# Fractal analysis of the vascular tree in the human retina

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# INTRODUCTION

Fractal analysis has emerged as a valuable tool for exploring and quantifying the irregularities and complexities present in retinal images. By characterizing the self-similarity and intricate structures within the retina, fractal analysis provides a unique avenue for detecting abnormalities, assessing vascular health, and advancing our comprehension of ocular conditions.

# OBJECTIVE

Our objective is to analyze the retinal images and get relevant results through fractal analysis in order to calculate the Fractal Dimension. **Fractal Dimension** measurements provide a numerical value that reflects the irregularity and branching patterns of blood vessels.

Through our initial literature review and reseach of the topic, we observe that the FD of the images can help detect various eye conditions such as Diabetic Retinopathy, Poor Vascular health, Glaucoma etc.

# MOTIVATION

The human eye is an intricate and vital organ, and its health is crucial for maintaining overall well-being.

- The retina, in particular, serves as a window to the systemic and ocular health of an individual.
- The early detection and monitoring of retinal diseases, such as diabetic retinopathy, age-related macular degeneration, and hypertensive retinopathy, are of paramount importance in preventing vision loss and preserving the quality of life.

# DATASET ANALYSIS

**STARE(STructured Analysis of the Retina):**This is a dataset for retinal vessel segmentation. It contains 20 equal-sized (700×605) color fundus images. For each image, two groups of annotations are provided [R1][R2].

**DRIVE (Digital Retinal Images for Vessel Extraction):** The DRIVE dataset typically consists of 40 high-resolution retinal fundus images [R1][R2].

**CHASE-DB1 (Cropped Healthy and Diabetic Eyes Database):** This dataset is a collection of retinal fundus images commonly used for research in the field of medical image analysis, particularly for tasks related to diabetic retinopathy and retinal vessel segmentation[R1][R2].

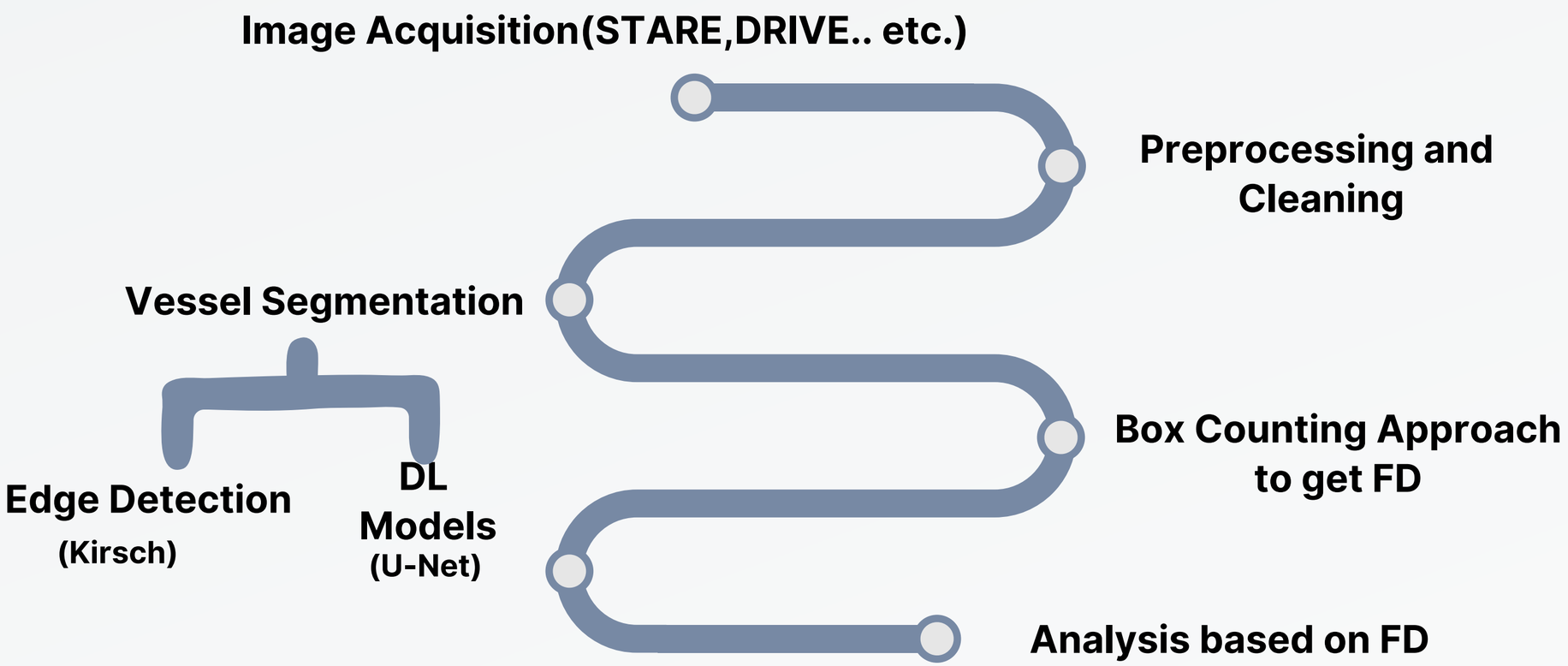
**HRF (High Resolution Fundus):** The exact number of images and their categorization may vary depending on the specific version or release of the dataset. Some versions may include images from various eye diseases[R1][R2].

# LITERATURE REVIEW

| Title and Date | Author(s) | Description | Results |
|---|---|---|---|
| A novel approach to diagnose diabetes based on the fractal characteristics of retinal images, 08 September 2003 | Shu-Chen Chong, Yueh -Min Huang | Higher FD may result in the patient being pathological and the algorithm for the same is discussed here. | Relation between the resolution of images and the Fractal Dimension of the image |
| Reliability of Using Retinal Vascular Fractal Dimension as a Biomarker in the Diabetic Retinopathy Detection, 17 August 2016 | Huang, F., Dashtbozorg, B., Zhang, J., Bekkers, E., Abbasi-Sureshjani, S., Berendschot, T.T. and ter Haar Romeny, B.M. | This paper provides a comparison between different approaches of segmentation and FD calculation | Fractal Dimension varies depending upon the technique used and the quality of the images |
| Comparison of various fractal analysis methods for retinal images,January 2021 | Deepika V,S.Shrinavsalu V.Jeyalakhshmi, P Latha, Rajiv Raman | Four methods for fractal analysis were discussed Box Counting,Fourier Fractal Dimension, Hausdorff Fractal Dimension, modified Hausdorff Fractal Dimension | Fractal Dimension Values which can be used for disease classification |
| Robust Methodology for Fractal Analysis of the Retinal Vasculature September 2016 | M. Z. Che Azemin*, D. K. Kumar, T. Y. Wong, R. Kawasaki, P. Mitchell, and J. J. Wang | Gabor wavelet transforms to enhance the retinal images. Fourier Fractal dimension is computed on these preprocessed images. | The Pearson's correlation coefficient between the fractal dimension computed using FFD |
| Detection of Retinal Microaneurysms using Fractal Analysis and Feature Extraction Technique, April 3-5, 2013 | Rukhmini Roy, Srinivasan Aruchamy, Partha Bhattacharjee | Proposes a method for detecting retinal microaneurysms (MAs) extracts fractal features from pre-processed retinal images. On extracted features it trains a classifier. | The method achieved an accuracy of 93.2% in detecting MAs, which is comparable to the performance of other state-of-the-art methods. |

| Title and Date | Author(s) | Description | Results |
|---|---|---|---|
| Automatic Diagnosis of Glaucoma from Retinal Images Using Deep Learning Approach on 2023 May 14. | Ayesha Shoukat | This paper proposes CNN and ResNet-50 based approach for automatic glaucoma detection from retinal images. | The proposed method can accurately diagnose glaucoma from retinal images, with 98.48% accuracy on the G1020 dataset. |
| Anatomical Structure Segmentation in Retinal Images with Some Applications in Disease Detection, November 2019 | Arunava Chakravarty | This paper explores different Conditional Random Field approaches for simultaneous segmentation of Optic Disc, Cup and other anatomical features. | This paper provides three different frameworks for segmenting different anatomical structures in the retinal image |

# METHODOLOGY



# PROGRESS SO FAR

1. Image Acquisition
   Downloaded and analyzed Standard datasets like STARE,DRIVE,CHASE_B1

2. Manual Segmentation of Optic Disk
   Removing the Optical Disk in order to extract the vascular tree pre-processed image.

3. Automated Segmentation using Kirsch Edge Detection and DL Model U-Net.

4. Proposed Box Counting Method for calculating the Fractal Dimension of the Segmented Image.

# Vessel Segmentation Approach(s)

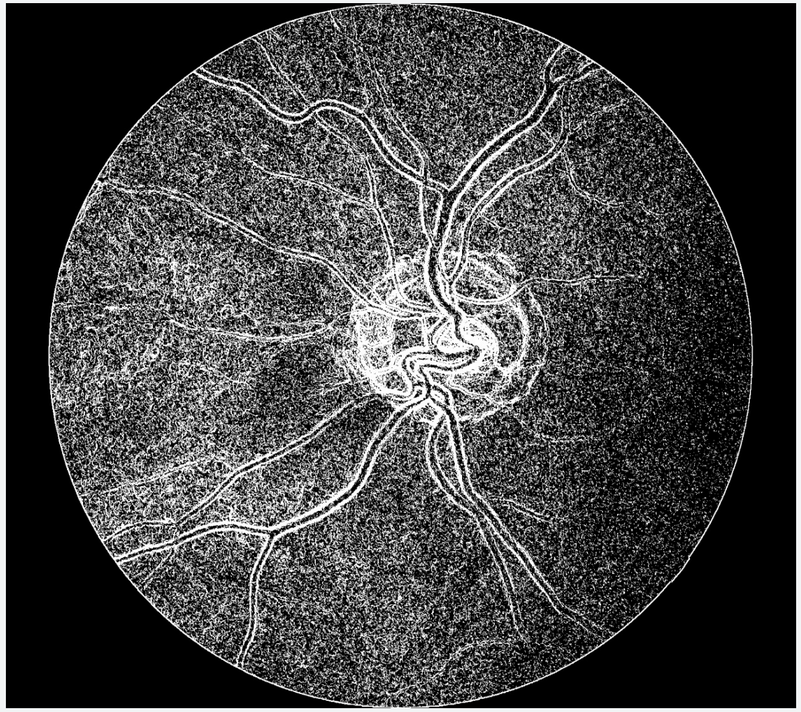
## Edge Detection

- Kirsch template based edge detection method was employed on the pre-processed retinal images to extract the blood vessels.

- The input image is convolved with eight templates corresponding to eight directions (N, S, E, W, NW, NE, SW, and SE). By sliding the template on the entire image, the maximum value of the edge magnitude is obtained.

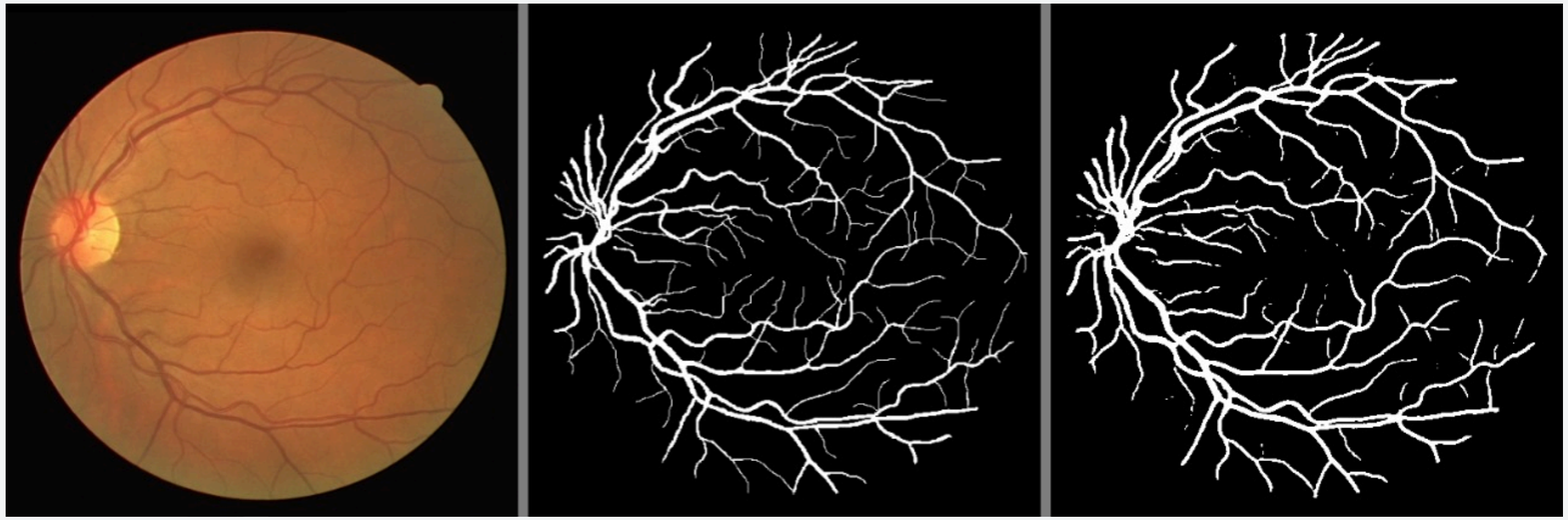
```
h1 = np.array([[5, -3, -3], [5, 0, -3], [5, -3, -3]], dtype=np.float32)/
h2 = np.array([[-3, -3, 5], [-3, 0, 5], [-3, -3, 5]], dtype=np.float32)
h3 = np.array([[-3, -3, -3], [5, 0, -3], [5, 5, -3]], dtype=np.float32)
h4 = np.array([[-3, 5, 5], [-3, 0, 5], [-3, -3, -3]], dtype=np.float32)
h5 = np.array([[-3, -3, -3], [-3, 0, -3], [5, 5, 5]], dtype=np.float32)
h6 = np.array([[5, 5, 5], [-3, 0, -3], [-3, -3, -3]], dtype=np.float32)
h7 = np.array([[-3, -3, -3], [-3, 0, 5], [-3, 5, 5]], dtype=np.float32)
h8 = np.array([[5, 5, -3], [5, 0, -3], [-3, -3, -3]], dtype=np.float32)
```

**Fig: (8) 3x3 masks are defined which are executed over the entire image.**



Kirsch Edge Detection Result

U-Net Architecture

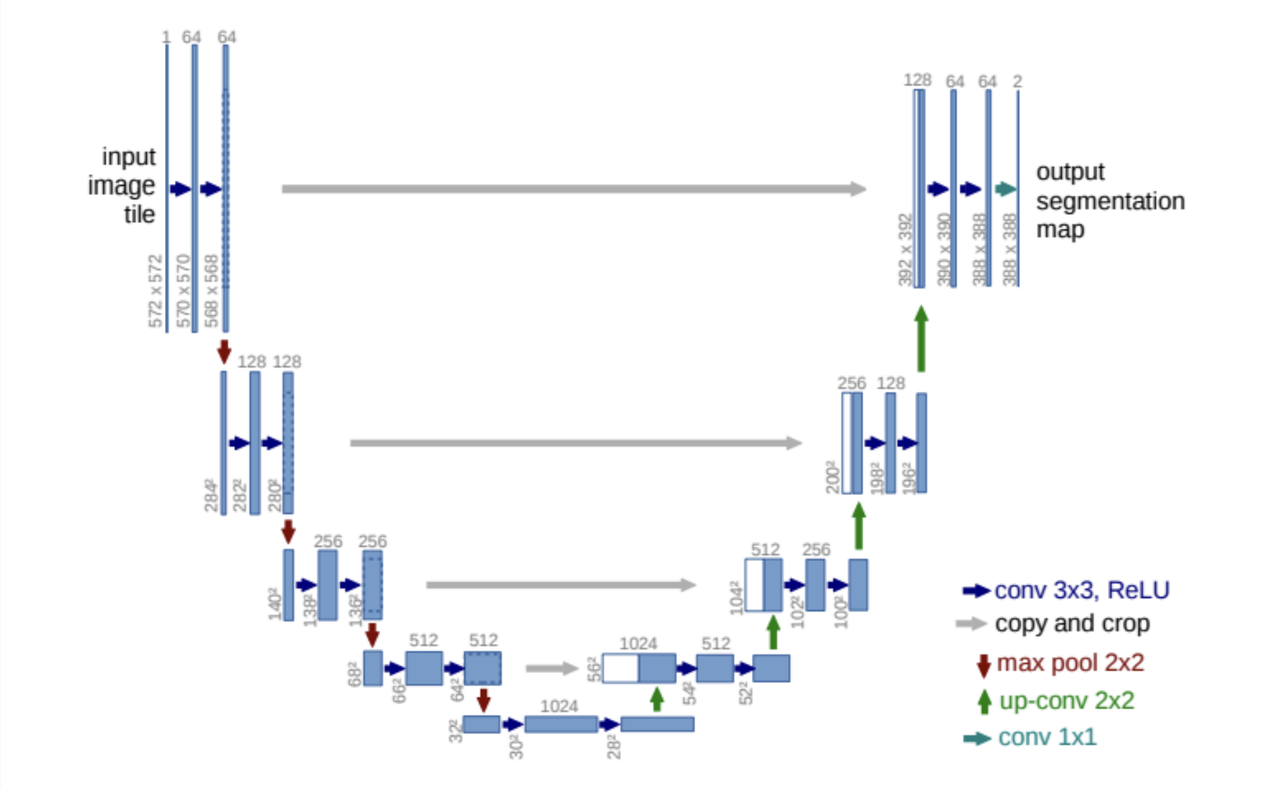


Ground Truth

Predicted Image

# Vessel Segmentation Approach(s)

## Deep Learning Model (U-Net)



# Fractal Analysis(Box Counting Approach for FD)

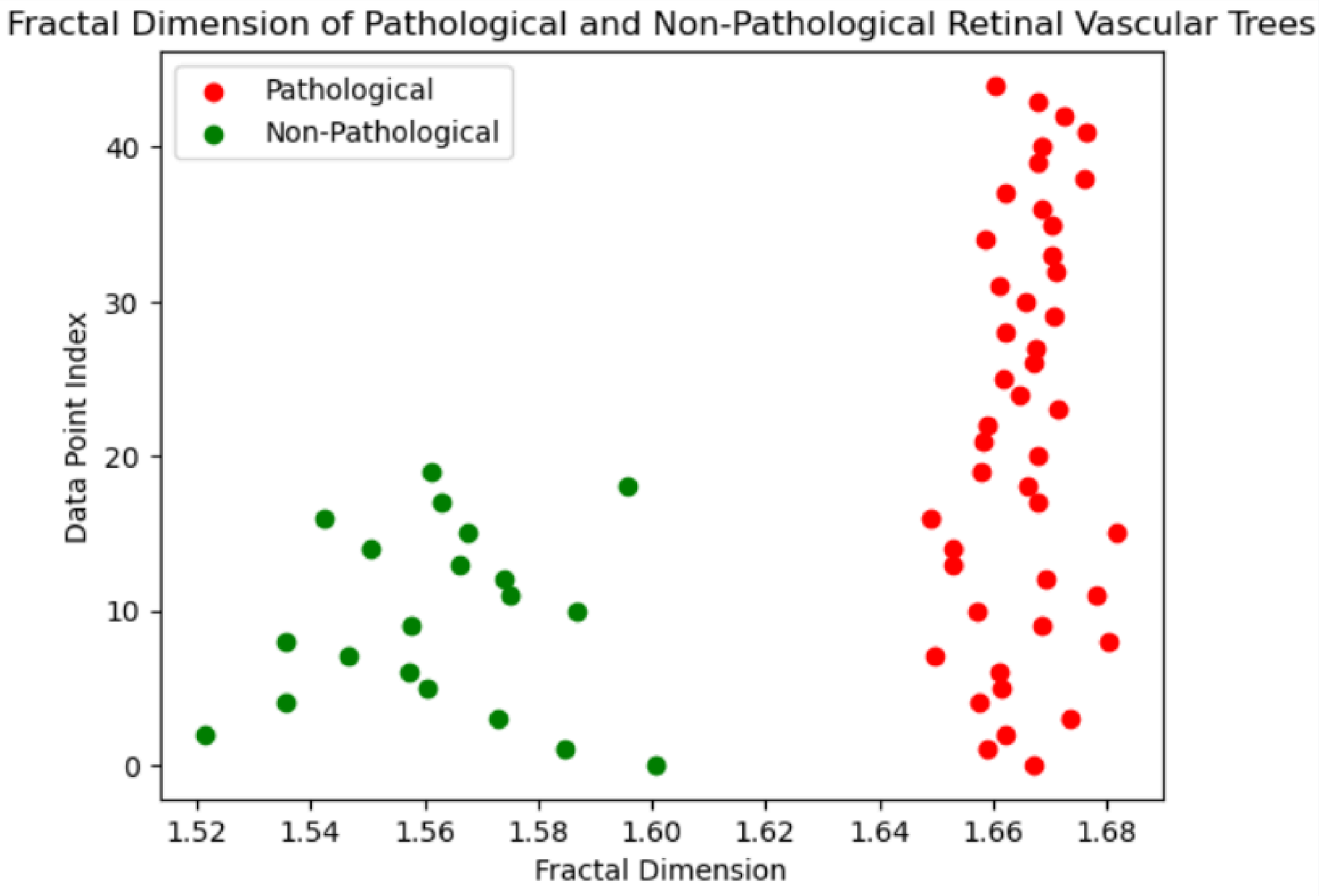
**One of the most popular method to calculate the Fractal Dimension (FD) is the Box Counting Approach.**

**We can calculate the FD by using four variations of the approach.**

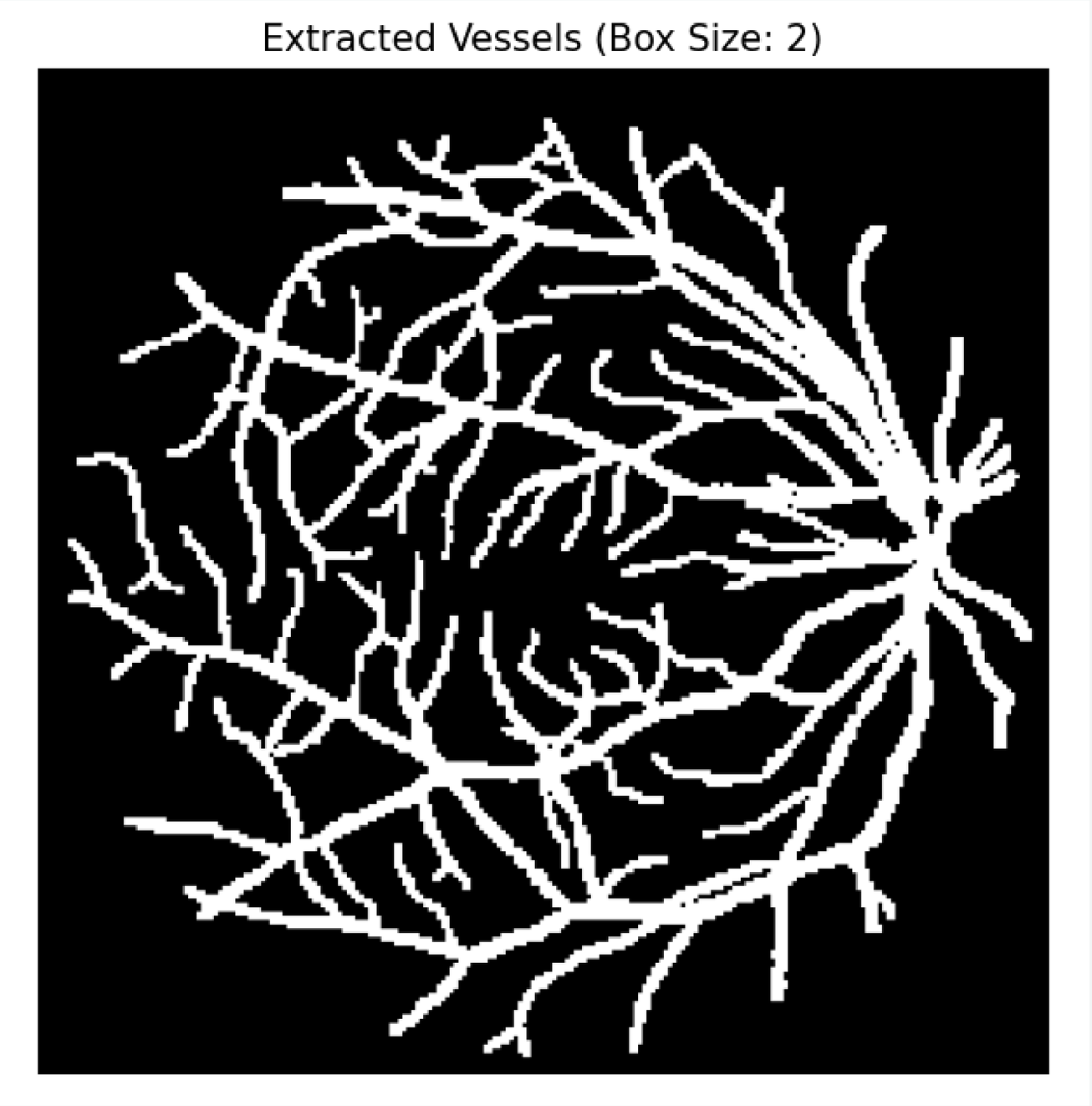
**(1) Different grid placement,**
**(2) Averaging multiple box-grid placements,**
**(3) Different smoothing effects, and**
**(4) Reducing the vessel thickness to 1-pixel thickness (skeletonized vasculature)**

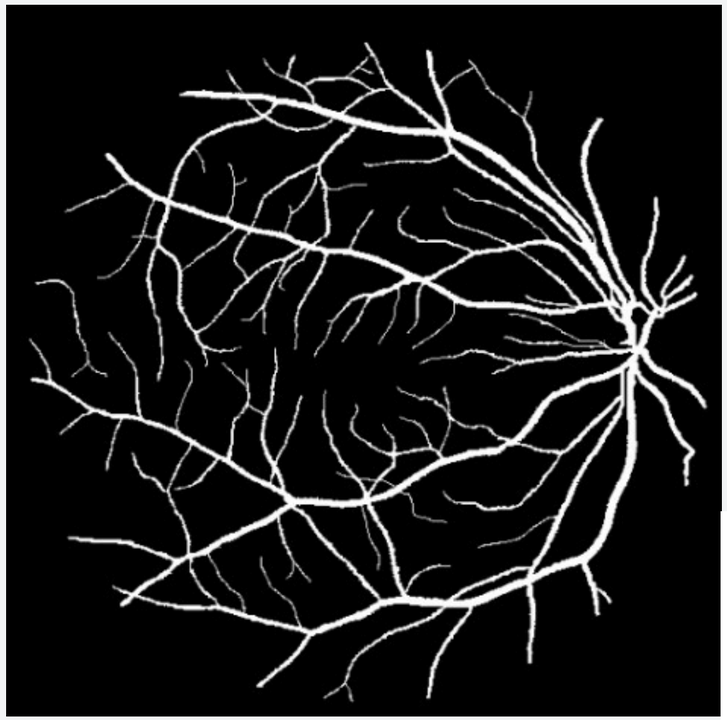
**However in research paper's, above approach was done using ImageJ plugin FracLac. We tried to do the same in python by focusing on only two steps:**

**1) Placement of box-counting grid**
**2) Calculation of the slope log Count versus log Size**


Fractal Dimension of Pathological and Non-Pathological Retinal Vascular Trees
Pathological
Non-Pathological
Data Point Index
0
10
20
30
40
1.52
1.54
1.56
1.58
1.60
1.62
1.64
1.66
1.68
Fractal Dimension

This image show how the box counting method is applied
in this particular case a box size of 2 is applied and number of boxes in the white region are being counted

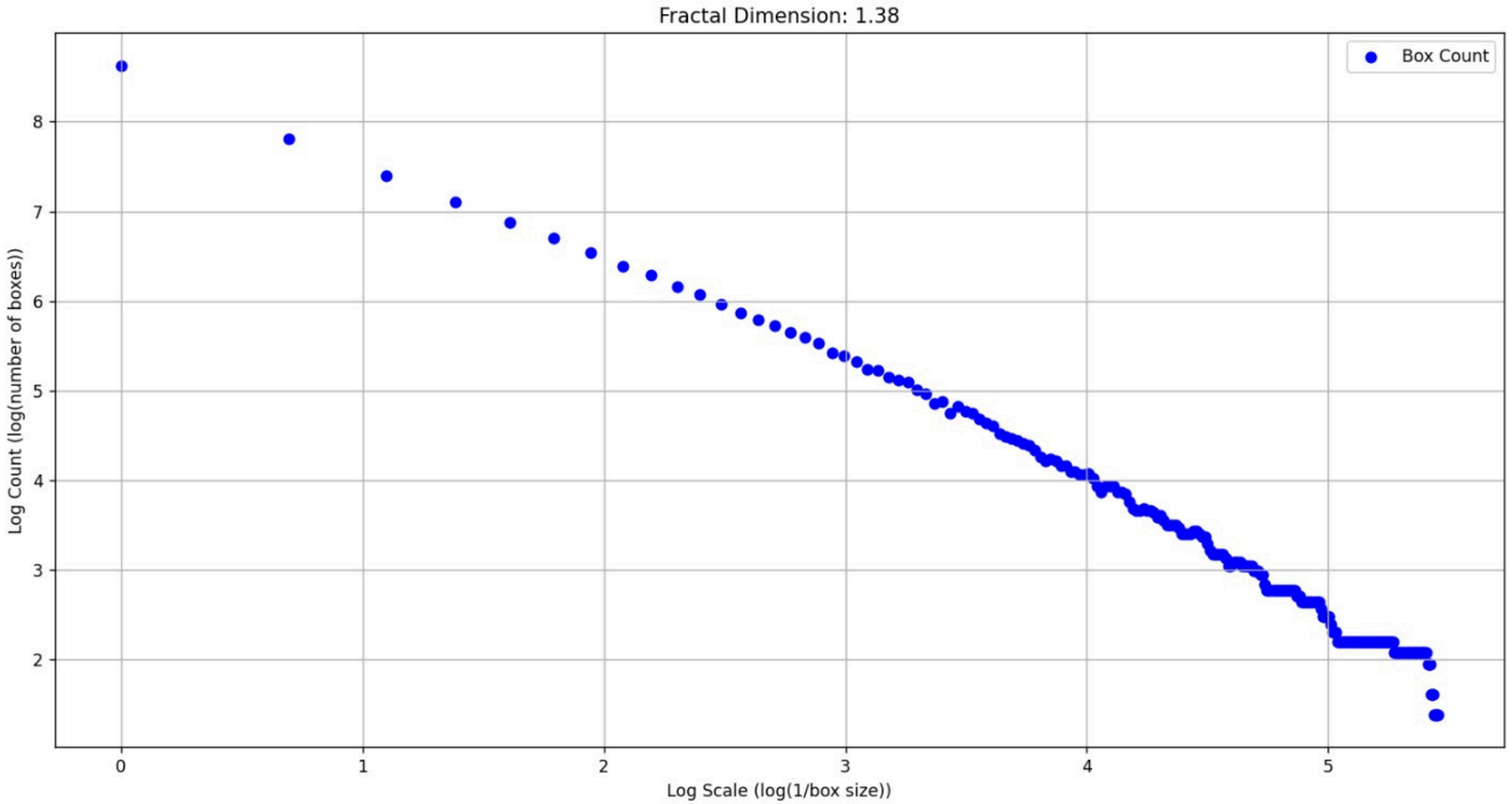




The Final Fractal Dimension is being calculated:

- Varying the box size and fitting the boxes to the white regions (vessel) of the image
- Then calculating the logarithmic value of the number of boxes and the inverse of the box size.
- Finally we apply the formula for fractal dimenion, for this we have calculated the slope for the linear regression line that was fitted on the box counts.

$$D = -\frac{\log(N)}{\log(S)}$$



# Thank You