VesSkel: Vessel Skeletonization and Graph-Based Phenotype Analysis in Retinal Fundus Images

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Retinal fundus imaging enables non-invasive assessment of the vascular system and plays an important role in the diagnosis of systemic and ocular diseases such as diabetic retinopathy and glaucoma. Quantitative analysis of retinal vessels often relies on vessel segmentation followed by skeletonization and extraction of structural features.

One widely used topology-preserving skeletonization approach is the algorithm proposed by Lee et al. (1994), which supports both 2D and 3D data. While first attempts on optimized 3D implementations are available, efficient and consistent parallelized implementations that work on 2D (and 3D) large biomedical image datasets remain limited.

The goal of this project is to develop an efficient, numba-parallelized implementation of the Lee94 skeletonization algorithm in 2D (and 3D) and apply it to retinal vessel segmentation masks from the High-Resolution Fundus (HRF) Image Database. Features of the resulting vessel skeletons should be examined with regard to their ability to distinguish between healthy, diabetic retinopathy, and glaucoma phenotypes.

The steps of this project can roughly be summarized as follows:

- Conduct a structured literature review on existing skeletonization and thinning algorithms and on existing skeletonization tools.

- Study the Lee94 thinning algorithm and its topological constraints in 2D (and 3D), implement and benchmark an efficient numba-parallelized 2D (and 3D) version of Lee94.

- Apply the algorithm to vessel masks from the HRF dataset and construct graph representations from skeletons (nodes: endpoints/bifurcations; edges: vessel segments).

- Extract quantitative skeleton and graph features (e.g., branching statistics, tortuosity, fractal dimension, ...) and analyze which features differentiate the three phenotypes

Requirements:

- Programming skills in Python, interest in performance optimization (numba, parallelization)

- Basic knowledge of image processing and graph theory

Literature:

- Odstrcilik, Jan, et al. "Retinal vessel segmentation by improved matched filtering: evaluation on a new high-resolution fundus image database." *IET Image Processing* 7.4 (2013): 373-383.

- Bumgarner, Jacob R., and Randy J. Nelson. "Open-source analysis and visualization of segmented vasculature datasets with VesselVio." *Cell reports methods* 2.4 (2022).

- Nunez-Iglesias, Juan, et al. "A new Python library to analyse skeleton images confirms malaria parasite remodelling of the red blood cell membrane skeleton." *PeerJ* 6 (2018): e4312.

- Lee, Ta-Chih, Rangasami L. Kashyap, and Chong-Nam Chu. "Building skeleton models via 3-D medial surface axis thinning algorithms." *CVGIP: graphical models and image processing* 56.6 (1994): 462-478.