LIRIS

AGENCE NATIONALE DE LA RECHERCHE ANR

UMR 5205 CNRS

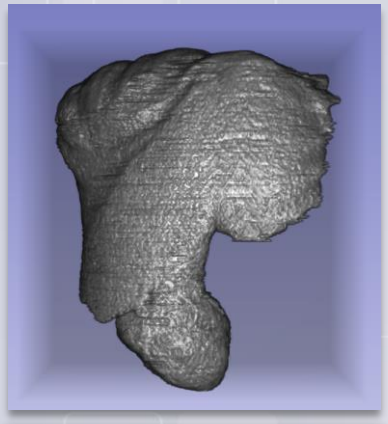
Vesselness Filters : A Survey with Benchmarks Applied to Liver Imaging

Jonas Lamy, Odyssée Merveille, Bertrand Kerautret, Nicolas Passat, Antoine Vacavant

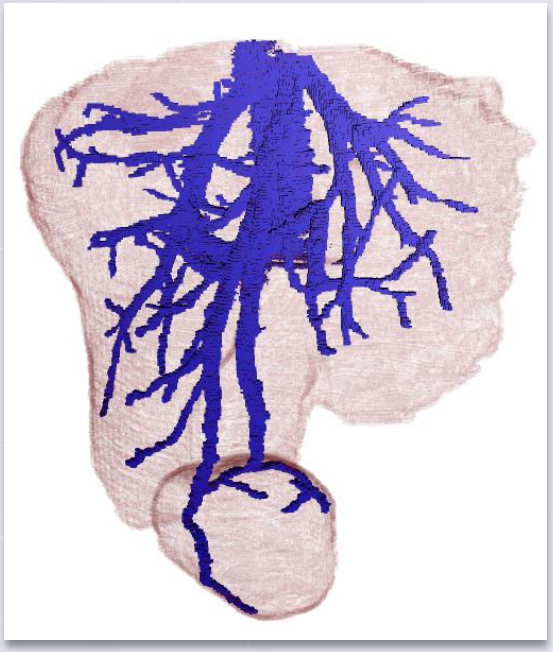
Laboratoire d'InfoRmatique en Image et Systèmes d'information

cnrs INSA Lyon 1 Université Lumière Lyon 2 École Centrale Lyon

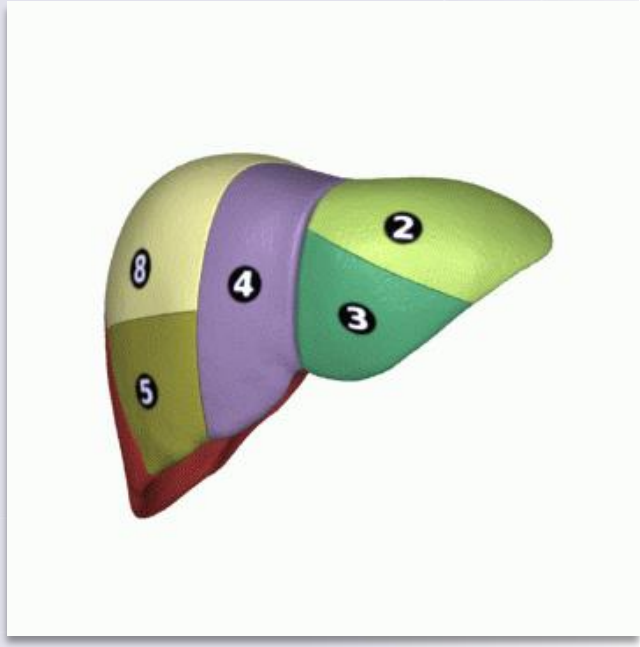
Segmentation



Raw data

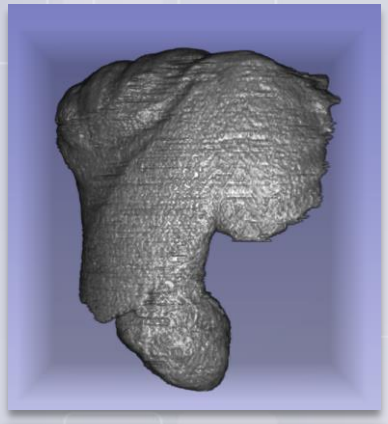


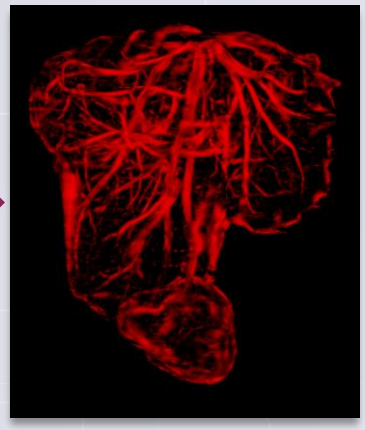
Segmentation

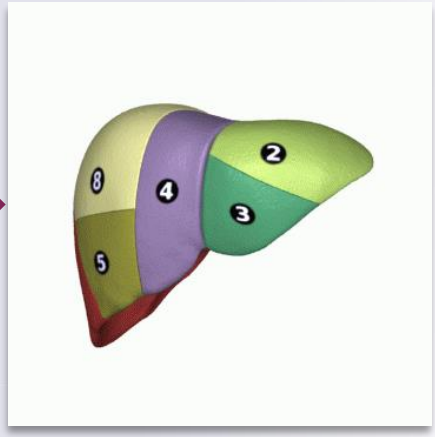


Medical application

Segmentation







Raw data

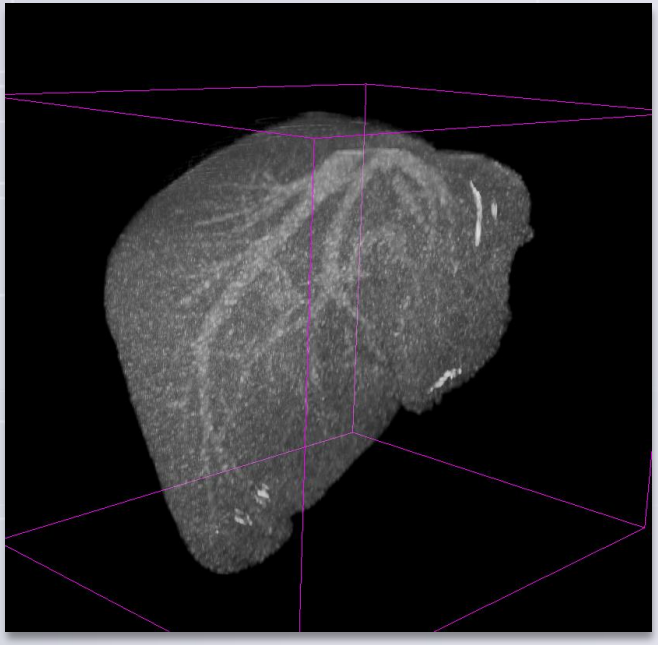
Pre-processing

Segmentation

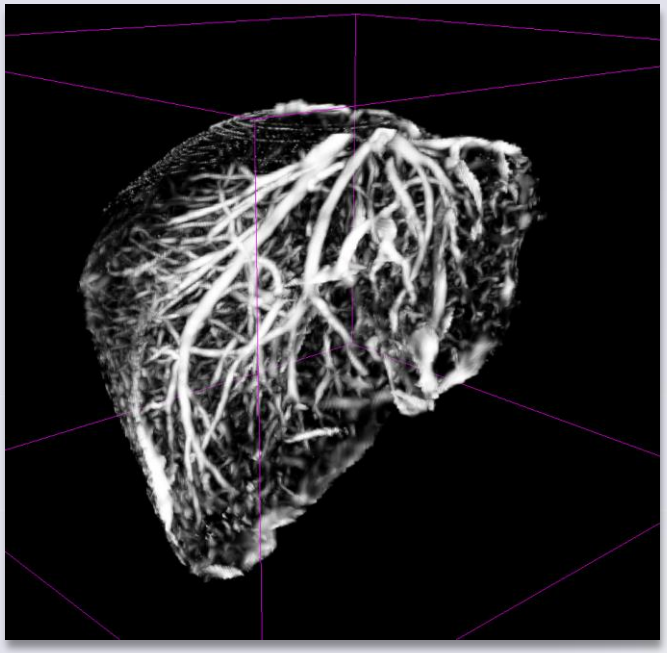
Medical application

Vessel enhancement

- **Goals:**
  - Improve the contrast of the vessels
  - Reduce the noise, artefacts and the signal of other structures



MIP view of a masked liver – Ircad database



Frangi vesselness filter result (MIP)

Motivation

- **Few papers deal with hepatic vessel enhancement**
  - Vessel segmentation papers often focus on eye fundus, cerebrovasculature, coronary arteries
- **Which enhancement filter should we use?**
  - Filters tested on a wide variety of data, often private
  - Heterogeneous implementation ecosystem
    - *Different languages and packages (C/C++, matlab, python,…)*
    - *Deprecated implementations*

Motivation

Need for a benchmark

- A quantitative comparison of vesselness filters in the same framework
- Provide implementations of filters in C++ as standalone programs
- Re-usable benchmark with any dataset and additionnal new filters

Which filters?

References	Method type	Key idea
[Sato, 1997]	**Hessian**	Reconnection of vessel discontinuities and noise removal
[Frangi, 1998]		Selective filtering of blobs, plates and tubes and noise removal
[Meijering, 2004]		Designed for weakly contrasted and thin vessels
[OOF, 2010]		Robust against the disturbance induced by adjacent objects
[Jerman, 2015]		Design a highly contrasted vesselness from volume ratio using fewer parameters than Frangi
[Zhang, 2018]		K-means based contrast enhancement added to Jerman vesselness
[RORPO, 2019]	**Morphology**	Find curvilinear structures using oriented path opening

Which filters?

References	Method type	Key idea
[Sato, 1997]	**Hessian**	Reconnection of vessel discontinuities and noise removal
[Frangi, 1998]		**Selective filtering of blobs, plates and tubes and noise removal**
[Meijering, 2004]		Designed for weakly contrasted and thin vessels
[OOF, 2010]		Robust against the disturbance induced by adjacent objects.
[Jerman, 2015]		Design a highly contrasted vesselness from volume ratio using fewer parameters than Frangi
[Zhang, 2018]		K-means based contrast enhancement added to Jerman vesselness
[RORPO, 2019]	**Morphology**	Find curvilinear structures using oriented path opening

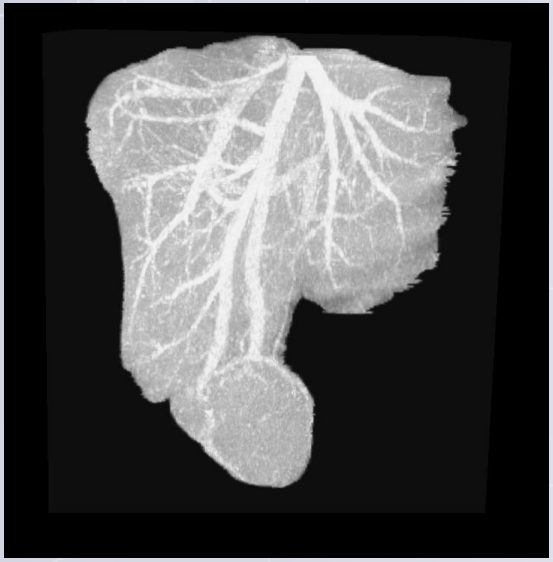
Which filters?

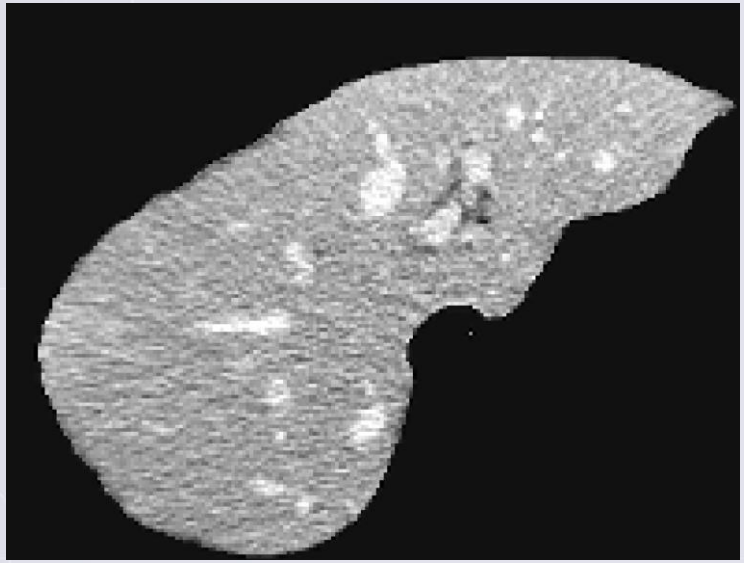
References	Method type	Key idea
[Sato, 1997]	Hessian	Reconnection of vessel discontinuities and noise removal
[Frangi, 1998]		Selective filtering of blobs, plates and tubes and noise removal
[Meijering, 2004]		Designed for weakly contrasted and thin vessels
[OOF, 2010]		Robust against the disturbance induced by adjacent objects.
[Jerman, 2015]		Design a highly contrasted vesselness from volume ratio using fewer parameters than Frangi
[Zhang, 2018]		K-means based contrast enhancement added to Jerman vesselness
[RORPO, 2019]	**Morphology**	**Find curvilinear structures using oriented path opening**

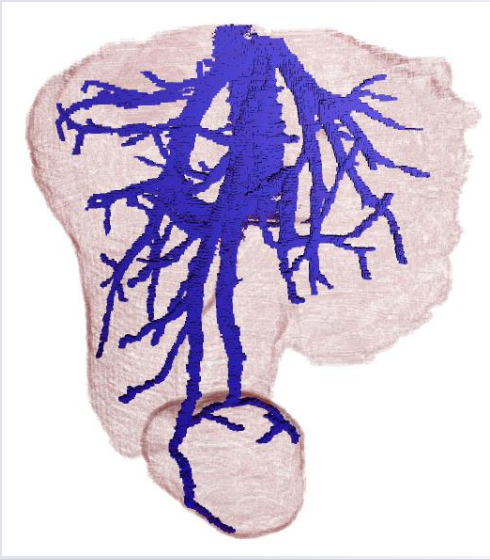
Which dataset?

- **CT Dataset**
  - Ircad dataset
    - 20 patients
    - Volumes size between [$512^2 \times 74$] and [$512^2 \times 260$] voxels
    - Axial slice resolution between 0.56 mm and 0.87 mm
    - Coronal slice between 1.00 mm et 4.00 mm
- **Synthetic dataset**
  - Vascusynth dataset
    - 10 groups of 20 images with varying bifurcation numbers from 1 to 56
    - Volume size [101 x 101 x 101] voxels
    - Isometric resolution of 1mm
    - Added MRI « artefacts »

Which dataset?

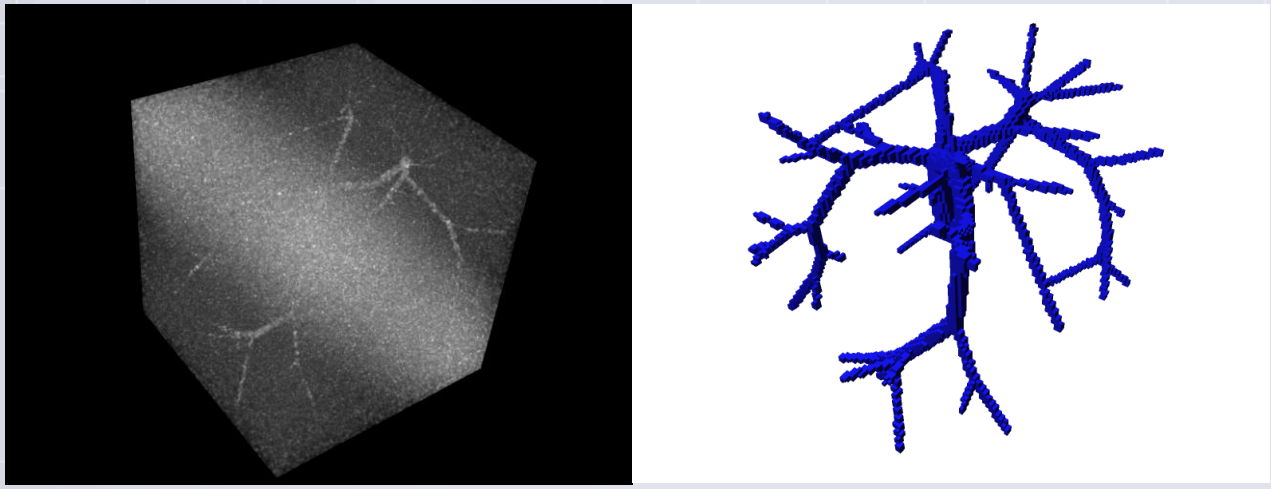






Ircad
3D view, slice, groundtruth

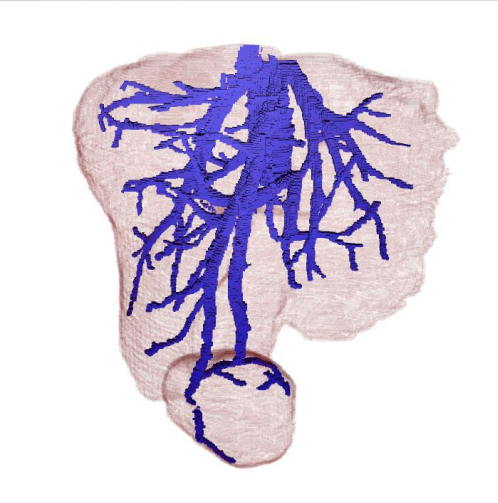
Which dataset?

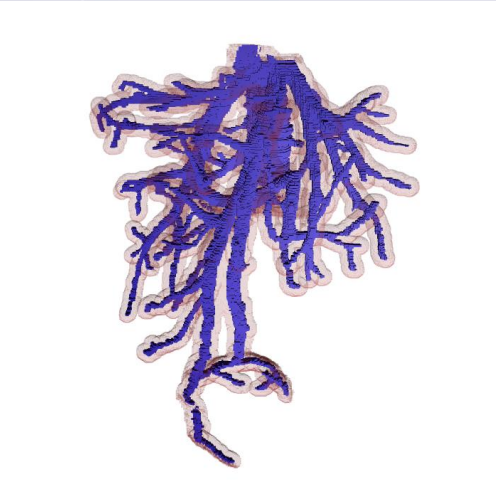


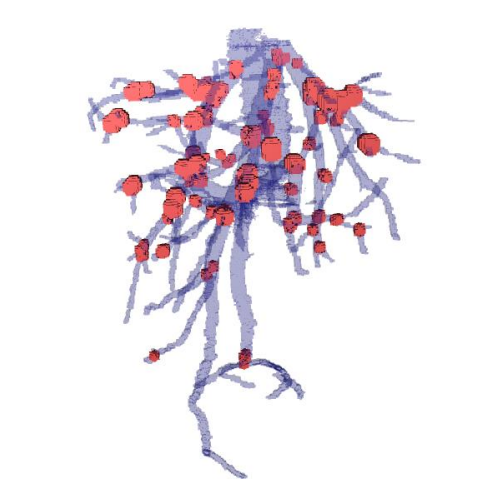
Vascusynth with Rician noise $= \{5, 10, 20\}$

Which area of interest?

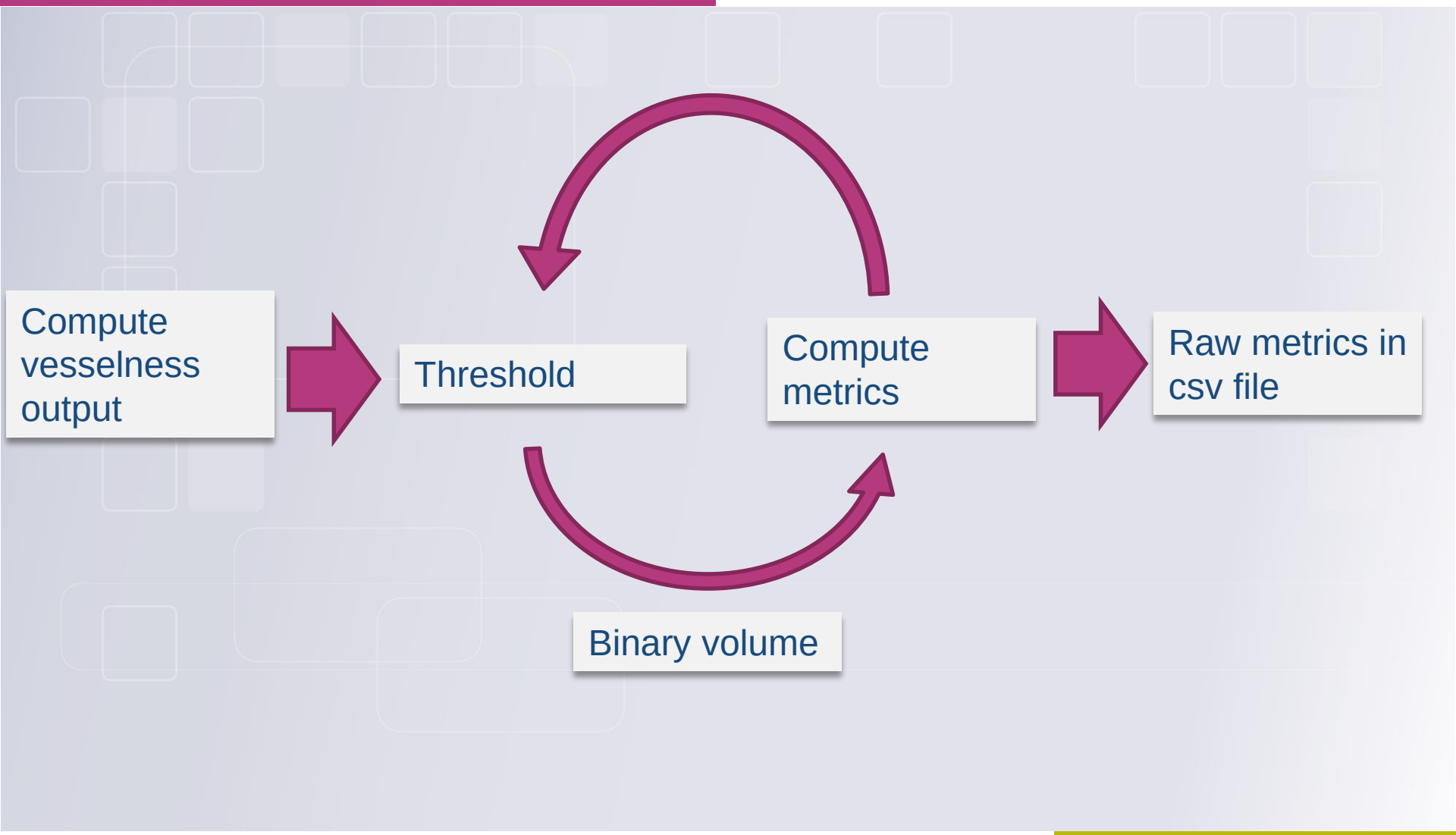
- **Metrics computed on 3 different regions of interest**
  - Whole liver, vessels neighbourhood, vessels bifurcations







Benchmark


Compute vesselness output
Threshold
Compute metrics
Raw metrics in csv file
Binary volume

Benchmark

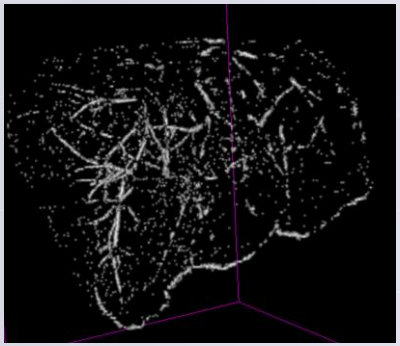
Compute vesselness output

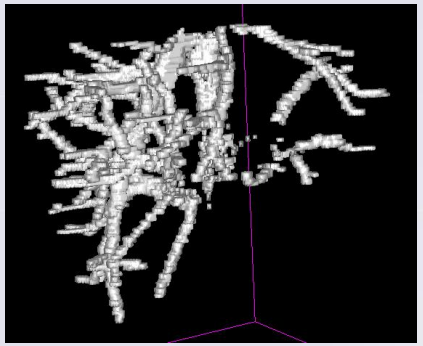
Threshold

Binary volume

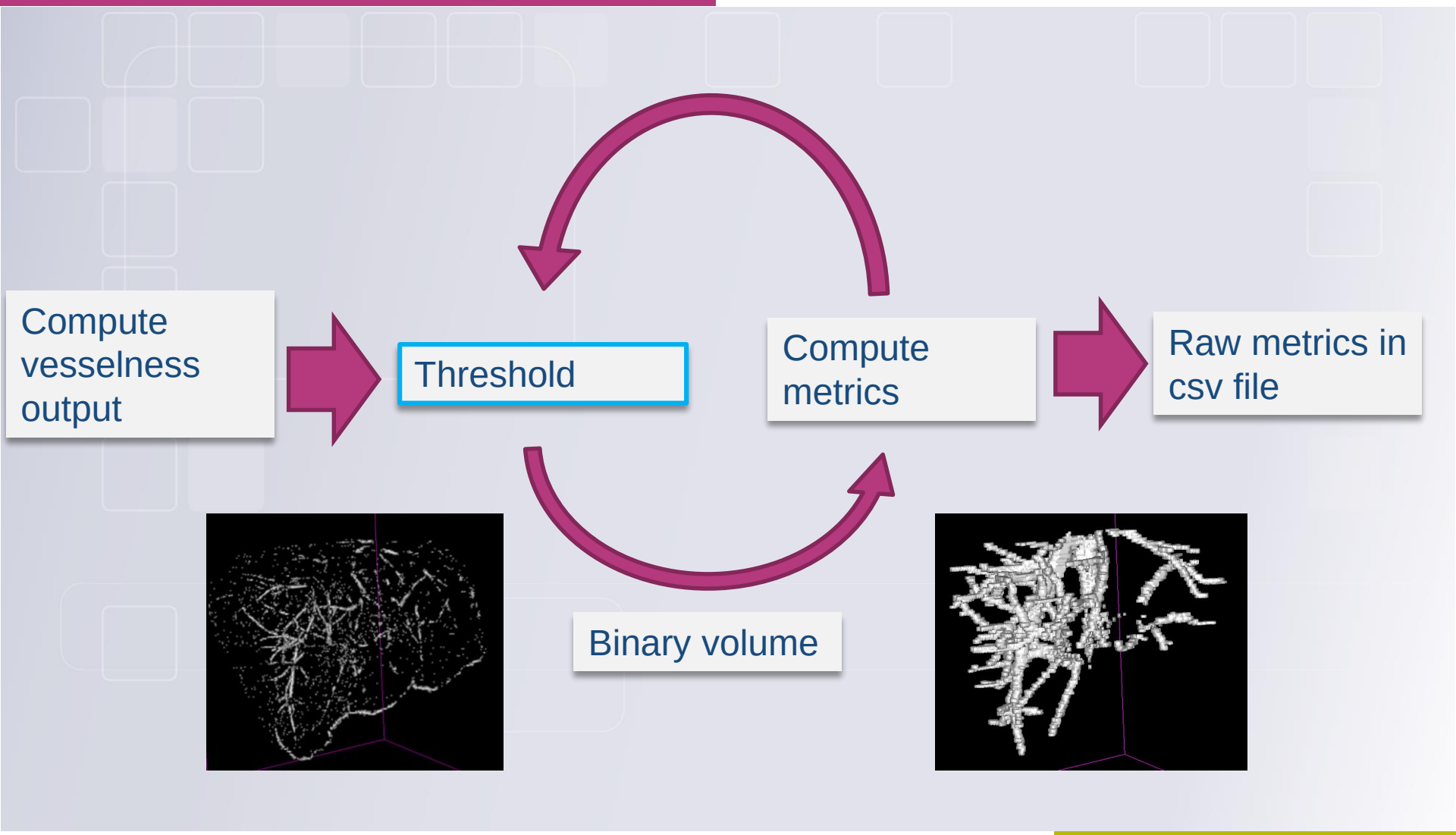
Compute metrics

Raw metrics in csv file

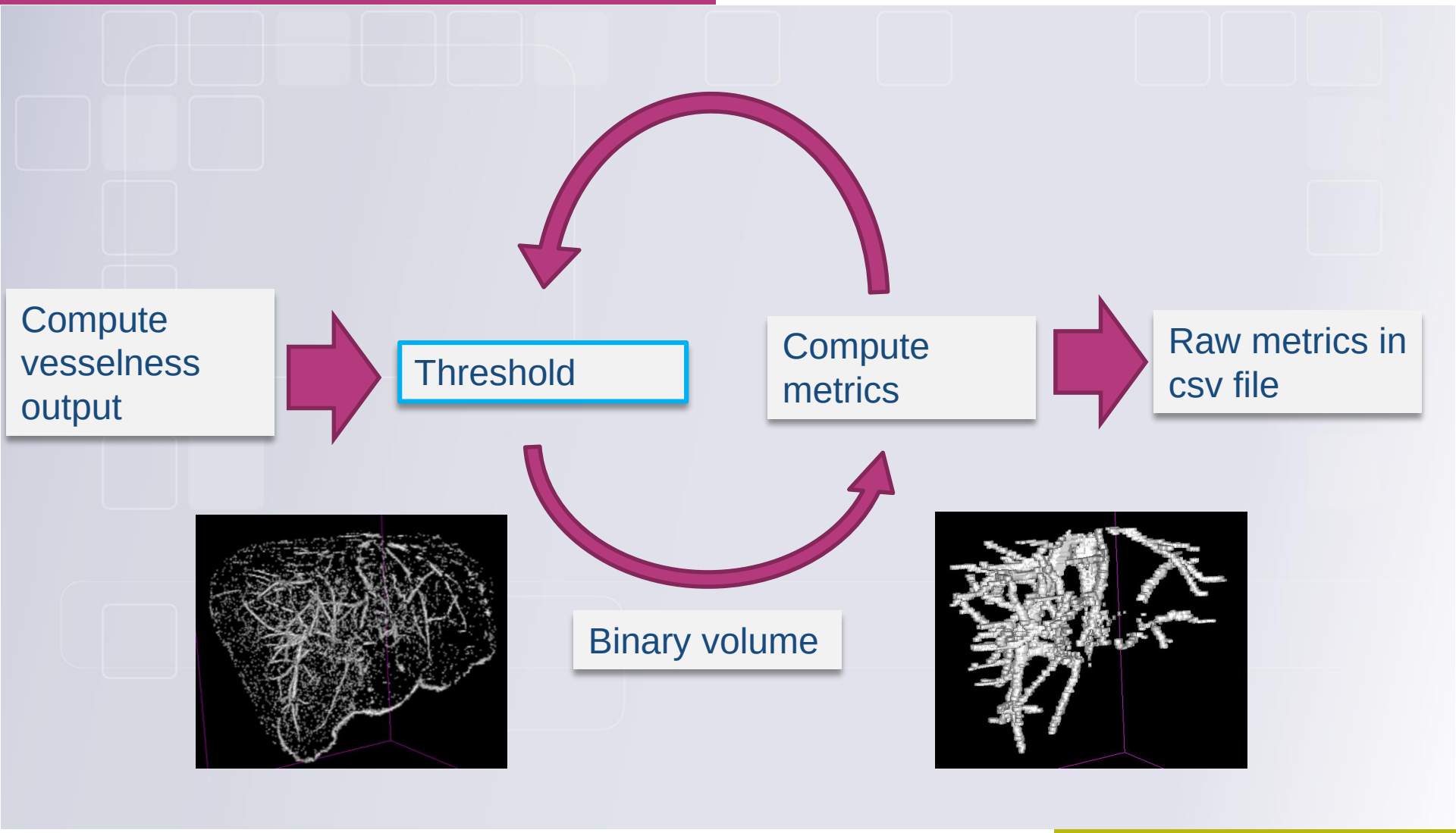




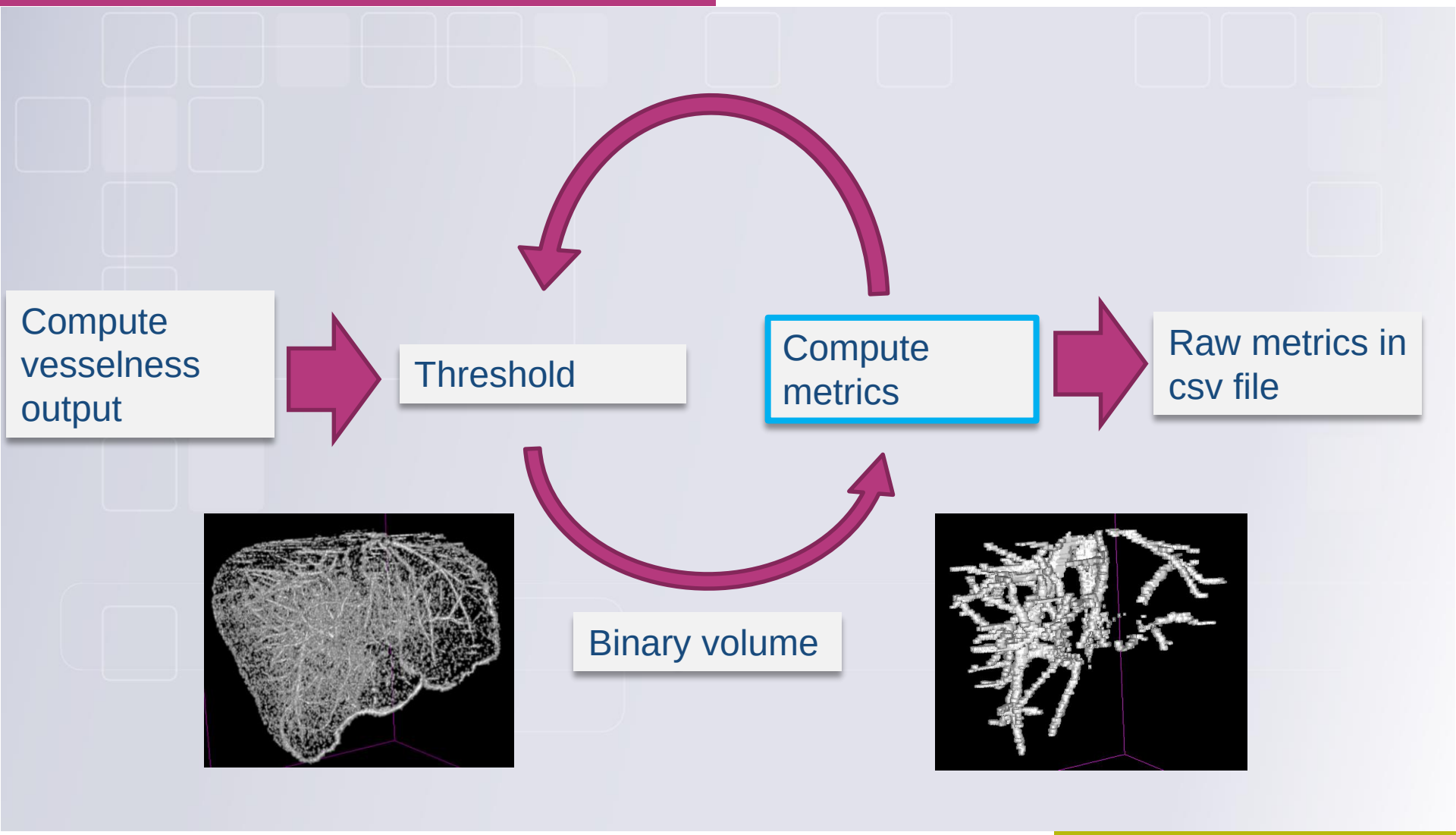
Benchmark


Compute vesselness output
Threshold
Compute metrics
Raw metrics in csv file
Binary volume

Benchmark


Compute vesselness output
Threshold
Compute metrics
Raw metrics in csv file
Binary volume

Benchmark


Compute vesselness output
Threshold
Binary volume
Compute metrics
Raw metrics in csv file

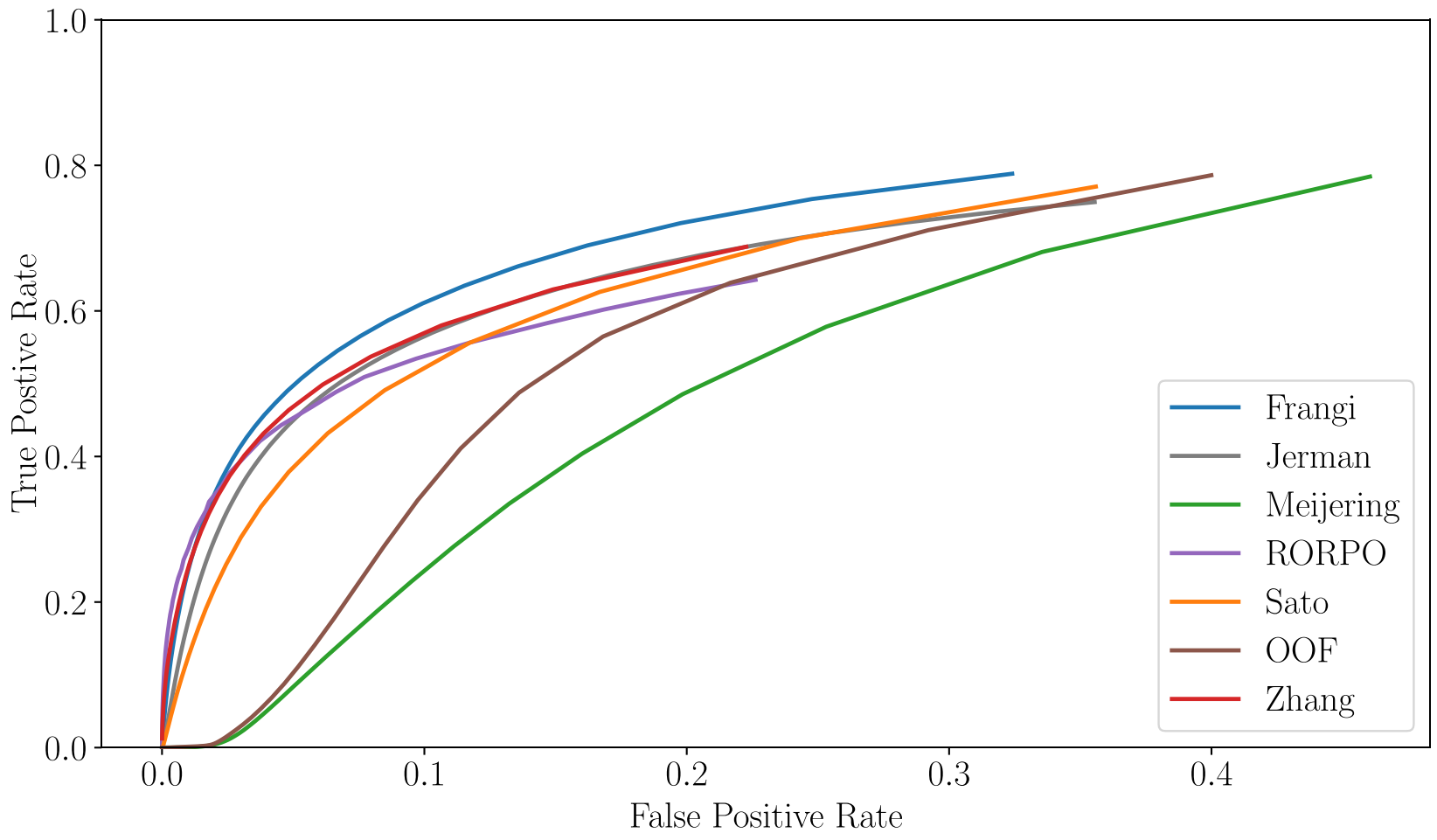
Metrics

- **Confusion matrix computed on thresholded vesselness outputs**

Metrics	Formula
True positive rate	$\frac{TP}{TP + FN}$
False positive rate	$\frac{FP}{FP + TN}$
Dice	$\frac{2 * TP}{2 * TP + FP + FN}$
Matthew's correlation coefficient (MCC)	$\frac{TP * TN - FP * FN}{\sqrt{((TP + FN) * (TP + FN) * (TN + FP) * TN + FN)}}$

True positive (TP), False positive (FP), True negative (TN), False negative (FN)

Results


1.0
0.8
0.6
0.4
0.2
0.0
True Postive Rate
0.0
0.1
0.2
0.3
0.4
False Positive Rate
Frangi
Jerman
Meijering
RORPO
Sato
OOF
Zhang

Conclusion

- **Filters should be chosen depending on the region of interest and the tolerated errors**
- **Liver MRI annotation needs more attention**
  - few public datasets
  - resolution of MRI
    - problematic for local 3D geometric study

Going further

- Survey of the filters in the paper
- Implementation of the benchmark + methods on github
  - *https://github.com/JonasLamy/LiverVesselness*
- Online demo
  - *https://kerautret.github.io/LiverVesselnessIPOLDemo/*

Github repository

Ipol online demonstration

IPOL Journal · Image Processing On Line

HOME · ABOUT · ARTICLES · PREPRINTS · WORKSHOPS · NEWS ·

Online Demonstration of Liver Vesselness Filters

article | demo | archive

Please cite the reference article if you publish results obtained with this online demo.

1. Select the method to test: Jerman

Method computed with: Liver mask (for IRCAD only)

2. Set the common scale parameters:

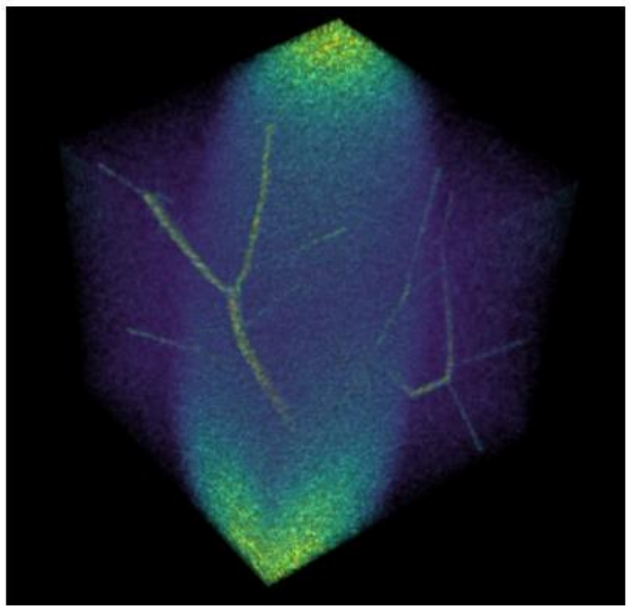
- *sigma min*: 2.7
- *sigma max*: 5.0
- *steps*: 2

3. Set the additional parameters used in Jerman and RuiZhang:

- *tau*: 0.74

4. Customize the display by choosing the mask applied to the result : No mask

run



AGENCE NATIONALE DE LA RECHERCHE

ANR

R·Vessel·X

ROBUST VASCULAR NETWORK EXTRACTION
AND UNDERSTANDING WITHIN HEPATIC BIOMEDICAL IMAGES

Contact : jonas.lamy@gmail.com

Github repository

Ipol online demonstration

LIRIS

References

[1] Y. Sato, S. Nakajima, H. Atsumi, T. Koller, G. Gerig, S. Yoshida, and R. Kikinis, “3D multi-scale line filter for segmentation and visualization of curvilinear structures in medical images,” in CVRMed-MRCAS, 1997, pp. 213–222.

[2] A. F. Frangi, W. J. Niessen, K. L. Vincken, and M. A. Viergever, “Multiscale vessel enhancement filtering,” in MICCAI, 1998, pp. 130–137.

[3] E. Meijering, M. Jacob, J.-C. Sarria, P. Steiner, H. Hirling, and M. Unser, “Neurite tracing in fluorescence microscopy images using ridge filtering and graph searching: Principles and validation,” in ISBI, 2004, pp. 1219– 1222.

[4] M. W. K. Law and A. C. S. Chung, “Three dimensional curvilinear structure detection using optimally oriented flux,” in ECCV, 2008, pp. 368–382.

[5] T. Jerman, F. Pernus, B. Likar, and Z. Spiclin, “Enhancement of vascular structures in 3D and 2D angiographic images,” IEEE T Med Imaging, vol. 35, pp. 2107–2118, 2016.

[6] R. Zhang, Z. Zhou, W. Wu, C.-C. Lin, P.-H. Tsui, and S. Wu, “An improved fuzzy connectedness method for automatic three-dimensional liver vessel segmentation in CT images,” J Healthc Eng, vol. 2018, pp. 1–18, 2018.

[7] O. Merveille, H. Talbot, L. Najman, and N. Passat, “Curvilinear structure analysis by ranking the orientation responses of path operators,” IEEE T Pattern Anal, vol. 40, pp. 304–317, 2018.

[8] J. Lamy, O. Merveille, B. Kerautret, N. Passat, A Vacavant. (2020). Vesselness filters: A survey with benchmarks applied to liver imaging, ICPR 2020