Generation, Description, and Storage of Dendritic Morphology Data

by Ascoli et al. (2001)

CPSC 644

Presented by Yoonsuck Choe

Different Views of Neuronal Morphology

- 'Cartesian' description:
  - Accurate mapping of dendritic morphology
  - Does not provide intuitive information
- Statistical description:
  - Distribution of morphological parameters
  - Intuitive, but not enough to provide complete/precise blueprint for the original data.
- Intermediate descriptoin: Topic of this paper
  - Algorithmic generation of full morphology based on a set of measured parameters
  - Data compression and amplification

Value of Neuronal Morphology Databases

- Construction of electrophysiological models
- Study effect of dendritic morphology on firing patterns
- Categorization into anatomical classes
- Study growth mechanisms
- Study effect of dendritic structure on axonal growth

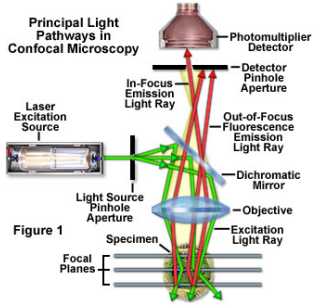
Main Issues

- Data acquisition: Complex process
- Format of the entries: Tradeoff between accuracy vs. insight

Data Acquisition Issues

- Selective staining
- Down to 0.1 µm resolution under optical microscopy: Enough to see soma, dendrites, and axons.
- Manual drawings and photomicrographs commonly used
- Issues:
  - Distortion due to fixation and sectioning
  - Electron microscopy can avoid some of these issues but it is very labor-intensive
  - Poor depth resolution: common problem form LM and EM

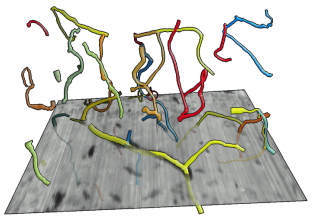
Dealing with Depth Resolution



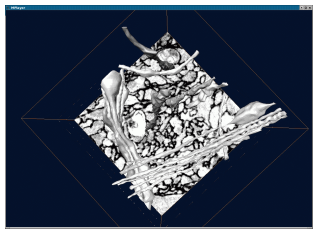
- Interference methods
- Confocal microscopy: 0.5 to 0.1 µm optical sectioning; tissue thickness is limited
- Multiphoton microscopy

Source:
http://www.microscopyu.com/articles/confocal/confocalintrobasics.html
http://www.microscopyu.com/ is an excellent resource on microscopy

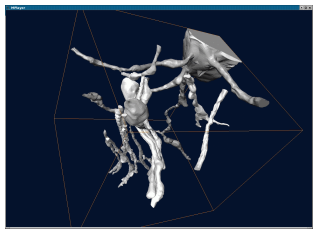
Tracing



Mayerich et al. (2007)



Busse et al. (2006)

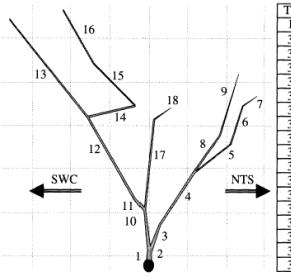


Busse et al. (2006)

- Extracting morphological information from microscopy images
- Traditional approach is “camera lucida” (allows one to superimpose the microscopic image and one’s hand-drawing). Modern version is marketed as Neurolucida (by Microbrightfield).
- Algorithmic approaches: flood filling, followed by thinning, etc.
- Advanced approaches: vector tracing, etc.

Morphological Data Formats

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



T	X	Y	Z	D	C
1	−1.5	−8.2	1.3	7.6	s
3	0.8	4.2	1.4	4.7	b
3	21.1	41.1	1.4	2.7	c
3	89.2	115.1	−5.3	2.2	b
3	153.6	163.5	3.0	1.3	c
3	184.9	218.1	−2.3	0.9	c
3	220.9	238.7	−13.7	0.6	t
3	159.9	183.9	−23.6	2.2	c
3	211.9	270.9	−35.2	1.4	t
3	0.6	58.1	−2.6	2.2	b
3	−0.5	75.9	−18.6	2.2	c
3	−40.5	180.0	−55.3	2.0	b
3	−156.4	281.8	−65.9	1.5	t
3	0.3	186.8	−7.0	1.5	c
3	−51.5	235.7	−27.0	1.5	c
3	−85.2	297.6	−41.5	1.0	t
3	75.3	198.3	−54.6	1.5	c
3	130.6	228.6	−81.3	1.0	t

- Set of pictures: limited utility
- SWC format: segments with ID, type, x/y/z position of end point, radius, and start point segment’s ID.
- Eutectic format: similar to SWC
- Neurolucida format: type, position and diameter, indentations to mark parent-child relationship

Shortcomings of Morphological Data Formats

- Accurate but not intuitive
- Large storage requirement
- Statistical distributions of morphological parameters can be one alternative:
  - Length distributions, size of soma, number of branches, branch diameter, position in the layer, tree shape (depth/width ratio, etc.), etc.
  - Not complete enough to reconstruct a realistic neuron

The Computational Alternative

- Use a small set of 'fundamental' parameters for algorithmic generation of neuronal structures
- Intuitive and also complete: best of both worlds
- Generation of large number of virtual neurons from small number of experimentally traced neurons is possible

Algorithms for Virtual Neuron Generation

- Local: use of local rules to grow out
  - Simpler, more intuitive
  - Parameter used in algorithm can be measured from experimental data
  - Small number of parameters
  - Good for studying structure-function relationship and emerging properties
- Global: deal with branches from the outside
  - More flexible
  - Extensive parameter search needed
  - Can be used to generate population of connected neurons

Local Algorithm: L-Neuron

- Based on L-systems for fractals and botanial tree generation
- Addition of a series of local neuroanatomical rules, described as 'production strings': grow forward, turn, taper, split, etc.
- Recursive growth: growth, bifurcation, resulting branch diameter, etc. depending on current tip's diameter.
- Hillman's fundamental parameter of shape: branch length, terminal length, daughter diameter ratio, and Rall's power coefficient
- Addition in L-neuron: angle, and dendritic path within a branch (fragmentation smoothness, etc.)
- Stochastic sampling of parameters
- Other enhancements: Tamori's equation, Burke's algorithm, tropism

Global Algorithm: ArborVitae

- Aims to synthesize brain anatomy and physiology
- Use limited experimental data emulate the genesis, outgrowth, and interactions among sets of neurons
- Core representation is a skeletal 3D branching structures of neurons described at the level of populations
- Morphological properties as random variables defined at the group level. Most growth decisions made from group-level distributions (fitted to experimental data).
- Argument for global approach: resource limit

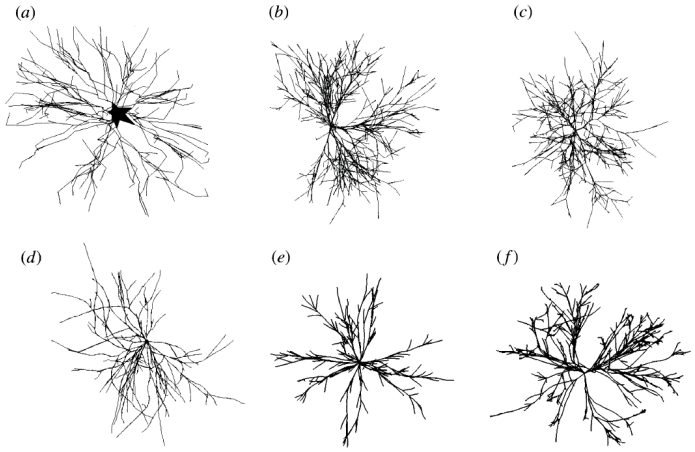
ArborVitae Operations

- Growth of whole cell
- Group resource quota enforced (global)
- Segments meander, branch, and taper
- Segments can be detailed with synapses, spines, etc.
- Append, extend, bifurcate
- Growth failure probability
- Environmental modulation (tropism)

ArborVitae: Two Algorithms

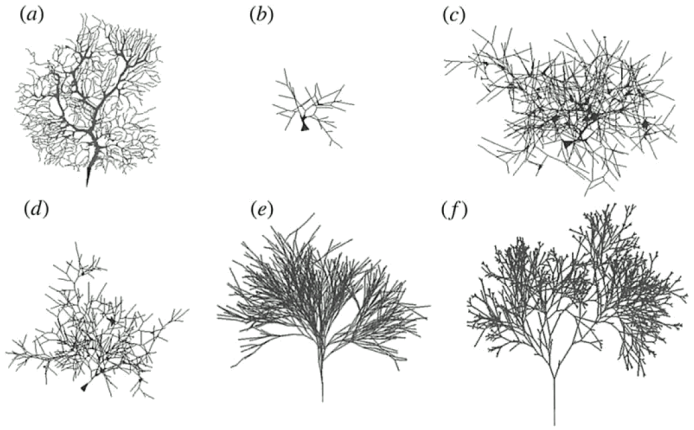
- Appending mode, followed by extending mode and bifurcating mode; computationally inefficient
- Bifurcation and extending not segregated into different steps in the synthesis

Results: Motor Neuron



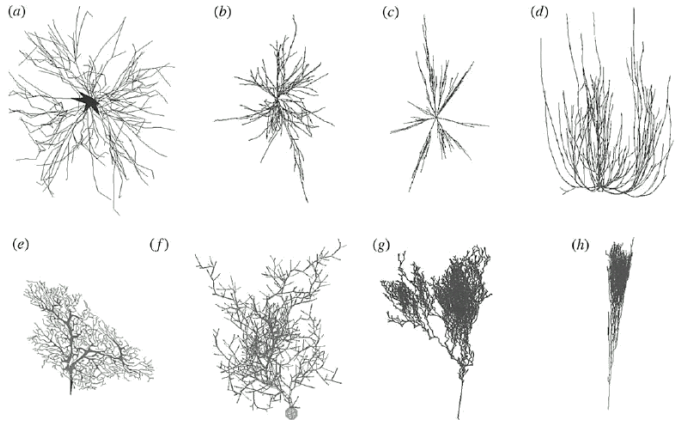
- Actual neuron; L-Neuron with Hillman, poliko option; Tamori variant
- L-Neuron with Burke's algorithm; ArborVitae with algorithm 1; ArborVitae with algorithm 2

Results: Purkinje Cells



- Actual neuron; L-Neuron with Hillman, w/o poliko option; w/ poliko option
- L-Neuron with Tamori variant; ArborVitae with algorithm 1; ArborVitae with algorithm 2

Results: Tropism



- Actual Motor neuron; L-Neuron plus Burke's algorithm plus moderate tropism; with excessive tropism; tropism in the y-axis
- Actual Purkinje cell; L-neuron plus Hillman's algorithm with poliko option and moderate tropism; ArborVitae plus algorithm 2 and tropism away from soma; greater tropism

Verification and Validation

- Which algorithm to use?: need to measure accuracy
- Experimental and synthetic neurons' parameter distributions should have the sme moments
- Comparison of mean and variance, with associated confidence figure

References

Ascoli, G. A., Krichmar, J. L., Nasuto, S. J., and Senft, S. L. (2001). Generation, description and storage of dendritic morphology data. *Philosophical Transactions of the Royal Society of London, B*, 356:1131–1145.