MICrONS Function - Connectivity Data Documentation

Andreas Tolias Lab

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Data Overview

The data in this release originates from the MICrONS collaboration. [1]. In summary, the activity of neurons in the visual cortex of a mouse were imaged with 2-photon (2P) microscopy while the mouse watched movies. Afterwards, the same chunk of brain tissue was extracted and imaged at high resolution with electron microscopy (EM). Every neuron was reconstructed in 3D (albeit to varying degrees of completion) and neuronal connections, called synapses, were automatically identified. To visually explore the data visit: `https://www.microns-explorer.org/cortical-mm3`.

The axes of the reconstructed EM volume and their anatomical directions in the brain are shown in Fig 1.

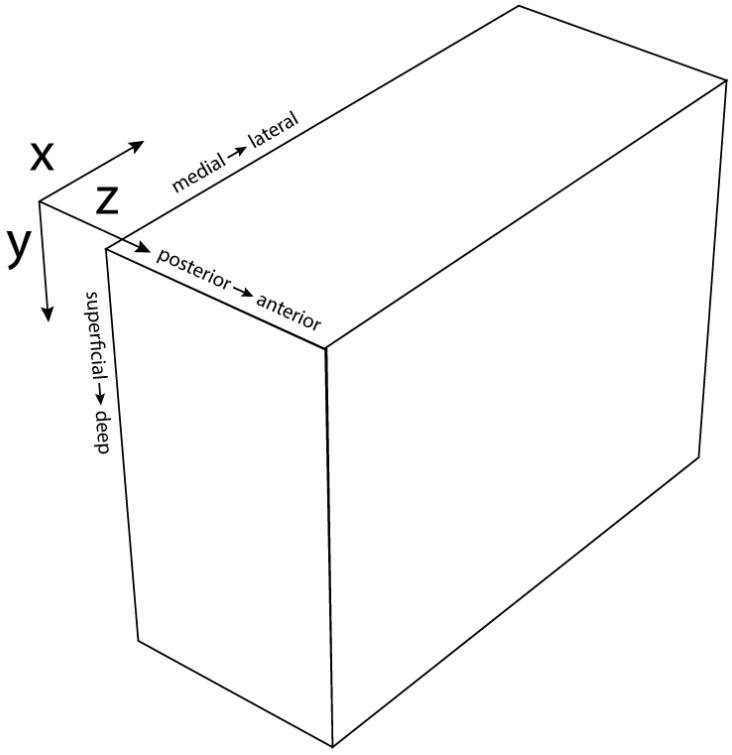

Figure 1: The axes and anatomical directions of the reconstructed EM volume.

Neuronal Compartments

Neurons are generally subdivided into three major compartments: Dendrites, Soma, and Axon. Both dendrites and axons typically originate at the soma, where the cell nucleus resides. All neurons in this release are of a specific type called cortical pyramidal neurons. The dendrites of cortical pyramidal neurons can be further subdivided into Apical, Basal and Oblique compartments. Basal dendrites originate at the soma and fan out laterally, while the single apical dendrite typically originates at the top of the soma and extends upwards towards the cortical surface. The apical dendrite can be divided into shaft and tuft, where the tuft branches upwards from the top of the shaft. Oblique dendrites originate from the apical shaft and radiate laterally. These dendritic compartments are thought to have important roles in signal processing. A schematic of these neuronal compartments is shown in Fig 2. The labels in this release were generated as described in [2].

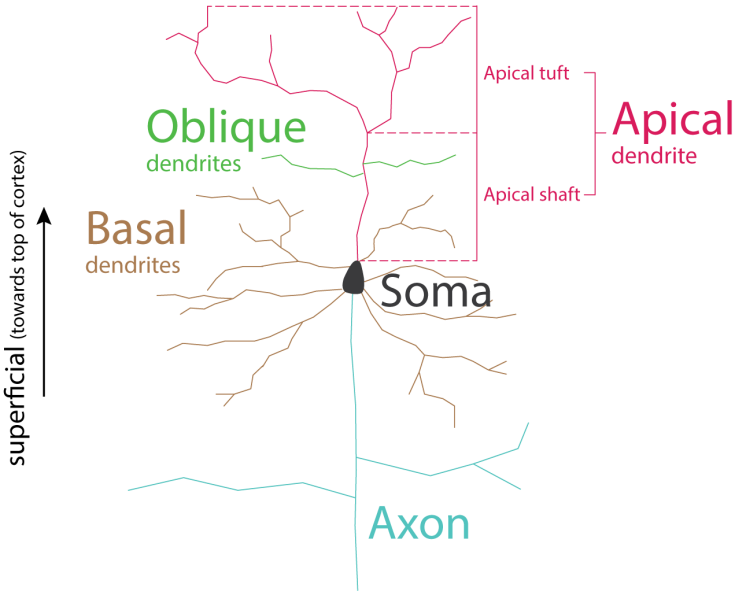

Figure 2: Schematic of cortical pyramidal neuron compartments.

Synapses & ADP's

Neurons send signals to other neurons with their axon and receive signals from their dendrites. The site at which communication occurs between the axon and dendrite is called a synapse. The neuron that formed the synapse with its axon is called the pre-synaptic neuron, and the neuron that formed the synapse with its dendrite is called the post-synaptic neuron. Synapses vary in size, and large synapses indicate a stronger connection between neurons. Fig 6 shows an example of a small vs a large synapse (as measured by the synaptic cleft volume). Additionally, a pair of neurons can have more than one synapse between them. An example pair of synaptically connected neurons and their synapse is shown in Fig 3.

When the axon of one neuron comes close to the dendrite of another neuron, we call this an axonal-dendritic proximity, or ADP. Every synapse results from an ADP, but not every ADP results in a synapse. When the ADP contains a synapse, we say the ADP has been "converted" to a synapse. It is of major interest to neuroscience what rules determine whether ADP's will convert to a synapse. In other words, what drives neurons to connect to each other, given that are within proximity (i.e. physically close enough)? Fig 4 shows an example synapse between an axon and a dendrite and a nearby dendrite that only forms ADP's with the axon.

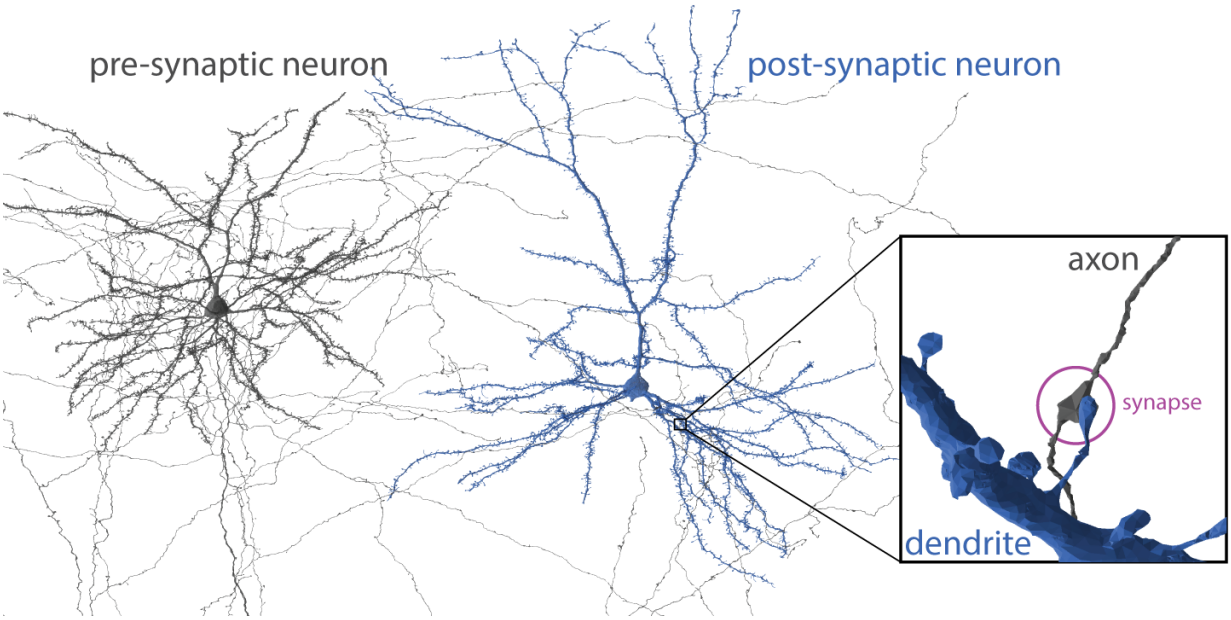

Figure 3: Pre-synaptic neuron (black) with its post-synaptic neuron partner (blue). Inset: Close-up of the synapse showing the axon (black) and the dendrite (blue) with the synapse highlighted in the purple circle.

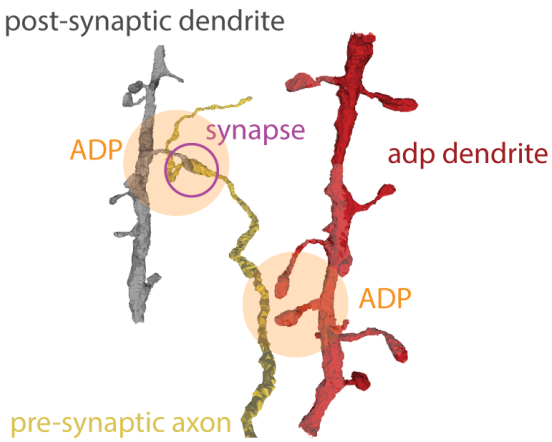

Figure 4: An example pre-synaptic axon (yellow) forming a synapse (purple circle) with the post-synaptic dendrite (gray) and forming an ADP (orange region) with a nearby dendrite (red). Note: the synapse is also contained within an ADP region.

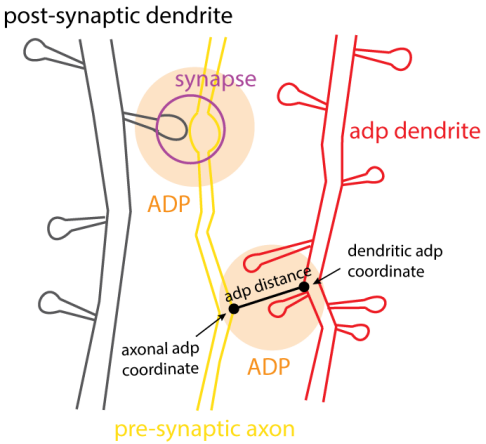

Figure 5: A schematic representation of Fig 4 with additional notation on the ADP between the pre-synaptic axon (yellow) and the ADP dendrite (red). Every ADP has a distance ("adp distance") that is measured between the two nearest points on the axon ("axonal adp coordinate") and dendritic skeleton ("dendritic adp coordinate"). Note: The ADP with the synapse also has these features though they are not annotated on the schematic.

Data Descriptions

There are three CSV files included in this release: 'data.csv', 'feature_weights.csv', 'morph_embeddings.csv'.

Each row in the 'data.csv' file contains information about one ADP. Two general types of information are included: per-neuron features and per-ADP features. Per-neuron features are features of a single neuron and in the CSV are prefixed with 'pre_' or 'post_' to refer to whether the feature originates from the neuron forming the ADP with its axon ('pre') or its dendrite ('post').

'feature_weights.csv' and 'morph_embeddings.csv' contains additional per-neuron functional features and morphoplogical features, they can be mapped to the ADPs included in 'data.csv' by matching the 'nucleus_id' column to either 'pre_nucleus_id' or 'post_nucleus_id' column in 'data.csv'.

*Some neurons do not have morphological embeddings and have NaN values instead

Features per neuron:			
Feature	Description	Additional Info	Ref
nucleus_id	ID of the neuron	integer	[3]
nucleus_x	x coordinate of the nucleus of the neuron	nanometers (nm)	[1]
nucleus_y	y coordinate of the nucleus of the neuron	nanometers (nm)	[1]
nucleus_z	z coordinate of the nucleus of the neuron	nanometers (nm)	[1]
brain_area	the brain area the neuron belongs to	V1 (primary visual area), AL (antero-lateral visual area), RL (rostrolateral visual area)	[1]
oracle	metric of neuronal response reliability to repeated visual stimulus presentation	ranges from 0 to 1, with 1 being most reliable	[4]
test_score	predictive performance of the deep learning predictive model on withheld test trials	ranges from 0 to 1, neurons with higher predictive performance are more likely to have meaningful feature weight and receptive field estimates	[4]
feature_weight_{i}	the i-th dimension of 512-dimension feature weight vectors from the readout layer of the deep learning predictive model	arbitrary unit and sign	[4]
rf_x	x coordinate of the readout location from the deep learning predictive model	correlates with the center location of the receptive field in visual space. ranges from 0 to 1960, with 0, 0 at the top left corner of the monitor (superior temporal aspect of left visual field)	[4]
rf_y	y coordinate of the readout location from the deep learning predictive model	correlates with the center location of the receptive field in visual space. ranges from 0 to 1080, with 0, 0 at the top left corner of the monitor (superior temporal aspect of left visual field)	[4]
morph_emb_{i}*	i-th dimension of 32-dimension morphological embeddings of dendritic arbor properties from a graph-based self-supervised learning approach	arbitary unit and sign	[5]

Features per Axonal-Dendritic Proximity (ADP):			
Feature	Description	Additional Info	Ref
axonal_coor_x	x value of axonal ADP coordinate	nanometers (nm)	[2]
axonal_coor_y	y value of axonal ADP coordinate	nanometers (nm)	[2]
axonal_coor_z	z value of axonal ADP coordinate	nanometers (nm)	[2]
dendritic_coor_x	x value of dendritic ADP coordinate	nanometers (nm)	[2]
dendritic_coor_y	y value of dendritic ADP coordinate	nanometers (nm)	[2]
dendritic_coor_z	z value of dendritic ADP coordinate	nanometers (nm)	[2]
adp_dist†	distance between the axonal ADP coordinate and dendritic ADP coordinate	nanometers(nm)	[2]
pre_skeletal_distance_to_soma	path length from the axonal ADP coordinate to the pre-neuron soma	nanometers (nm)	[2]
post_skeletal_distance_to_soma	path length from the dendritic ADP coordinate to the post-neuron soma	nanometers (nm)	[2]
compartment	label of neuronal compartment where ADP resides on the postsynaptic neuron	axon, oblique, apical, basal, soma, apical_tuft, apical_shaft	[2]
connected	whether at least one synapse is present at the ADP	boolean	[1]

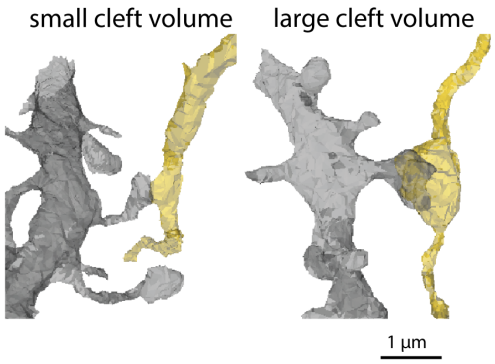

Figure 6: Example of a small (left) vs large (right) synapse (as measured by synaptic cleft volume).

†The coordinates for axonal (ADP) and dendritic structures in this dataset are stored as points on their respective skeletons, without taking into account the width of axons and dendrites. However, when calculating ADP (axonal-dendritic proximity) distances, we apply corrections for these widths. Consequently, ADP distances may not precisely match the direct Euclidean distances between axonal and dendritic coordinates, but they exhibit a high degree of correlation.

References

[1] MICrONS Consortium, J Alexander Bae, Mahaly Baptiste, Caitlyn A Bishop, Agnes L Bodor, Derrick Brittain, JoAnn Buchanan, Daniel J Bumbarger, Manuel A Castro, Brendan Celii, et al. Functional connectomics spanning multiple areas of mouse visual cortex. *BioRxiv*, pages 2021–07, 2021.

[2] Brendan Celii, Stelios Papadopoulos, Zhuokun Ding, Paul G Fahey, Eric Wang, Christos Papadopoulos, Alexander B Kunin, Saumil Patel, J Alexander Bae, Agnes L Bodor, et al. Neurd: automated proofreading and feature extraction for connectomics. *bioRxiv*, 2023.

[3] Leila Elabbady, Sharmishtaa Seshamani, Shang Mu, Gayathri Mahalingam, Casey Schneider-Mizell, Agnes Bodor, J Alexander Bae, Derrick Brittain, JoAnn Buchanan, Daniel J Bumbarger, et al. Quantitative census of local somatic features in mouse visual cortex. *bioRxiv*, pages 2022–07, 2022.

[4] Eric Y Wang, Paul G Fahey, Kayla Ponder, Zhuokun Ding, Andersen Change, Taliah Muhammad, Saumil Patel, Zhiwei Ding, Dat T Tran, Jiakun Fu, et al. Towards a foundation model of the mouse visual cortex. *bioRxiv*, pages 2023–03, 2023.

[5] Marissa A Weis, Stelios Papadopoulos, Laura Hansel, Timo Lüddecke, Brendan Celii, Paul G Fahey, J Alexander Bae, Agnes L Bodor, Derrick Brittain, JoAnn Buchanan, et al. Large-scale unsupervised discovery of excitatory morphological cell types in mouse visual cortex. *bioRxiv*, pages 2022–12, 2022.