Image-based Diagnosis of Chiari Disease

Elle Buser, Emma Hart, Ben Huenemann, and Justin Smith

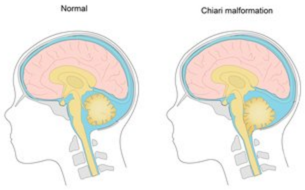
Emory University
REU/RET Summer Research
Mentor: Lars Ruthotto

July 27, 2021

Understanding Chiari Malformation

What is Chiari Malformation?

Chiari Malformation Type I (CMI) is a problem that occurs in the cerebellum and brain stem.



The brain tissue on the Chiari patient extends into the spinal canal NHS 2019

Symptoms of Chiari Malformation

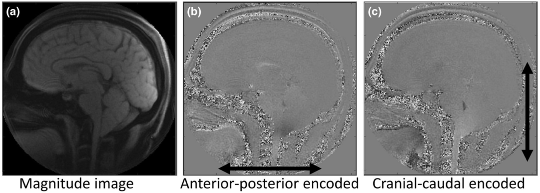
Some of the symptoms include:

- dizziness
- neck pain
- poor hand coordination
- severe headache
- vision and speech problems

Diagnosing Type I Chiari Malformation (CMI)

Findings of Nwotchouang et al. 2020

- CMI is not easy to detect from anatomical images
- DENSE imaging provides a better method
- Deformation of the cerebellum and brainstem is significantly larger in CMI patients than in controls



Nwotchouang et al. 2020

Diagnosing Type I Chiari Malformation (CMI)

Segmentation

- These findings motivate our work to automatically segment the cerebellum and brain stem.
- With these regions identified automatically, diagnosis from DENSE imaging can become cheaper and more feasible for wide-scale screening.

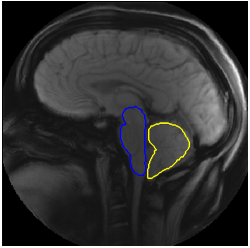
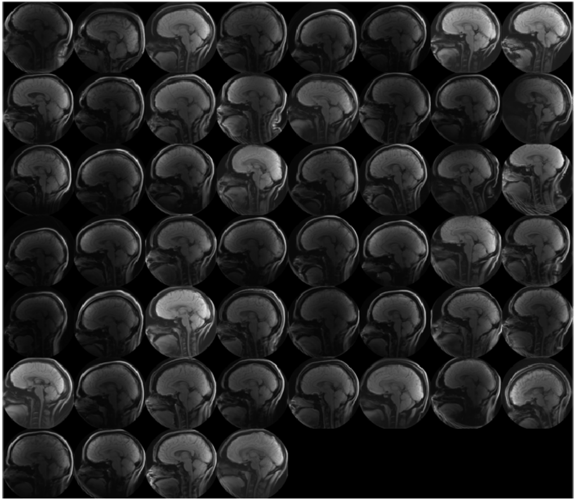


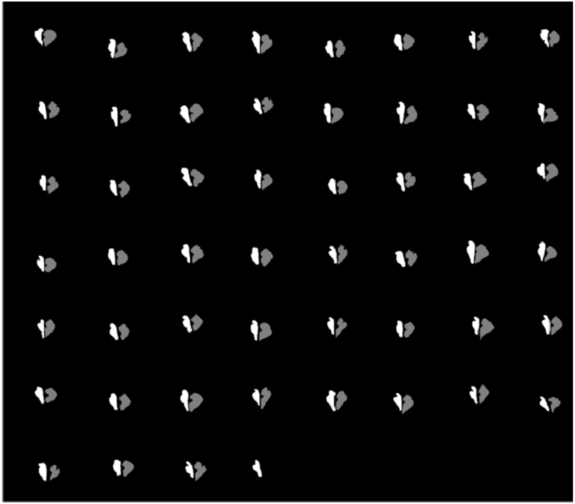
Figure: Brain stem outlined in blue, cerebellum in yellow

Dataset



- 52 subjects in training set
- Each image 256x256 pixels
- Images provided by John Oshinski's Lab at Emory University

Dataset

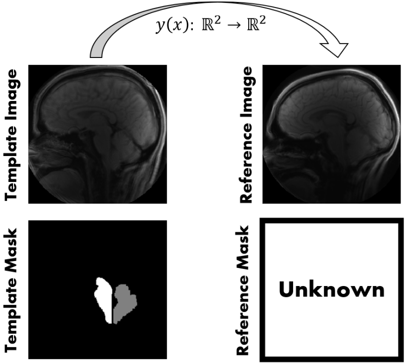


- 52 subjects in training set
- Each image 256x256 pixels
- Images provided by John Oshinski's Lab at Emory University

Segmentation Approaches

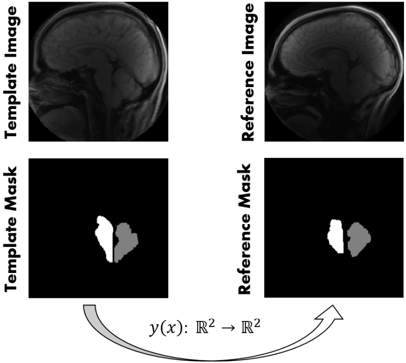
- Atlas-Based Segmentation
  - Explanation
  - Finding the Transformation
  - Data Normalization
  - Dice and Jaccard Metrics
  - Example
- Machine Learning
- Combining Methods and Other Improvements

Atlas-Based Segmentation



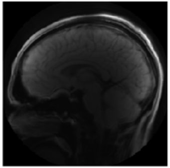
- Map a known **template image** to a new **reference image** with some $y : \mathbb{R}^2 \to \mathbb{R}^2$
- Apply $y : \mathbb{R}^2 \to \mathbb{R}^2$ to **template mask** to find **reference mask**

Atlas-Based Segmentation

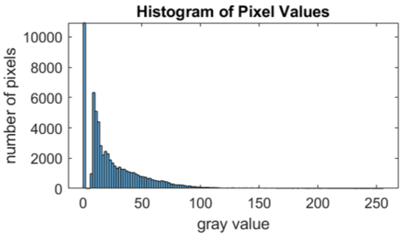


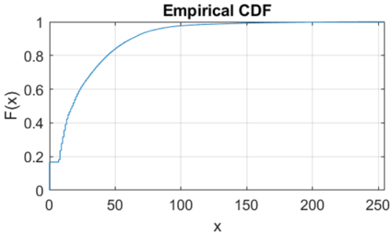
- Map a known **template image** to a new **reference image** with some $y : \mathbb{R}^2 \to \mathbb{R}^2$
- Apply $y : \mathbb{R}^2 \to \mathbb{R}^2$ to **template mask** to find **reference mask**

Data Normalization

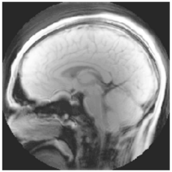


- Dramatically varying brightness and contrast in original images
- Histogram equalization
- Image Processing Toolbox

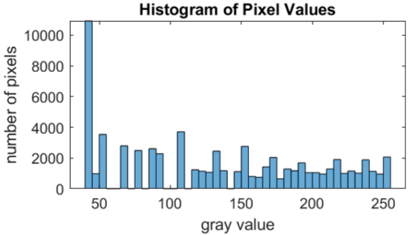


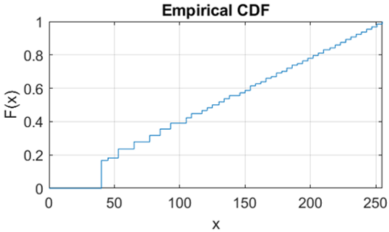


Data Normalization

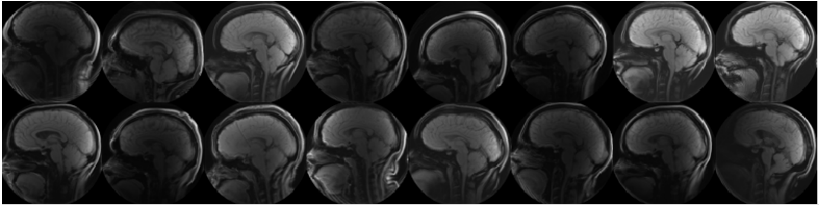


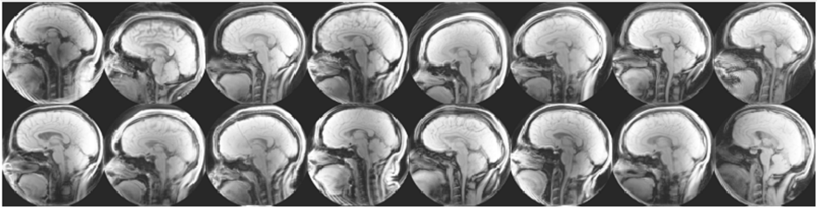
- histeq() uses the CDF as a mapping to normalize the histogram
- Helps increase contrast and make images all more similar to each other





Data Normalization





Finding the Transformation

Flexible Algorithms for Image Registration (FAIR) Toolbox

The FAIR MATLAB toolbox Modersitzki 2009 includes functions designed for this kind of image registration

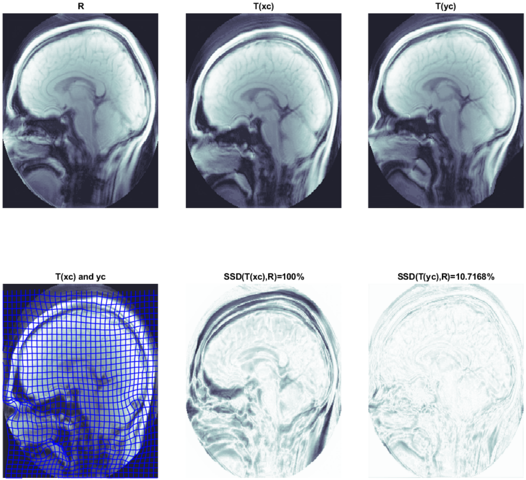
This project uses:

- Matrix-Based Hyper Elastic Regularizer
- Sum of Squared Deviations (SSD) Distance Method
- Gauss Newton Optimization

Atlas-Based Example: Image Transformation

FAIR Registration

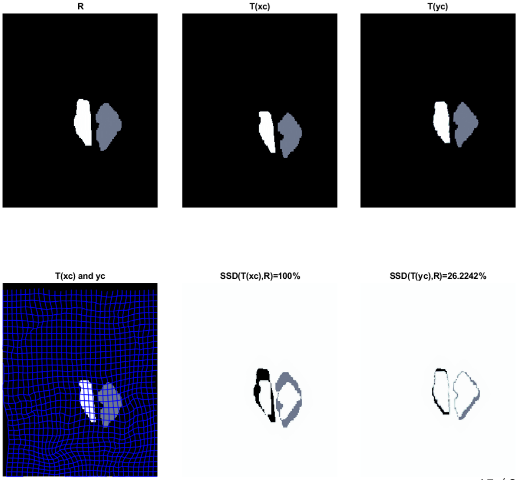
- Distance Measure: Sum of Squares
- Regularizer: Matrix-based Elastic
- Multilevels: 5-8
- Pre-registration: Rigid
- Registration Parameter: $\alpha = 1000$
- Runtime: 17 sec



Atlas-Based Example: Mask Transformation

FAIR Registration

- Distance Measure: Sum of Squares
- Regularizer: Matrix-based Elastic
- Multilevels: 5-8
- Pre-registration: Rigid
- Registration Parameter: $\alpha = 1000$
- Runtime: 17 sec



Dice/Jaccard

More Segmentation Metrics

- Dice is the overlap of the sum.
- Jaccard is the overlap of the union.

$$\text{Dice} = \frac{2||A \cap B||}{||A|| + ||B||}$$

$$\text{Jaccard} = \frac{||A \cap B||}{||A \cup B||}$$

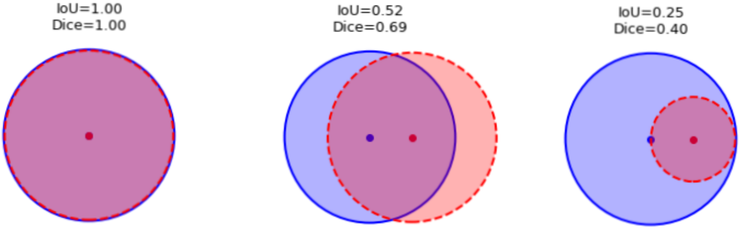


Figure: Comparison of Dice and Jaccard (IoU) Monteux 2019

Atlas-Based Example: Dice/Jaccard Measures

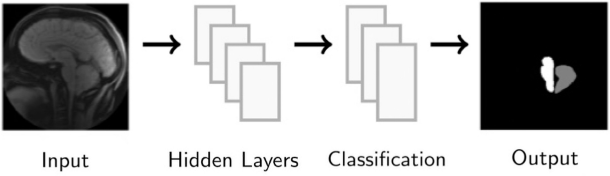
	Dice Original	Dice Transformed	Jaccard Original	Jaccard Transformed
Brain stem	0.643	0.902	0.474	0.822
Cerebellum	0.645	0.887	0.476	0.798
Full Mask	0.644	0.894	0.475	0.808

Machine Learning

What is Machine Learning?

The study of computer algorithms that improve automatically through experience and by the use of data.

- Goal: Train a model to segment the MRI images into 3 classes: cerebellum, spinal cord, and background.
- U-Net: A convolutional neural network



Machine Learning: Hopeful Beginnings

With Our Data...

Problems

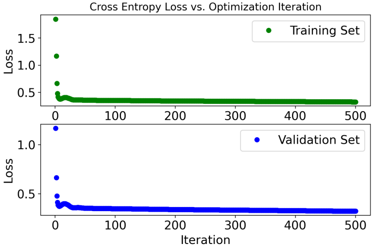
- Limited training data
- Difficulties in classification
- Our model predicts all pixels are background

Potential Solutions

- Fine tuning parameters and setting constraints
- Using machine learning with atlas-based segmentation

Current Results

- Have a running loss function and optimizer which uses default settings (learning rate=0.001, momentum=0.9)



What comes next...

- Creating a method for how to choose the reference subject
- Experimenting with segmenting the brain before segmenting the cerebellum and brain stem
- Utilizing Normalized Gradient Fields as a way to measure how well we think our masks segment the cerebellum and brain stem (even when we do not have an available mask)
- Conducting some statistical analysis to determine the importance of precisely segmenting the brain and cerebellum

Bibliography

- Modersitzki, Jan (2009). *FAIR: flexible algorithms for image registration*. Vol. 6. Fundamentals of Algorithms. Society for Industrial and Applied Mathematics (SIAM), Philadelphia, PA.
- Monteux, Angelo (May 2019). *Metrics for semantic segmentation*. URL: https://ilmonteux.github.io/2019/05/10/segmentation-metrics.html (visited on 06/29/2021).
- NHS (2019). *Chiari Malformation*. URL: https://www.nhs.uk/conditions/chiari-malformation/ (visited on 06/30/2021).
- Nwotchouang, Blaise Simplice Talla et al. (Dec. 2020). "Regional Brain Tissue Displacement and Strain is Elevated in Subjects with Chiari Malformation Type I Compared to Healthy Controls: A Study Using DENSE MRI". In: *Annals of Biomedical Engineering*, pp. 1–15.