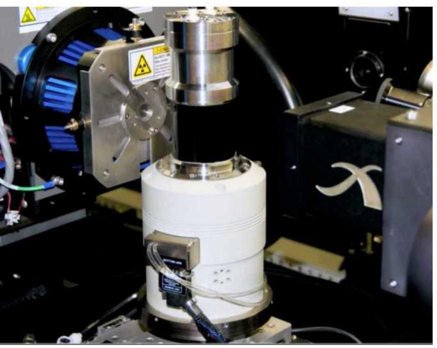
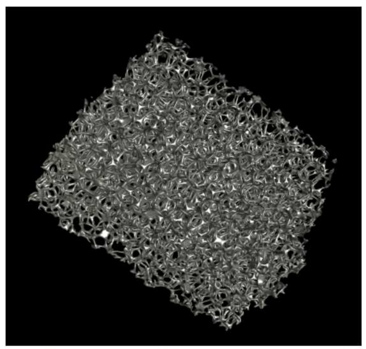
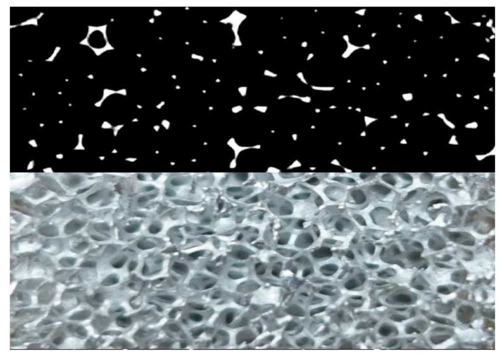
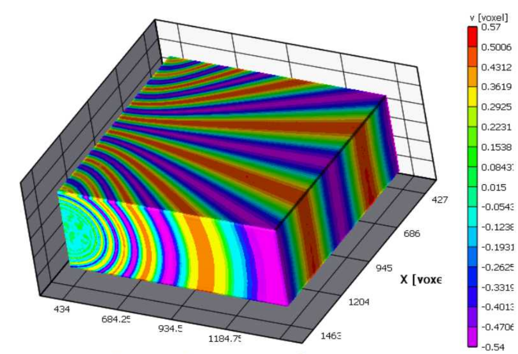
SAND2018-12101PE









Numerical Deformation for Digital Volume Correlation

By Samuel Fayad

Phil Reu and Ryan Goodner

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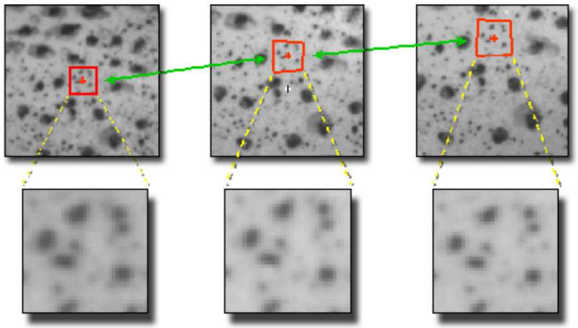
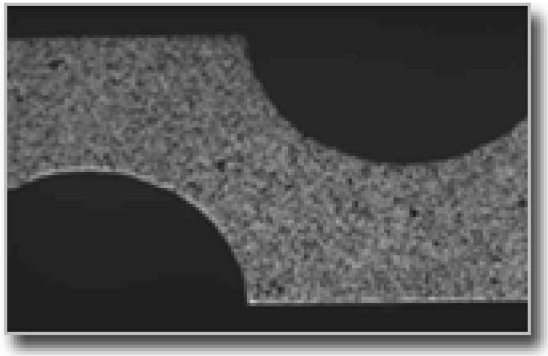
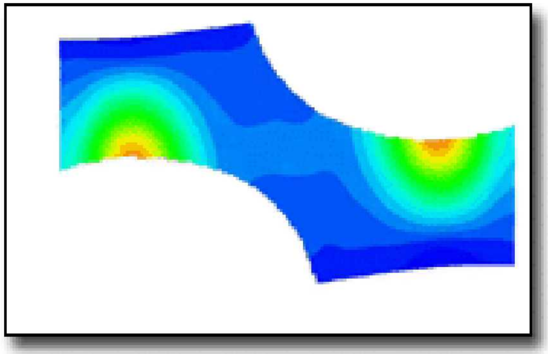
Outline

- Background on DIC/DVC
- Motivation
- Overview of Analytic Equations
- Development of Deformation Code
- Optimization for Volumetric Data
- Code Verification
- Examples of use
- DVC/DIC performance
- Synthetic Noise

Background

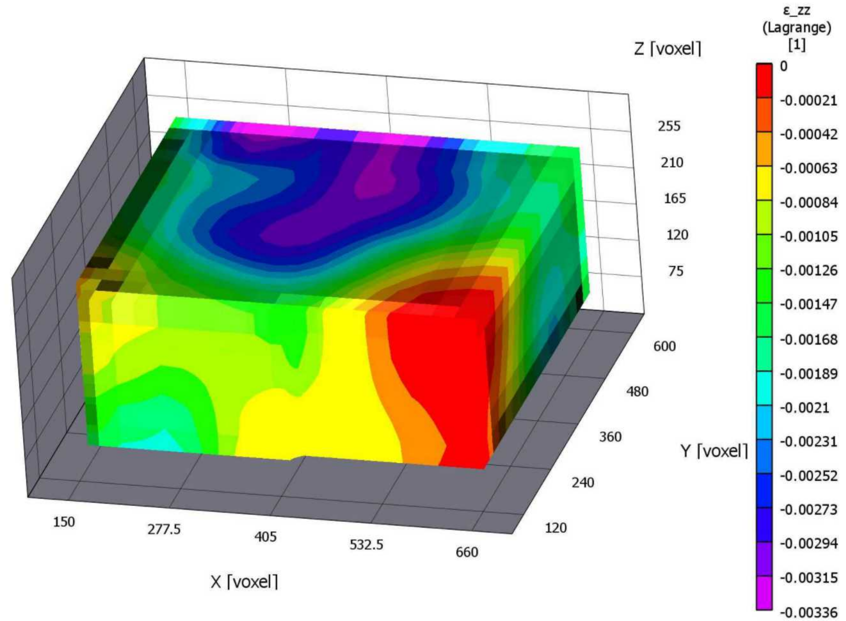






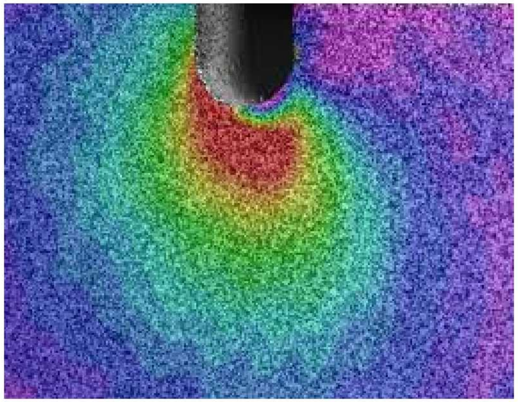
Correlated Solutions, **Principle of Digital Image Correlation Overview**

Displacement and deformation measurements based on the grayscale tracking of local pixel clusters of size NxN. Used often in material characterization research.



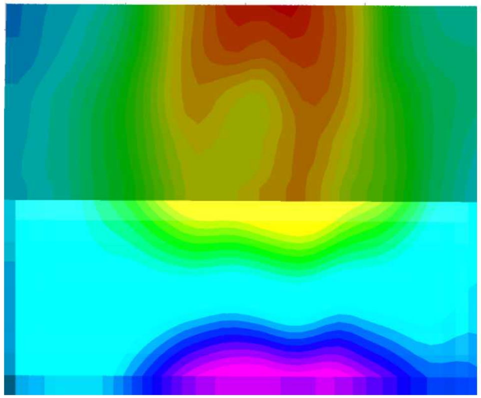
DVC, the 3D analog of DIC

Spatial and Displacement Resolution

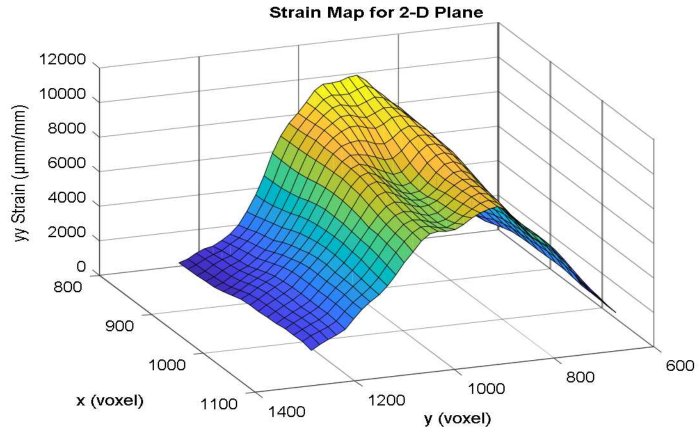


J.P. Parmigiani, **Failure of Notched Laminates Under Out-of-Plane Bending, Phase V Update**

Concentrated strains can be difficult to detect due to the spatial averaging of the chosen window.

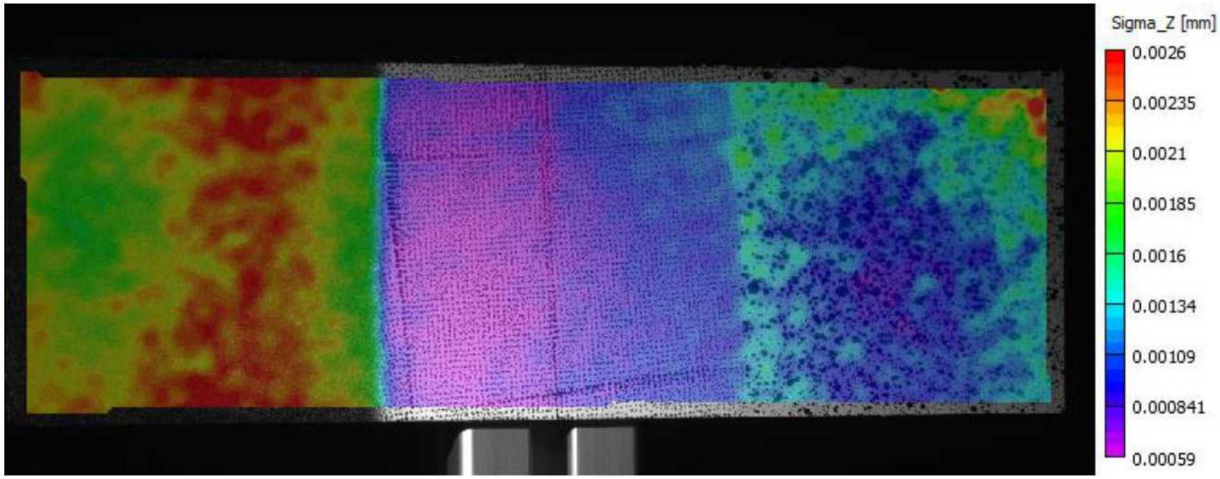


Al Foam subject to a reversed three point bend test



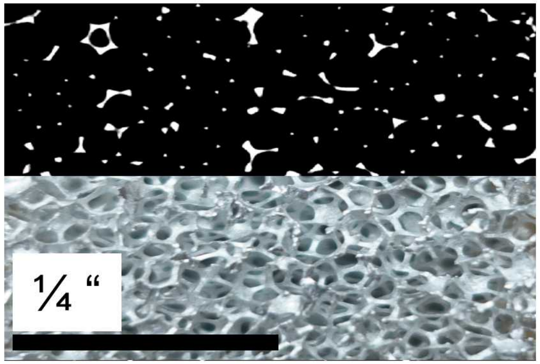
High strain gradients are also difficult to resolve

Limitations from Speckle Pattern



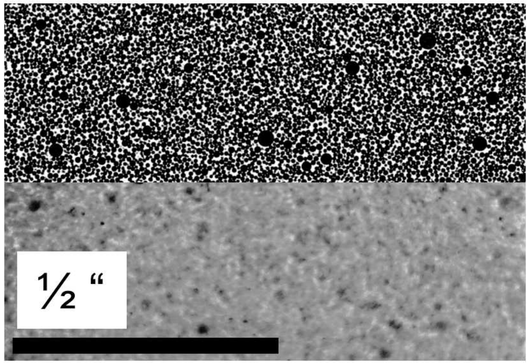
N. Lovas, **Speckle Pattern Fundamentals,** Correlated Solutions

Speckle Density vs Resolution



CT slice

Digital image

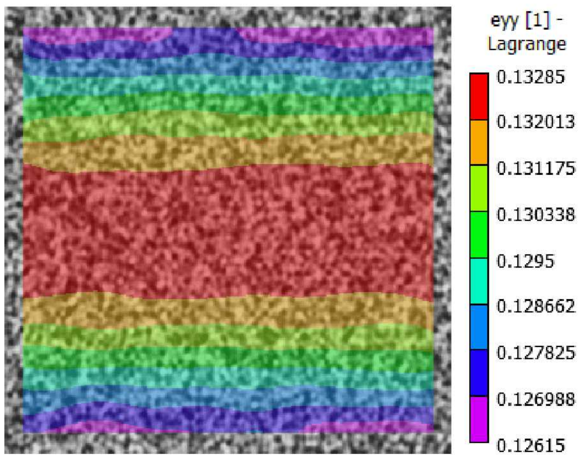


Low Density Al Foam

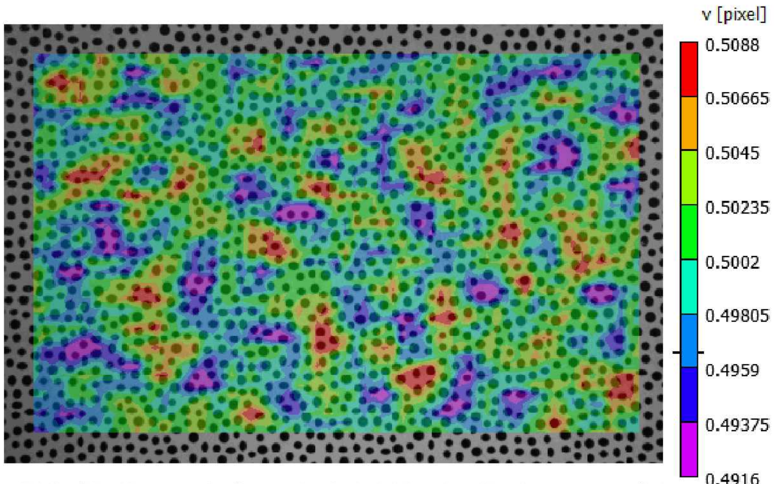
High Density Polyurethane Foam

Accurate numerical deformation needed for quantitative error analysis

Numerical Deformation for DIC

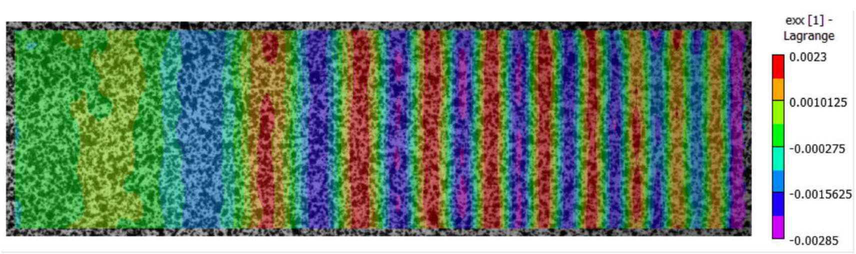


DIC Challenge 1: Sample 10 sinusoidal strain (TexGen)

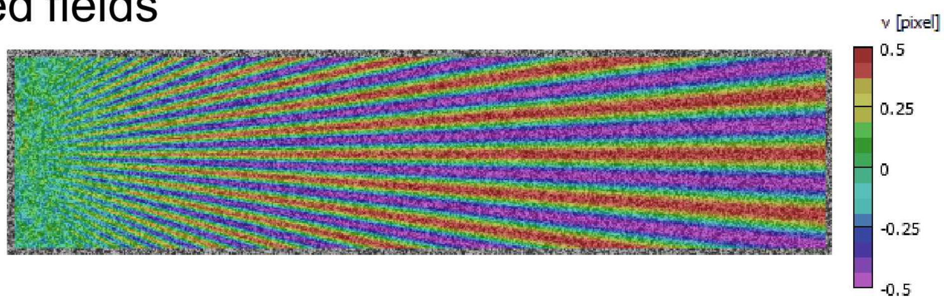


DIC Challenge 1: Sample 6 rigid body displacement (binned)

FFT deformed fields



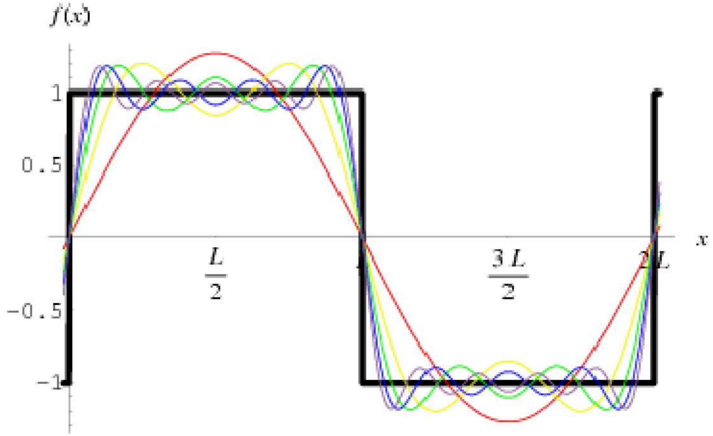
DIC Challenge 1: Sample 14 varying strain



DIC Challenge Star Displacement Pattern

This method was attractive for DVC applications due to the success in DIC and simplicity of application

Fourier Transform



Weisstein, Eric W. "Fourier Series--Square Wave."

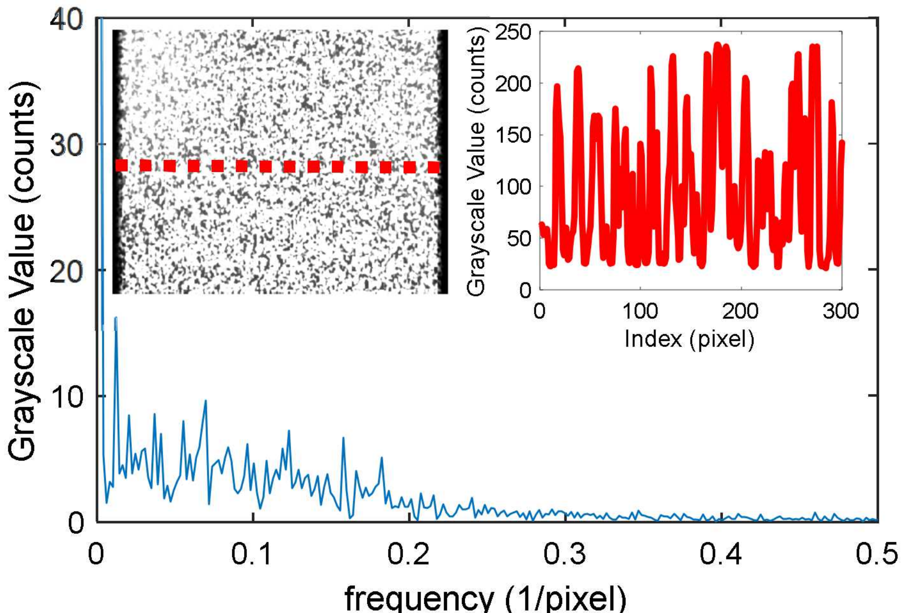
$$DFT:\ X_k = \sum_{n=0}^{N-1} x_n * e^{-\frac{2\pi i}{N}kn}$$

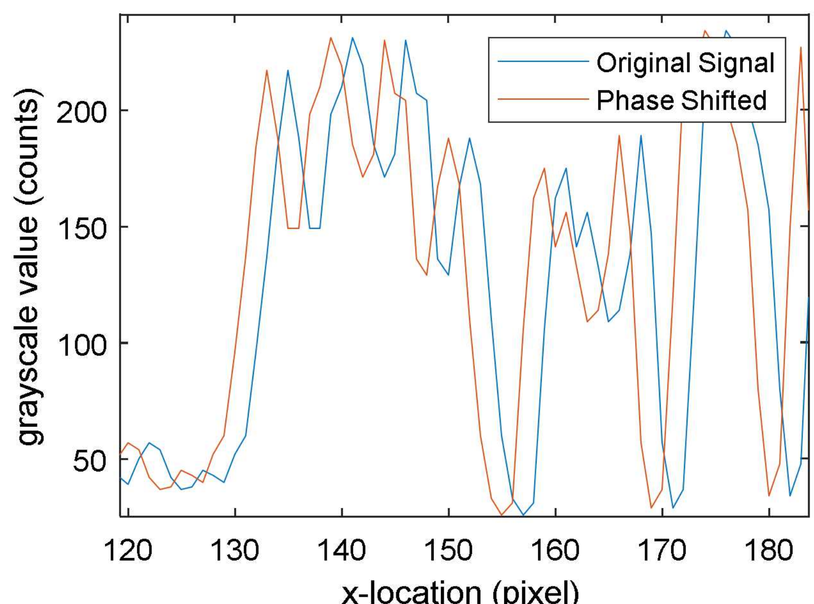
$O(n^2)$

FFT

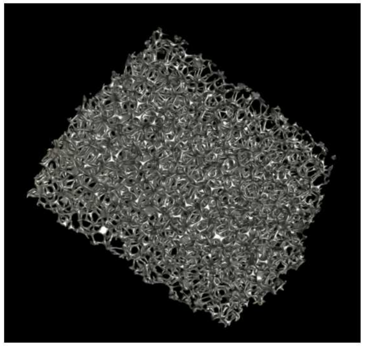
$O(n\log(n))$

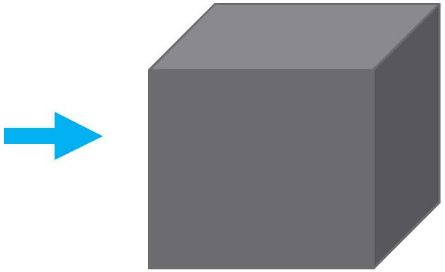
Fourier Phase Shift Equation $I'_{i,j} = \mathcal{F}^{-1}\left[\mathcal{F}\left(I_{i,j} * w_{i,j}\right) * \mathrm{e}^{-2i*\pi*\varphi*\frac{k}{L}}\right]$





Conversion to Volumetric





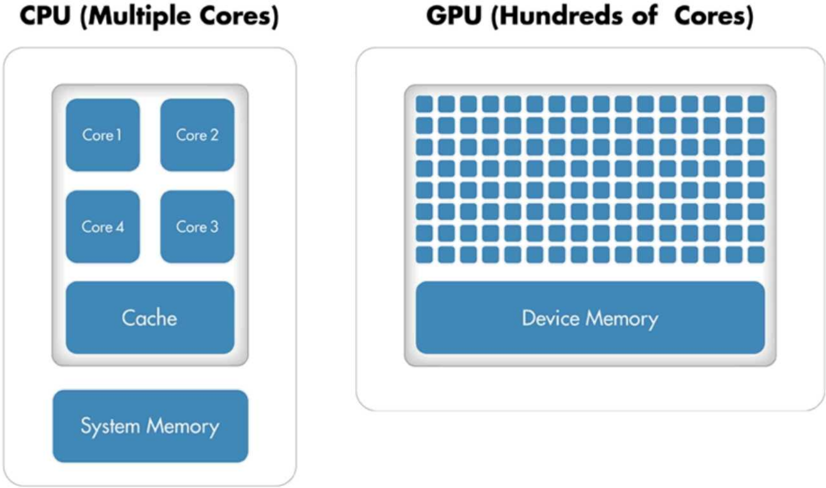
CT voxel array of dimension N^3

Number of operations for single dimension displacement:

$O(\log(N) * N^3)$ Per Tiff

CPU not ideal for large scale calculation

GPU-Based Processing



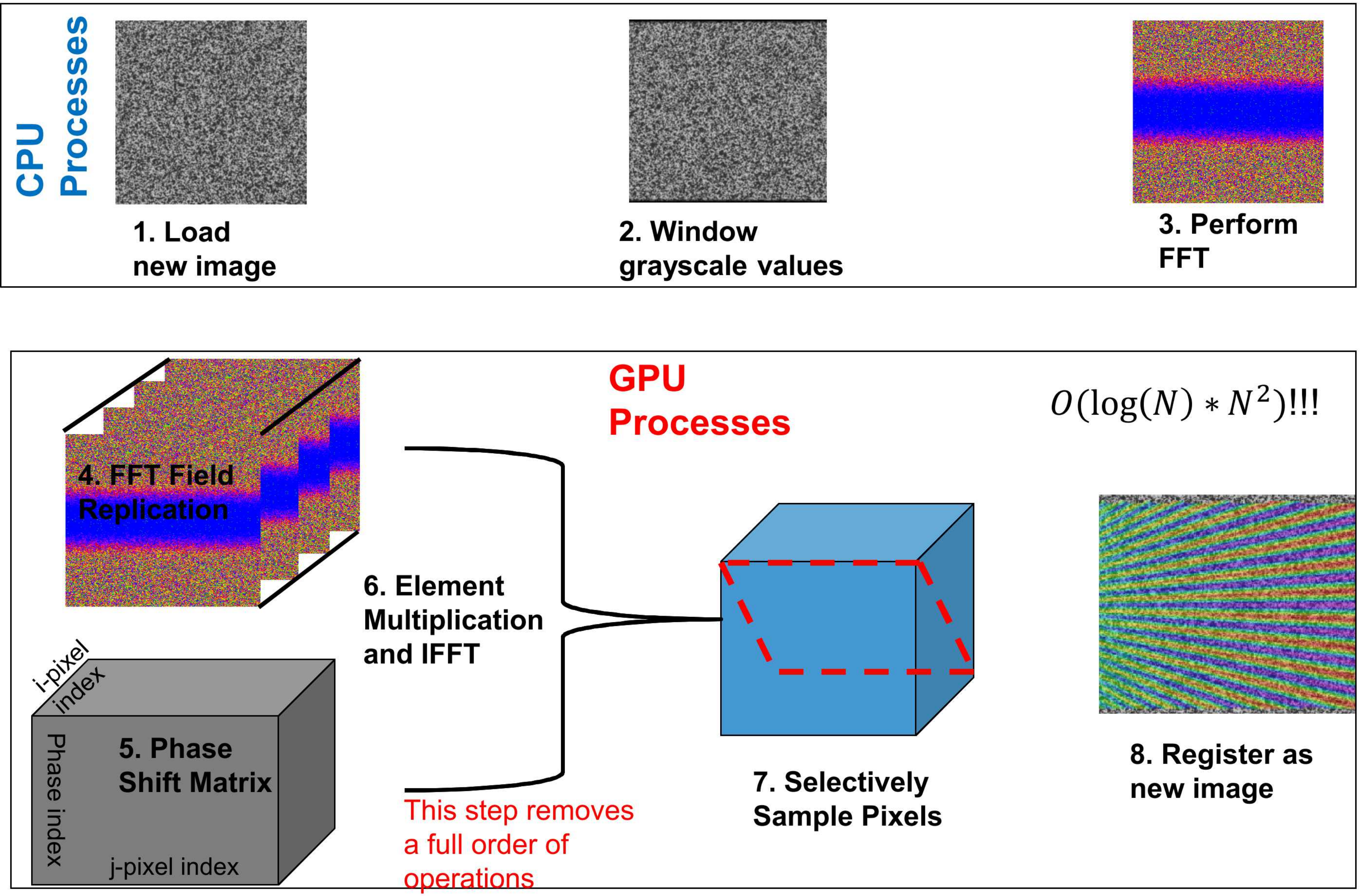
Graphic by J. Reese, MathWorks

- Large number of cores allows for data parallelism.

- Decreases operations/core.

- Requires data restructure.

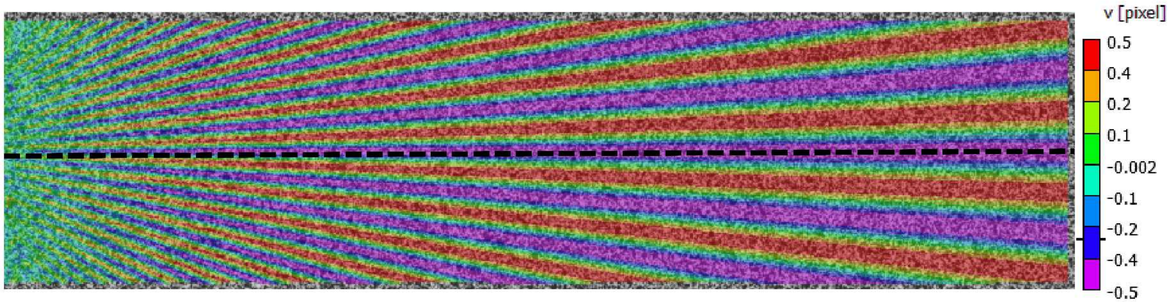
Optimized Deformation



Code Verification

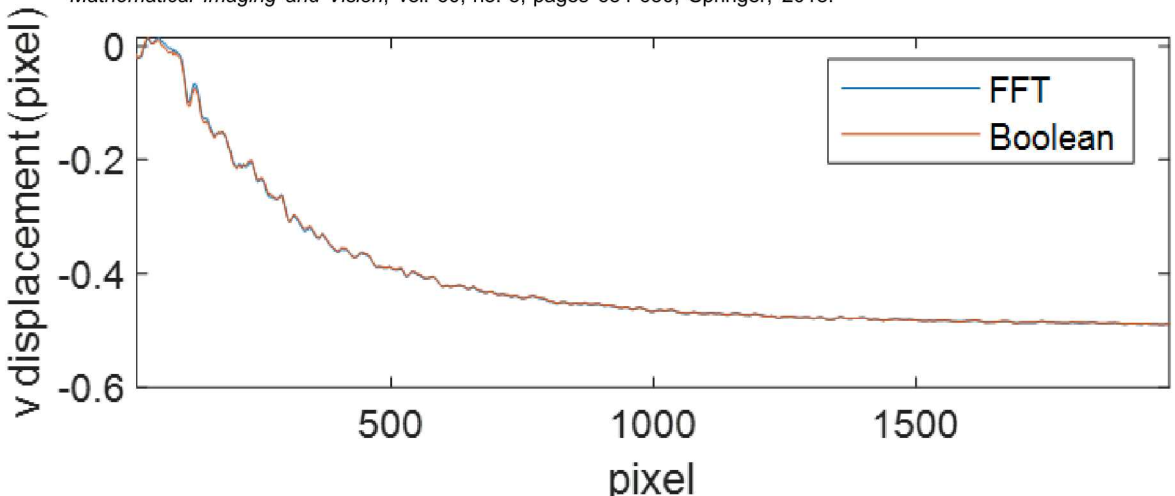
- Decreased time for a 501x2000 resolution image from11 minutes to 0.3 seconds for simple deformations

- 1.8 seconds for complex deformations, Boolean method ~ 70 minutes. For full tiff stacks, computational cost is impractical.



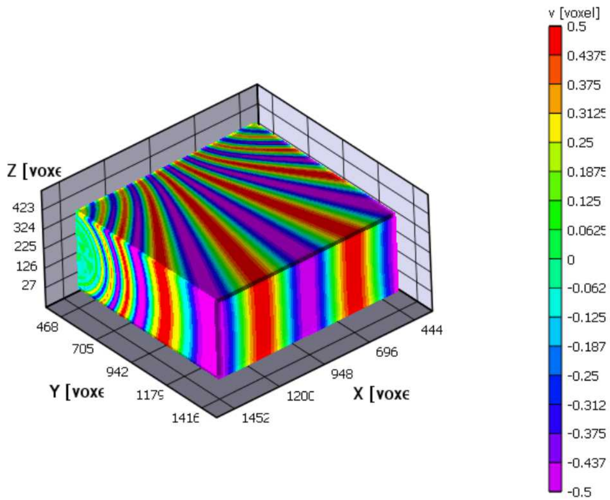
Star displacement pattern

F. Sur, B. Blaysat, M. Grédiac. **Rendering deformed speckle images with a Boolean model.** *Journal of Mathematical Imaging and Vision*, vol. 60, no. 5, pages 634-650, Springer, 2018.



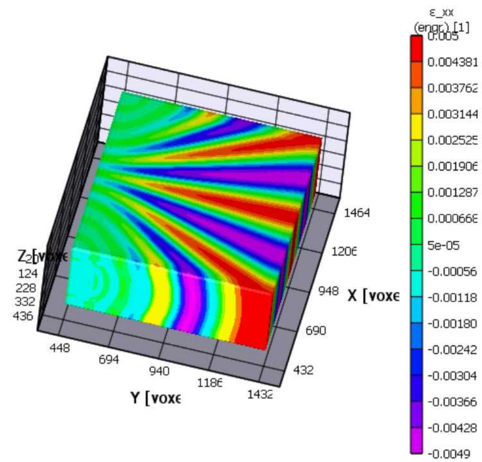
Displacement Results for Displayed Line Cut

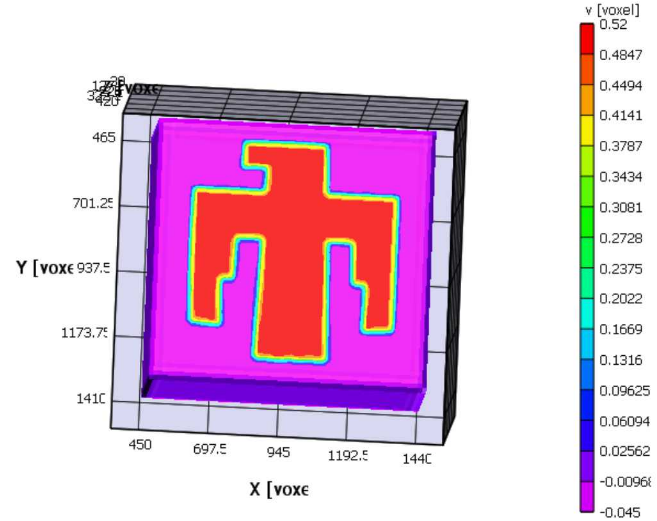
Deformation Fields



Star displacement function.

Star strain function.

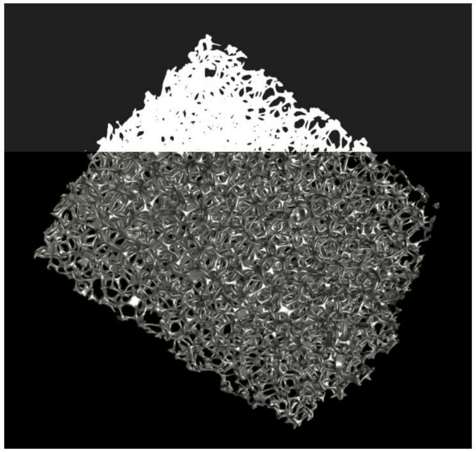




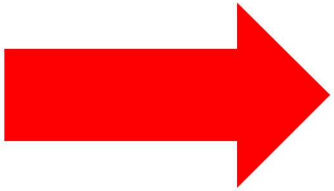
Any pre-defined deformation

DIC/DVC Error Characterization

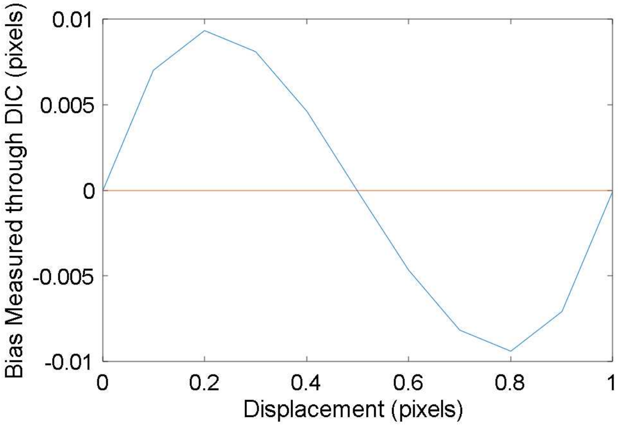
Determining Displacement Resolution



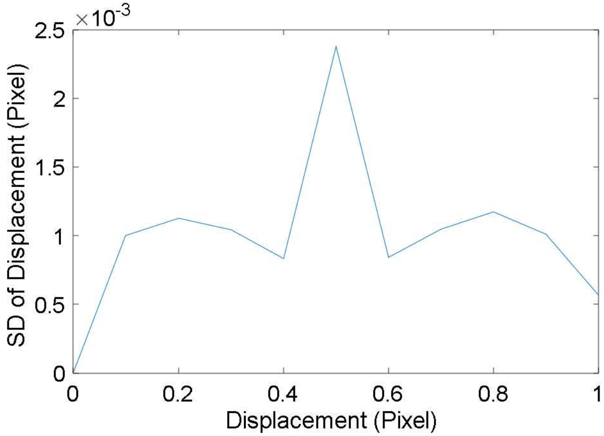
Rigid body displacement



Processing of full-field results



Sub-Pixel Interpolation bias

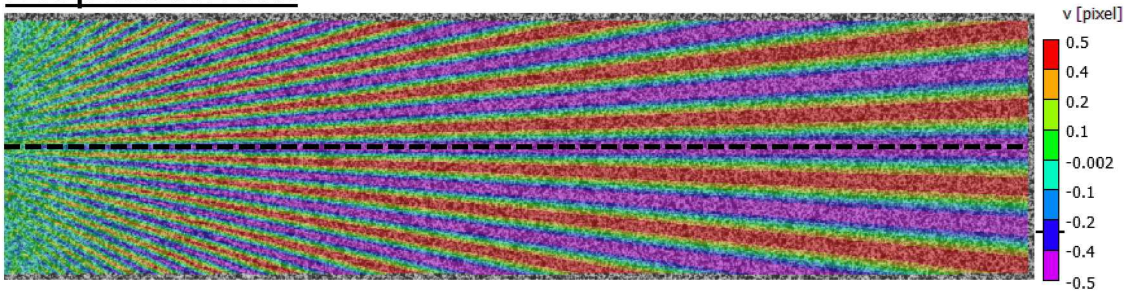


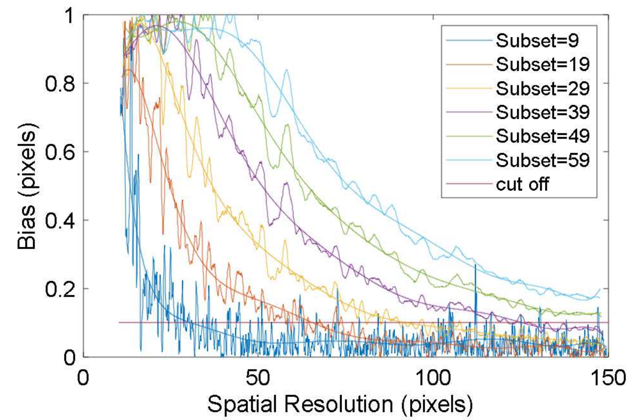
Sub-Pixel Random Error

DIC/DVC Error Characterization Cont.

Spatial Resolution

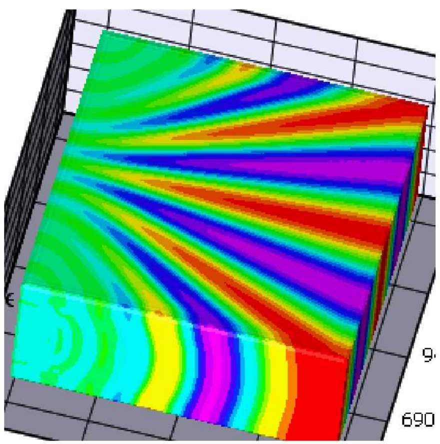
Displacement



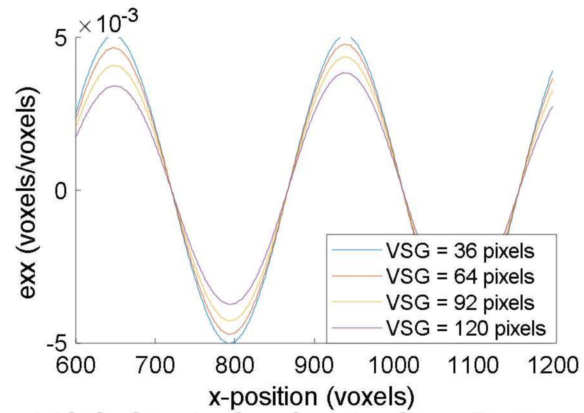


Spatial Resolution Study for the displacement Star Pattern

Strain

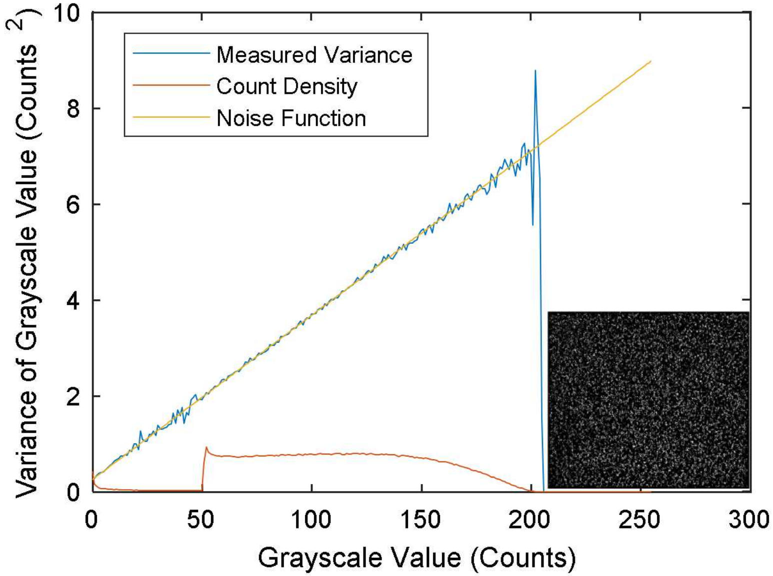


Star strain function

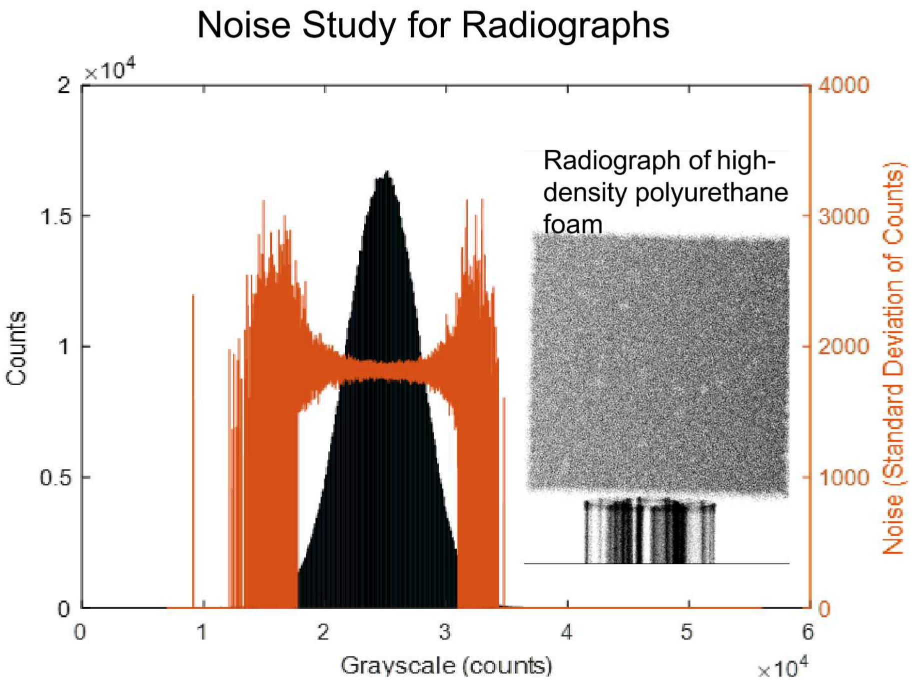


VSG Study for Strain Star Pattern

Synthetic Detector Noise For CT Data



Validation of Random noise addition for digital images.



Determining System DVC Limits

- Scan the sample at the reference state
- Determine the spatial resolution from the predefined allowed attenuation
- Determine displacement resolution from the standard deviation of displacement from different noise profiles
- Adjust parameters accordingly to match the type of accuracy needed for your particular experiment

Conclusion

- Developed an FFT deformation code optimized for large data sets
- Accuracy of deformation code is comparable with other methods
- Can be used to quantify error in DVC codes

Later work includes developing synthetic noise profiles and quantifying the effects of noise interpolation from deformed CT data.

Thank you!

- Any questions?