Gouraud Shading to Improve Appearance of Neuronal Morphology Visualization

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Abstract

This study is focused on Gouraud Shading's approach to improve appearance of neuron visualization. Neuron visualization is a computational tool that is able to describe, generate, store and render large set of three-dimensional neuronal morphology in a format that is compact, quantitative, and readily accessible to the neuroscientists. This tool enlightens its ability as a powerful computational modeling of neuronal morphology to explore greater understanding in neuron developmental processes and structure-function relationships. However, after a thorough investigation, one of the problems discovered in neuron structure prediction is related to misleading in generating digitalized neuron raw data toward realistic neuron morphology visualization. For that reason, many approaches have been proposed in previous studies in order to perform such visualization based on stochastic sampling data of morphological measures from digital reconstructions of real neuron cells. Therefore, comparison among these approaches has been conducted to recognize a suitable approach. It is still at a preliminary stage in research development. This exercise reveals a constraint to

reconstruct neuron model towards greater realism efficiently is still remains as an essential challenge in biological computing and visualization to provide a broad appearance of neuron knowledge distribution. As a result, the areas of comparative neuron analysis can be aided through presenting the knowledge of realism virtual neuron morphology. As a proposal, Gouraud Shading's approach is applied for this purpose. Gouraud Shading is a visualization shading technique to perform a smooth lighting on the polygon surface without heavy computational requirement in calculating lighting for each pixel but at vertices only. The conclusion is summarized based on verification exercise between our framework's results with existing results from three neuron visualization applications. The comparison analysis is done in term of reliability and smoothness of surface neuron presentation. Roughly the proposed framework achieved the objective to solve the problem encountered in presenting virtual neuron data.

Keywords: Neuron morphology data, visualization, Gouraud Shading

1. INTRODUCTION

Basically, the neuron visualization application depends on the product information and neuron structure presentation criteria to simplify and contribute to an extensive study of brain's functions and/or dysfunctions. By applying such applications especially in lab-experimenting, it potentially facilitates scientist's life to do thorough analysis in determining the relations between neuron's connection and its function. Thus, apparently, extraction and accuracy is an important aspect in generating the reconstruction neuron morphology visualization.

The development of digital neuron visualization is rapidly increases as a significant prerequisite in the quantitative exploration of cellular neuroanatomy. Recently, neuron morphology data has been gathered and published in digital databases offering variety of dendritic structure. One of the famous databases is known as Duke Southampton [23]. However, the approach that is applied in this database presents static image of neuron. As such, there is a certain situation where neuron structure is unable to be extracted in details because of no interaction facility to manipulate the neuron's presentation. It requires specific tool to apply this useful data for knowledge distribution.

Based on the above review, a lot of approaches have been proposed by previous researchers. Findings from these studies showed that the core rationale of these executions were prominence on tool for constructing and generating the anatomical neuron network model. These established applications' approaches are able to provide facility to access simulation of neuron morphological but they remain to offer a greater biological realism of virtual neuron model. Finally, in our proposed framework, we are able to produce comparable neuron model as per existing application's output as well as toward realistic presentation in order to be applied by a group of scientists who are involved in neuron analysis study.

The reminder of the paper consists of a detailed explanation on the proposed approach, description of neuron computational environment and data used in material and method to improve appearance of neuronal morphology visualization, the result and discussion of proposed approach, and the conclusions of the achieved results.

2. PRELIMINARIES

The practice of medicine and biologic investigations lies in direct, fully immersive, real-time multisensory fusion of real and virtual information data streams into online, real-time available during actual clinical procedures or biological experiments had offered the potential for revolutionary innovation in biomedical application. These goals are able to be materialized and realized with major facilitation progress of current high-performance computing, advanced image processing and high-fidelity rendering capabilities. With these advances offered in the current technology, there are several significant applications of three-dimensional visualization established to perform an impact to the practice of medicine and biological research.

The study of biology always dependent on visualizations tools to explore the relationship of an anatomic structure [22] to biologic function to detect and treat disease that disturb or threaten normal life processes. The value of biomedical images i.e neuron cells largely depend on the context from which they are obtained either for the scientific or medical interest and goals that motivate their production and use. However, the valuable potential of 3D visualization in neuron cells remains mostly unexploited and practical tools remain undeveloped. The most recent requirement is to continue advances in visualization technology to the level of utilization, so that they can provide new tools and procedures that physicians can apply to treat their patients and empower scientists in neurology studies of structure-to-function relationships.

As such, a particular challenge in imaging science for biomedical applications need to be focused is to provide realistic displays, interactive manipulation and simulation and accurate and reproducible measurements. This is because an adequate description of neuronal morphology is significantly for investigating the influence of morphology in information processing of neurons.

Neuron Data Acquisition

Basically neuroanatomical experiments result in chemically processed tissue accumulated on a microscope slide. This corresponding observable microscope image can only be further manipulated in a limited way. It involves the computer acquisition or digitization as a key step toward the flexible, quantitative, an extensive analysis and modeling of these data. The result from digital files is represented by data in numerical (machine-readable) format. A major benefit of digital representation of neuronal morphological is a virtually and geometrically feature captured by the cylindrical-based description can be measured statistically and analyzed quickly, reliably, and precisely [19].

This digitally neuron raw data have been stored in different format in several published databases for easy sharing and allowing for visualizing and capturing purposes. There are three (3) popular digital adopted formats to describe neuron morphology which are ‘SWC’, ‘Neurolucida’ and ‘Eutectic’ format. Even though it is provided in a different format, it is still used in the basic structure of neuron data [2]. These files can range from 500 lines for small and simple cell to 10,000 or more lines for large and complex cells. In this purpose, ‘SWC’ format will be applied and details explanation about its basic structure will discuss. This neuron morphology data was acquired from Duke-Southampton website. This database provides neuron cell images for rat hippocampus that consists of CA1 pyramidal cell, DG granule call and CA3A pyramidal cell in different age as per example in Figure 1. Generally, before neuron can be visualized by the extractor, digitalized neuron data will be loaded into the system.

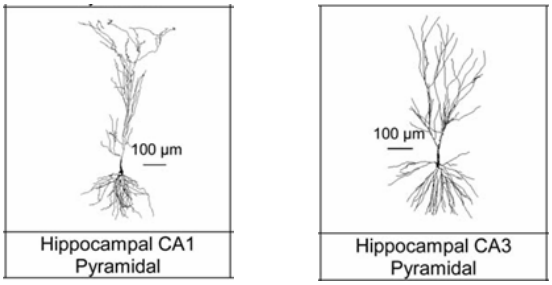

FIGURE 1: Sample cell of neuronal morphology used as data for this study [11].

'SWC' format is for describing the structure of neuron in the simplest way and has been designed to emphasis on compactness and uses the minimum amount of information and number of fields to fully describe the branching structure [17]. Basically in 'SWC' format, each neuron dendritic segments is represented by an identification number (ID, the number reported next to the branches in the picture), a type of distinguish basal (T), Cartesion positions (X,Y,Z in micrometers), radius (R), and end-point connection (C, presenting the label of the parent) [2,12,23] as per stated in Figure 2, refer to the right panel. As shown in Figure 2, each tracing point is represented as a row of seven numbers [2,12,23] that describes the properties of a single compartment, an arbitrarily sized piece of a segment.

ID	T	X	Y	Z	R	C
1	1	–1.5	–8.2	1.3	3.8	–1
2	3	0.8	4.2	1.4	2.3	1
3	3	21.1	41.1	1.4	1.3	2
4	3	89.2	115.1	–5.3	1.1	3
5	3	153.6	163.5	3.0	0.6	4
6	3	184.9	218.1	–2.3	0.5	5
7	3	220.9	238.7	–13.7	0.3	6
8	3	159.9	183.9	–23.6	1.1	4
9	3	211.9	270.9	–35.2	0.7	8
10	3	0.6	58.1	–2.6	1.1	2
11	3	–0.5	75.9	–18.6	1.1	10
12	3	–40.5	180.0	–55.3	1.0	11
13	3	–156.4	281.8	–65.9	0.8	12
14	3	0.3	186.8	–7.0	0.8	12
15	3	–51.5	235.7	–27.0	0.8	14
16	3	–85.2	297.6	–41.5	0.5	15
17	3	75.3	198.3	–54.6	0.8	10
18	3	130.6	228.6	–81.3	0.5	17

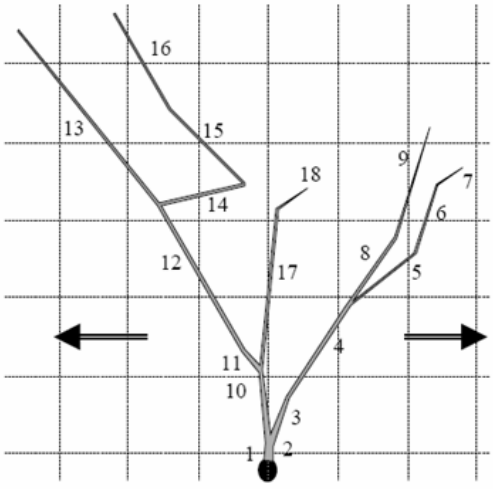

FIGURE 2: Digital representation of neuron morphology from 'SWC' format data (left panel) [12].

This segment may either branch into further segment at a bifurcation or end at a terminal (both of these segments are also represented as compartments), make up the entire neuron shapes. These varieties of neuron shapes attain through a development process called of elongation and branching of axonal and dendrites extensions [1,2,3,4].

Such digital reconstruction files are efficient and allow extensive morphometric analysis to be produced from implementation of biophysical virtual neuron models as allowing 'pseudo-3D' rendering and animation in modern computer graphics [12]. In general, this digital format consists of a plain text file that each line describing the cylindrical geometry of neuronal segment and its connection to derive any morphological measurement.

Reconstructing and Modeling

The tracing process involves converting described neuronal morphology from Cartesian data into a digital three-dimensional (3D) coordinates and branch connectivity of the corresponding trees. In this process, the link segment of digitized neuron data is traced automatically from identified format data mentioned previously and followed by generating a branching of cylindrical neuron compartments. The system will scan the uploaded data in order to differentiate between HEADER

part and CARTESIAN data. This process will recognize the first character represented by "#" in the HEADER. After all the "#" character has been emphasized and the HEADER part has been traced, the system will read and translate the neuron CARTESIAN data line by line. The simulated neuron branching from CARTESIAN data is generated by continuous compartment as shown in Figure 3

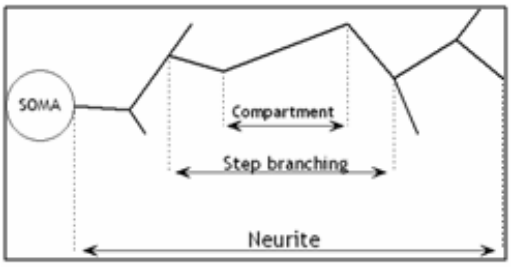

FIGURE 3: A part of simulated neurons.

The traced data is visualized via reconstruction model aims at finding minimal algorithms for generating trees which reproduce the statistical properties of observed neuronal shapes [2]. Reconstruct virtual neuron applying dissimilar color to represent different type of neuronal segment. The first soma was indicated by sphere and cylindrical to represent neuron connection consist of dendritic and axon. As summarized, the reconstruction process is illustrated as per Figure 4.

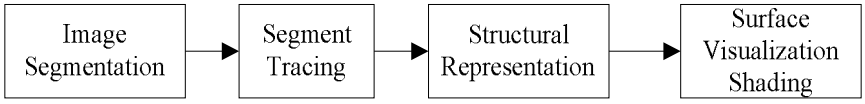

FIGURE 4: A summary of neuronal morphology reconstruction pipeline.

Surface visualization shading approaches

According to J.C Fiala [19], the most reliable method is computer aided tracing profiles on neuron segments followed by rendering it with appropriate shading. Shading technique is the process of assigning colors to the pixels. The implementation with a smooth shading and lighting is understood can assist in reconstructing neuron morphologies toward realistic visualization. The purposed of shading algorithms is to smooth the appearance of polygonal model by reducing the impact of sharp edge in order to give the eye the impression of a smooth curved surface.

In is this part, Gouraud shading (GS) technique is applied to neuron surface visualization in order to perform a smooth lighting on the polygon surface without the heavy computational requirement of calculating lighting for each pixel but at vertices only. This approach was applied because it able to provide the objects i.e the series of cylindrical that as neuron connection towards realistic surface. The comparison between curved surfaces rendered using flat shade polygons and curved surface rendered using Gouraud Shading is shown in Figure 5.

GS also called intensity interpolation provides a way to display smooth shaded polygons by defining the RGB color components of each polygon vertex based on the color and illumination to eliminate intensity discontinuities. GS is the simplest rendering method and it computed faster than Phong Shading. It does not produce shadows and reflections. GS smoothes the appearance of the object by linearly interpolating intensities along scan lines.

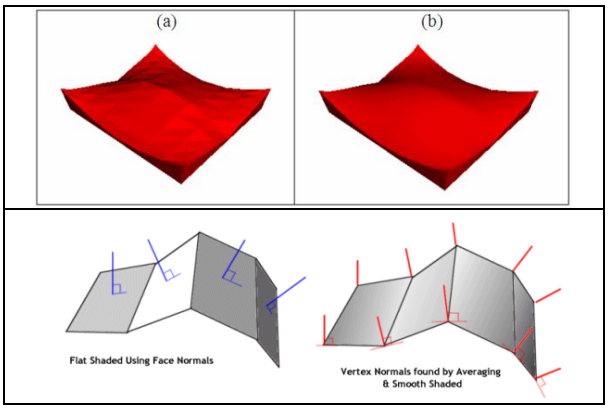

FIGURE 5: A comparison between curved surface using (a) flat shaded and (b) Gouraud shaded.

The purpose of GS is to eliminate Mach bands, discontinuities in intensity along polygon edges. It reduces the visibility of polygonal edges by blurring the intensity across the boundaries of adjacent polygons. The underlying strategy is to compute the intensities for the pixels in 3 steps:

- Calculate the intensities at the individual vertices of the polygon
- Interpolate these vertex intensities along the edges of the polygon
- Interpolate these edge intensities along scan lines to the pixels in the interior of the polygon (as per illustrated in Figure 6)

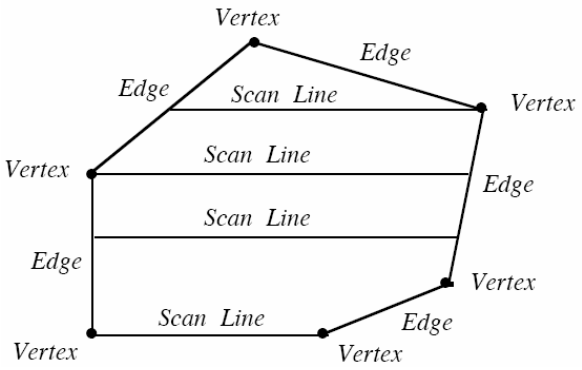

FIGURE 6: Gouraud shading mechanims.

In order to compute the intensity at a vertex, we require to obtain the unit normal vector at the vertex. Since each vertex may belong to many polygons, we first use Newell's formula (equation 1.1) to calculate the unit normal for each polygon containing the vertex.

$$N = \sum_{k=0}^{n} P_k \times P_{k+1}. \qquad \{P_{n+1} = P_0\} \tag{1.1}$$

We then calculate the unit normal vector by everaging the unit normal of the polygons containing the vertex:

$$N_{vertex} = \frac{\sum_{vertex \in Polygon} N_{polygon}}{\left| \sum_{vertex \in Polygon} N_{polygon} \right|}. \tag{1.2}$$

Finally, we apply equation 1.3 to compute the intensity at the vertex.

$$I_{uniform} = \underbrace{I_a k_a}_{ambient} + \underbrace{I_p k_d (L \bullet N)}_{diffuse} + \underbrace{I_p k_s (R \bullet V)^n}_{specular}, \quad (1.3)$$

Once we have the intensities at the vertices, we can apply linear interpolation to compute intensities first along edges and then along scan lines.

Notice that for adjacent polygons, intensities necessarily agree along common edges because the intensities agree at common vertices. Moreover, on both sides of an edge, the value of the intensity near the edge is close to the value of the intensity along the edge. Thus linear interpolation of intensities along scan lines blurs the difference in intensities between adjacent polygons. This blurring eliminates Mach bands and provides the appearance of smooth curved surfaces.

The Gouraud Shading algorithm is an example of a scan line algorithm. A scan line algorithm is an algorithm that evaluates values at pixels scan line by scan line, taking advantage of the natural coordinate system induced by the orientation of the scan lines.

3. CONSLUSION & FUTURE WORK

Comparative Discussion

In this study, the system is developed to visualize neuron structure focuses on rat hippocampus cells, generate digitalized data from 'SWC' format and rendered its surface using Gouraud Shading approach. This is a new simplified prototype for constructing neuron structure model with properties closely matches with 3D neuronal morphology and connectivity.

The 3D scene is created using an OpenGL graphics window for previewing the 3D representation neuron. When a neuron is loaded to the scene, a 3D representation is generated from the object's component traces. The scene is rendered with the fidelity of the computers' OpenGL implementation and this generally allows the diffuse, ambient, emissive and transparency properties of objects to be specified. An OpenGL has been chosen to create the 3D model since it significantly speeds up the rendering and the real-time visualization.

Due to result raised from analyzing constraints of neuron structure prediction, a proposed area of comparative neuron study will be aided by performing the knowledge of virtual neuron connection structure. This study is focus to two main constraints where the first scope is related to misleading in generating digitalized neuron raw data toward realistic neuron morphology visualization. Previously, this data is represented as static view in archive database and certain developed neuron visualization system requires programming expertise to apply it. When the structure is restricted to achieve, this framework is introduced to visualize neuron raw data by integration of reconstruction model and surface rendering technique aim to produce neuron morphology toward realistic structure presentation. From this proposed approach, the framework's result was validated based on comparison with produced result from three selected existing program. The validation is measured in term of visualization quality towards greater realistic biological performance and accuracy of presentation virtual neuron. The development from our proposed framework was produced a neuron model as accurate as existing application.

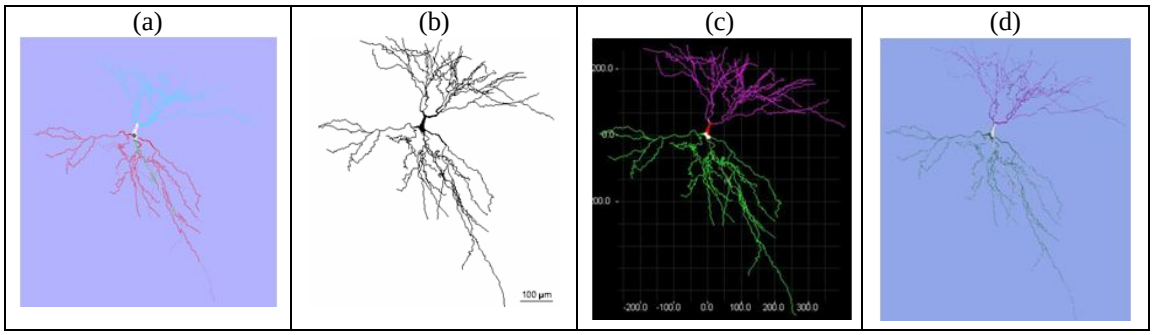

FIGURE 7: Validation and comparison result of visualizing neuron model of digital file between (a) our proposed framework and existing application, (b) result from Duke-Southampton which only presented static neuron model, (c) result achieved from CVapp program which having time constraints to fetch list of neuron selection and (d) result produced from neuroConstruct program which still presented a less realistic neuron especially for solid presentation type and slow in re-perform the neuron model after displaying other type of visualization mode.

Figure 7 shown the result discovered from comparison exercise for one of neuron sample. In this effort, Gouraud shading techniques has been embedded in our proposed neuron visualization application. The major contribution by introducing such shading algorithms in this framework is able to furnish smooth appearance of polygonal model by reducing the impact of sharp edge in order to give eyes the impression of a smooth curved surface. In CVapp, its application is for editing and converting morphology files either read or write the data from variety format i.e neurolucida .ascii, SWC, genesis .p and neuron .hoc. Still, each compartment presented in CVapp is listed as a line with its coordinates, parent compartment, and diameter. neuroConstruct also one of application that the creation, visualization, and analysis of networks of multicompartmental neurons in 3D space. It provides a number of functions to facilitate the clear display of large networks, cells with complex morphologies and individual synaptic connections. These include showing the dendrite and axon as lines or just showing ball-shaped somata rather than the full 3D structure of each cell. Even both applications able visualize neuron reconstruction model, however they still not emphasize on the appearance of neuron model which rendered the model by default without applied any shading. The priorities for those developments are only focus on ability to generate accurate network models wit properties that closely match the 3D neuronal morphology and connectivity of different brain regions. Still, in neuroConstruct [8] envisioned in its extensions will allow greater biological realism. Only in late 1990, one development [21] had applied volume rendering techniques with shading to reconstruct and visualize a 3D volumetric model of a dendritic. The shading helps accentuate the 3D shape of the dendrite but can represent the 3D shape of the model with accuracy limited only.

This shading implementation understood to assists in reconstructing neuron morphologies toward realistic visualization. Nevertheless, while smooth lighting was well captured to the polygon surface, others resulted constraint was occur in the neuron connection. The application encountered disconnect neuron segment whilst presented in the virtual environment. Even implementation of this algorithm has produced useful displays of 3D neurons images but also prove to be cumbersome, especially when the algorithm is used to detect and display soft issues for example this such neuron cells. The time required to segment the volume, isolate the desired surface (as is required by any 3D surface display). As such, even though shading application manage to provide smooth and realistic surface, it seem less suitable to be applied by its own for anatomical structure visualization i.e neuronal morphology. Thus, as the way forward, in this paper introduce an algorithm to overcome such problem to enhance the neuron connection towards smoother surface visualization. It will be valuable by integrating the shading technique with other application approach that will produce better image presentation virtual neuron morphology.

Currently, this program is focus in generating neuron connectivity phase and from this execution, we facing the second constraint which related to discontinue neuron connection between each

neuron segment in our generated virtual neuron result. To solve this encountered constraint we will propose to apply bounding curve interpolation, the algorithm returns points along a curve that passes exactly through the points at specific instants and forms a smooth curve for points in between in the next implementation phase. In this development phase, the evaluation is done based on comparison between our resulted virtual neuron with others three existing applications.

Subsequently, in the future, it will be an important task to enhance such neuron connection. As such, for the future work, the plan for combining current result with curve interpolation technique is required to improve neuron connection. It also would be more comprehensive and efficient by retrieving generation of neurons against another digital files database and format such as 'Neurolucida' for assisting the comparison analysis.

Conclusion

Neuroanatomy is leading the pack of success stories in neuroinformatics [20]. An important aims in computational anatomy at the single-cell level consists of creating algorithms to generate virtual neuron structures that are morphologically corresponding to real neuronal dendrites. This goal may contribute a powerful knowledge distribution for the creation of large-scale, low-level model of neuron structure, activity and function. Virtual experiments can be carried out quickly, reliably, safely and inexpensively to allow the exploration of a large number of promising questions, and optimal experimental conditions. Virtual experiments can also examine the theoretical effect of each model parameter separately by precisely reproducing all other initial conditions.

Along with a numbers of on-going projects in categorizing the types of neuronal structures or mapping the neuronal networks, these facilities will provide valuable information to understand and manipulate neuronal morphology. In this article, we has reviewed some of these developments comprises of neuronal reconstruction in modeling digital morphological files and in databasing of neuronal morphologies.

The most important note that has been highlighted in this paper is the impact of neuronal morphology databases and its presentation. It depends on the availability of simple software tools that can extract flexibility a variety of user-defined morphological parameters from the archives database. As such, our priority in proposed reconstructing program is emphasizes to simplify the virtual function to be impacted for the signal transformation properties. Therefore, it will allow to be thoroughly analyzing to determine the relation between neuron's function and its relevant disease.

Roughly the proposed framework achieved the objective to solve the constraint encountered in presenting virtual neuron morphology data. Hopefully, these variations will be used in future work to improve the appearance of the neuron morphology connection in this proposed algorithm. We anticipate that the presented facts can be helpful and useful for the researchers in this field and the general audiences who may keen interests in exploring the ideas of neuron reconstruction visualization.

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