Supervised Algorithm to Accurately Segment Brain Vasculature

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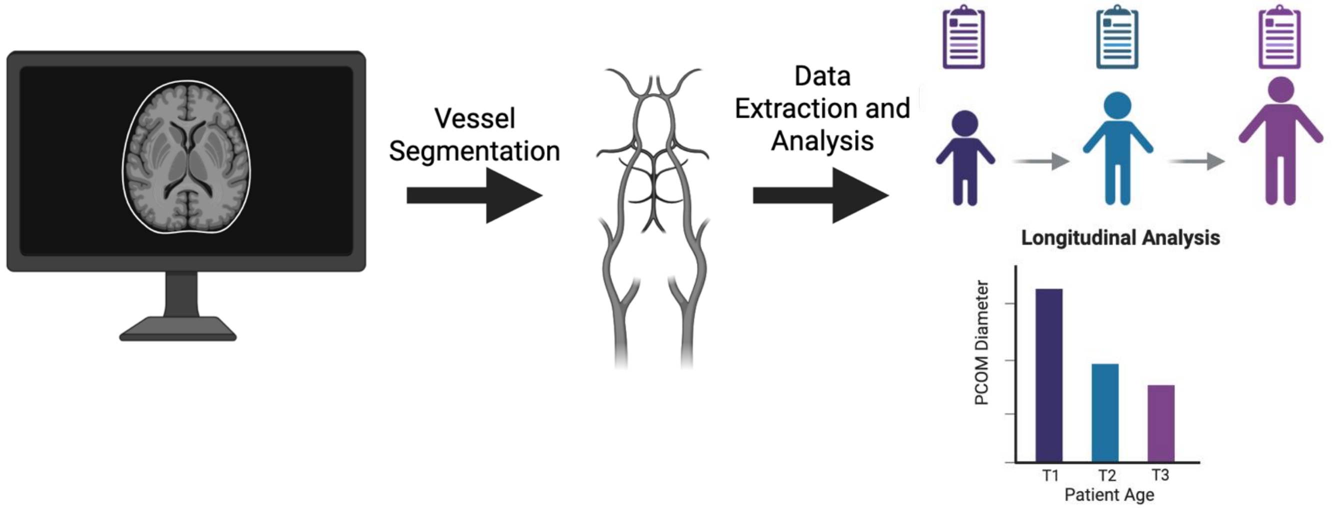
John Lorence[2], Satyaj Bhargava[2], Benjamin Cohen[2], Anisha Virmani[4], Isaiah Jefferson III[2], Therese Nneji[2], Minjie Wu[2,3], Howard Aizenstein[2,3], George Stetten[1,2].

[1]Robotics Institute, Carnegie Mellon University; [2]Department of Bioengineering, [3]Department of Psychiatry, [4]Department of Psychology, University of Pittsburgh

Importance of Vessel Segmentation

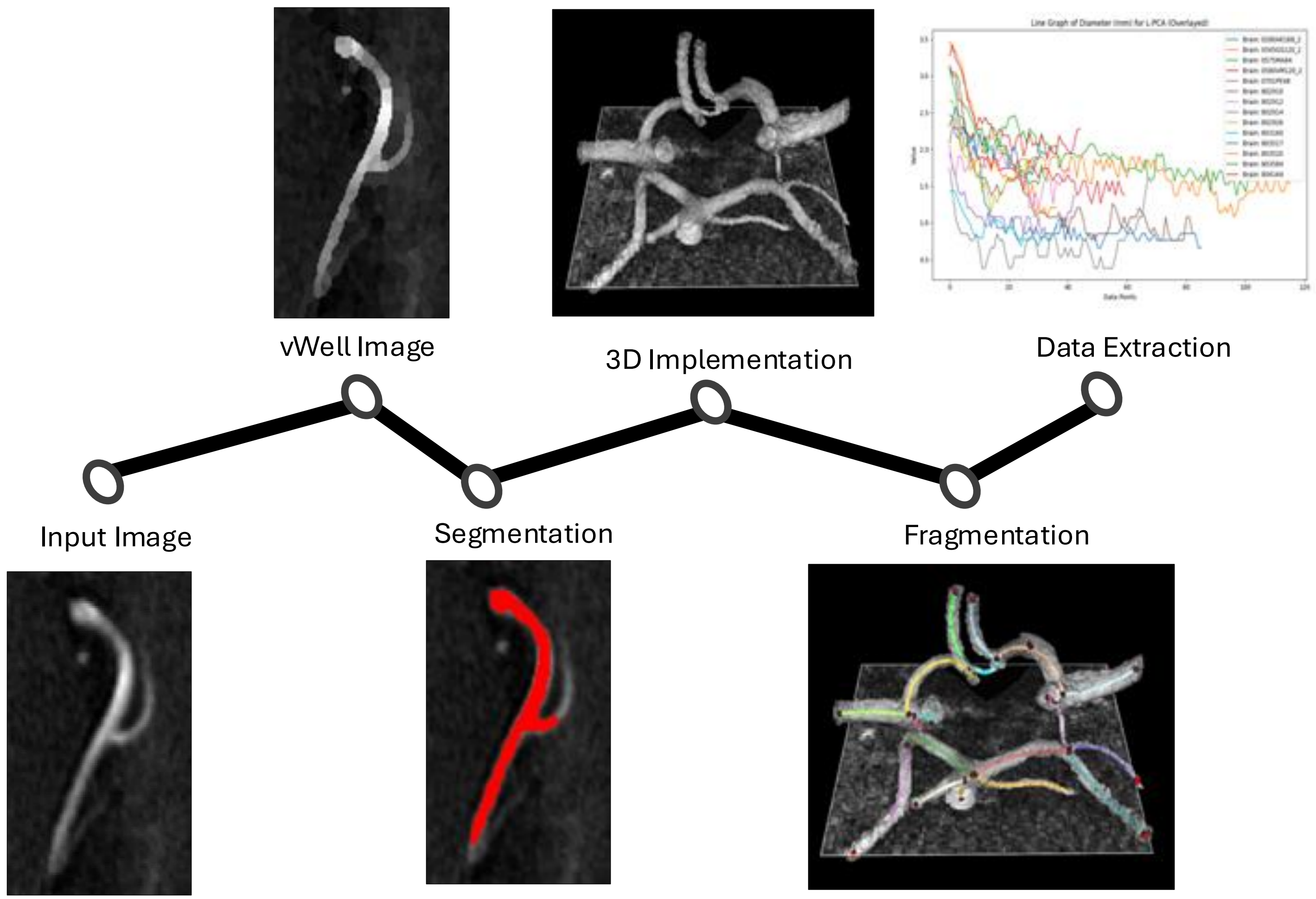
- Brain vasculature increasingly recognized in etiology of neurodegenerative illnesses such as Alzheimer's
- Image segmentation isolates vessels from brain scans for computer analysis but remains an ongoing challenge



- Current approaches involve leveraging machine learning, but remain difficult due to lacking training data
- Manual segmentation is the gold standard, but remains time consuming and subjective

Integrating Human and Computer Supervision

- Develop a novel algorithm for accurate and verifiable segmentation and analysis for TOF-MRA images



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VIA

vWell Image

- "Variance Image" determined by 3x3 kernels
- Voxels point adjacently to neighbor with lowest variance
- Retraced homogenous regions dubbed 'vWells'

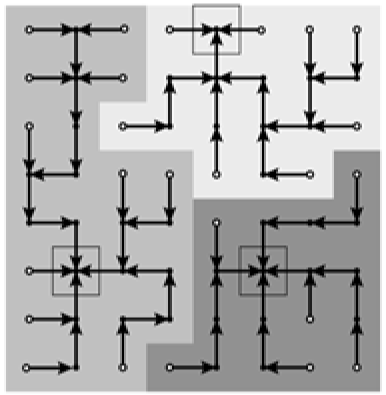
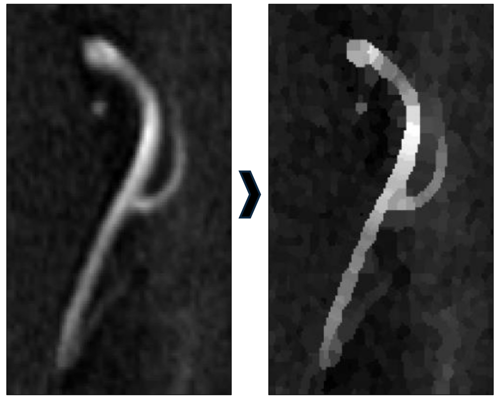


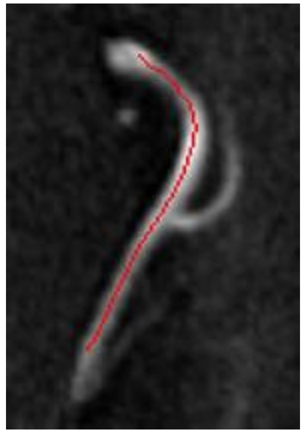
Image of descending variance graph



2D input image processed into vWells.

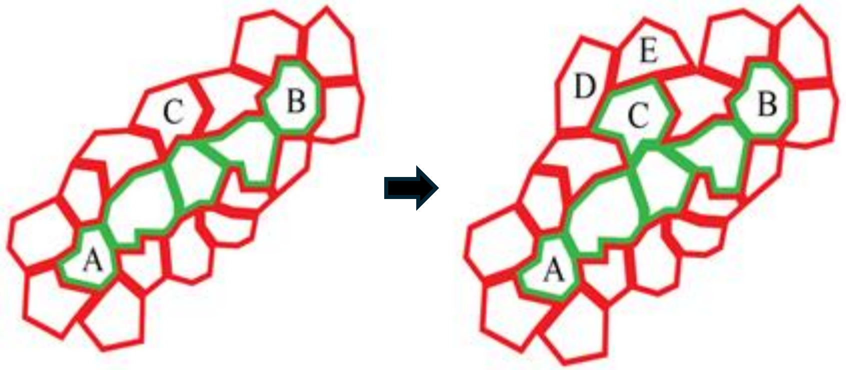
Pathfinding

- vWells treated as graph structure
- Greedy algorithm finds best path
- Combination of Dijkstra's & A-star algorithms
- Minimizes difference between adjacent vWells from start to end.



Shortest path found between two placed points

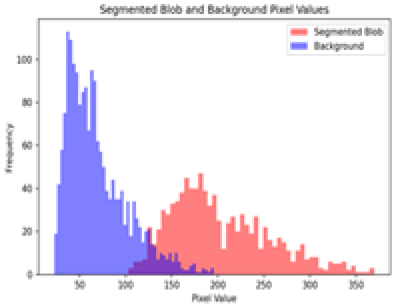
Region Grow



- Initial shortest path = blob
- Iterates and considers each background, picking best
- T-score difference maximized

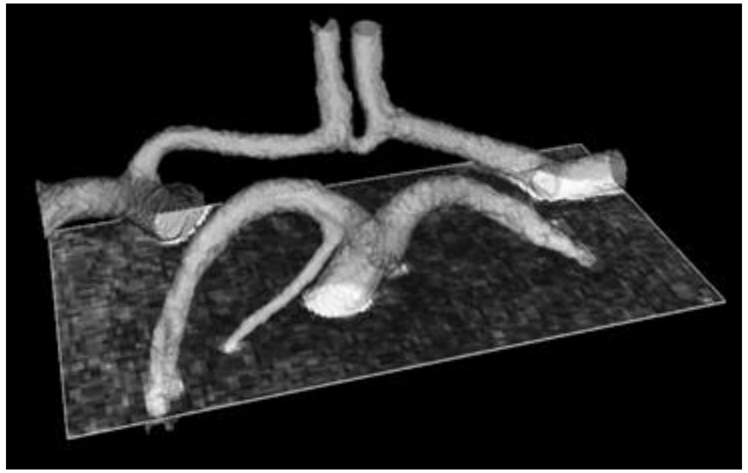
"Blob"

"Background"

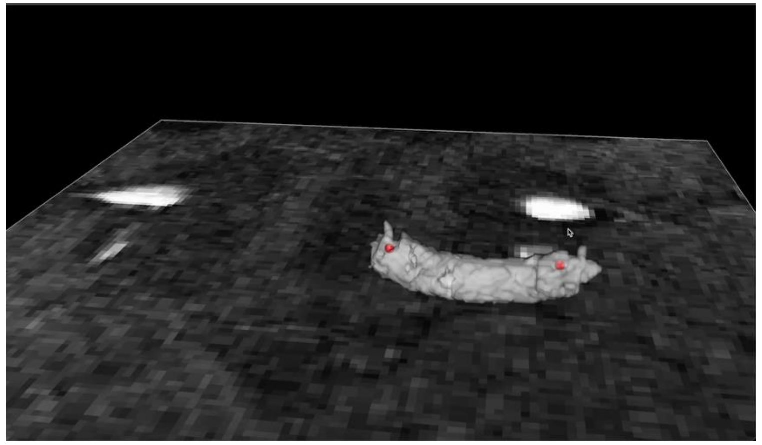


Histogram of constituent voxel intensities

3D Segmentation



- Semi-transparent rendering
- Movable plane widget
- User ability to pick points, fill holes, and adjust t-score threshold



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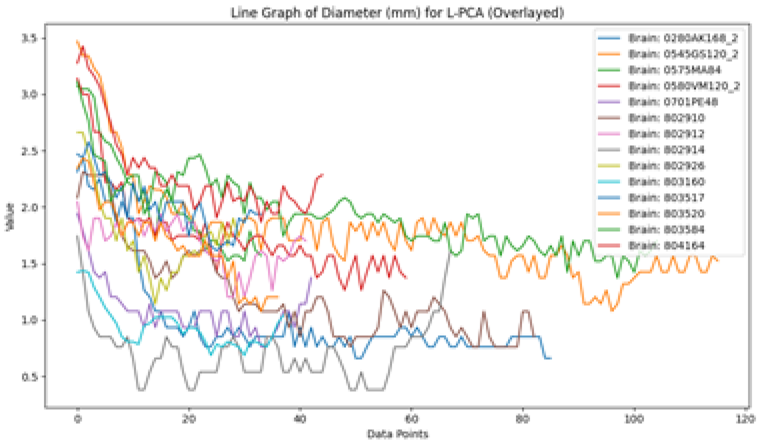
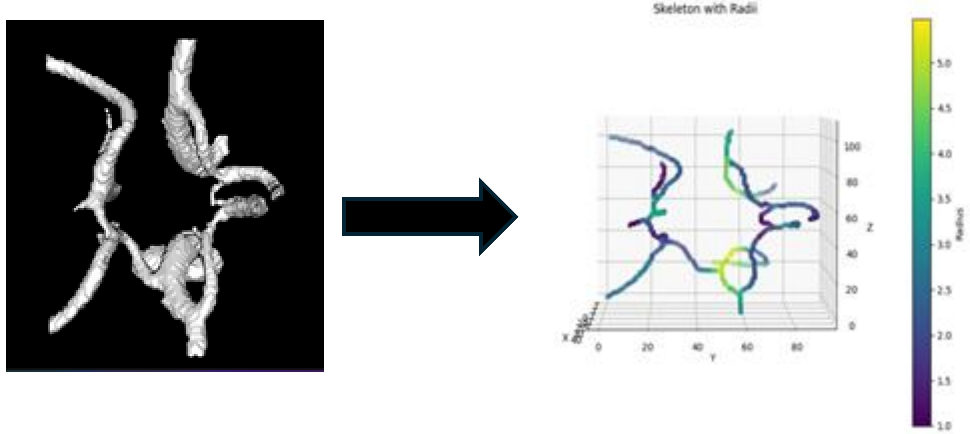
Results

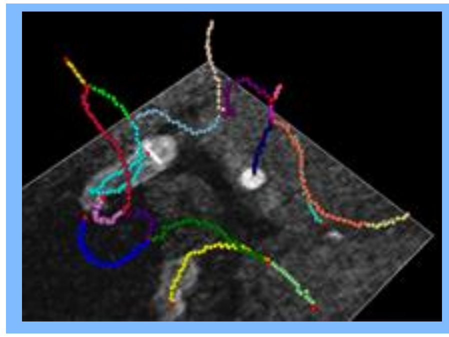
- Complete segmentation used to extract metrics such as radius, curvature, length, and tortuosity



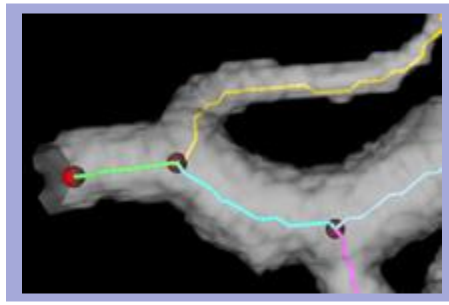
Finding Radius & Diameter

- Uses Euclidean Distance Transform
- Determines nearest distance to "0"

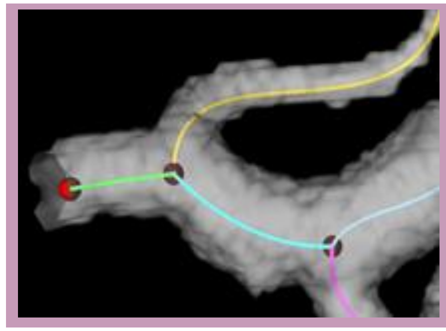




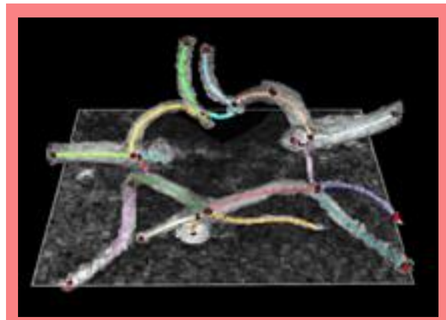
"Brushfire" scales down vWell voxels into a chain code



Branchpoints detected through number of "features" in kernel



Skelton image fitted into 3D polynomial



Additional metrics derived from fitted polynomials

Curvature:

$$\kappa = \frac{\|r'(t) \times r''(t)\|}{\|r'(t)\|^3}$$

Vessel length:

$$S = \int_{t_1}^{t_2} \sqrt{x'^2 + y'^2}\, dt$$

Limitations

- Lacks full automation, requiring human oversight for noise correction
- Medial axis dependent on skeletonization, sensitive to minor discrepancies

Future Directions

- Enhance automation capabilities with machine learning
- Utilizing Principal Component Analysis (PCA) to get accurate medial manifold
- Involvement in the analysis of clinical information

Conclusions

- Novel algorithm utilizing variance regions allows for quick, accurate semi-autonomous segmentations verifiable in real-time
- High-level segmentations can be analyzed in the elucidation of neurodegenerative diseases

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