Separation of contrast agents from tissue via an unfolded deep learning scheme

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Introduction and motivation

Contrast enhanced ultrasound (CEUS) imaging enables vascular visualization with high contrast using inert microbubbles (MBs). CEUS processing requires separating tissue signal from the MB signal, prior to subsequent processing:

1. SVD filtering - selection of the cutoff threshold in SVD is data-dependent. Wrong selection leads to cluttered CEUS signal.
2. We propose a low-rank and sparse (L+S) decomposition via an iterative algorithm. No need to a-priori estimate the rank of the tissue signal.
3. We also propose to unfold the corresponding iterative algorithm via recently developed deep-learning techniques to improve its convergence speed, reconstruction quality and reduce its computational complexity.

Problem formulation

Given an acquired movie, the beamformed, demodulated IQ signal can be described as:

$$D(x,z,t) = L(x,z,t) + S(x,z,t) + N(x,z,t)$$

D – Acquired signal (matrix form $\boldsymbol{D}$)
L – Low-rank tissue signal (matrix form $\boldsymbol{L}$)
S – Sparse MB signal (matrix form $\boldsymbol{S}$)
N – Additive noise

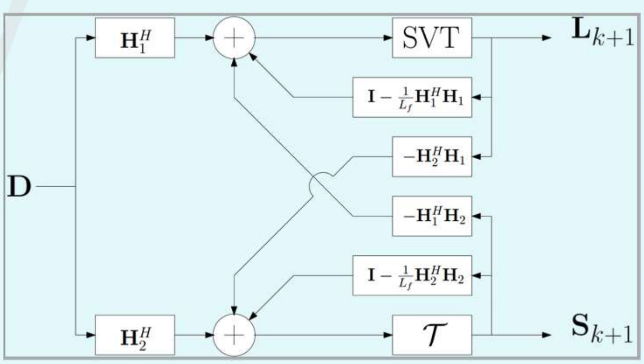
We solve the following minimization problem:

$$\min_{\boldsymbol{L},\boldsymbol{S}} 0.5||\boldsymbol{D}-\boldsymbol{L}-\boldsymbol{S}||_F^2 + \lambda_1||\boldsymbol{L}||_* + \lambda_2||\boldsymbol{S}||_{1,2}$$

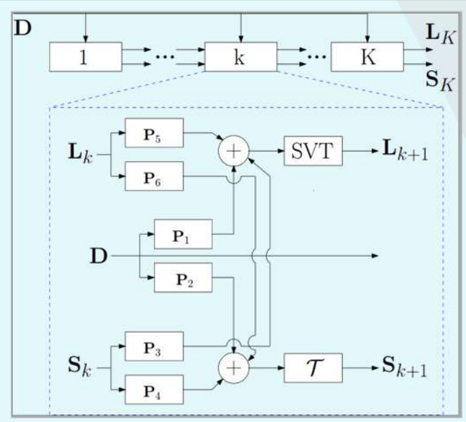
Solution is obtained either by:

1. Iterative algorithm – FISTA (Beck and Teboulle, SIIMS, 2009)
2. Deep learning via unfolding (Gregor and LeCun, ICML, 2010)

Solution paradigms



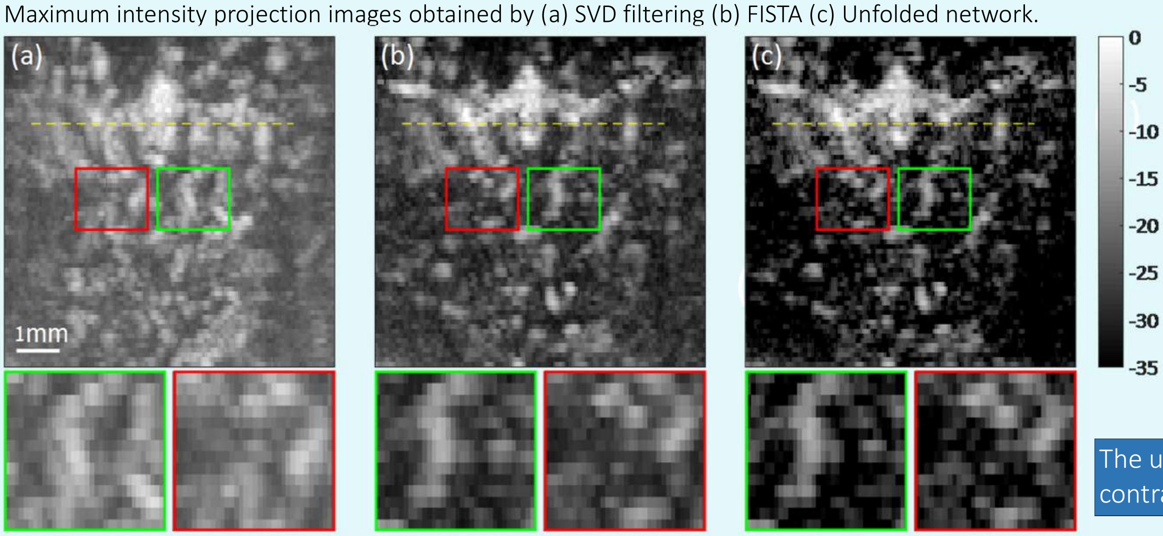
Iterative FISTA scheme for general, known measurement matrices $\boldsymbol{H}_1$ and $\boldsymbol{H}_2$

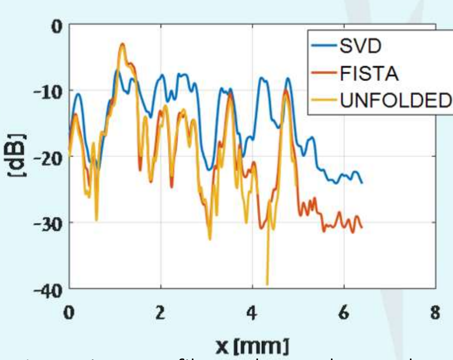


Unfolded network scheme

In-vivo tissue suppression of a rat brain scan

Maximum intensity projection images obtained by (a) SVD filtering (b) FISTA (c) Unfolded network.





Intensity profile taken along the dashed yellow line.

The unfolded network achieves the highest contrast and reconstruction quality.