# MR for ULTRA-SR: Improved Localization with Morphological Image Processing

Scott Schoen Jr, Anthony E. Samir, & Viksit Kumar

Center for Ultrasound Research and Translation
Harvard Medical School and Massachusetts General Hospital
Boston, MA USA

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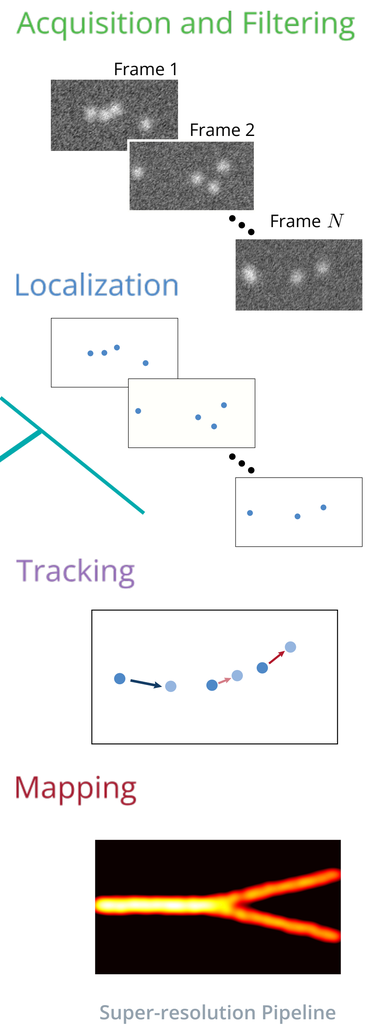
## Introduction

Ultrasound Super-resolution (SR) broadly comprises: (1) Aquisition of imaging data (2) Filtering the data to select for micro-bubble signals (3) Localizing individual scatterers (4) Tracking these points and finally (5) Visualizing the result.[1]

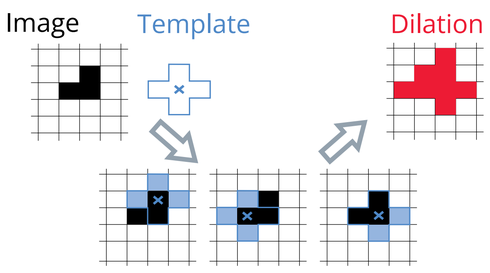
SR enables massive gains in spatial resolution, but the computational expense and degraded time resolution motivate enhancements to each step.


We apply Morphological Reconstuction[2] to the Challenge dataset to enhance Localization. Exploiting efficient image processing techniques enables fast, sensitive localization, and subsequent tracking for mapping of the hemodynamics. The Accumulated Points themselves can also provide an enhanced spatial image directly, further



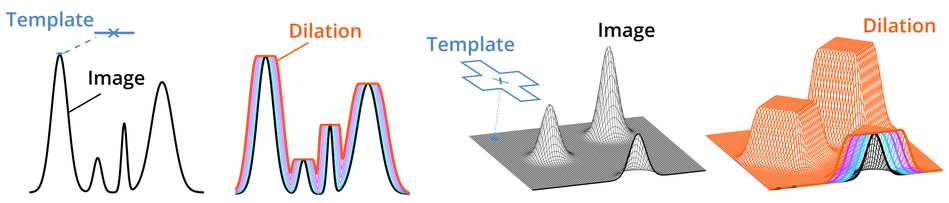

Super-resolution Pipeline

## Methods



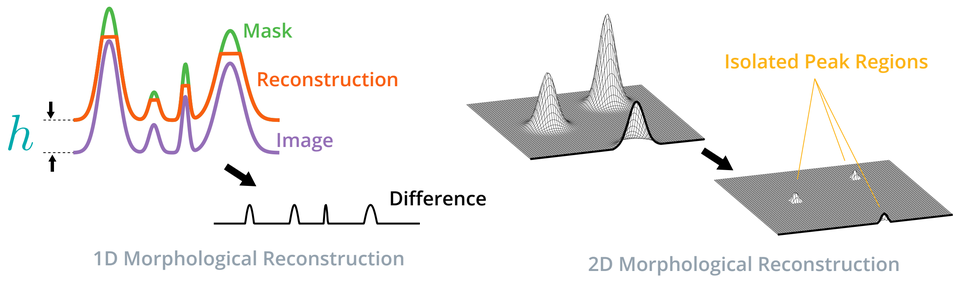

Binary dilation assigns 1 to all 0-valued pixels within the template's convolution with the original image.

**Morphological Reconstruction (MR)** process fdilates a grayscale marker image repeadtedly until it fills a specified mask.



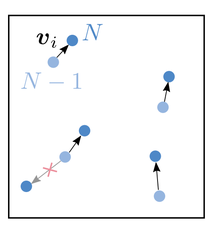

1D Grayscale Dilation — 2D Grayscale Dilation

If the **mask** is a shifted (by some offset $h$) version of the **image**, the difference between the image an its reconstruction simplifies peak detection for local maxima with different amplitudes.[3]



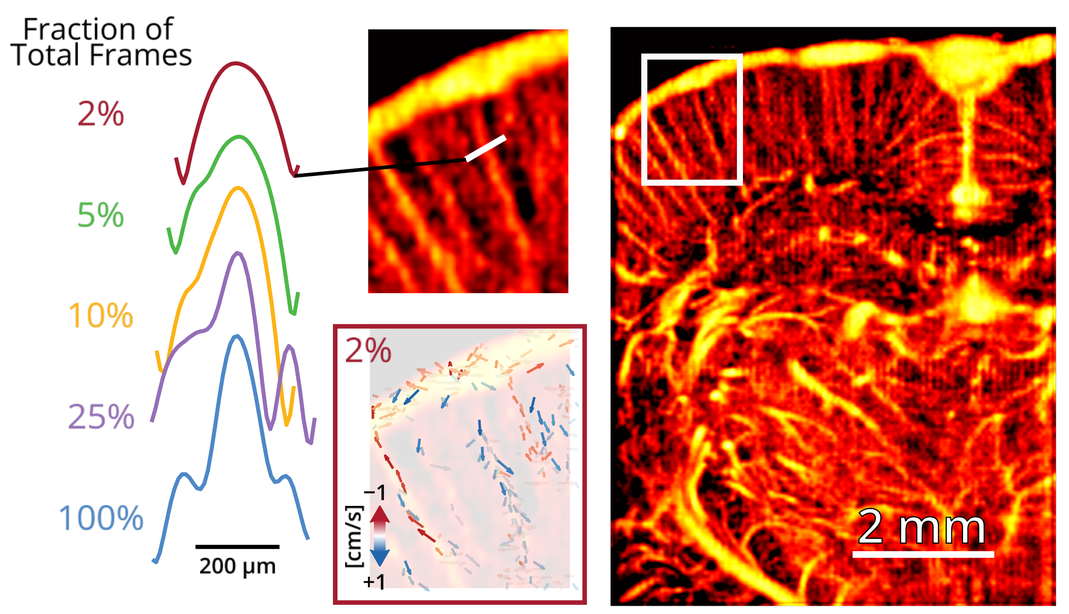

1D Morphological Reconstruction — 2D Morphological Reconstruction

The centroids of each **peak region** are taken as the bubble locations. MR was applied after deconvolution and SVD filtering, and tracked using a nearest neighbor pairing (Munkres algorithm).[4]




Velocimetry via Tracking

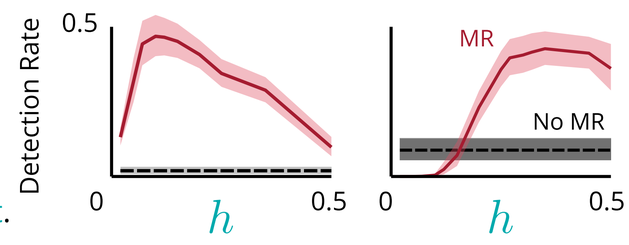
## Results

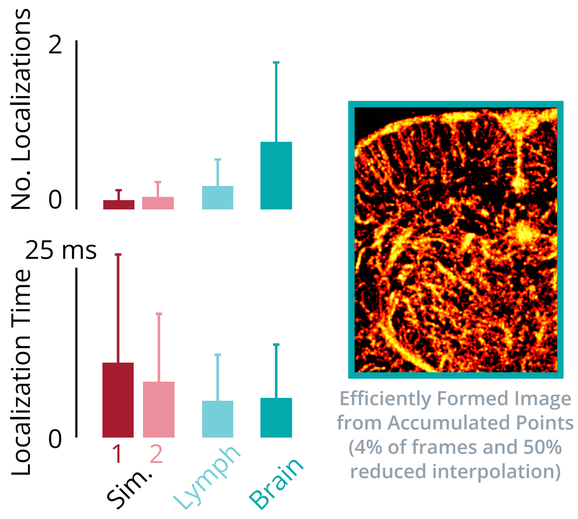



MR enables sensitive detection of micborbubbles in the micro-vasculature. Profiles show vessels as small as 105 µm were achieved with 2 % of the dataset compared to 70 µm with the full dataset, prior to any tracking. Further, tracking with even this small portion of the dataset enables velocimetry of the flow.

### Accuracy & Efficiency

For the test dataset, detection rates (i.e., TP×φ, where φ is the fraction of peaks detected in each frame) of about 50 % with heruristically chosen offset.






Efficiently Formed Image from Accumulated Points (4% of frames and 50% reduced interpolation)

For the challenge datasets, the number of localizations per frame roughly matched the characteristic dimension of the frame (e.g., 10 for a 10-by-10 pixel image), and each required several milliseconds. Efficiency can be prioritized: the brain image at left required only **11.3 s total**, including data loading, processing, and display with MATLAB.

## Takeaways

- MR provides a sensitive, accurate, and efficient means of localization
  - Hundreds of peaks per frame achieved, requiring a few milliseconds each
  - Formulation naturally extends to 3D, with possibilities for efficient volumetric SR.
  - MR Localization may augment other pipelines

## References

1 Christensen-Jeffries et al. *Ultrasound Med. Biol.* **46**(4) (2020)

2 Schoen Jr et al. *IEEE T. Ultrason. Ferr.* **68**(6) (2021)

3 Vincent *IEEE T. Image Process.* **2**(2) (1993)

4 Tinevez and Cao *MATLAB File Exc.* (2016)

See Also US Patent Application US 2022/0011270 A1 (2021)

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curt.mgh.harvard.edu

scottschoenjr.com