NEURON TRACING ALGORITHMS

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Background

Studying neuronal morphology is an essential step towards understanding the brain neuronal tissue functionality. In other words, understanding how the tissue structure reacts in different scenarios and understanding the role of neuronal cell network features can be inferred from the structure of the neuronal tree.

Tackling such challenge can be based on image analysis: visualizing neuronal structure using microscopy imaging and developing image analysis computational tools to quantitatively measure the structure. That means processing stacks of images to obtain digital representation (trace) of the cell morphology in 3D and measuring the size, amount and connectivity of the extracted cellular contents. Such task presently relies mainly on manual tracing and the aim is to automatize the process and substitute the manual labour with computer algorithms that would be faster and precise enough to compete with humans.

References

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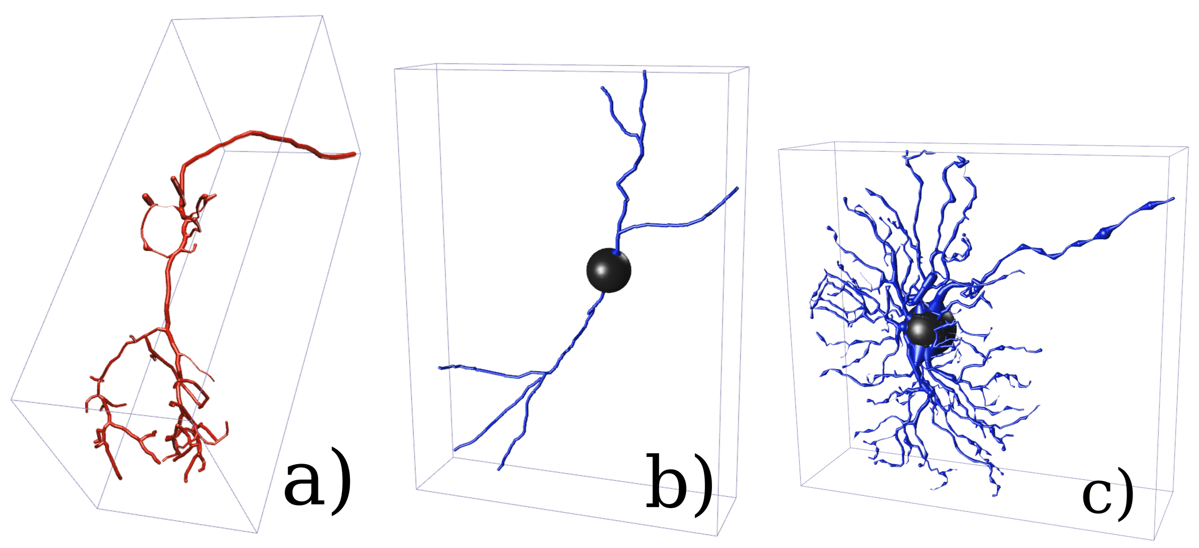
[3] T.A. Gillette, K.M. Brown, K. Svoboda, Y. Liu and G.A. Ascoli. DIADEMchallenge.Org: A Compendium of Resources Fostering the Continuous Development of Automated Neuronal Reconstruction. *Neuroinform, 9:303-304, 2011.*

[4] G.A. Ascoli, D.E. Donohue and M. Halavi. NeuroMorpho.Org: A Central Resource for Neuronal Morphologies. *J Neurosci., 27:9247-51, 2007.*

[5] H. Peng, Z. Ruan, F. Long, J.H. Simpson and E.W. Myers. V3D enables real-time 3D visualization and quantitative analysis of large-scale biological image data sets. *Nature Biotechnology, 28(4):348-353, 2010.*

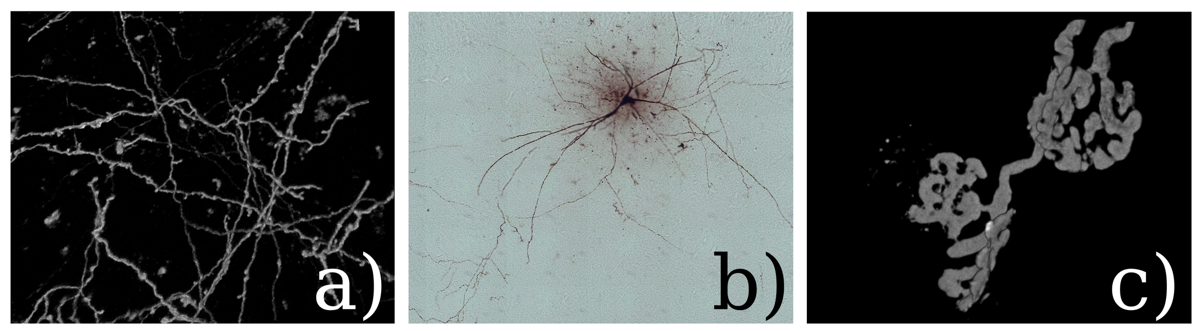
Challenge

Appearance - one of the main characteristics of neurons is their tree-like structure consisting of various branching styles. Therefore, neurons exhibit challenging diversity in variations of the 3D tree morphology that needs to be captured.



Neuron types (reconstructions provided by `NeuroMorpho.org`, [4]): a) axonal neuron (olfactory bulb), b) interneuron (neocortex), c) principal neuron (retina).

Imaging - different modalities provide with the images of different characteristics such as noise or contrast.



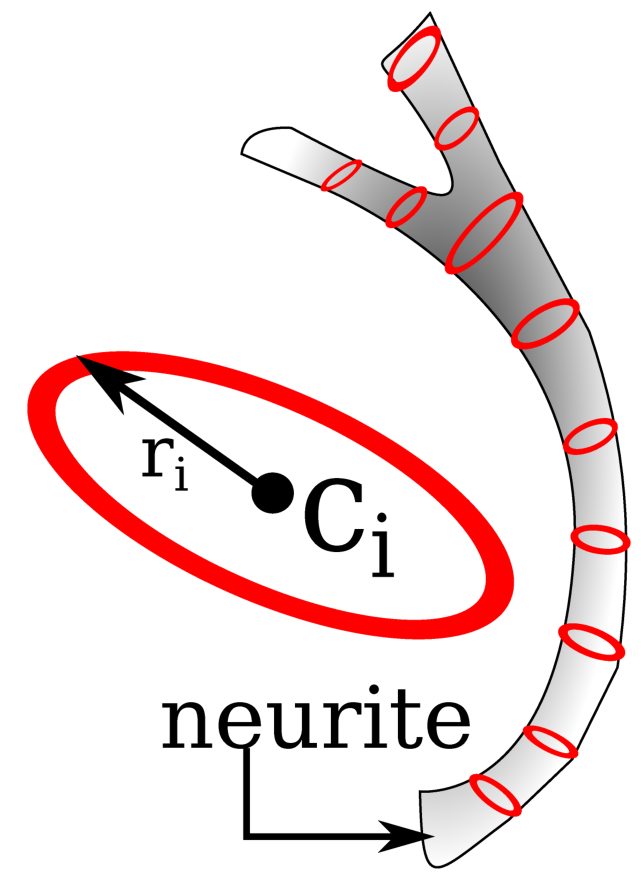
Imaging methods (DIADEM challenge images, [2]): a) 2-photon lasers scanning microscopy, b) transmitted light brightfield, c) confocal microscopy.

Current neuron analysis practice involves storing all the captured image data for later processing. Raw images are sparse and have limited scientific usability. It is necessary to further automate the process since manual tracing tends to be laborious and extremely time-consuming.

Artificial intelligence - despite neuron tracing being relatively mature problem, the state of the art of neuron tracing algorithms does not provide with fully automatic methods, accurate or robust enough to replace often used manual or semi-automatic tracing.

Digital reconstruction methodology

Image analysis generally consists of four stages resulting in full digital reconstruction [1]: image preprocessing, cell body segmentation, tree segmentation and spine segmentation. Segmentation proves to be the most decisive and volatile stage of neuron reconstruction. Each stage employs various image processing and computer vision approaches to comprehend the 3D structure.



Branch trace scheme.

Digital reconstruction (tracing) methods describe the cell in a comprehensive manner - as a sequence of body centerlines (centerpoints) c_i, radii r_i together with the connectivity information (sequence).

Tracing can be based on **global** or **local** processing:

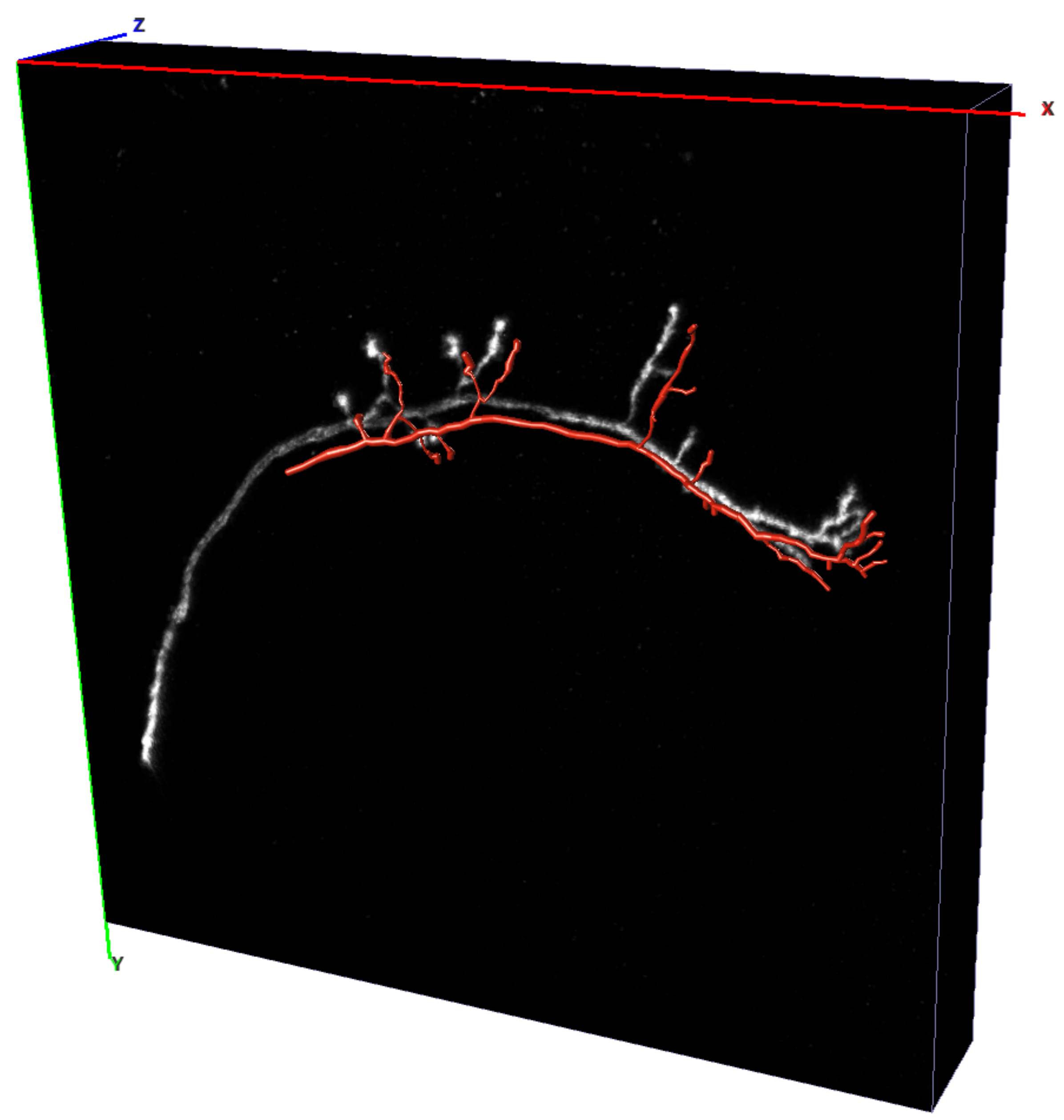
- global - performs image processing algorithms (e.g. binarization, skeletonization) on the complete image space.
- local - processes only the regions where cell structures exist.

Both paradigms are challenged by image inhomogeneities. Local tracing focuses on the relevant areas only. Starting from the detected points of interest $\{c_0, r_0\}$, local tracing recursively predicts the next iteration's neurite segment $i+1$: $\{c_{i+1}, r_{i+1}\}$ and associates it with the previous iteration's trace i.

Project objective

Develop neuron tracing approach that is:

- ✓ Automatized - independent from human interaction as much as possible.
- ✓ Versatile - generally applicable for different imaging modalities and neuron types.
- ✓ Accurate - precise enough to compete with manual tracing being significantly faster at the same time.
- ✓ Robust - capable of comprehending the structure with the presence of noise or image artefacts.



Tracing outcome - original & reconstruction of Olfactory Projection Fiber neuron [3].
(Rendered using Vaa3D visualization tool [5])