

Orientation-Driven Ultrasound Compounding

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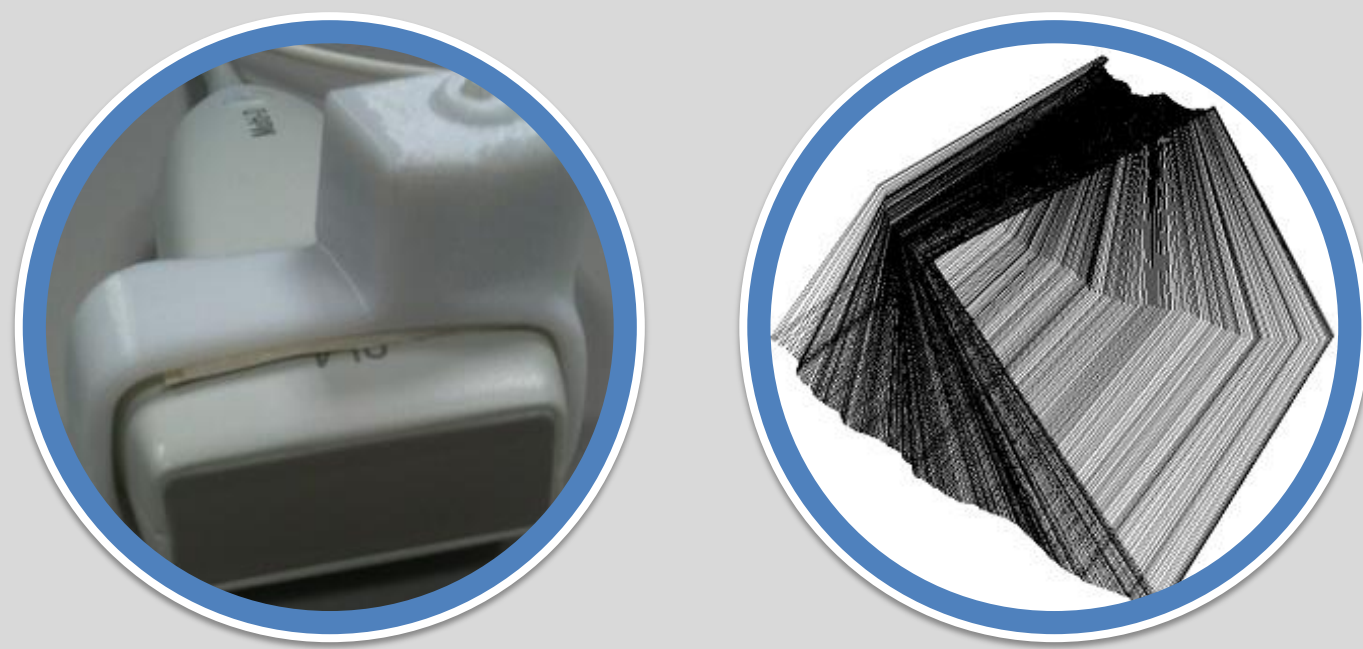
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Introduction

Complex Ultrasound Image Formation

- Dependent on angle, probe pressure, patient positioning, ...
- Same anatomy may yield different information if scanned from different perspective or at different time



Traditional US Compounding Techniques:

- Assume undistorted input data
- Require constant pressure, linear trajectory

Clinical applications do not have this setup!

- Artifacts where pressure changes/frames overlap
- Averaging may yield inaccurate/incorrect results

Our Vision: Free Clinicians from Restrictive Scanning Protocols!

- Allow arbitrary trajectories
- Support incremental acquisition with interactive feedback on reconstruction

Our Contributions:

- Orientation-driven pressure compensation and frame clustering
- Uncertainty-based incremental information fusion

Methods

Orientation-Driven Inter-Frame Registration

- Correlation between US frames depends on proximity and orientation to each other [1]
- Windowed SSD with orientation-driven correlation term:

$$\sum_{\substack{p \in P \\ p' \in P'}} \sum_{n=-N}^N C(i, i+n) \cdot (I_i(p) - I_{i+n}(p'))^2,$$

$$C(i, j) := e^{\frac{n^2}{2\sigma^2}} \cdot \left(1 - \frac{2}{\pi} \arccos \left(\frac{n_i \cdot n_j}{\|n_i\| \|n_j\|} \right) \right)$$

Pressure Compensation

- Apply deformable inter-frame registration to a grid of independent 1cm x 1cm patches

Orientation-Driven Frame Clustering

- Hierarchical clustering by frame orientation
- Compounding of clusters into independent volumes
- Uncertainty-based (e.g. Confidence Maps [2]) fusion of the compounded clusters

$$I(x) = \frac{\sum_{c \in C} (1 - U_c(x)) I_c(x)}{\sum_{c \in C} 1 - U_c(x)}$$

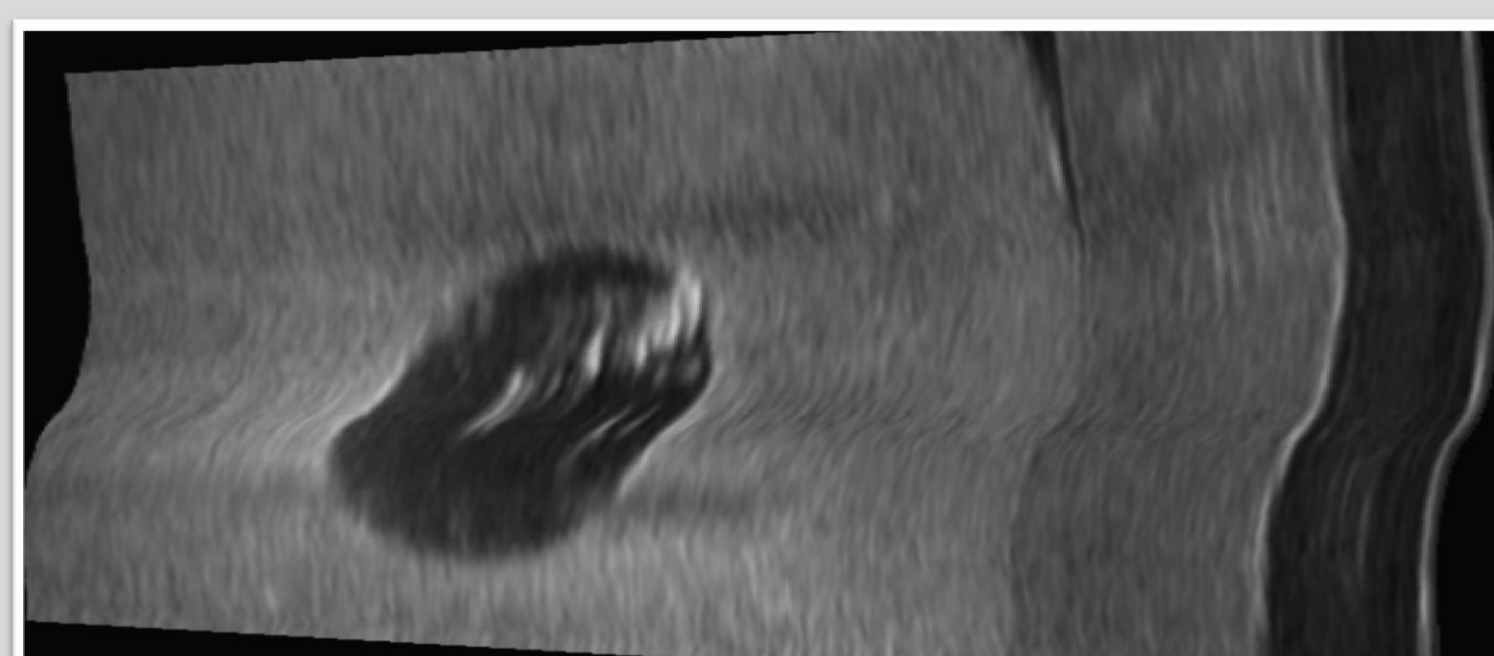
Incremental Compounding

- The above compounding scheme can be rewritten into an incremental in-place algorithm

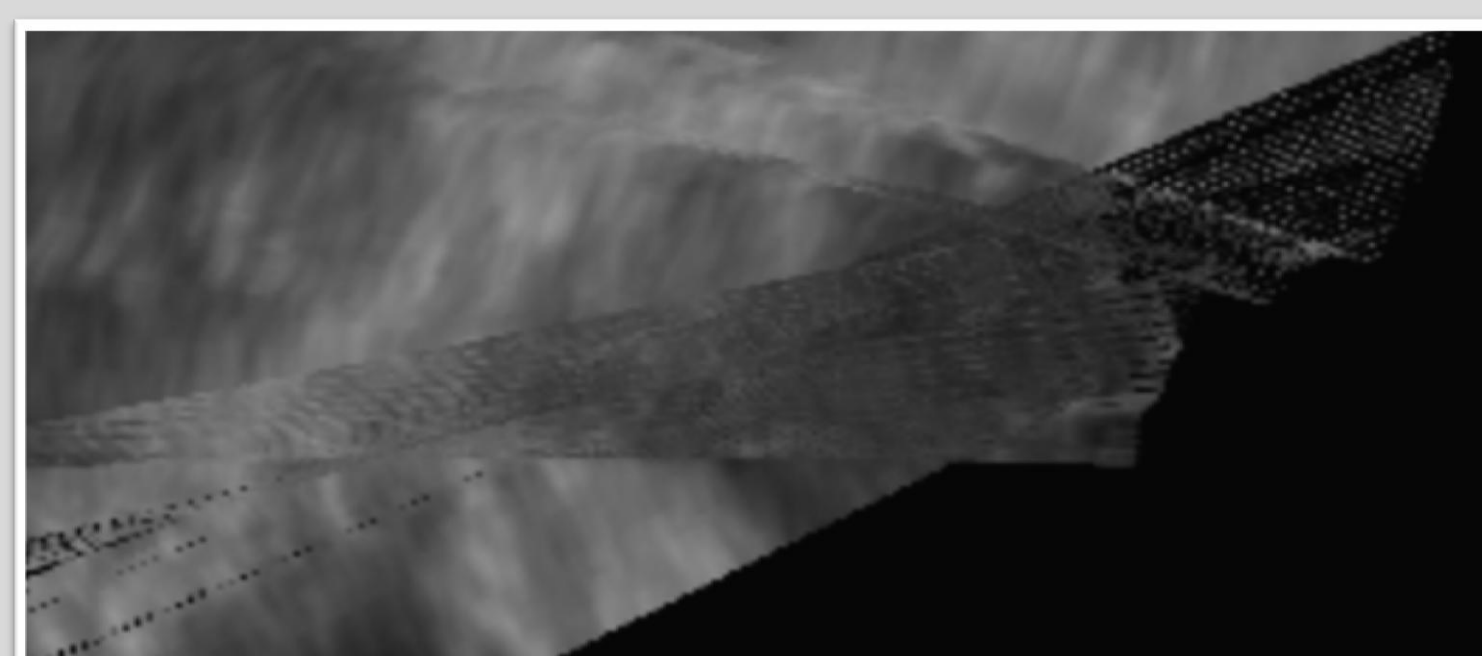
$$I_i = \frac{U_{i-1} I_{i-1} + (1 - U_c) I_c}{U_{i-1} + (1 - U_c)},$$

$$U_i = U_{i-1} + (1 - U_c)$$

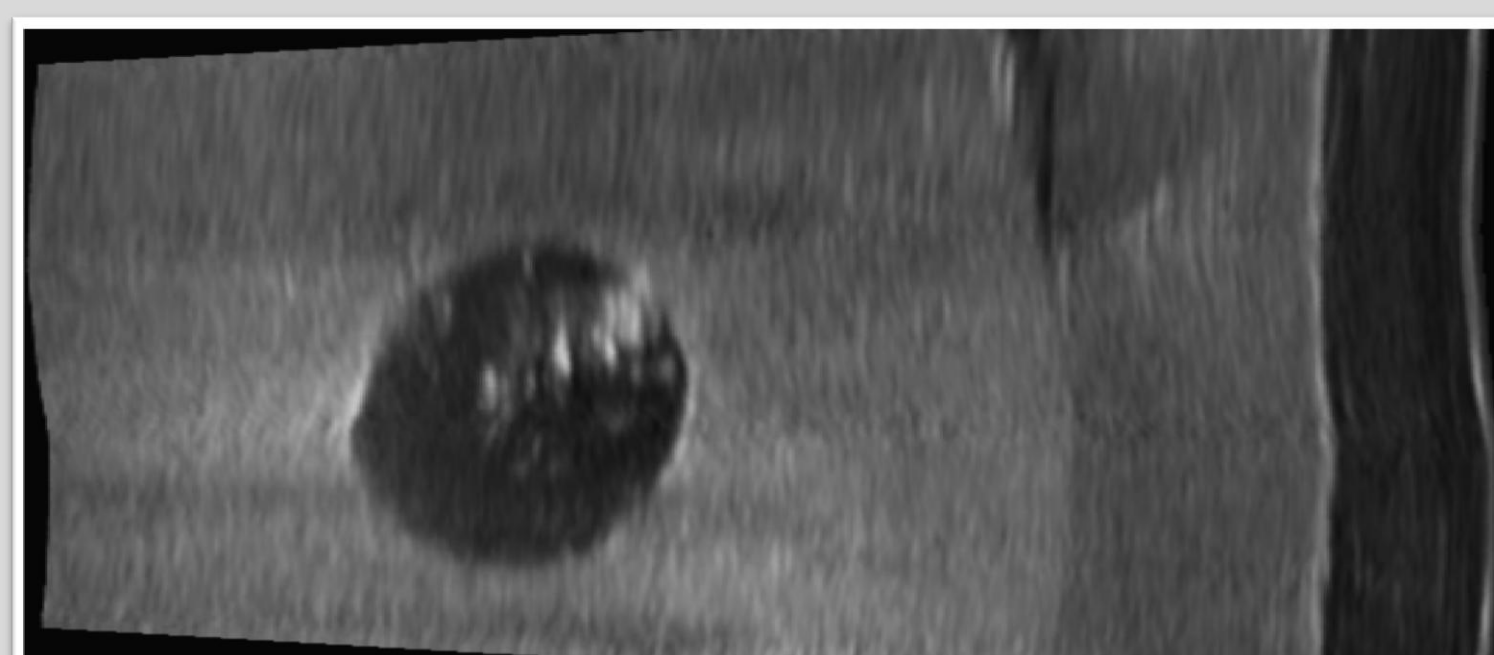
Results



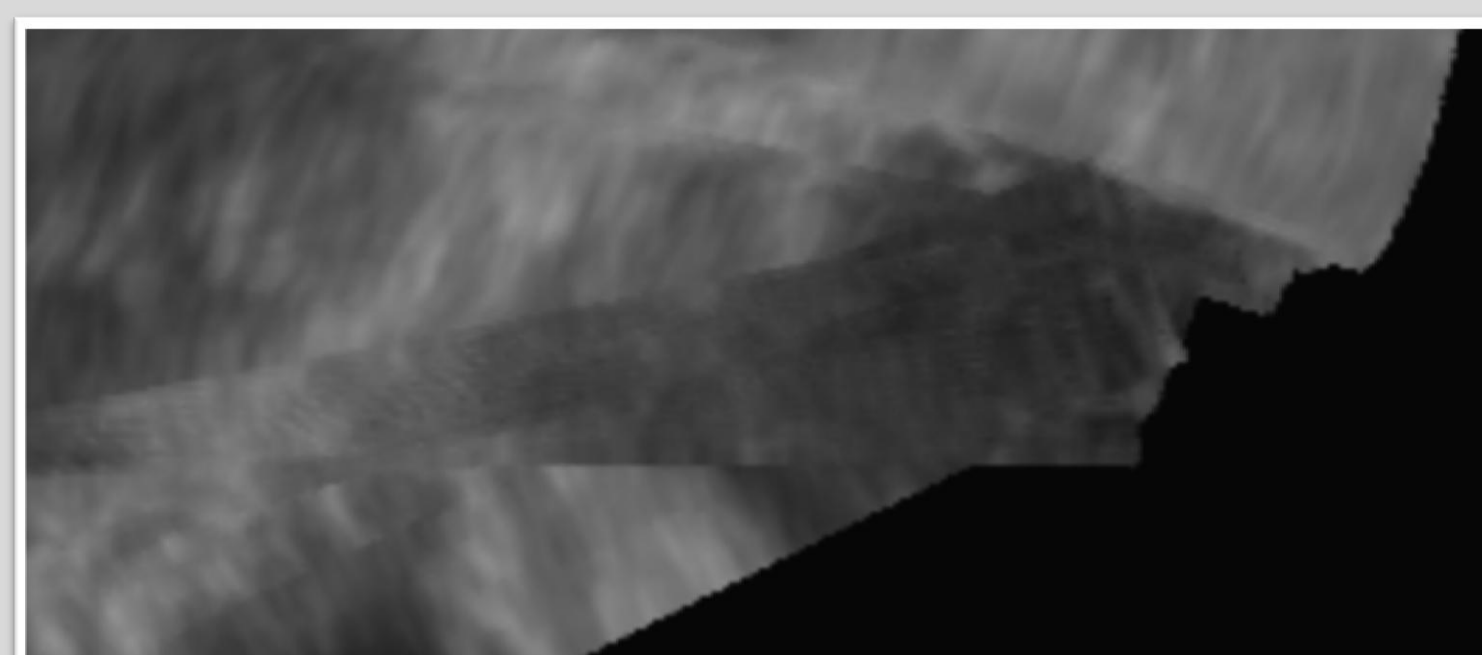
No pressure compensation



No clustering



With pressure compensation



Frame clustering and uncertainty fusion

Accuracy

- Comparing average target diameter in liver phantom
- Compounded US: 14.63 ± 0.48 mm
- CT: 14.5 ± 0.84 mm

Registration Quality

	Baseline		Our Technique	
	NCC	SNR _{dB}	NCC	SNR _{dB}
Phantom / constant pressure	0.90	19.39	0.94	23.16
Phantom / pressure changes	0.81	13.02	0.94	22.47
In-vivo leg / constant pressure	0.72	9.21	0.76	11.69
In-vivo leg / pressure changes	0.67	8.53	0.75	11.03

Conclusion

- Orientation-driven compounding approach superior to traditional techniques
- Important step towards „real“ 3D Freehand Ultrasound

References

- [1] Housden, R., et al. „Sensorless Reconstruction of Unconstrained Freehand 3D Ultrasound Data.“ *Ultrasound in Medicine & Biology* 33.3 (2007)
- [2] Karamalis, A., et al. „Ultrasound confidence maps using random walks.“ *Medical Image Analysis* 16.6 (2012)