Friedrich-Alexander-Universität
Medizinische Fakultät

Integration of Structural and Diffusion Metrics in Fetal MRI: A Model to Support Clinical Evaluation

Presenter: Javier Muñoz
Supervised by: Prof. Dr.-Ing. Jana Hutter & M.Sc. Nyvenn de Castro

Master's Thesis in Medical Engineering
April 17th 2025
Erlangen, Germany

Integration of Structural and Diffusion Metrics in Fetal MRI

Camila’s Story....

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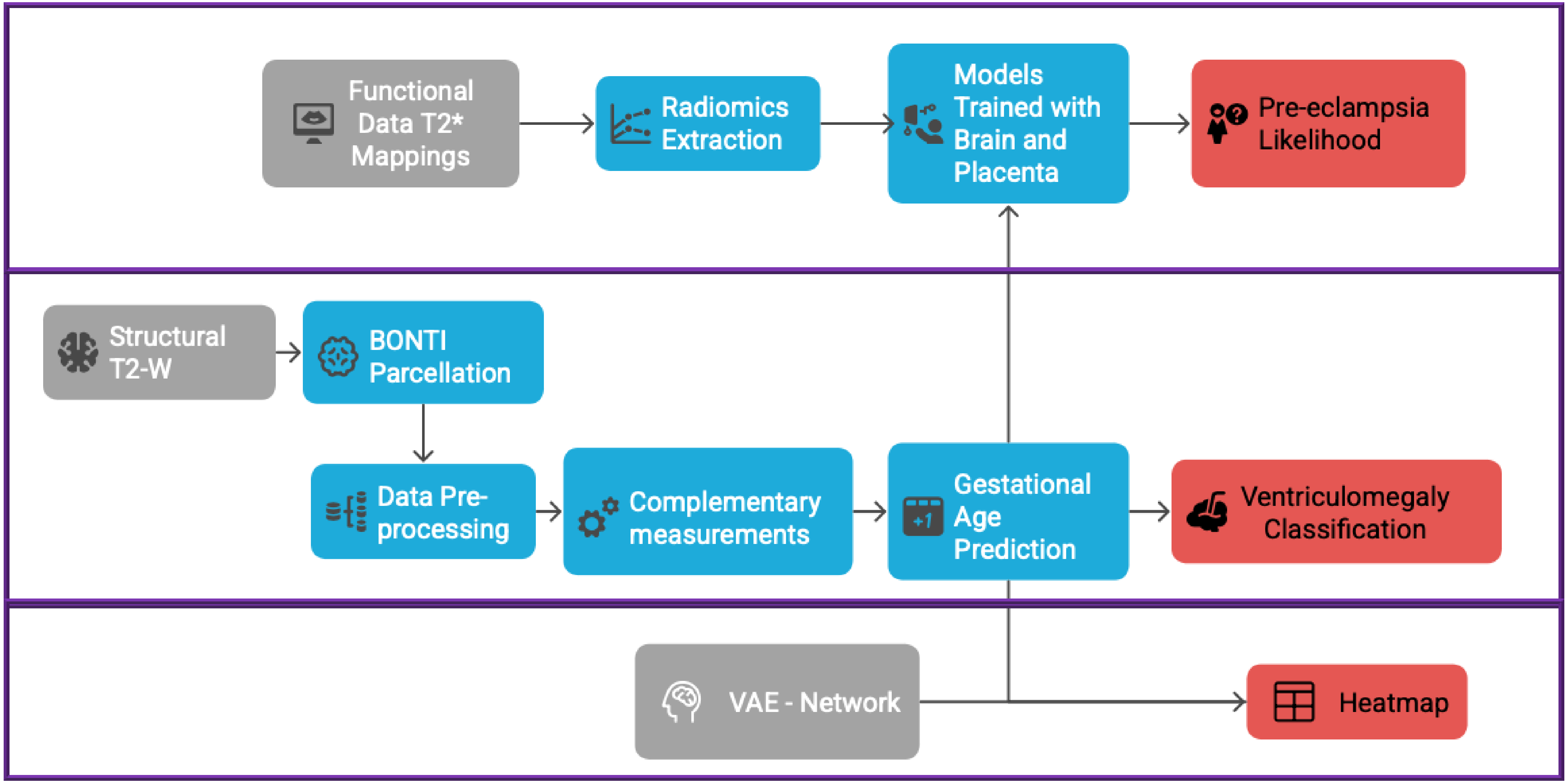
Camila's Story....

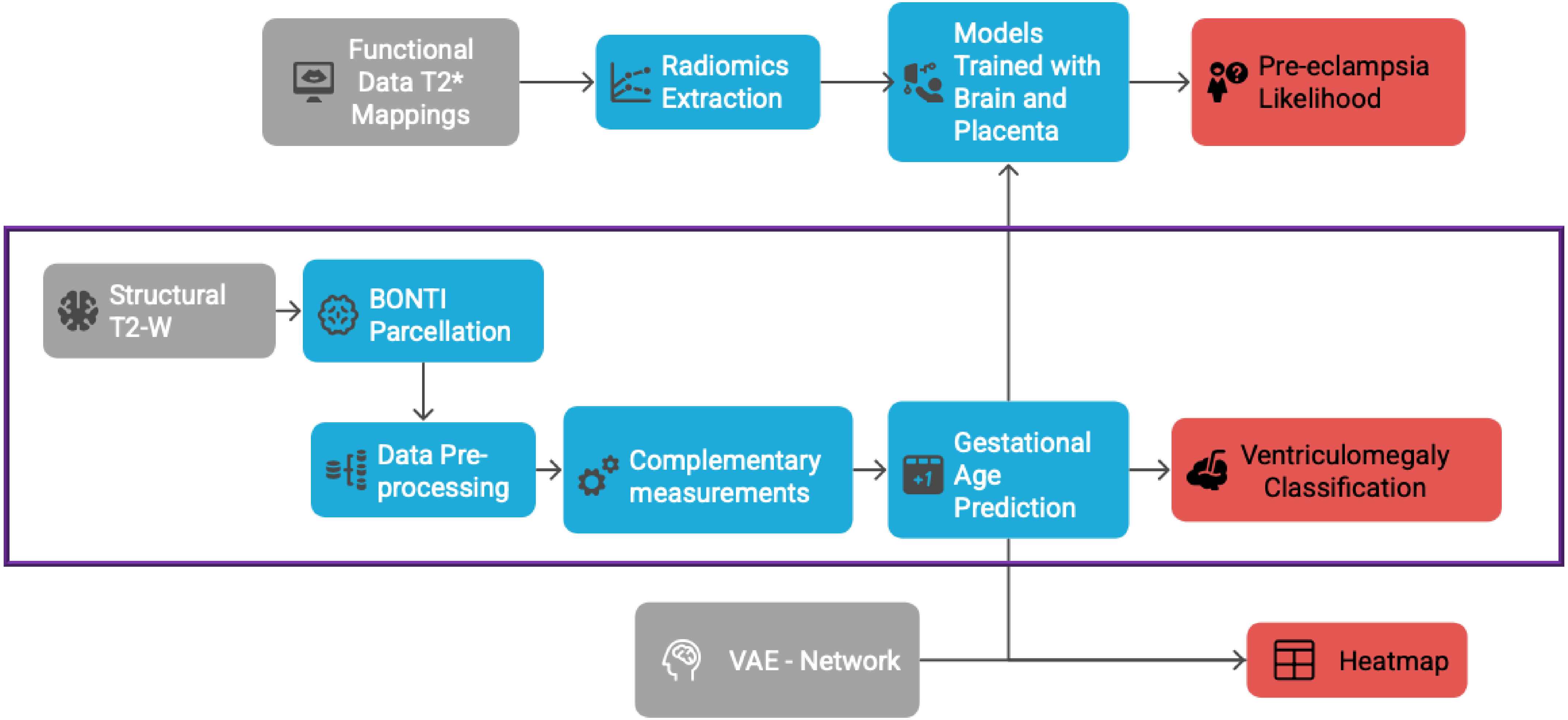
General Pipeline

General Pipeline



Structural T2 weighted

General Pipeline



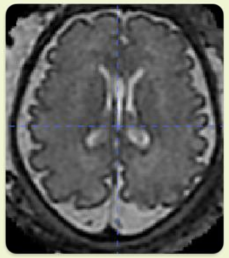
Data Management

Data Acquisition / Data processing

DATA ACQUISITION

Functional data

Structural data



DATA PROCESSING

PRE-PROCESS

- Data Imputation
- Pixel Intensity Normalization
- Image Resize
- Image Registration

1

BRAIN FEATURE EXTRACTION

- Brain tissue parcellation (BOUNTI)
- Brain Measurements
- Brain Tissue Volumes

2

PyRadiomics FEATURE EXTRACTION (BRAIN AND PLACENTA) with T2*

- First Order Analysis
- 3D-2D Analysis
- GLCM - GLRLM

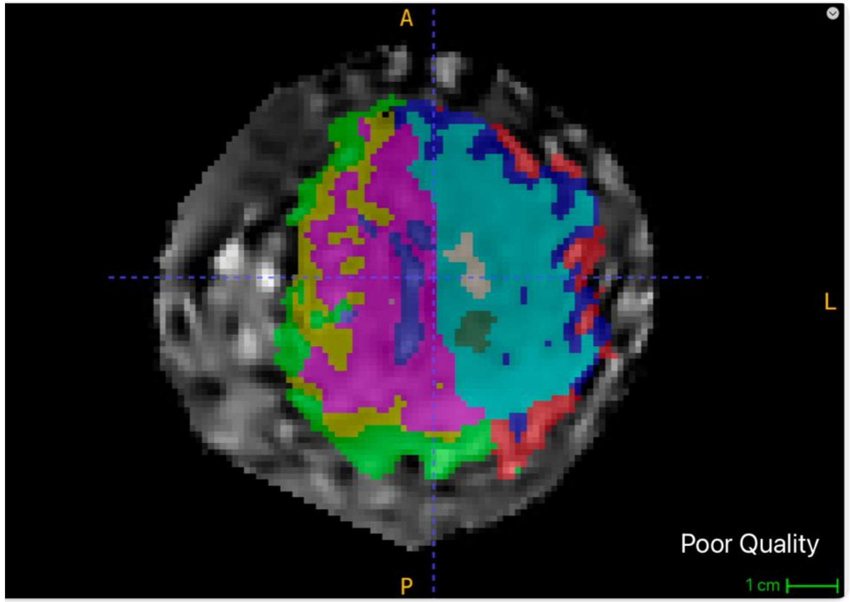
3

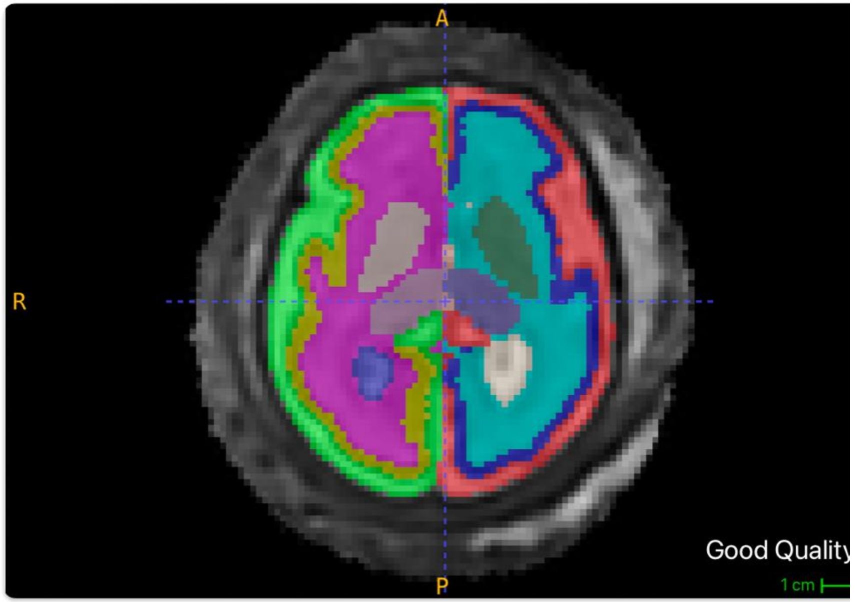
DIMENSIONALITY REDUCTION

4

- RFE (Recursive feature elimination)

BOUNTI and Pre-processing Steps





- BOUNTI generates 19 parcellation areas inside the brain
- T2-w Pixel intensity inside range $0 \leq Pi \leq 1$
- Image resizing with SimpleITK library to preserve orientation, spacing and direction beside the voxel size
- Registration with SimpleITK library translation and rotation

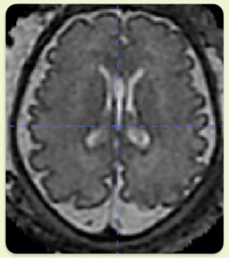
Data Management

Data Acquisition / Data processing

DATA ACQUISITION

Functional data

Structural data



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DIMENSIONALITY REDUCTION

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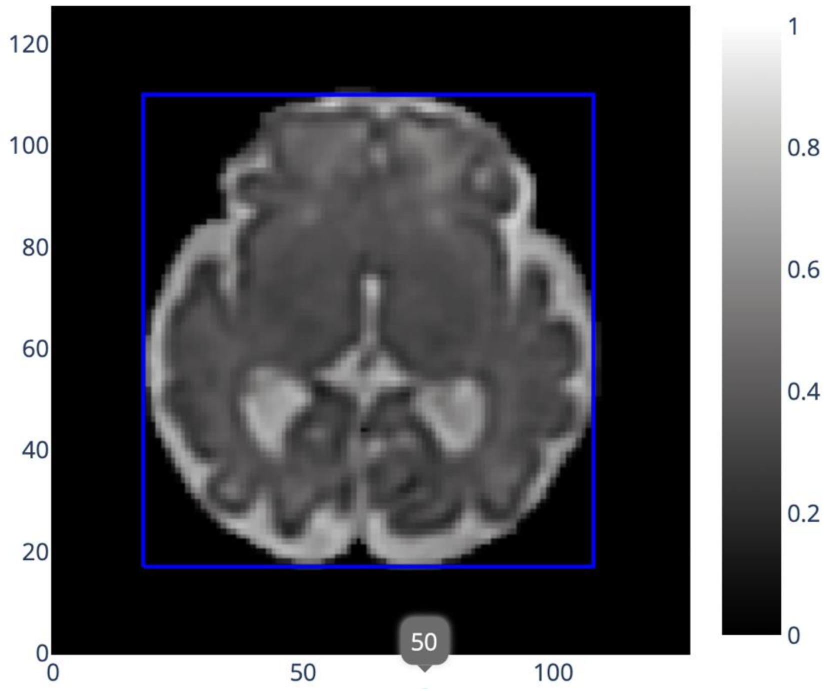
Brain measurements



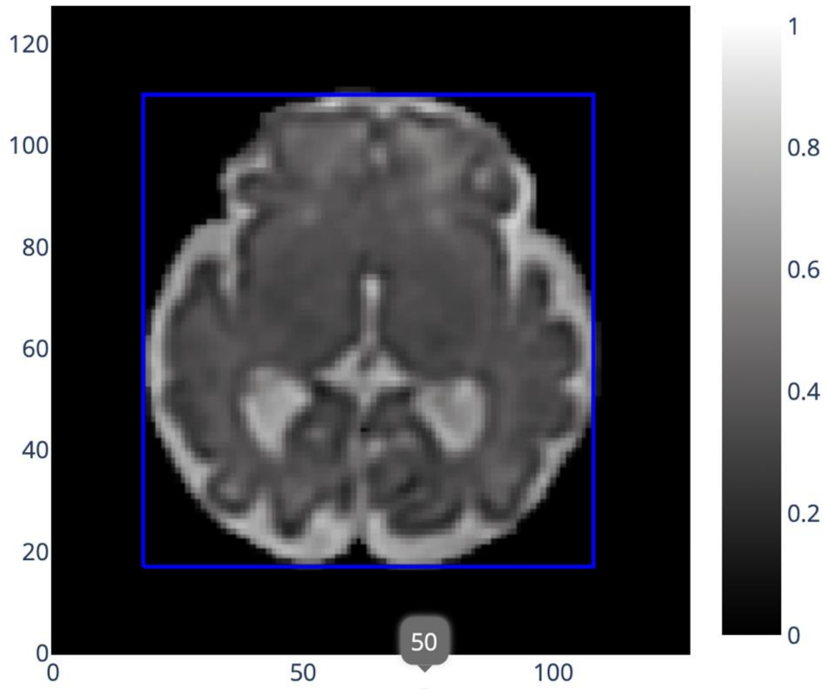
34.8 GA Subject

- **Volumes cm3**
- Biparietal Diameter mm
- Head Circumference mm
- Transverse Cerebral Diameter mm
- Cortical Gray Matter cm3
- Parenchyma cm3
- Cerebellum cm3
- Percent Ventricular Asymmetry

$$PVA = \frac{\max(Left\ ventricle, Right\ ventricle)}{\min(Left\ ventricle, Right\ ventricle)} - 1 * 100$$

- Volume Ratio Ventricles/Parenchyma cm3

Brain measurements



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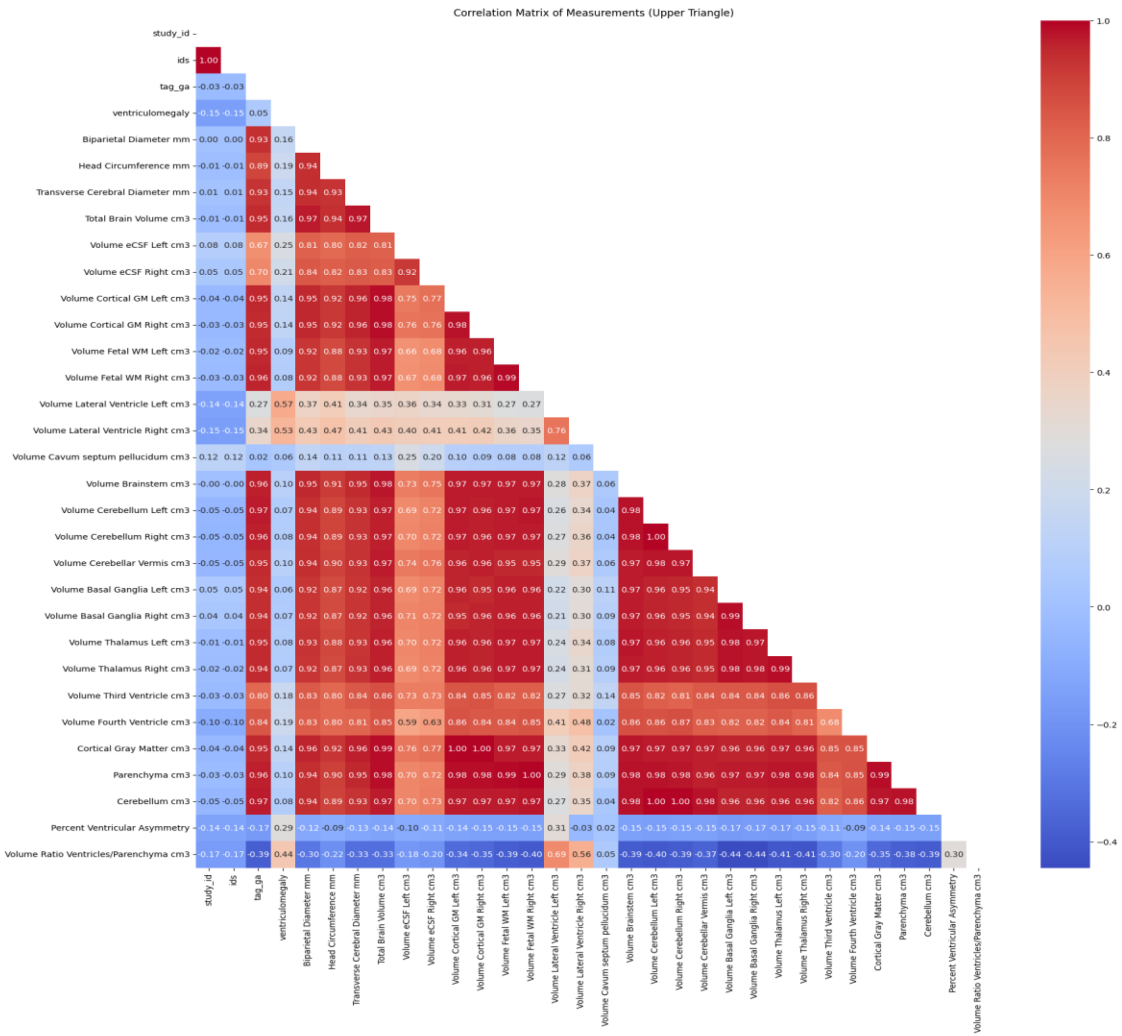
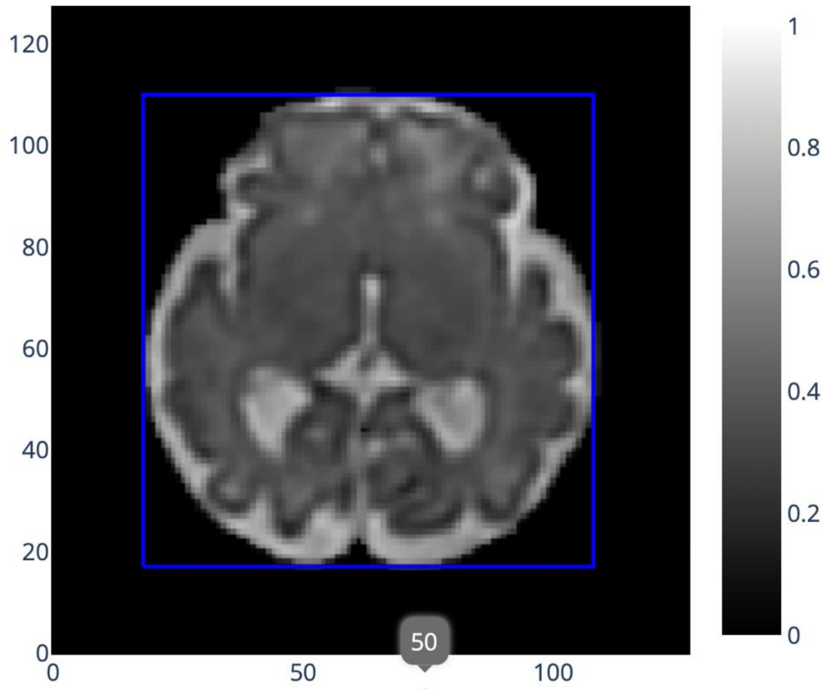


Brain measurements



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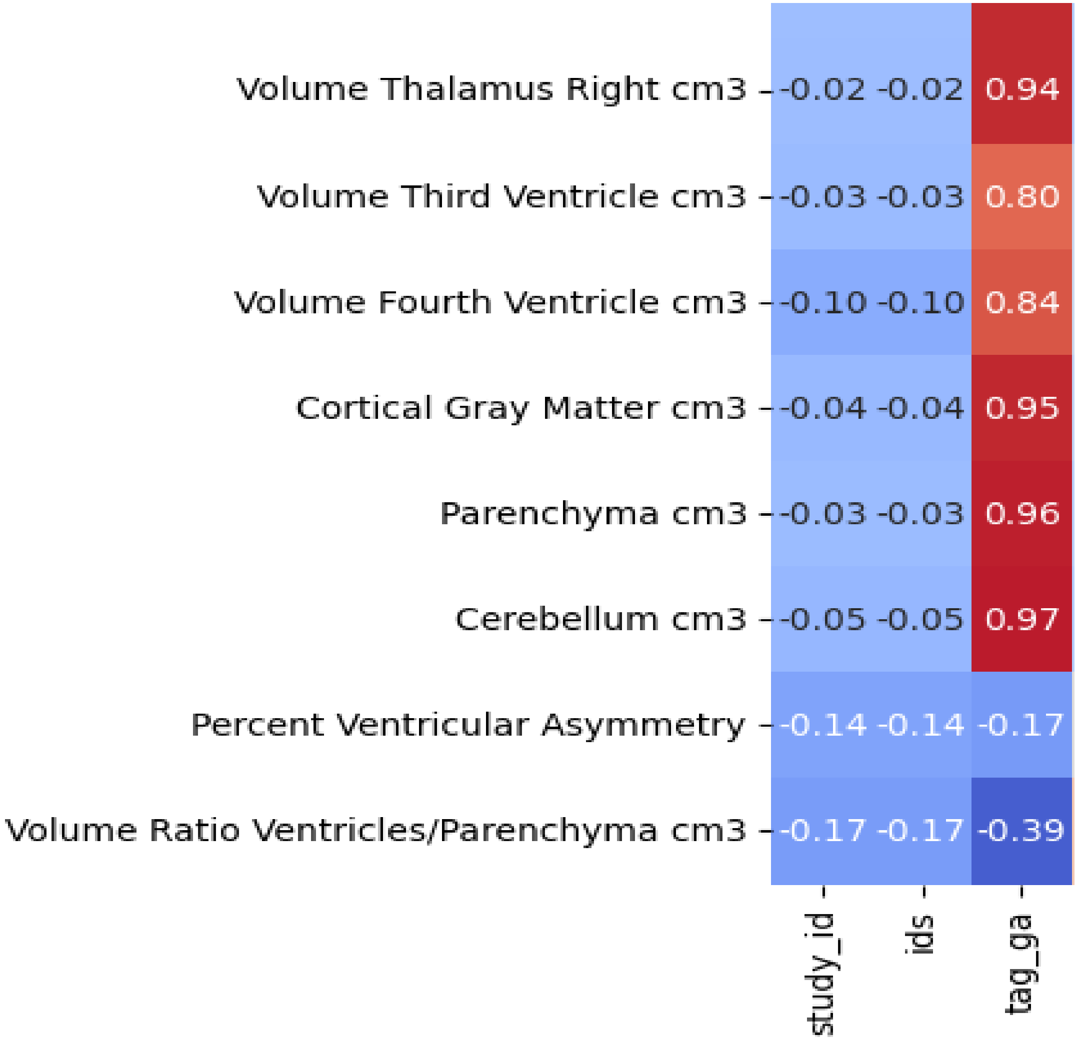

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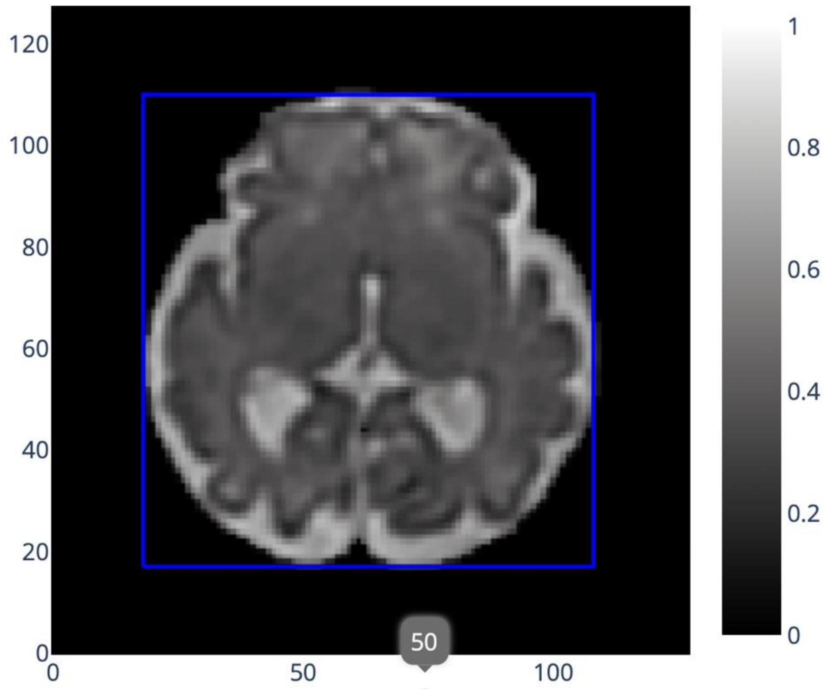

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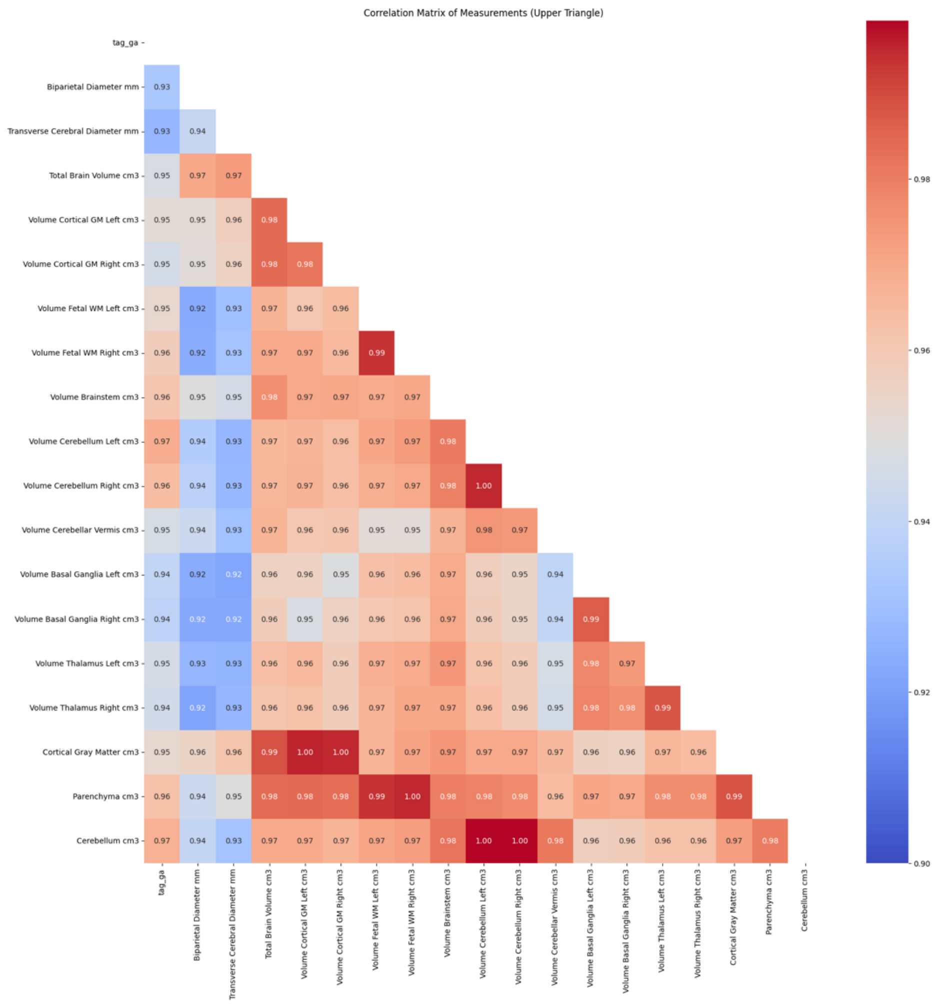
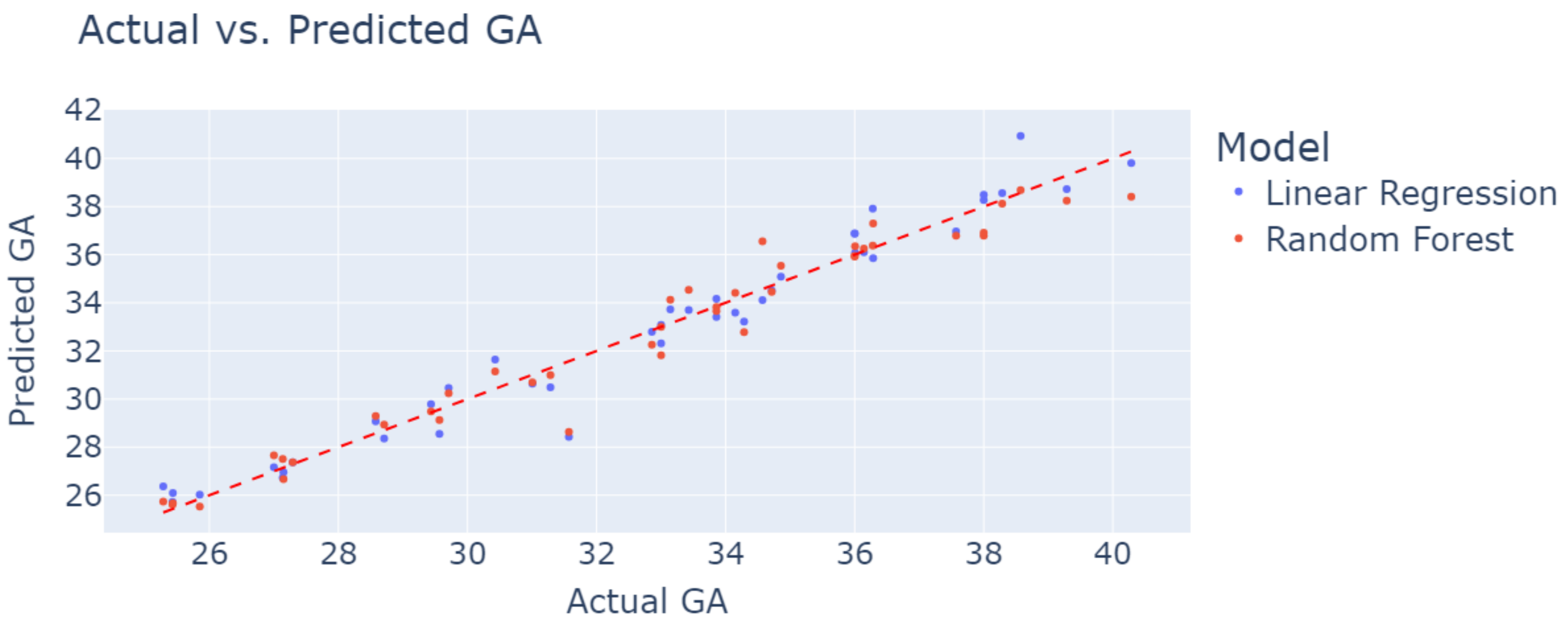


GA Prediction

Model Comparison

```
Model Comparison:
                Model       MAE       MSE      RMSE       R²
0   Linear Regression  0.606544  0.725109  0.851533  0.95895
1       Random Forest  0.613716  0.748772  0.865316  0.95761
```



GA Prediction

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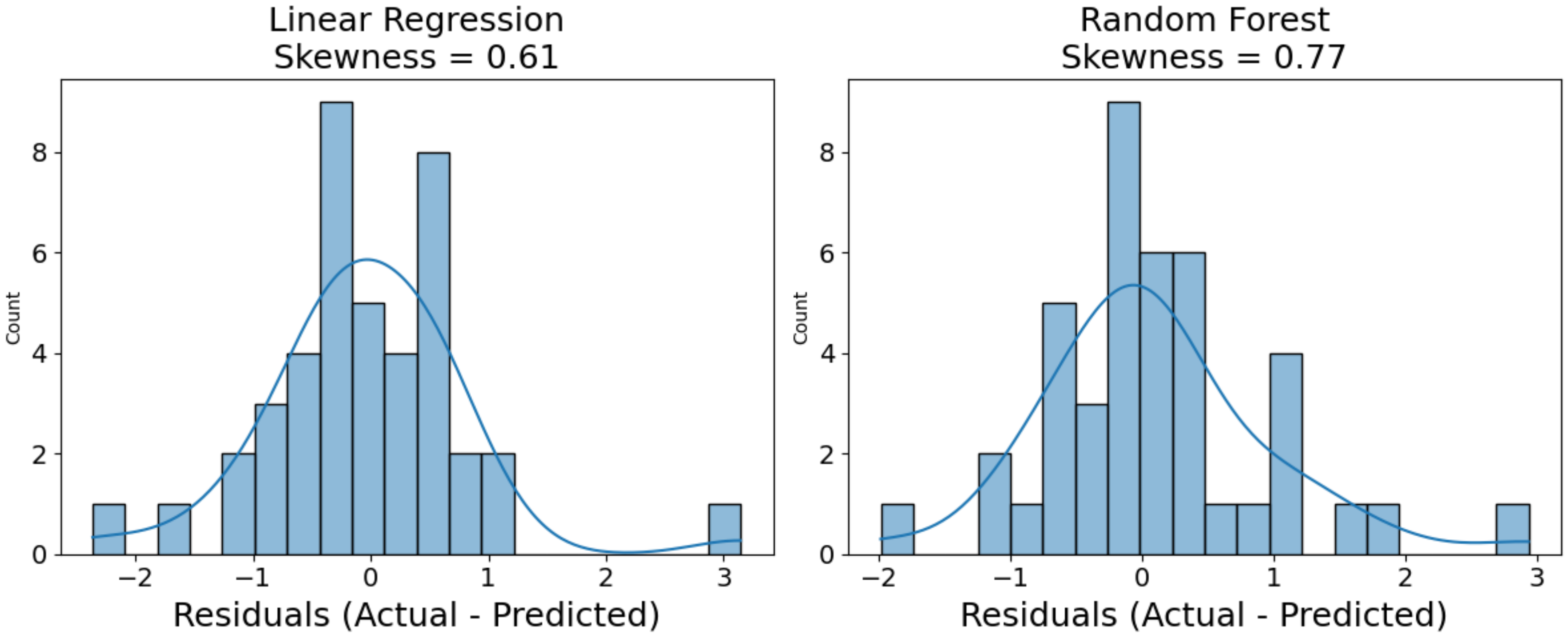
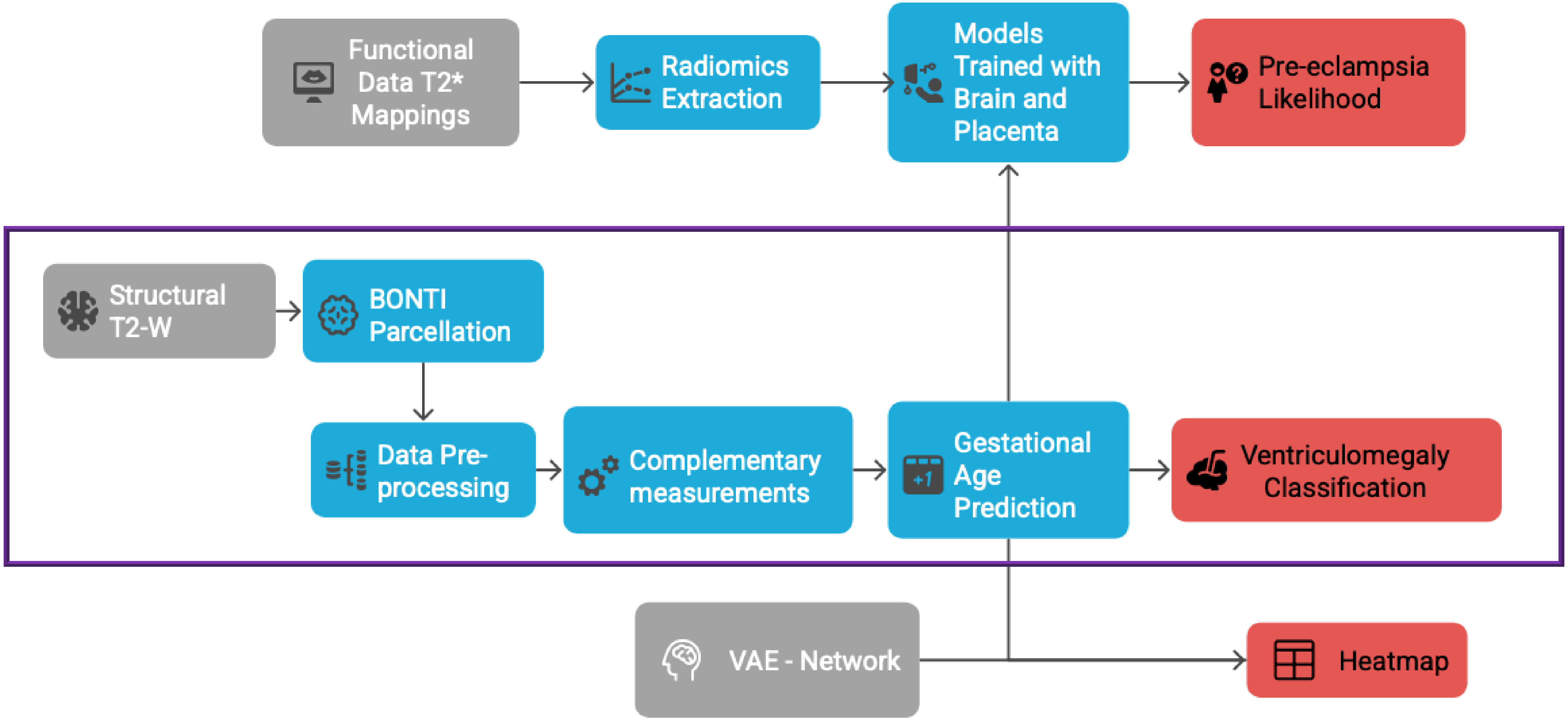
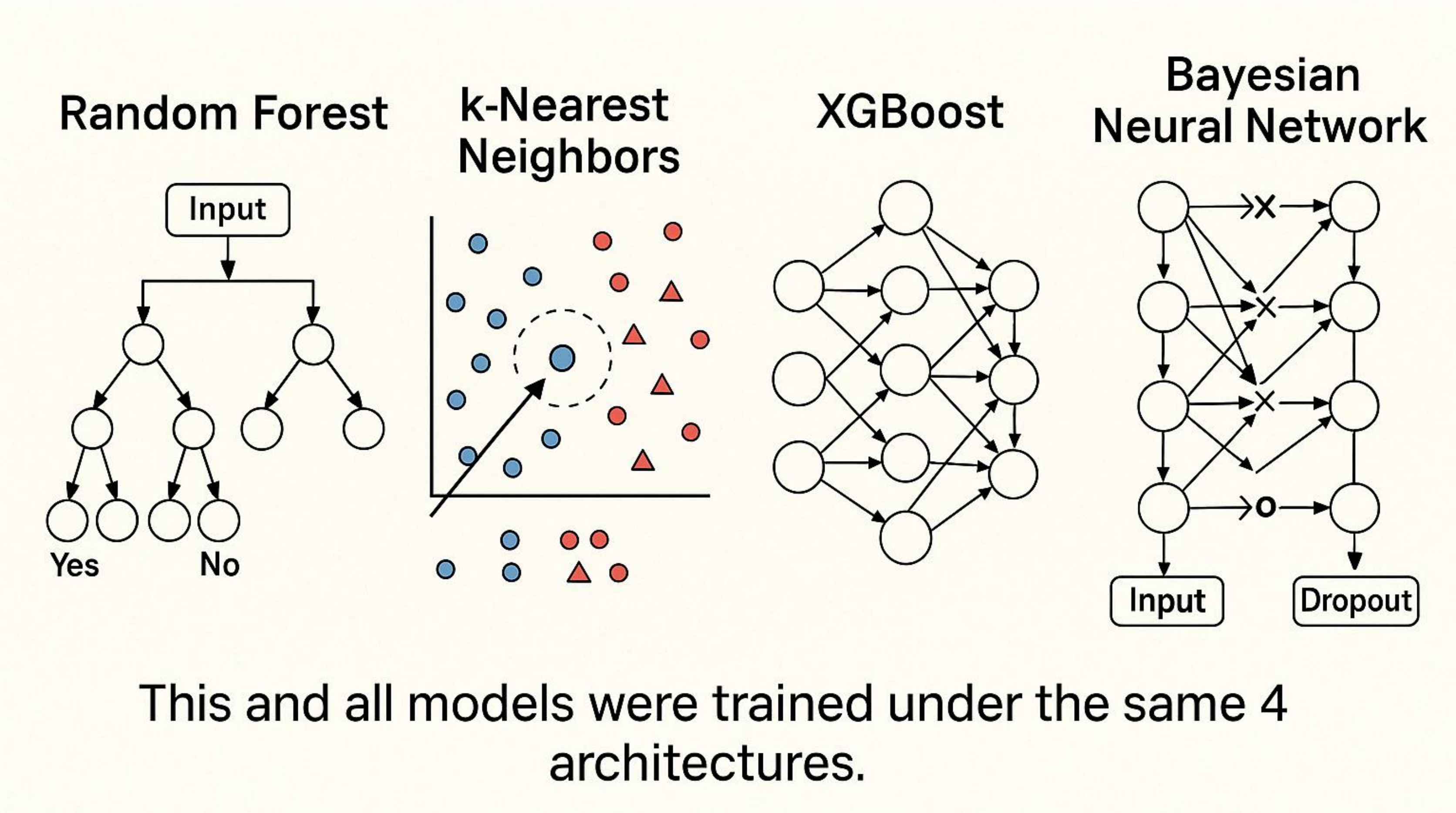


General Pipeline



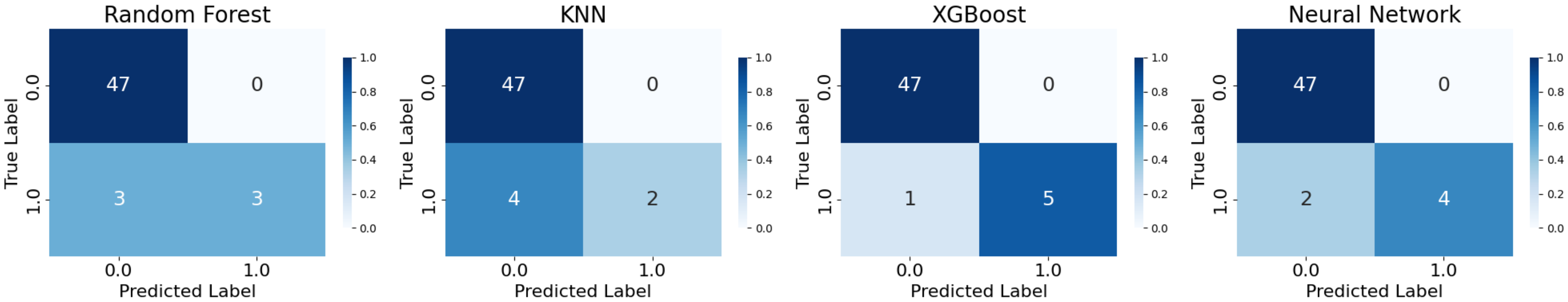
Proposed Models



Ventriculomegaly Classification

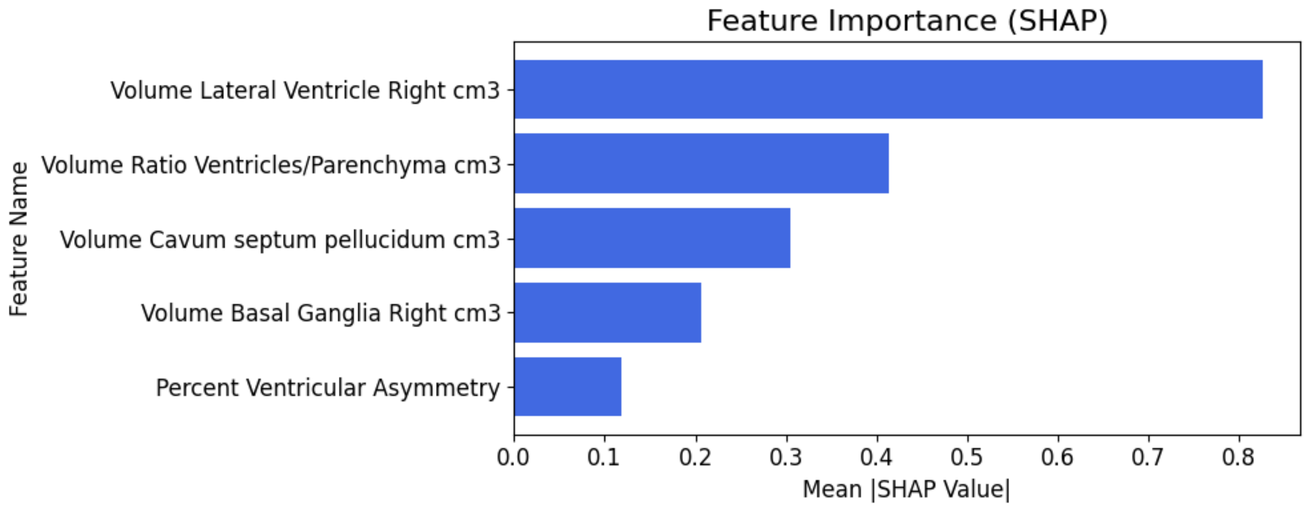
Model Comparison

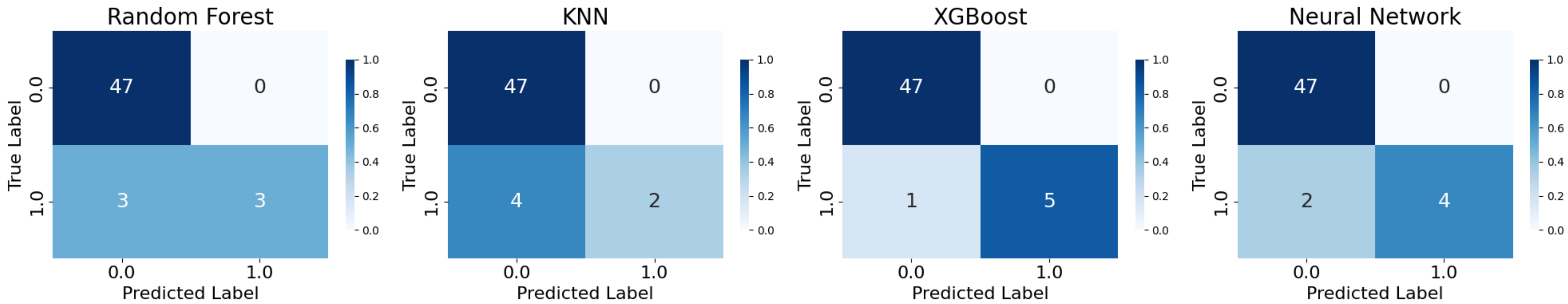
Model	Accuracy	Precision	Recall	F1 Score
Random Forest	0.962	0.963	0.962	0.958
KNN	0.924	0.930	0.924	0.907
XGBoost	**0.981**	**0.981**	**0.981**	**0.980**
Neural Network	0.962	0.963	0.962	0.958



Ventriculomegaly Classification

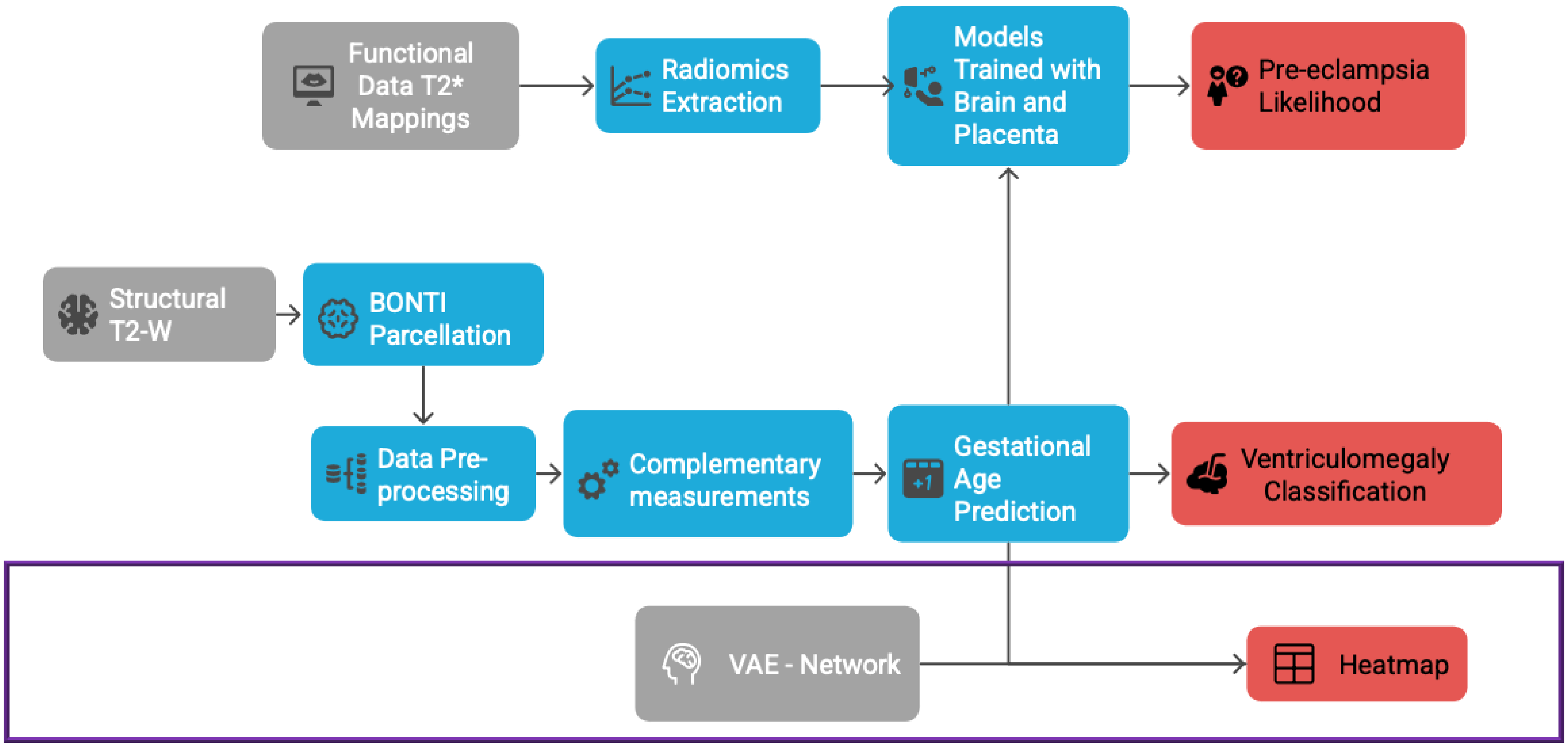
Which features influence?





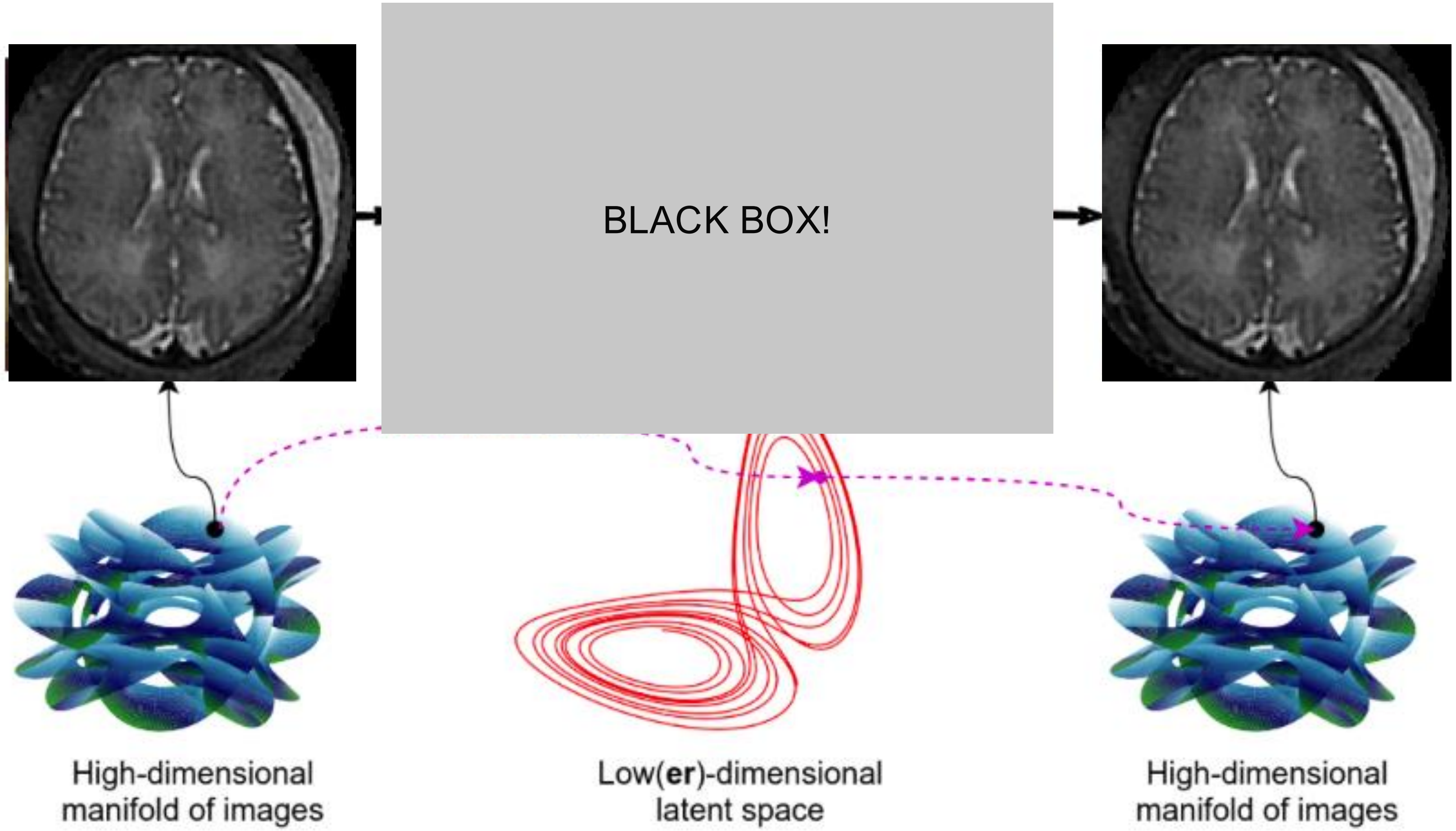
VQ-VAE Heatmap brain abnormalities

General Pipeline



Variational Autoencoder

What is a VAE?



[1]

[1] Pinaya, Walter H.L., Petru-Daniel Tudosiu, Robert Gray, Geraint Rees, Parashkev Nachev, Sebastien Ourselin, and M. Jorge Cardoso. “Unsupervised Brain Imaging 3D Anomaly Detection and Segmentation with Transformers.” Medical Image Analysis 79 (July 2022): 102475. https://doi.org/10.1016/j.media.2022.102475.

Variational Autoencoder

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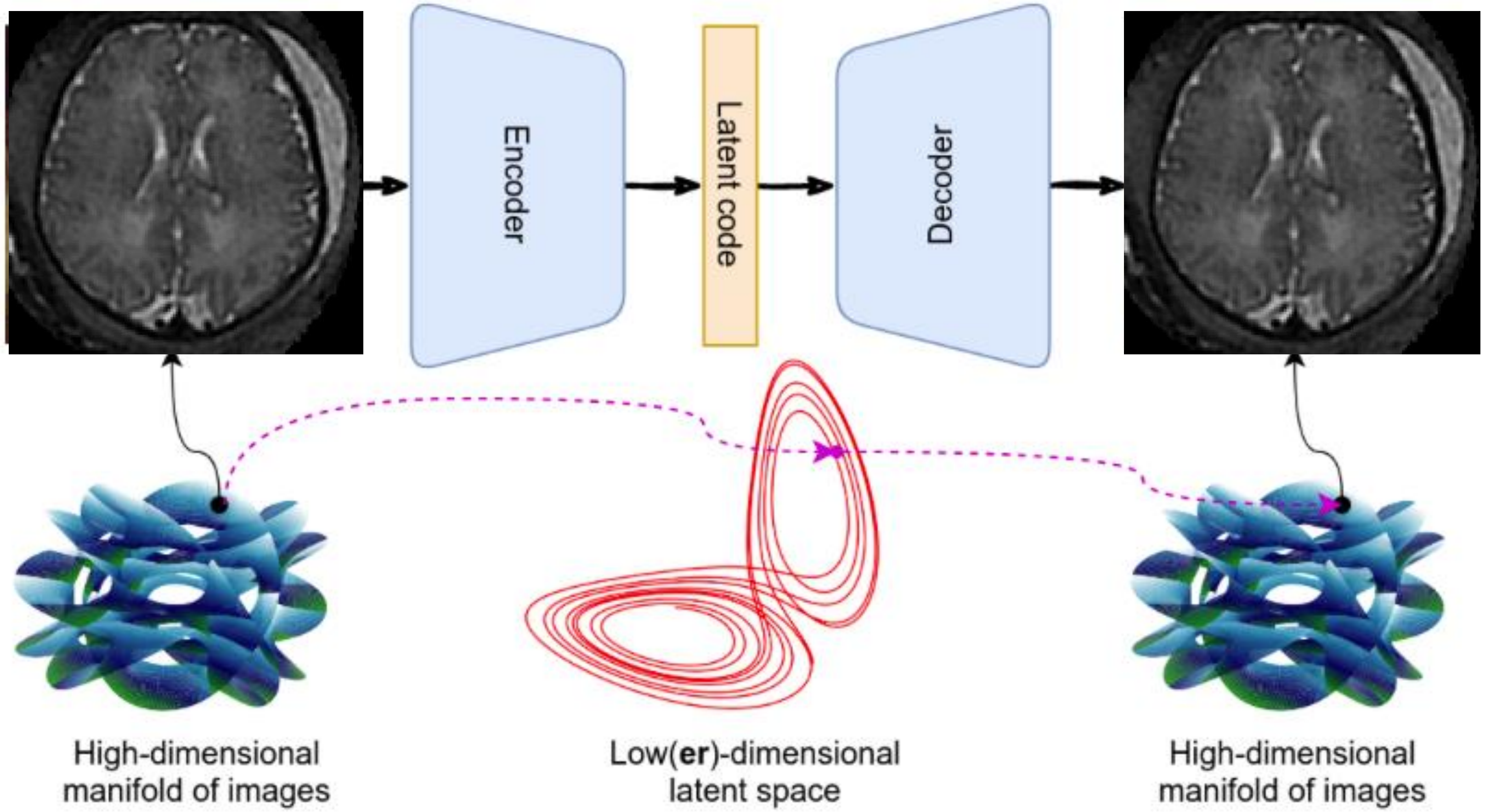

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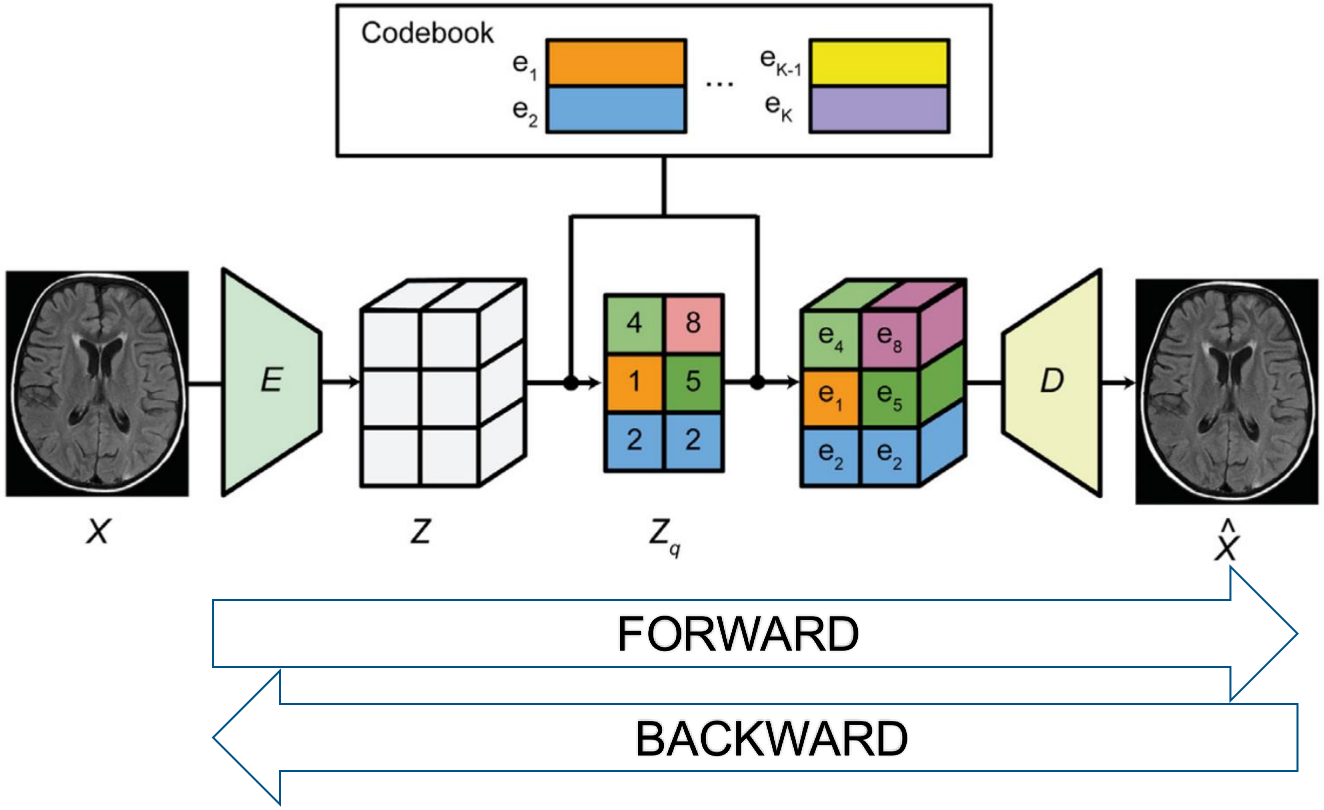
Model Training

How to perform the output

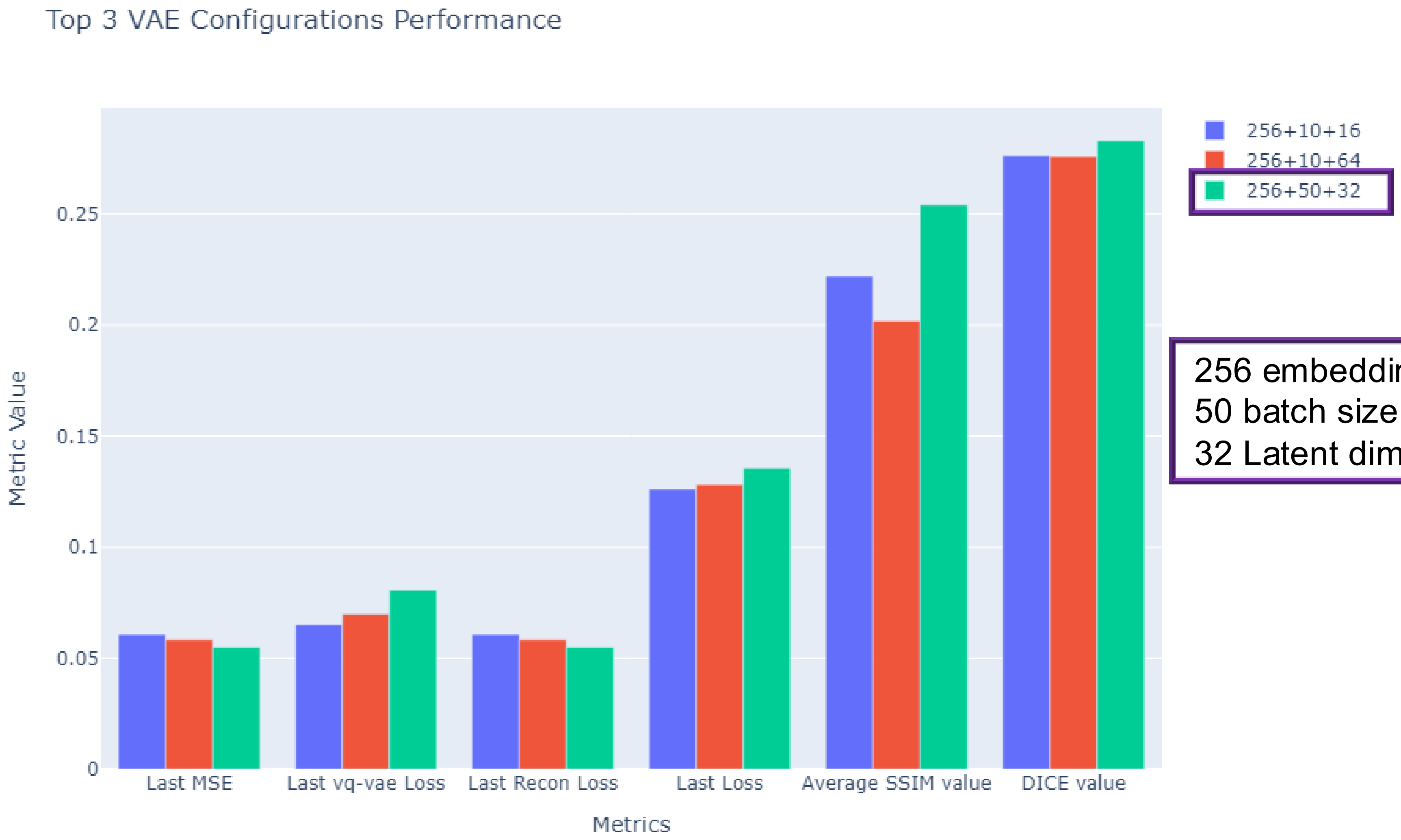


- Checkpoints saved
- Early Stopping
- LR = 1e-4
- Adam Optimizer

$$\mathscr{L}_{VQ-VAE} = \mathscr{L}_{recons} + \mathscr{L}_{codebook} + \beta \mathscr{L}_{commit}$$

Model Training

How to perform the output



256 embeddings
50 batch size
32 Latent dimension

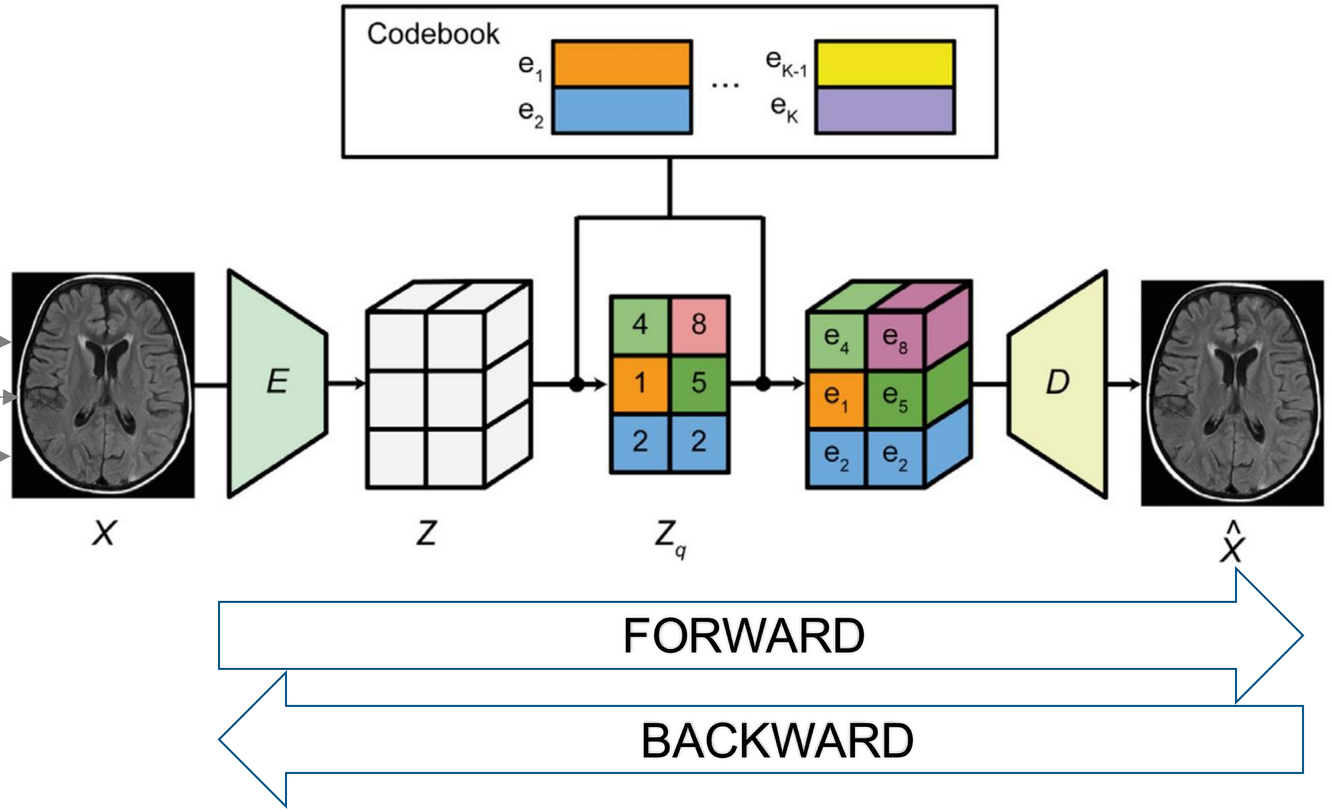
Model Training

How to perform the output

From 23 Weeks – 24 Weeks

From 24 Weeks – 25 Weeks

From 25 Weeks ....



- Checkpoints saved
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VQ-VAE Model Output

Heatmap of ventriculomegaly positive case

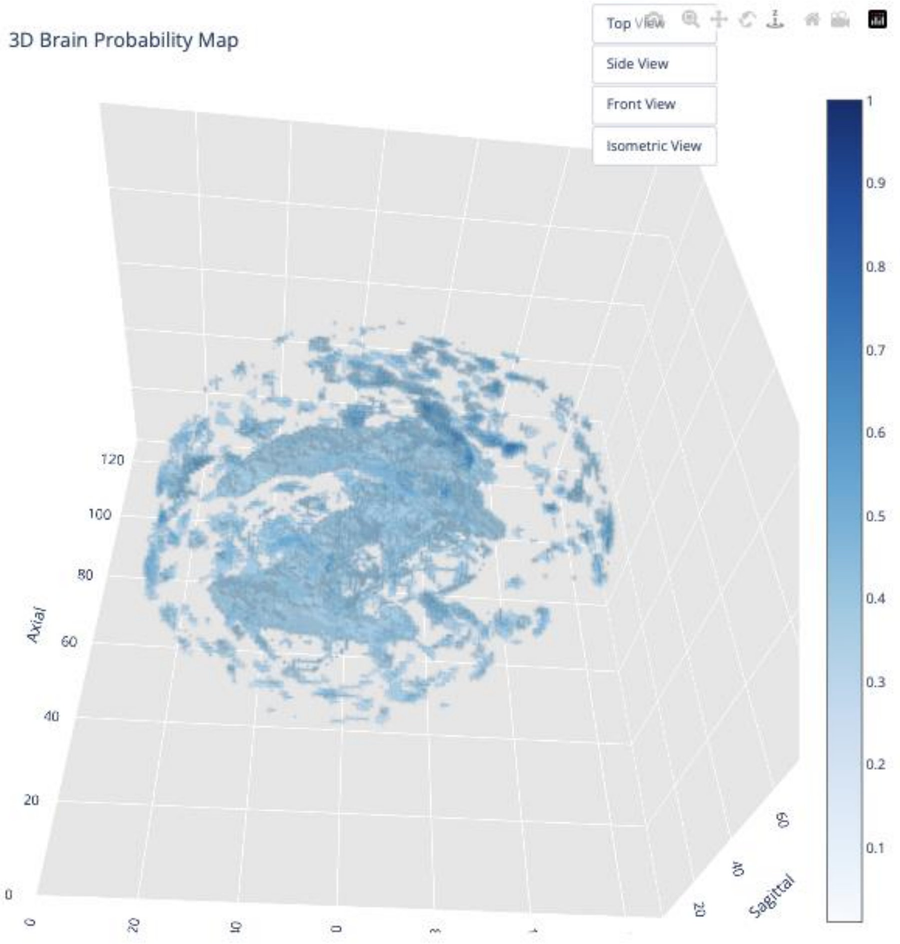
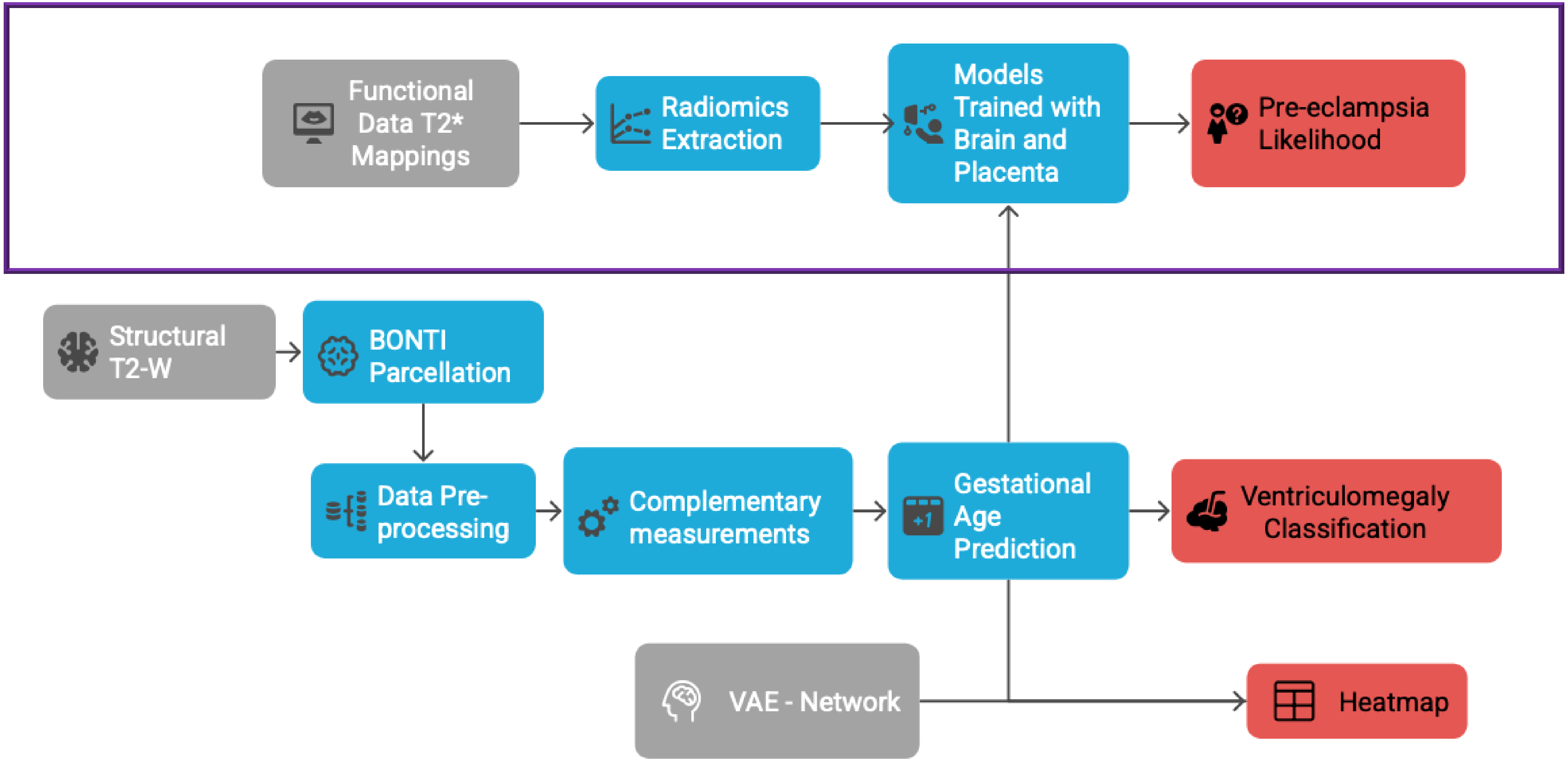


Table 3.2: Performance comparison of top VQ-VAE configurations **(embeddings + batch size + latent dim)**

Metric	**256+10+16**	**256+10+64**	**256+50+32**
Last MSE	0.060	0.058	**0.054**
Last VQ-VAE Loss	0.065	0.069	0.080
Last Reconstruction Loss	0.060	0.056	**0.054**
Last Loss	0.126	0.128	0.135
Average SSIM	0.222	0.201	**0.254**
DICE	0.276	0.275	**0.282**

Functional data T2* mapping

General Pipeline



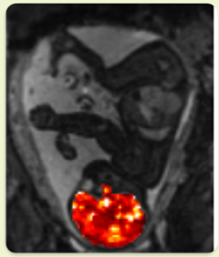
Data Management

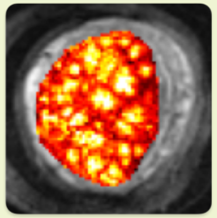
Data Acquisition / Data processing

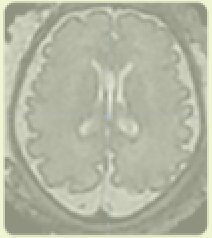
DATA ACQUISITION

Functional data

Structural data







DATA PROCESSING

PRE-PROCESS 1

- Data Imputation
- Pixel Intensity Normalization
- Image Resize
- Image Registration

BRAIN FEATURE EXTRACTION 2

- Brain tissue parcellation (BOUNTI)
- Brain Measurements
- Brain Tissue Volumes

PyRadiomics FEATURE EXTRACTION (BRAIN AND PLACENTA) with T2* 3

- First Order Analysis
- 3D-2D Analysis
- GLCM - GLRLM

DIMENSIONALITY REDUCTION 4

- RFE (Recursive feature elimination)

Pre-eclampsia Model Output

Which organ?

Brain

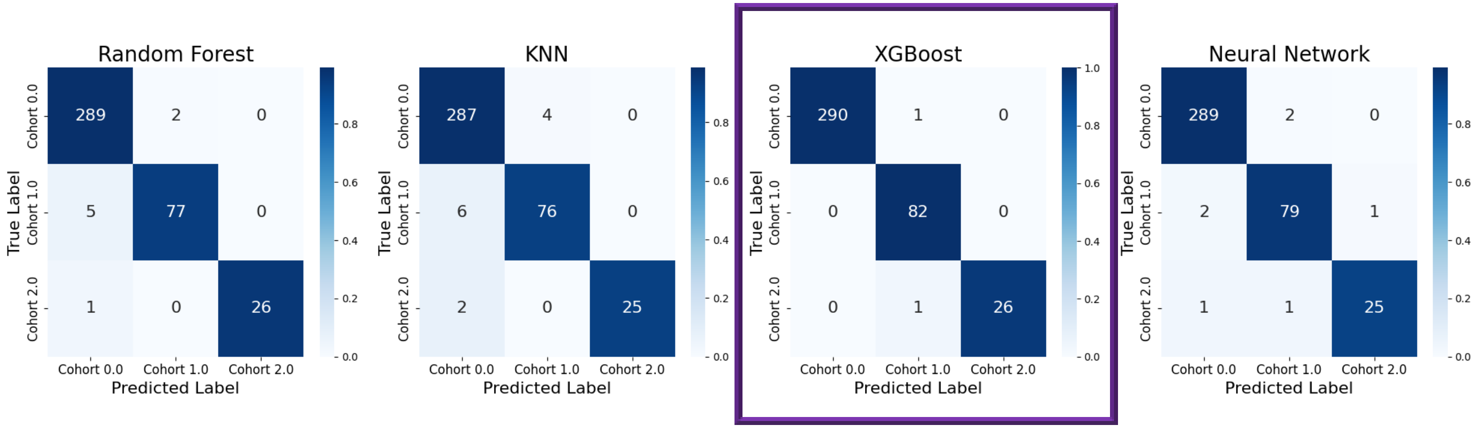


Table 3.4: Pre-eclampsia Probability Models Performance Comparison based on brain T2* mapping

Model	Accuracy	Precision	Recall	F1 Score
Random Forest	0.980	0.980	0.980	0.979
KNN	0.965	0.964	0.965	0.964
XGBoost	**0.995**	**0.995**	**0.995**	**0.994**
Neural Network	0.972	0.972	0.972	0.972

Placenta

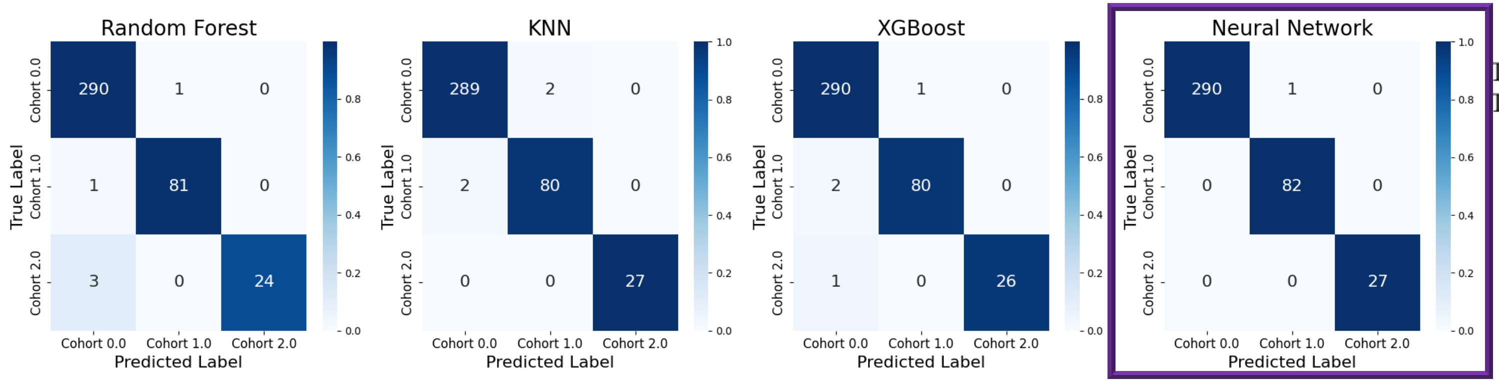
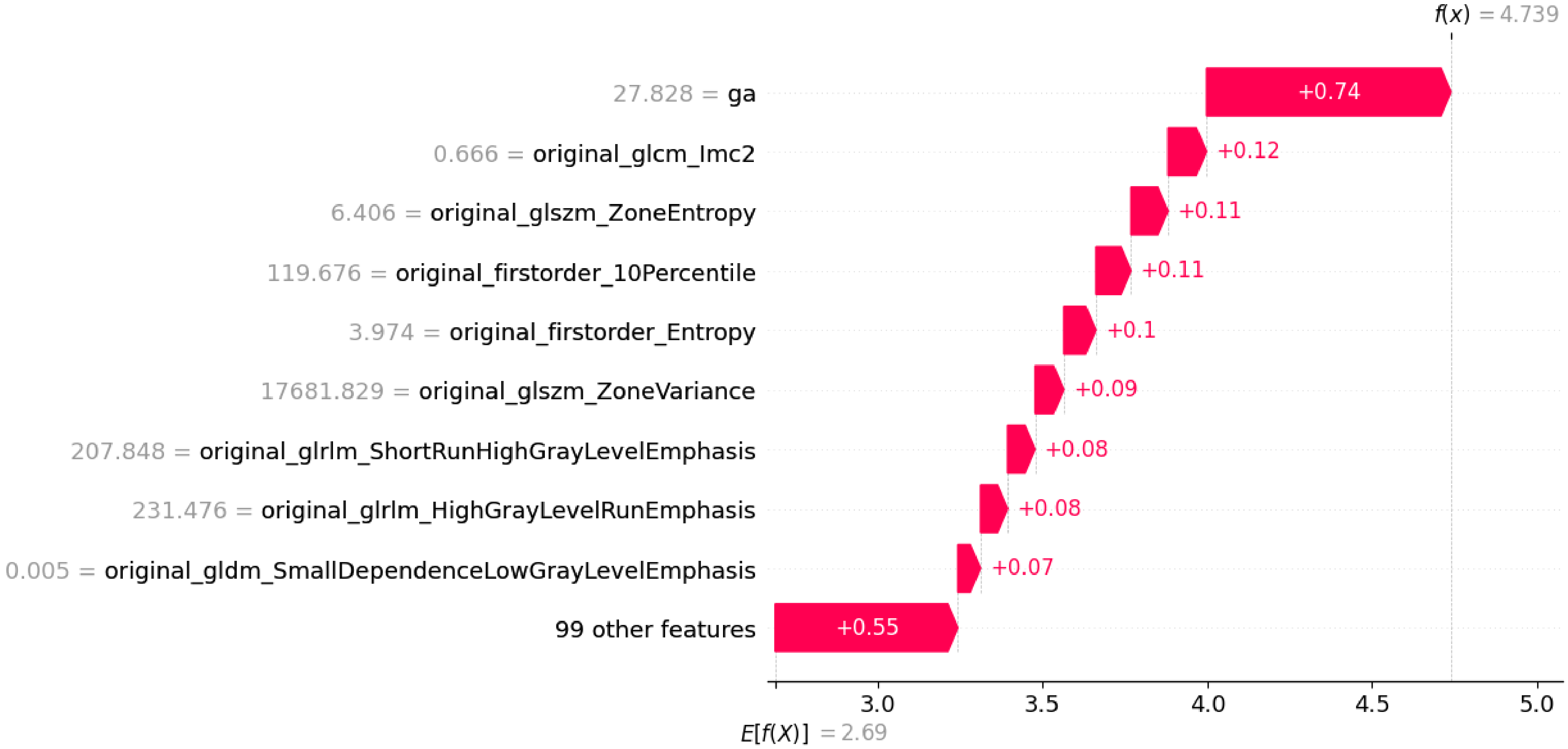


Table 3.5: Pre-eclampsia Probability Models Performance Comparison based on placental T2* mapping

Model	Accuracy	Precision	Recall	F1 Score
Random Forest	0.987	0.987	0.987	0.987
KNN	0.990	0.990	0.990	0.990
XGBoost	0.990	0.990	0.990	0.990
Neural Network	**0.997**	**0.997**	**0.997**	**0.997**

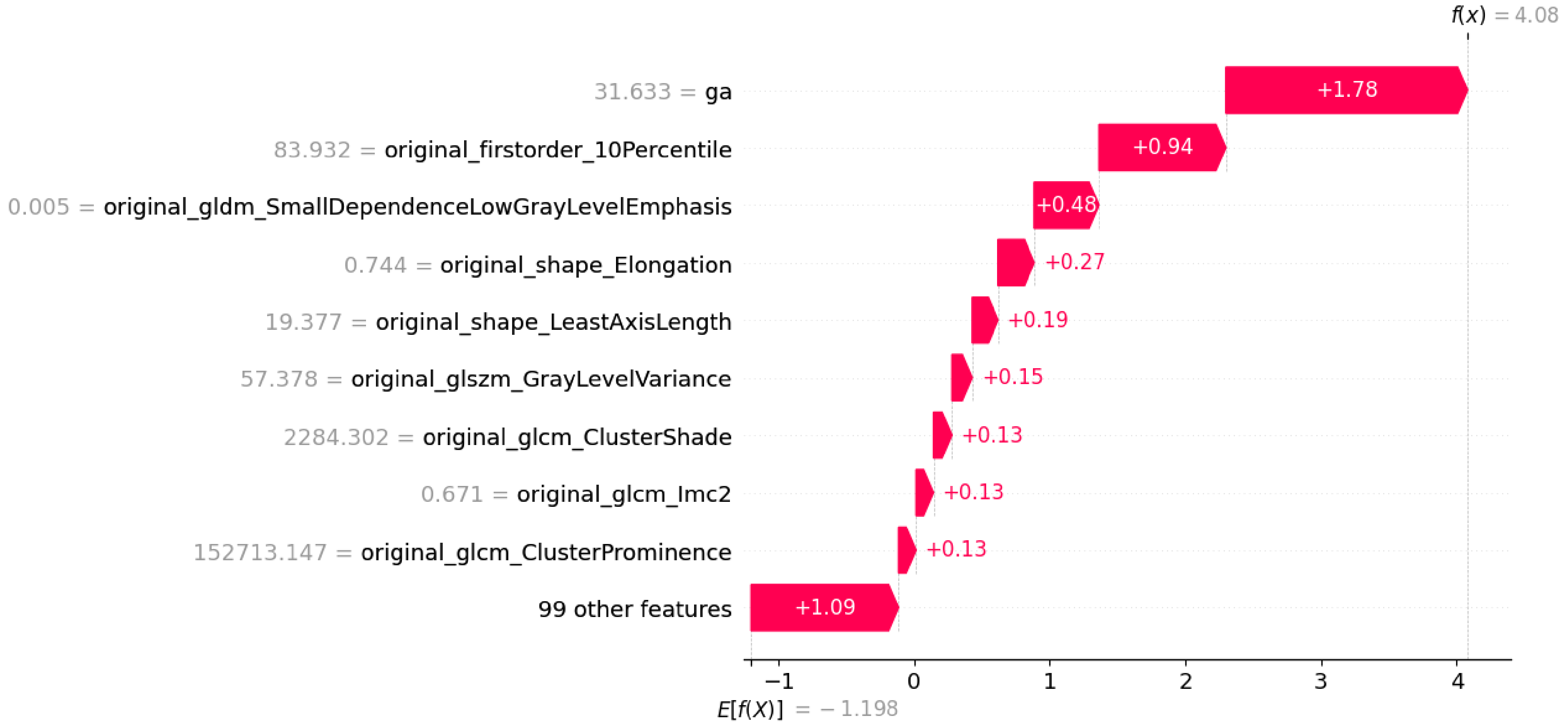
Bayesian Neural Network – Cohort 0 Negative cases

Which feature influence?



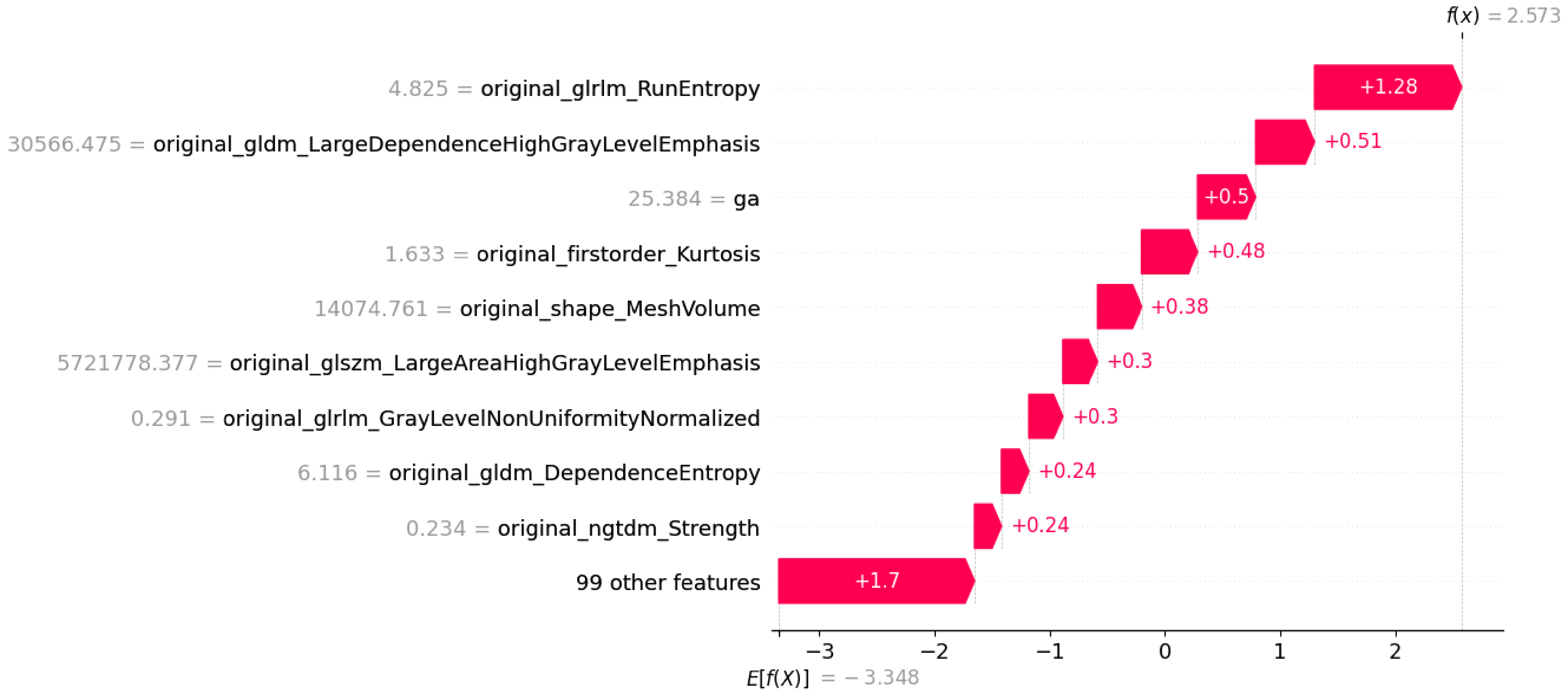
Bayesian Neural Network – Cohort 1 Positive cases

Which feature influence?



Bayesian Neural Network – Cohort 2 Chronic hypertension

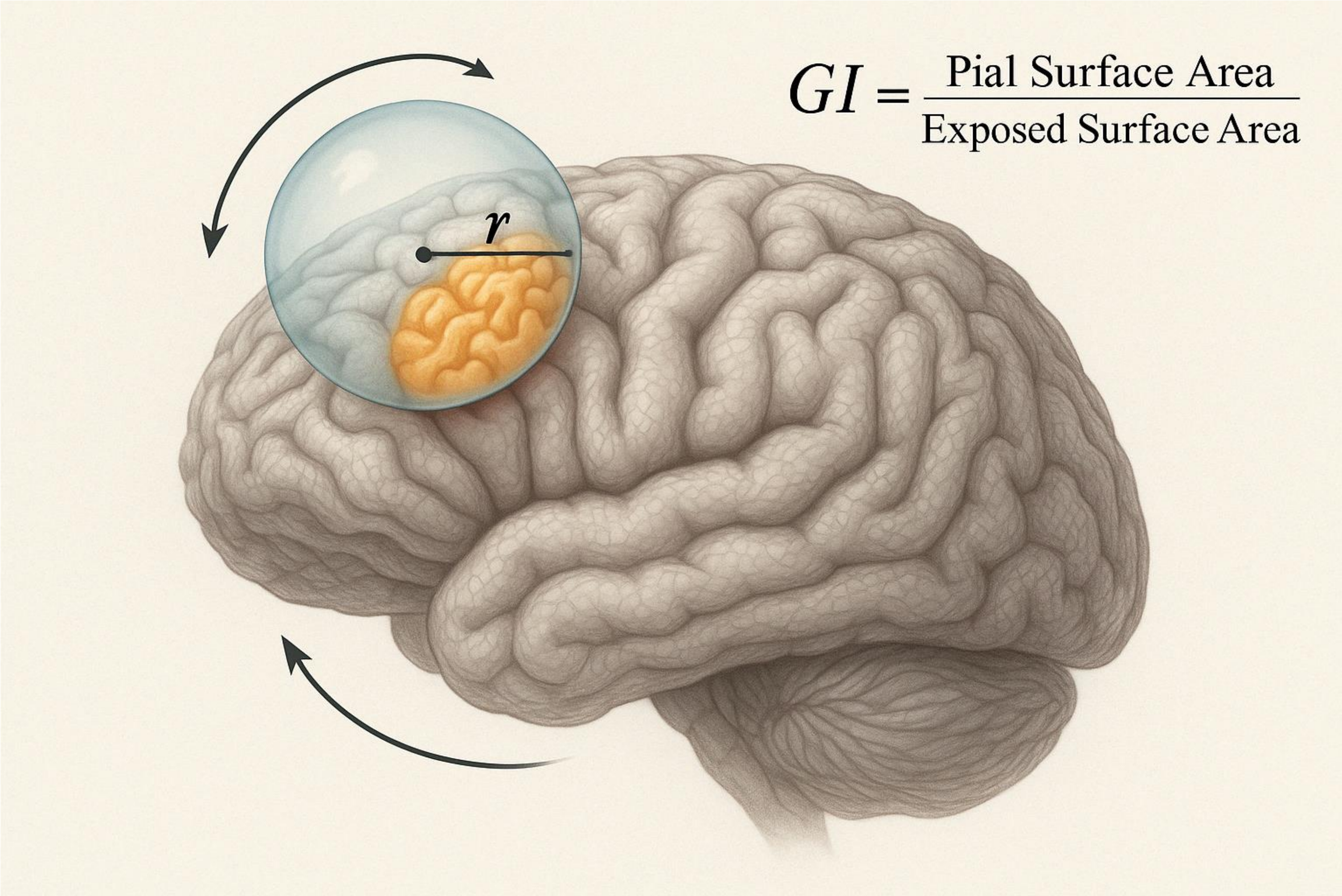
Which feature influence?



Gyrification Index Exploratory Experiment

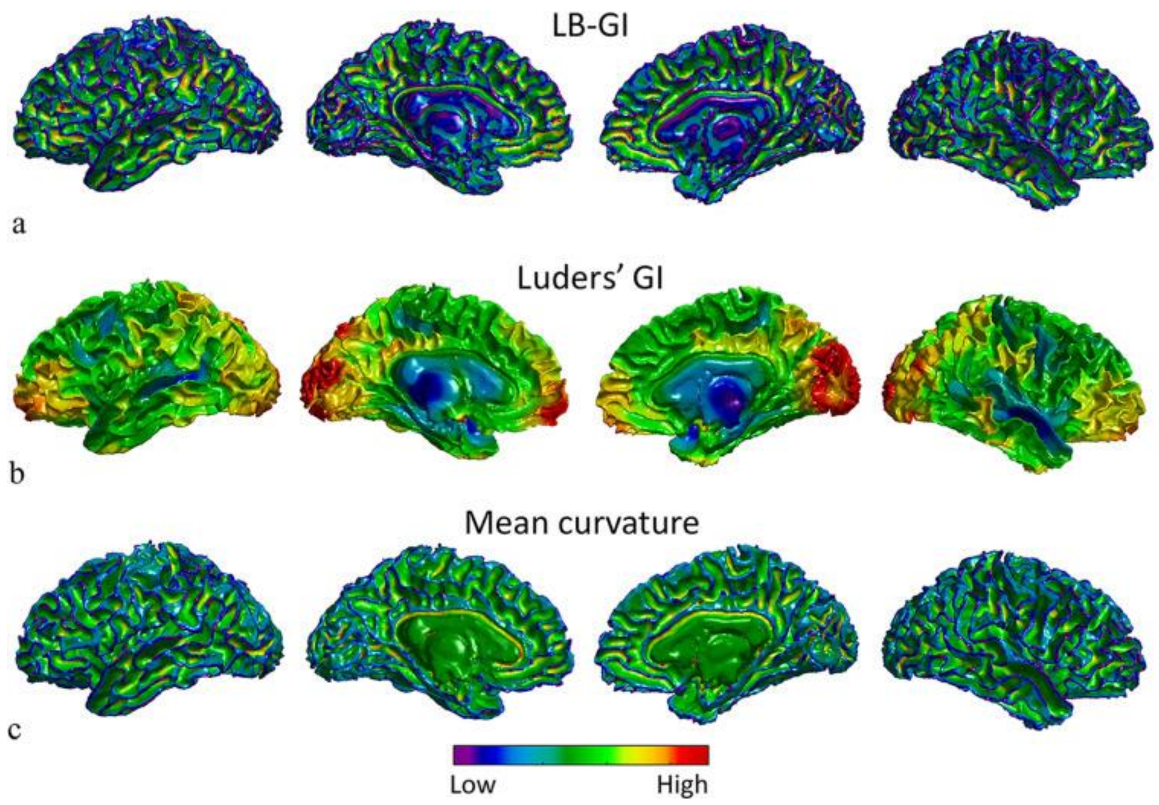
Gyrification Index

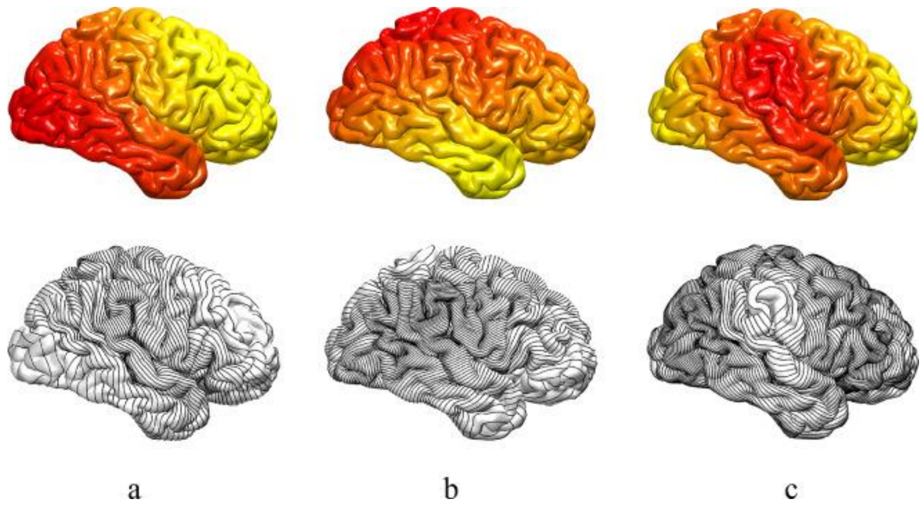
Idea…



Gyrification Index

Australia has done a good job ...





[1] Wang, Y., Xu, T., Kennedy, D. N., Zhang, J., Sadaghiani, S., Han, Y., & Liu, H. (2021). A gyrification analysis approach based on Laplace Beltrami eigenfunction level sets. NeuroImage, 229, 117758. https://doi.org/10.1016/j.neuroimage.2021.117758

Conclusions

Conclusions

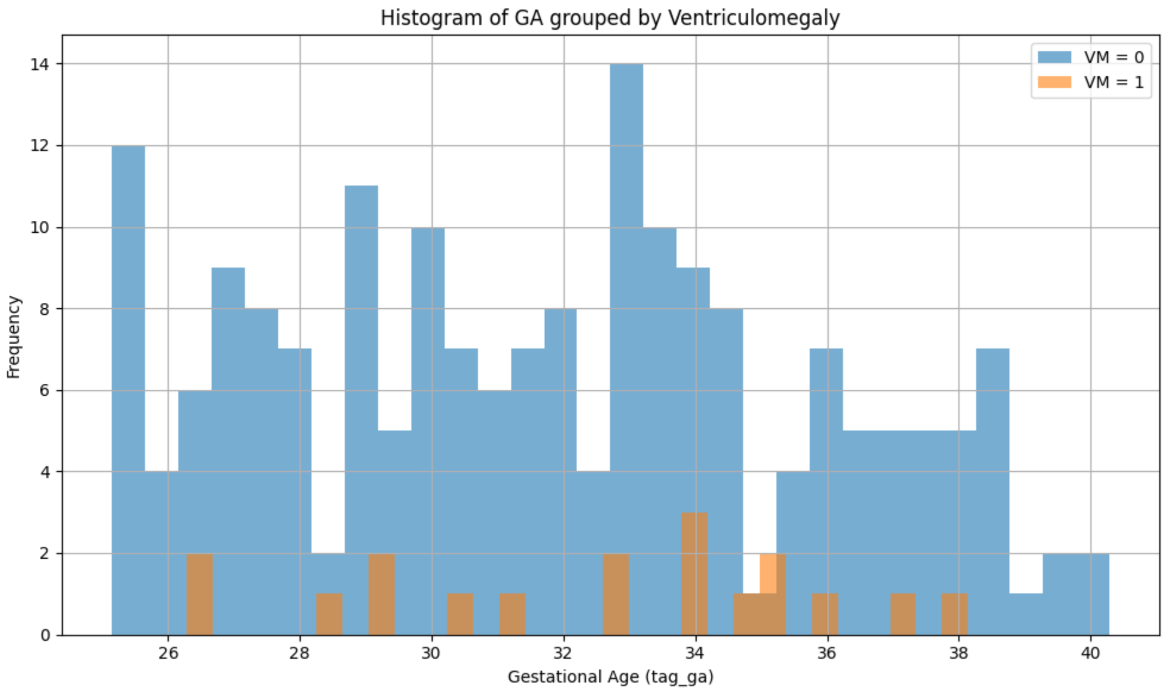
- GA prediction is feasible with **Linear Regression** and **Random Forest** models
- **XGBoost** is the top-performing model for ventriculomegaly classification
- **VQ-VAE** shows potential for anomaly detection but needs more training data and validaton
- The **placenta** is a key region for pre-eclampsia prediction based on data and literature
- **Gyrification Index (GI)** is a marker of brain development linked to mental health conditions in research

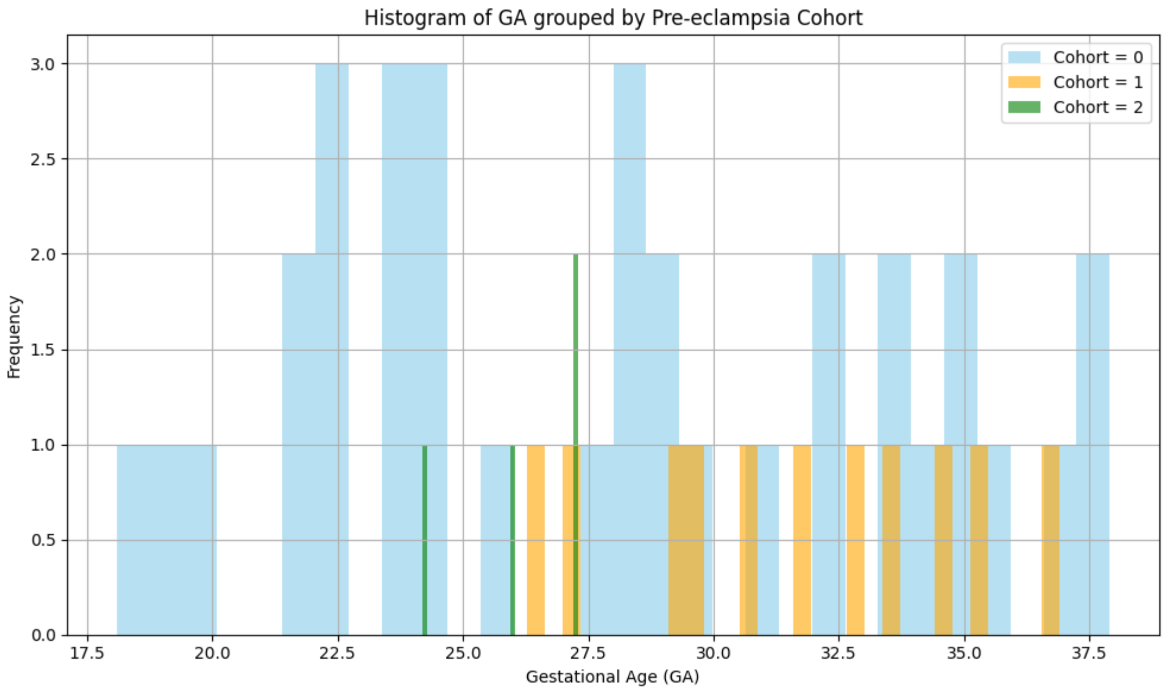
Conclusions

- Models (Bayesian NN, XGBoost) run efficiently on CPUs
- Modular “LEGO” framework for easy integration
- Results affected by data imbalance
- Output can be displayed as an interactive web report

Future Directions

Include multi-center information





18 positive

53 negative

291 Cohort 0

82 Cohort 1

27 Cohort 2

Future directions

Future Directions

Clinical validation across sites

Gyrification Index (GI) refinement: Improve GI computation (e.g., University of Melbourne)

Expand to additional conditions: Extend the framework to include other prenatal conditions like fetal growth restriction (FGR), congenital heart defects (CHD), and cortical folding abnormalities

Include MRI contrasts: Incorporate Diffusion MRI (ADC), Intravoxel Incoherent Motion (IVIM), and T1-weighted imaging for richer tissue characterization

Teleradiology and LMIC applications: Adapt the tool for use in resource-limited settings with web-based interfaces (or EMR) and cloud support for remote fetal imaging assessment

Machine Learning are decision support mechanisms, not diagnostic tools!