Intracranial Aneurysm Pose Estimation with Deep Learning

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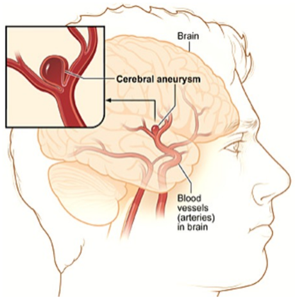
Introduction

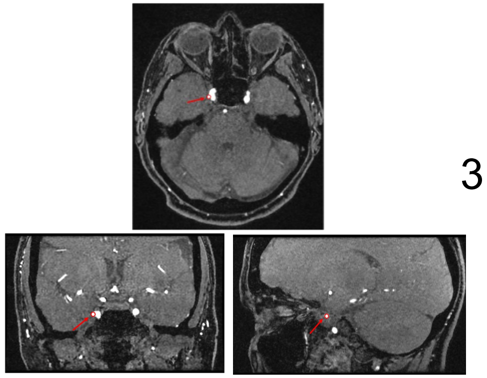


Challenging clinical problem:

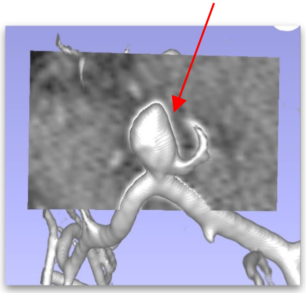
- Intracranial aneurysms:
  - Abnormal focal dilation of cerebral blood vessels.
  - Very small structures (1-30mm), mostly ball-shaped.
- Detection and evaluation from TOF-MRA data:
  - Navigating through different 2D cut planes: manual and time-consuming task.

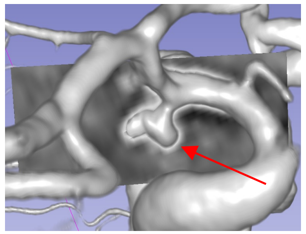
Objective: Automated detection and appropriate visualization

- Reformatted Plane for better understanding.
- Analyse connection to parent vessel.



3D TOF-MRA Image → **Pose Estimation** → Aneurysm Localization + Orientation Estimation





DSA: Digital Subtraction Angiography.

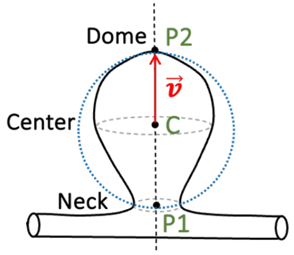
Introduction

Challenges:

- **Data Scarcity:**
  - Limited and private datasets.
- **Class Imbalance:**
  - Aneurysms are rare (0 to 4/patient)
  - Small structures in MRA data (≈10/1M voxels).
- **Data Annotation:**
  - Difficult and time-consuming expert labelling.
  - How to label aneurysm orientation?

Our proposed method

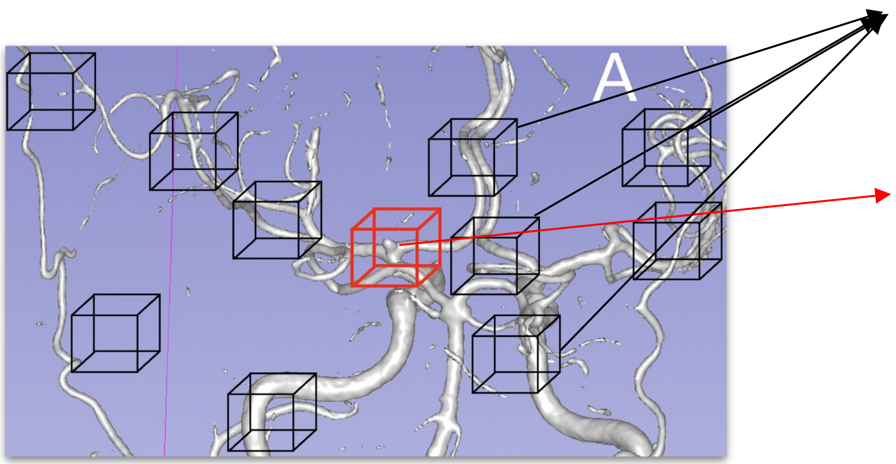
Efficient Data Strategy



1. **Data annotation:**
   - Simple and fast annotation: Sphere defined by two points (P1, P2).
   - Approximately 4 times faster than the voxel-wise annotation [2].

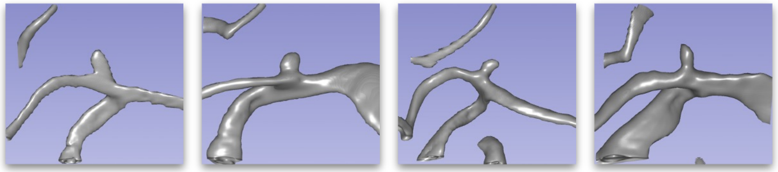
2. **Small non-intersecting patches:**
   - Small patches of 96x96x96 voxels (38.4x38.4x38.4 mm): larger training samples.
   - Non-Intersecting patches: Reliable background modeling.

3. **Data sampling and generation:**



TOF-MRA image with one aneurysm.

- **Negative patches: aneurysm-free**
  - Selecting 40 candidate patches per patient.
  - Mostly centered on blood vessels.
- **Positive patches: with aneurysm**
  - Centered on aneurysms, duplicated 50 times.
  - Apply random deformable distortion for varied shapes.



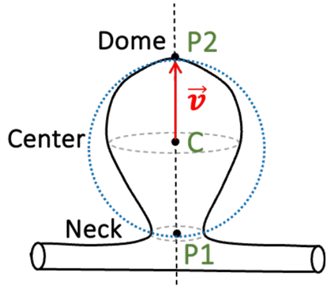
Some instances generated for the aneurysm.

[2] Di Noto et al. Towards automated brain aneurysm detection in TOF-MRA: open data, weak labels, and anatomical knowledge, Neuroinformatics, 2022.

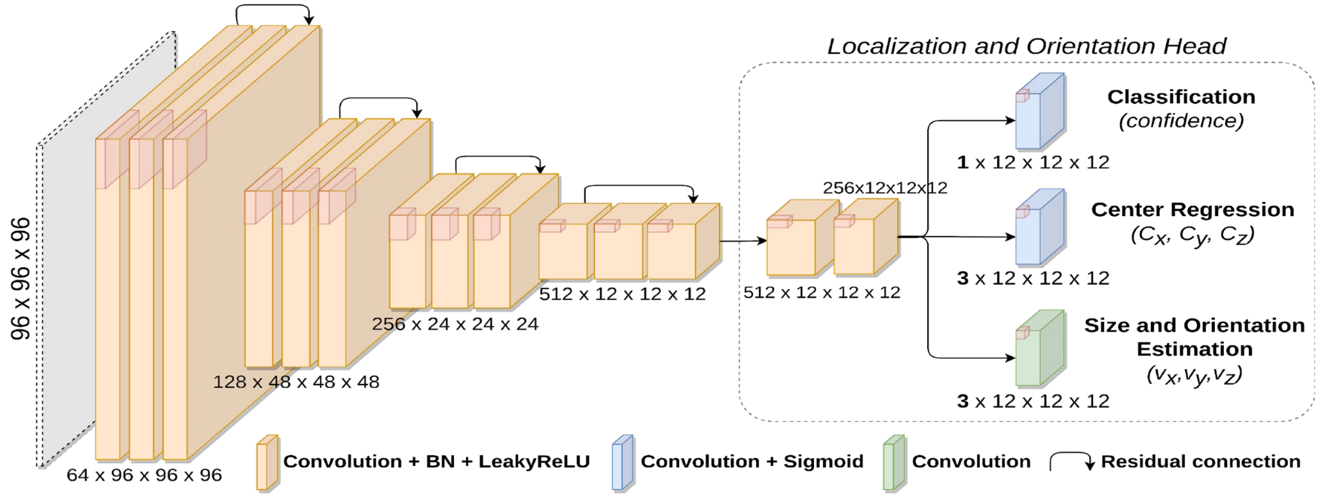
Our proposed method

Deep learning architecture

- **End-to-end 3D CNN**: Inspired by the 2D YOLO [3].
- Adapted for both pose estimation and object detection tasks:
  - **For Pose Estimation**:
    - **Localization**: Center coordinates C = (Cx, Cy, Cz) = (P1+P2)/2.
    - **Orientation**: Size and Orientation $\vec{v}$ = (Vx, Vy, Vz) = P2-C.
  - **For Object Detection**:
    - **Spheres:** Center C and radius $|\vec{v}|$.



Patches of 96x96x96 voxels = (12x12x12=) 1728 cells of 8x8x8 voxels each



Our proposed pose estimation and object detection architecture.

High class imbalance
Positive (P) and Negative (N)

Loss function

=

BCE (P) + 0.5 x #P x BCE (N)

+

5 x MSE(Cx,Cy,Cz, Vx,Vy,Vz)

+

5 x (1 - Cosine similarity($\vec{v}$))

[3] Redmon et al. Yolov3: An incremental improvement, arxiv preprint, 2018.

Our proposed method

Implementation details

- **Training:**
  - 200 epochs.
  - Learning rate = 10^{-2}.
  - Batch size = 32.
  - Balanced batch sampling: Random selection
    Batch = 4 negative patches + 28 positive patches
- **Inference:**
  - Split into 96x96x96 patches with an isotropic voxel resolution of 0.4mm.
  - Overlapping patches: 16 voxels.
  - Non maximum suppression (Spheres, IoU = 10%).

BCE: Binary Cross Entropy.
MSE: Mean Squared Error.

Evaluation study

5-Fold cross validation

- **Datasets:** 402 subjects

TOF-MRA	# Subjects	# Aneurysms	Mean size (mm)
In-house	*132*	*206*	*3.97 ± 2.32*
CHUV [2] (public)	*270*	*164*	*3.74 ± 2.17*

- **Aneurysm Pose Estimation:** No existing SOTA to compare with.

	Center Localization (mm)		Orientation (°)	
	Median	Range	Median	Range
In-house	*0.49*	*0.05 - 1.74*	*11.91*	*0.21 - 68.35*
CHUV [2]	*0.48*	*0.05 - 1.43*	*12.27*	*1.05 - 68.30*

- **Aneurysm detection:** Spheres (IoU > 10%).

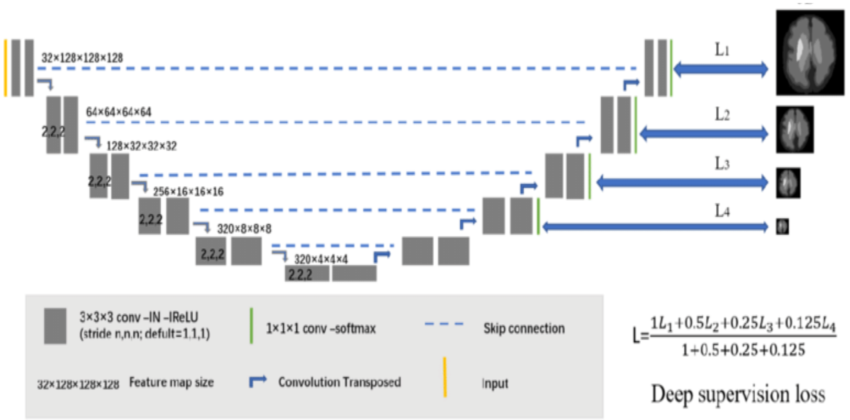
***Dataset**: CHUV [2]*	Average Precision (%)	Sensitivity (%)	FP/case
nnDetection [4]	*73.68 ± 6.38*	*84.76 ± 4.72*	*0.67 ± 0.12*
nnUNet [5]	*72.46 ± 4.74*	*71.95 ± 9.11*	*0.13 ± 0.06*
Ours	*76.60 ± 5.24*	*82.93 ± 5.92*	*0.44 ± 0.04*

[4] Baumgartner et al. nnDetection: a self-configuring method for medical object detection. MICCAI, 2021
[5] Isensee et al. nnu-net: a self-configuring method for deep learning-based biomedical image segmentation. Nature methods, 2021.

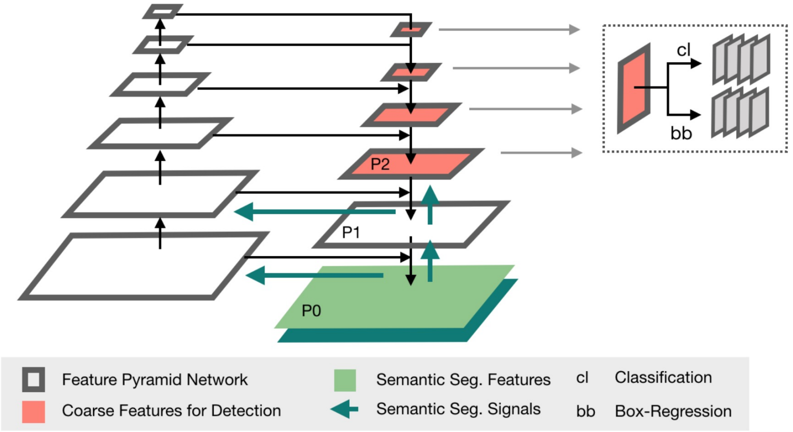
Evaluation study

nnUNet and nnDetection : Fully automated methods

- **Image Segmentation:** nnUNet [4]
  - Based on UNet architecture.
  - Patch size: 224 x 256 x 56 voxels.
  - Loss function: CE + BCE.
  - Deep supervision.



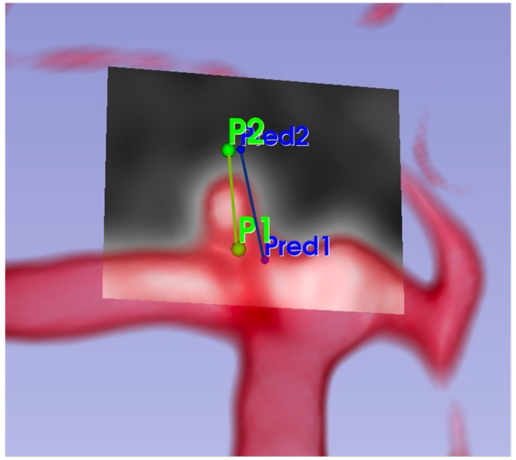
- **Object Detection:** nnDetection [5]
  - Based on RetinaUNet [6] architecture.
  - Patch size: 256 x 256 x 56 voxels.
  - Detection Loss : BCE + Generalized IoU.
  - Segmentation Loss: Dice + BCE.



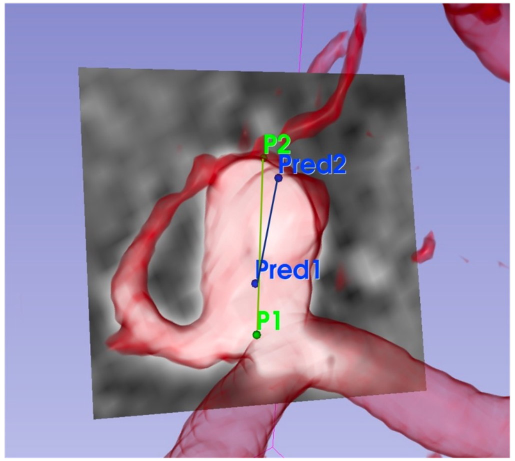
[4] Baumgartner et al. nnDetection: a self-configuring method for medical object detection. MICCAI, 2021
[5] Isensee et al. nnu-net: a self-configuring method for deep learning-based biomedical image segmentation. Nature methods, 2021.
[6] Jaeger, Paul F Retina U-Net: Embarrassingly simple exploitation of segmentation supervision for medical object detection, Machine Learning for Health Workshop, 2020.

Qualitative results

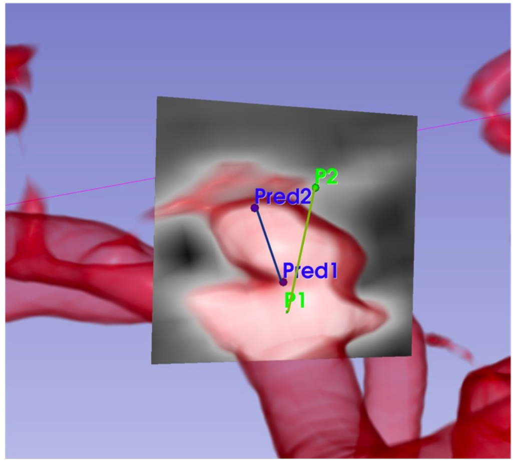
GT annotation (P1, P2) **vs** Predictions (Pred1, Pred2) = C ± $\vec{v}$



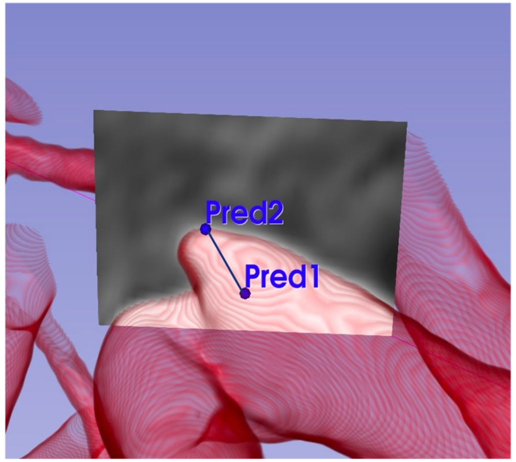
(1) Detection of a very small 1.97mm aneurysm (Error: 0.82 mm; 8.20°).



(2) Spherical-shaped 7.69mm *aneurysm (Error:* 0.72mm ,10.62°*).*



(3) Large orientation error of 41.54° for a complex-shaped 3.52 mm aneurysm.



(4) Detection of unlabeled aneurysm of 3.50mm (expert sensitivity <100%).

Conclusion

- **Conclusion**
  - The pose estimation architecture has shown promising results.
  - Can also be applied to classical object detection tasks.
  - Orientation errors are primarily due to annotation uncertainty for small and complex-shaped aneurysms.

- **Perspectives**
  - Develop a clinical definition for aneurysm orientation.
  - Conduct evaluations in clinical settings.

- Code and annotations are publicly available at https://gitlab.inria.fr/yassis/DeepAnePose.