Ultrasound Speckle Reduction

After Coded Excitation and Pulse Compression

By: Josh Ullom
Advisor: Dr. José Sánchez
Bradley University
ECE Department

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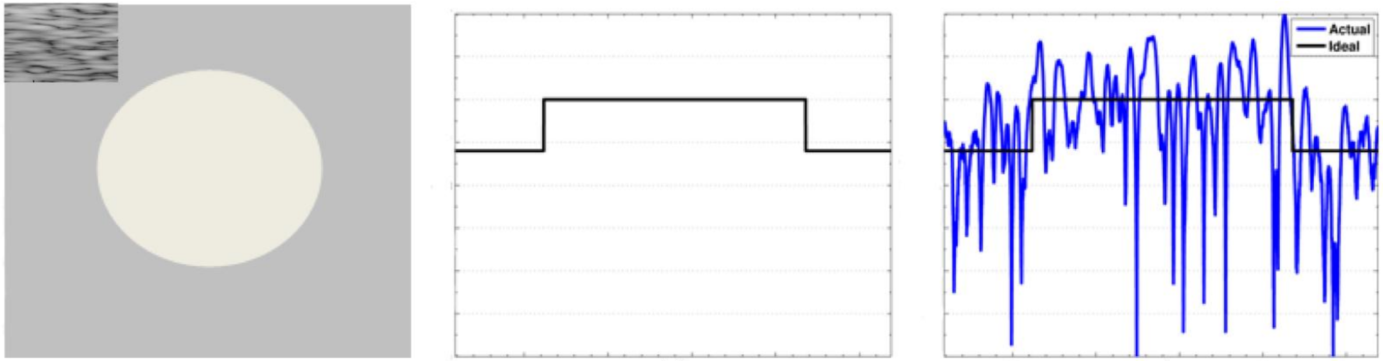
BRADLEY UNIVERSITY

Overview

- Goals
- Background
- Filters
- Quantifying Results
- Results
- Conclusion

Goals

- Reduce speckle
  - Improve contrast
  - Preserve key features



a) b) c)

- Significance: improve diagnostic ultrasound
  - Earlier detection of cancer
  - Easier identification of small, threatening lesions

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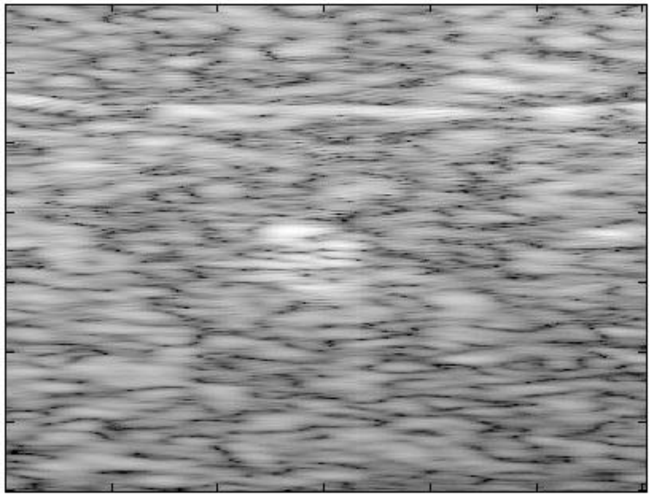
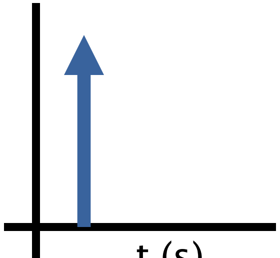
Background – Conventional Pulsing

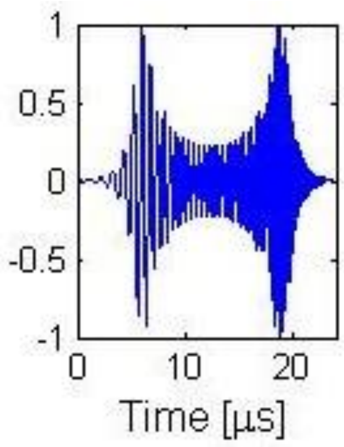


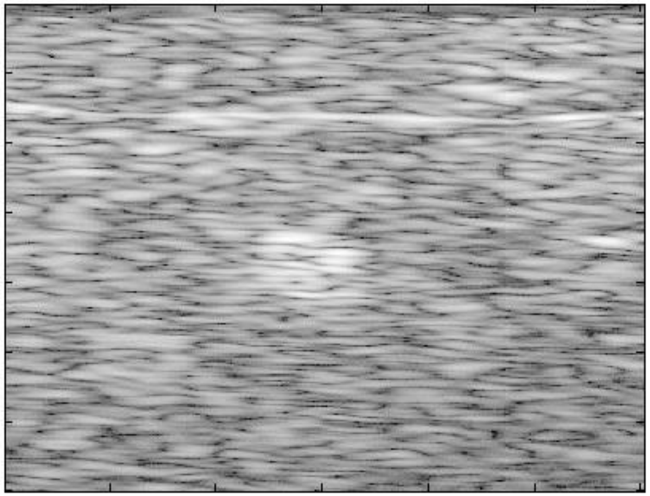
Delta Excitation



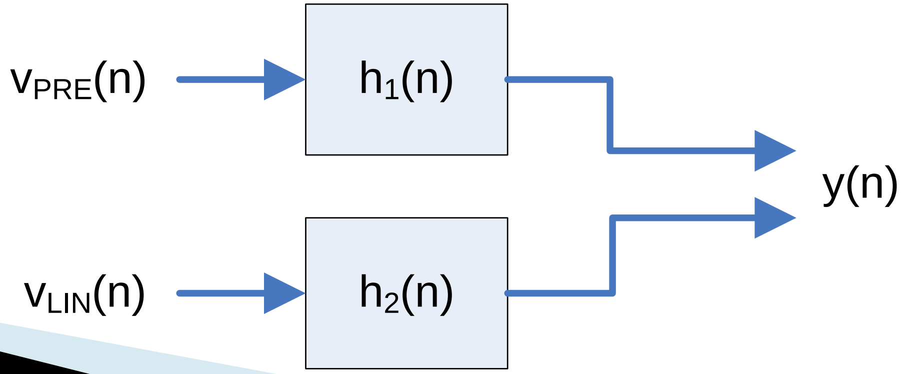
Background – REC

Preenhanced Chirp





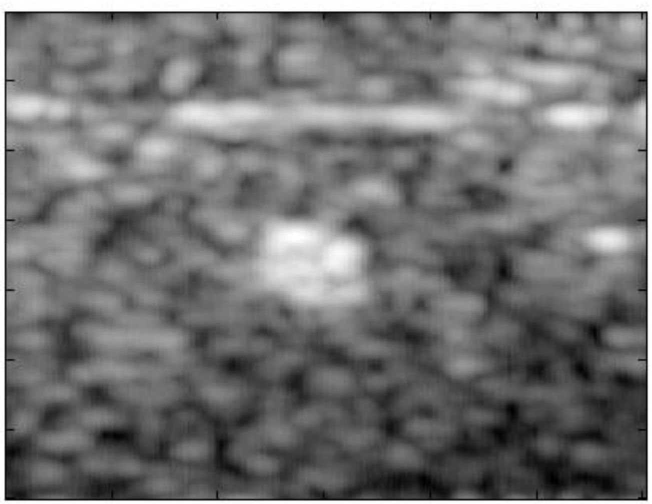
Convolution Equivalence for 2x BW



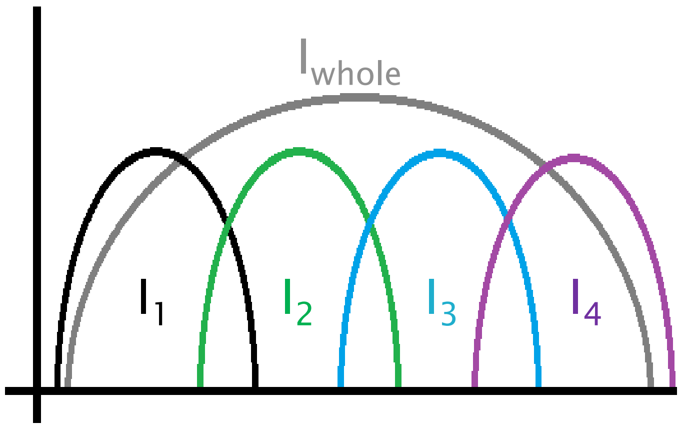
Background – REC-FC

Dr. Sanchez's study
– averaging schemes

I_1 I_2 I_3 I_4 –Partially decorrelated speckle



Filter banks



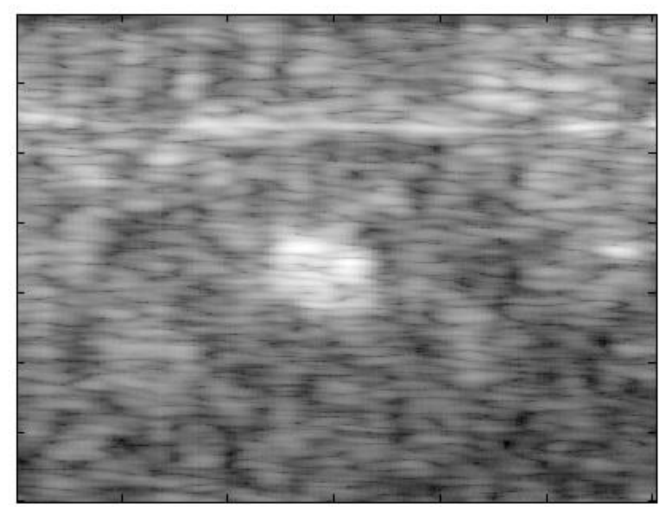
More contrast
More blurring
Less speckle

Background – eREC-FC

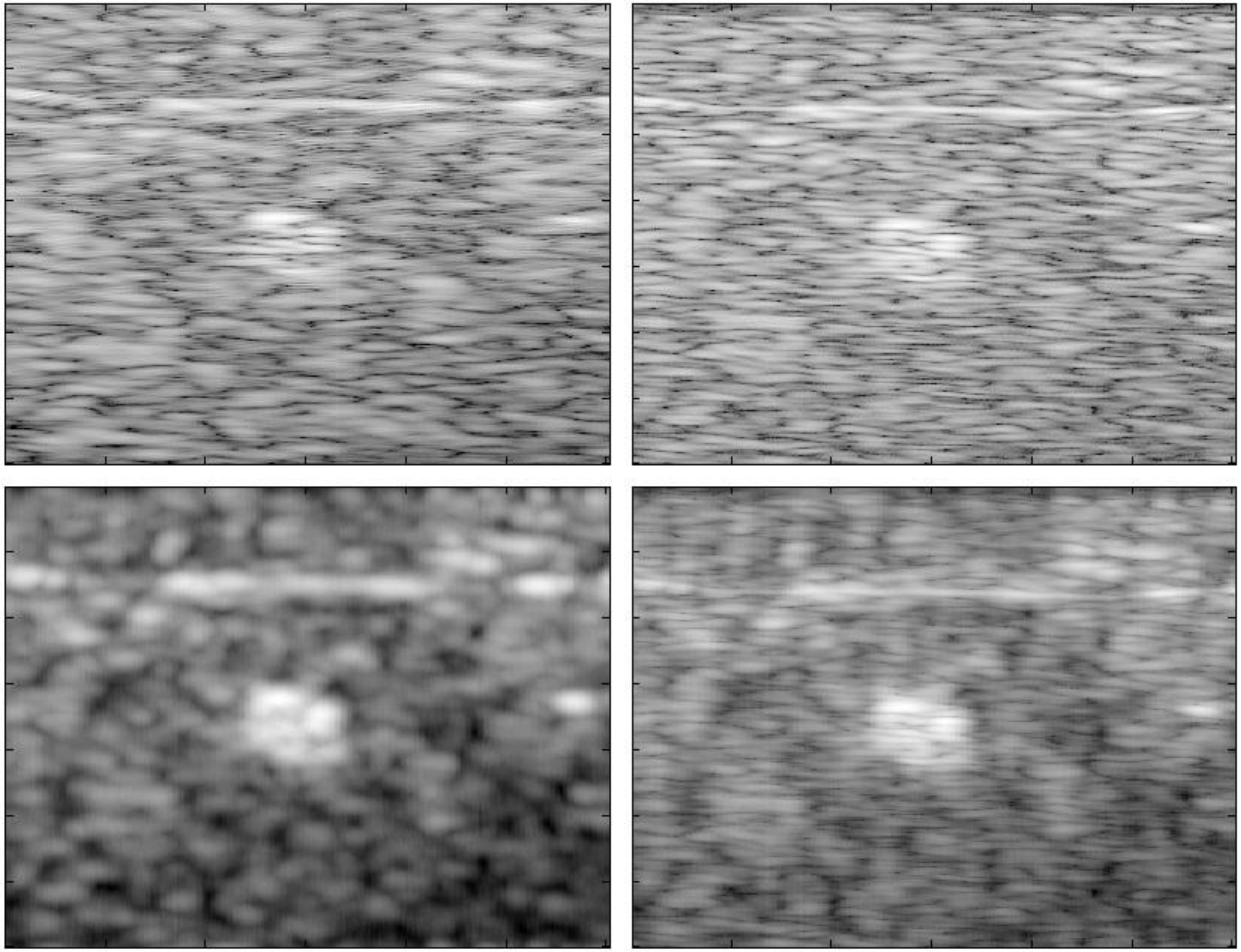
Dr. Sanchez's study – averaging schemes

Average of images generated at different subband widths

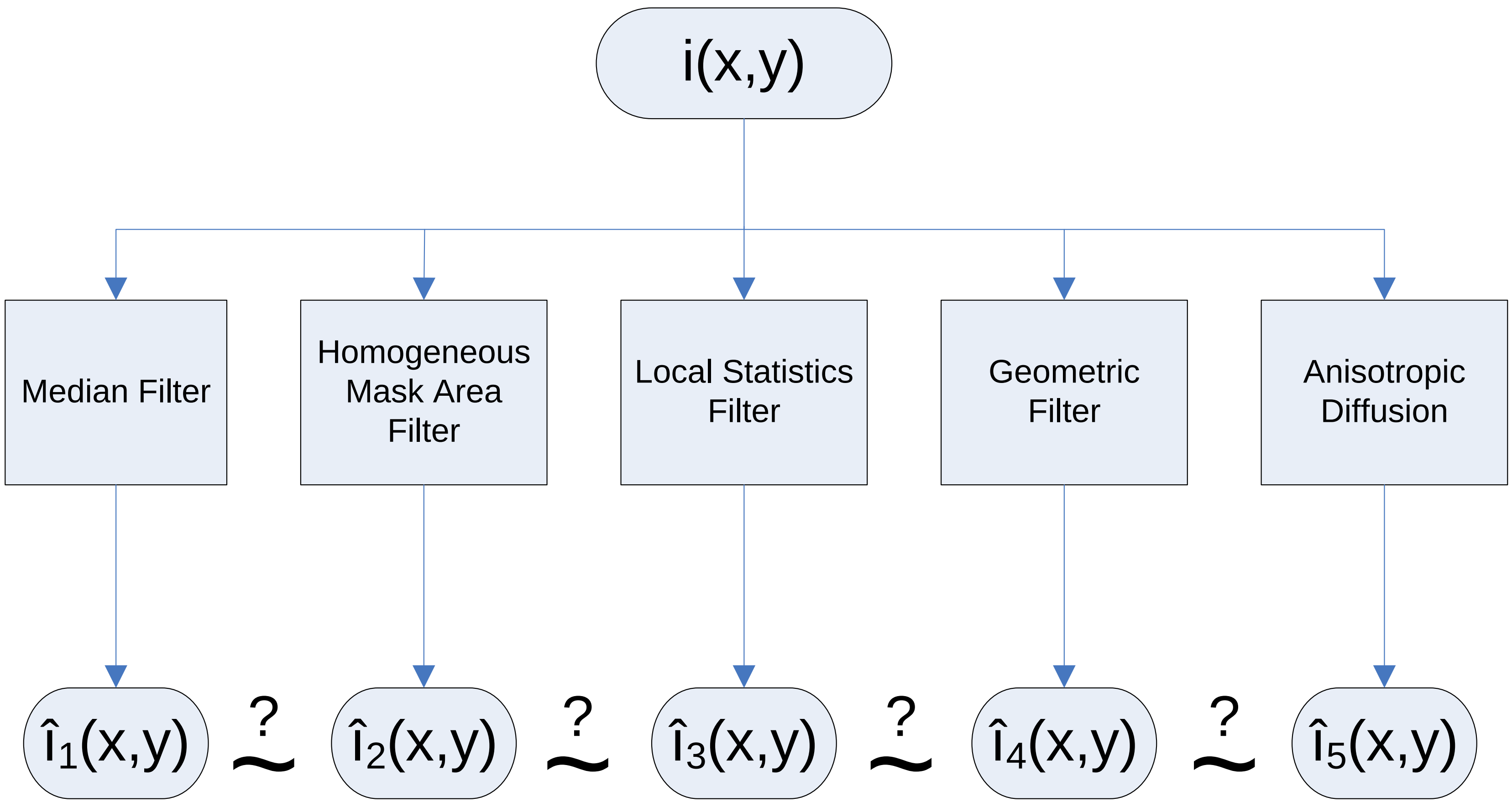
- Improve contrast
- Minimal loss of resolution



Background – Comparison



Background – Postprocessing



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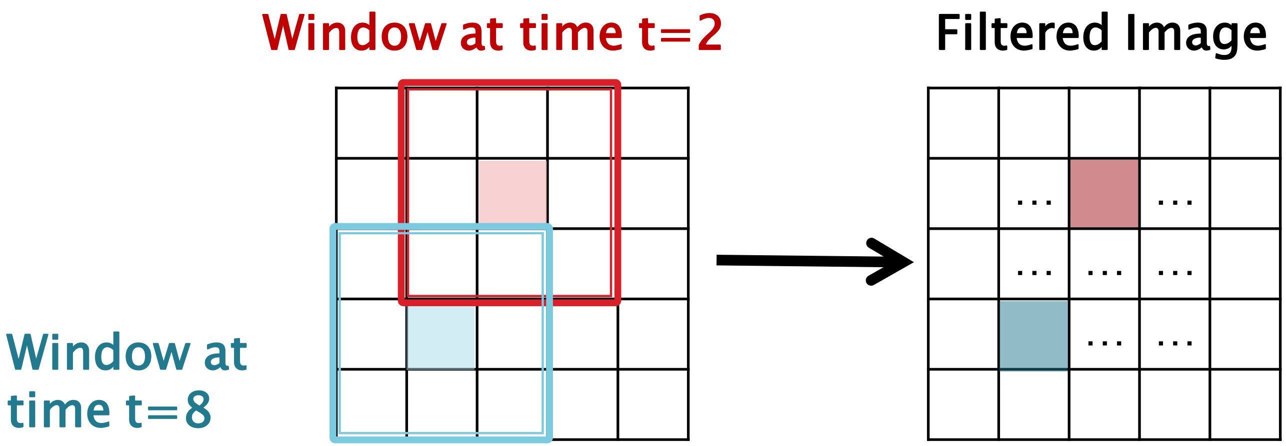
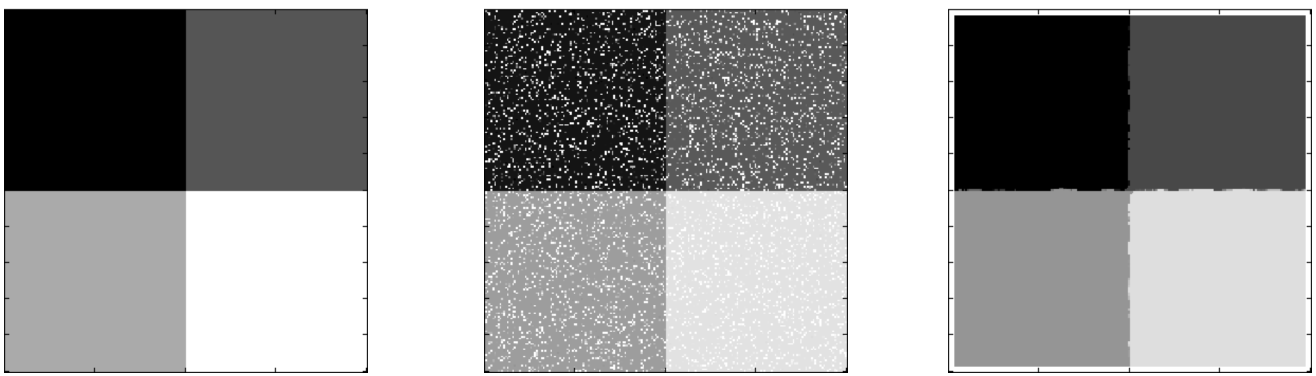
Filters – Windowing

- Moving, overlapping window
- (n x n), odd n



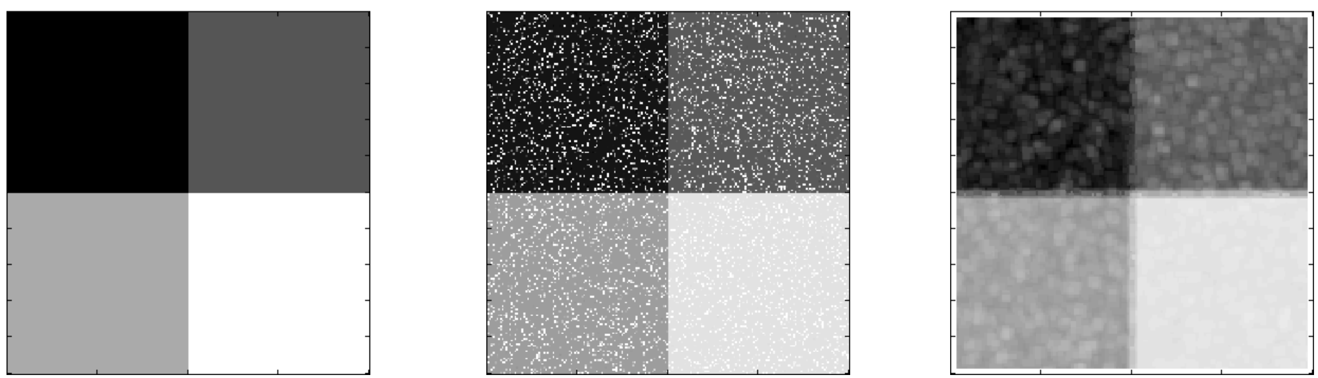
Filters – Median [1]

Median of pixels in a moving window



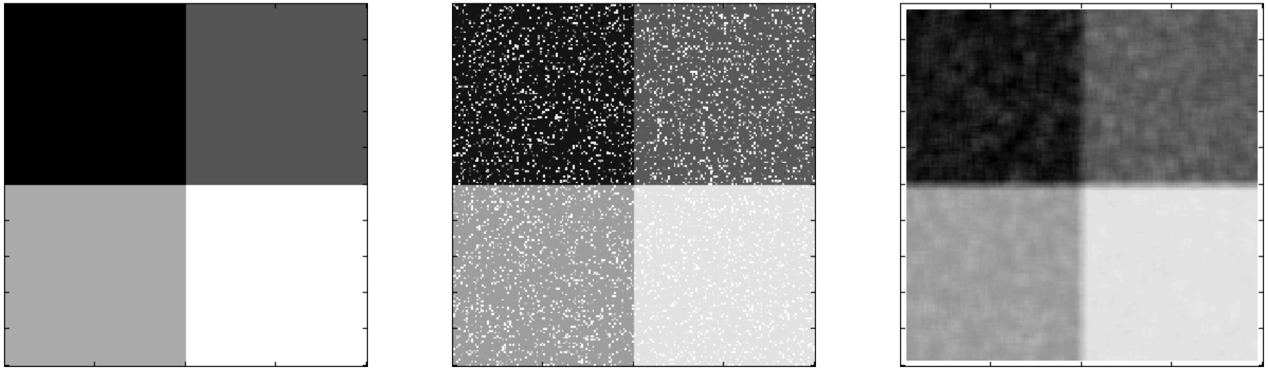
Filters – Homogenous Mask Area [2]

Subwindow m x m inside n x n window, $m = n - 2$
Mean region of smallest speckle index ($\sigma^2/\bar{y}$)



Filters – Local Statistics [2]

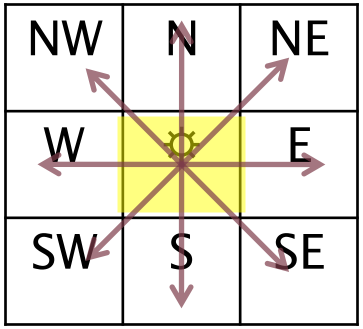
- Lee
  - $k_{lee} = (1 - \bar{y}^2\sigma^2) / (\sigma^2 (1 + \sigma_n^2))$
- Local Statistics Filter
  - Estimate $\sigma_n^2 = \Sigma\, \sigma^2/\bar{y}$
  - $f = \bar{y} + k(y - \bar{y})$

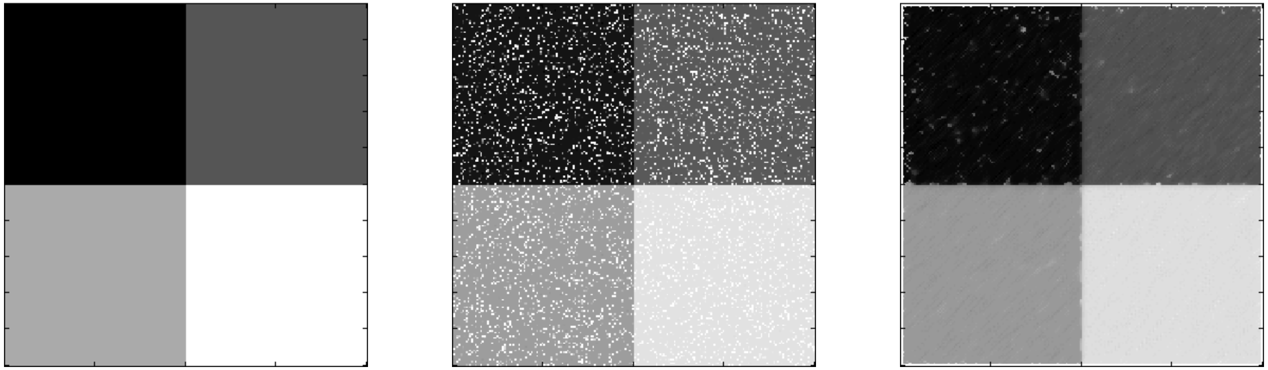


Filters – Geometric [3]

Iterative approach using neighboring pixels:

N–S
E–W
NW–SE
NE–SW



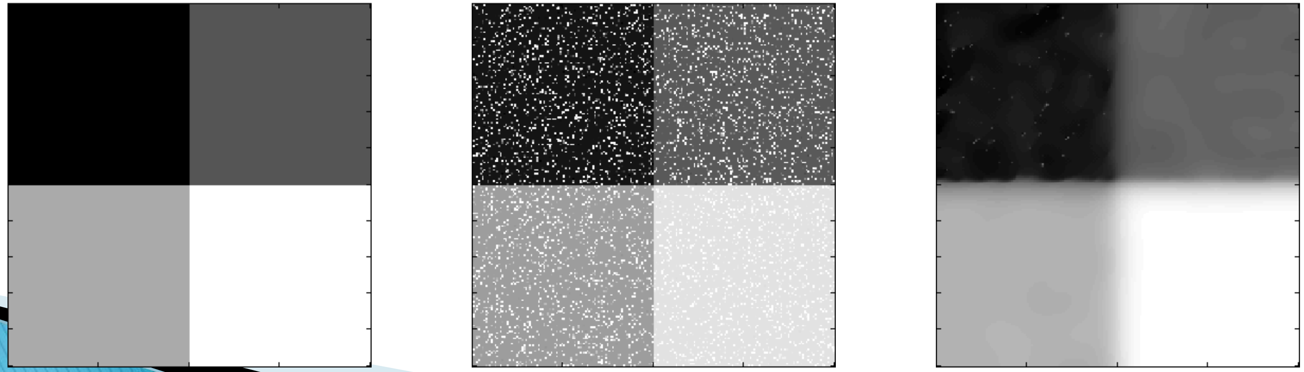


Filters – SRAD [4]

Iterative approach based on anisotropic diffusion model

- Smooth image in homogeneous regions
- Preserve edges
- Image altered by solving a nonlinear PDE

$$\begin{cases} \dfrac{\partial I}{\partial t} = div[c(|\nabla I|) \cdot \nabla I] \\ I(t=0) = I_0 \end{cases} \qquad c(x) = \frac{1}{1+\left(\dfrac{x}{k}\right)^2}$$



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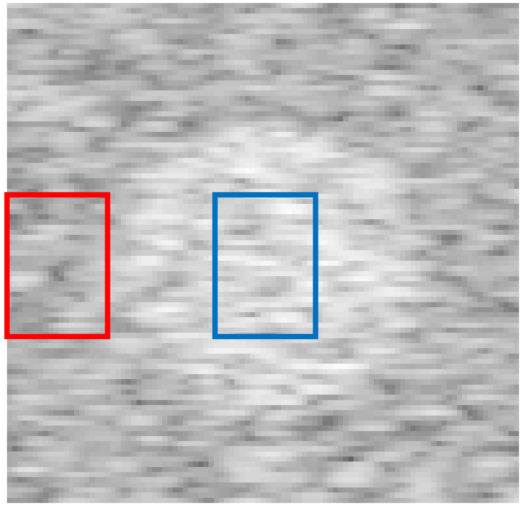
Quantifying Results – Contrast

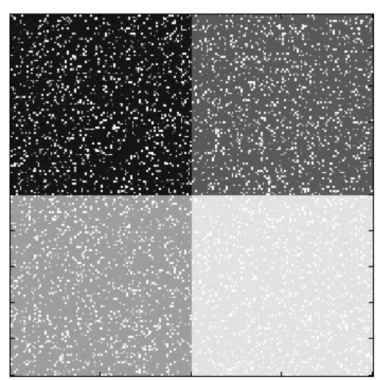
- Contrast-to-Noise Ratio (CNR) [5]
  - $$CNR = \frac{\left|\mu_B - \mu_T\right|}{\sqrt{\sigma_B^2 + \sigma_T^2}}$$



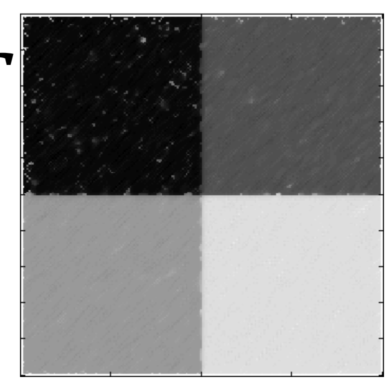
Quantifying Results – Speckle

- Comparative Signal-to-Noise Ratio (cSNR) [2]
  - $cSNR = 10\log_{10} \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(g_{i,j}^2 + f_{i,j}^2\right)}{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(g_{i,j} - f_{i,j}\right)^2}$

g



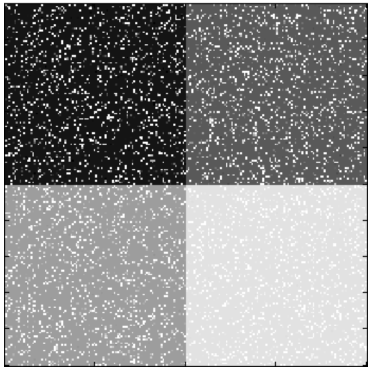
f



Quantifying Results – Overall

- Mean Squared Error (MSE) [2]
  - $$MSE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(g_{i,j} - f_{i,j}\right)^2$$

g



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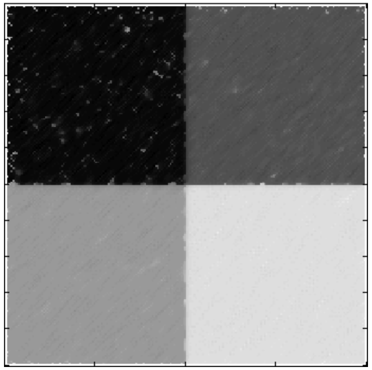

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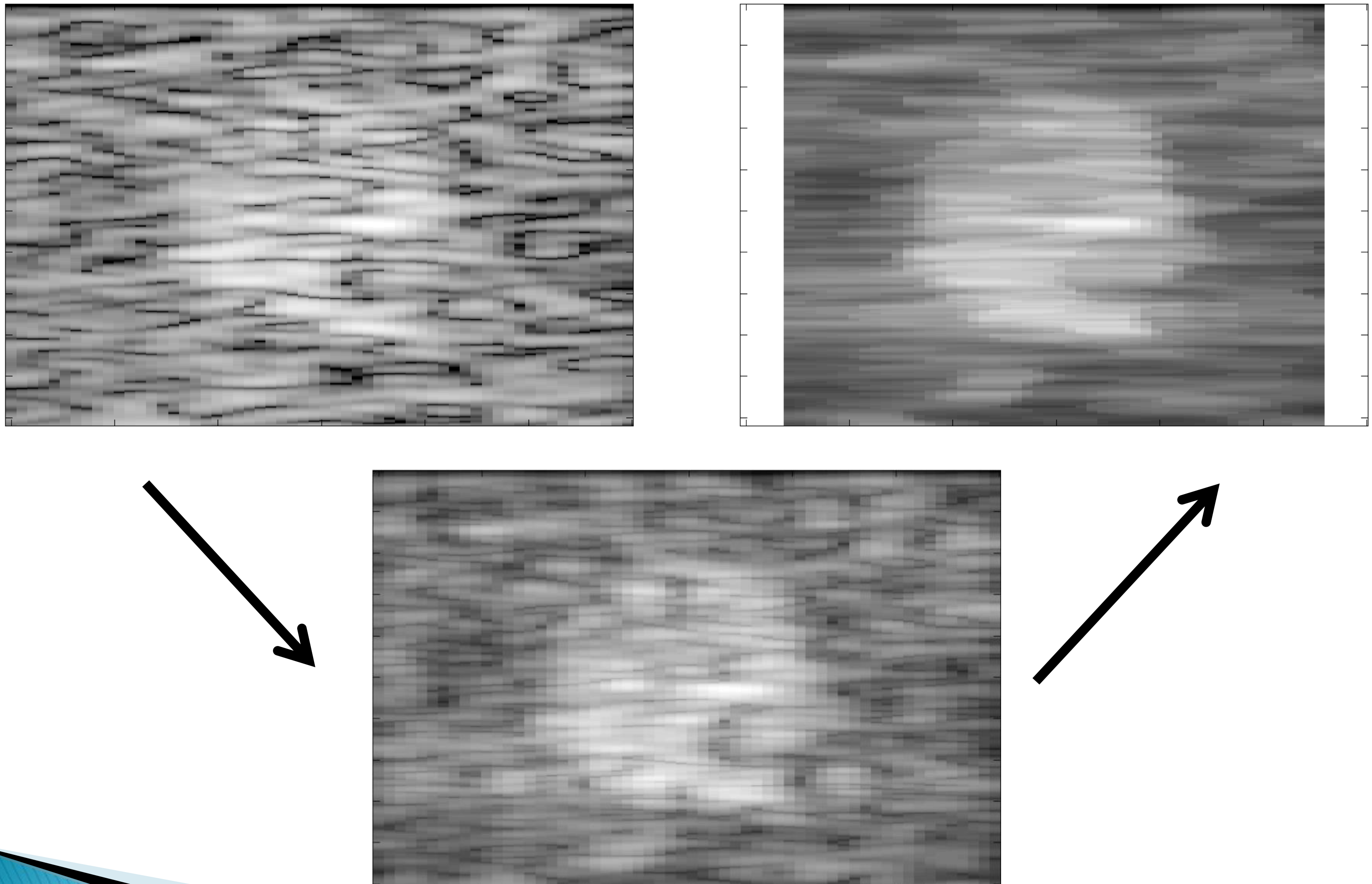
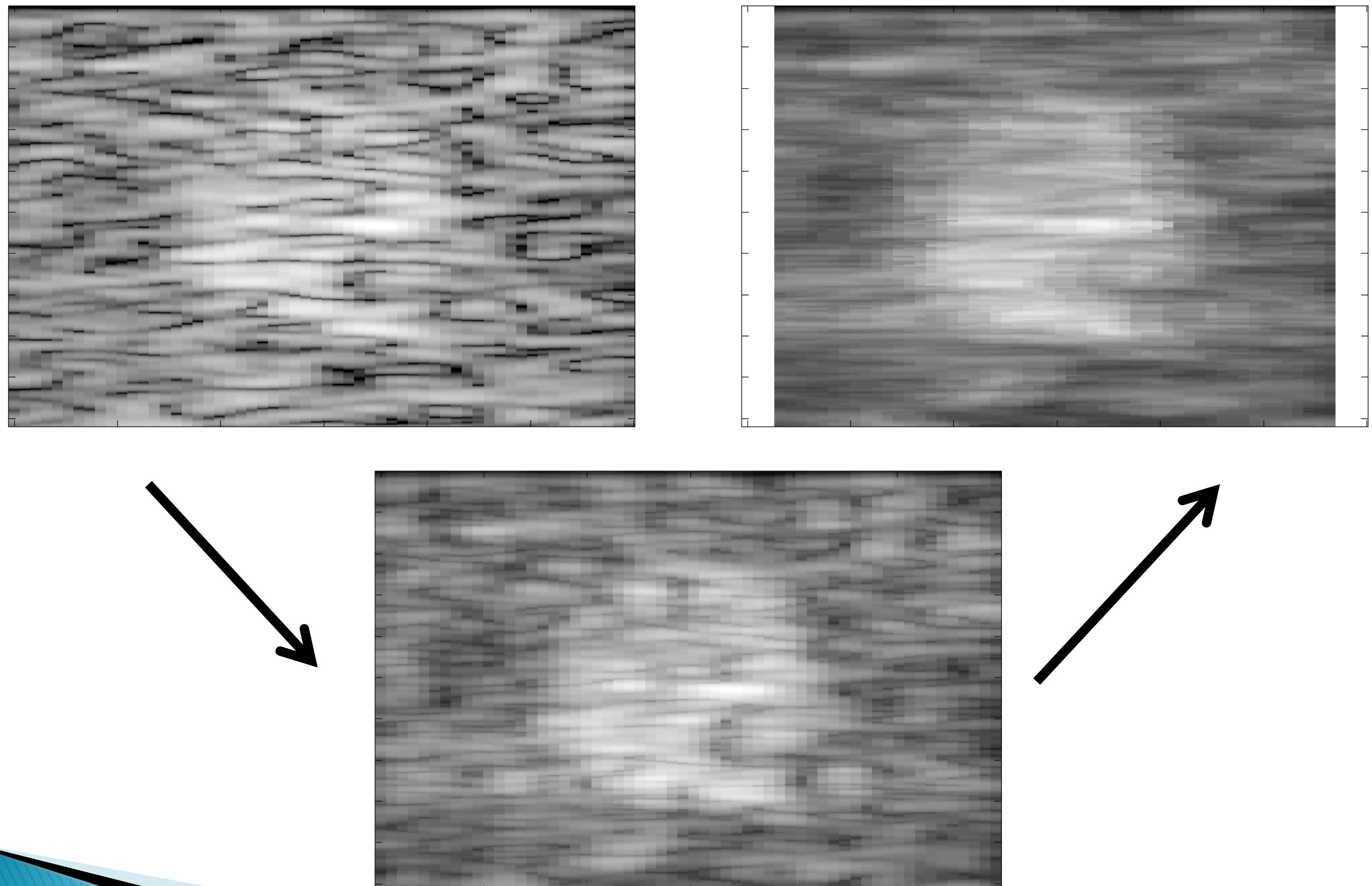
Simulations

- 30 tissue-mimicking phantoms
  - Hyperechoic (+6 dB contrast)
  - 20 scatterers per resolution cell volume
- Based on real single-element transducer
  - Center frequency = 2.25 MHz
  - f/2.66

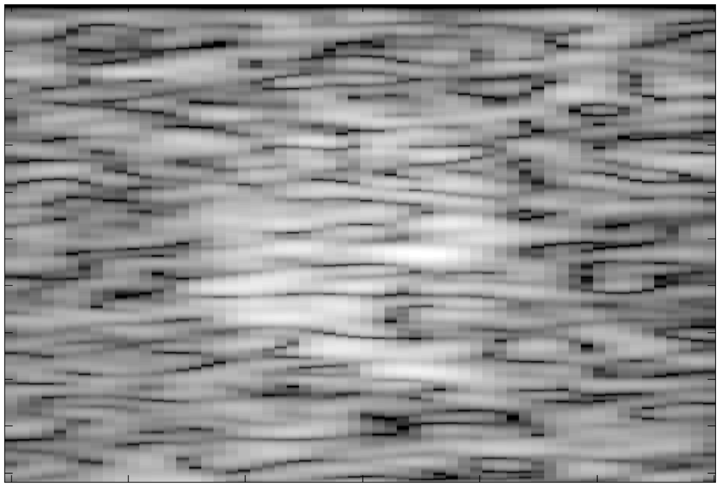
Median Filtering

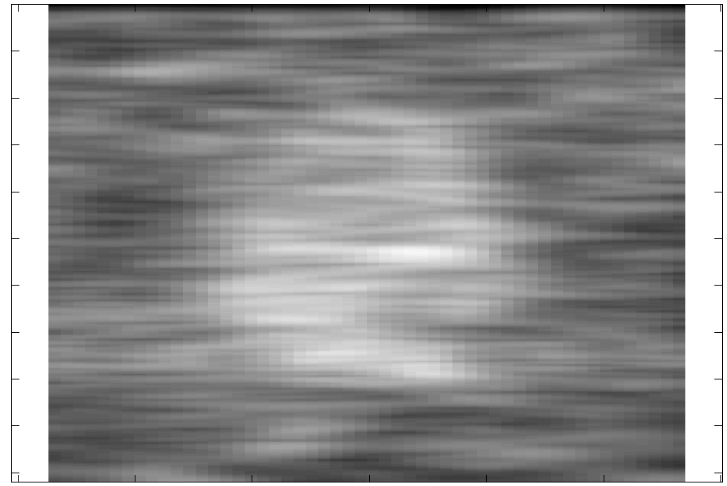


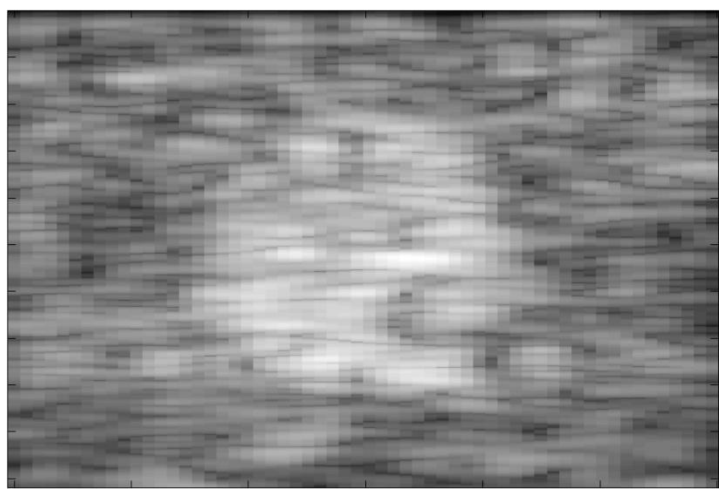
Homogeneous Mask Area Filtering



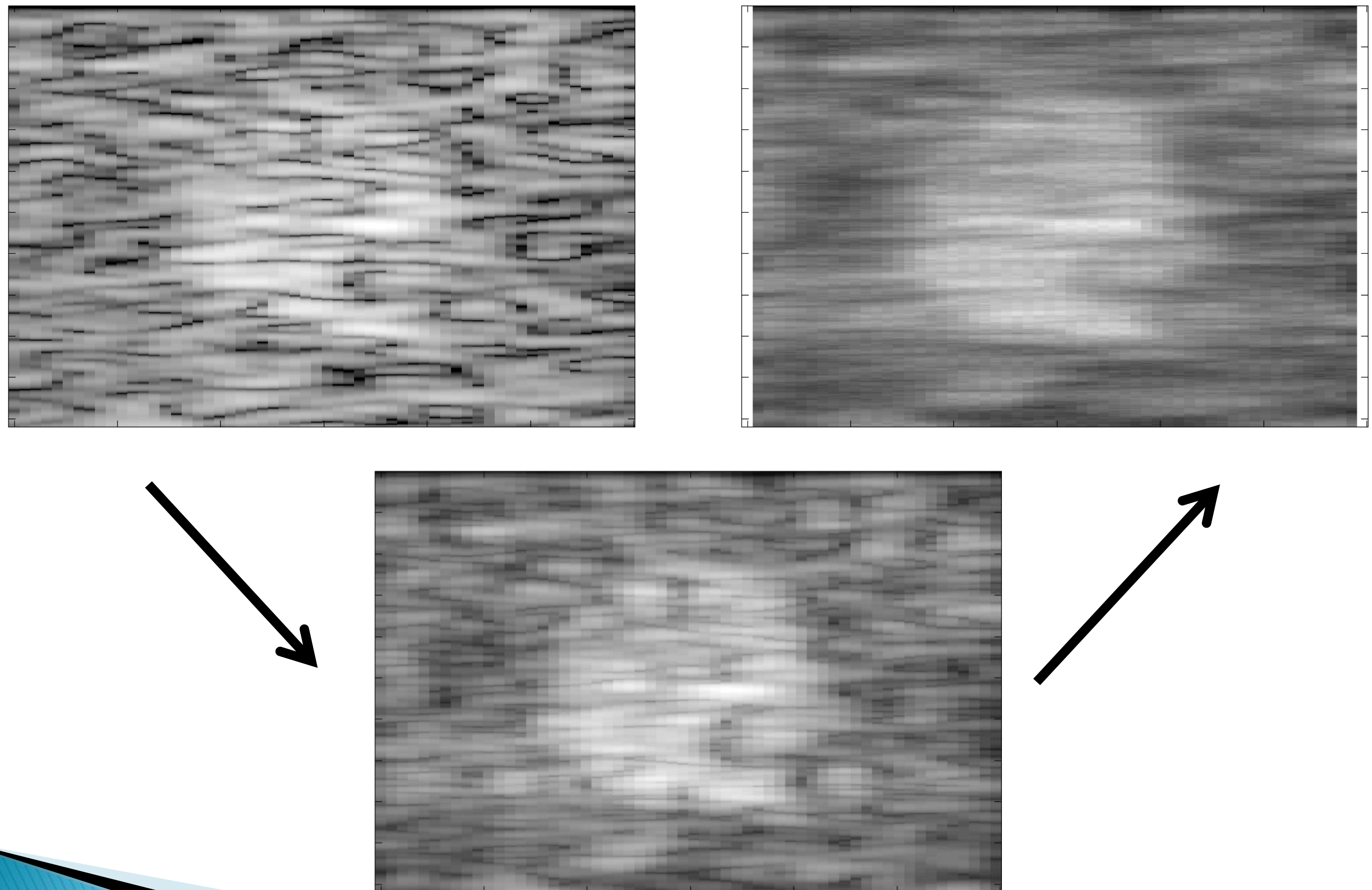
Lee Filtering



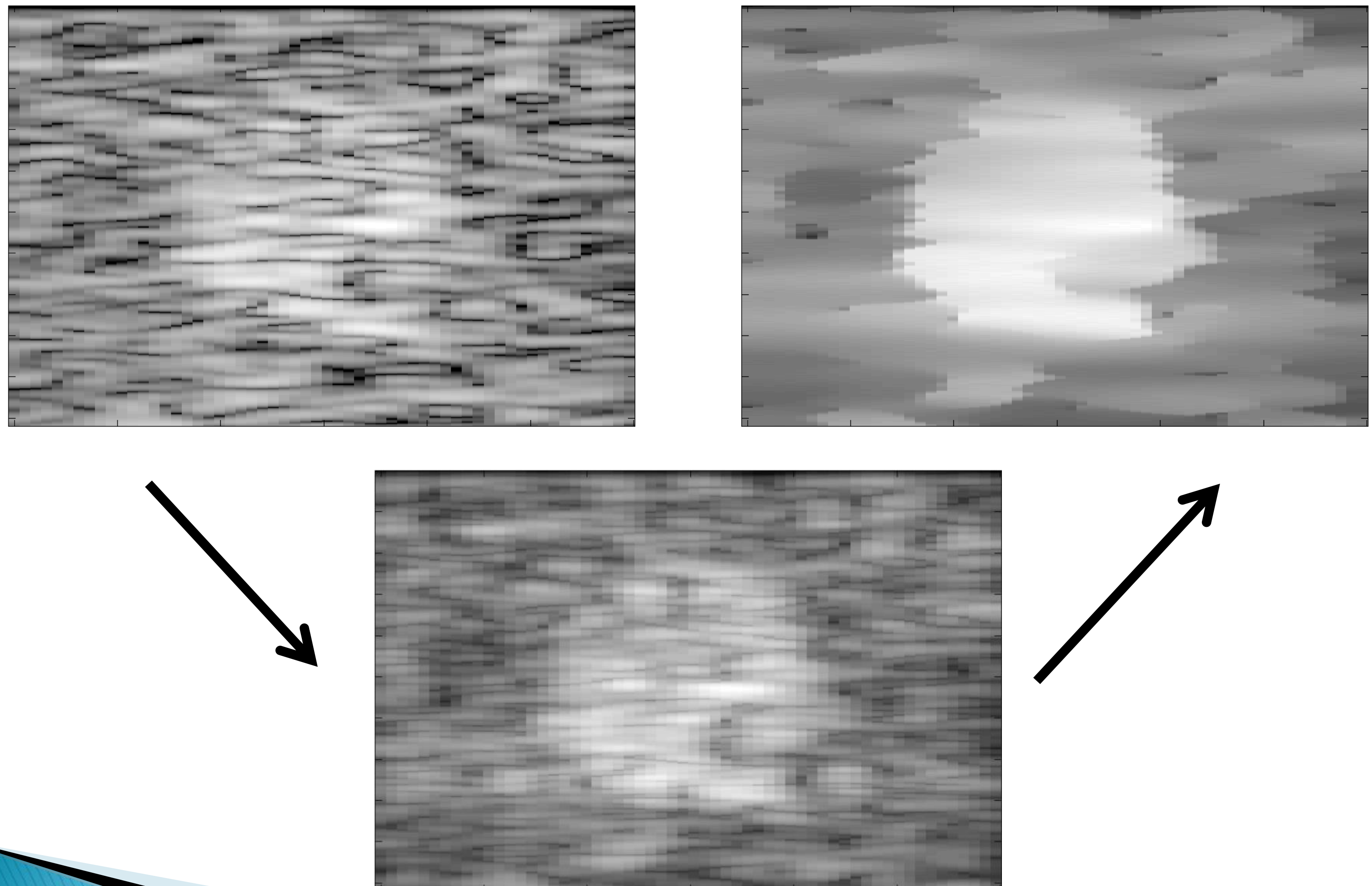




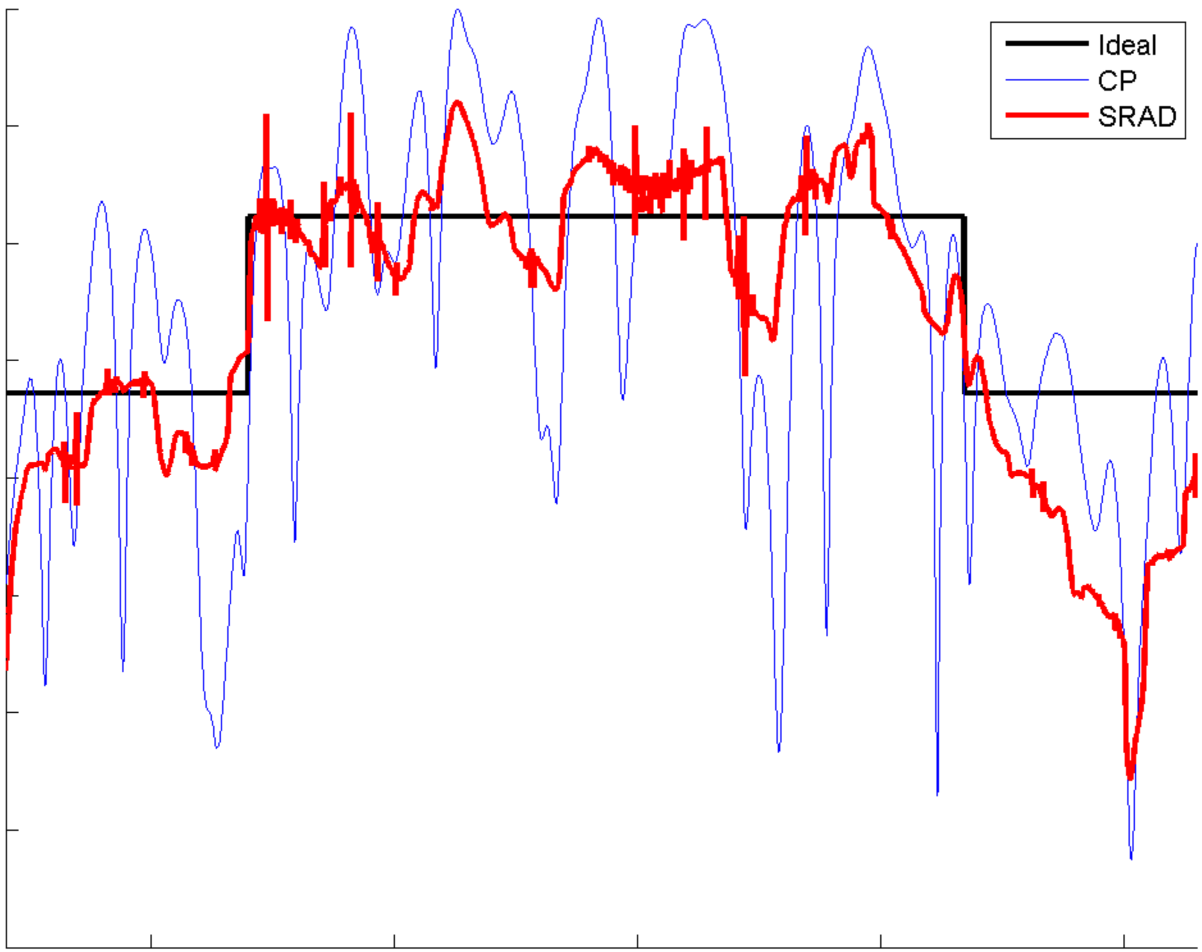
Geometric Filtering



SRAD

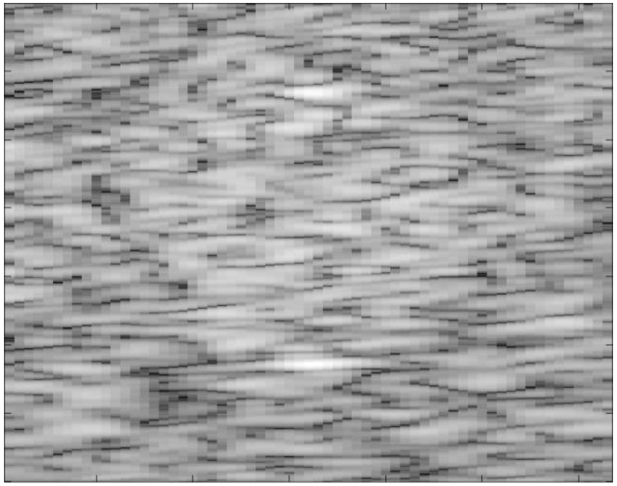


SRAD – Axial Profile

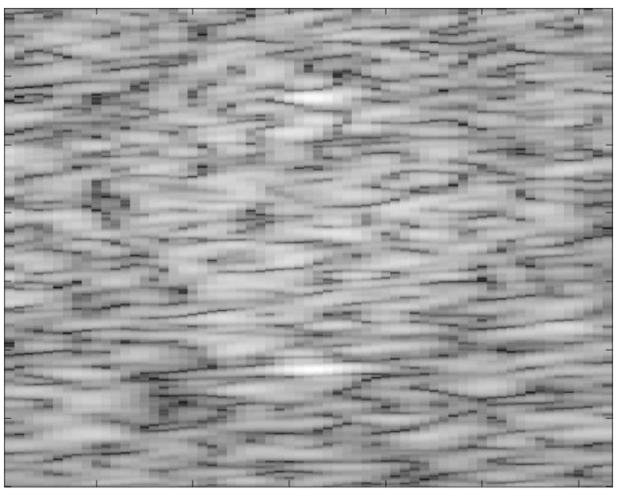
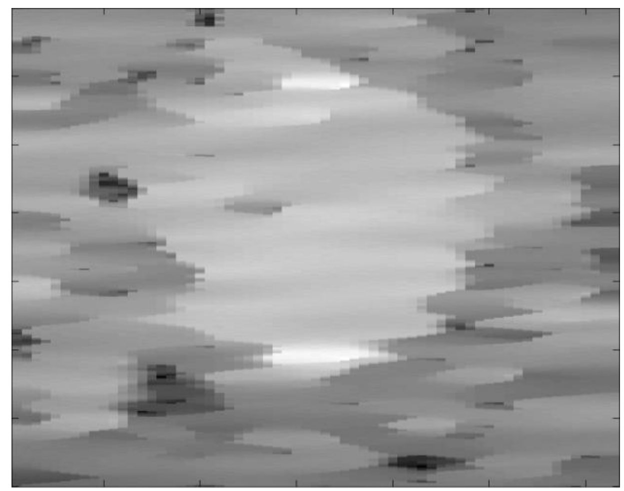


Experimental Example – Less Contrast

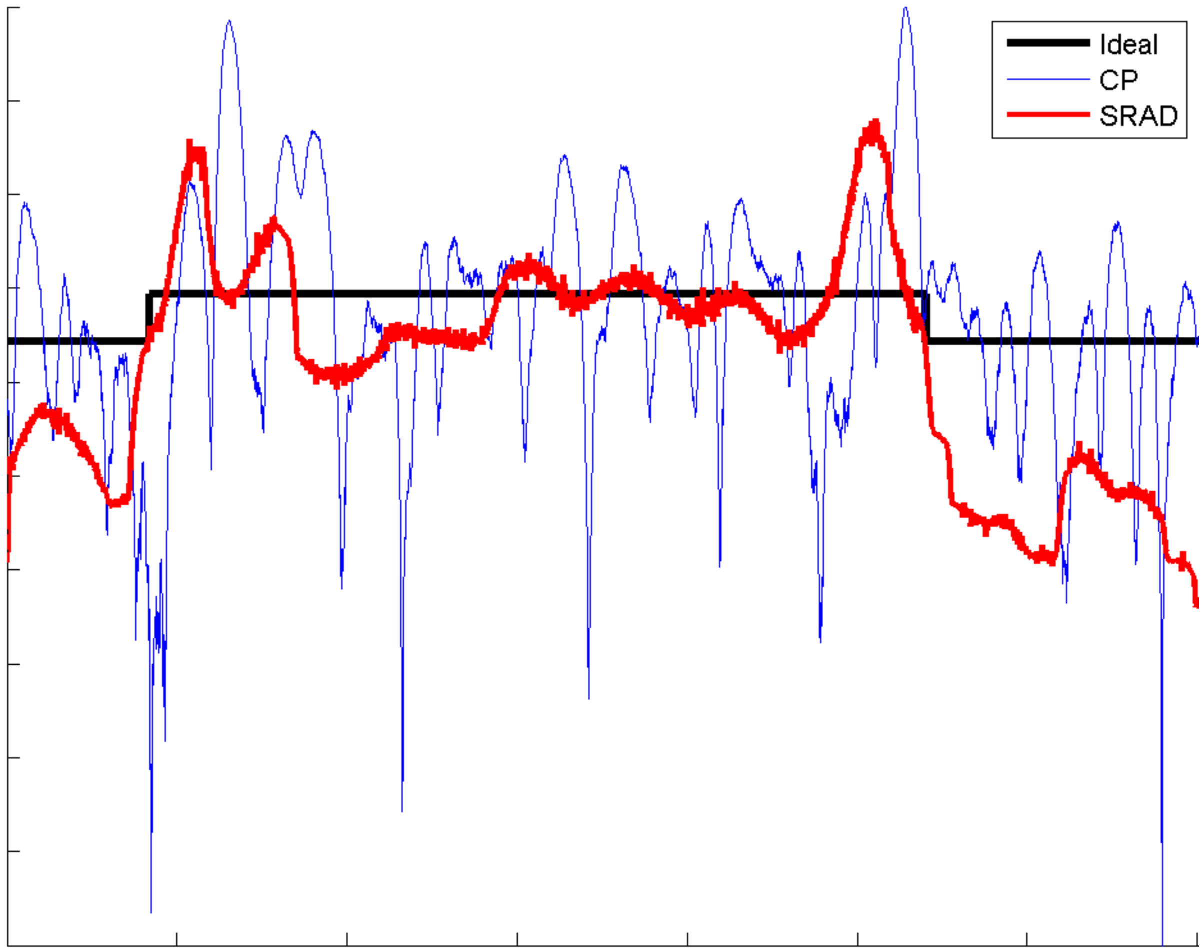
CP



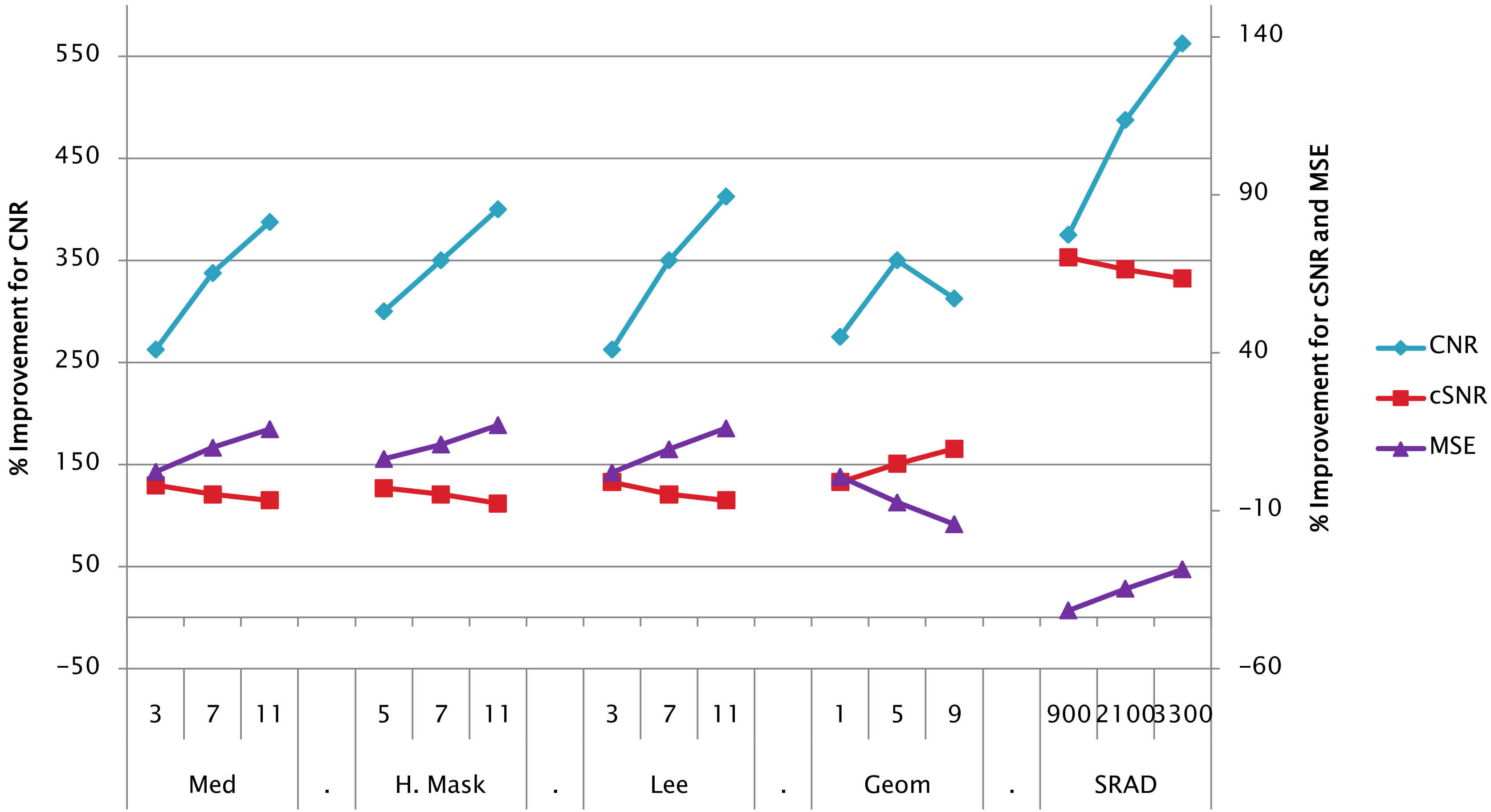
Experimental Example – Less Contrast

CP   SRAD

Experimental Example – Less Contrast Axial Profile



Results – Percent Improvements



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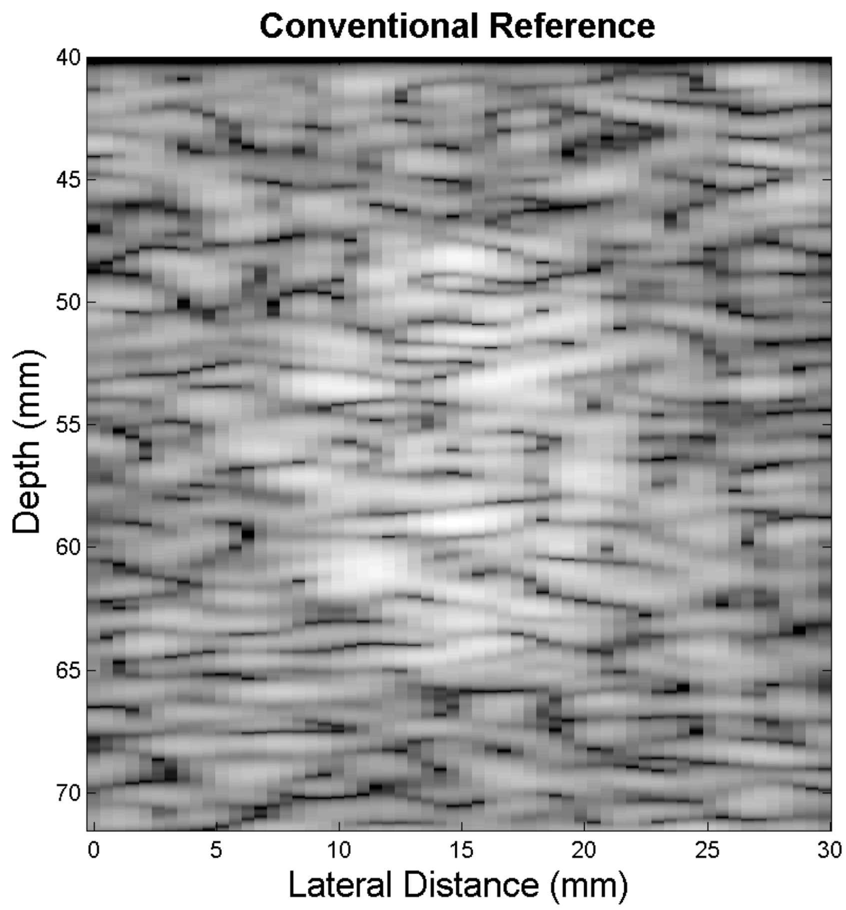
Conclusion

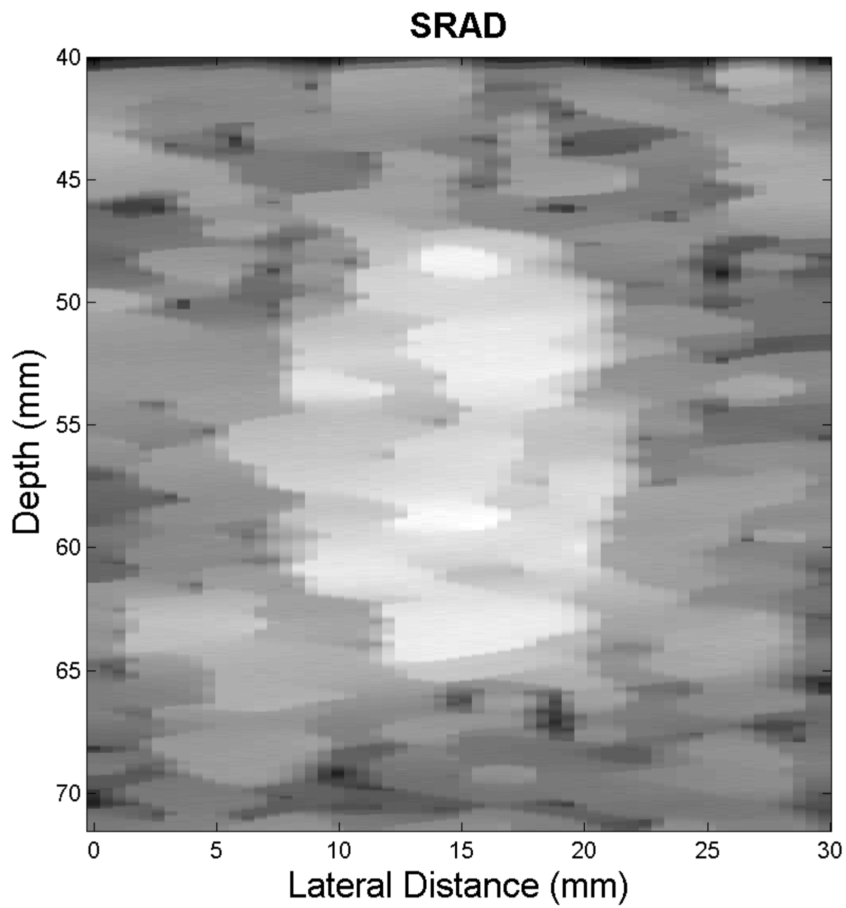
- Reduce speckle and improve contrast while preserving features
- Quality of ultrasound improved
- Results & the Future

Conclusion



Conventional Reference
Depth (mm)
40
45
50
55
60
65
70
0
5
10
15
20
25
30
Lateral Distance (mm)

Conclusion


SRAD
Depth (mm)
40
45
50
55
60
65
70
0
5
10
15
20
25
30
Lateral Distance (mm)

References

[1] M. O. Ahmad and D. Sundararajan, “A fast algorithm for two-dimensional median filtering,” *IEEE Trans. Circuits and Syst.*, vol. CAS-34, no. 11, pp. 1364-1374, Nov. 1987.

[2] C. P. Loizou, C. Christodoulou, C. S. Pattichis, R. Istepanian, M. Pantziaris, and A. Nicolaides. “Speckle reduction in ultrasound images of atherosclerotic carotid plaque,” *14th International Conference on Digital Signal Processing, 2002*, vol. 2, pp. 525-528, 2002.

[3] L. J. Busse, T. R. Crimmins, and J. R. Fienup, “A model based approach to improve the performance of the geometric filtering speckle reduction algorithm,” *IEEE Ultrason. Symposium*, pp. 1353-1356, 1995.

[4] Y. Yu and S. T. Acton, “Speckle reducing anisotropic diffusion,” *IEEE Trans. Image Process.*, vol. 11, no. 11, pp. 1260-1270, Nov. 2002.

[5] M. S. Patterson and F. S. Foster. “The improvement and quantitative assessment for B-Mode images produced by an annular array / cone hybrid.” *Ultrason. Imag.*, vol. 5, no. 3, pp. 195-213, Jul. 1983.

Questions?

Additional Information

- Patents:
  - U.S. Provisional Patent Application, Ser. No. 61/029,479, filed Feb. 18, 2008, by Dr. Oelze, entitled "Ultrasonic Imaging Speckle Suppression and Contrast Enhancement Technique."

- Anisotropic Diffusion
  - Nonlinear PDE

$$\begin{cases} \frac{\partial I}{\partial t} = div[c(|\nabla I|) \cdot \nabla I] \\ I(t=0) = I_0 \end{cases}$$

P. Perona and J. Malik, "Scale space and edge detection using anisotropic diffusion," *IEEE Trans. Pattern Anal. Machine Intell.,* vol. 12, pp. 629–639, 1990.

Additional Information

- Geometric Filtering
  - a = left/top pixel, b = center pixel, c = right/bottom pixel

  - if $a \geq b+2$, $b = b+1$;
  - if $a > b \leq c$, $b = b+1$;
  - if $c > b \leq a$, $b = b+1$;
  - if $c \geq b+2$, $b = b+1$;

  - if $a \leq b-2$, $b = b-1$;
  - if $a < b \geq c$, $b = b-1$;
  - if $c < b \geq a$, $b = b-1$;
  - if $c \leq b-2$, $b = b-1$;

Additional Information

- REC Technique

$$h_1(n) * v_1(n) = h_2(n) * v_2(n)$$

$$v_{PRE}(n) = v_{LIN}(n) * \varphi(n)$$

$$V_{PRE}(\omega) \times H_1(\omega) = V_{LIN}(\omega) \times H_2(\omega)$$

$$V_{PRE}(\omega) = V_{LIN}(\omega) \times \frac{H_2(\omega)}{H_1(\omega)} = V_{LIN}(\omega) \times \psi(\omega)$$

$$\psi(\omega) = \frac{\mathrm{H}_1^*(\omega)}{|\mathrm{H}_1(\omega)|^2 + |\mathrm{H}_1(\omega)|^{-2}}$$

$$V_{PRE}(\omega) = V_{LIN}(\omega) \times H_2(\omega) \times \psi(\omega)$$

M. L. Oelze, "Bandwidth and resolution enhancement through pulse compression," *IEEE Trans. Ultrason., Ferroelectr. Freq. Contr.*, vol. 54, no. 4, p. 770, Apr 2007.