Fast Low-Cost Single Element Ultrasound Reflectivity Tomography Using Angular Distribution Analysis

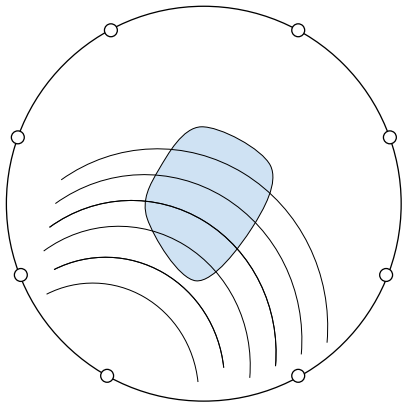
Andrey Kuzmin [1] Xiang Zhang [2] Jonathan Fincke [2] Micha Feigin [2]
Brian Anthony [2] Victor Lempitsky [1]

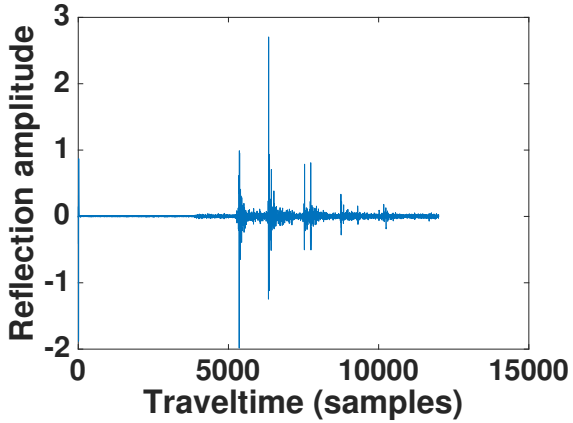
[1] SkolTech
[2] MIT

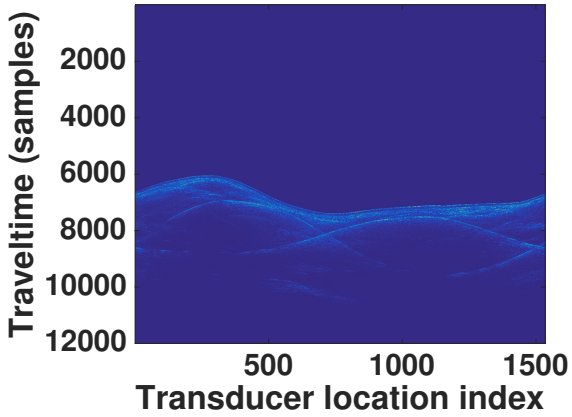
April 15, 2016

Plan

Ultrasound reflection tomography

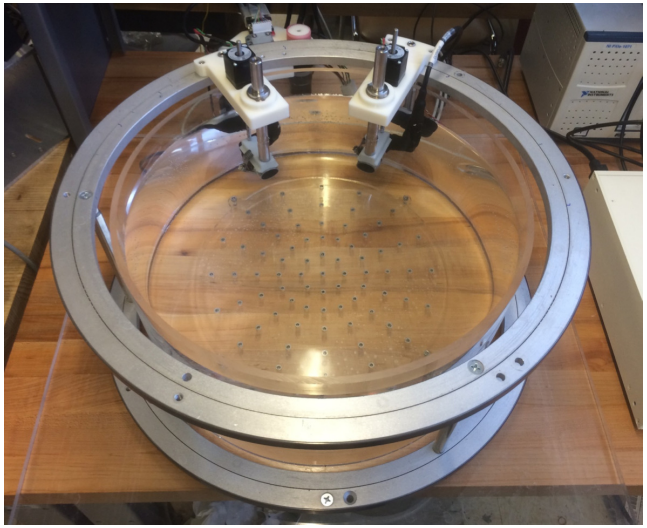


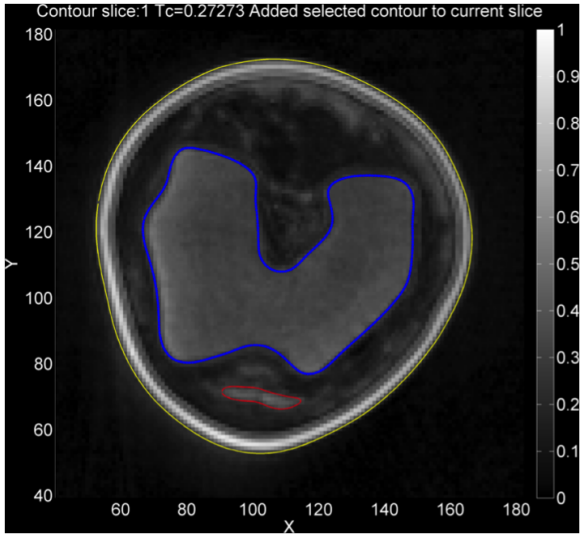




- A 2d reflectivity field is recovered based on back-scattered echo
- The reflection amplitude (A-line) is recorded at each location
- Each value in the A-line corresponds to a certain traveltime
- A-lines for multiple locations are stacked into a 2D image

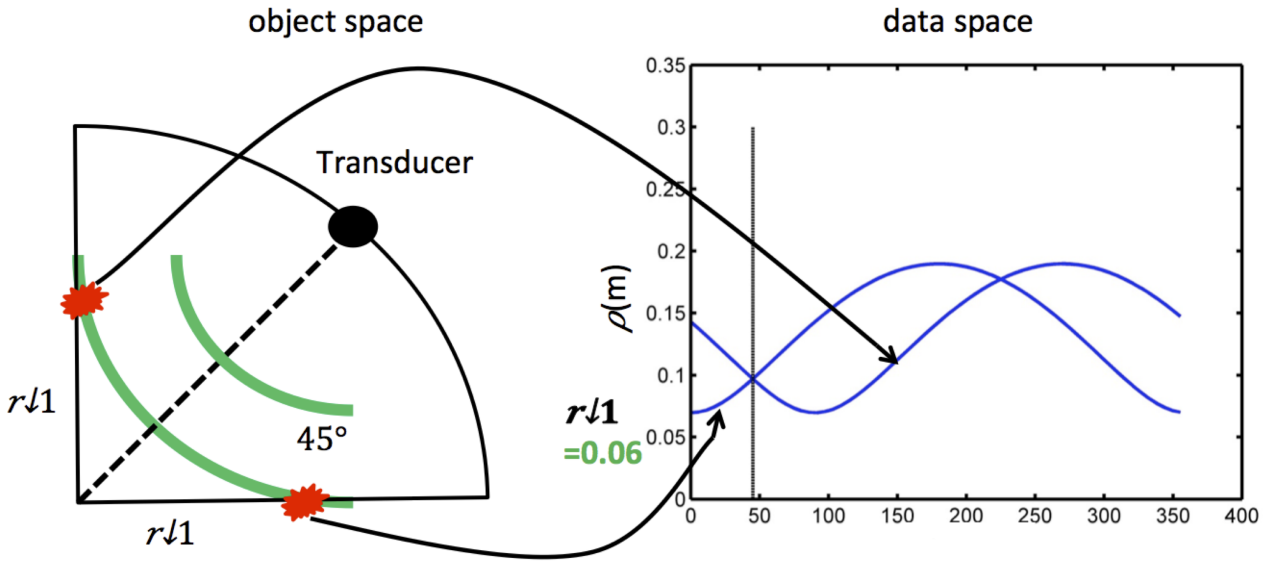
The single element setup





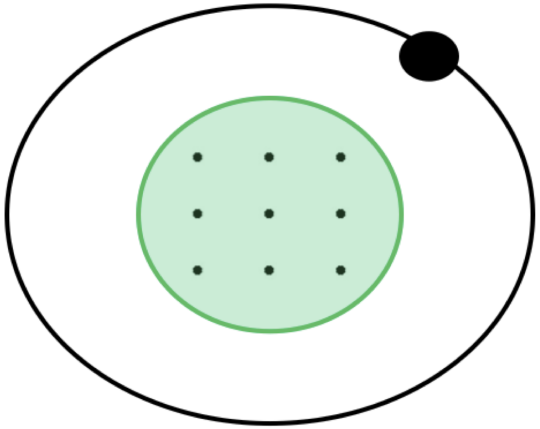
- A single wide fan-out transducer element at 5 MHz
- 1500 locations, acquisition time is approximately 3 seconds
- A limb imaging task for prosthetics fitting is considered
- A potential low-cost alternative to MRI aimed at bone contour detection

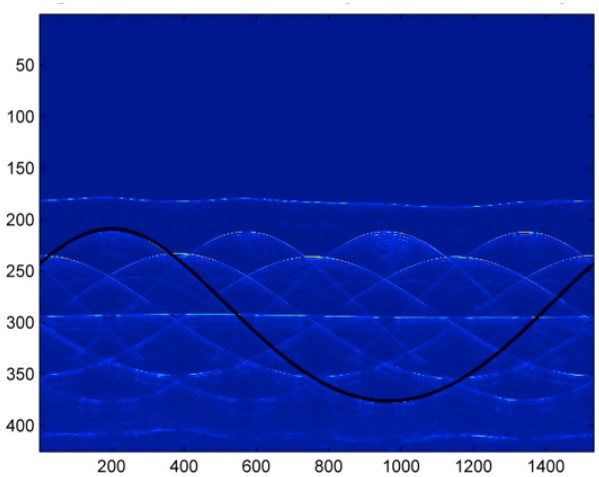
The data space and the object space

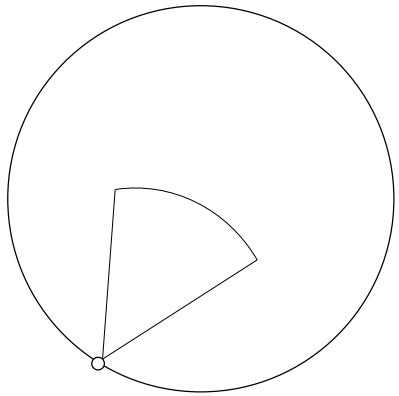


- The speed of sound is assumed to be constant
- Two coordinate systems are considered: the device coordinate system i.e. *the object space* and the reflection data (r, j) coordinate system i.e. *the data space*
- A single (r, j) pair corresponds to a circular in the object space
- A single point in the object space corresponds to a sinusoid in the data space

Traditional back-projection methods

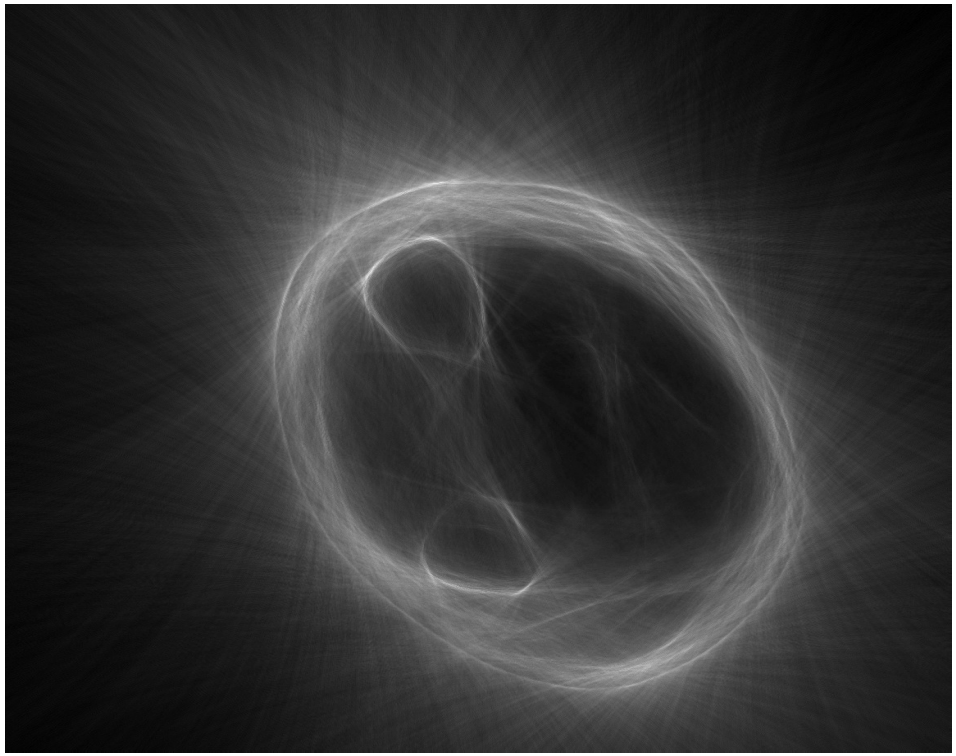






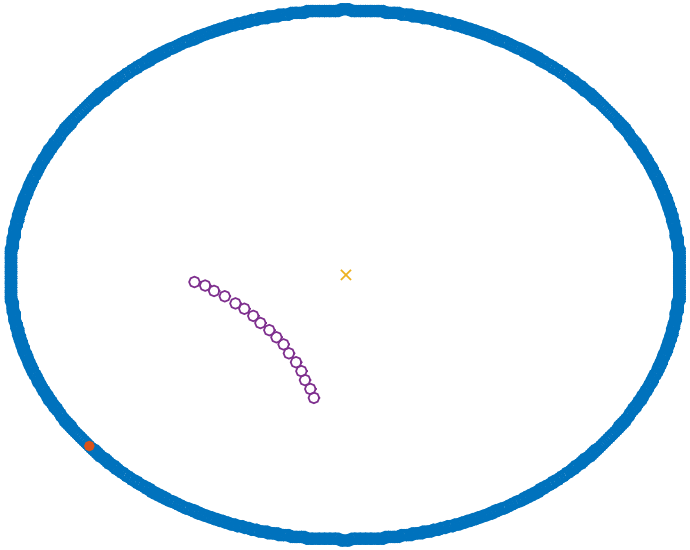
- The reflectivity field at each point as estimated as the integral along the corresponding curve in the data space
- The intensity at each sample is spread uniformly across a circular arc

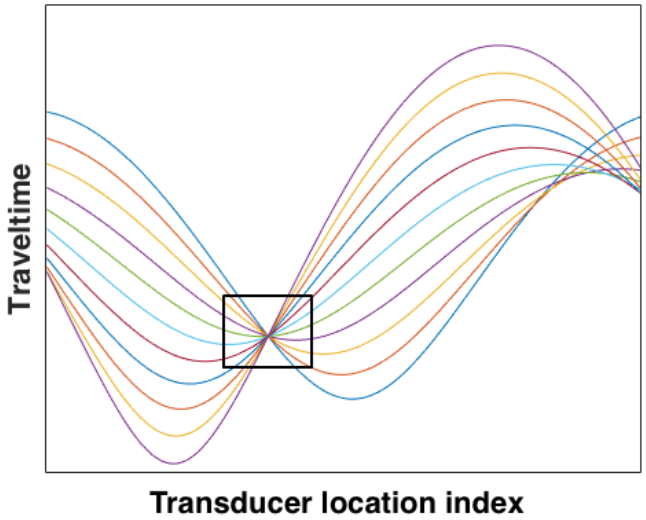
Traditional back-projection methods



- The circular integration paths cause the artifacts
- The recovered images suffer from the overall bluriness
- There are halo-type effects around strongly reflecting surfaces

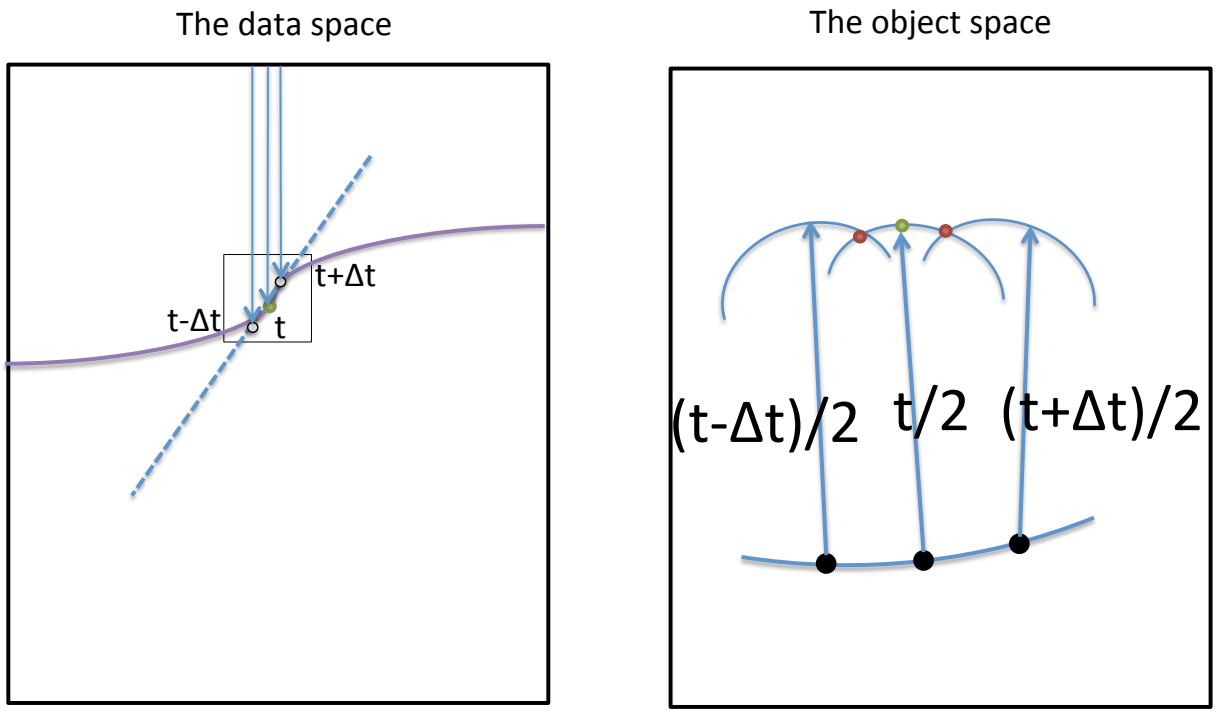
Angular distribution analysis





- The angular distribution is estimated for each arc in the object space
- Each point of the arc back-projects in a sinusoid line in the data space
- The resulting family of sinusoids naturally intersects yielding the family of directional filters

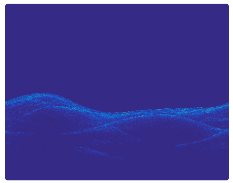
The dominant orientation estimation



- The full angular distribution can be replace by a delta function i.e. *the dominant orientation*
- Estimated locally based on the image covariance
- A direct mapping exists based on the dominant orientation

Reconstruction pipeline

Angular distribution estimation



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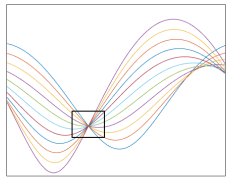
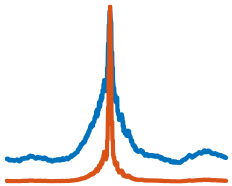
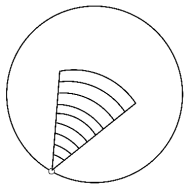


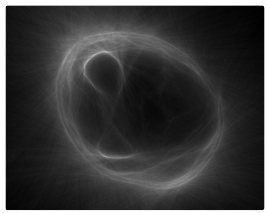
Angular distribution processing



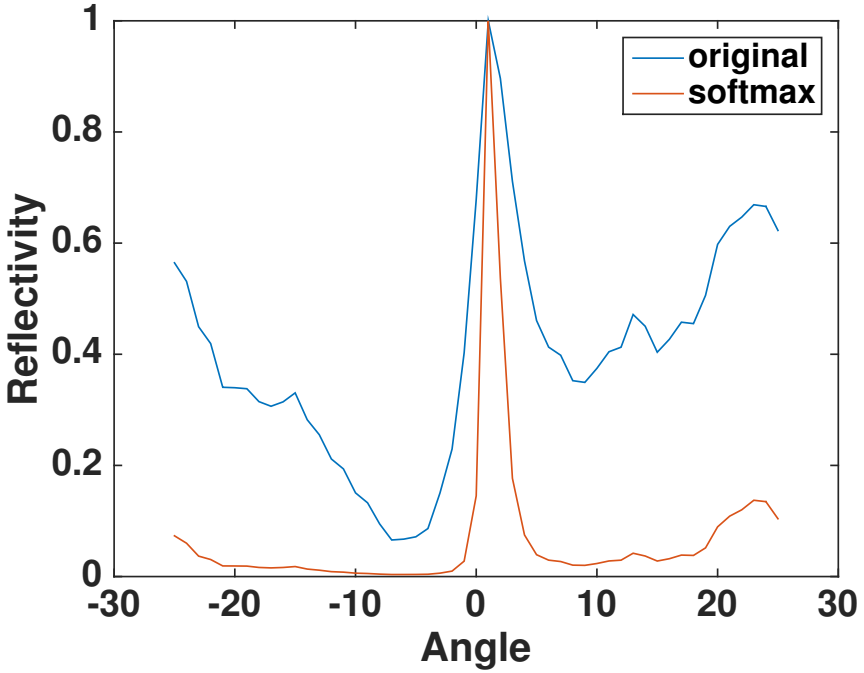
Back-projection to the object space



sum



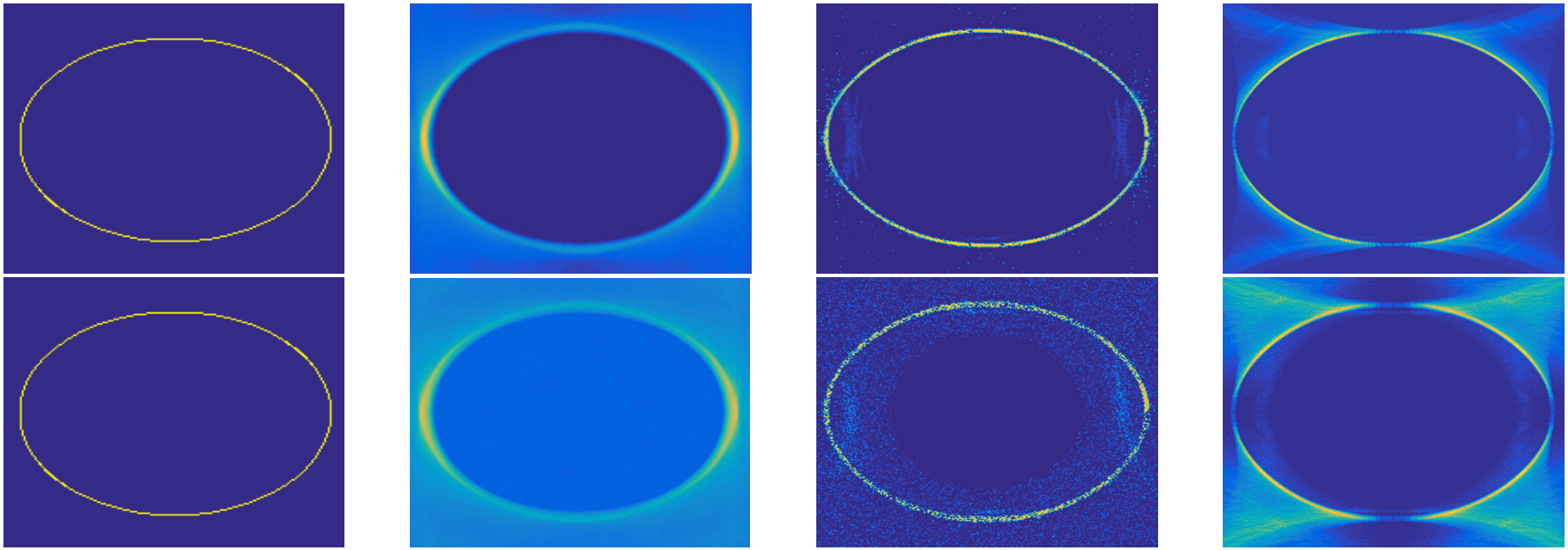
Angular distribution processing



$$p(\Theta) = \frac{\exp\left(\alpha\tilde{p}(\Theta)\right)}{\int_{\Phi}\exp\left(\alpha\tilde{p}(\Phi)\right)\,d\Phi}$$

- Each angular distribution is passed through a *softmax* normalization
- The extreme case ($\alpha \to \infty$) corresponds to the delta function i.e. *dominant orientation*

Synthetic phantom experiment



- The reconstruction of two-dimensional strongly reflecting boundary is based on the time-domain simulation (first row)
- A white noise of moderate level was added to the data image in order to examine robustness of considered methods (second row)

Real data experiments

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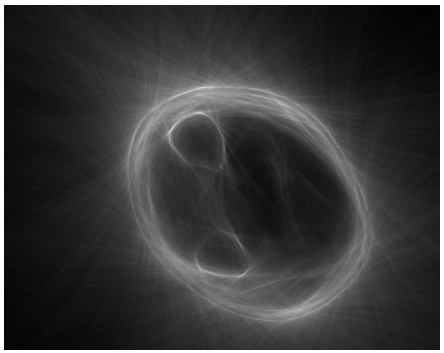
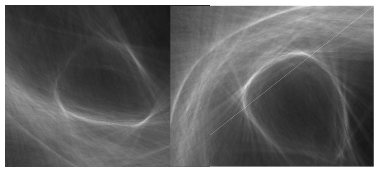
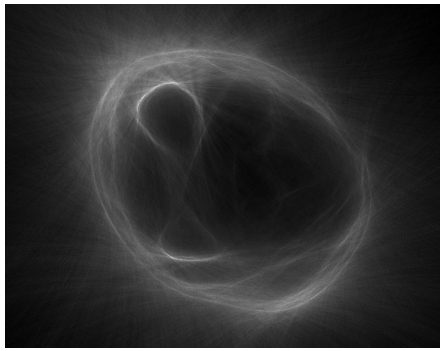
Patient 1





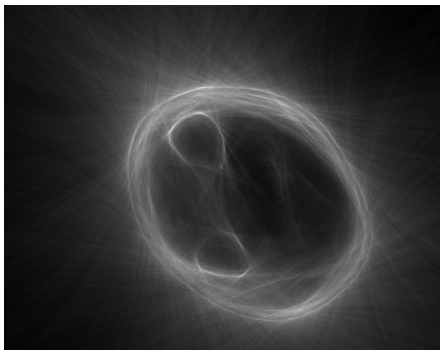
Patient 2

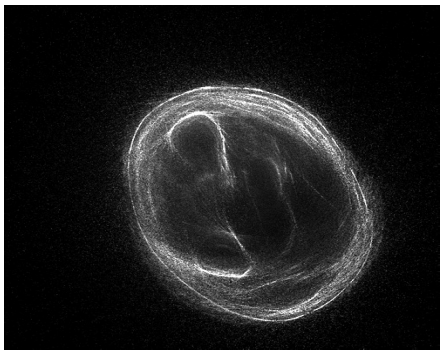


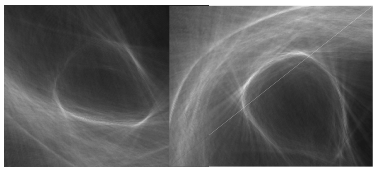
the uniform distribution

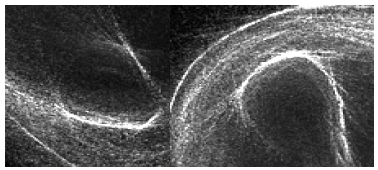
Real data experiments

Patient 1

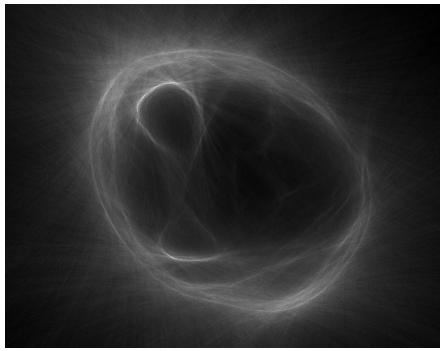


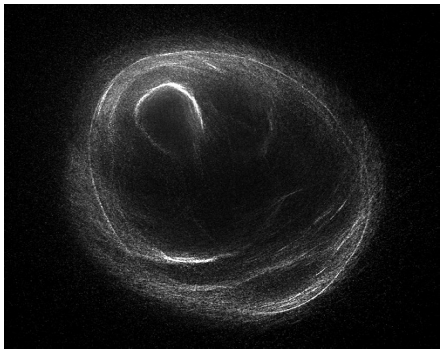






Patient 2



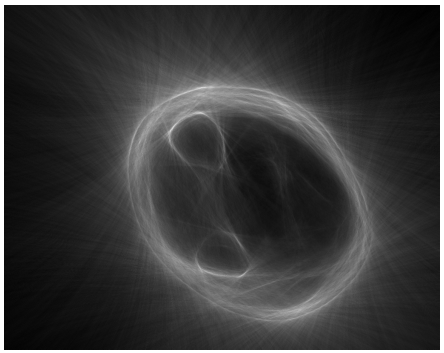
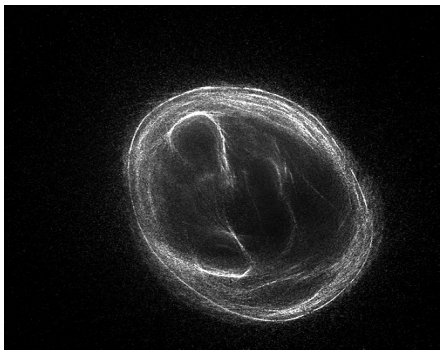
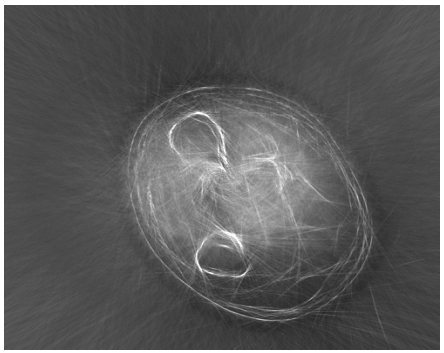


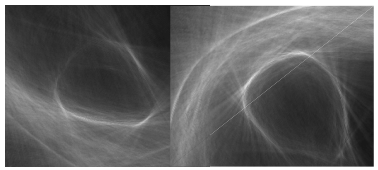
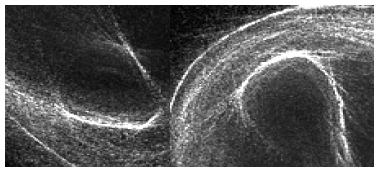
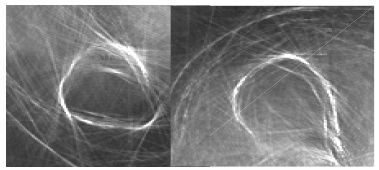
the uniform distribution

the dominant orientation

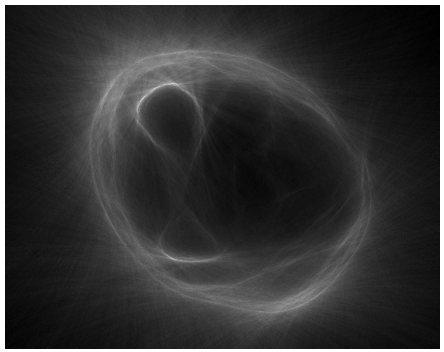
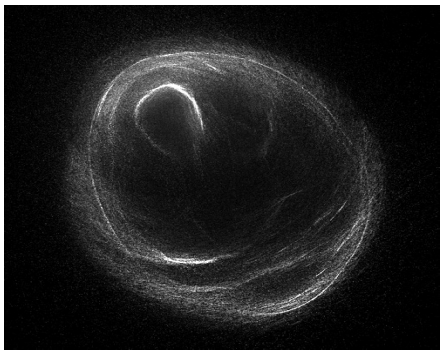
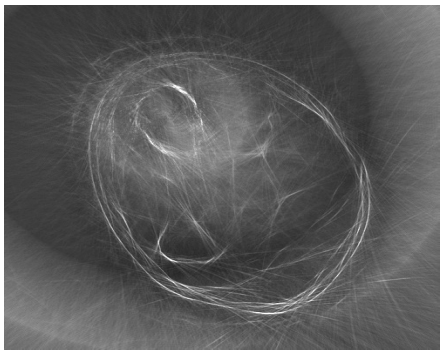
Real data experiments

Patient 1

Patient 2

the uniform distribution

the dominant orientation

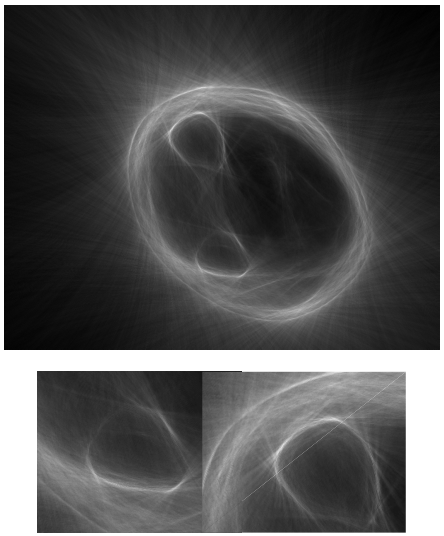
the full angular distribution

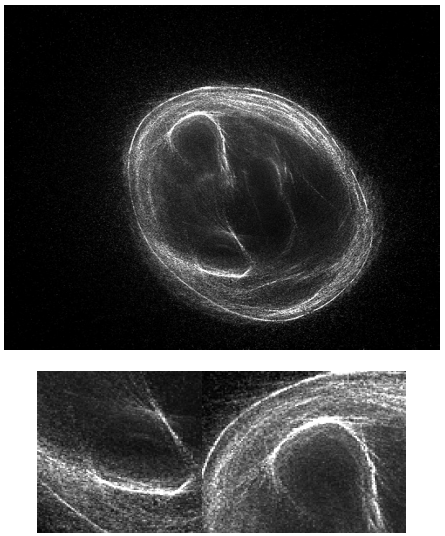
Real data experiments

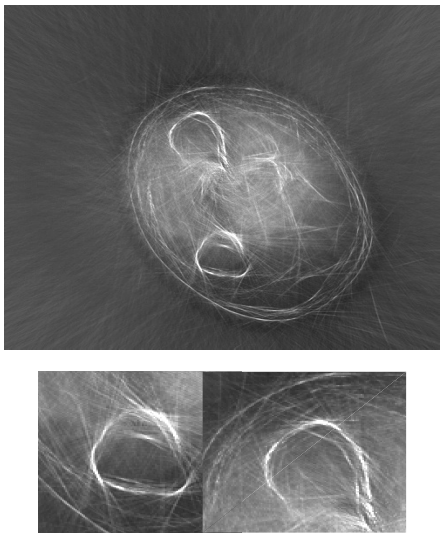
Skoltech

Patient 1

Patient 2







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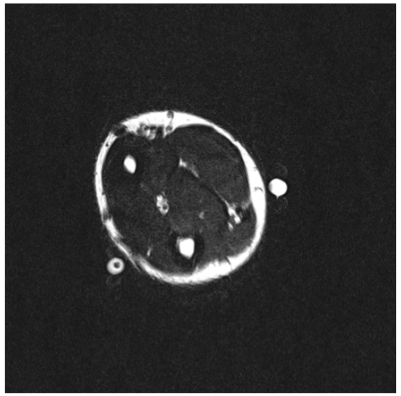

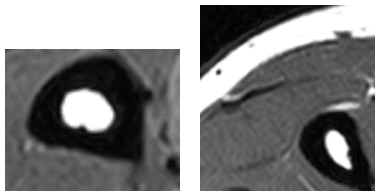

Sample forearm MRI fragments

Conclusion

- A new reconstruction method for ultrasound reflectivity tomography
- Back-projection to the device geometry based on angular distribution analysis
- Two specific methods based on the angular distribution are considered
- The method is fast and allows efficient parallelization
- The proposed method outpeforms the traditional methods showing less artifacts and higher level of detail

Thank you for your attention.
Questions?