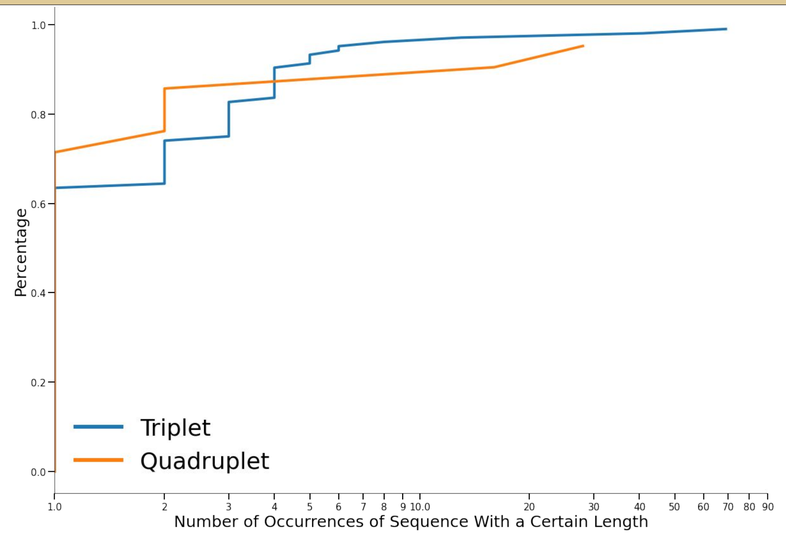

Fig 3: Cumulative distribution function (CDF) that describes the distribution of number of occurrences for sequences with a given length. Based on the CDF, about 60 percent of the triplet appear at least one time and about 70 percent of the quadruplet appear at least one time.

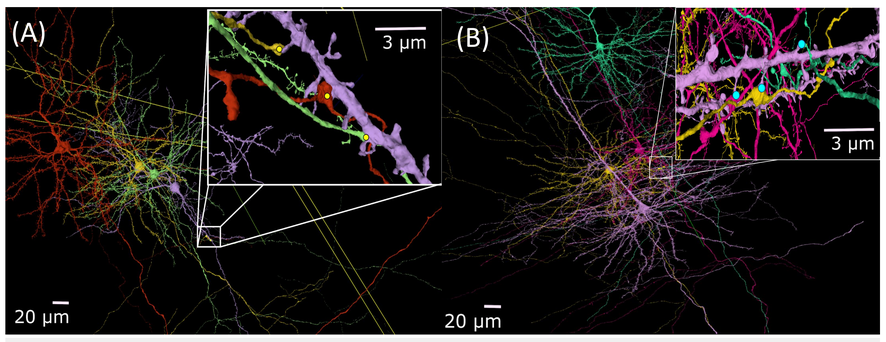

Fig 4(A): Axons of three pyramidal cells (Red, Yellow, Green) converge to form synapses (yellow circles) on a 10-µm stretch of a fourth neuron's dendrite (Purple). The fourth neuron is an inhibitory neuron. Inset: The order of their synapses, found on small protrusions called "spines", induces the sequence Yellow-Red-Green.
Fig 4(B): Axons of three pyramidal cells (Magenta, Yellow, Green) converge to form synapses (cyan circles) on a 10-µm stretch of a fourth neuron's dendrite (Purple). The fourth neuron is also a pyramidal cell. Inset: The order of their synapses, found on small protrusions called "spines", induces the sequence Magenta-Yellow-Green.

Results and Analysis (continued)

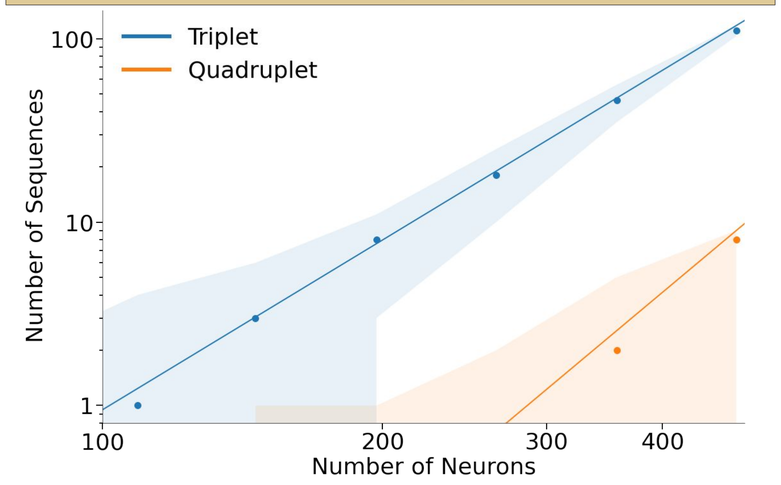

Fig 5: As the number of axons traced increases, triplets and quadruplets increase with a power of 3.16 (blue line) and 4.35 (orange line), respectively. For example, tracing axons of 357 neurons, sampled randomly from 492 proofread pyramidal cells over 100 independent trials, yields a median of 46 triplets and 2 quadruplets, with 90% of the trials (shaded) yielding between 35 and 55 triplets and 0 and 5 quadruplets.

Conclusion and Future Work

- None of the sequences of presynaptic neurons we have found so far repeats on another dendritic stretch. This suggests the future work needs to predict additional neurons to proofread to find more instances of their corresponding sequences or their subsequences as well as to estimate the dissimilarity and error-correcting capacity of these sequence codes.
- The number of sequences we find does follow a power-law as the number of presynaptic neurons sampled increases suggesting compounding returns for tracing and proofreading more pyramidal cells in the MICrONS dataset.

References

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