Image Registration for Diagnosis of the Chiari Malformation

Emma Hart, Elle Buser, Ben Huenemann

Emory University
REU/RET Summer Research
Mentors: Lars Ruthotto, Justin Smith

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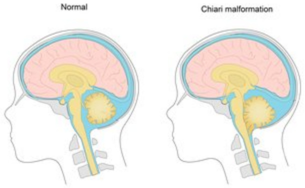
Understanding Chiari Malformation

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

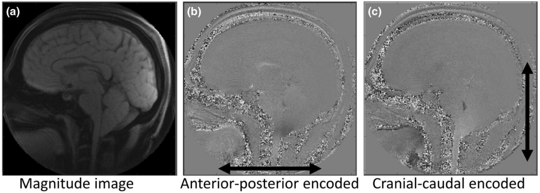
Some of the symptoms include:

- dizziness
- neck pain
- poor 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
- Deformation Encoding with Stimulated Echoes (DENSE) MR 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.

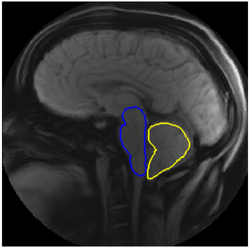


Figure: Brain stem outlined in blue, cerebellum in yellow

Dataset

For each patient:

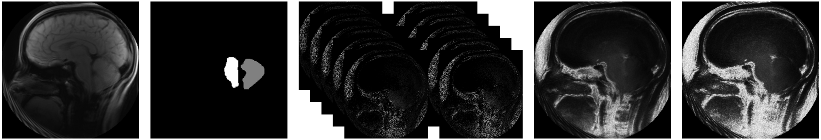


Figure: From left to right, an example of one patient's (1) magnitude MR image; (2) mask; (3) DENSE images representing one cardiac gate each; (4) temporal mean DENSE image; and (5) temporal peak DENSE image

- 52 subjects in training set
- Each image 256x256 pixels, grey values between 0 and 255
- Images provided by Dr. John Oshinski's Radiology Lab

Segmentation Methods: Full Paper Overview

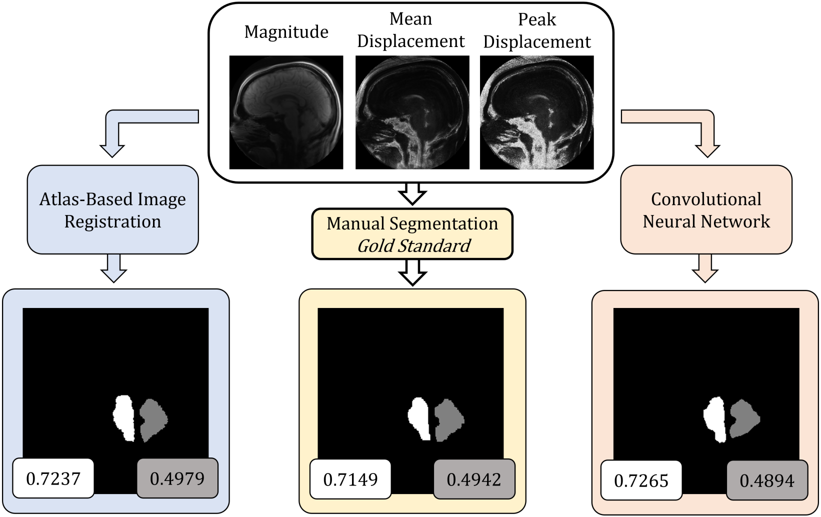


Image Registration

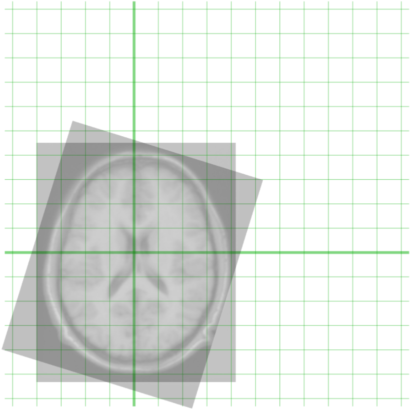


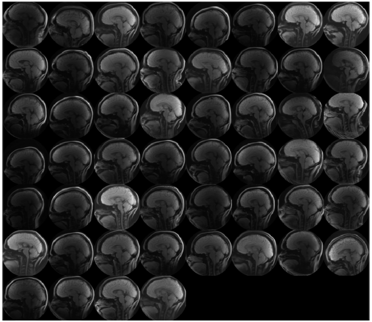
Figure: Andrew Janke - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=9437062

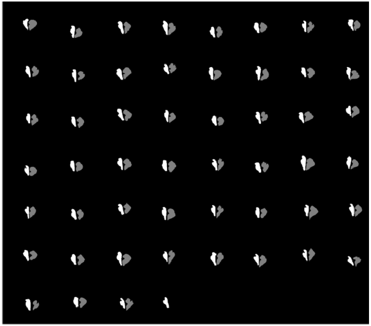
- Technique used to integrate multiple images together
- Transforms coordinate systems to align images
- Addresses rotation/scale/skew

Image Registration

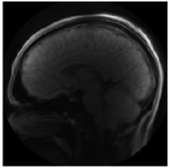
Idea in Our Application

Use what we know, in our bank of already segmented template images, to learn segmentation for a new reference image

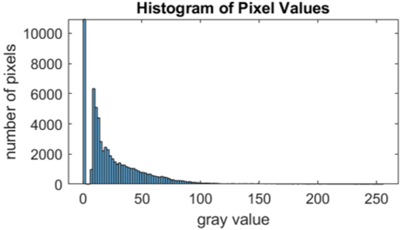


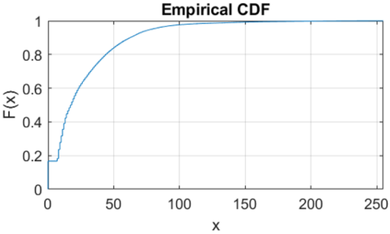


Data Normalization

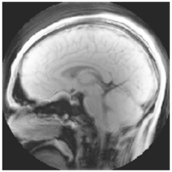


- Dramatically varying brightness and contrast in original images
- Complicates registration

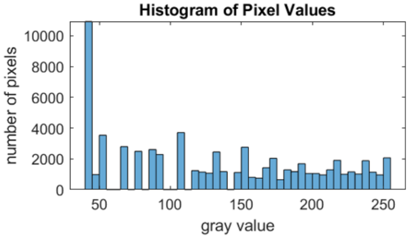


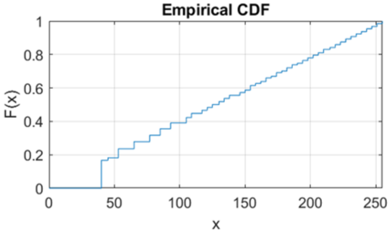


Data Normalization

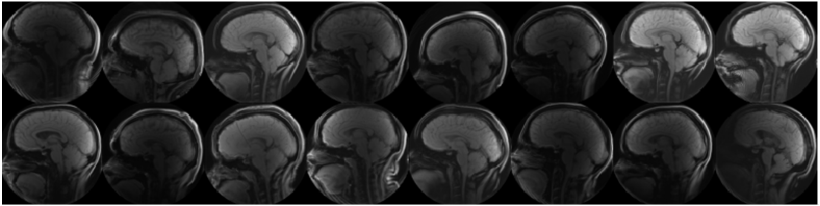


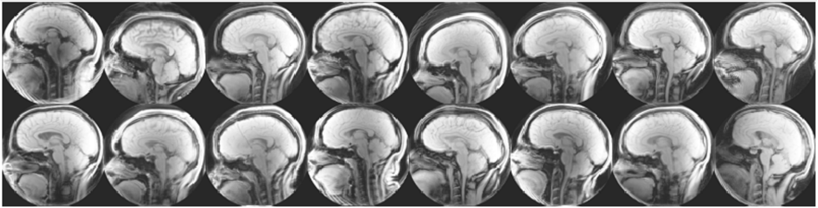
- histogram equalization uses the CDF as a mapping to normalize the histogram
- Helps increase contrast and make images all more similar to each other



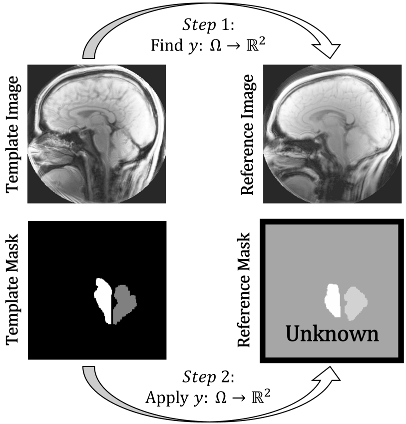


Data Normalization





Atlas-Based Segmentation



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

Finding the Transformation

Flexible Algorithms for Image Registration (FAIR) Toolbox

We implemented methods using this MATLAB toolbox (Modersitzki 2009) that includes functions designed for this kind of image registration

Finding the Transformation

Introducing Notation

Thinking about images as interpolated functions

- Coordinates of pixels in the image grid: $\Omega \subseteq \mathbb{R}^2$
- Template image $\mathcal{T} : \quad \Omega \to \mathbb{R}$
- Reference image $\mathcal{R} : \quad \Omega \to \mathbb{R}$
- Transformation: $y : \quad \Omega \to \mathbb{R}^2$

Aiming to Find

$$\mathcal{T}[y](x) \approx \mathcal{R}(x) \quad \text{for all} \quad x \in \Omega.$$

Finding the Transformation

Objective Functional

$$\mathcal{J}_{\mathrm{atlas}}[y] = D_{\mathrm{SSD}}[\mathcal{T}[y], \mathcal{R}] + \alpha \mathcal{S}[y]$$

- Sum of Squares Distance: $D_{\mathrm{SSD}}[\mathcal{T}[y], \mathcal{R}] = \frac{1}{2} \int_{\Omega} (\mathcal{T}[y](x) - \mathcal{R}(x))^2 dx.$
- Regularization parameter: α
- Regularization functional: $\mathcal{S}$

Example

FAIR: E6_Hands_affine.m

Multilevel Optimization Approach

Why are we thinking about images like functions?

- Gauss Newton optimization – dependent on initial guess
- Relatively hard optimization problem to find this transformation y when using our original 256x256 pixel images (many local minima)
- By thinking about the images as functions, this allows us to find coarser (ie, "more pixel-y") representations
- Idea: use coarser representations to find make an easier optimization problem and find a better initial guess to use on our actual finer image

Example

FAIR: E3_multilevel.m, E6_Hands_MLPIR.m, (E9_Hands_MLIR_SSD_mbElas.m, using different regularizer)

Atlas-Based Example: Image Transformation

Back to our setting: we choose a template from our “bank” of already segmented images that we think looks closest to our new reference image, then apply registration

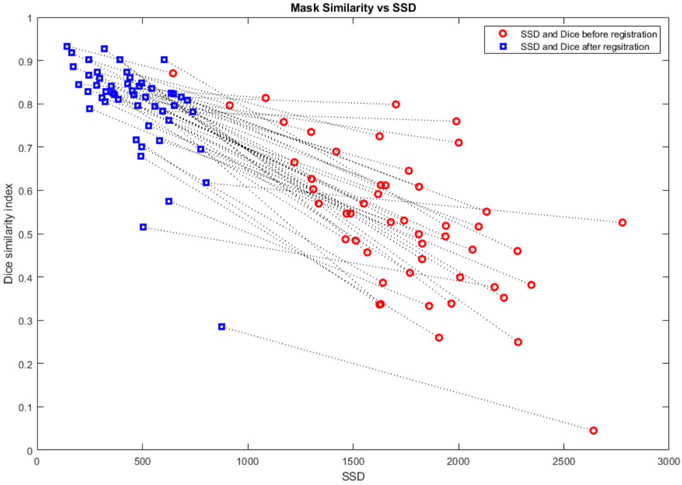
FAIR Registration

- Distance Measure: Sum of Squares
- Regularizer: Hyperelastic
- Multilevels: 5-8
- Registration Parameter: $\alpha = 1000$

Example

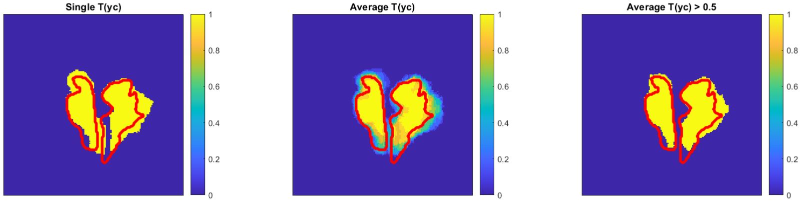
chiari_example.m

Mask Similarities Before and After Registration



Averaging Registrations

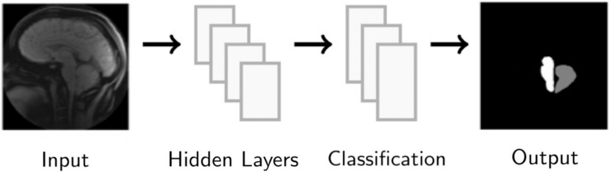
- Can perform registrations with many different templates
- We "average" together registrations, and choose to include pixels in our output segmentation only if many agree



Example

chiari_example_average.m

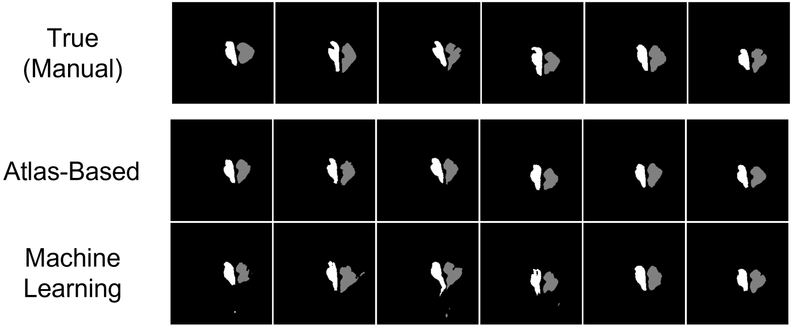
Machine Learning



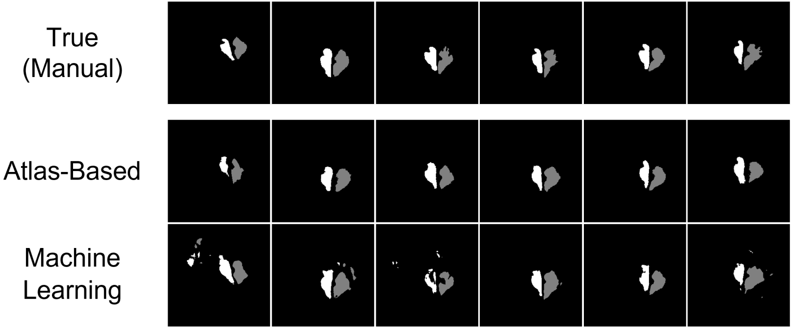
How can machine learning be applied to this same segmentation problem?

Ask Elle! Using U-net, roughly equivalent segmentations were found. (Okay, they were usually better.)

Results



Results



Questions/Comments/Anything Else?

If you're interested in some casual light reading, our paper is available at: https://www.siam.org/publications/siuro/volume-15 (DOI: 10.1137/21S1448392)

Thanks for coming!

Bibliography

Modersitzki, Jan (2009). *FAIR: flexible algorithms for image registration*. Vol. 6. Fundamentals of Algorithms. Society for Industrial and Applied Mathematics (SIAM), Philadelphia, PA.

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.