

# 2nd Workshop on Nanoscience: Carbon-Related Systems and Nanomaterials

July 4-7, 2012

R203, 2F, NCTS, NCKU

## Digitization of Complex 3D Nano Structure by Fast Automatically Structural Tracing Algorithm (FASTA)



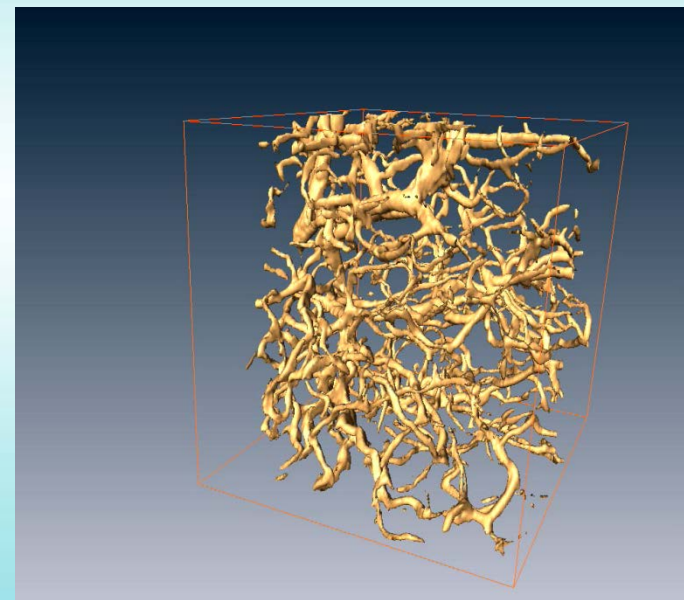
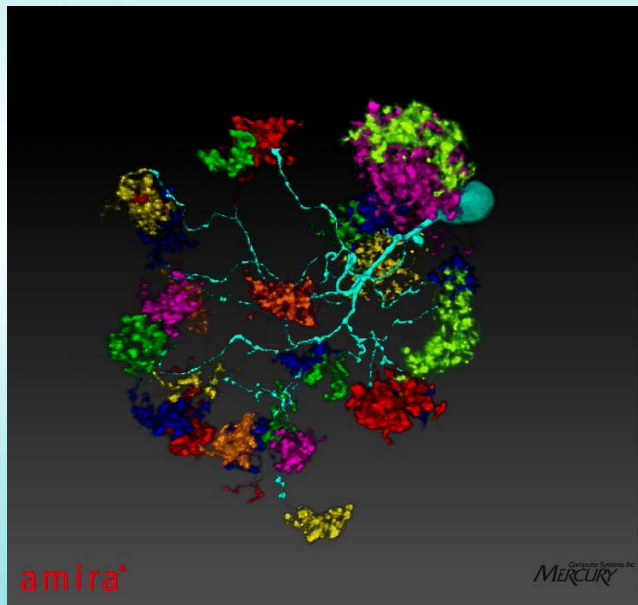
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# Outline

- ✚ Introduction
- ✚ The algorithm
- ✚ Results
- ✚ Summary

In recent years, numerous 3-D digital nano images were taken from confocal laser scanning microscope, X-ray and other imaging techniques for complex structures like neurons, blood vessel, collagen, fibers, etc...



However, a quantitative analysis these complex structures to obtain useful information is very challenging.

# Spatial analysis

- ✦ Volume (easily)
- ✦ Surface area (easily)
- ✦ Position (easily)
  
- ✦ Fiber diameter (?)
- ✦ Fiber length (?)
- ✦ Total branch number (?)
- ✦ Fiber branch angles (?)
- ✦ Local vector of fiber (?)
- ✦ Cross section area of fiber (?)
- ✦ Branch level (?)
- ✦ ..... etc.

All these parameters with “?” marks are determined only when the structure are **traced**.

However, most of the labs trace their images **manually** or **semi-manually** so far.

Disadvantage of manual tracing

- **very labor intensive**
- **lack of objectivity**

Is any faster and more objective method which can trace the structure automatically?

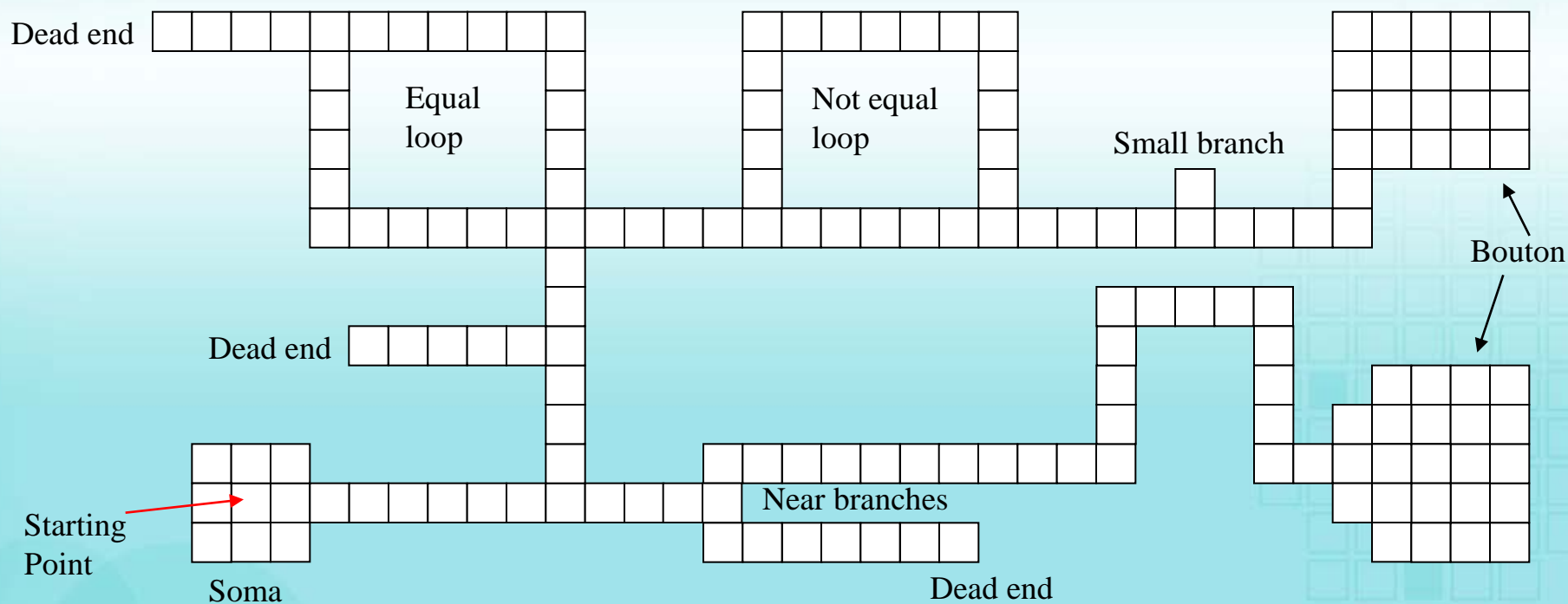
# The tracing algorithm

- ✦ Image voxels are encoded based on the idea of **source field** method. Every voxels in a connected cluster is encoded by a number representing the sequential distance of the shortest path from the origin.
- ✦ A **codelet  $i$**  is defined by voxels with coding number  $i-1$ ,  $i$ ,  $i+1$ . Its center of mass (CM) is calculated by all these voxels.
- ✦ The tracing for one connected cluster is carried out simply by **following the codelets sequentially with increasing indices** through all the encoded voxels.

# The tracing algorithm

- ✦ Skeleton are connected by the of each codelet for a segment or branch.
- ✦ The cross section area for a codelet is defined by one-third of the number of voxels in this codelet.
- ✦ Stopping criteria:
  - ✦ Reached the branches (when a codelet has disconnected voxels)
  - ✦ Reached the dead end (when no any further voxels can be traced)
  - ✦ Reached the loop (when reach the voxels which had been traced before)
  - ✦ ..... etc.

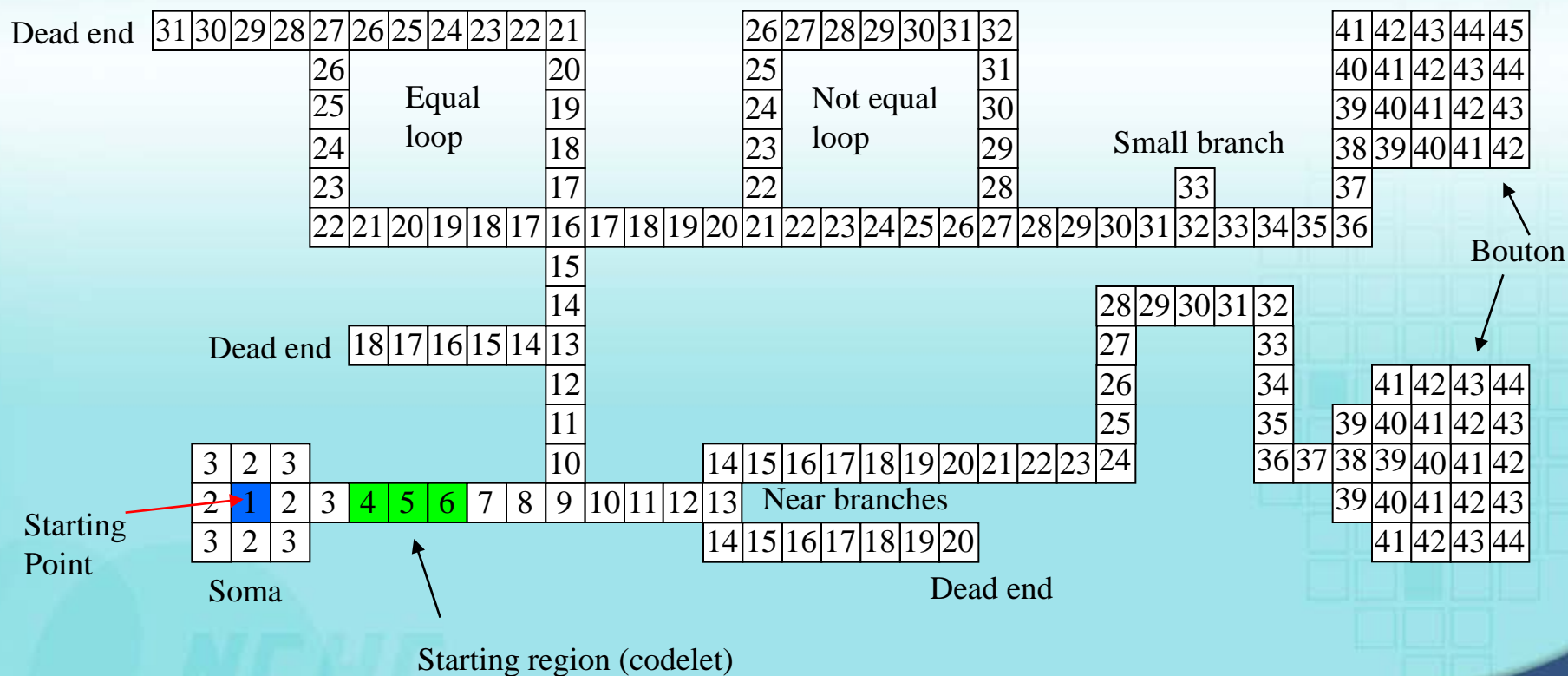
# An example: lattice neuron



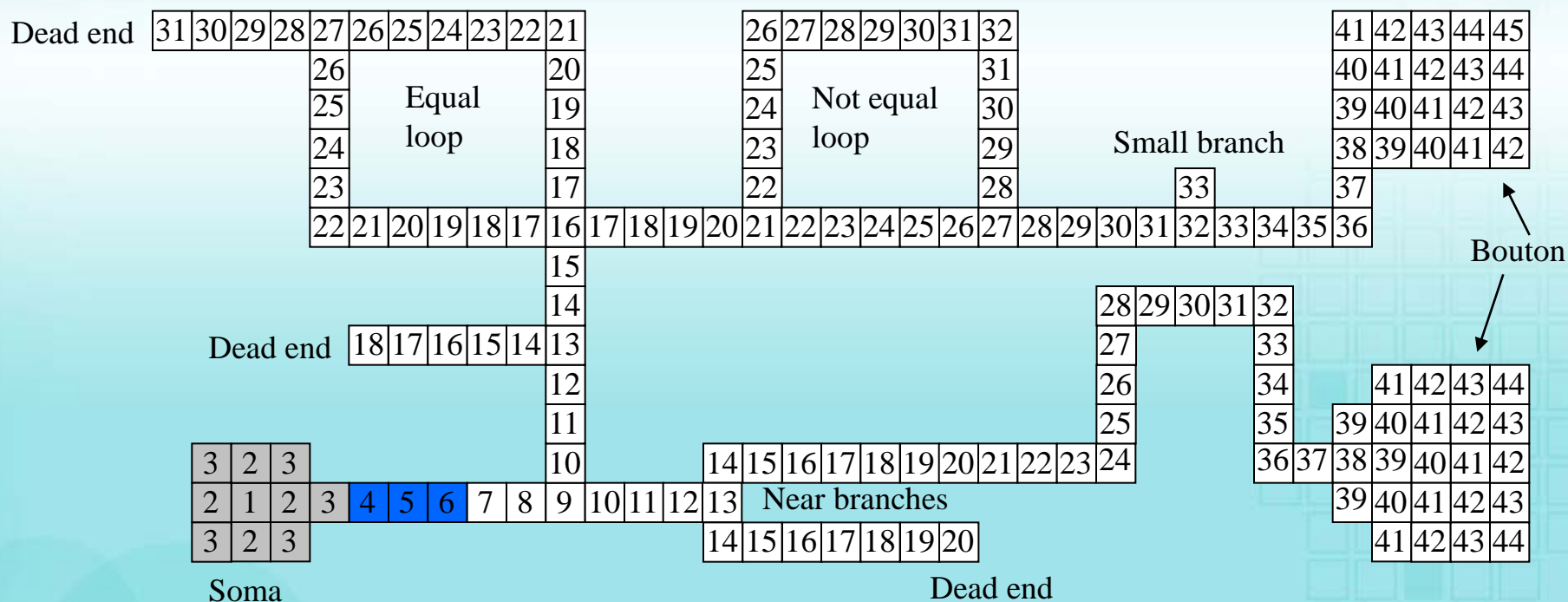
Note : this tracing procedure can be extended to the 3D data without loss of generality.



# An example: lattice neuron (encoded)



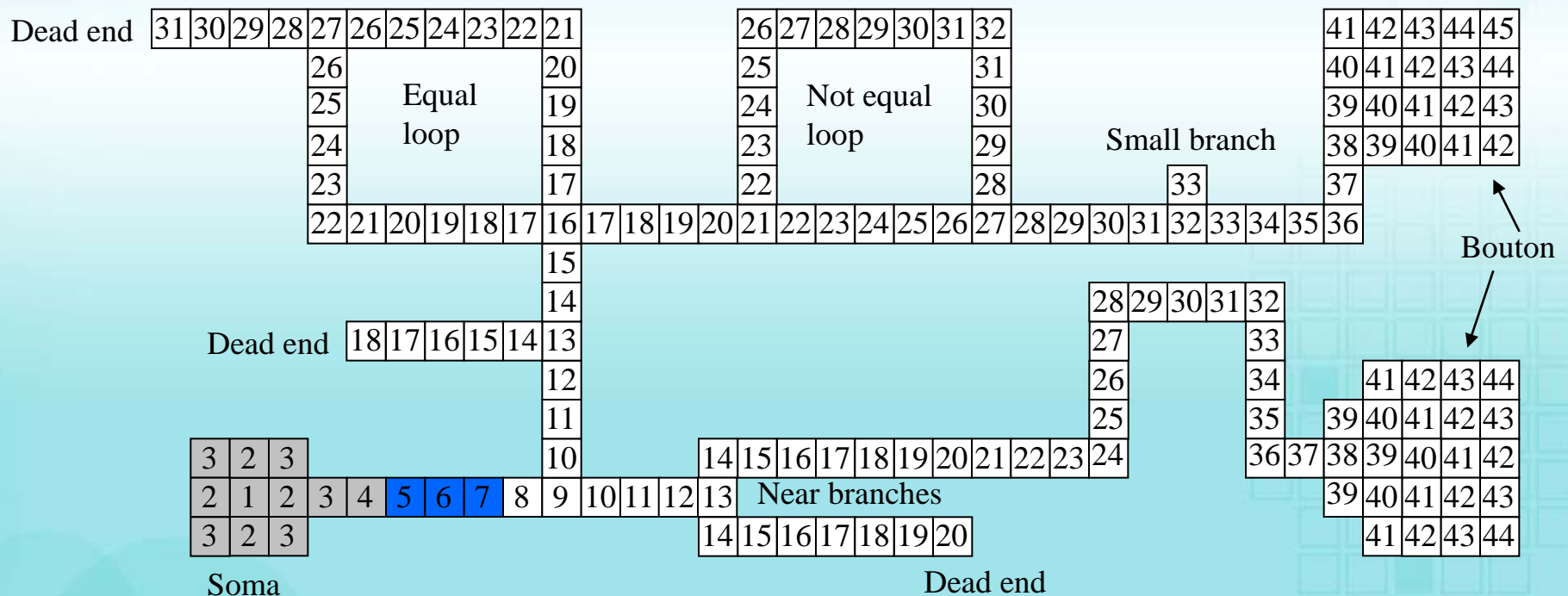
# An example: lattice neuron (tracing)



= tracing now  
 = used

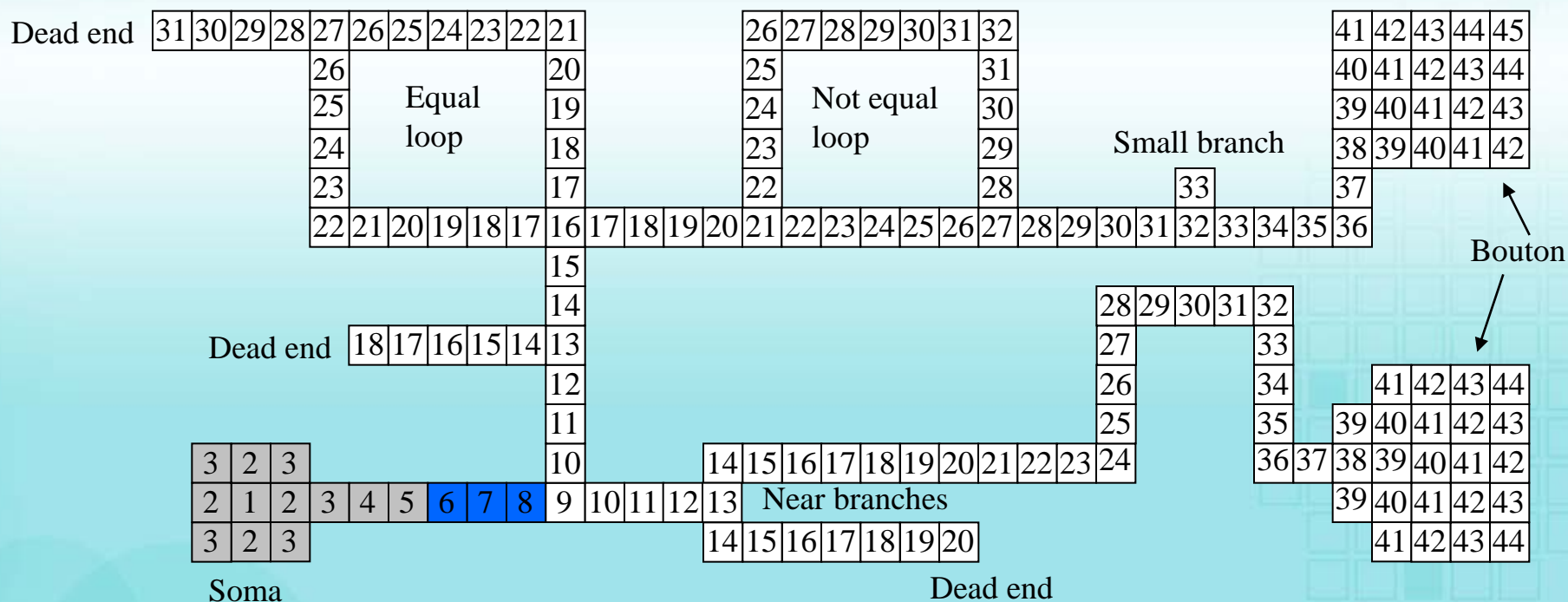
Note : the CM for each codelet is called **Center Point (CP)**.

# An example: lattice neuron (tracing)



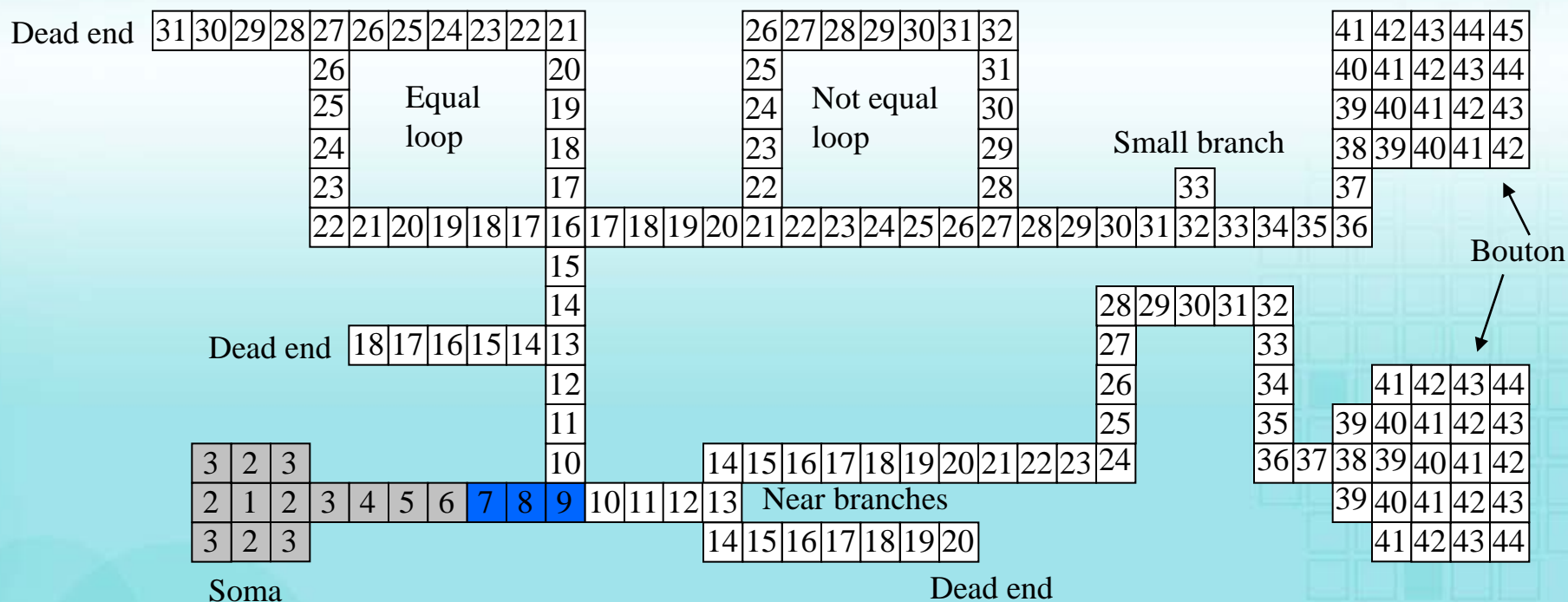
= tracing now  
 = used

# An example: lattice neuron (tracing)



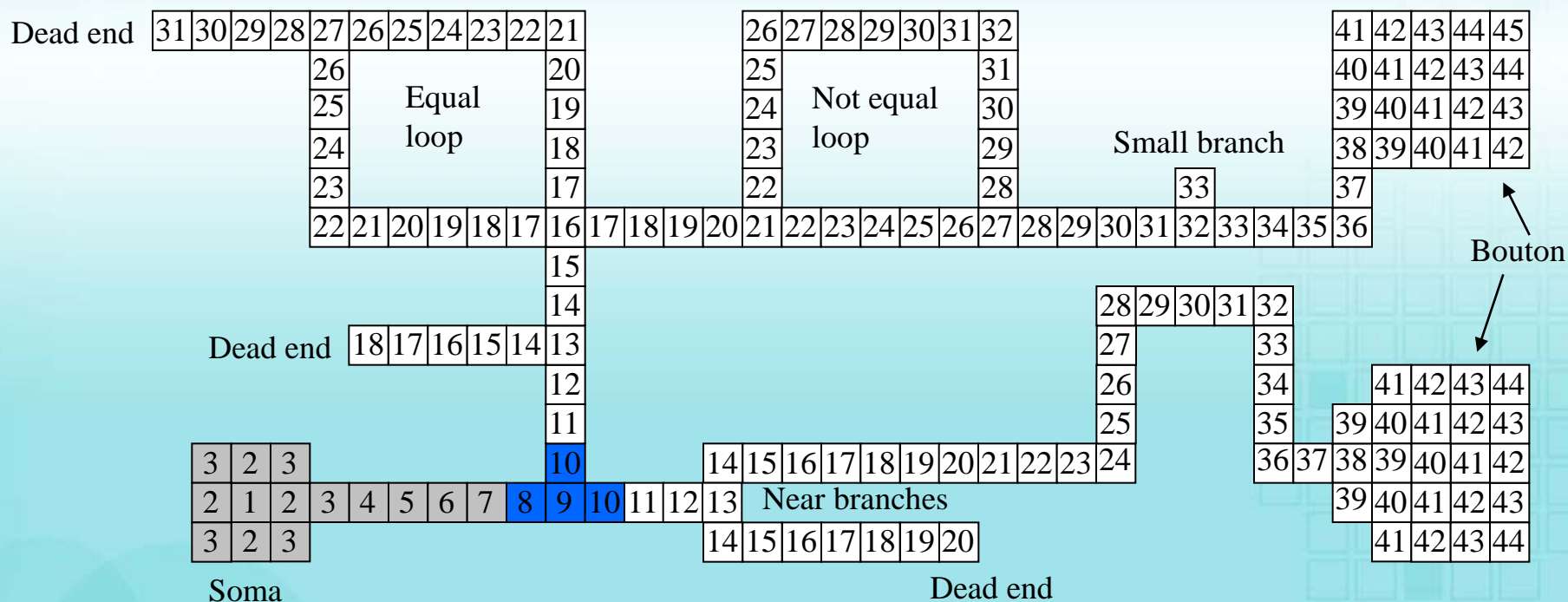
= tracing now  
 = used

# An example: lattice neuron (tracing)



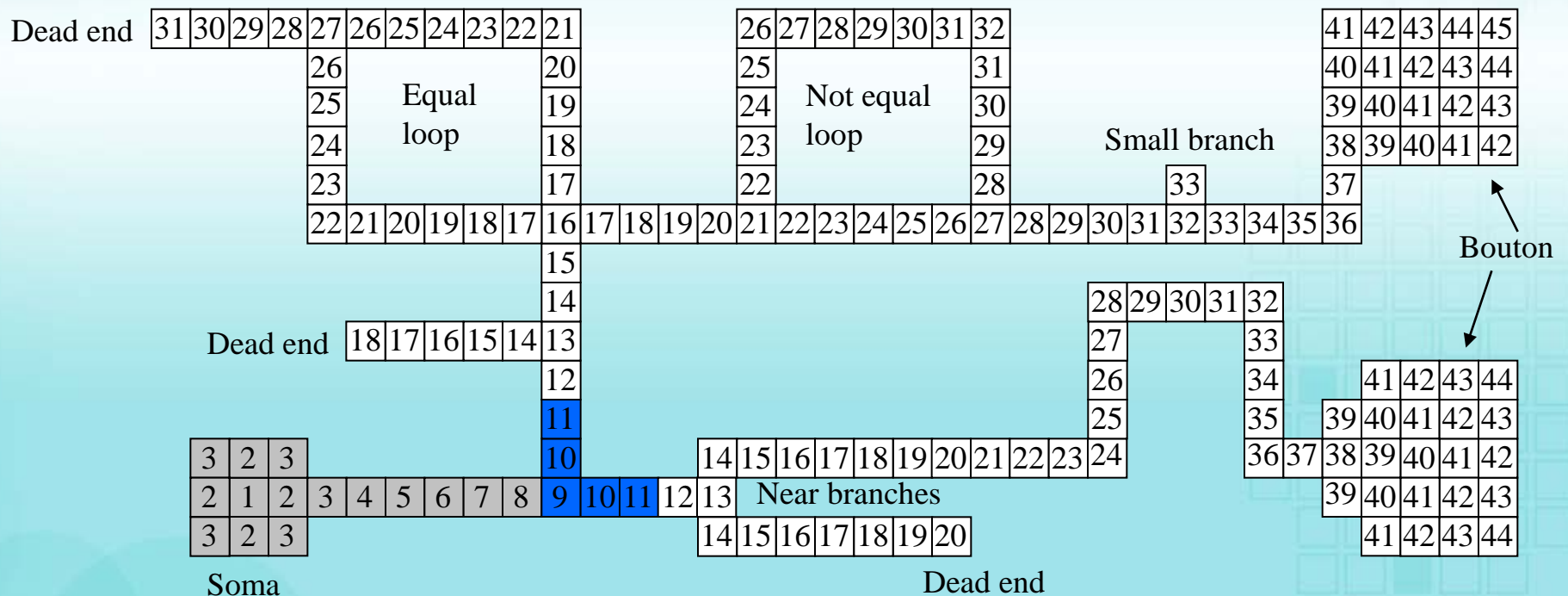
- = tracing now
- = used

# An example: lattice neuron (tracing)



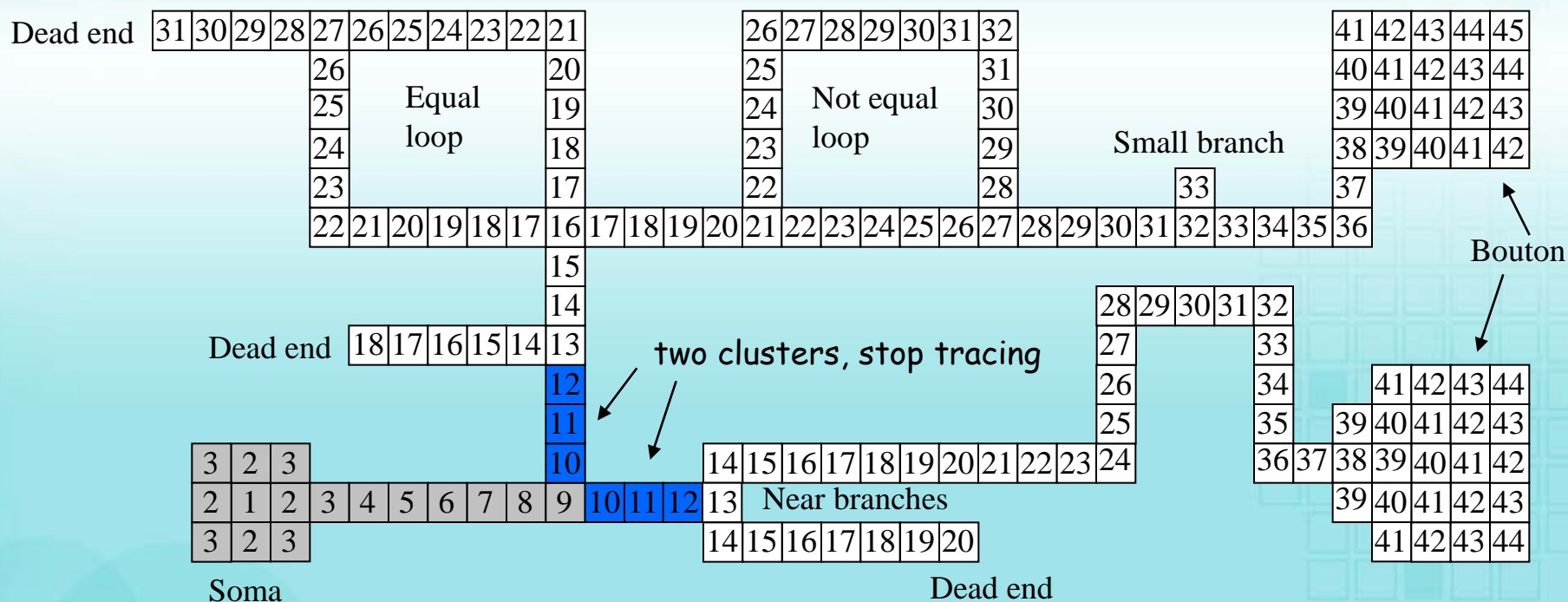
- = tracing now
- = used

# An example: lattice neuron (tracing)



= tracing now  
 = used

# An example: lattice neuron (tracing)

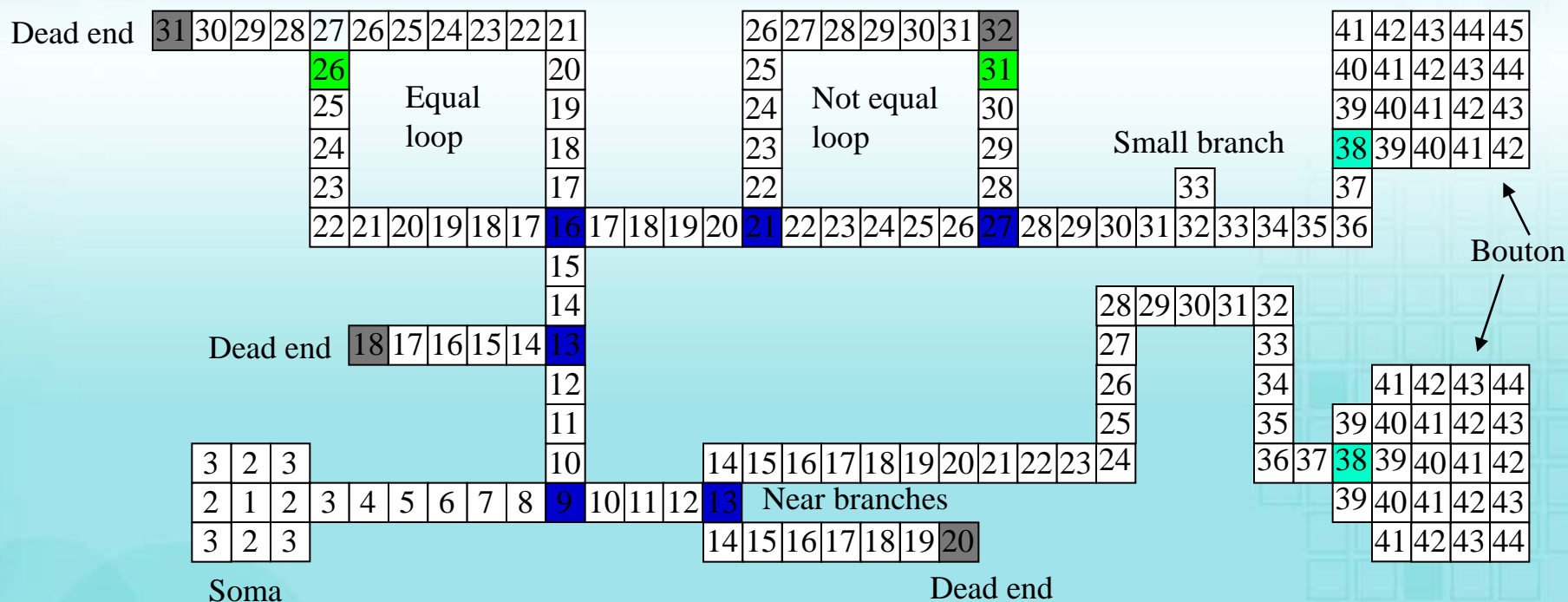


■ = tracing now  
 ■ = used

■ = new starting point for next tracing  
 ■ = the stopping point for the first tracing, i.e. **Branch Point (BP)**

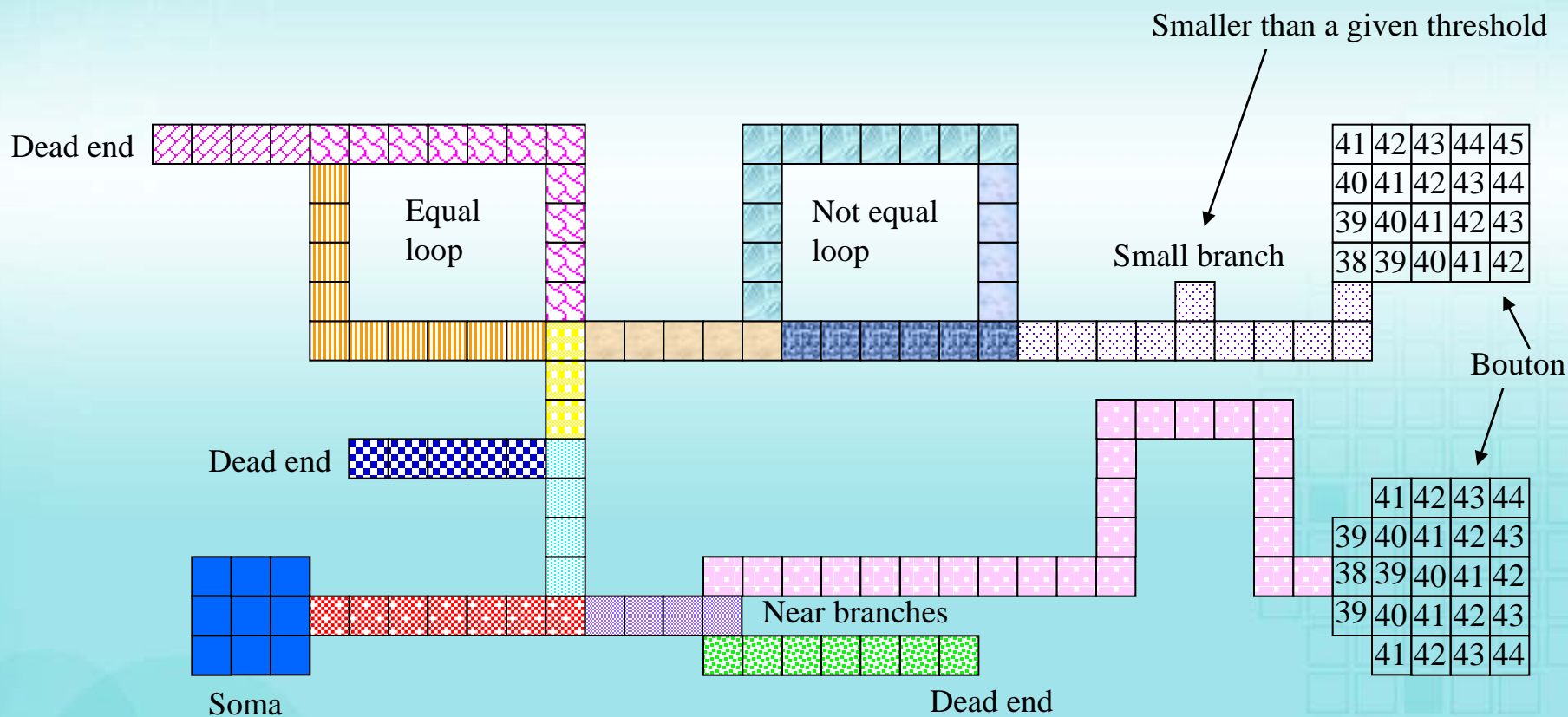


# An example: lattice neuron (traced)



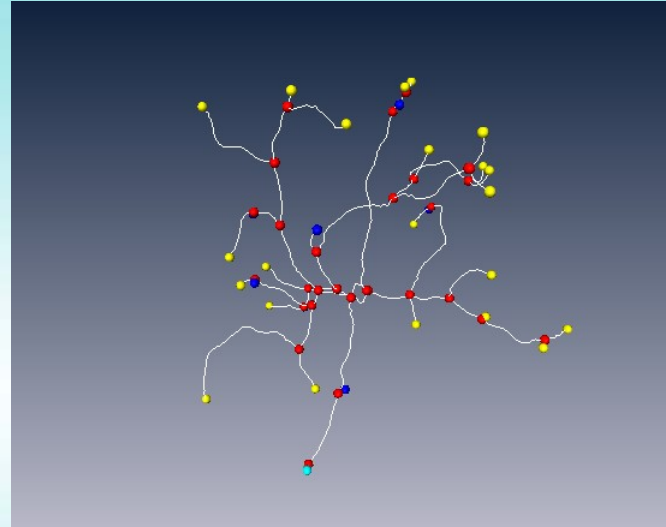
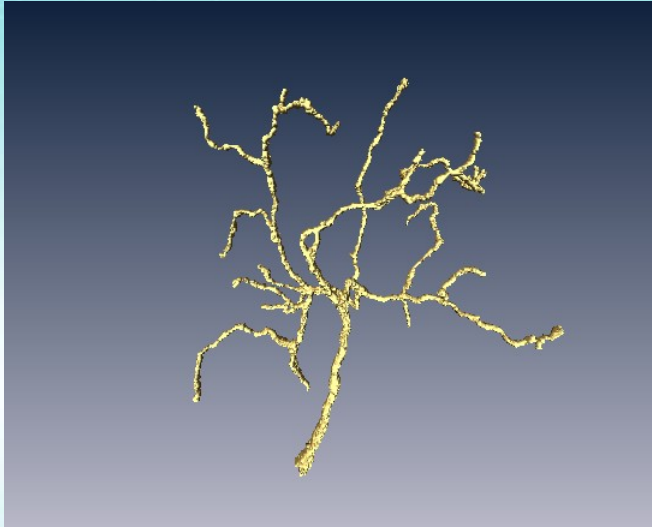
- = Branch Point (BP)
- = Loop Point (LP)
- = End Point (EP)
- = Bouton Point

# An example: lattice neuron (traced)

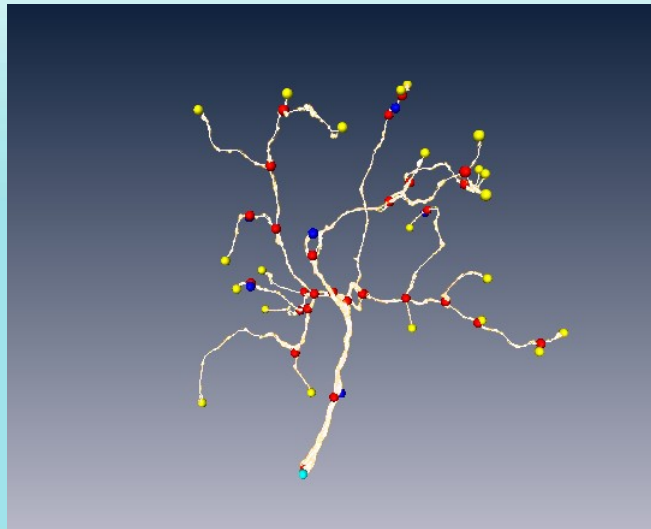


All fiber segments, # = 14

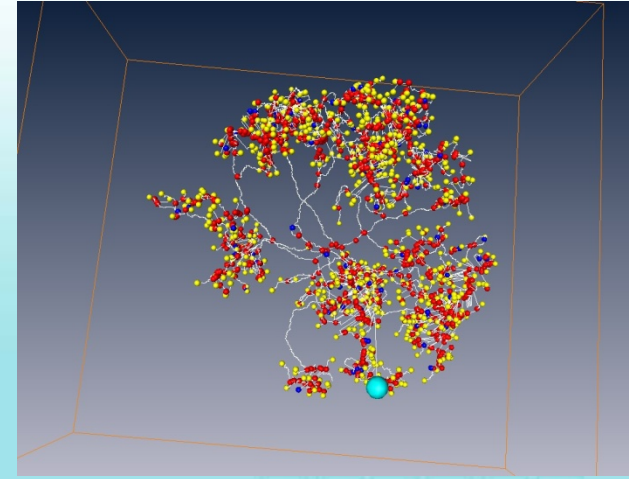
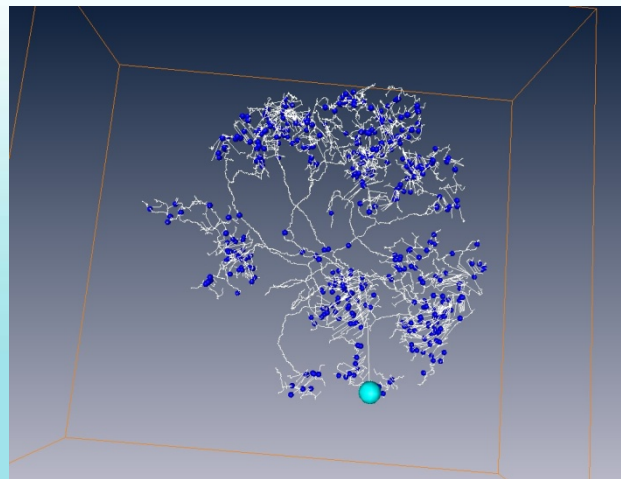
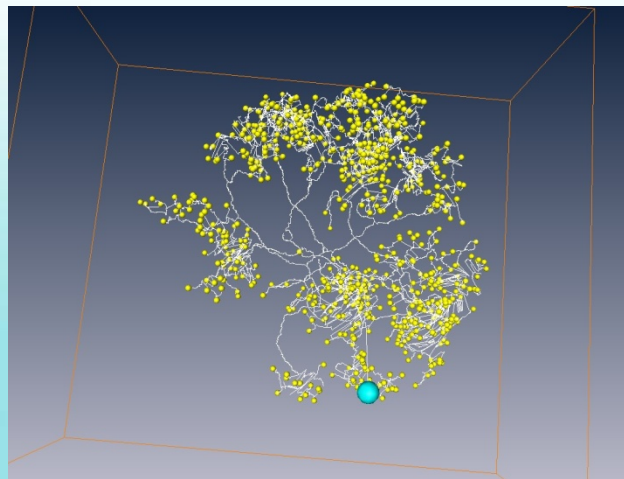
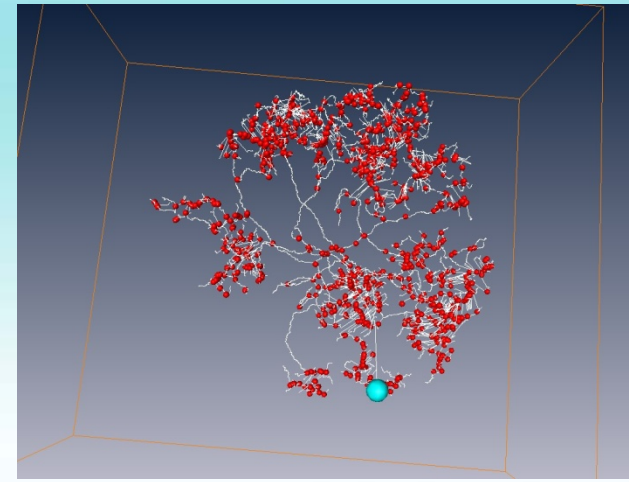
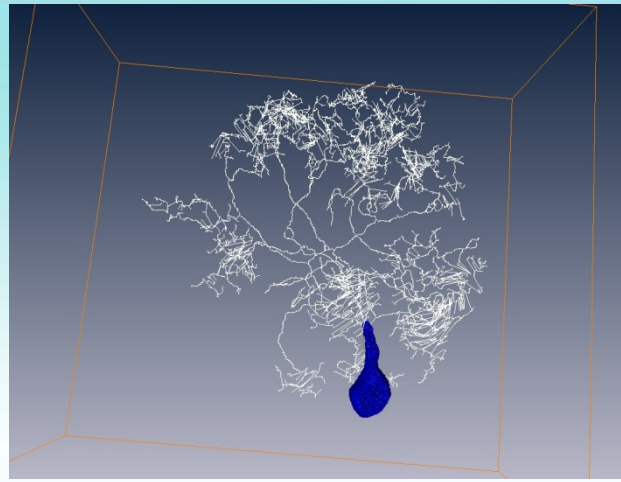
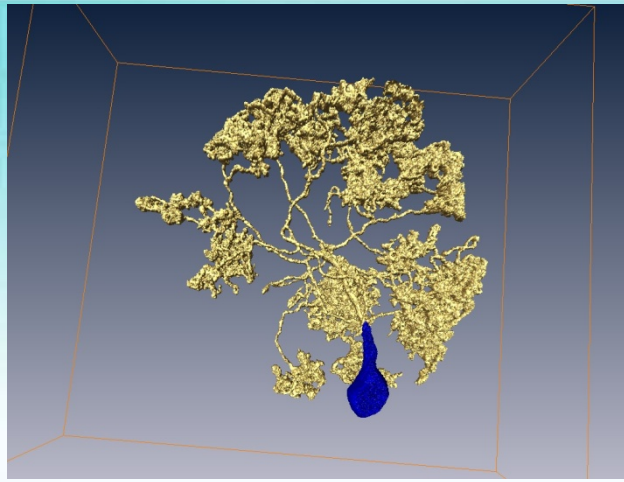
# A tree example



**red** - branch point  
**yellow** - end point  
**blue** - loop point  
**cyan** - starting point



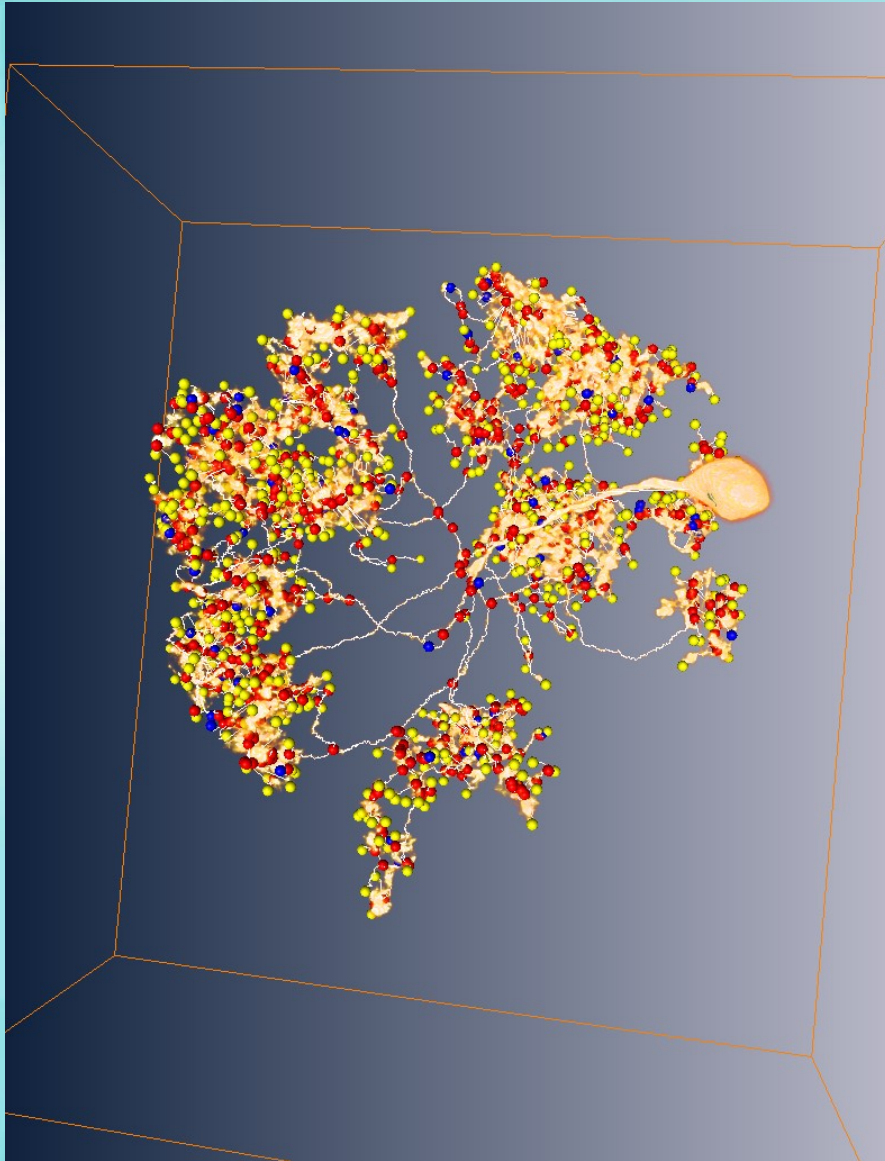
# 3D image of a neuron and its tracing results



Blue part = soma region  
White line = skeleton of neuron fiber

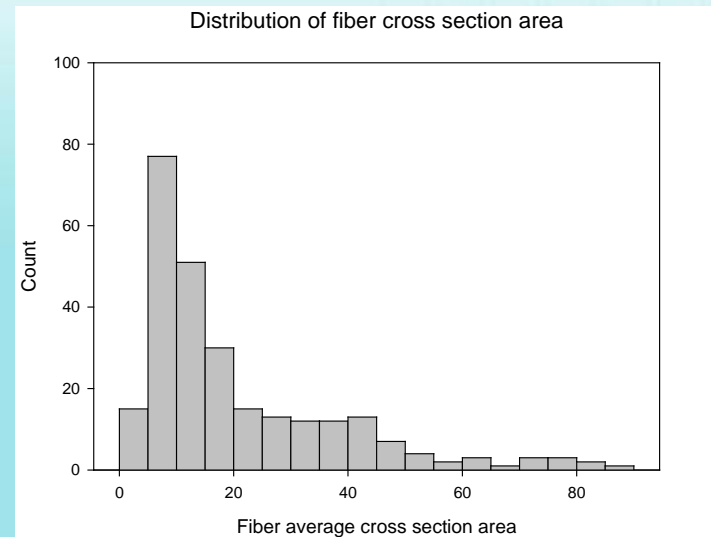
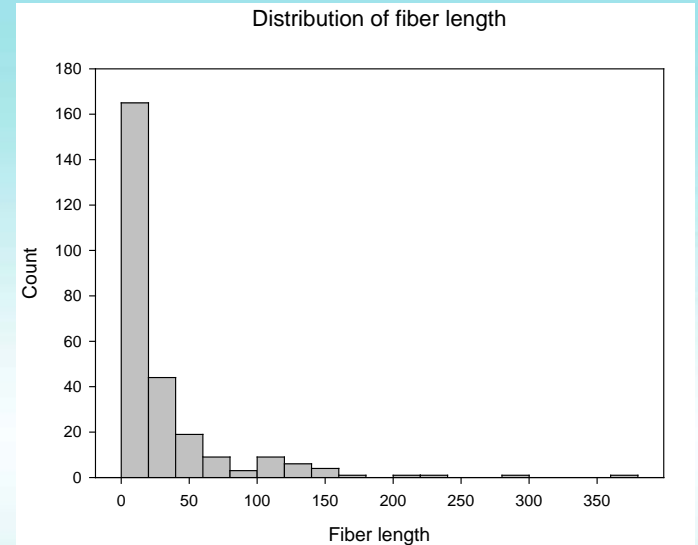
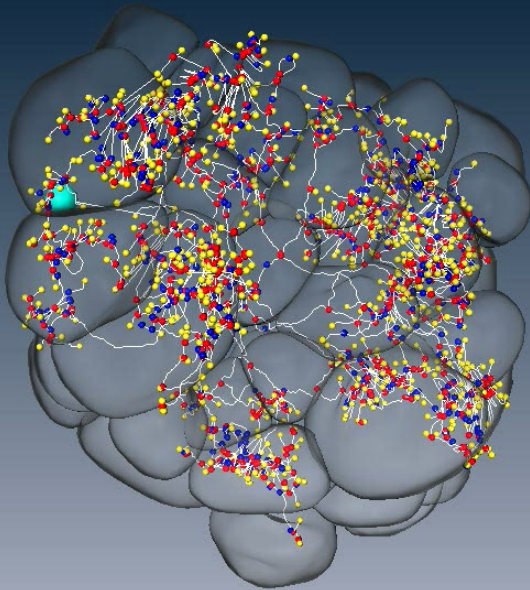
Red points = branch points  
Yellow points = end points  
Blue points = loop points

# 3D image of a neuron and its tracing results

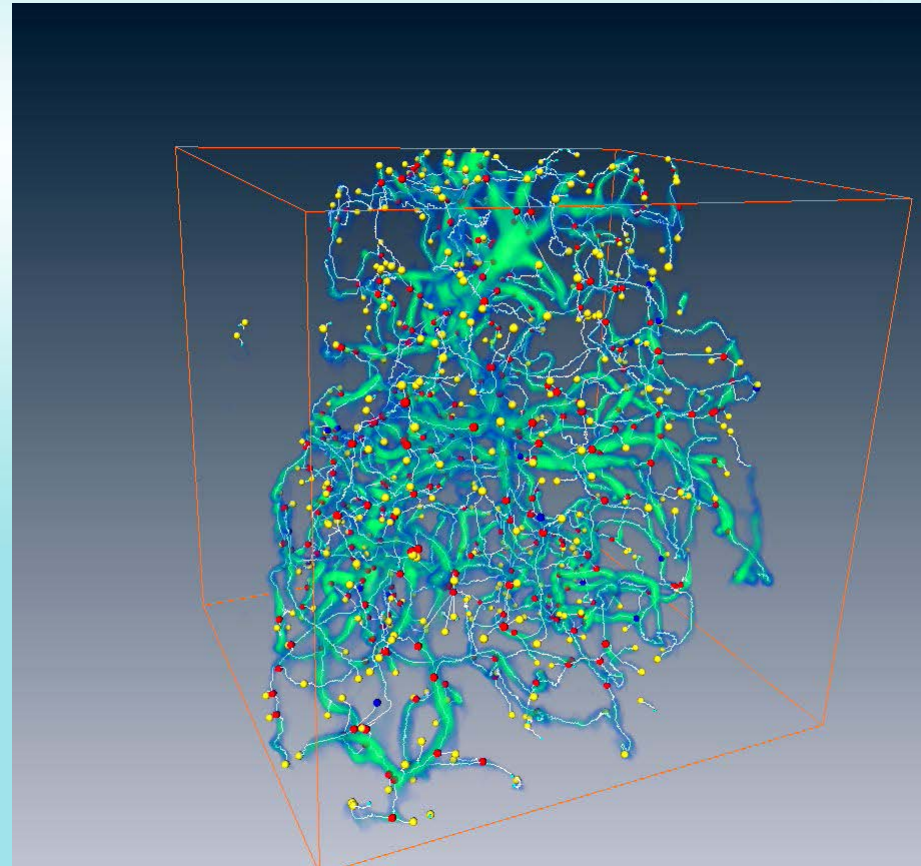
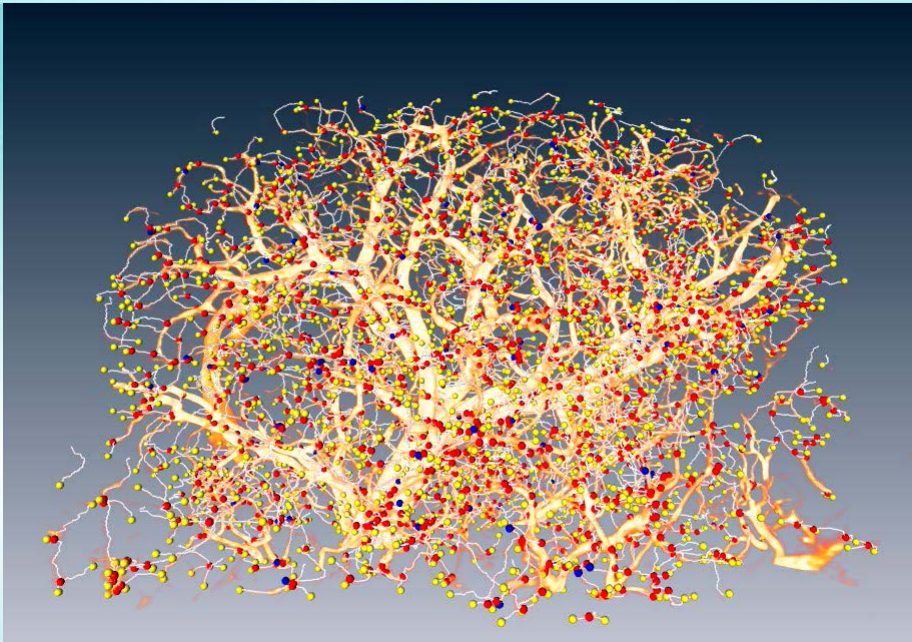


- Center of mass (soma part) = ( 47, 285, 154)
- Volume of cell body = 716360
- Surface area of cell body = 413596
  
- The neurite length (before 1st branch) = 230.912155
- The neurite average cross section area (before 1st branch) = 24.022358
- Fiber angle at 1st branch point = 65.91 deg.
- Total branch number = 264
- Total fiber length = 8282.3239

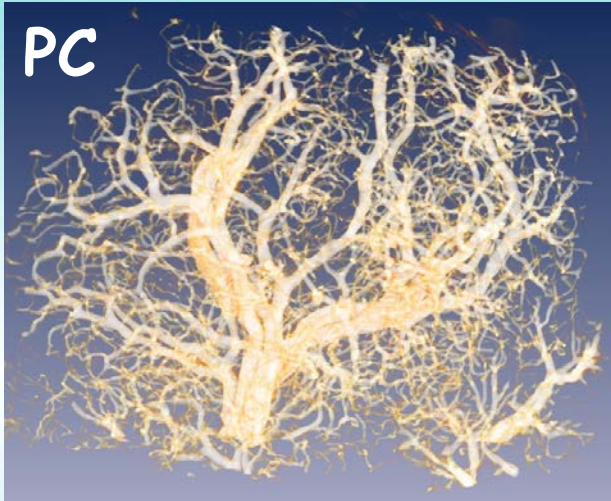
# 3D image of a neuron and its tracing results



# Blood vessels and its tracing results



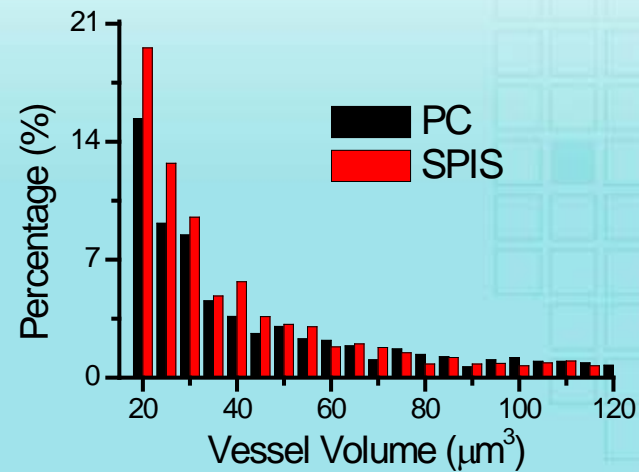
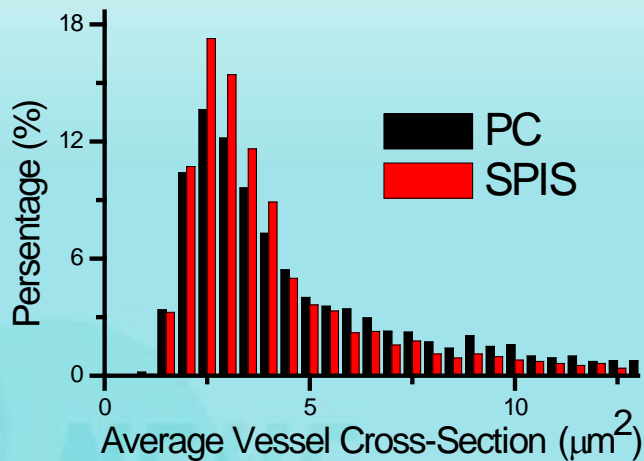
# Blood vessels and its tracing results



PC (pancreatic cancer in mice)



SPIS (activated by ionizing radiation)





# Summary

- ✦ The structures can be traced automatically by this algorithm without pre-treating the data.
- ✦ Skeleton, branch points, end points, cross section area, branch angles, and other characteristic quantities (structural indices) can be found easily.
- ✦ This algorithm can be applied to not only neuron-like structures but also other kinds of complex structures, such as tree-like structures, network structures ... etc.
- ✦ Images can be traced in minutes which means we can use different setting and threshold for tracing and analyzing the raw data iteratively...

US patent: US 2011/0157177 A1

Accepted by Biotechnology Advances ...

(<http://www.sciencedirect.com/science/article/pii/S0734975011002126#FCANote>)

# Other applications

- ✦ Blood vessel configurations for studying cancer (angiogenesis)
- ✦ Collagen in skin tissue for detecting diabetes
- ✦ Fibril morphology in polymetric materials
- ✦ ..... etc.

# Collaborators

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Brain Research Center

**Prof. Ann-Shyn Chiang**  
**Maxwell Meng-Fu Shih**

NanoX Laboratory, Institute of Physics, Academia Sinica  
National Synchrotron Radiation Research Center

**Prof. Yeu-Kuang Hwu**  
**Chia-Chi Chien**

**Thank you for your  
attention!**

