The following algorithms must be implemented:

- Calculation of the modulus of the gradient using convolutions with derivatives of the Gaussian function.
- Suppression of non-maxima of the gradient modulus (component of Canny's algorithm).
- End result of Canny's edge detection algorithm.

The modulus of the gradient must be normalized so that the maximum value of the modulus of the gradient becomes 255: after calculating the modulus of the gradient, find the maximum value of $g_{max}$ and multiply the result by $255 / g_{max}$.

The result of the Canny algorithm is a binary mask: pixel values should only take values of 0 or 255.

In the Canny algorithm, all its auxiliary steps must be correctly implemented: calculation of the gradient modulus, non-maximum suppression, and hysteresis. The input parameters of the Canny algorithm are three numbers: the Gaussian filter parameter (sigma) used to calculate the derivatives, and two threshold values specified as coefficients relative to $g_{max}$ - the maximum value of the gradient modulus in the image.

## Additional part of the task

The following algorithm must be implemented:

- Isolation of vessels in fundus images using the ridge detection algorithm.

The ridge detection algorithm is implemented similarly to the Canny algorithm with the difference that:

- Instead of the modulus of the gradient, the maximum modulo eigenvalue of the Hessian matrix is taken.
- The eigenvector for the given eigenvalue is taken as the direction for suppressing nonmaxima.

Vessels in the processed images are darker than the background, so the pixels in which the largest eigenvalue is negative in modulus should be excluded from the result.

The "spine" check ($|L1| >> |L2|$) can be omitted.

The result of non-maximum suppression should be normalized to the range [0, 255] similarly to the mandatory part of the task.

The result of vessel selection is the union of normalized images after suppression of non-maxima obtained for different values of the Gaussian filter parameter (sigma). The recommended values are 2, 3, and 4. Pooling is pixel-by-pixel maximization.

## Recommendations

- A common mistake when calculating the image gradient is convolution with the derivative of a one-dimensional Gaussian function. It is correct to take the two-dimensional Gaussian function and calculate the derivatives of the two-dimensional function.

## Command line parameter format

The program must support launching from the command line with a strictly defined command format:

```
python main.py (command) [parameters...] (input_image) (output_image)
```

Command List:

| | |
|---|---|
| grad (sigma) | Calculation of the modulus of the gradient |
| nonmax (sigma) | Result of Non-Maximum Suppression |
| canny (sigma) (thr_high) (thr_low) | Edge detection using the Canny algorithm. The first parameter is the sigma for calculating the gradient, the next two parameters are real numbers - the larger and smaller thresholds, respectively |
| vessels | Vessel detection according to the proposed algorithm |