APPLIED MATHEMATICS & STATISTICS

Proofreader Evaluation and Analysis toolKit (PEAK) for Nanoscale Connectomics

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Idea

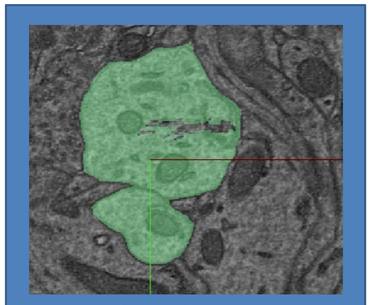
PEAK is seeking to improve quality of the largest high-resolution mouse visual cortex connectome by leveraging statistical principles for evaluation of proposed connectome edits.

Objectives

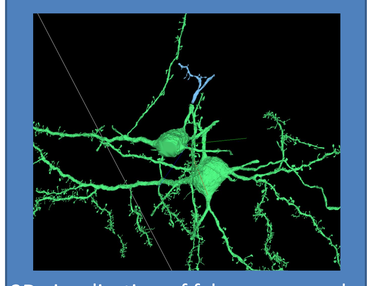
- Improve reconstruction integrity of the IARPA MICrONS dataset using manual proofreading edits evaluated by PEAK.
- Efficiently and effectively attribute performance scores evaluating individual proofreaders, considering multiple facets of the proofreading process including active proofreading time, correction difficulty, etc.

Opportunity & Challenge

- The increasing size of datasets renders state-of-the-art algorithms such as CNNs intractable due to computational cost.
- By abstracting the data to represent a brain graph as opposed to voxel-wise labelling, AGENTS provides a computationally cheaper method for cell segmentation.
- Predominant error types resulting from automated reconstruction include false merges and false splits, fixed primarily through manual proofreading by expert proofreaders.
- Millions of errors currently exist in the data. Limited numbers of expert proofreaders gives rise to a unique opportunity for citizen science to improve efficiency of error corrections; thus, a need arises to evaluate proofreader performance and quality.



EM data of false merge



3D visualization of false merge and false split

Impact

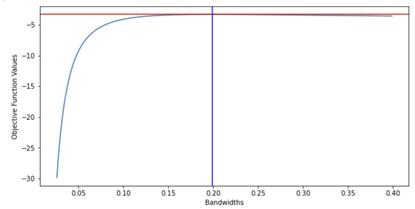
- Improve connectome quality using PEAK to assess and evaluate proposed connectome edits, enabling mass numbers of minimally trained proofreaders to quickly correct large volumes of data.
- Co-registration of structural and functional data is enhanced by improved connectivity information between individual neurons resulting from large scale manual proofreading edits.

Action

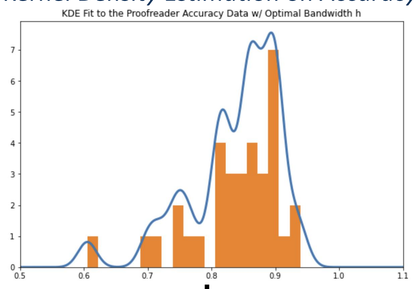
Prior Performance Scores

Collect results from proofreading tasks

Optimal Bandwidth Value Determination



Kernel Density Estimation on Accuracy



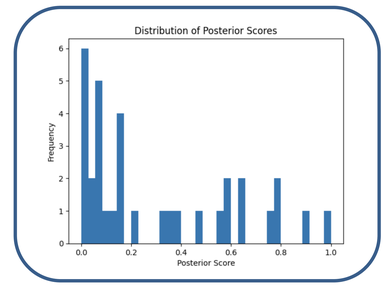
Compute CDF of Estimate Distribution

$$P[\theta|X] = \frac{P[X|\theta]\,P[\theta]}{P[X]}$$

θ : confidence in neuroanatomical edits
X : proofreader edits to the connectome dataset

Equation 1: Bayesian Paradigm Formula

Posterior Scores



Likelihood Metric

Assign Proofreading Tasks

Average Accuracy Rate

Average Completion Time

Other Performance Metrics

$S_f = [S_1, S_2, ..., S_n]$

$1/T_f = [1/T_1, 1/T_2, ..., 1/T_n]$

$1/D_f = [1/D_1, 1/D_2, ..., 1/D_n]$

$\phi(b_i) = (\frac{1}{2\pi})^{\frac{p}{2}} |\Sigma|^{\frac{-1}{2}} \exp(\frac{-1}{2}(\vec{x} - \vec{\mu})|\Sigma|^{-1}(\vec{x} - \vec{\mu}))$

Multivariate_normal $(\vec{\mu}, \vec{\sigma})$

PEAK Ground Truth Extraction Framework

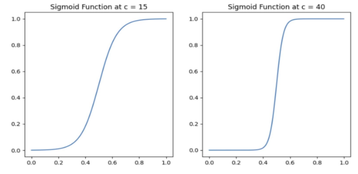
Use Posterior Scores → Apply Sigmoid Transformation → Determine Maximum Scores for each decision

n ~ the number of proofreaders completing a specific proofreading task

d_i ~ the decision made by proofreader i, $1 \leq i \leq n$

Let $Y = [y_1, y_2, ...y_n]$ ~ prior or posterior scores for each proofreader

Extract Final Task Decision



Results

- Measured performance of 26 student proofreaders over 6 months on 90 neuroanatomical correction tasks. Used PEAK to predict ground truth using proposed edits and proofreader performance metrics.

88% Accuracy rate for traditional methods

93.3% Accuracy rate for PEAK

- Significance testing (Two-way ANOVA) comparing accuracy rates of each evaluation model resulted in F-statistic = 34.395 and P-value = 2.486e-15. Therefore, we reject the null hypothesis and conclude significant results.

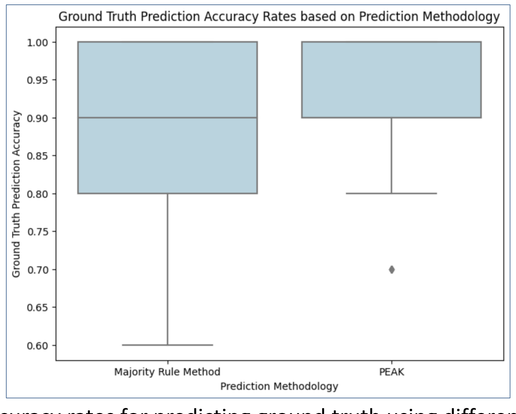


Fig. Accuracy rates for predicting ground truth using different methodologies on 500 random samples of 10 tasks

Acknowledgements

[1] Nathan Drenkow, Justin Joyce, Jordan Matelsky, Reem Larabi, Jennifer Heiko, Dean Kleissas, Brock Wester, Erik C. Johnson, William Gray-Roncal, "Leveraging Tools from Autonomous Navigation for Rapid, Robust Neuron Connectivity", bioRxiv 2020.04.30.070755, Available: https://doi.org/10.1101/2020.04.30.070755
[2] Reilly EP, Garretson JS, Gray Roncal WR, Kleissas DM, Wester BA, Chevillet MA and Roos MJ (2018) Neural Reconstruction Integrity: A Metric for Assessing the Connectivity Accuracy of Reconstructed Neural Networks. Front. Neuroinform. 12:74. doi: 10.3389/fninf.2018.00074