Intracranial aneurysm detection using deep learning

Presentation D1

Tangram Team

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Prepared by:
Youssef Assis

Under the supervision of:
Erwan Kerrien
René Anxionnat
Overview

1. Context
2. Previous work
3. Recent works
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Introduction

Intracranial aneurysm

- An abnormal localized bulge at the blood vessel surface (1-30mm, avg 6mm).
- **Prevalence**: 3 to 7% of the general population.
- **Reason**: weakness in the wall of the blood vessel.
- **Risk**: rupture → hemorrhage → high morbidity/mortality.
Introduction

(a) Axial  
(b) Sagittal  
(c) Coronal

Figure: Slice axes
Introduction

Figure: MRA\textsuperscript{1} volume rendering (Aneurysm = $10^{-6}$ global volume)

\textsuperscript{1}Magnetic Resonance Angiography
Introduction

Challenges

• **Data scarcity**
  - Small and private data sets (patient privacy).
  - 1-2 aneurysms per patient.

• **Data annotation**
  - Labeling medical imaging is difficult and requires experts.
  - Time consuming.

• **Class imbalance**
  - Aneurysms are small structures in MRA data ($\approx 10/1m$ voxels).

• More computational power to process 3D volumes.
Previous work

Data annotation

**Voxel-wise annotation**

- Labeling each voxel of the aneurysm.
- Tedious and tainted with intra- and inter-rater variability.
- Hard and time consuming.

**Our proposed annotation**

- Approximate each aneurysm by a sphere defined by two points, the center of the neck and the dome.
- Rough but fast annotation.
Previous work

Data selection

How to select patches?

Vessel signal is also scarce: risk of detecting vessels vs background

- **Positive patches**: centered on each aneurysm.
- **Negative patches**: centered half on blood vessels and half on parenchyma.
Data synthesis

Class imbalance: few positive patches vs many negative patches.

- **Positive patches** are duplicated and deformed by a random distortion (3D cubic spline transform).

Figure: Generation of divers aneurysm shapes
Main idea: focus on data

- Simpler (and faster) data annotation: larger database.
- Small patch approach: less memory consumption.
- Guided patch selection: manage scarcity.
- Positive patch synthesis: handle class imbalance.
Previous work

5-fold cross-validation

- Sensitivity 0.82@0.61 FPs/case.
- ADAM top list:
  - abc: 0.68@0.40
  - mibaumgartner: 0.67@0.13
- FROC analysis: 0.80@0.40, 0.72@0.13 (AUC$^2=85.24\%$).

$^2$Area Under Curve
Recent works

Dataset

Data Quantity: 111 → 471 patients

- CHRU Nancy: +21 patients
- CHUV Lausanne\(^3\) 2021: +269 (/350) patients
- ADAM Challenge\(^4\) 2020: +70 (/113) patients

Improved annotation

- Refined annotations: Otsu thresholding

\(^3\)Weak labels and anatomical knowledge: making deep learning practical for intracranial aneurysm detection in TOF-MRA, 2021
\(^4\)https://adam.isi.uu.nl
Recent works

Evaluation - Metrics

- **Dice metric**
  - Adapted for segmentation tasks.

- **ADAM challenge**
  - Positive detection: if the candidate location coordinate is within the radius distance of the ground truth centre of mass location of the aneurysm.

- **Object detection tasks (computer vision papers)**
  - The Average Precision (AP) value for recall values.
  - Based on Intersection over Union (IoU).
Recent works
Network Architectures - Small aneurysm detection

Deep Supervised U-Net

- Small aneurysm signals are missed during the down-sampling operations.
- Forcing the decoder blocks outputs to yield a meaningful segmentation map according to the target image.

Figure: Deep Supervised U-Net (loss = $\sum_{i=1}^{3} loss_i$)
Recent works
Network Architectures - Small aneurysm detection

Self-Attention mechanism U-Net

- Focus and place more "Attention" on the relevant parts of the high-level feature maps.

Figure: Self-attention U-Net
Recent works

Network Architectures - Contextual information

**Dual U-Net with Attention mechanism**

- Integrate information about the surface of the vessels surrounding the aneurysms.
Recent works

Results

- Equivalent results with nnU-Net\(^5\): AP = 80.24%.
- Less memory consumption & training time (20h vs 7 days for nnU-Net).

Figure: Performance of our method U-Net (left) vs nnU-Net (right)

Conclusion

- Approach that focuses only on data and achieves competitive results compared to state-of-the-art methods.
- Models explainability.
- Regression problems:
  - Predict bounding spheres with confidence score (e.g. YOLO).
  - Predict the associated main axis of each detected aneurysm.

Figure: Visualization of Patch Embeddings using UMAP\textsuperscript{6}

\textsuperscript{6}Uniform Manifold Approximation and Projection for Dimension Reduction, 2020