Discovering the intrinsic structure of ciliary motion

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Goal

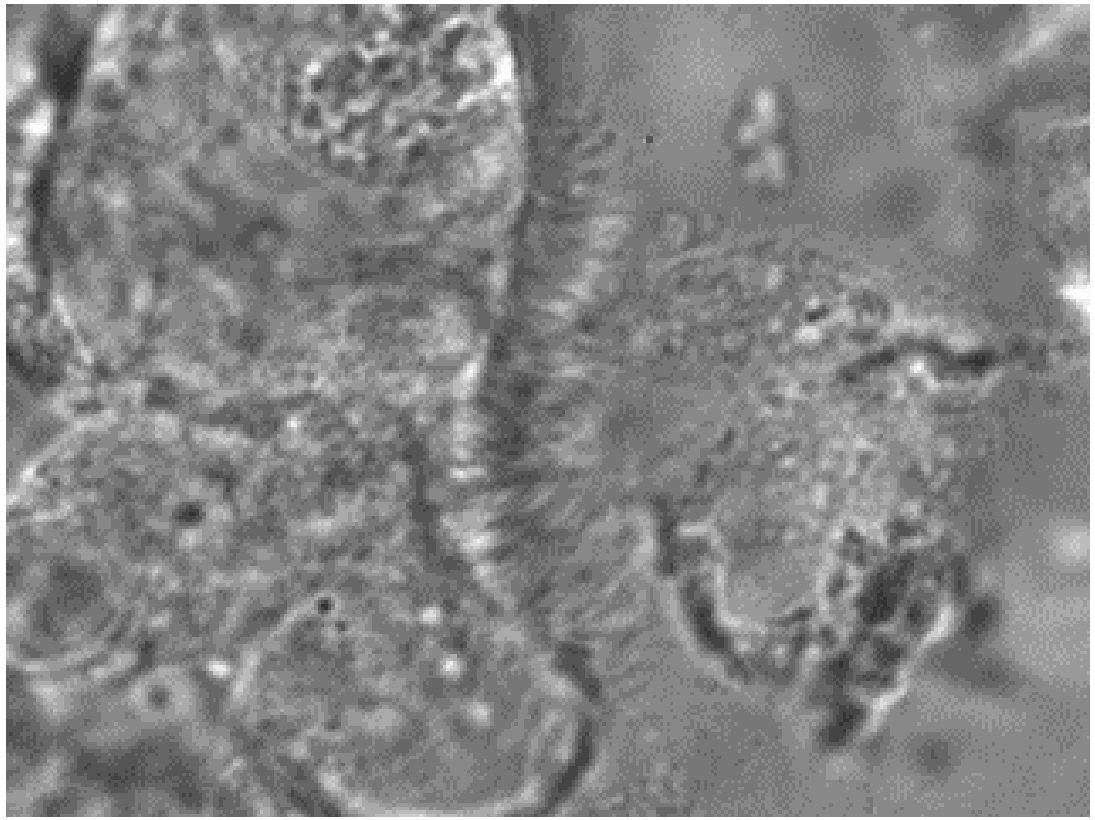
Quantify ciliary motion in terms of motion primitives via clustering and

discover motion primitives indicative of abnormal ciliary motion

Types of Cilia

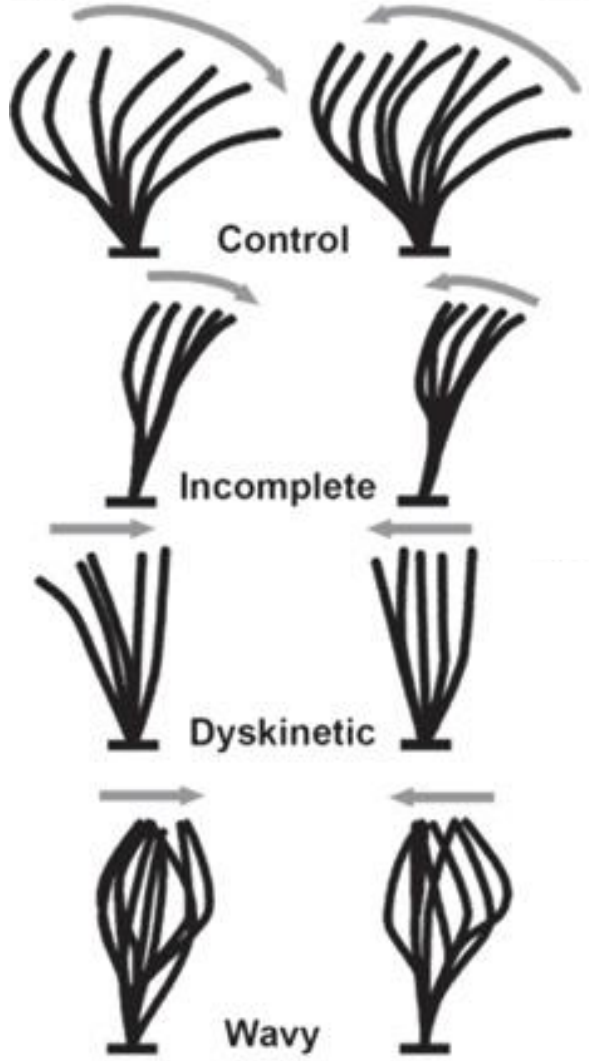
- Motile or immotile

- Motile cilia in respiratory tract beat in two steps
  - Power stroke
  - Recovery stroke



Ciliary Motion - Ciliopathies

- Sinopulmonary disease
- Heterotaxy/Kartagener's
- Congenital heart disease



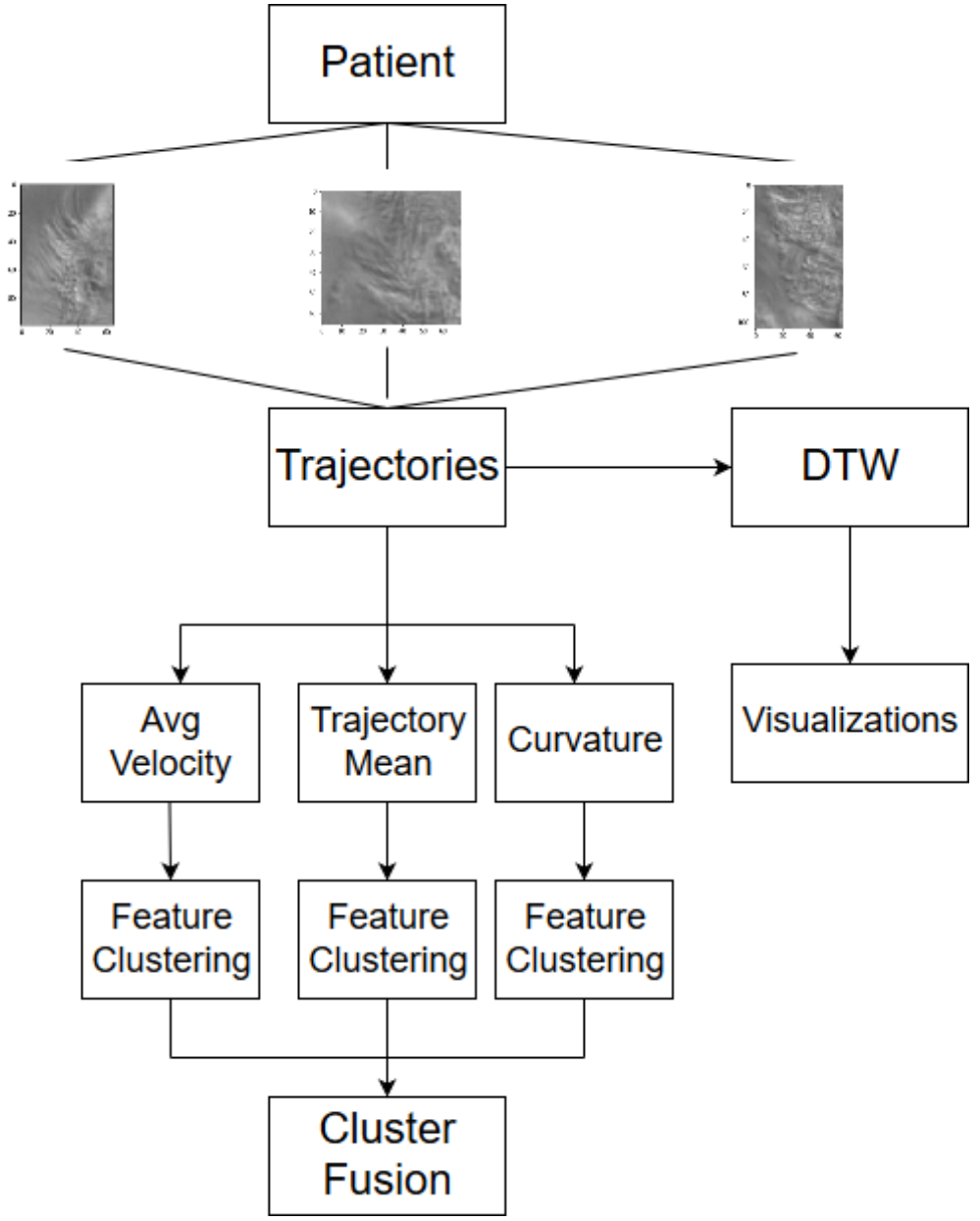
Shannon P. Quinn, et al. Automated identification of abnormal respiratory ciliary motion in nasal biopsies. Science Translational Medicine, 7(299):299ra124{299ra124, 2015.

Manual detection of abnormal ciliary motion

- Visual examination by experts in detecting ciliary beat abnormalities
- Electron microscopy
- Ciliary beat frequency

Shannon P. Quinn, et al. Automated identification of abnormal respiratory ciliary motion in nasal biopsies. Science Translational Medicine, 7(299):299ra124{299ra124, 2015.

Approach

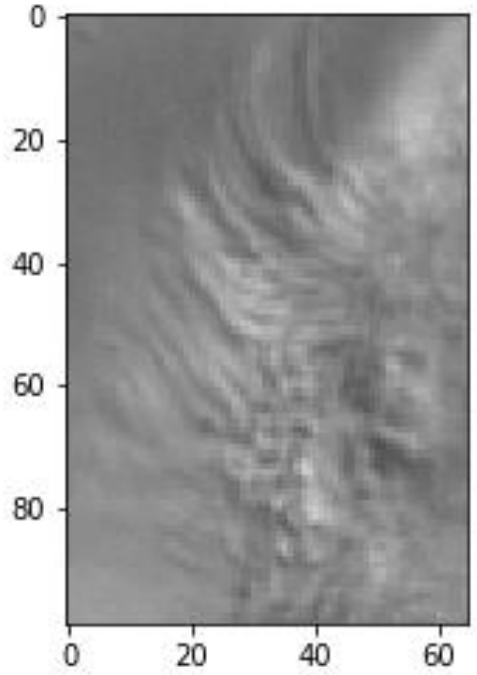

Patient
Trajectories
DTW
Avg Velocity
Trajectory Mean
Curvature
Visualizations
Feature Clustering
Feature Clustering
Feature Clustering
Cluster Fusion

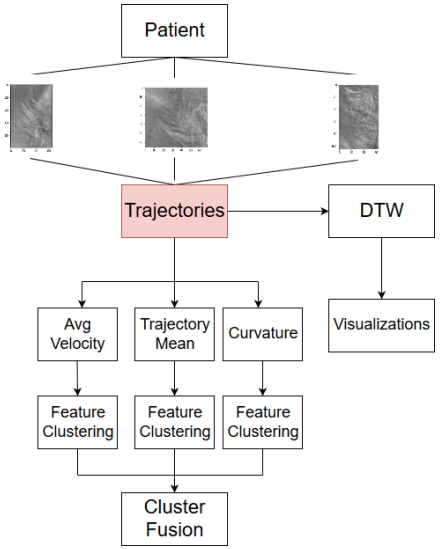
Dataset

- 78 patients
- Nasal brush biopsy
- Labeled by clinicians on a discrete scale from 1 – 4

Optical Flow

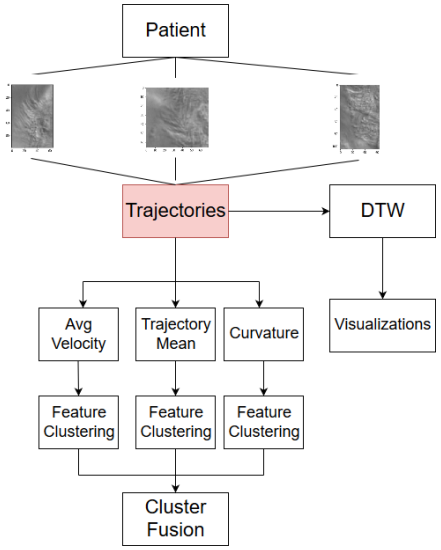
- Apparent motion of objects between two frames
- Horizontal change and vertical change





Trajectories

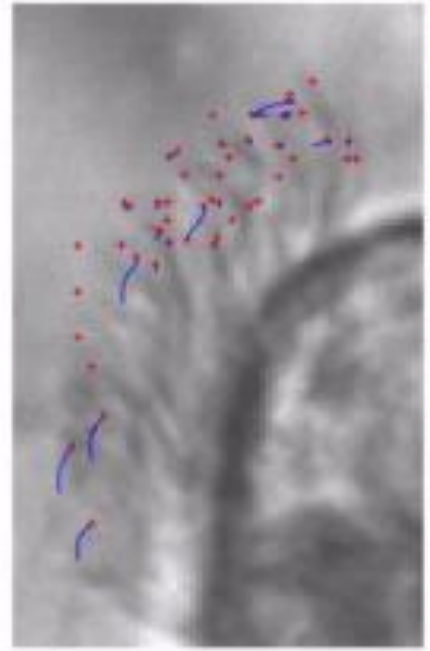
- Describe ciliary motion as trajectories
- Dense trajectories



$$P_{t+1} = (x_{t+1}, y_{t+1}) = (x_t, y_t) + (M * \omega_t)|_{(x_t, y_t)}$$

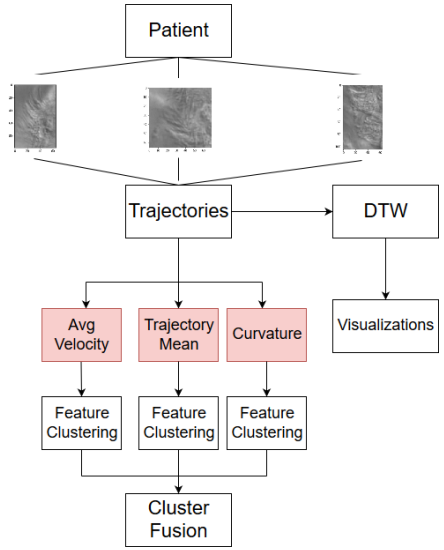
$$P_1, P_2, P_3, \ldots, P_M$$

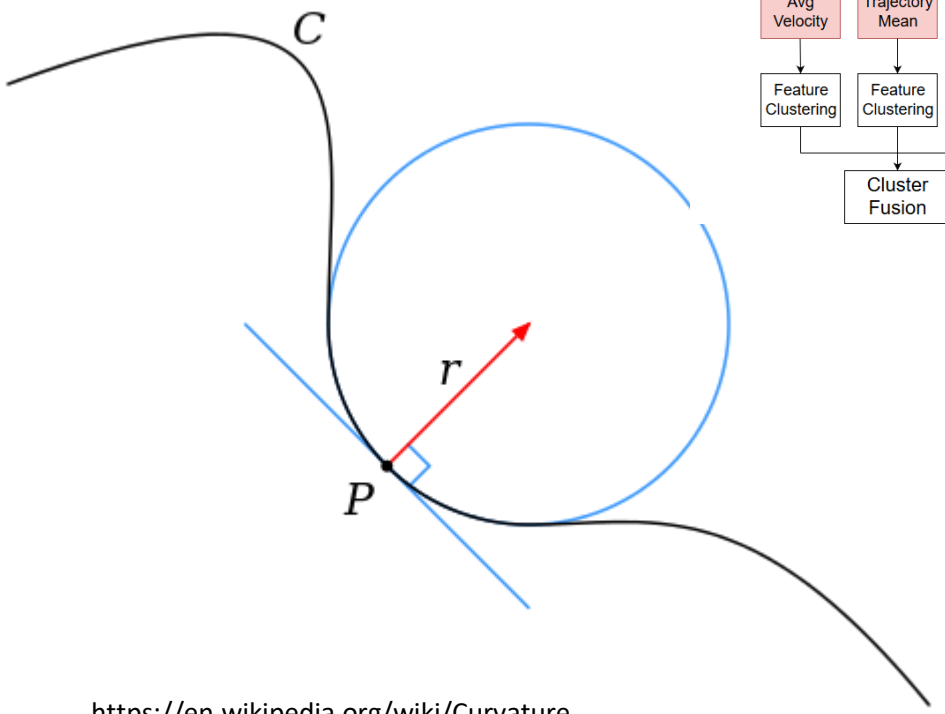
Wang, H., Kläser, A., Schmid, C. et al. Int J Comput Vis (2013) 103: 60. https://doi.org/10.1007/s11263-012-0594-8



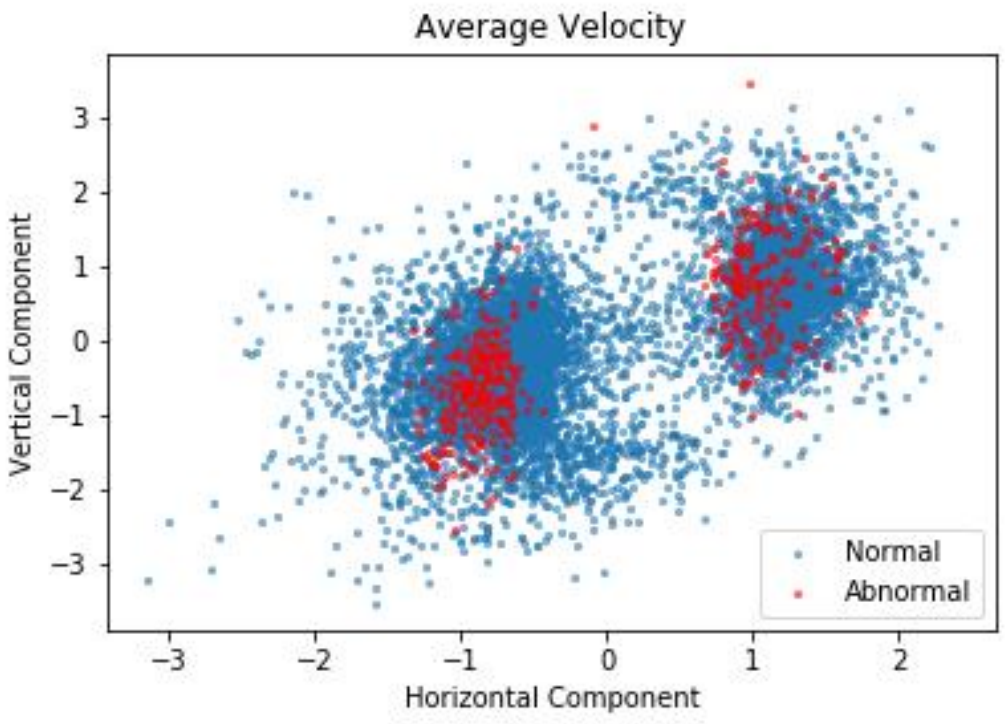
Feature Engineering

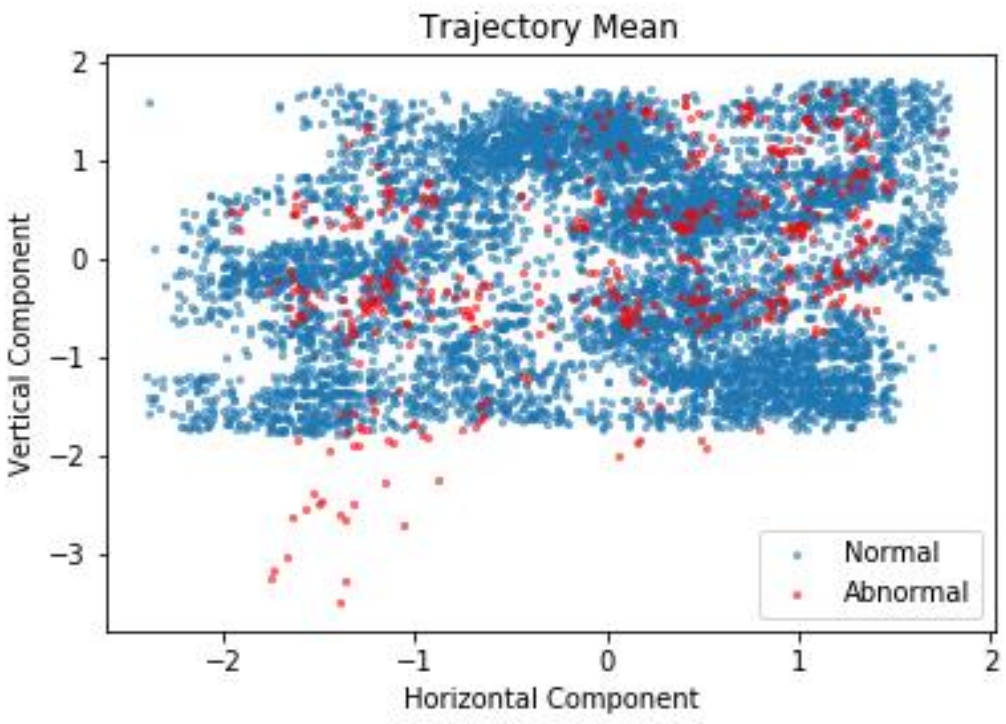
- Average velocity
- Trajectory mean
- Curvature





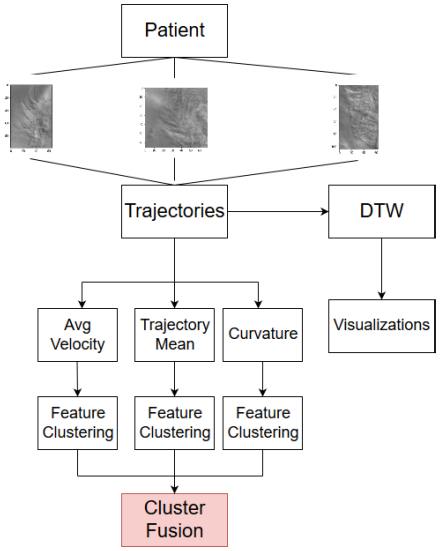
https://en.wikipedia.org/wiki/Curvature





Features – average velocity/trajectory mean

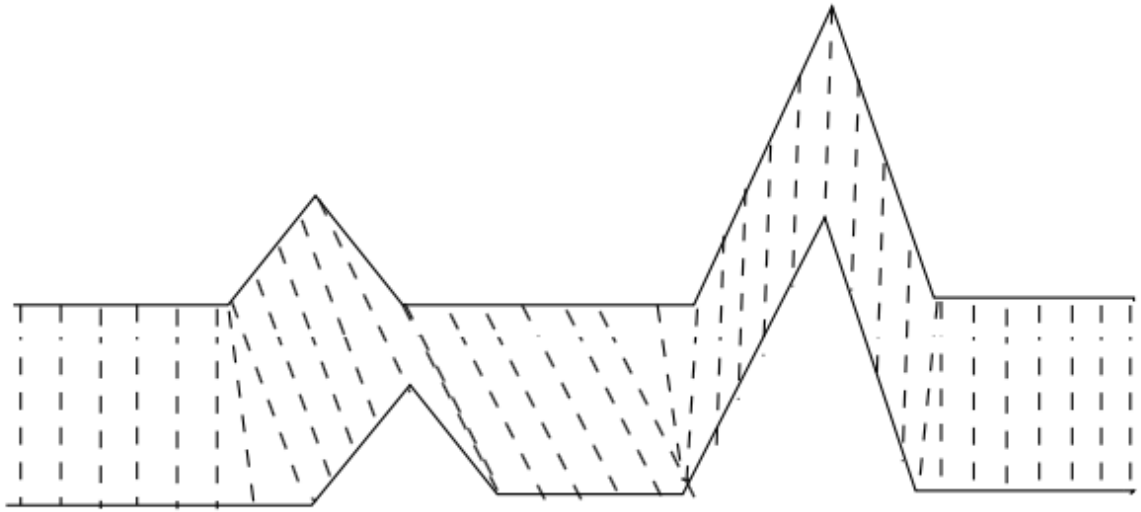
Clustering



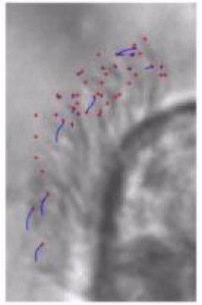
- dbscan for each feature space
- Cluster fusion
  - Pick median feature
  - Combine clusters by picking largest intersection with median feature

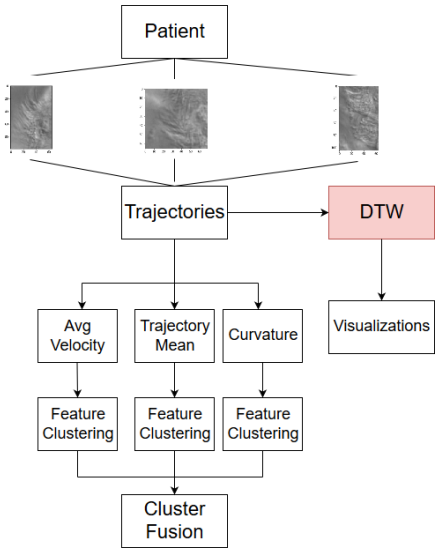
N. Anjum and A. Cavallaro, "Multifeature Object Trajectory Clustering for Video Analysis," in *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 18, no. 11, pp. 1555-1564, Nov. 2008.

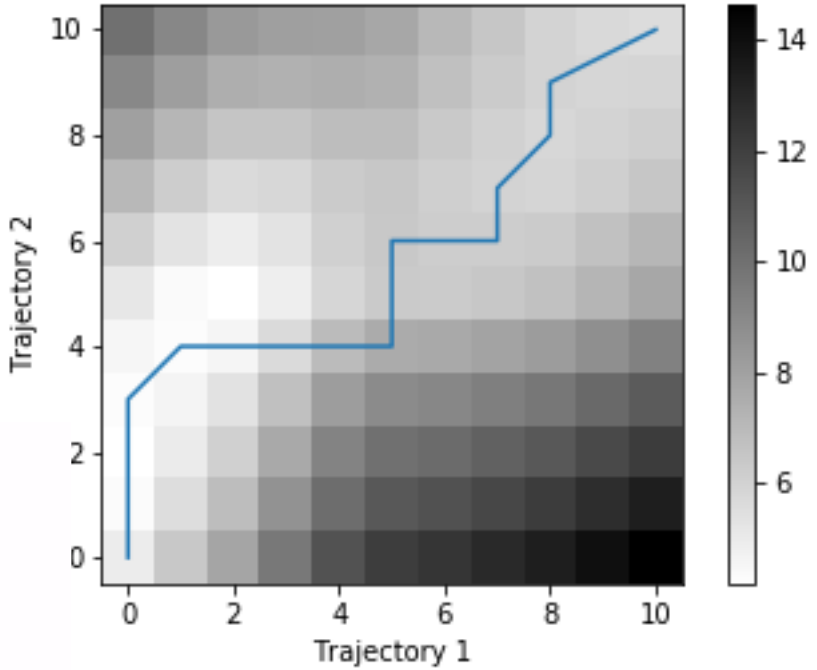
Dynamic time warping



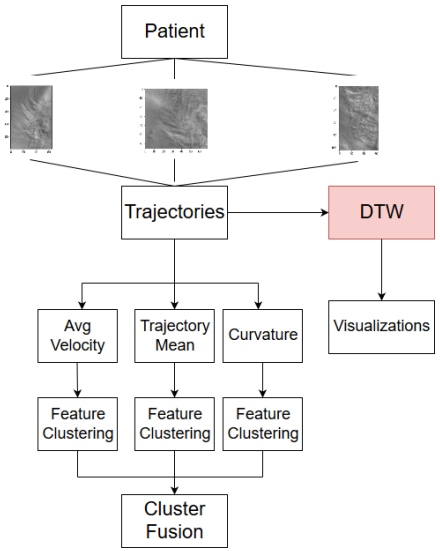
https://en.wikipedia.org/wiki/Dynamic_time_warping

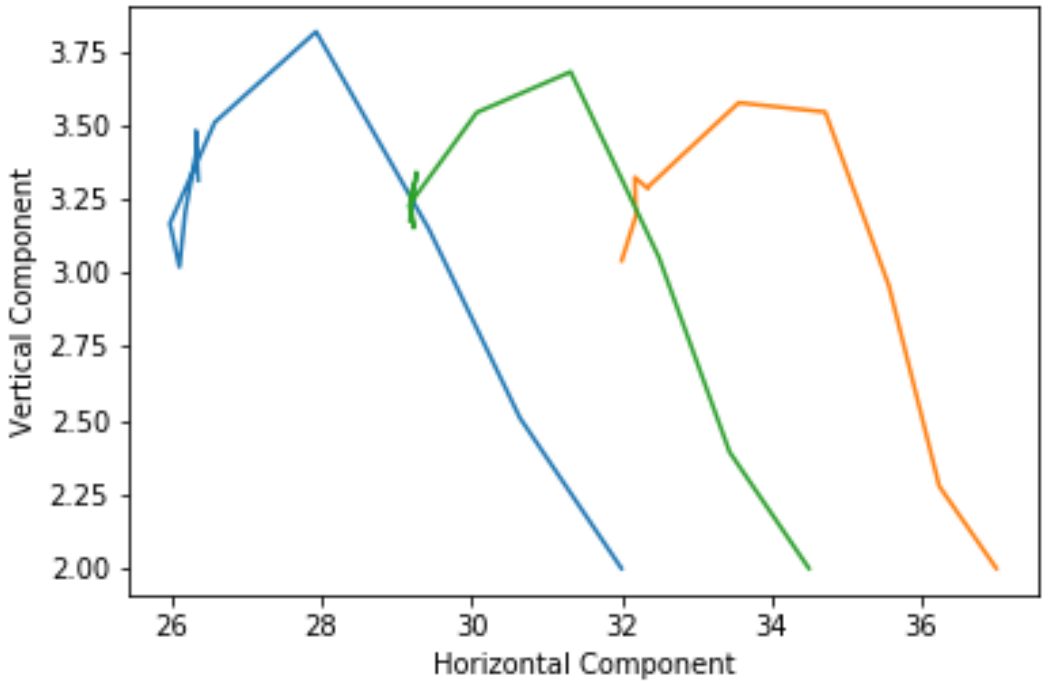


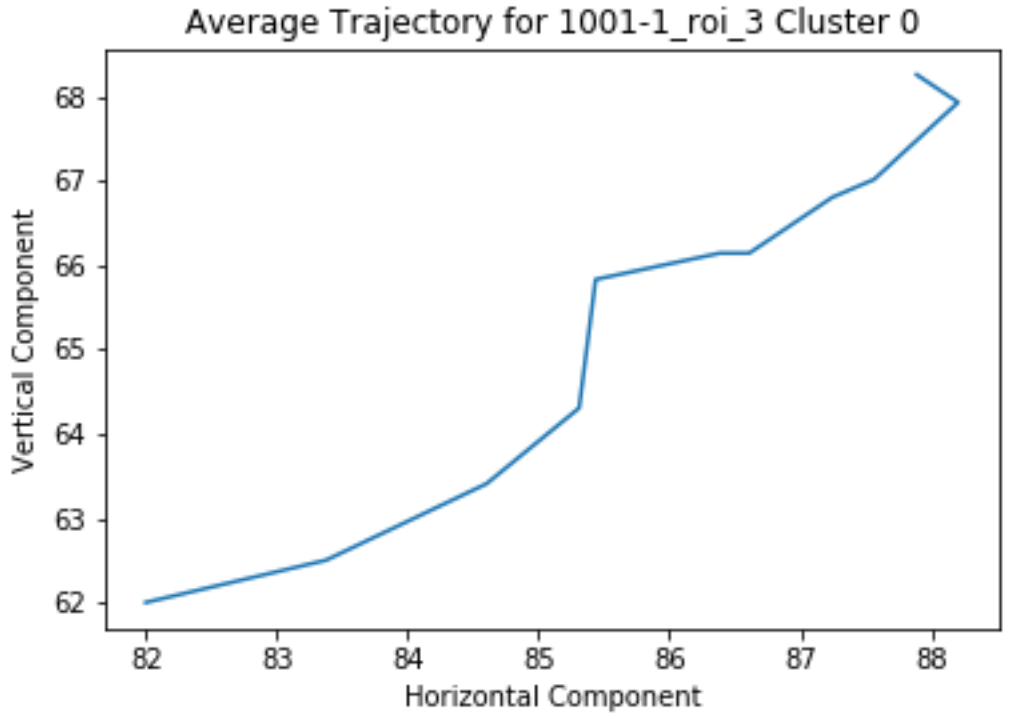


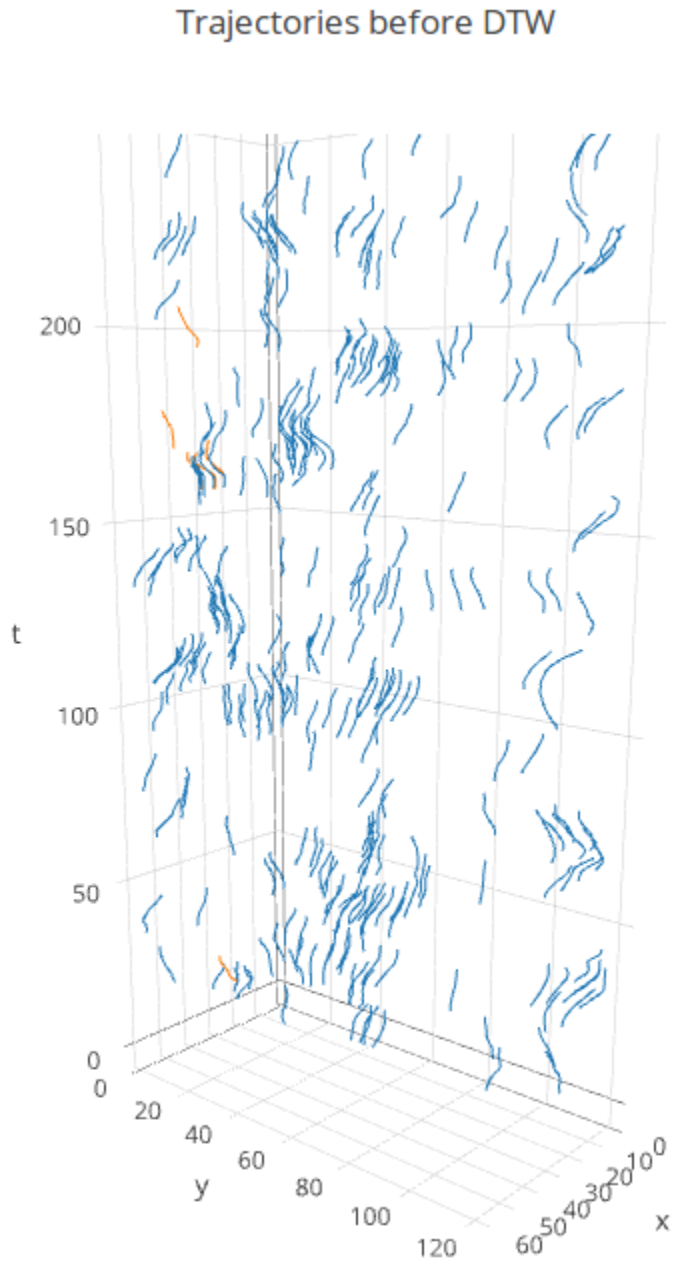


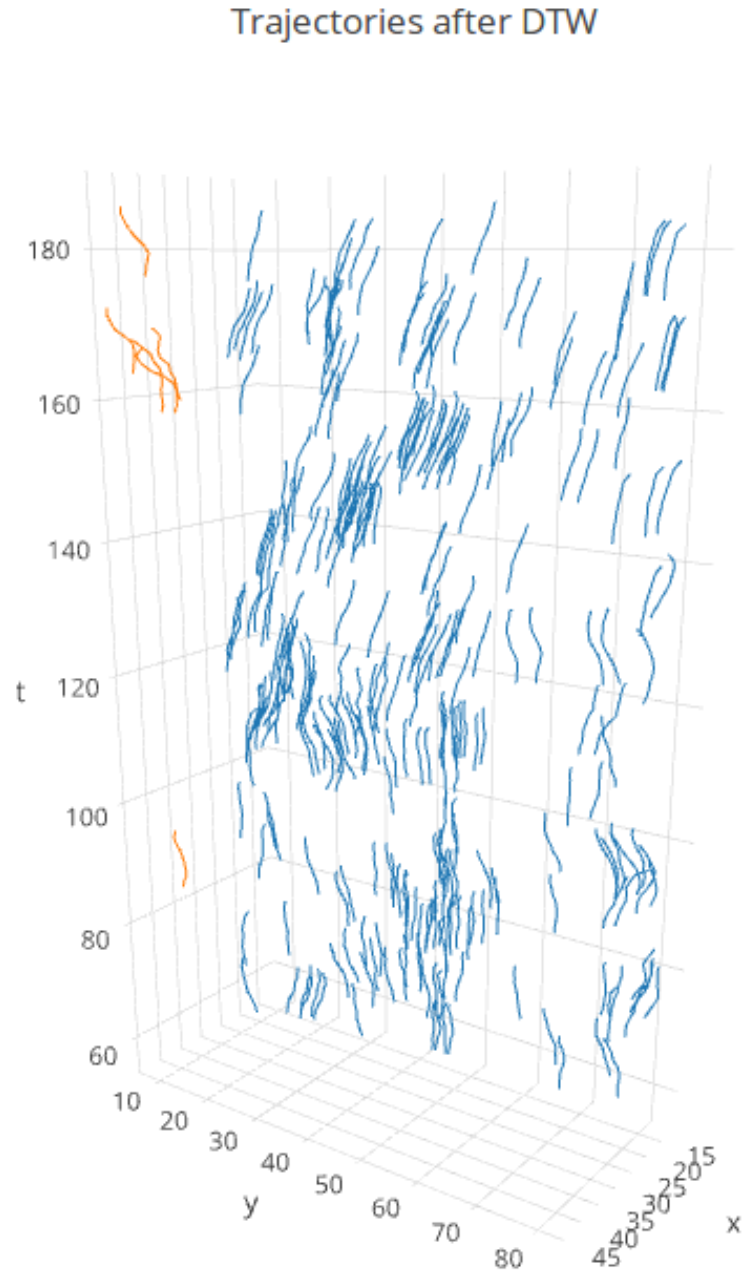
Dynamic time warping – avg trajectory





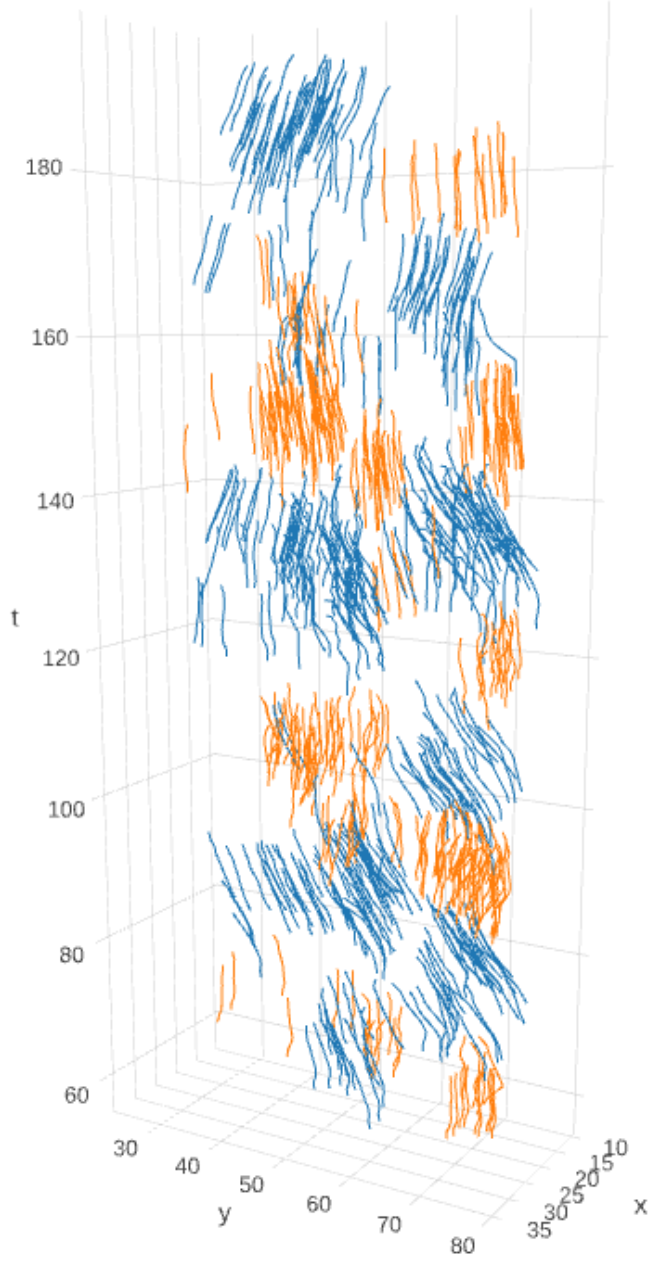



Trajectories before DTW
200
150
t
100
50
0
0
20
40
60
80
100
120
y
0
10
20
30
40
50
60
x


Trajectories after DTW
180
160
140
t
120
100
80
60
10
20
30
40
50
60
70
80
y
15
20
25
30
35
40
45
x

Clustering – trajectories average velocity

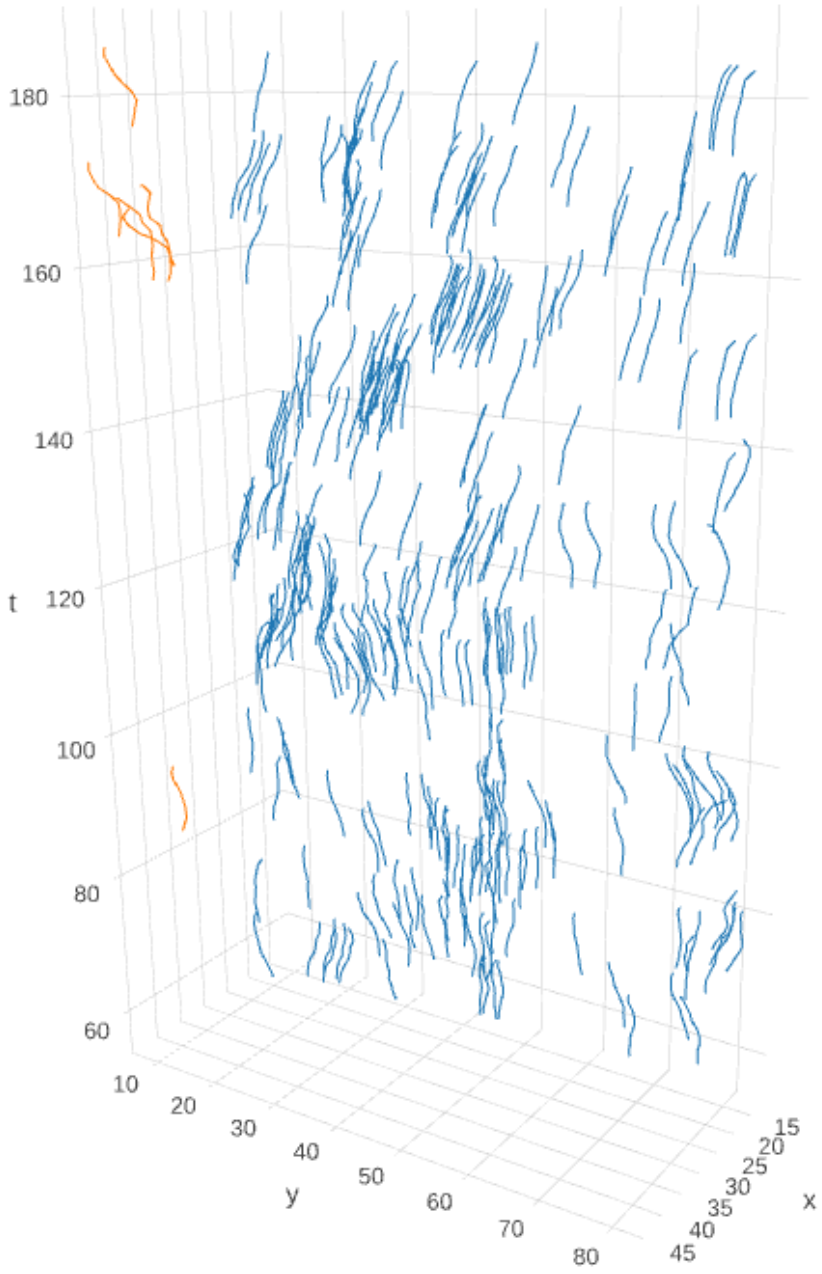
- Trajectory points (x, y, t)
- Labeled according to average velocity clustering
- Location and velocity related



Clustering – final trajectories

- Trajectory visualization

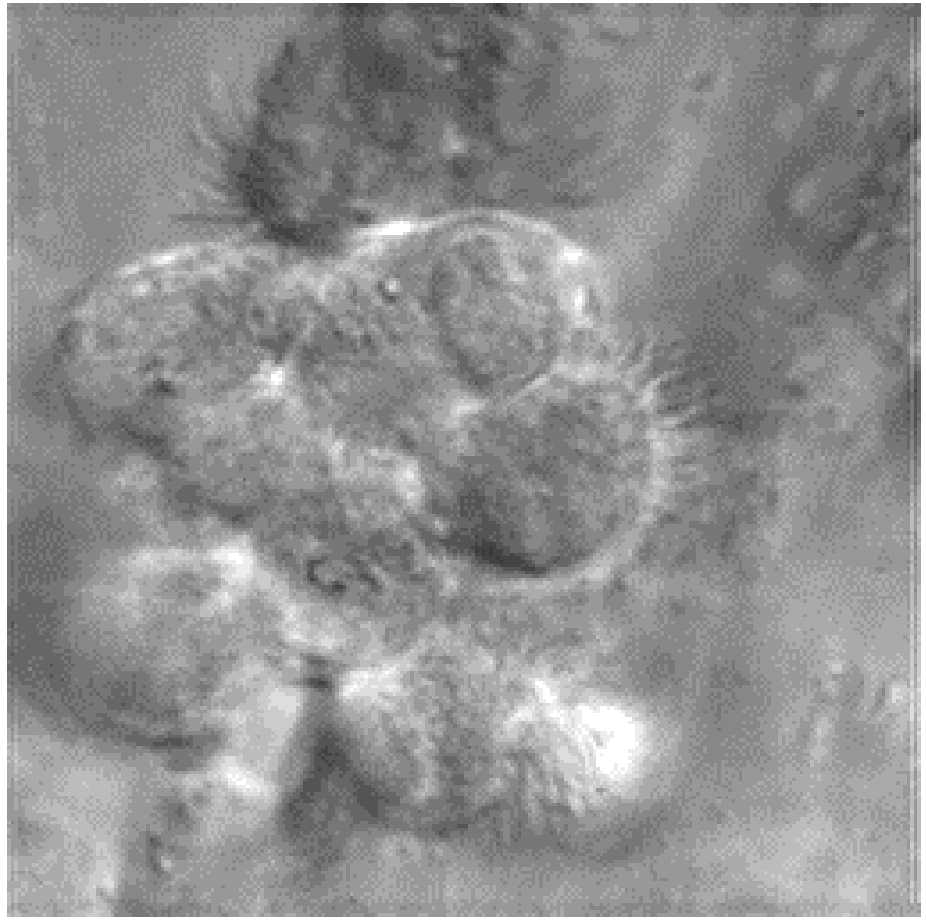
- Labeled according to their final cluster



Cilia ratio in each cluster

Label	Cluster 0	Cluster 1	Cluster 2	Cluster 3
1 – most normal	0.846	0.698	0.513	0.000
2	0.000	0.000	0.000	0.000
3	0.043	0.067	0.128	0.000
4 – most abnormal	0.110	0.235	0.358	1.000

- 4 clusters discovered – intrinsic motion patterns
- Little variability in abnormal motion
- Stronger variability in normal motion
  - Historically categorized as power/recovery stroke



Future Directions

- Show clusters to clinicians to refine clusters
- Use topic modeling for cluster ratio

Acknowledgements

- Mentor - Dr. Chakra Chennubhotla
- Maurice Marx
- Dr. Sherif Khattab
- NSF
- You!

- Questions?