Sparsity-Based Deconvolution of Low-Dose Perfusion CT Using Learned Dictionaries

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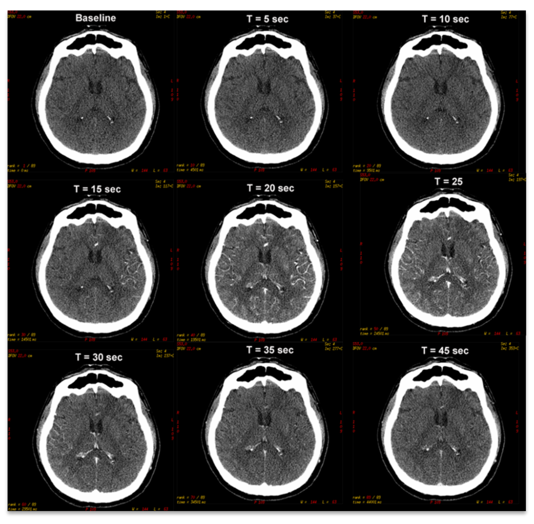
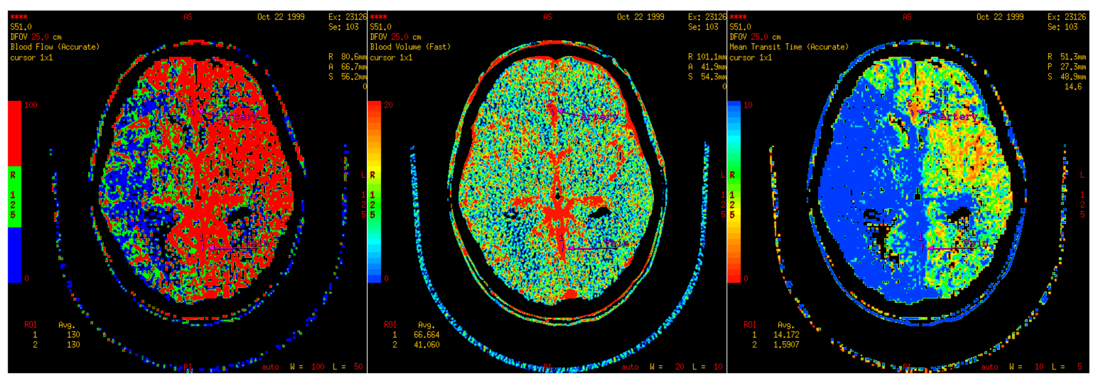
1. Introduction to Perfusion CT (PCT)

- Brain PCT useful for evaluation of cerebrovascular diseases, especially stroke and vasospasms



Sanelli PC, Lev MH, Shetty S. Neurographics 2005;4:1-74



CBF	CBV	MTT
ml/100gm/min	ml/100gm	sec
Rate of blood flow through arteries, veins and capillaries	Volume of blood in arteries, veins and capillaries	Average time from arterial inlet to venous outlet

Challenging to estimate perfusion parameter maps

- Noisy contrast enhancement profile
- Oscillatory nature of current methods

} noise and artifacts in perfusion maps

Priors used to estimate perfusion parameters

- Temporal convolution model [1]
- Spatial coherence and boundary [2]
- High-dose perfusion map database

2. Sparse perfusion deconvolution (SPD)

- Perfusion parameter model (Indicator-dilution theory [1])
  - First pass of contrast bolus yields time-density curves (TDC) for each voxel of tissue

$$C_v(t) = CBF\int_0^t C_a(\tau)R(t-\tau)d\tau$$

- Least square solution is straightforward
  - Highly sensitive to noise in low-dose PCT
- Perfusion parameter estimation based on dictionaries

$$J = \mu_1\|\mathbf{C}-\mathbf{C_a}\mathbf{R}\|_2^2 + \|x-\mathbf{D}\alpha\|_2^2 + \mu_2\|\alpha\|_0$$

  - D is a dictionary learned from high-dose CBF map patches
  - x is the CBF map we want to estimate
  - α represents a sparse vector so that Dα can approximate x with certain error tolerance
  - A similar formulation has been used in image denoising [3]

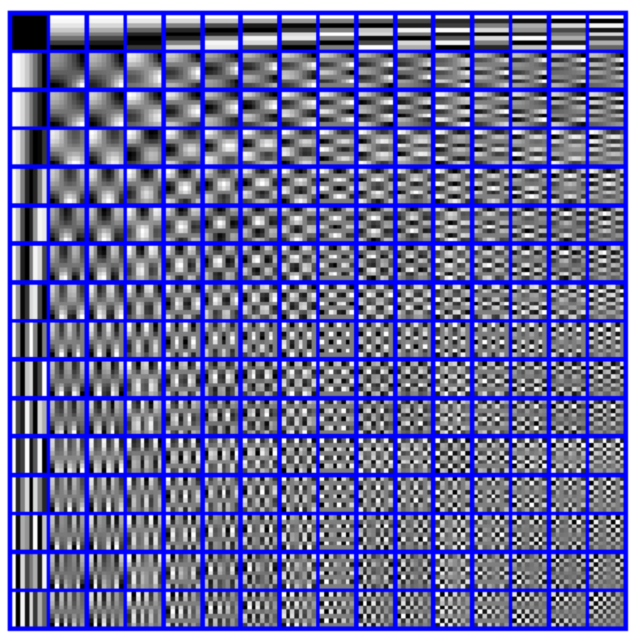
3. Dictionary learning and sparse coding

- Dictionary learning: K-SVD
- Sparse coding: Iterative process

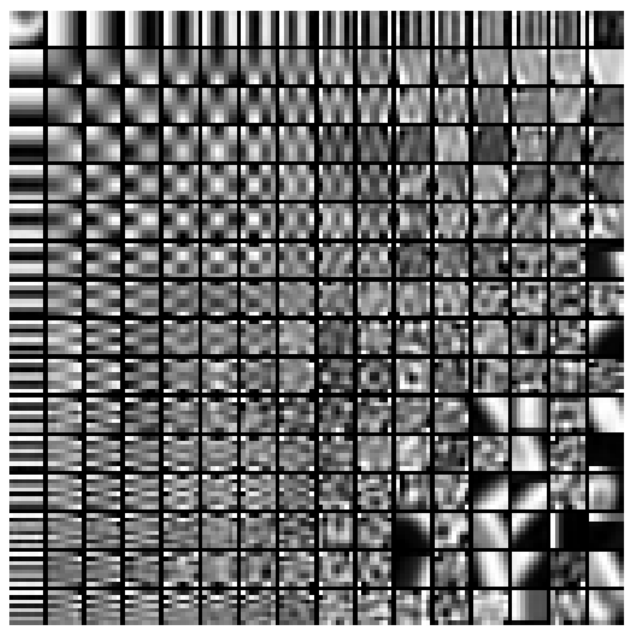
$$J = \mu_1\|\mathbf{C}-\mathbf{C_a}\mathbf{R}\|_2^2 + \|x-\mathbf{D}\alpha\|_2^2 + \mu_2\|\alpha\|_0$$

2. Quadratic problem   1. OMP

4. Learned dictionary from high-dose CTP

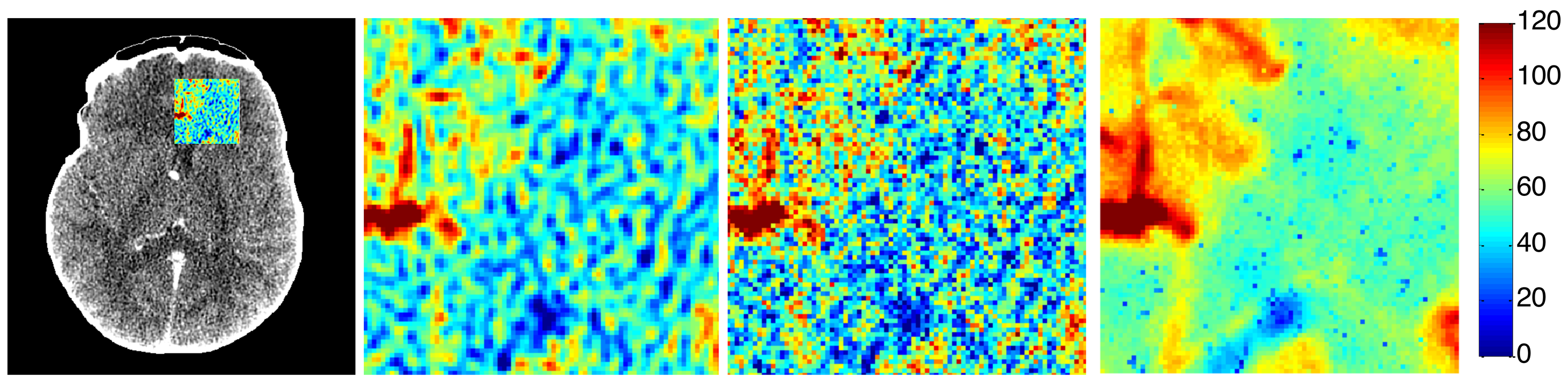


DCT dictionary



Globally trained dictionary using high-dose CBF maps

5. LACA estimation for cTSVD[4] and SPD

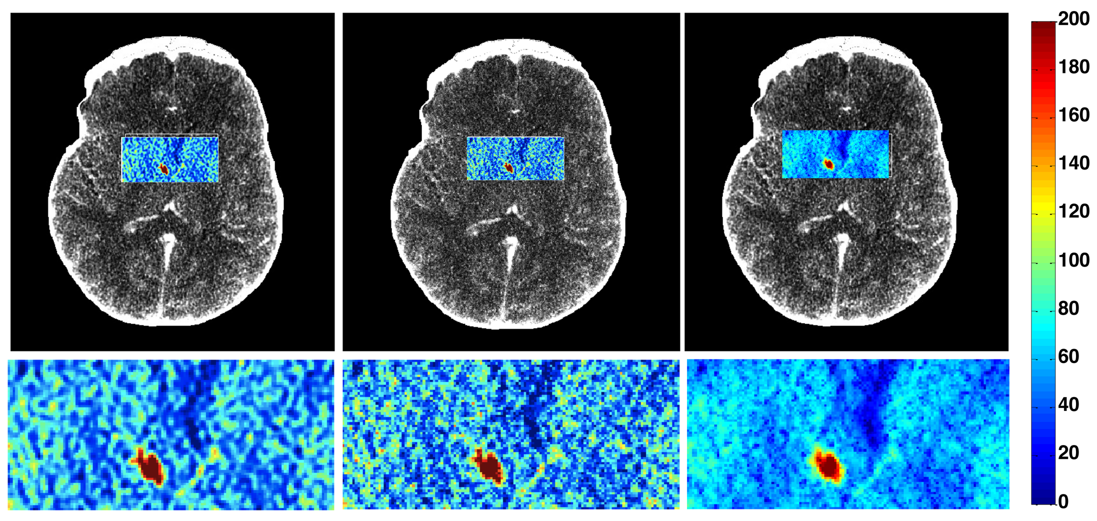


CTP & LACA ROI | cTSVD @ 190mA | cTSVD @ PSNR=20 | SPD @ PSNR=20

Standard Deviation

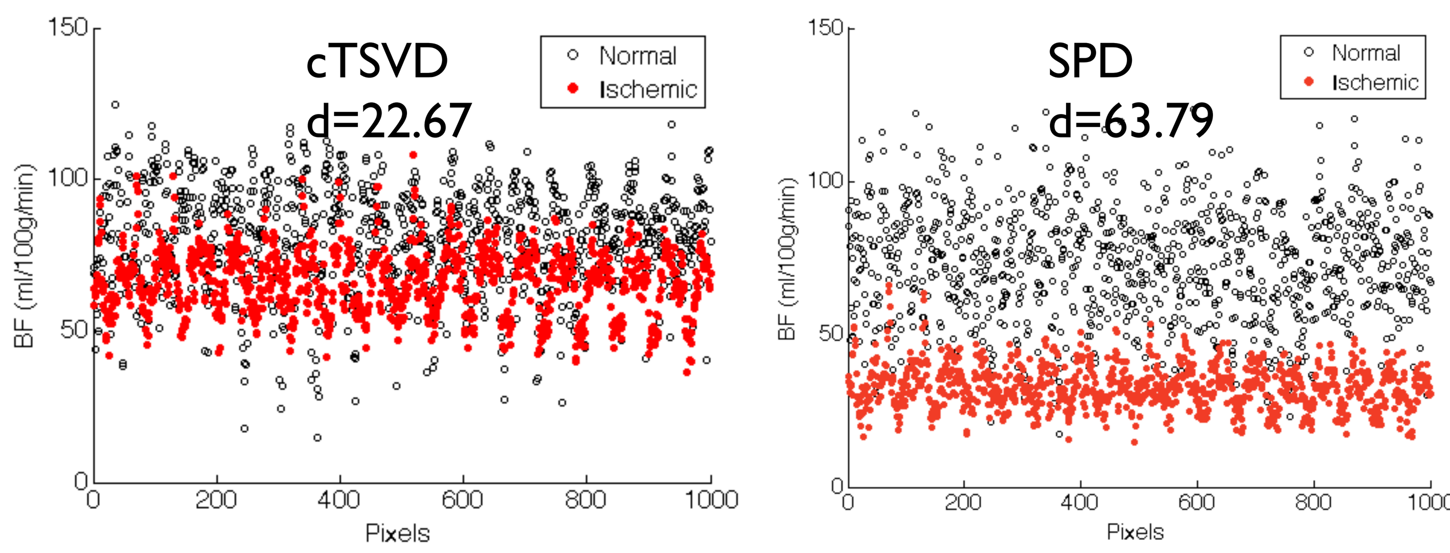
PSNR	20	40	60	80
TSVD	56.09	47.11	23.14	22.98
SPD	41.94	42.12	16.44	16.47

6. Ischemic tissue clustering



(a) cTSVD in high-dose (b) cTSVD in low-dose (c) SPD in low-dose

$$d = \frac{m_1 - m_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$



7. Conclusion/Discussion

- Novel sparsity-based deconvolution algorithm to estimate CBF in low-dose CTP
- Train a dictionary using CBF maps of high-dose CTP
- Outperform cTSVD algorithm and improve the diagnostic performance of differentiation between ischemic and normal tissues

References

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[4] Wittsack, H.J., et. al.: CT-Perfusion Imaging Of The Human Brain: Advanced Deconvolution Analysis Using Circulant Singular Value Decomposition. CMIG 2008

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