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Low-dose CT Image Processing and Reconstruction with Deep Learning

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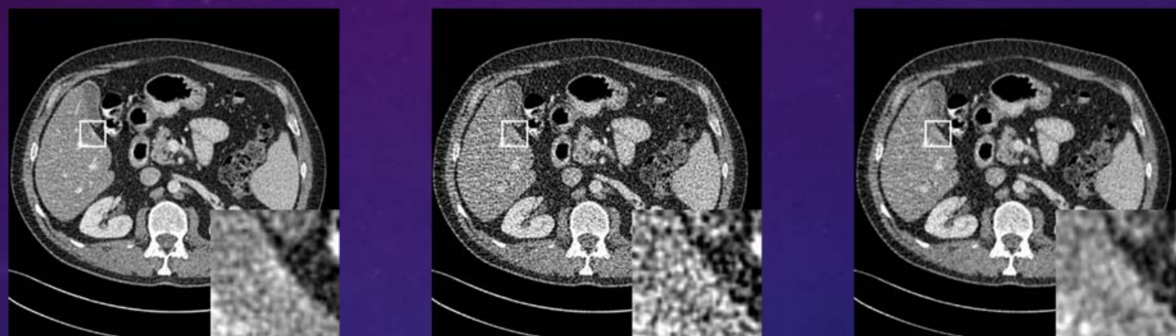
Outline

- Introduction
- Motivation: Using deep learning to improve the image quality of low dose CT
- Low dose CT denoising using deep learning
  - Denoising using cascaded CNN



- Low dose CT Reconstruction using deep learning

- Conclusion and Future Work
  - Deep Learning Can Help Low Dose CT Reconstruction!
  - A Better Framework/Network?

CIAI Lab

Image Recon and Analysis

Image Recon:

- PET
- CT
  - Low Dose CT
  - Spectrum CT/Material Decomposition
  - Phase Contrast CT
  - Static CT / Nano CT
- MRI/Optical
- Microscope – EM
- Hybrid: PET/CT, PET/MRI

Image Analysis:

- Image Denoising and Restoration
- Segmentation and Registration
- Novel Image Biomarkers
- Radiomics/Radiogenomics
- Diagnosis/Progonosis

First Place!

Artificial Intelligence in Medicine

Deep Learning Methodology:

- High Dimensional CNN
- Missing Data Problem
- Learning Annotation
- Transfer Learning
- Novel Network Structures
- Optimization/Compression Networks

Deep Learning Applications:

- Tumor Detection in Digital Pathology
- Emphysema / Pneumothorax Detection
- Lung Cancer Detection
- AD detection
- Diagnosis and Prediction of COPD
- Prediction of the Progression of Diabete
- ………

First Place!

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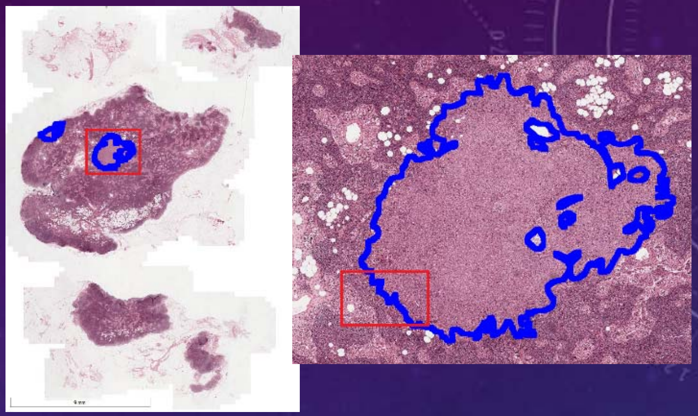

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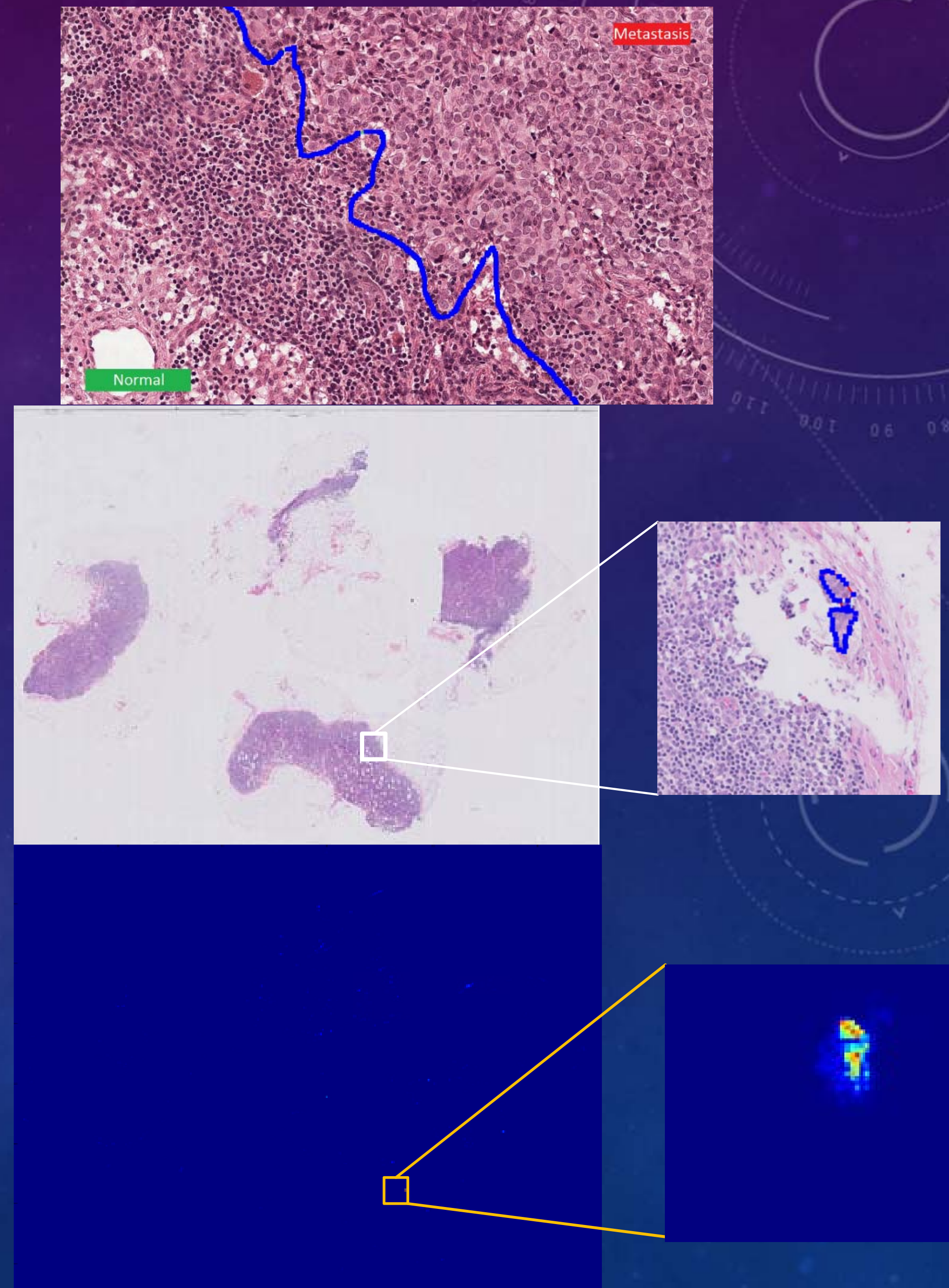
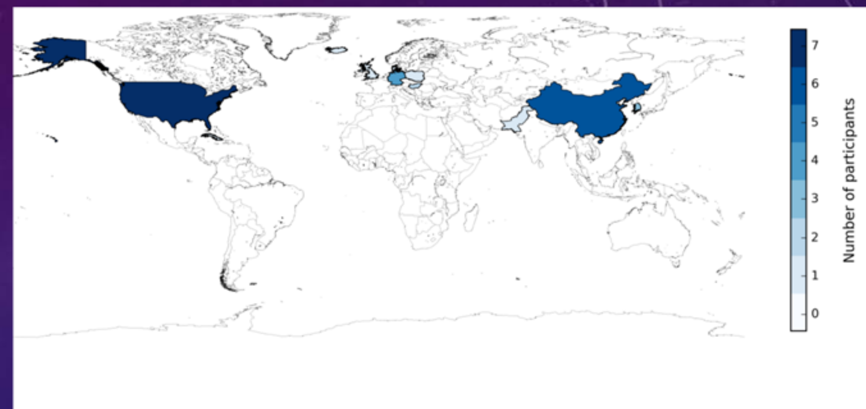


Low Dose CT Grand Challenge

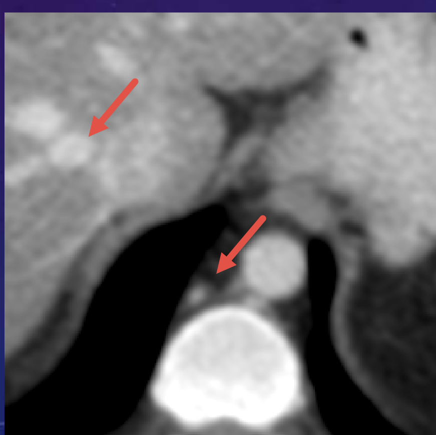
- First CT Grand Challenge
- Public Available Data and Parameters
- An Open Test Bed for CT Algorithms

First Place!

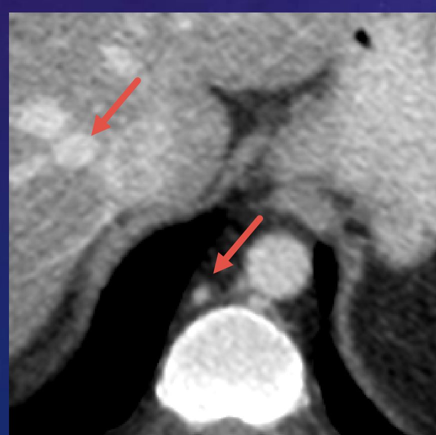
- World Wide Participants



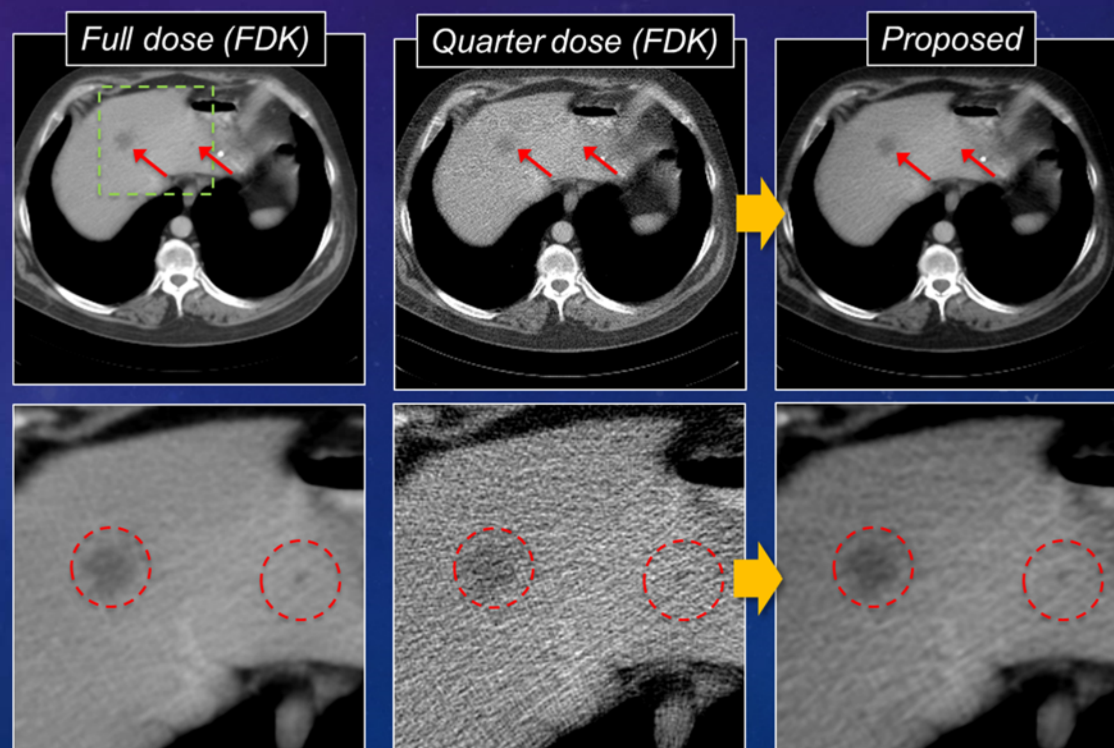
Spatially Encoded Non-Local Penalty



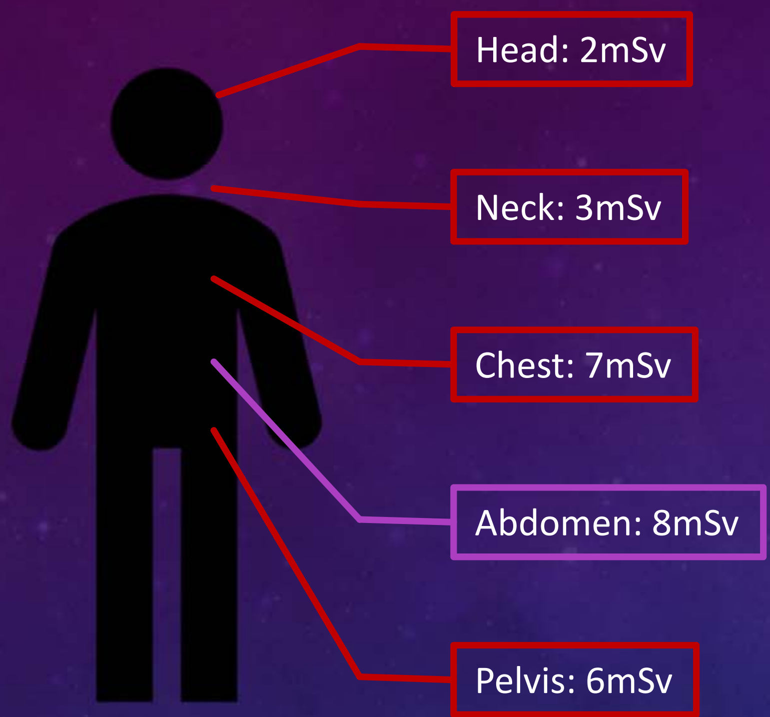
Traditional non-local mean

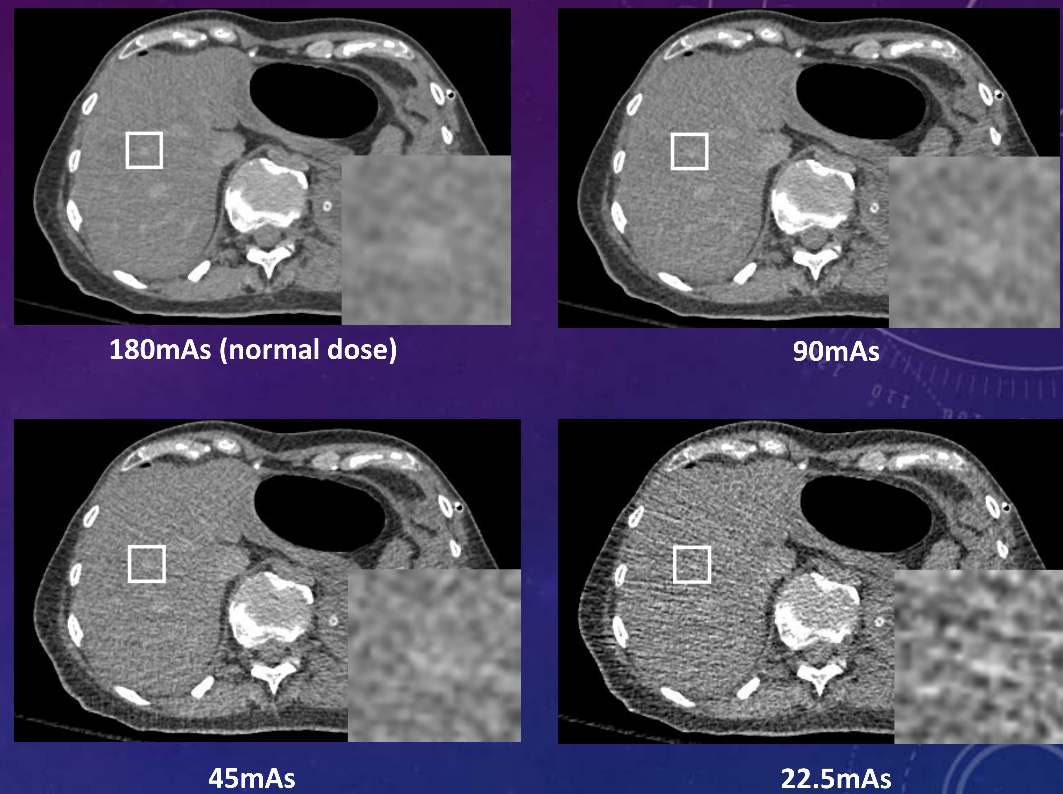


New non-local mean



Typical Low-dose CT





ICRP recommended 1-year public dose limit: ***1mSv***

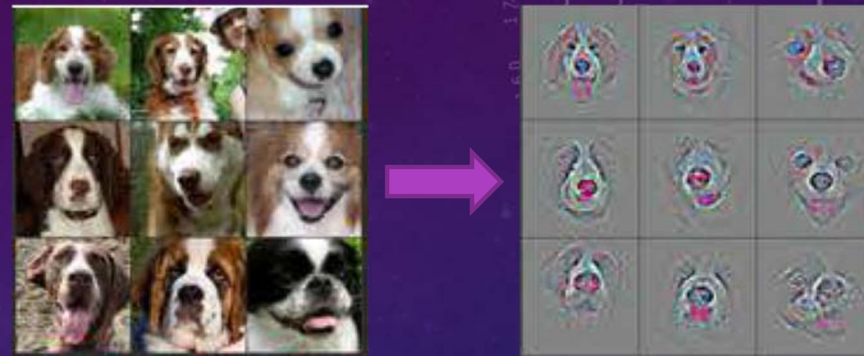
Method	Assumption	Pros	Cons
Mean Filter	I.i.d. Gaussian noise	Simple	Severe Blurring
Total Variation	Piecewise constant	Edge-preservation	Staircase artifacts
Non-local Mean	Self similarity	Better performance	Edge blurring
KSVD	Image patches are low-rank	Even better performance	Time-consuming

Mettler Jr F A et al. Effective doses in radiology and diagnostic nuclear medicine: a catalog 1. Radiology, 2008, 248(1): 254-263.

Deep Learning

- Deep learning can automatically capture important features in the images

People

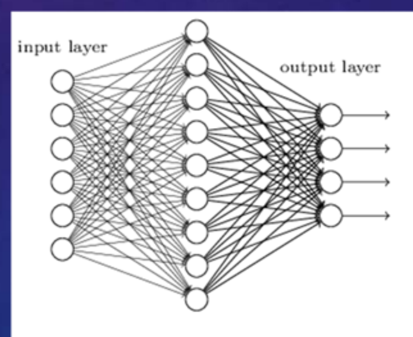


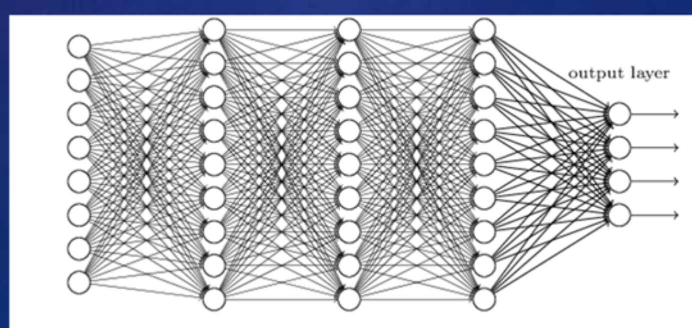
Dogs

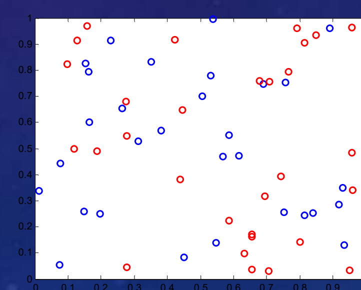
- Deep learning is a subset of machine learning that uses many layers (>= 3 except for input and output layers) of nonlinear units for feature extraction

cats

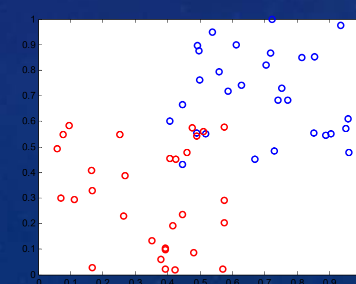
dogs







Bad features for discrimination



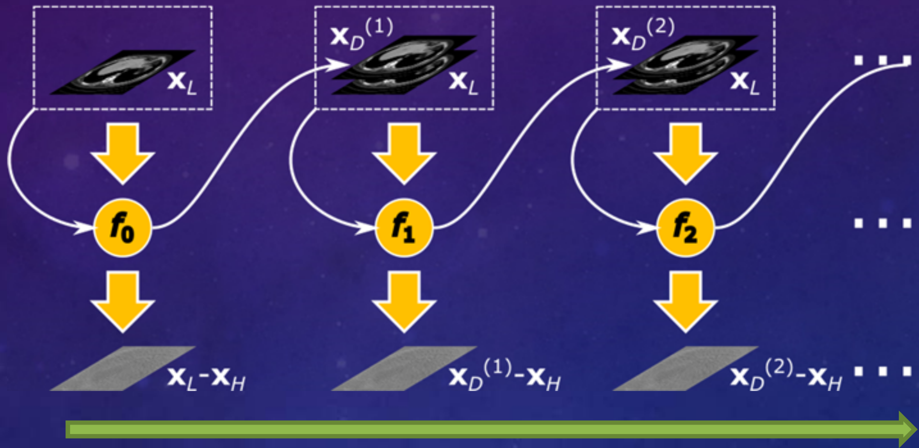
Good features for discrimination

Zeiler M D, Fergus R. Visualizing and understanding convolutional networks. European conference on computer vision. Springer International Publishing, 2014: 818-833.

Cascaded Learning

- Use cascaded CNN to compensate for the spiky artifacts in the results
  - After a CNN was trained, it was used to process the training dataset then a new CNN was trained with the processed data

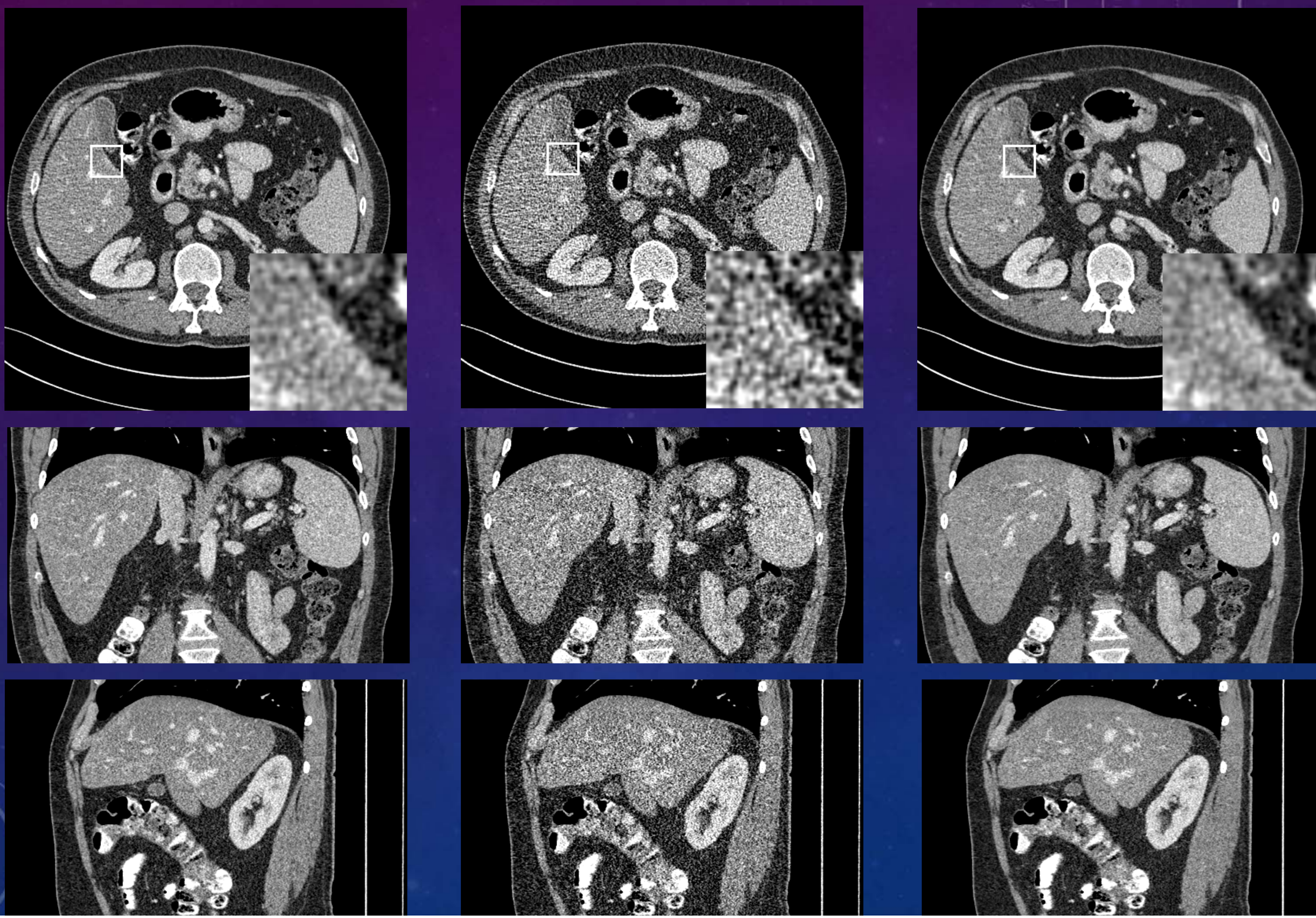
1 CNN



8 cascades of CNNs

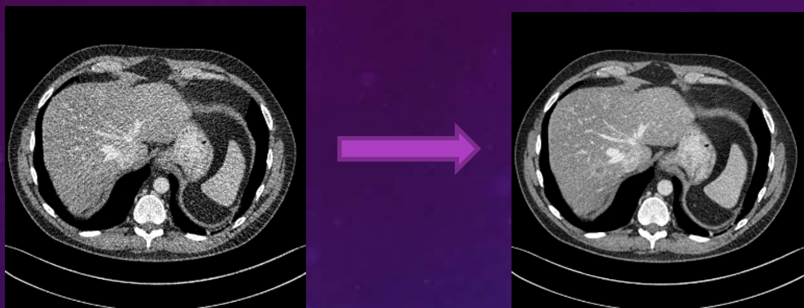
Results

180mAs (normal dose) | *Noisy* 45mAs SSIM = 0.661 | *CNN* 45mAs SSIM = 0.753



Deep Learning Based CT Recon

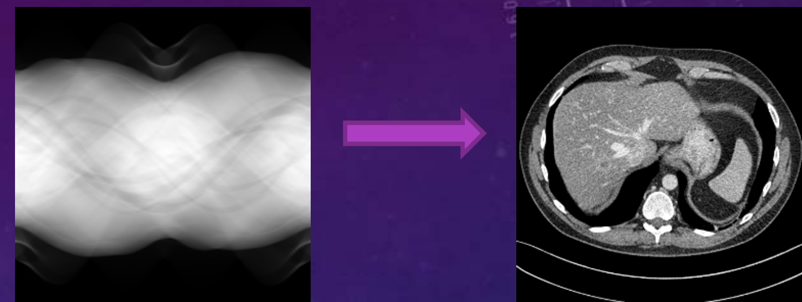
Image Denoising



Pros:
- Real time
- Greatly improved SNR

Cons:
- Chances for generating false positivity
- “What was lost is lost”

Image Reconstruction



Pros:
- Better image quality
- Lower false positivity rate

Cons:
- Slow
- Image noise changes during iterations

- Iterative CT image reconstruction problem is usually formulated as

$$\mathbf{x} = \arg\min \quad ||\mathbf{Ax} - \mathbf{p}||_{\mathbf{w}}^2 \quad + \quad \lambda R(\mathbf{x}; \boldsymbol{\theta})$$

Fidelity term with system matrix **A**, raw data **p** and noise matrix **w**

Penalty term with penalty function *R*, its parameters **θ** and hyperparameter **λ**

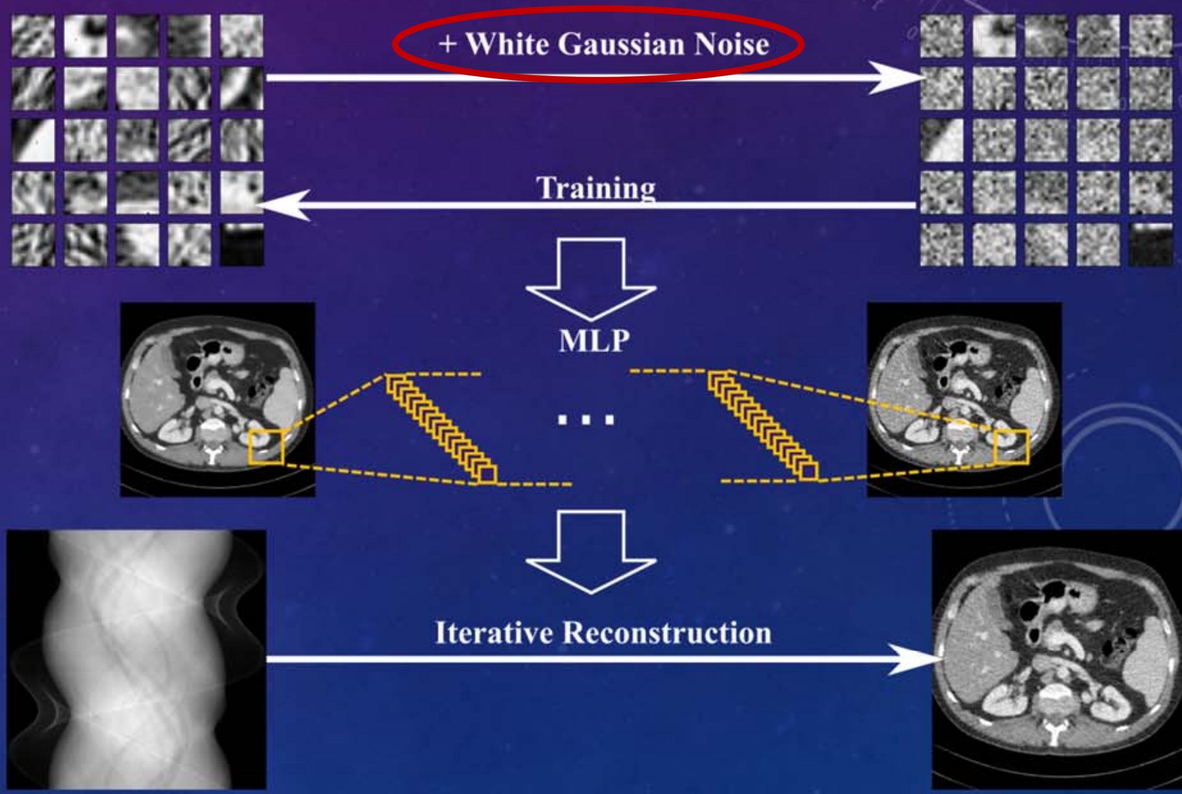
Train Prior Functions with Deep Learning

- Because noises in **x** changes during the iterations, it has to be learned in an **unsupervised** way;
- A solution with denoising autoencoders:

$$\mathbf{x} = \arg\min \|\mathbf{Ax} - \mathbf{p}\|_{\mathbf{w}}^2 + \lambda \|\mathbf{x} - f(\mathbf{x})\|_2^2$$

f(**x**) is the trained neural networks

No need for noise simulation



Wu D, et al. *Iterative Low-dose CT Reconstruction with Priors Trained by Artificial Neural Network. Transactions on Medical Imaging (submitted).*

Results

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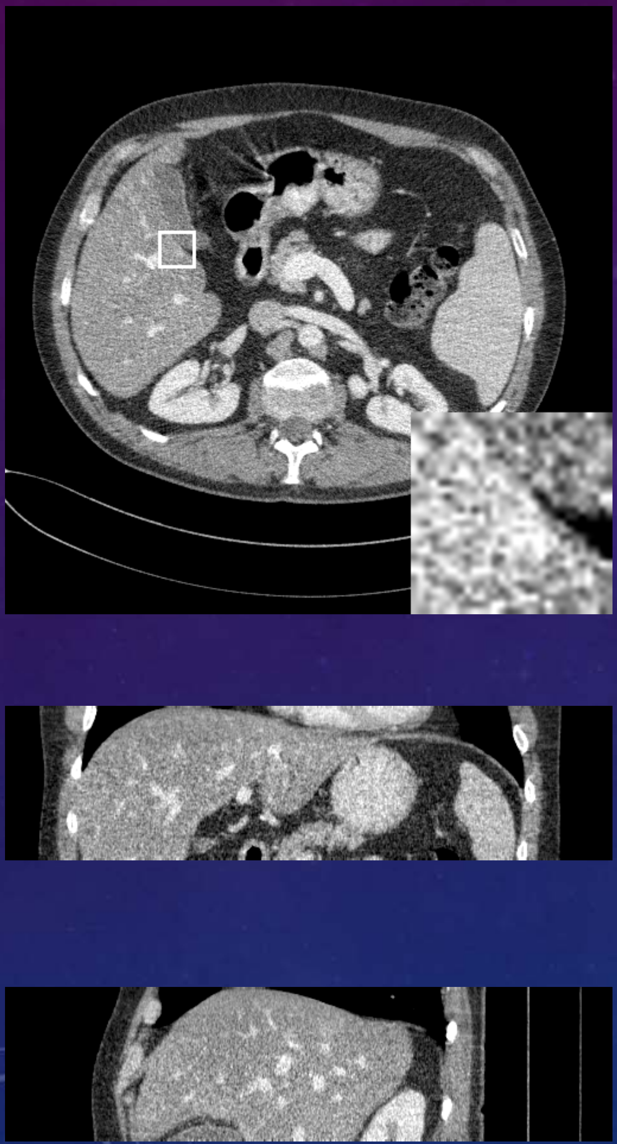
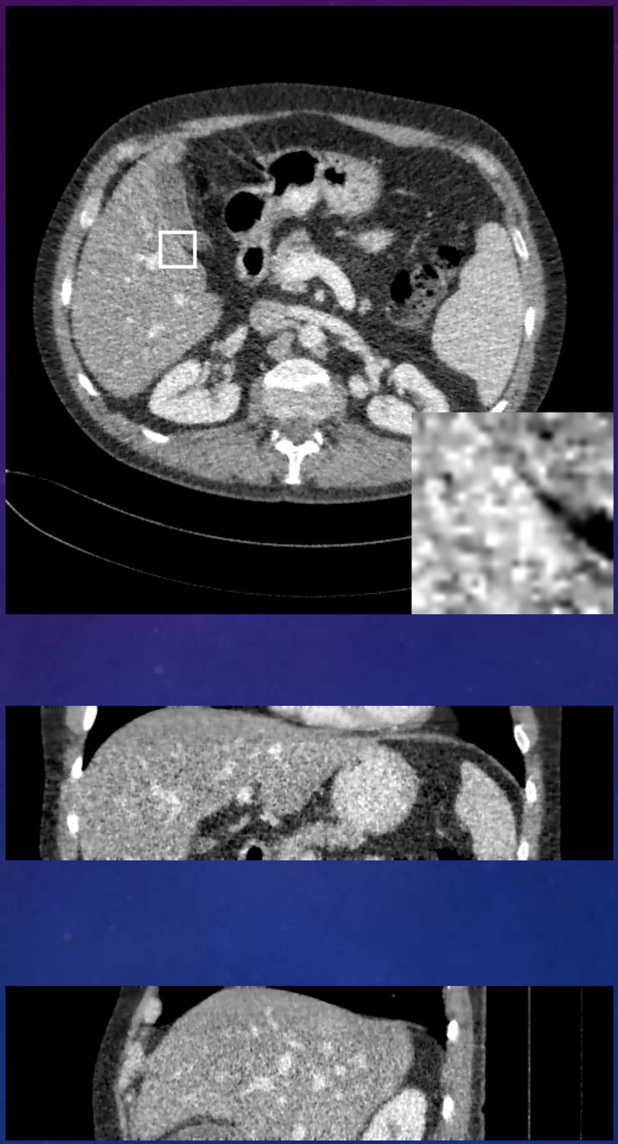


TV 45mAs **SSIM = 0.851**

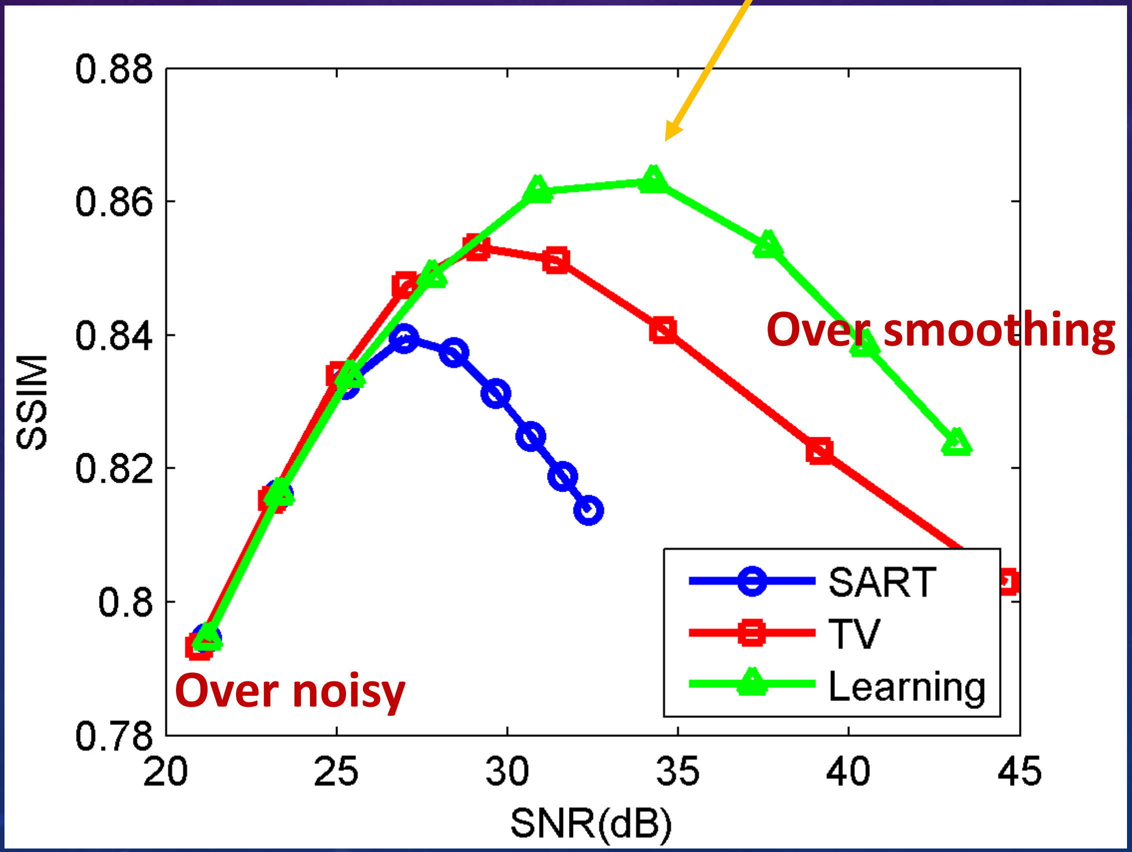


Learning 45mAs **SSIM = 0.863**

Quantitative Results

- SNR – SSIM tradeoff for different hyperparameters
  - Higher SNR – better noise suppressing
  - Higher SSIM – better structural preservation

Best tradeoff point for noise suppressing and structure preservation



Future Works

- "No ground truth" learning
  - Eliminate the need of precise noise modeling
- Reinforcement learning
  - Eliminate the need of hyperparameter tuning for reconstruction
- Diagnosis oriented learning
  - Generate images most suitable for diagnosis
  - Reduce false positive / negative rates

Thanks for your attention !

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