



浙江大学爱丁堡大学联合学院

ZJU-UoE Institute

Lecture 08 - Tracing of tube-like structures

Nicola Romanò - nicola.romano@ed.ac.uk

Recap

In the past lectures...

We have seen how to

- ✓ Use Numpy and Matplotlib/Scikit-Image to display and manipulate images

In the past lectures...

We have seen how to

- ✓ Use Numpy and Matplotlib/Scikit-Image to display and manipulate images
- ✓ Preprocess images, e.g. by modifying their histograms, or by using convolutional filters. This allows us to enhance contrast, sharpen or blur the image, find edges, etc.

In the past lectures...

We have seen how to

- ✓ Use Numpy and Matplotlib/Scikit-Image to display and manipulate images
- ✓ Preprocess images, e.g. by modifying their histograms, or by using convolutional filters. This allows us to enhance contrast, sharpen or blur the image, find edges, etc.
- ✓ Use morphological operators to perform image processing, e.g. erosion, dilation, opening, closing, etc.

In the past lectures...

We have seen how to

- ✓ Use Numpy and Matplotlib/Scikit-Image to display and manipulate images
- ✓ Preprocess images, e.g. by modifying their histograms, or by using convolutional filters. This allows us to enhance contrast, sharpen or blur the image, find edges, etc.
- ✓ Use morphological operators to perform image processing, e.g. erosion, dilation, opening, closing, etc.
- ✓ Extract features from an image, to be used for further processing (blob, lines, circles, texture...)

In the past lectures...

We have seen how to

- ✓ Use Numpy and Matplotlib/Scikit-Image to display and manipulate images
- ✓ Preprocess images, e.g. by modifying their histograms, or by using convolutional filters. This allows us to enhance contrast, sharpen or blur the image, find edges, etc.
- ✓ Use morphological operators to perform image processing, e.g. erosion, dilation, opening, closing, etc.
- ✓ Extract features from an image, to be used for further processing (blob, lines, circles, texture...)
- ✓ Segment an image into different regions, e.g. by thresholding, clustering, watershed, etc.

In this lecture...

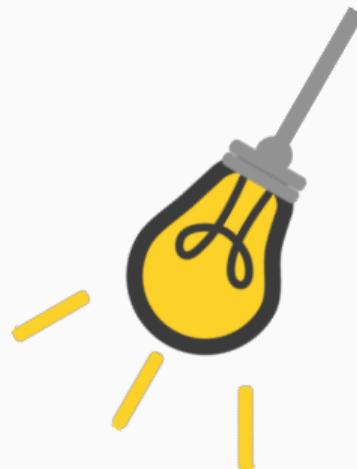
We are going to put all of this together today to see how we can perform more complex image processing.

As an example, we are going to talk about how to combine these techniques to trace tube-like structures, such as blood vessels and neuronal processes.

Note that these techniques can be modified *ad-hoc* to be applied to a variety of different problems.

Learning objectives

- Describe the issues associated with tracing tube-like structures
- Describe pipelines for processing these types of images
- Give examples of strategies to extract features from these complex datasets.



Introduction

What is tracing?

In biomedical imaging, **tracing** is the process of segmenting tube-like structures in images.

In the literature, this is often called tracking, which should not be confused with motion tracking.

This is often applied to blood vessels and neuronal processes.

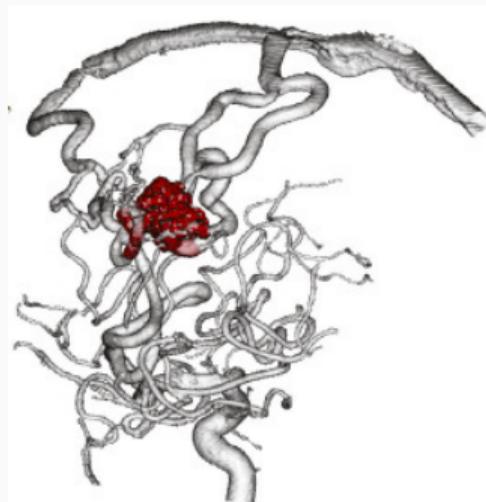
What is tracing?

In biomedical imaging, **tracing** is the process of segmenting tube-like structures in images.

In the literature, this is often called tracking, which should not be confused with motion tracking.

This is often applied to blood vessels and neuronal processes.

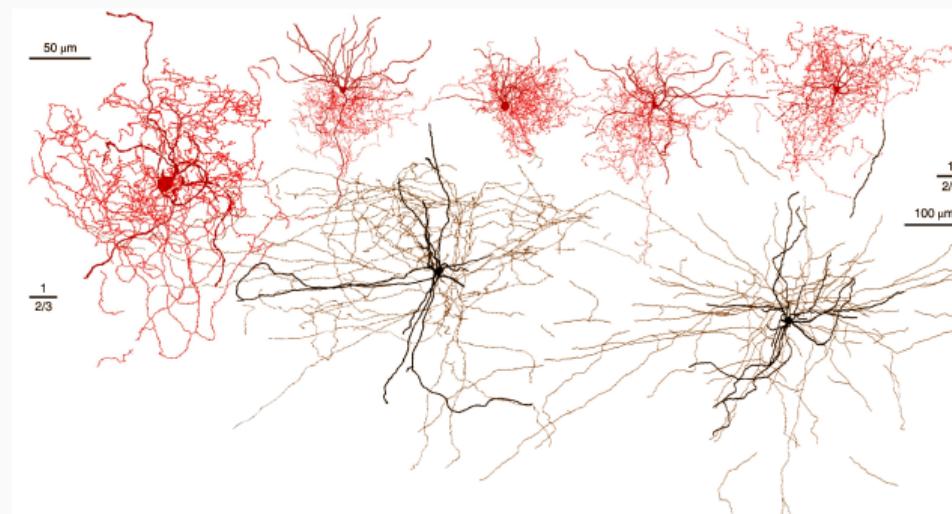
These techniques have been used in the past to study the anatomy of the brain, analysis of aneurysms.



Babin et al. 2018 - Arteriovenous malformation in the brain.

Challenges

- Complex morphologies
- Often need to work in 3D
- Can require a lot of computational power



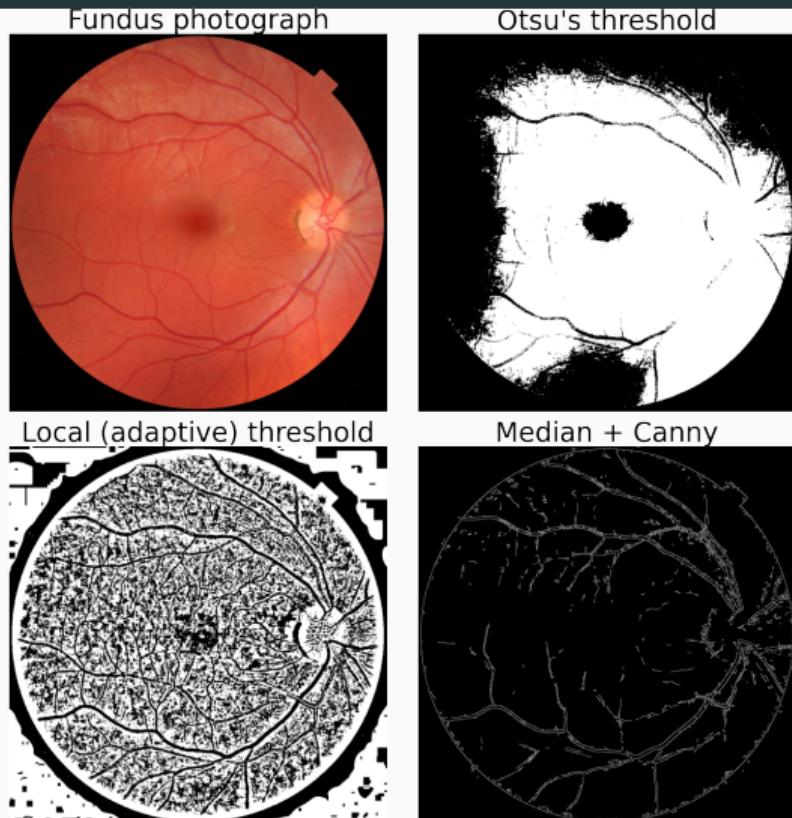
Boldog et al. 2018 - 3D reconstruction of rosehip neurons in the human brain.

Blood vessel detection

Detecting blood vessels

Vessels can be characterised by colour, gradient, and contrast.

However, simple segmentation strategies are often sub-optimal.



Source: Mikael Häggström 2014, Fundus photograph of a normal right eye.

Bottom-hat filtering

Morphological operators can be often used to improve the image before thresholding.

For example, **bottom-hat filtering** has been often used to help in segmenting blood vessels.

Bottom-hat filtering

Morphological operators can be often used to improve the image before thresholding.

For example, **bottom-hat filtering** has been often used to help in segmenting blood vessels.

It involves applying a morphological closing to the image and then subtracting the original image from the result. By using a structural element larger than the structures of interest, we can isolate them from the image.



Bottom-hat filtering

Morphological operators can be often used to improve the image before thresholding.

For example, **bottom-hat filtering** has been often used to help in segmenting blood vessels.

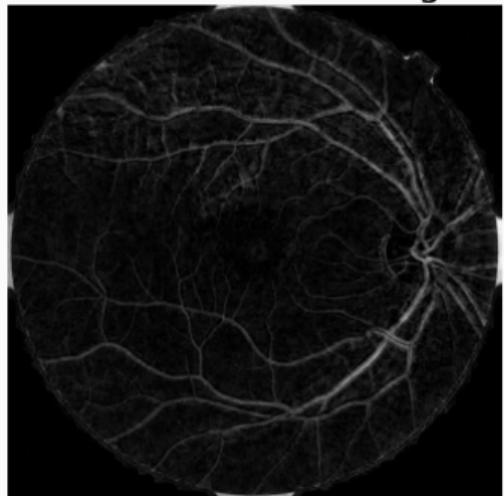
It involves applying a morphological closing to the image and then subtracting the original image from the result. By using a structural element larger than the structures of interest, we can isolate them from the image.



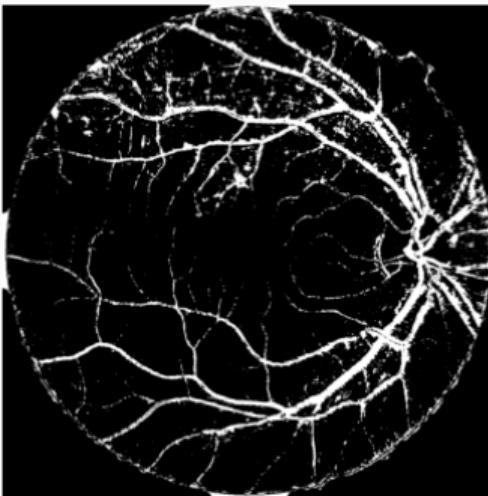
- Bottom-hat filtering extracts objects **darker** than the background.
- Lighter objects can be extracted using **top-hat filtering**
- For top-hat, you subtract a morphological opening of the image from the original image itself.

Bottom-hat filtering of blood vessels

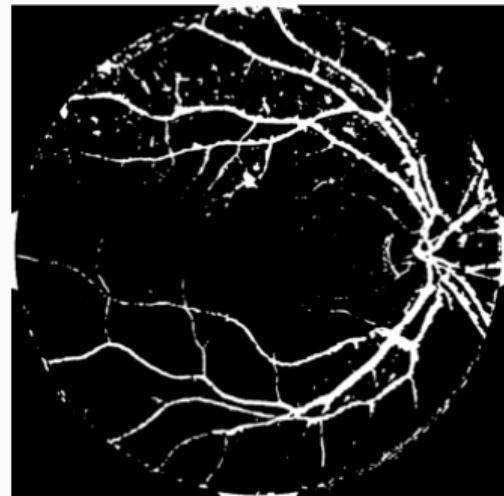
Bottom-hat filtering



BH + Otsu's

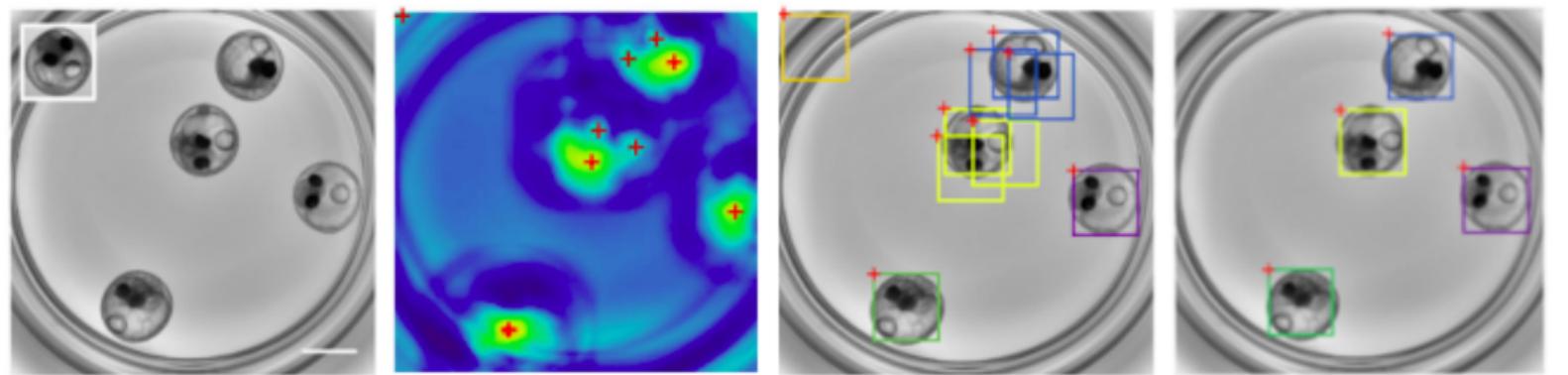


BH + Median + Otsu's



Template matching

Template matching allows finding small parts of an image matching a template image. The cross-correlation between the template and the image is calculated pixel-wise and the maxima are taken as matches.



Thomas and Gehrig, 2020 - Template matching (followed by non-maxima suppression) to identify fish embryos in a plate.

Template matching

Template matching allows finding small parts of an image matching a template image. The cross-correlation between the template and the image is calculated pixel-wise and the maxima are taken as matches.

Template matching can be used for blood vessel detection by assuming that the cross section of the vessels is approximated by a Gaussian.

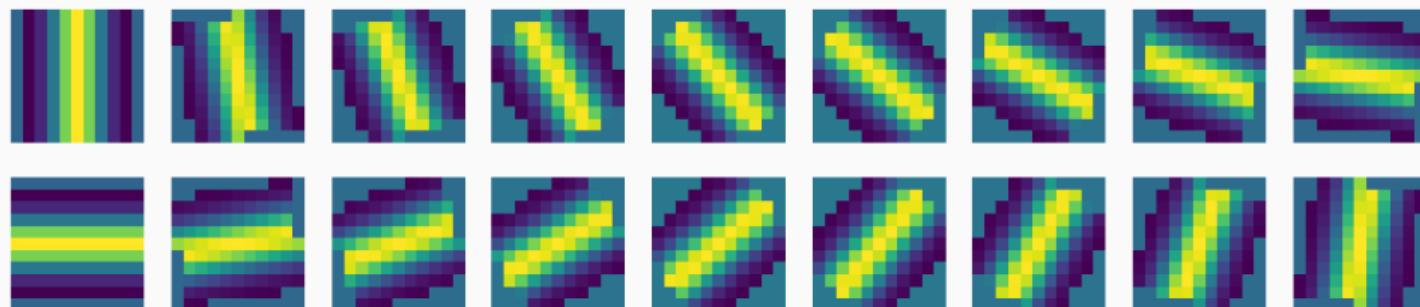
Template matching

Template matching allows finding small parts of an image matching a template image. The cross-correlation between the template and the image is calculated pixel-wise and the maxima are taken as matches.

Template matching can be used for blood vessel detection by assuming that the cross section of the vessels is approximated by a Gaussian.

We design a series of templates, at various angles for piece-wise detection (in pieces of length L).

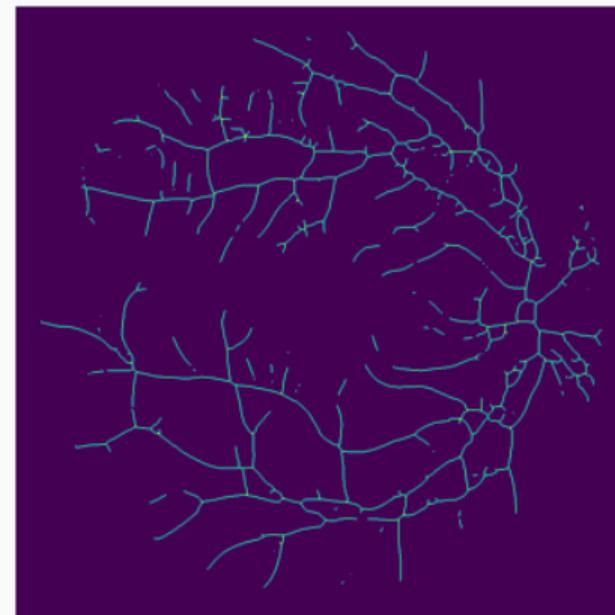
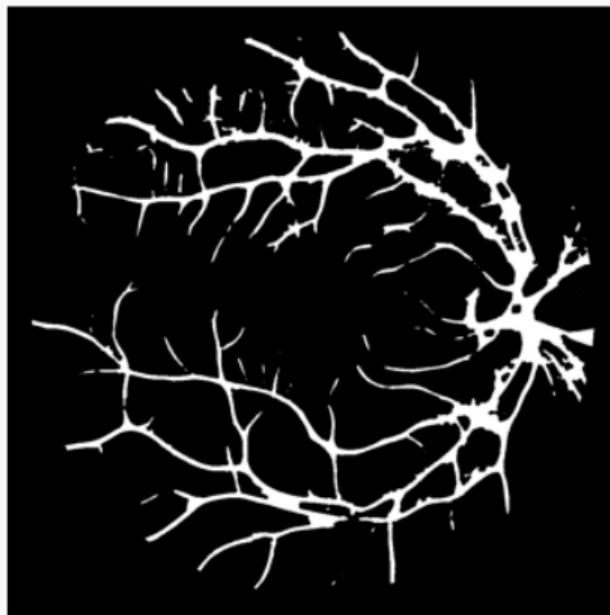
$$K(x, y) = -e^{(-x^2/2\sigma_x^2)} \quad \text{for } |y| \leq \frac{L}{2}$$



Skeletonization

Skeletonization, or center-line extraction is an useful morphological operation that can help delineating tube-like structures in images.

It works by thinning the image repeatedly until no more thinning is possible.



Green channel → bottom-hat filtering → template matching → remove small objects → skeletonization.

From skeleton to graphs and features

Skeletonization can be mapped to a graph, a mathematical structure which allows for easier analysis of the structure.

Features can be extracted to find vessel length, number and location of branching points, tortuosity, discriminate arteries and veins etc

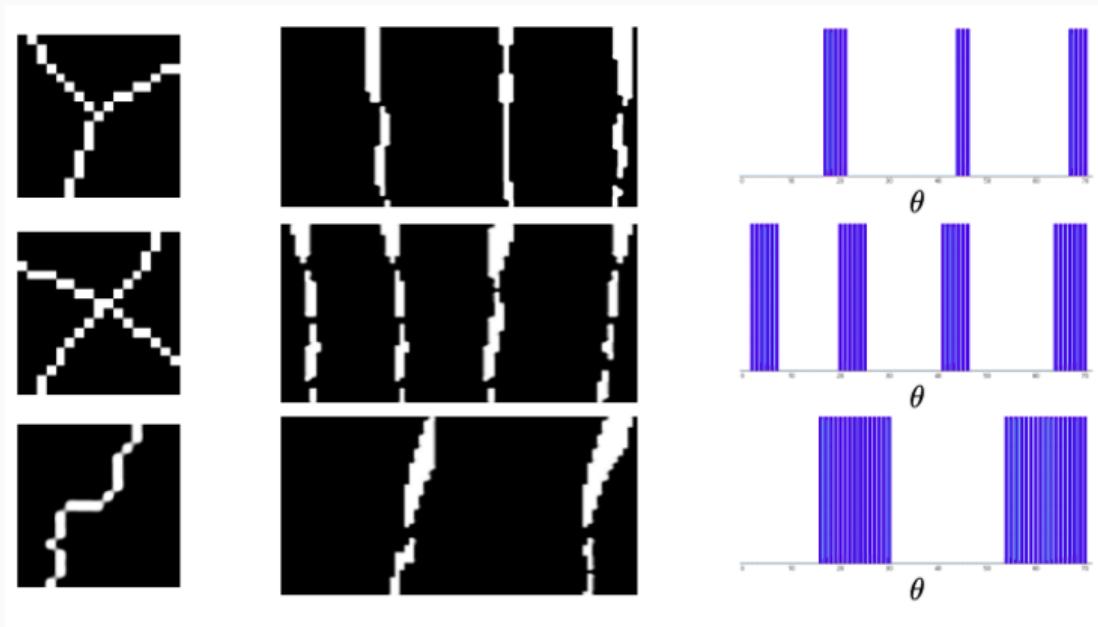
HOG features can be used to find the direction and bifurcation points of vessels.



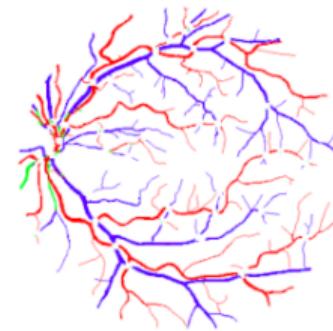
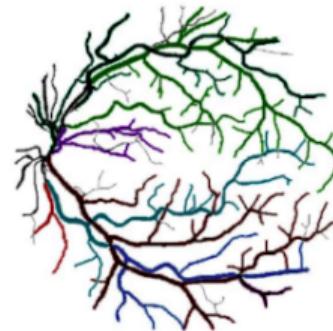
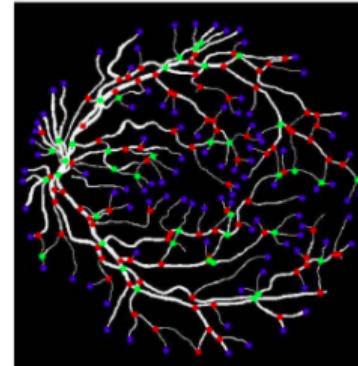
Srinidhi, 2017

Classification of intersections

Other than HOG features, other strategies have been used for classifying structural features of a vascular network. For example, detection of key-points followed by polar projection has been used to classify branches.



Example of a complete pipeline



Neuronal tracing

Neuronal tracing

Neuronal processes are another example of tube-like structures that can be traced in images. Similar approaches, such as skeletonization and template matching, can be used to detect neuronal processes.

Finding the soma

Tracing often starts by identifying the soma, as the starting point for neuronal processes.

There are many different methods for finding the soma. Simple approaches include thresholding and morphological operations.



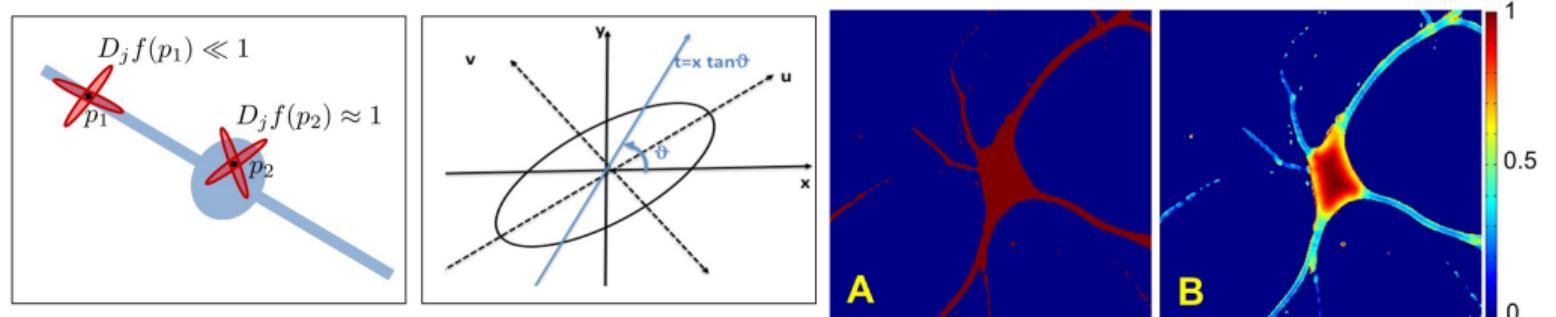
Low-pass filtering was obtained by convolving the image with a large Gaussian kernel, before Otsu's thresholding. Small objects were removed to isolate the soma.

Finding the soma

Tracing often starts by identifying the soma, as the starting point for neuronal processes.

There are many different methods for finding the soma. Simple approaches include thresholding and morphological operations.

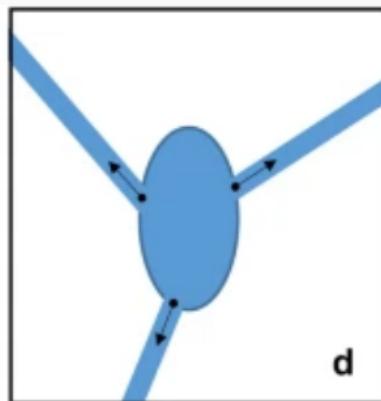
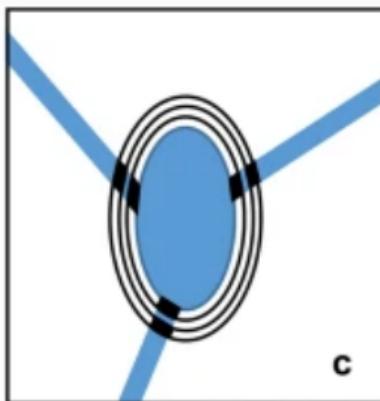
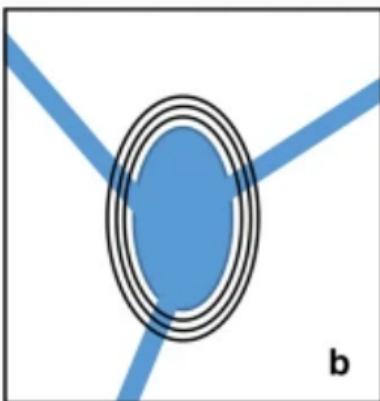
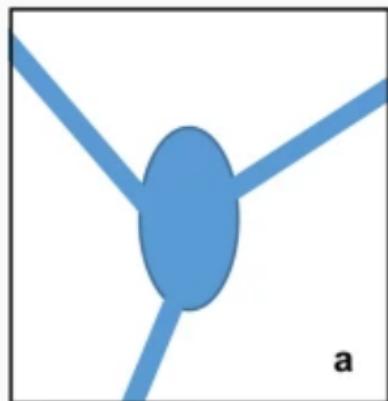
Other more sophisticated approaches have been proposed, such as the use of oriented filters.



Kayasandik et al. 2018 - The response to kernels oriented at different angles is used to discriminate the soma from the rest of the cell.

Neural process seed points

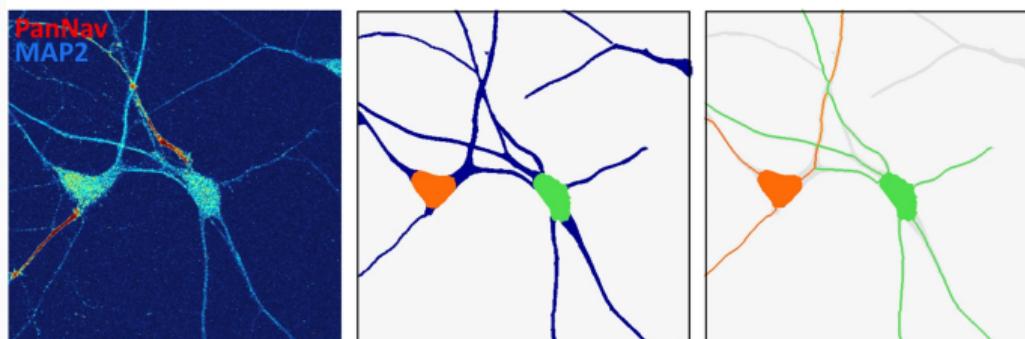
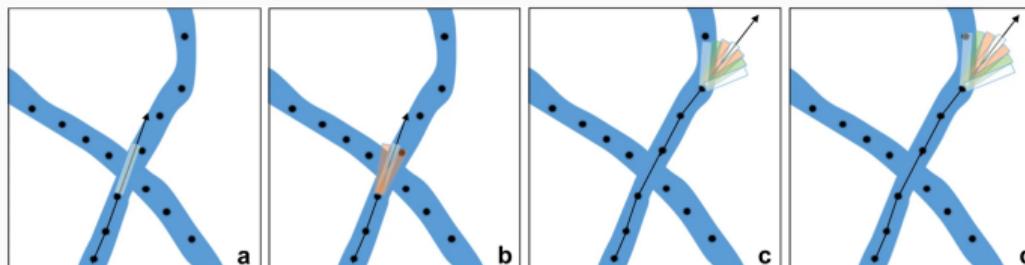
Calculating the difference between incremental morphological openings of the soma we can find the start of the neuronal processes and their orientation.



Tree tracing - finding seed points

This is the trickiest part of tracing neuronal processes.

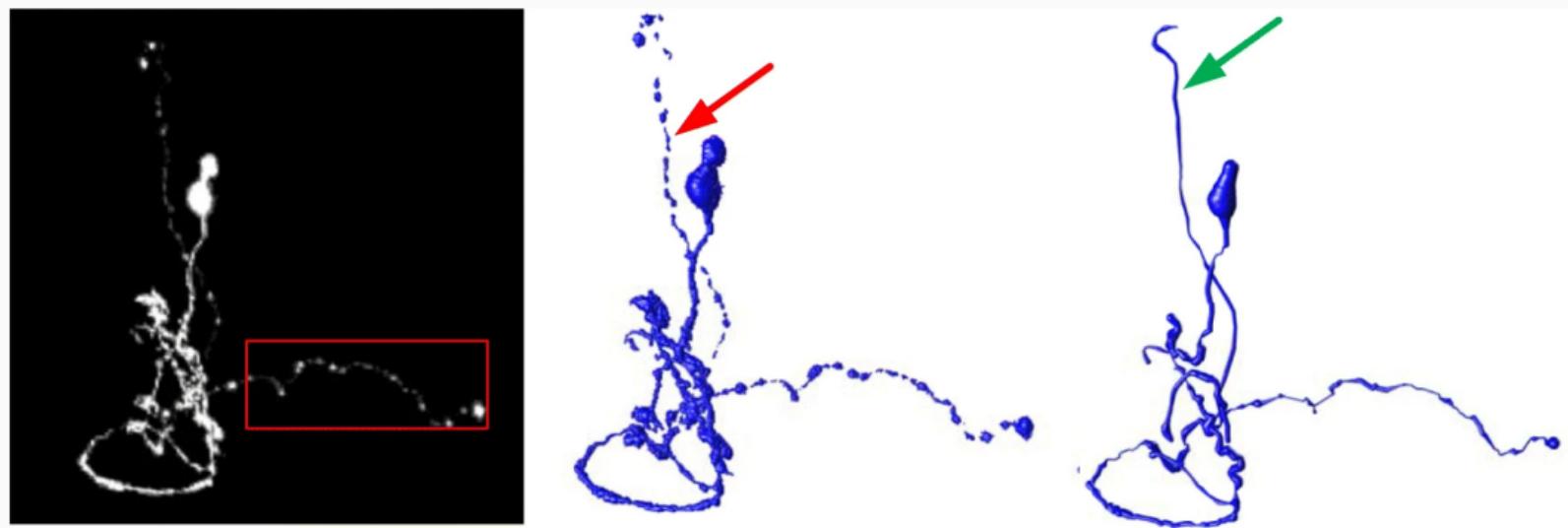
Some methods define points on the centerline of the neuronal process, then search the neighbourhood for the closest point in the orientation of the process.



Tree tracing

Other more complex algorithms have been used.

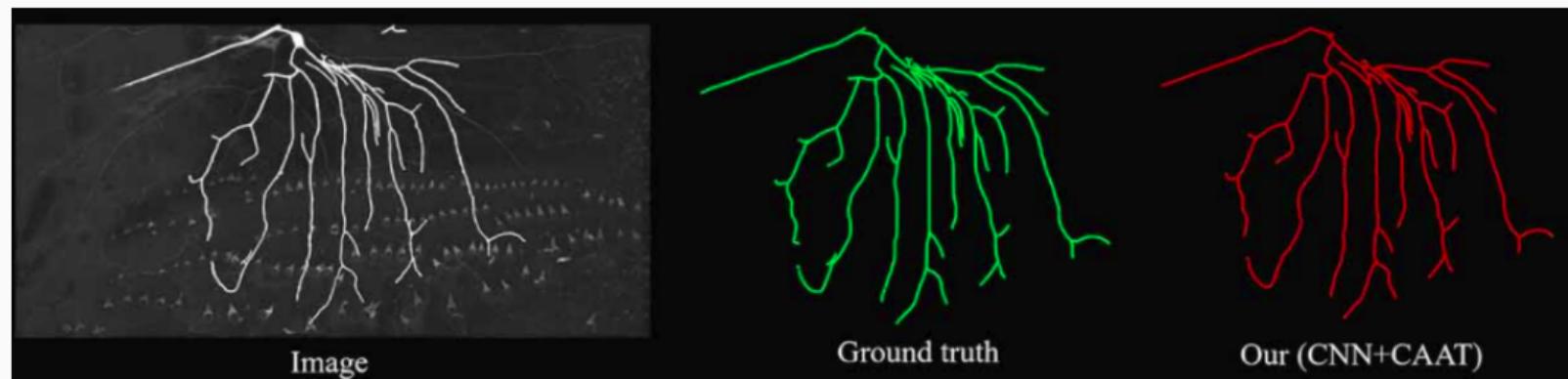
For example, the fast marching algorithm, which was developed to solve the Eikonal equation; this is a non-linear equation for example used to describe the propagation of a wavefront.



Modern methods for tracing

The advent of machine learning has allowed for the use of more sophisticated methods for tracing vessels and neuronal processes.

We will look at some of these methods later in the course.



Huang et al. 2021, Tracing of neurons in 3D using convolutional neural networks.