Automatic Reconstruction of Neuron Morphology: The Survey on Reconstruction of Neurons

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Abstract: *The tracing of neurons and automatic reconstruction of neuron morphologies involves various techniques. Neurons have complex axonal and dendrites morphologies that are the structural building blocks of neural circuits. The neural cells microscopic image provides important structural information about the constituents of brain that forms the basis for many neuroscience studies. Reconstruction of the (3D) three dimensional neuron morphology is important to understand brain's structure and function .3D of image stacks in real time is provided by the V3D system. Structural information into digital tree like reconstruction is done for computational analysis of neuron that has been captured. Multi-scale tracking techniques used to detect branching structures of neurons. Probabilistic filtering by sequential is used for tracing neuronal branches in microscopic image stacks. Analysis of neuronal morphology is done by SWS format. In this paper, our main goal is to present the review of automatic reconstruction of neurons using various techniques and purpose the comparison between each of them along with their respective pros and cons.*

Keywords: *Neuron morphology, V3D system, Multi-scale tracking, Probabilistic filtering, SWS format*

I. INTRODUCTION

This paper provides a comprehensive survey on automatic reconstruction of neurons by tracing neurons. Brain is considered to be one of the most composite and mystifying biological structure. Over past few decades, biologist or researchers' have developed tools and algorithms to reconstruct 3D neuron morphology. Big Neuron project is launched to compare automated algorithms. Structure of the neural circuits is an important challenge in neuroscience and can illuminate the understanding of their function. Reconstruction of same neurons is done by comparing axonal branches. Design of automatic or semi-automatic reconstructing methods is done by novel imaging technique, using microscopic images of stacks. Tree shaped neuronal cell together forms a powerful information processing unit, it performs functions that are crucial to all living organisms. Quantative measurement and statistical analysis of neuronal cell and network properties from microscopic data rely on the ability to obtain accurate digital reconstructions of the branching structures in the form of directional tree of connected nodes. Automating neuron reconstruction includes solving fundamental computer vision problems such as detecting and segmenting tree like image structures.

Reconstruction of neuron morphologies in light microscope images is essentially done to understand brain structures and functions. In this task, the input is images and the output is usually a tree structure, which can be described by the SWC file format. Although numerous neuron reconstruction software tools have been developed for producing SWC files none of them have taken full advantage of the SWC format to optimize the user interface for efficient and accurate reconstruction as shown in figure 1.

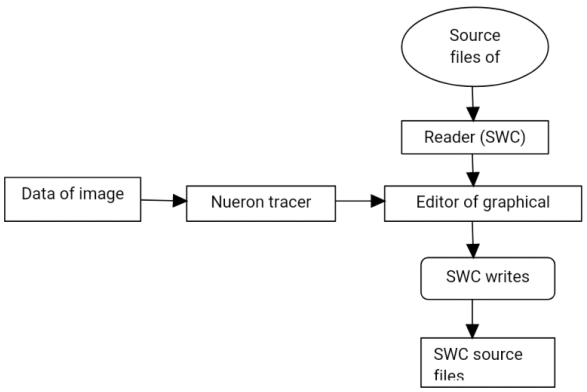

Fig 1: Workflow of reconstructing or editing a neuron structure in the SWC

Our aim to contribute in this survey is to provide developments in the field by proposing a novel fully automated neuron reconstruction method based on probabilistic filtering techniques. Starting from seed points that have a high probability of being centered at neuronal branches, our method recursively traces these branches by sequential Monte Carlo estimation, using state transition and measurement

models designed specifically for this purpose. This results in a series of possibly overlapping but probabilistically independent estimates of the branches, which are subsequently combined into a refined estimate of the actual branch centre lines using mean-shifting. Our main contribution is to introduce multi-scale techniques, combining both local and global information, for automatic detection and separation of branches. Our algorithm does not rely on ridge information, requires only a single initialization by the user and appears robust on tests on noisy data-bases.

II. RELATED WORK

The number of neuron tracing tools was developed including manual, semi automatic and full automatic for analysis and correcting faulty results of neuron structures. With the increasing capabilities of computers it became possible to store and process 3D images of neurons by [Cohen et al, Belichenko and Dahlstr¨om]. More recently, the state-of-the-art in the field has moved towards full automation of neuron reconstruction, and various freely available software tools are now available for this purpose though the need for flexible editing tools has remained unabated Neuron reconstruction methods typically have a modular design where each module or stage of the processing pipeline deals with different structural objects. Depending on the sub problems being solved, modules can operate independently, or work together for example to combine local and global processing, possibly requiring multiple iterations. Several sub problems that can be identified in the literature include image pre-filtering and segmentation soma (cell body) detection and segmentation, landmark points extraction, neuron arbor tracing and assembling the final tree-like graph structure. In the remainder of this section we briefly review techniques for solving each of these sub problems. Since our primary goal in this paper is to present a new method, the review is not meant to be exhaustive, but to put our method into context.

The data sets used in this study come from the DIADEM challenge (Brown et al., 2011; Gillette et al., 2011). Specifically, used data from olfactory projection fibers, a neocortical layer 6 neuron, cerebellar of climbing fibers and a hippocampal CA3 inter neuron. All data sets were originally manually reconstructed in 3D into SWC files. In Multi-scaling technique for generating synthetic data sets the actual photon count $n(x, y, z)$ was randomly generated for each voxel from the corresponding Poisson distributions[3]:

$$p(n \mid x, y, z) = \frac{\exp[-\mu(x, y, z)]\mu(x, y, z)n}{n!}$$

In Multi-Scale tacking techniques branching detection uses the Dijkstra's algorithm initialize multi-scaling procedure by [Anaa Choromanska Shih-Fu Chang &Rafael Yuste][4] defined the spread of points in the set P as:

$$spread(P) = \max(\mathrm{p1}, \mathrm{p2}, \in \mathrm{p}, \mathrm{p1} \neq p2) \frac{\| \mathrm{p1} - \mathrm{p2} \|}{\mathrm{R}}$$

In automated neuron reconstruction from 3D fluorescence microscopy images using Sequential [Monte Carlo Estimation] here the pipeline of proposed method consists of six steps: Soma Extraction, Seed Extraction, Branch Tracing, Trace Refinement, Node grouping and Tree Construction. It make use of node grouping algorithm[6]. The node links within a group are accumulated and their indexes mapped to the group node index list.
This results in a new set $\hat{N} = \{ \hat{n}1, \ldots, \hat{n}P \}$, $P \leq M$, of group nodes:

$$\hat{\mathrm{n}}\mathrm{k} = \{\mathrm{P_k}\ , \mathrm{R_k}\ , \mathrm{C_k}, \mathrm{I_k}\}$$

$$\hat{n}k = \frac{\sum_{n \in N} \Psi(n - n_k)\ .n}{\sum_{n \in N} \Psi(n - n_k)}$$

In Reconstruction of neuron based on the SWC framework, have built neu Tube 1.0 as a GUI application upon four core modules: 2D visualization, 3D visualization, image analysis, and neuron structure operation explained by [Linqing Feng, Ting Zhao, and Jinhyun Kim][5].

Next, V3D provides a highly efficient and ergonomic platform for visualization-based bioinformatics. In particular, it features two critical and advantageous techniques, i.e. a responsive 3D viewer for multi-gigabyte volumetric image data and a 1- or 2-click pinpointing method. The output of such analyses, or of fully automatic analyses. The software runs on all major computer platforms (Mac, Linux, and Windows).

V3D comes with a carefully designed graphical user interface, and supports the most common file formats. These features make it useful not only for neuroscience, but also in molecular and cell biology, and general biomedical image engineering explained by [Hanchuan Peng, Zongcai Ruan, Fuhui Long, Julie H. Simpson, and Eugene][1]. The emerging flood of multidimensional cellular and molecular images poses enormous challenges for the image computing community. The V3D visualization engine optimizes OpenGL calls to maximize the 3D rendering throughput of a computer graphics card[1].

The critical review of the discussed Automatic Reconstruction of neuron morphologies in different papers are shown in below table 1:

***Table I*:** Reconstruction of neuron using different techniques in different papers from [1] to [6].

SL.No.	Title	Author and Year	Proposed Technique	Algorithm Used	Pros	Cons
1)	V3D enables real-time 3D visualization and quantitative analysis of large-scale biological image data set	Hanchuan Peng, Zongcai Ruan, Fuhui Long, Julie H. Simpson, and Eugene W. Myers (2010)	Quantitative analysis in microscopy image stacks	3D traced neuron	Maximize the 3D rendering throughput a computer graphics card. Fast and robust	Restriction on image size
2)	Automated tracing of neurites from light microscopy stacks of images	Paarth Chothani, Vivek Mehta, and Armen Stepanyants (2011)	3D LM stacks of images	Automated tracing algorithm	Faster and easier to connect broken branches with editing software than to find and repair erroneous connections	Complete connectome description of large circuits unrealistic, at least for the time being.
3)	Automatic 3D neuron tracing using all-path pruning.	Peng H (2011)	3D laser scanning microscopy	Maximal-covering minimal-redundant (MCMR) sub graph algorithm	APP method to trace the 3D structure of a neuron fast.	Anisotropic property of image voxels makes it hard to estimate the radii of neuron reconstruction nodes.
4)	Automatic reconstruction of neural morphologies with multi-scale tracking	Anaa Choromanska Shih-Fu Chang &Rafael Yuste (2012)	Multi-scale tacking	Dijkstra	This technique posses ability to detect branching structure appear a promising stratergy for automatic neuronal reconstruction	It poor results on highly overlapping neural process when using blurred images.
5)	Efficient Neuron Reconstruction Software Based on the SWC Format	Linqing Feng, Ting Zhao, and Jinhyun Kim (2014)	SWS format (neu.Tube 1.0)	Semi-automated tracing algorithm	It improves efficiency of reconstructing neuron structures accurately.	It is not designed to solve the problem of high-throughput neuron tracing.
6)	Automated Neuron Reconstruction from 3D Fluorescence Microscopy Images	Miroslav Radojevi´c1. Erik Meijering1 (2018)	Probabilistic filtering by sequential Monte carlo Estimation	Node grouping	PNR(Probabilistic Neuron reconstruction is a robust method	During tracing no single method can posses post-processing step.

The analysis states that, the above proposed techniques which are forwarded are having their respective algorithms which are unique to their data, which are computed to give the results as outputs. The processing capability differs from one technique to the other. Also there are numerous advantages and disadvantages for the proposed techniques and algorithms used. Each and every technique is best to their own approach towards automatic reconstruction of neurons, which is depending on the data to be taken as an input. Since the research on the "Automatic reconstruction of neuron morphology" topic from year to year is improving with respect to performance

III. CONCLUSION

We have presented the review on methods of different images of reconstruction of neurons that are presented so far. The advantages and disadvantages are discussed as comparative analysis. In addition to this we have given the information about different kinds of proposed techniques and the algorithm used which are frequently used for research studies as well as performance evaluation metrics. In spite of huge research, there is no universally accepted method for tracing of neurons, as of the result of reconstruction of neuron morphology is affected by lots of factors. Thus there is no single method which can be considered efficient. All methods are equally good for that particular type of reconstructing neuron. Due to this, reconstruction of neurons remains a challenging problem in Image processing.

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