

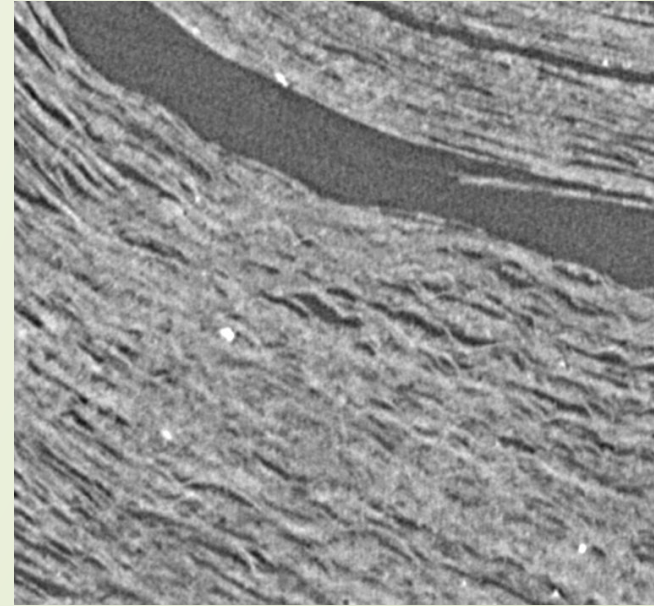


How VA Sheet Tracer works

Contact our algorithm dev at tom.wei@mail.utoronto.ca for more detailed explanations and questions

The Trouble With Segmentation

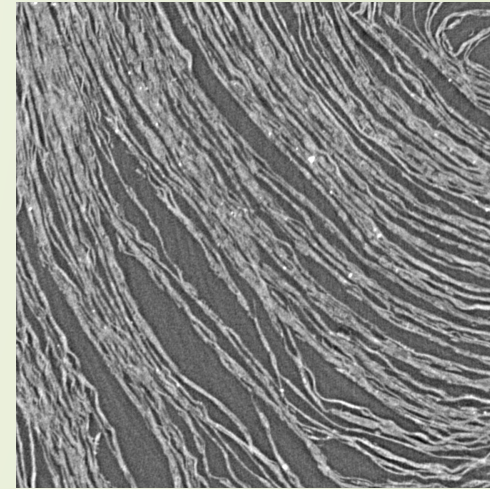
- ❑ Segmentation is a hard problem for humans, and even harder for machines
- ❑ Cases where objects are clearly separated are trivial, but what about when they touch? When they tear?
- ❑ In this scenario, our human brain learns to use context cues to determine how a segment should proceed
 - ❑ Local texture of papyrus fibers
 - ❑ Exclusion of air gaps



- ❑ In this image, we know that segmentations should move from the top left to the bottom right or vice versa, even in regions where there is no gap between sheets

Image Textures

- Scroll scans, even when noisy, have local texture information
- The dominant direction of 'flow' in an image region determines which direction a segmentation should propagate in the absence of edges that an edge detector can see
 - 2D Fourier Transform of image represents textures quite well, with highest signal in the direction of strongest variation (l.e. orthogonal to papyrus layers)
 - Integral of complex modulus over a radial spoke will tell us how strong the variation is along the angle of that spoke



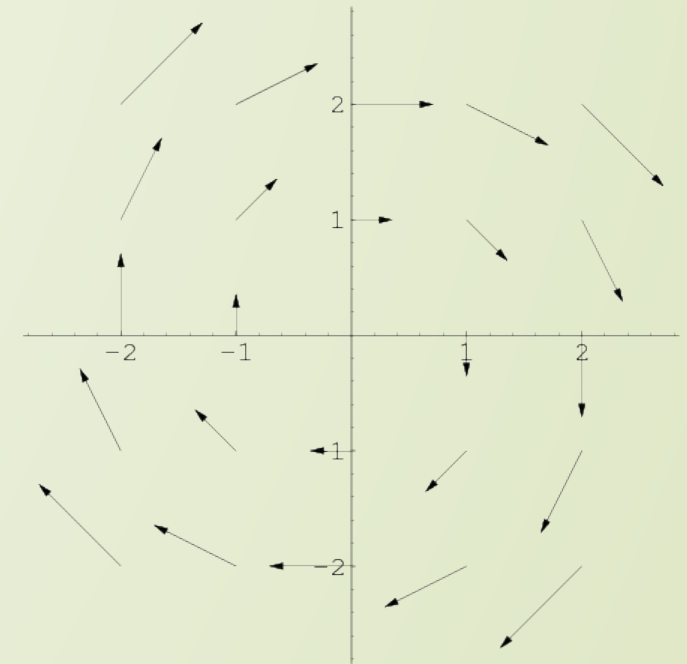
- Small image section with layers moving from top left to bottom right or vice versa



- Its fourier transform, with strong signal orthogonal to papyrus sheets

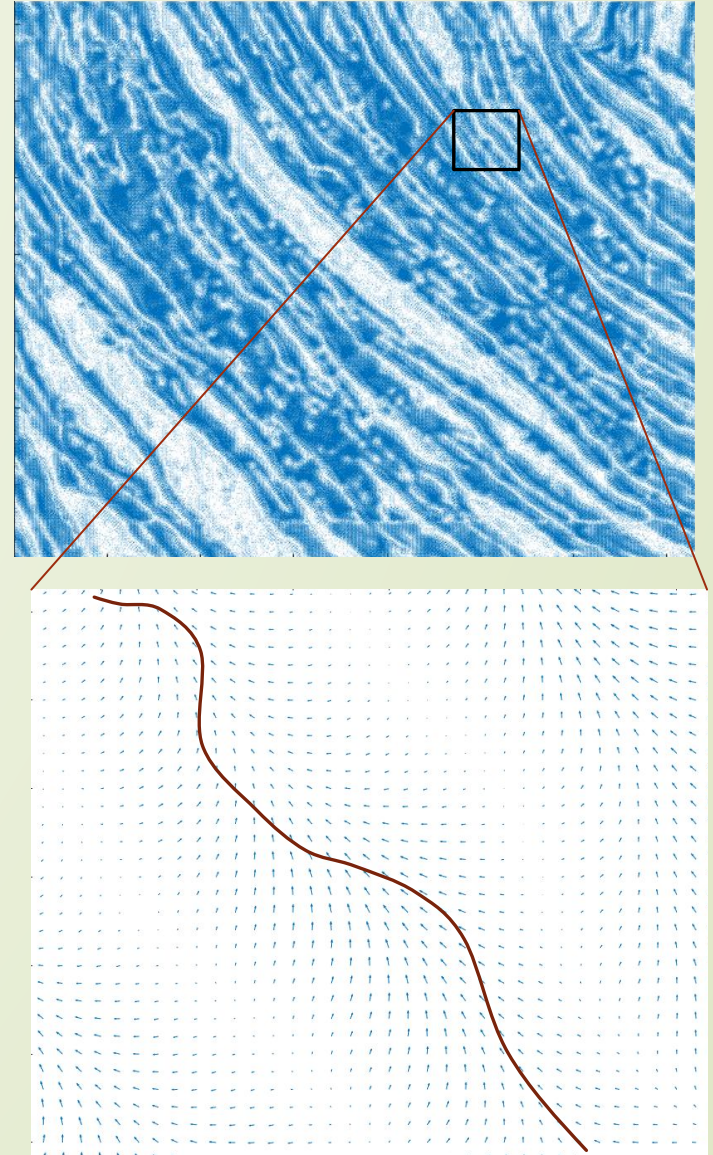
Vector Field Representation

- If the 'dominant textural direction' is known at each point, a vector field can be created using vectors orthogonal to the FFT's most intense radial spoke
- Because the FFT is conjugate symmetric, these vectors can sometimes face 180 degrees away from each other. All vectors are projected onto a circle about the scroll's centre and negated as necessary so that the vectors roughly flow 'clockwise' around the image.
- Drawing a streamline through this vector field should produce a good first estimate for segmentation if a seed point is given.



Empty Space

- Empty space should be avoided unless absolutely necessary when propagating a segmentation so that segments do not 'leave' papyrus sheets
- Gaussian of sobel filter is used as edge detector locally, and thresholds set such that empty space 'repels' segmentation streamlines (note: streamline to the right is exaggerated to illustrate effect of empty space)



Tears, Holes and Gaps

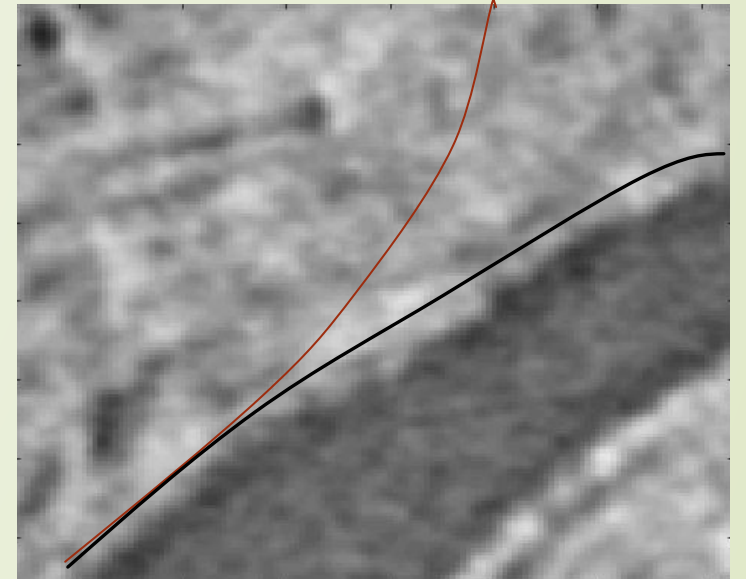
- We want to fill empty holes and tears, but only within sheets and not between them
- Solution: directional morphological dilation. Find vector that is cosine-similar to local sheet direction and Gaussian dilate in that direction. Threshold result and use as mask to distinguish between holes/tears (permeable to streamlines) and empty space (mostly impermeable to streamlines)



- Result: tears are closed but sheets remain distinct

Edges

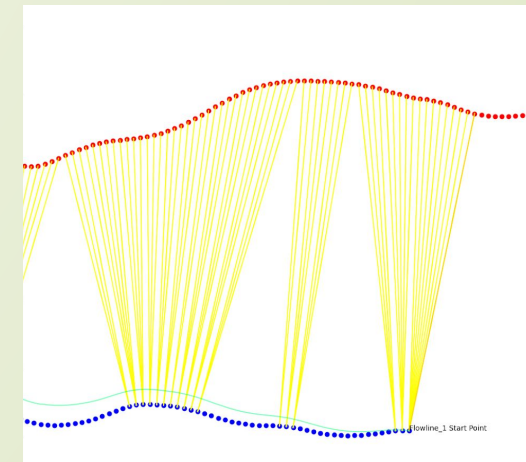
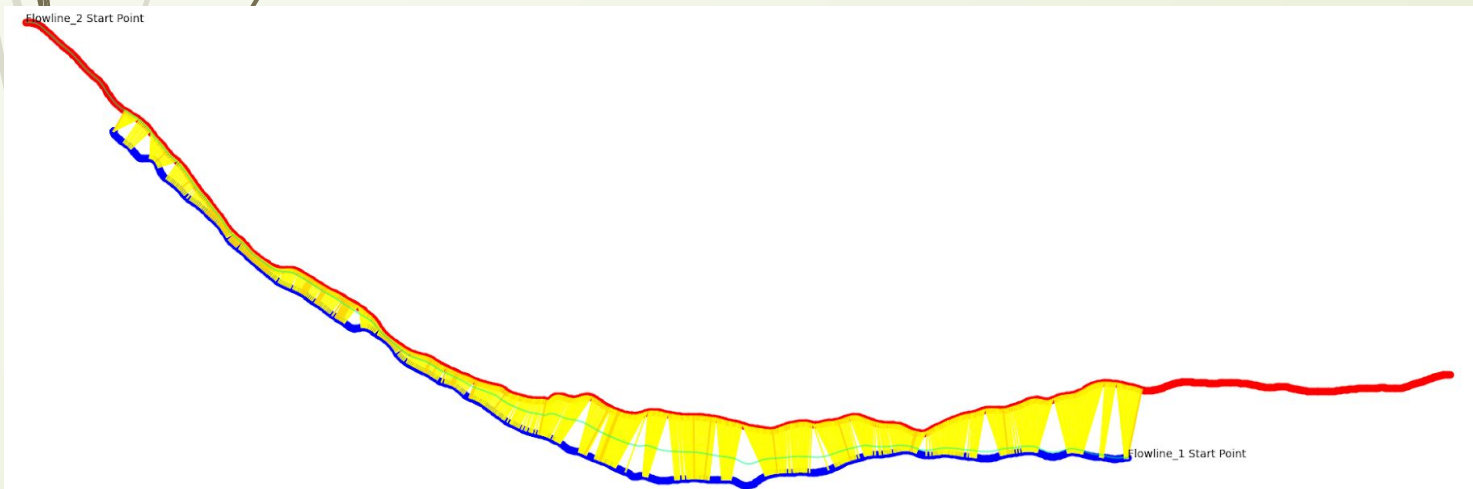
- Edges contain important information about flow direction and should not be ignored
- Segmentation streamline should 'follow and hug' edges when a strong one is detected, subject to other constraints.
 - Without this 'hugging' behaviour, regions of low intensity would repel the streamline into regions of uniform high intensity.



- Undesired behaviour (red): repelled by empty space
- Desired behaviour (black): 'hugs' edge

Landmarks

- If a set of points is known to be in the same segment, vectors should be used to interpolate a curve between them.
- How to do this when error only propagates in one direction (away from the initial seed point?)
- Set next point as seed point, draw streamline in a 'reversed' vector field.
 - Not a true reversal, since repulsion and hugging behaviour should remain the same wrt. space and edges.
- Use weighted average of bijective nearest neighbour points to find smooth curve connecting two points (green)





What Does This Mean?

Although the algorithm is nascent and thus not entirely optimized, improvements to performance as well as scale will allow for:

- ❑ Reduced labour, resulting in greater segmentation efficiency and output
- ❑ Strong segmentation accuracy in difficult segments for human visual systems to process
- ❑ Future potential for fully-automated segmentation pipelines scalable with hardware and computing power.



VA Sheet Tracer: Next Steps

- ❑ Sufficiently competent automated seeding algorithm (under development) can generate segments without the use of human segmenters
- ❑ Hardware acceleration available for many pipeline components, may allow work with large sets of images.
- ❑ Improved contextual behaviours (local parallelization of streamlines)
- ❑ Confidence metrics based in information theory to measure quality of streamlines.
- ❑ Z-direction interpolation algorithms (optical flow, contextual re-seeding etc.) to reduce required seed point density and human labour.