Optical Flow Algorithms for CSF Analysis

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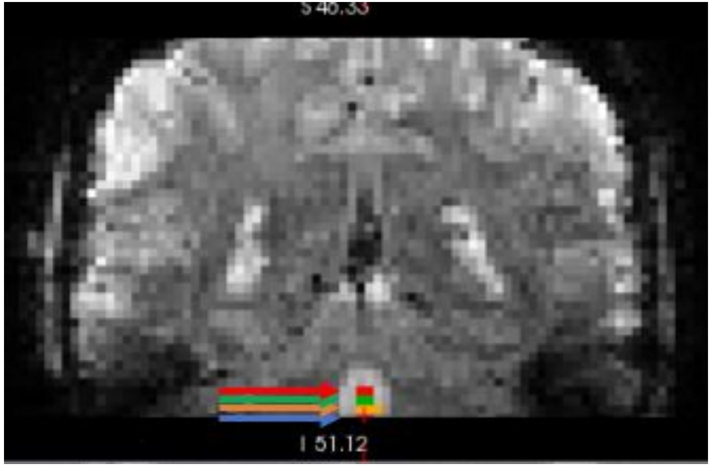
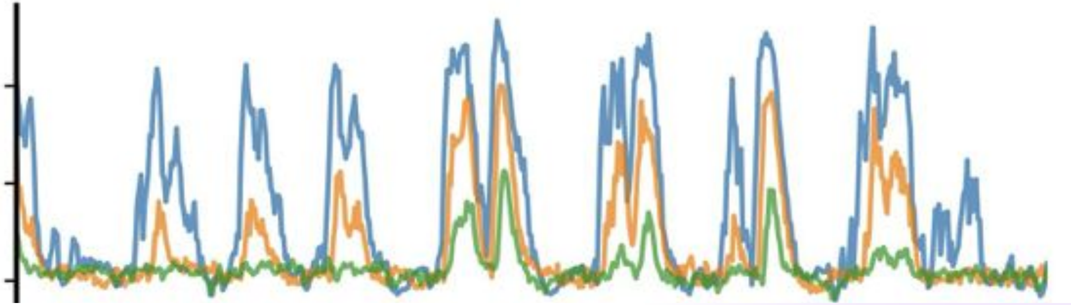
Background + Motivation

- CSF flow in the 4th ventricle has been shown to be influenced by many factors, especially arousal state, evoked sensory stimulation, and systemic physiology
- Fluid flow is an inherently complex physical system, additionally complicated by the MR inflow effect
- Most of the research to date focuses on analyses in the time or frequency domain of spatially averaged signals
- Thus, potential spatial patterns of flow that might change across conditions might be missed by traditional analysis methods

Standard Analysis Method



X slice of brain



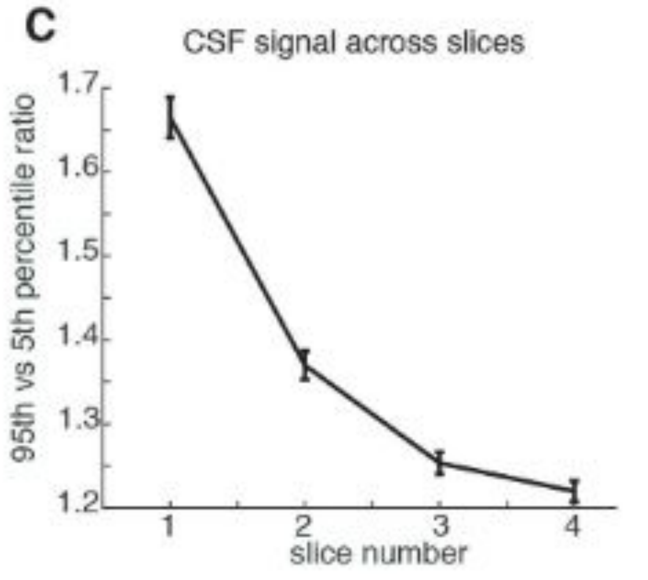
Time series over brain voxels

Are there important spatial patterns?

- We sometimes look at the intensity decay across z-slices, but this method doesn't capture spatial patterns

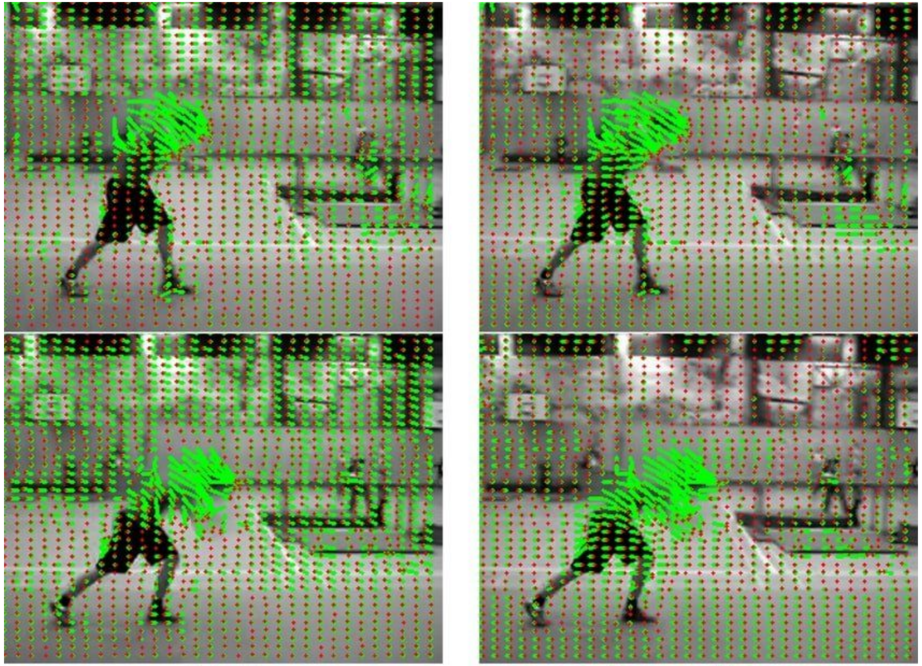
- How can we capture spatio-temporal features of CSF flow in the 4th ventricle?

- In analysis of 2D videos, optical flow algorithm are used to track motion of objects, compute directions of change over time

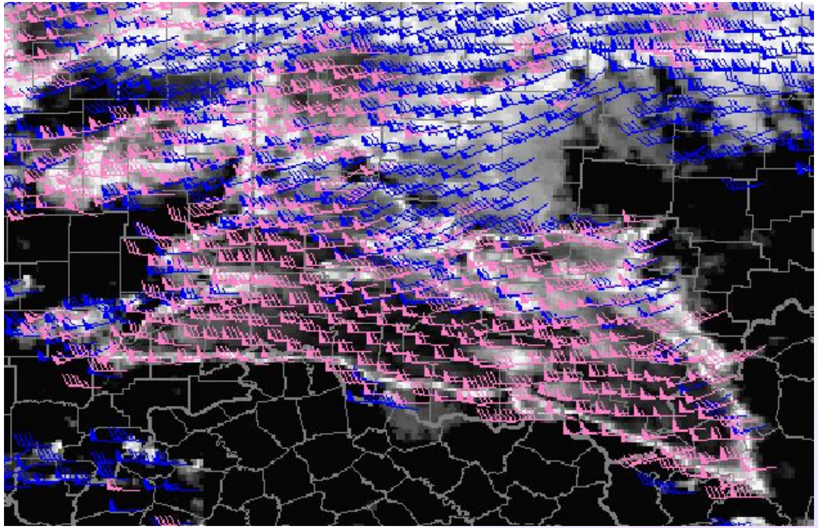


Fultz et al, 2019

Optical Flow Applications



Optical flow vectors   Compensated flow vectors



Dense Optical Flow Algorithm

Description

- We focus on this type since CSF fluid attenuates and cannot be tracked like an object moving through the ventricle
- Computes a “dense” flow field estimation covering all pixels that explains how local image intensities change from frame to frame

$$I(x, y, t) = I(x + \Delta x, y + \Delta y, t + \Delta t)$$

Assuming the movement to be small, the image constraint at $I(x, y, t)$ with Taylor series can be developed to get:

$$I(x + \Delta x, y + \Delta y, t + \Delta t) = I(x, y, t) + \frac{\partial I}{\partial x}\Delta x + \frac{\partial I}{\partial y}\Delta y + \frac{\partial I}{\partial t}\Delta t + \text{higher-order terms}$$

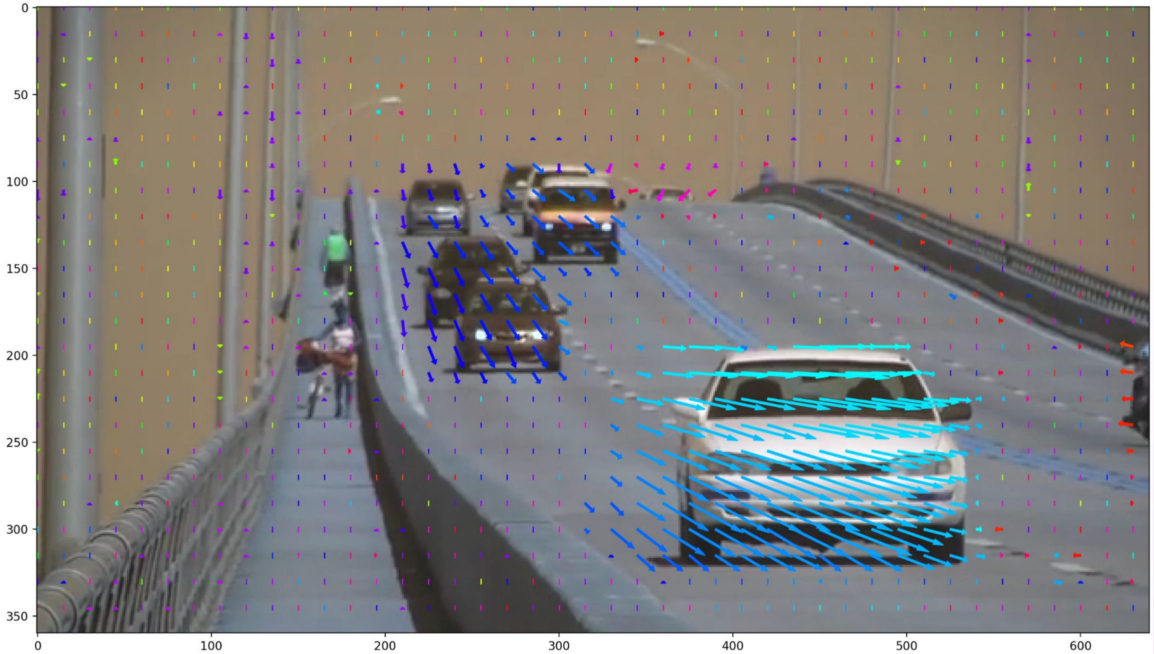
- Gunnar-Farneback implementation

- Flow direction indicated by color

Dense Optical Flow Example

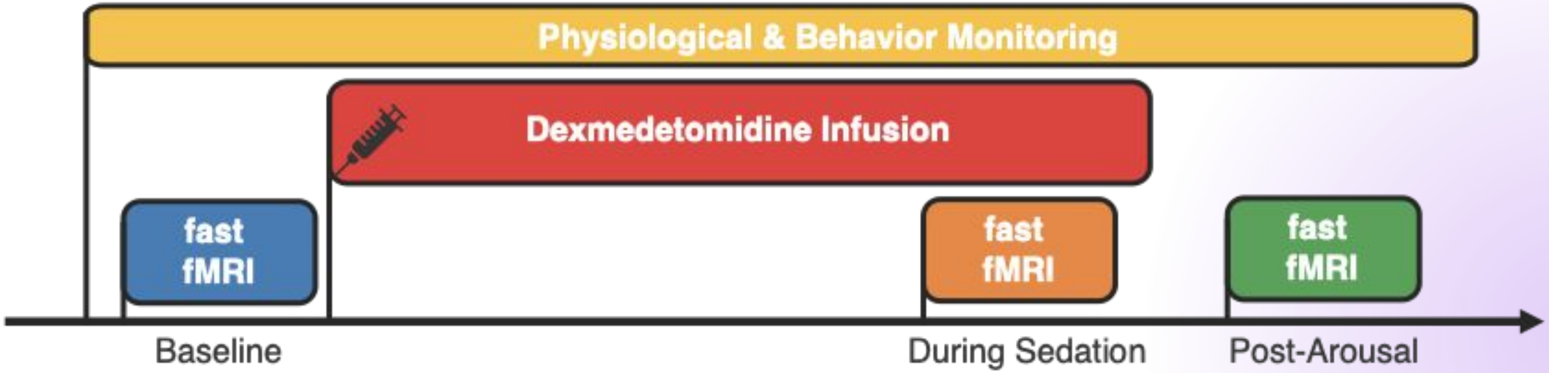
Original Video

Mean Optical Flow Over 51 Frames



Dataset

- 7T fast fMRI sequences collected from participants receiving dexmedetomidine sedation
- 580 volumes, 0.499s TR, 2mm isotropic voxels
- Data preprocessed with slice timing correction and motion realignment



Methods

DATASET PARAMETERS:

96 96 96 580
[X, Y, Z, time frame]

↓

OVER ALL TIME STAMPS t = 0 → 578

- get X-slice of time frame t and t+1
- calculate the dense optical flow between the two time frames

↓

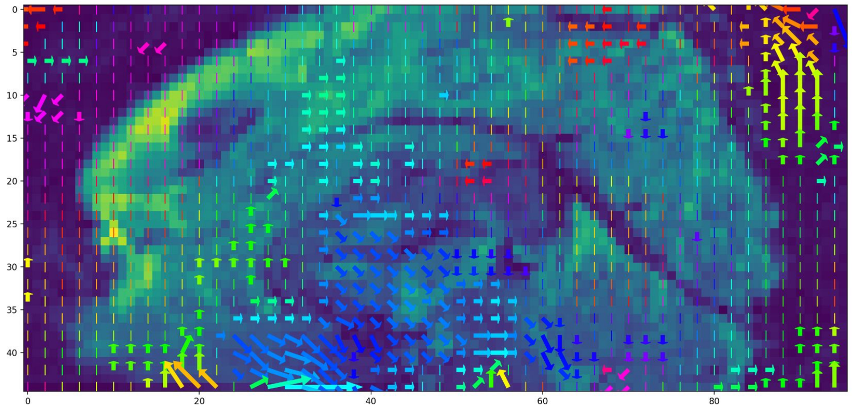
PLOT WITH ARROWS:

- plot arrows in Cartesian coordinates on flow changes
- use color also as indication of direction

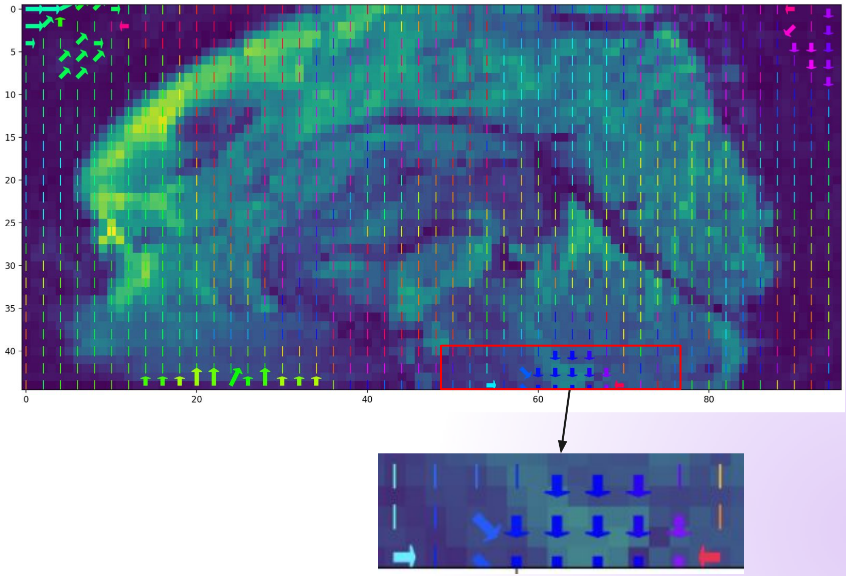
Arrow Color Direction:

One Calculation vs. Averaged

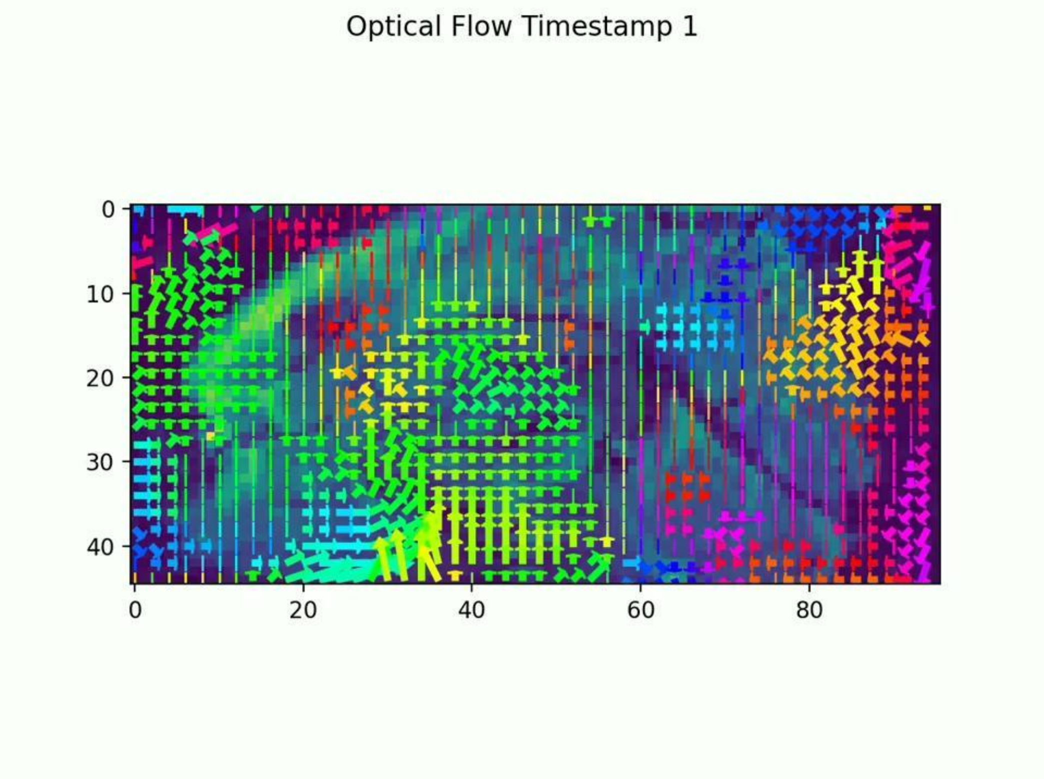
One Frame



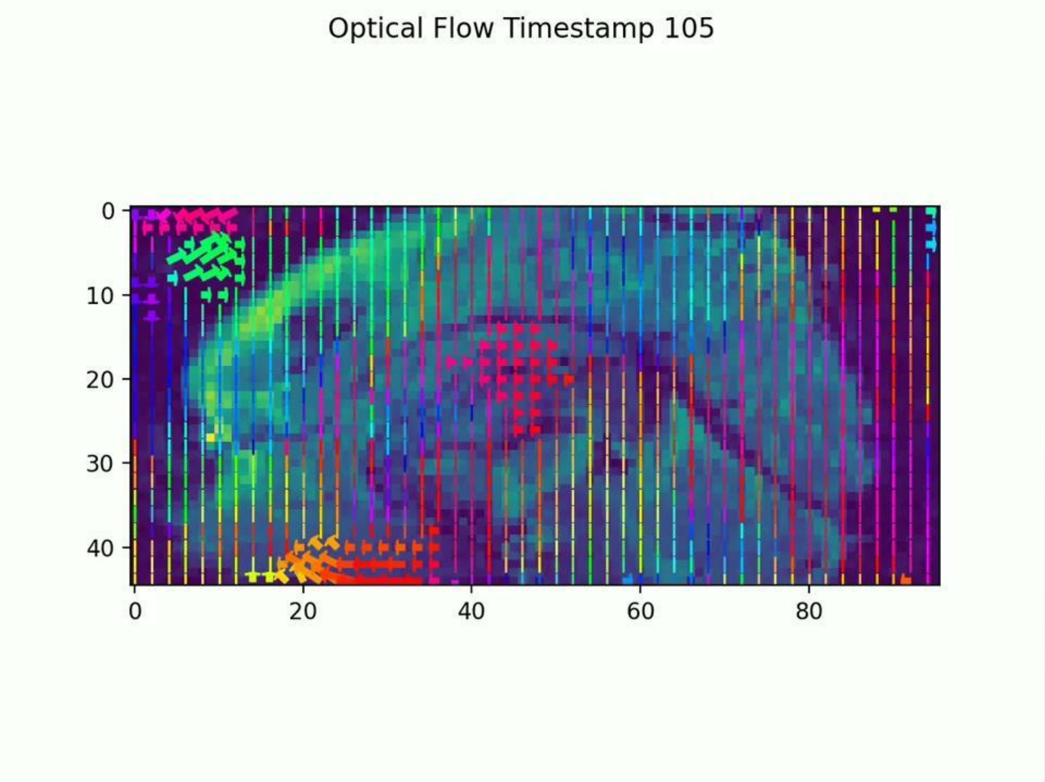
Averaged Frames



Optical Flow (All Time Stamps)



Smoothed Over Time (3 Time Stamps)



Angle Distributions Method

DATASET PARAMETERS:

96 96 96 580
[x, y, z, time frame]

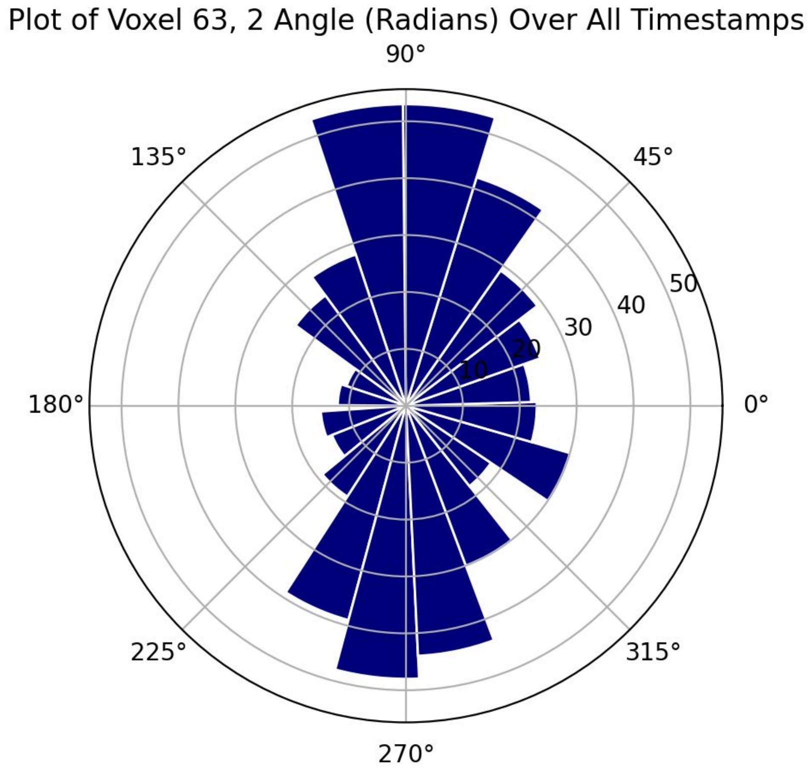
OVER ALL TIME STAMPS $t: 0 \rightarrow 578$

- get X-slice of time frame t and t+1
- calculate the dense optical flow between the two time frames

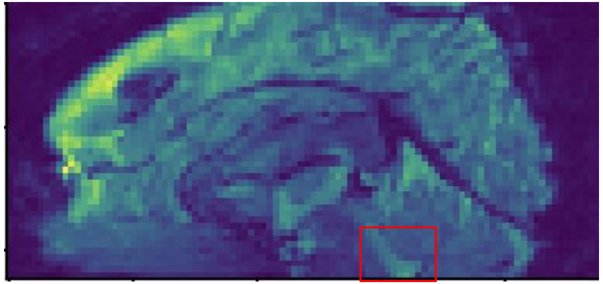
CALCULATE ANGLES

- extract x & y optical flow vectors @ voxels
- calculate the angle (arctan)
- plot angle distributions of flow over a voxel over all time frames

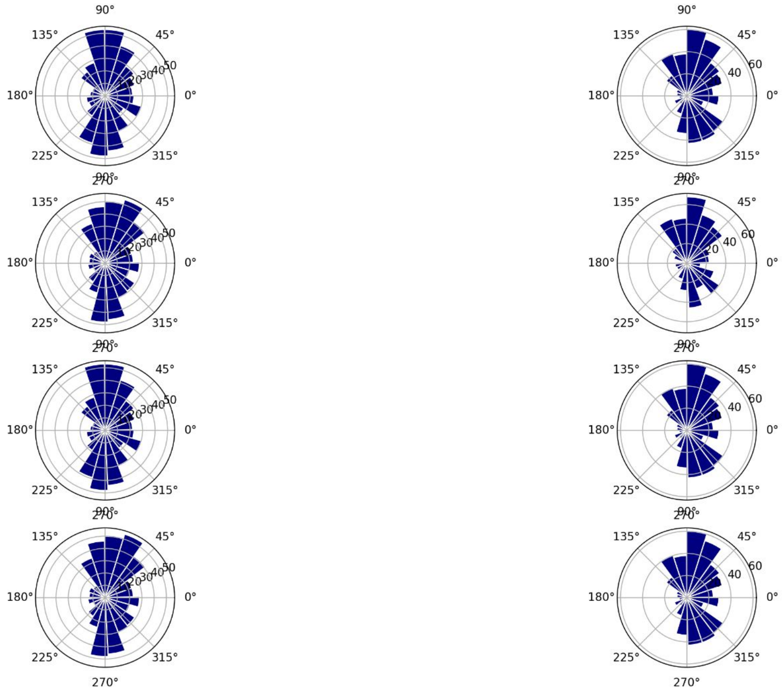
Example Ventricular Voxel



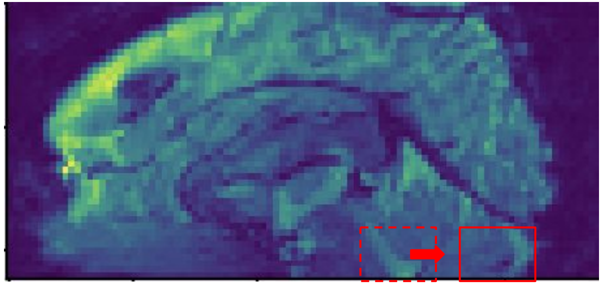
4th Ventricle Mask Voxels

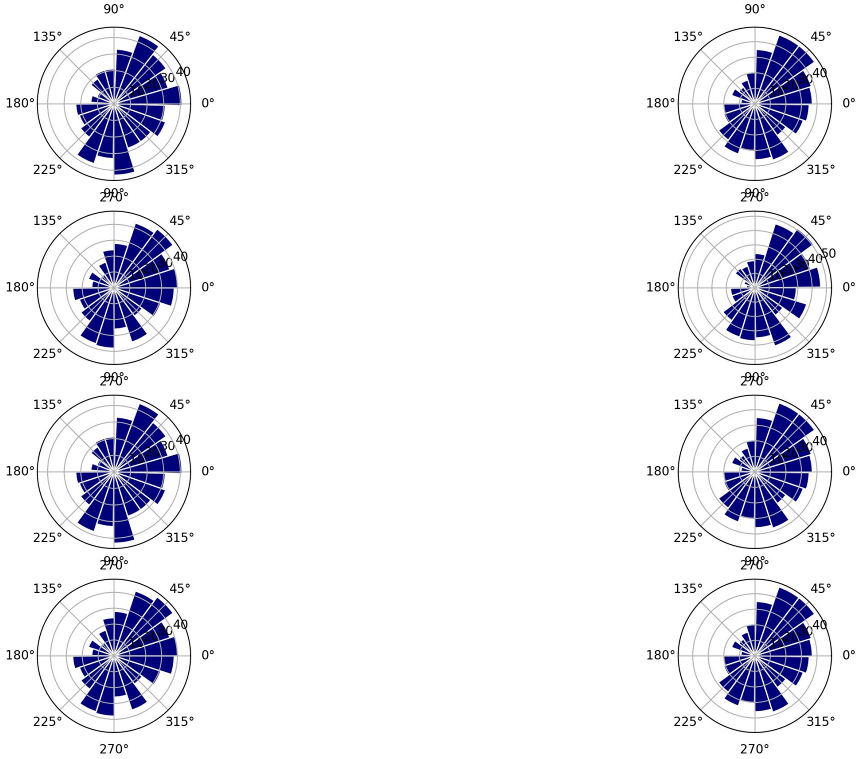


Plot of All X-Axis Masked Voxel Angles (Degrees) Over All Timestamps



“Control” Cerebellum voxels

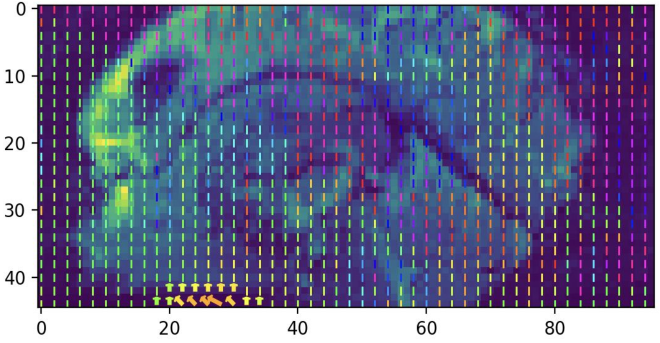




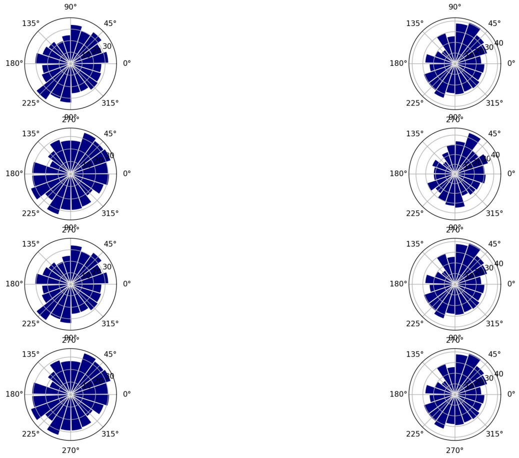
Comparing Pre vs Dex Scan

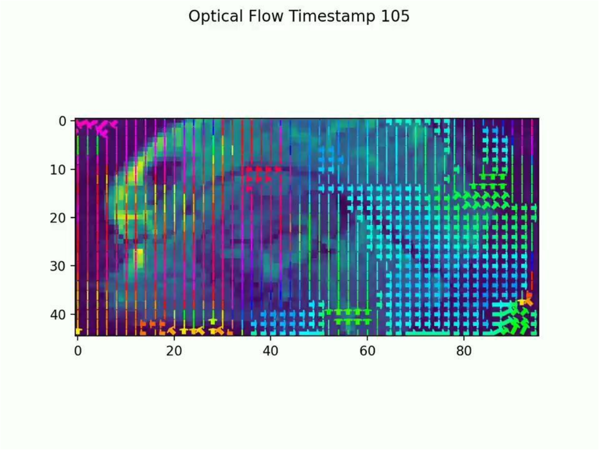
- Different dataset (Pre)
- Data seems more sporadic, and flow

Mean Flow Over X Slice



Ventricle Voxel Angles





Next Steps

- Continue to explore what the output of this algorithm can show us about spatio-temporal features of CSF flow in the 4th ventricle

- Model 3D optical flow

- Continue to explore different datasets and evaluate what factors make the data a good candidate for optical flow algorithms
  - Compare across brain states (sedation, natural sleep, drowsiness, etc)
  - Compare across different populations or conditions (age, mood, sleep deprivation)

```
void cv::calcOpticalFlowFarneback ( InputArray        prev,
                                    InputArray        next,
                                    InputOutputArray  flow,
                                    double            pyr_scale,
                                    int               levels,
                                    int               winsize,
                                    int               iterations,
                                    int               poly_n,
                                    double            poly_sigma,
                                    int               flags
                                  )
```

Python:

```
cv.calcOpticalFlowFarneback( prev, next, flow, pyr_scale, levels, winsize, iterations, poly_n, poly_sigma, flags ) -> flow
```

Citations

- https://docs.opencv.org/3.4/d4/dee/tutorial_optical_flow.html
- https://viso.ai/deep-learning/optical-flow/#elementor-toc__heading-anchor-4
- Fultz NE, Bonmassar G, Setsompop K, et al. Coupled electrophysiological, hemodynamic, and cerebrospinal fluid oscillations in human sleep. *Science*. 2019;366(6465):628-631. doi:10.1126/science.aax5440

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