AIstroSight

Vascular Segmentation of fUS Images using Deep Learning

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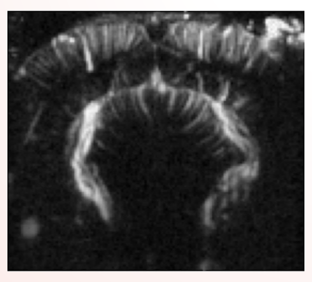
Contribution

- **First** deep learning application for **fUS vascular segmentation**
- **Competitive segmentation performance** compared to state-of- the-art
- **Optimal performance** with only **100 temporal frames** from the fUS stack
- **Strong generalization** across varying brain states
- Improvement of **fUS signals interpretation**, supporting preclinical neurovascular research

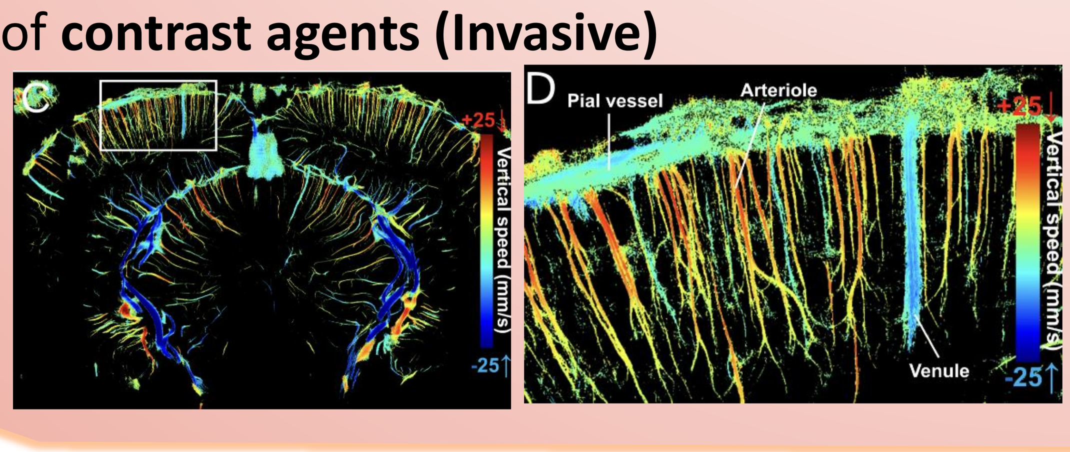
Functional Ultrasound Imaging (fUS)



- Captures **changes in CBV** related to **neuronal activity**
- ➢ Achieves **high spatial** and **temporal resolution**
- ➢ How to identify vascular compartments linked to neuronal activity?

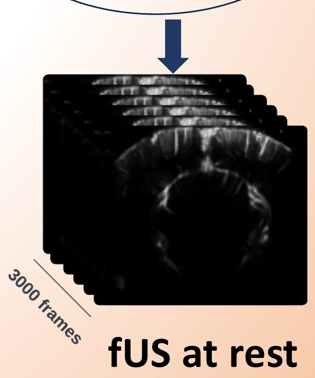
Ultrasound Localisation Microscopy (ULM)

- Advanced imaging employing ultra-fast sampling **to improve spatial resolution** to few microns
- ➢ Requires **the injection** of **contrast agents (Invasive)**
- ➢ Use it for Automatic Annotation of fUS !



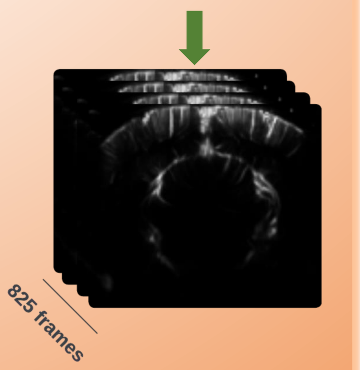
Data Acquisition

- ➢ A stack of 3000 of Power Doppler frames (112x128 pixels)



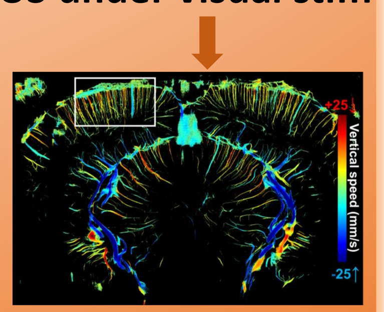
fUS at rest

- ➢ A stack of 825 of Power Doppler frames (112x128 pixels)

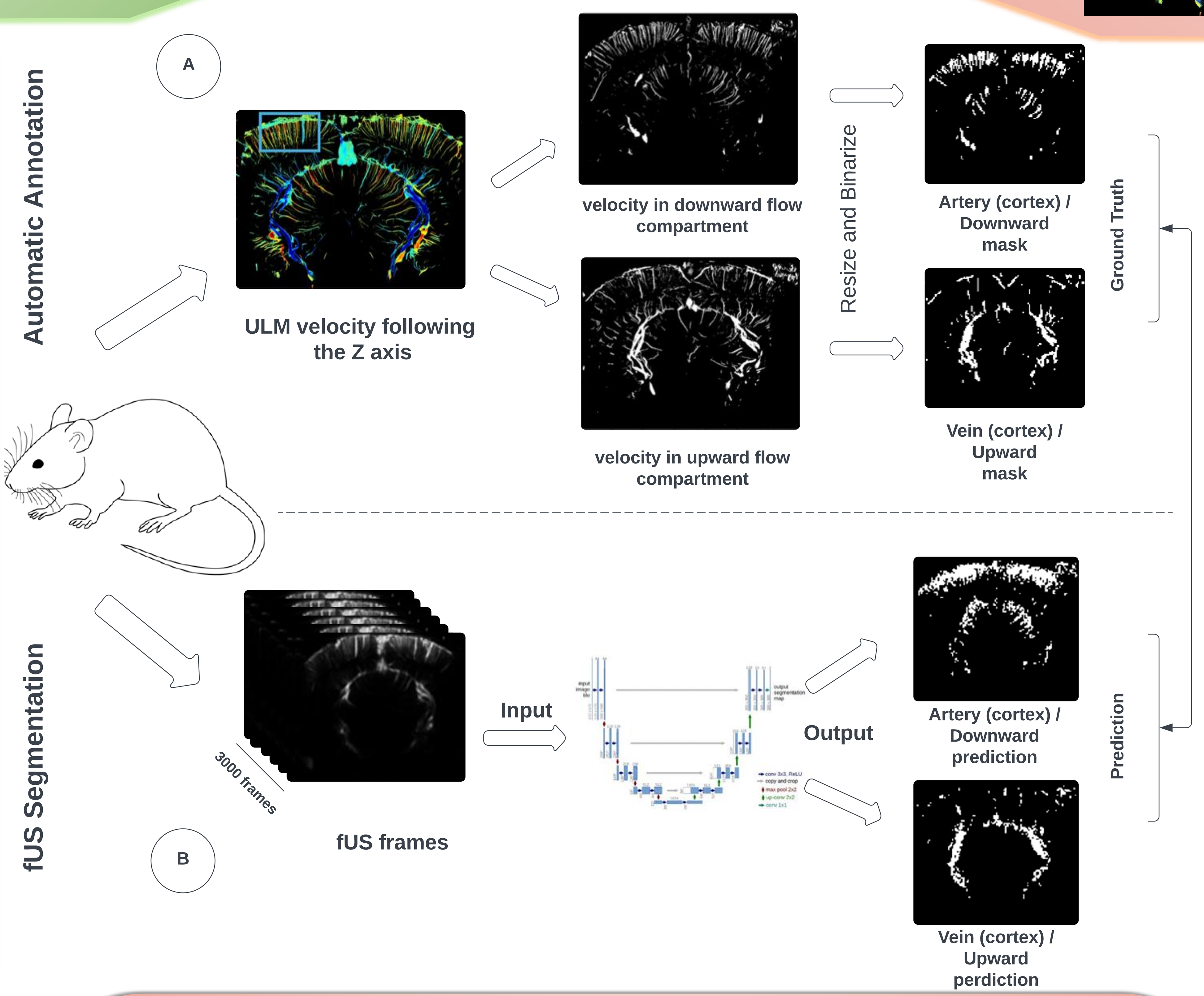


fUS under visual stim

- ➢ ULM velocity following the Z-axis (7008 x 5490 pixels)



ULM



fUS Segmentation

- Benchmarked 7 UNet models
  - UNet
  - RestNet
  - Unet++
  - Attention UNet
  - MultiresUNet
  - RestNet
  - UCTransNet
  - TransUNet
- Used 4 loss functions

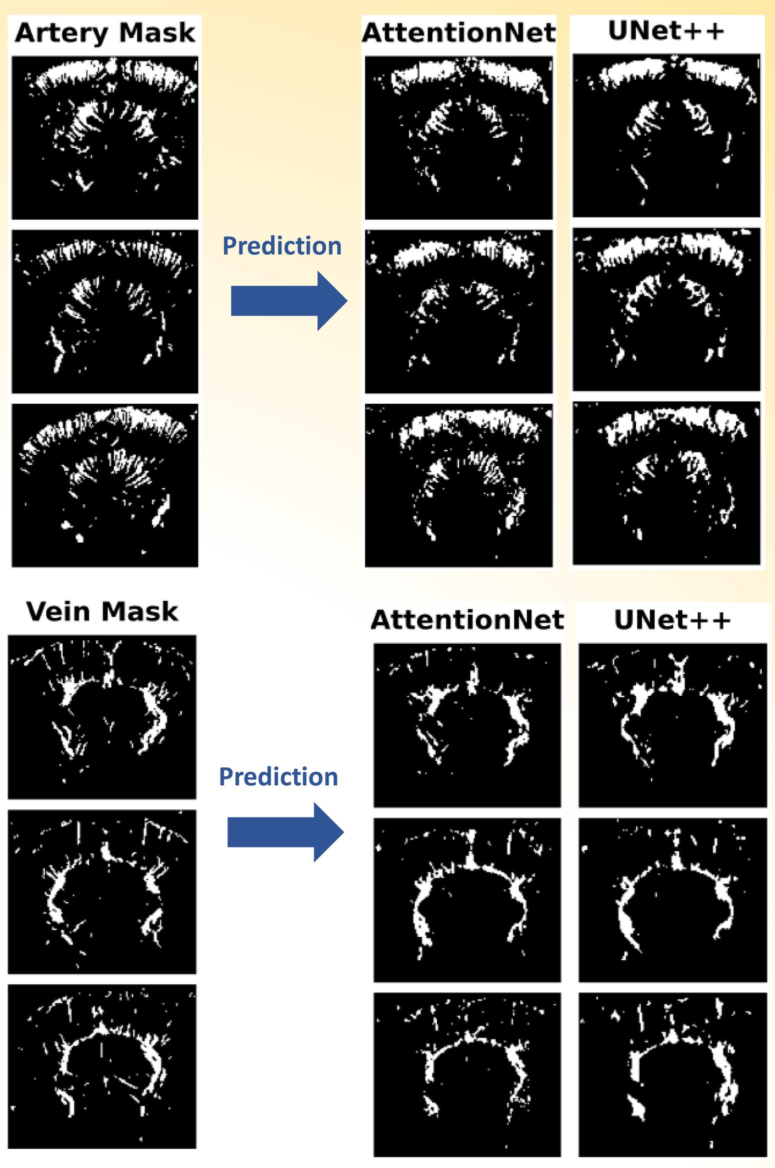
$$\mathcal{L}_{Dice\_CE} = \alpha\,\mathcal{L}_{CrossEntropy} + \beta\,\mathcal{L}_{Dice}$$
$$\mathcal{L}_{CF\_V} = \alpha\,\mathcal{L}_{CrossEntropy} + \beta\,\mathcal{L}_{VesselDensity}$$
$$\mathcal{L}_{CF\_B} = \alpha\,\mathcal{L}_{CrossEntropy} + \gamma\,\mathcal{L}_{FractalDim}$$
$$\mathcal{L}_{CF} = \alpha\,\mathcal{L}_{CrossEntropy} + \beta\,\mathcal{L}_{VesselDensity} + \gamma\,\mathcal{L}_{FractalDim}$$

- ➢ $\mathcal{L}_{VesselDensity}$ computes the **propotion** of **arteries** and **veins** in the image
- ➢ $\mathcal{L}_{FractalDim}$ includes an apriori about **vessel shape complexity**

- Trained **all models** with different losses (**28 configurations)**
- Dataset = fUS stacks of 3000 **frames at rest**
- Metrics reported over **a 7-fold cross validation**

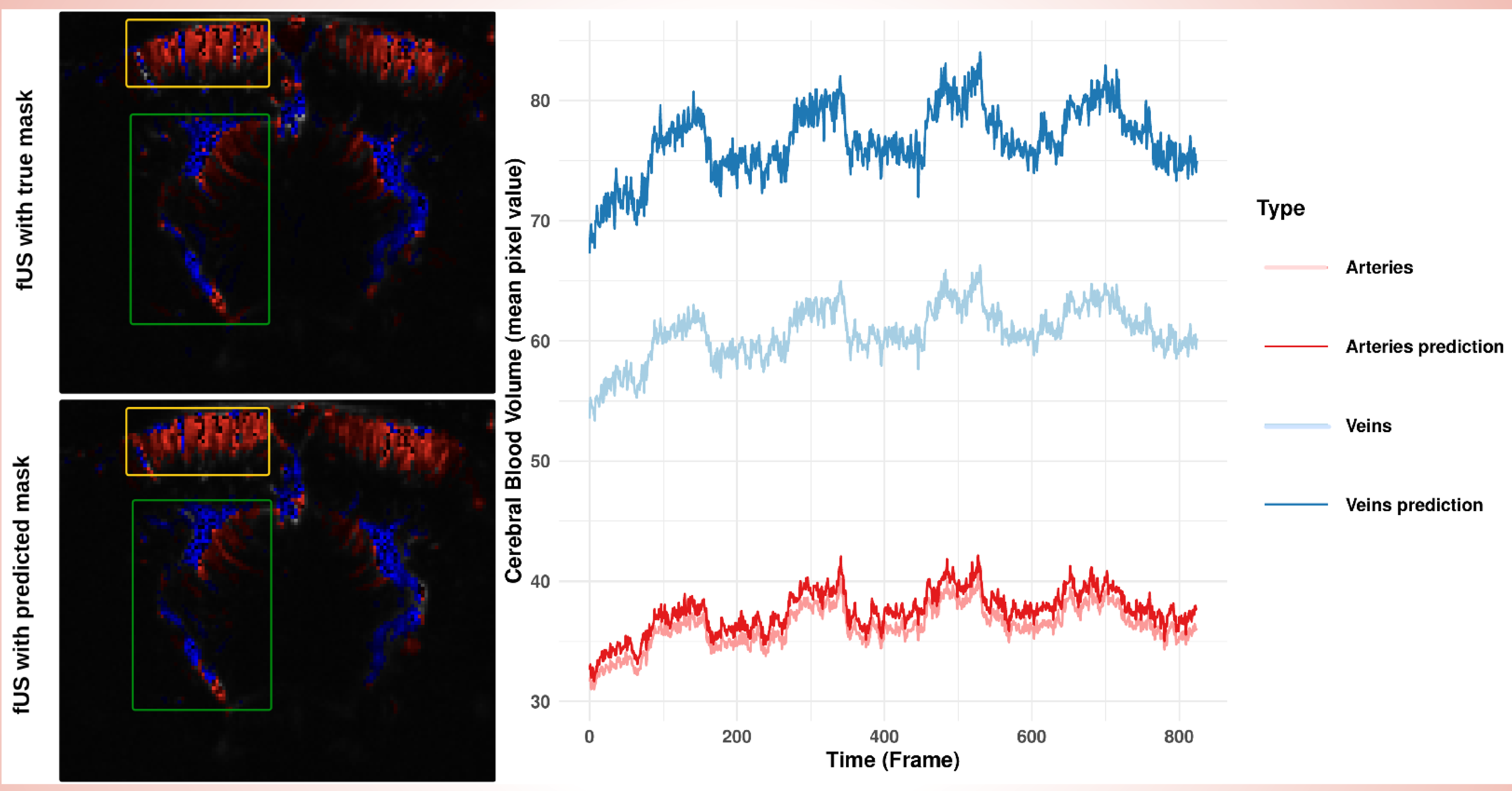
Best Performance

- Achieved by **Attention UNet** and **Unet++** trained with a CF loss
  - ➢ Accuracy : **89%**
  - ➢ F1 score : **70%**
  - ➢ IoU: **57%**



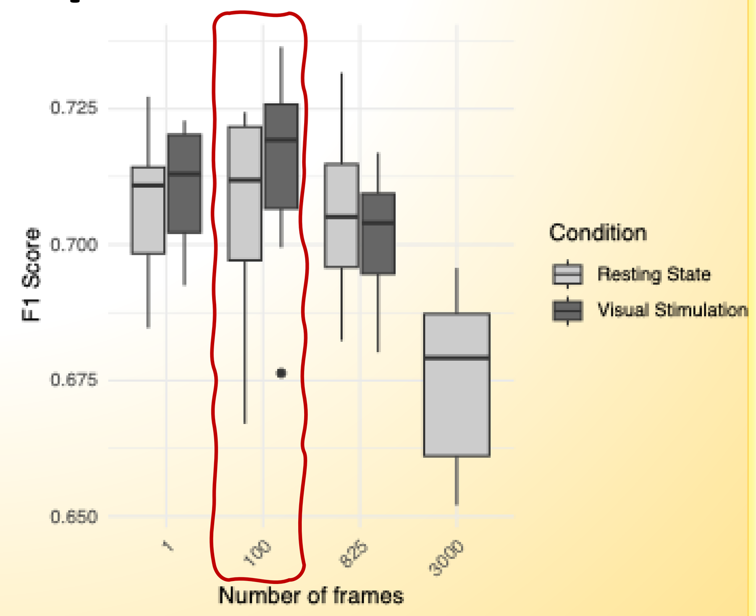
Visualizing vascular structures in fUS imaging

- **Overlaid masks** of arteries in red and veins in blue over a random fUS frame taken under **visual stimulation**
- **Extracted true and predicted CBV** evolution over time in the **cortex region**



- Noticed the **4 patterns** related to the **response to visual stimulation**
- **Over all rats :**
  - ➢ 0.98 of correlation for arteries and 0.55 for veins in the **cortical** region
  - ➢ **0.87** of correlation for **downward flow** and **0.98** for **upward flow** in the **lower** regions

Impact of fUS Depth on performance



- **Reducing** the number of frames **improved** metrics
- ➢ Best performance with **only 100 frames**

Cross-Condition efficacy of fUS-models

- **Train on rest state** and **test on visually stimulated** session
  - ➢ Used **different rats** for each condition
- Reached an **accuracy of 90%** and **F1 score of 0.71%**

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Poster N°21