LiveMesh: A tool for real-time rendering of neuronal cells from morphologies

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Overview

Introduction

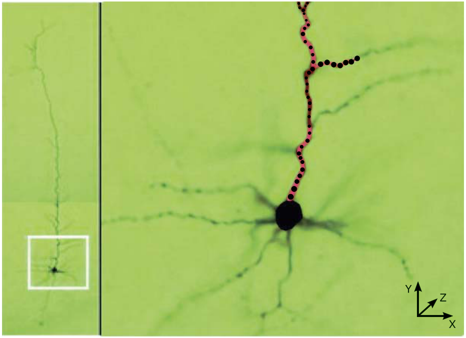
Goal of my semester project at EPFL Blue Brain Project (BBP) :

"A first prototype of a GPU-based tessellation library for the generation of neuron membrane mesh representations from parametric descriptions of neurons."

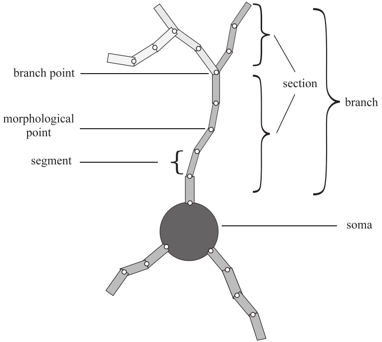
Involved:

1. State-of-the-art study.
2. Geometry processing review.
3. OpenGL 4 pipeline: vertex processing.
4. Libraries: Qt, GLEW, vmmlib, Boost
5. BBP infrastructure: BBPSDK, NeuMesh, Buildyard, gerrit, vizcluster

Background



(a)



(b)

Figure: Neuron reconstruction[1]. (a) Bright field microscopy view of a neuron. (b) Schematic view of the neuronal anatomy.

[1] Source: [Las+12]

Proposed method: OpenGL 4 hardware tessellation

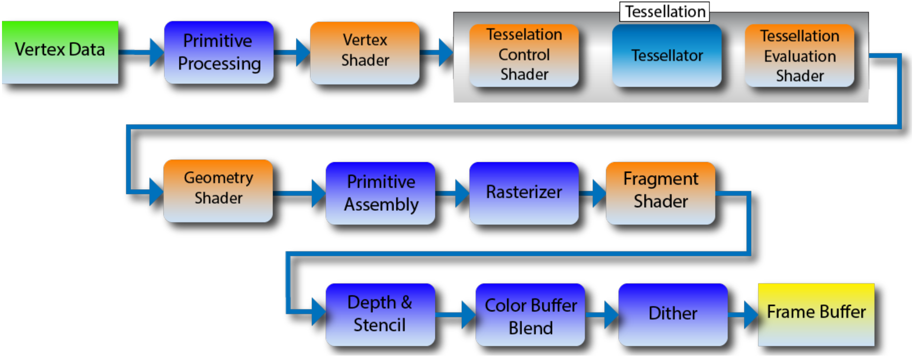


Figure: OpenGL 4 pipeline adds three stages for hardware tessellation[2].

[2]Source: http://3dgep.com/introduction-to-opengl-and-glsl/

Proposed method: Tessellation example

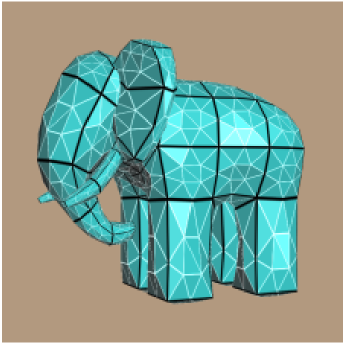


Figure: Catmulls Gumbo model defined by a mesh of bicubic Bzier patches[3].

[3] Source: http://prideout.net/blog/?p=49

Proposed method: axons and dendrites (1)

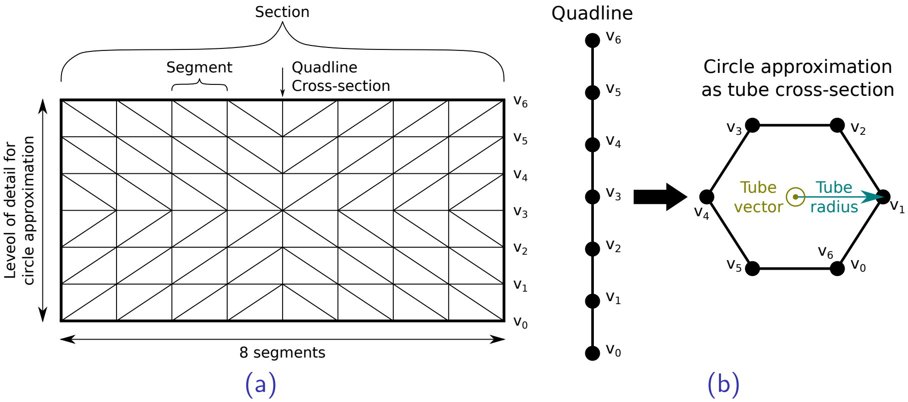


Figure: Sections as tubes. (a) Quad patch generated by the Tessellator. (b) Transformation of a quadline to a cross-section.

Proposed method: axons and dendrites (2)

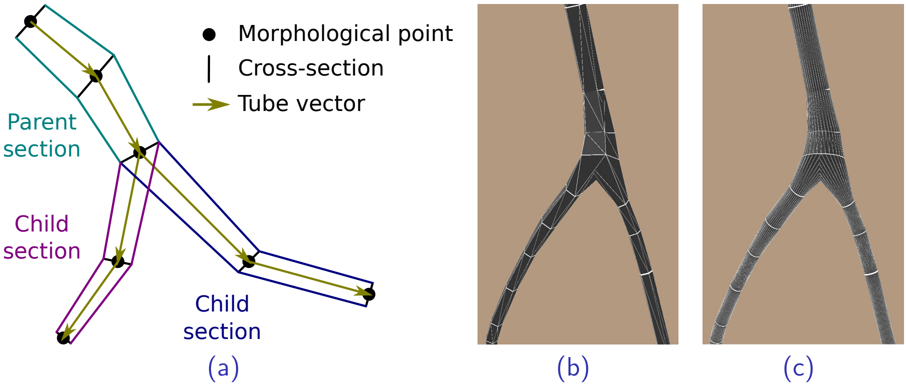


Figure: Cross-sections and branching. (a) Cross-sections alignment and sections branching. (b) Real example with a tessellation factor of 5. (c) Tessellation factor of 32.

Proposed method: Somas (1)

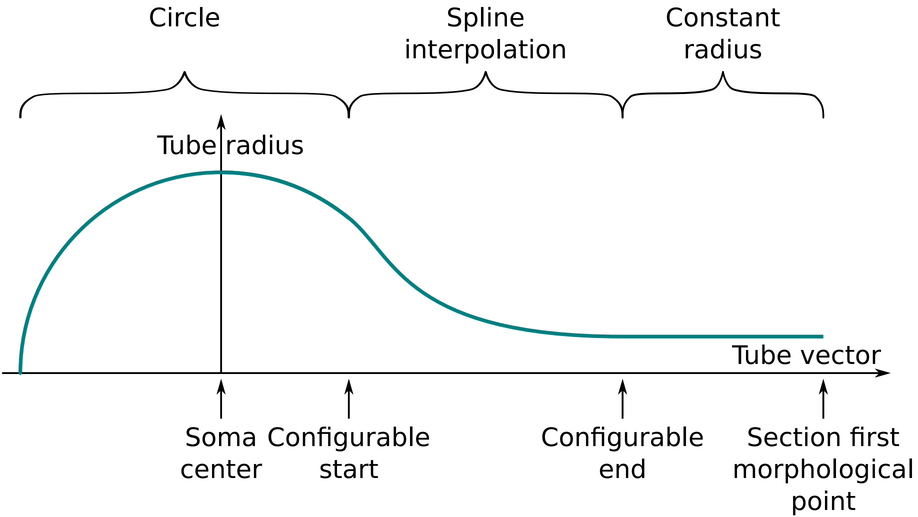
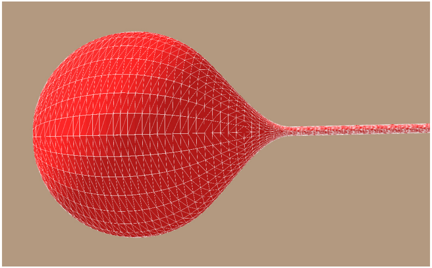


Figure: Radius evolution of first-order sections to create the soma.

Proposed method: Somas (2)


(a)

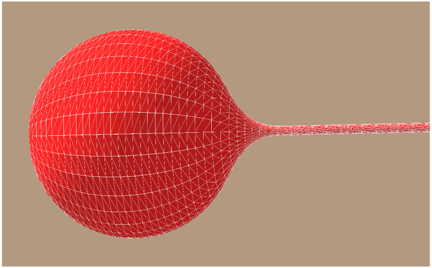
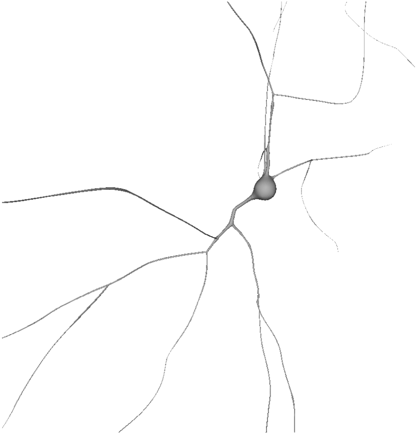

(b)

Figure: Junction of first-order section and soma. (a) Interpolation starts at 70%, ends at 150% of soma radius. (b) Interpolation starts at 90%, ends at 150% of soma radius.

Results: global view comparison

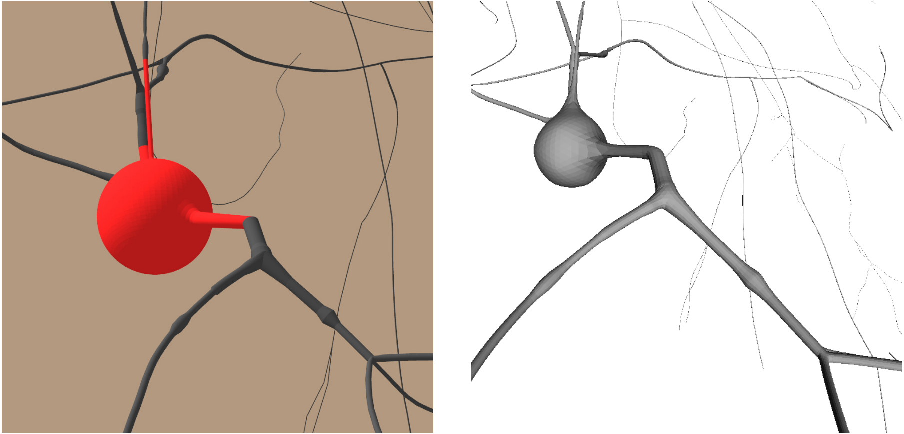
(a) LiveMesh.



(b) NeuMesh.

Figure: Comparison of LiveMesh and Neumesh on a single cell, global view.

Results: detail view comparison



(a) LiveMesh. (b) NeuMesh.

Figure: Comparison of LiveMesh and Neumesh on a single cell, detail view.

Results: space and bandwidth savings (1)

LiveMesh generates the mesh online,
no intermediate results stored on disk.

- *C040426* morphology in HDF5 format: ~ 240 kB
- NeuMesh generated mesh in the Polygon File Format: ~ 9 MB[4]

That's 36 times more data to store !

[4] At least 3 MB to store the positions of the 240062 vertices.

Results: space and bandwidth savings (2)

C040426: 271 sections, 6926 segments.

LiveMesh:

1. Vertex buffer: 6926 segments, 4 values per segment, 4 bytes per floating point value $\approx$ 108 kB
2. Index buffer: 387 sub-sections, 32 segments per sub-section, 4 bytes per unsigned int $\approx$ 48 kB
3. Total: 160400 bytes

Vertex counts: from 37k to 800k (tessellation factor of 3 to 64)

Discussion: alternative and limitation

Alternative:

1. Subdivision surface on a coarse approximation

Limitation:

1. Produced mesh is not watertight: overlap and inner surfaces

Discussion: future directions (1)

Use prior knowledge about:

1. Branches smoothness
2. Soma shape
3. Branching

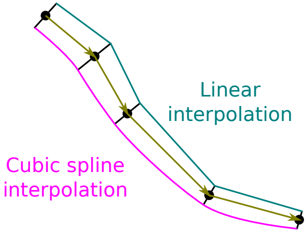


Figure: Linear versus cubic spline interpolations.

Discussion: future directions

1. Dynamic level of detail
2. Spines
3. Mesh exportation
4. Integration in BBP rendering infrastructure

Conclusion

Advantages over NeuMesh:

1. Real-time online rendering
2. No storage of the mesh
3. Lower memory bandwidth
4. Concise: 1000 lines of C++, 300 lines of GLSL

Meshes:

1. Accurate representation of neuron morphologies
2. Simplest algorithm based solely on the morphology
3. No use of prior knowledge

References

[Las+12] Sébastien Lasserre et al. "A neuron membrane mesh representation for visualization of electrophysiological simulations". In: *Visualization and Computer Graphics, IEEE Transactions on* 18.2 (2012), pp. 214–227.

Thanks

And, questions ?