Center for Biomedical Imaging

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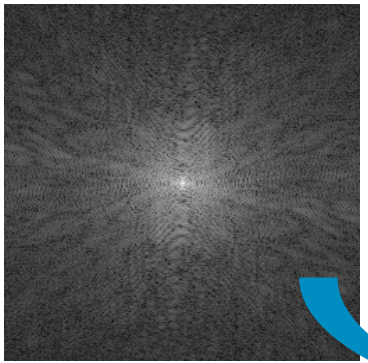
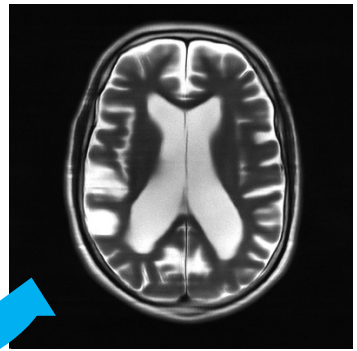
CAI²R

DL-based MRI reconstruction: A Radiologist's Perspective



Yvonne W. Lui MD FACR



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Disclosures

- no financial disclosures
- lead collaboration partner at NYULH w/ Facebook AI Research, Siemens Healthineers

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pop quiz

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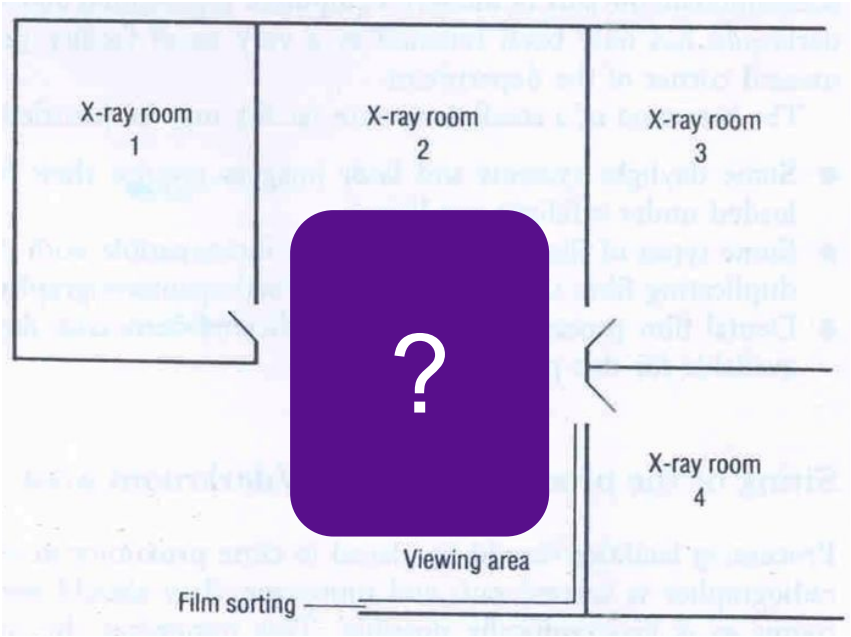
1980s – What's at the heart of the Radiology Department?

a) Patient changing area
b) Radiologist
c) Break room
d) CT scanner
e) Film library
f) Something else



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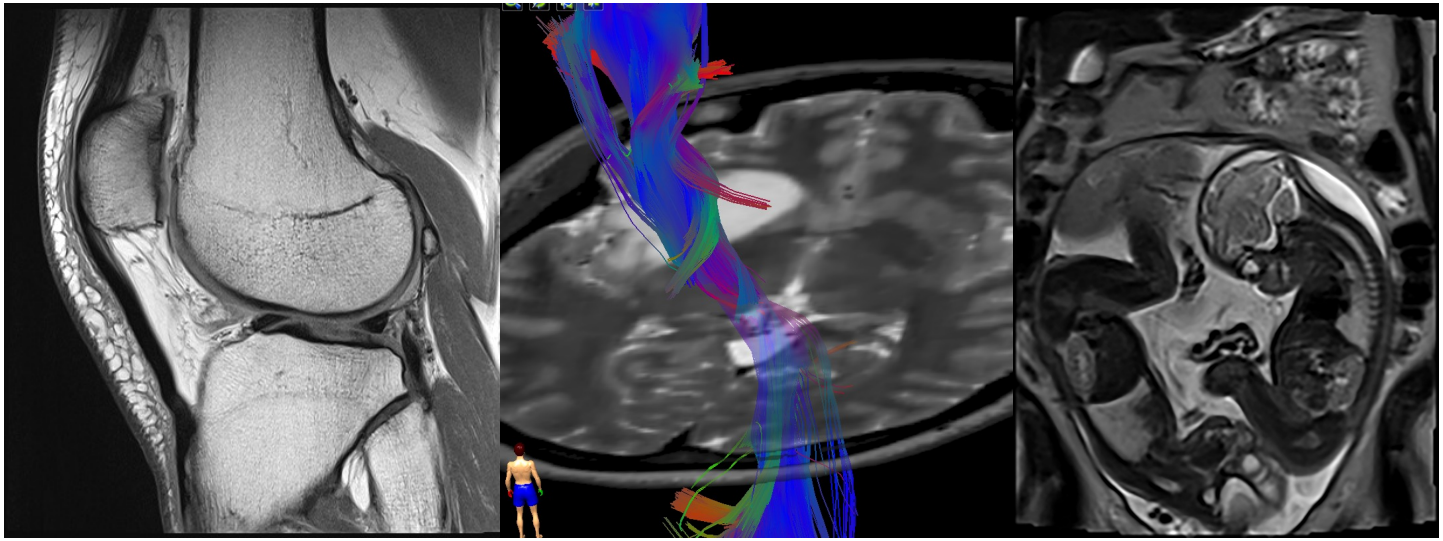
Case Study

Problem: MRI



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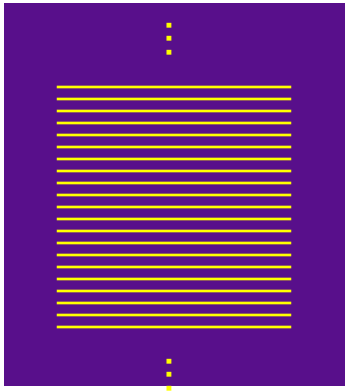
why so slow?



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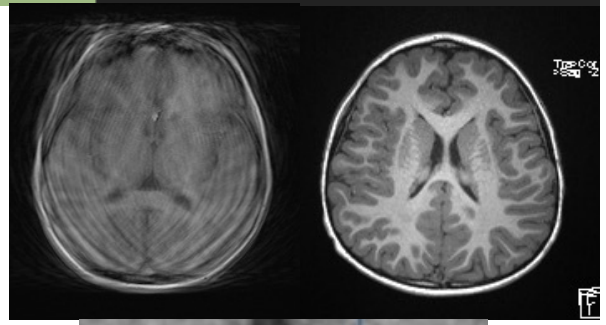
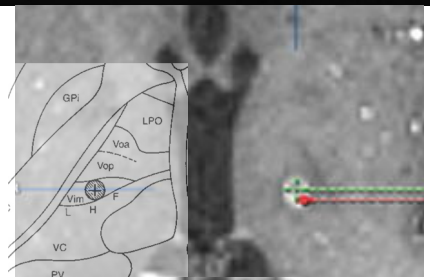
- Patient comfort
- Image quality
- Precision
- Pediatrics
- Elderly
- Claustrophobia
- Anesthesia / sedation
- Accessibility
- Cost

Tech Note 1	Pt is moving during the test, ran some sequences from uncooperative protocol. Best images possible. by RICCI ALEXANDRA (RICCIA03)
Ordering MD	SERRUYA I. JOSE (718)830-3772
Reason for Exam	epilepsy





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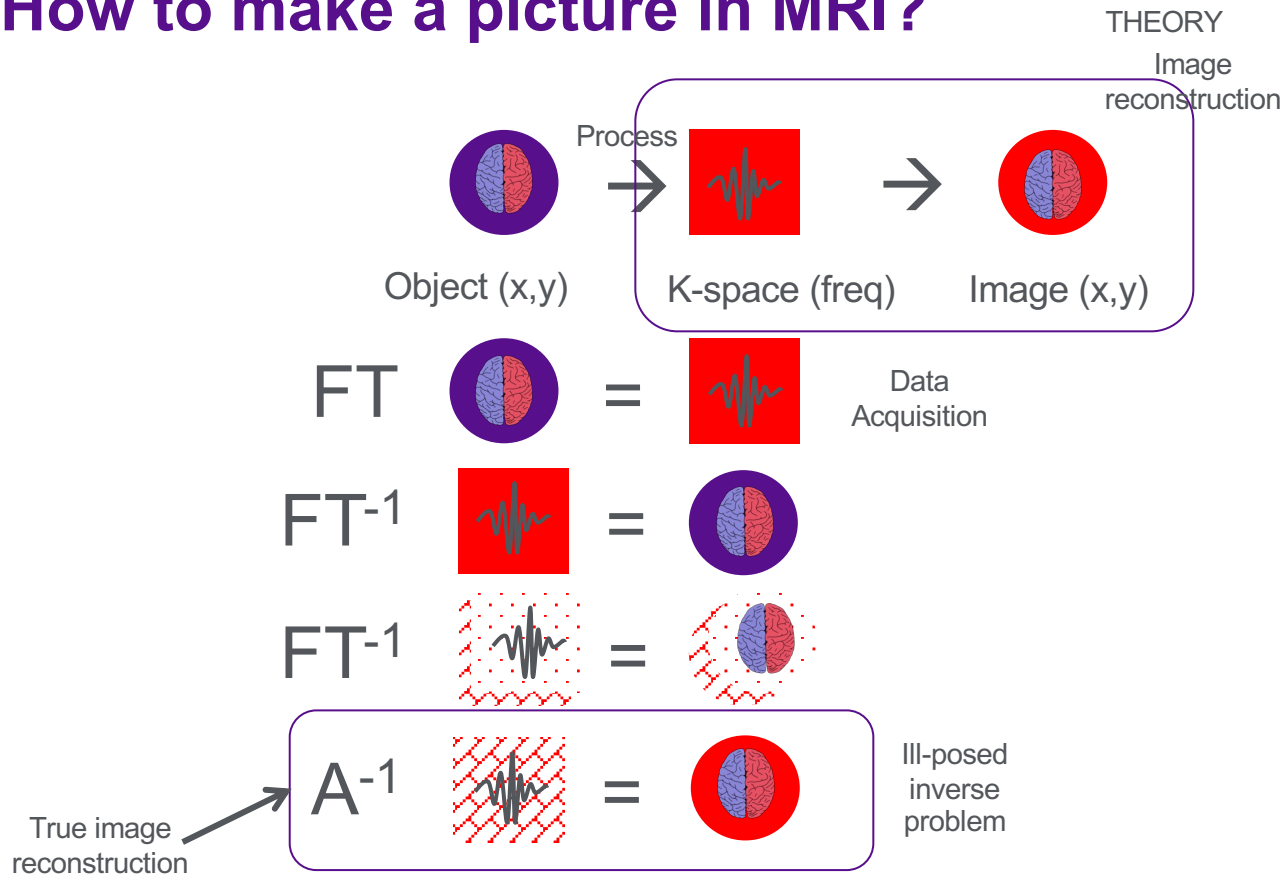
How to make a picture in MRI?



Hansen and Kellman, JMRI; Image reconstruction: an overview for clinicians

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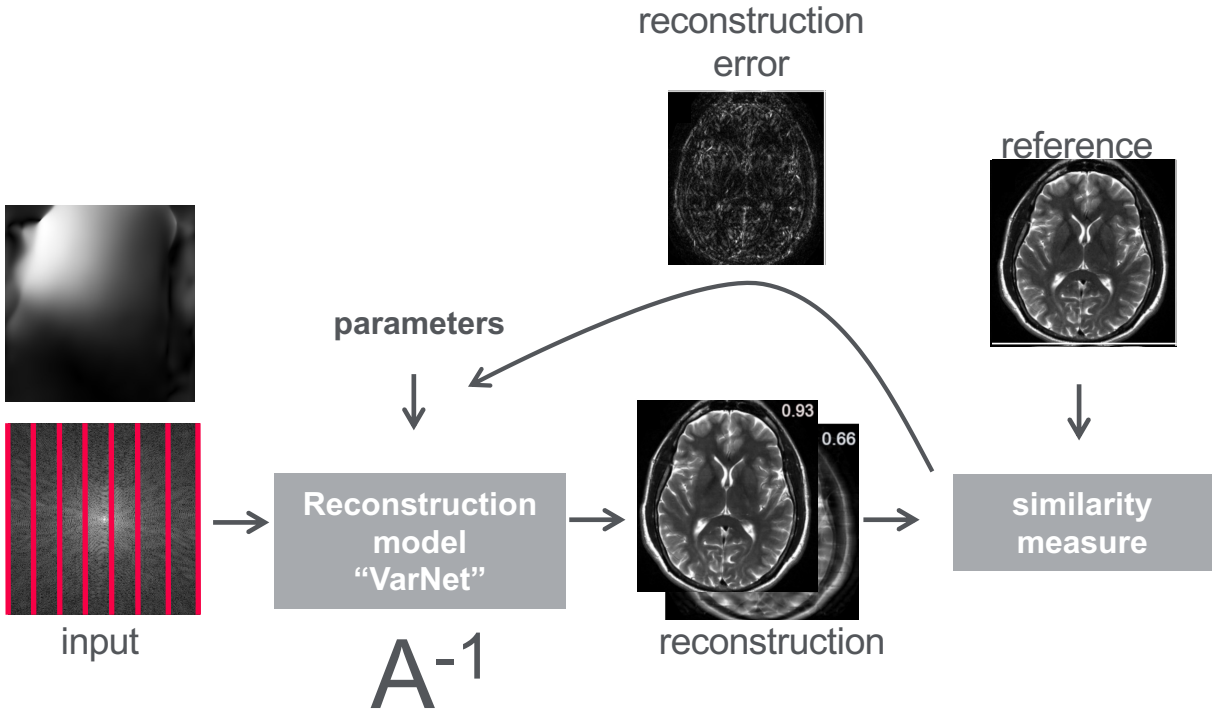
Learning for image reconstruction



adapted from Hammernik MRM 2018

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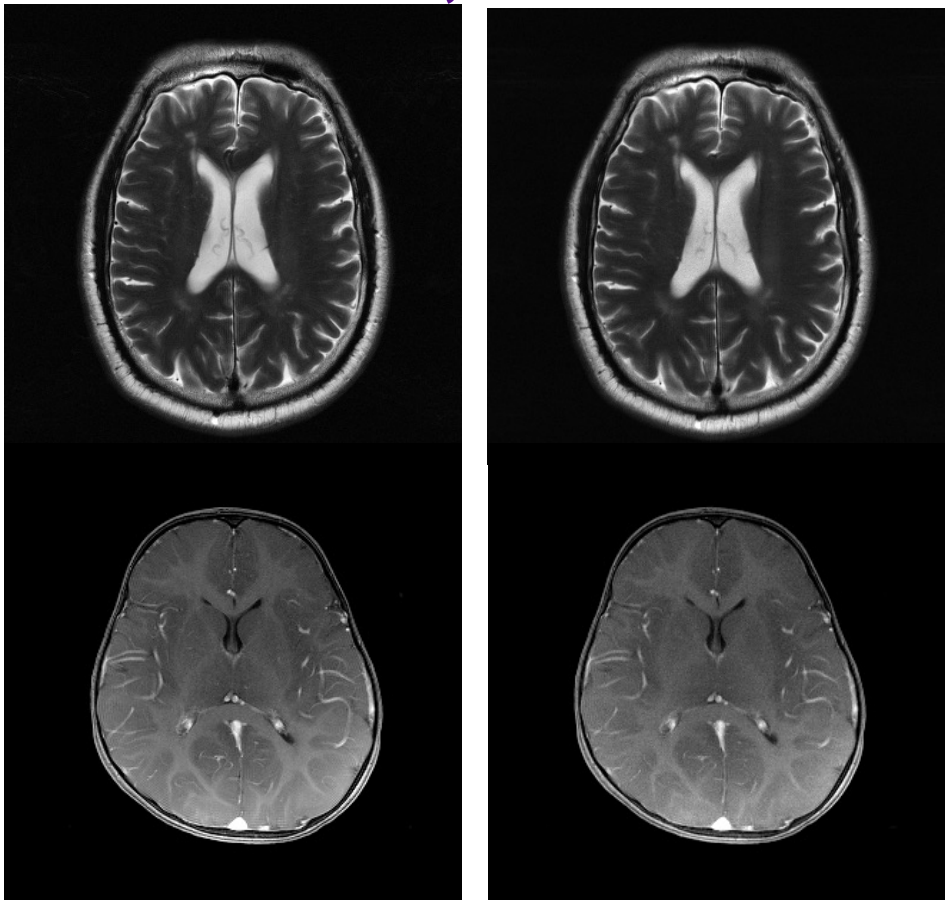
Ground Truth, 6x acceleration



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Using Deep Learning to Accelerate Knee MRI at 3 T: Results of an Interchangeability Study

4X VarNet

Recht et al, AJR 2000

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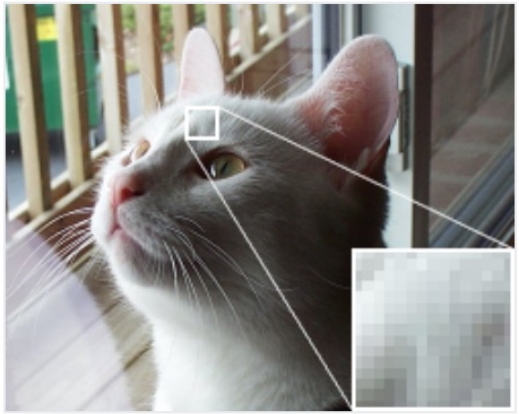
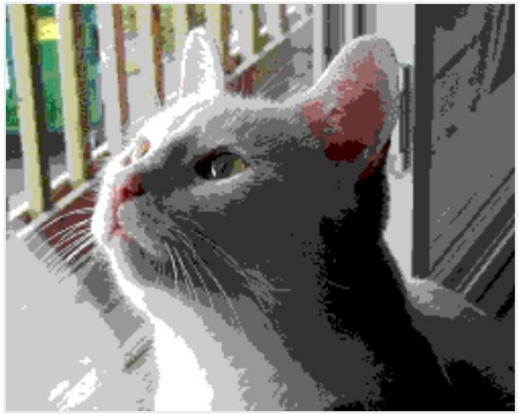
Dithering





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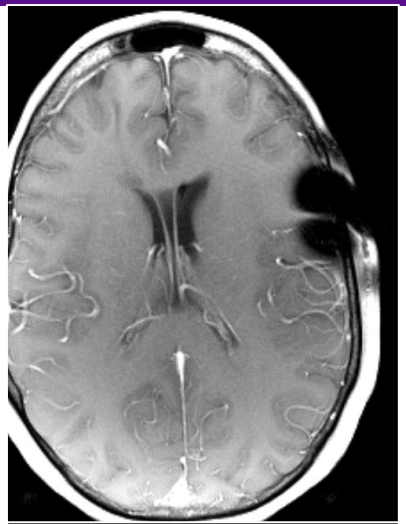
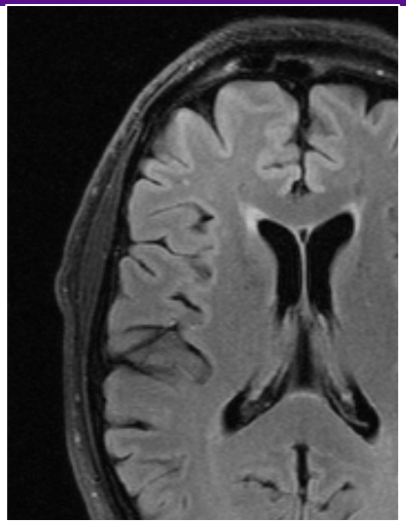
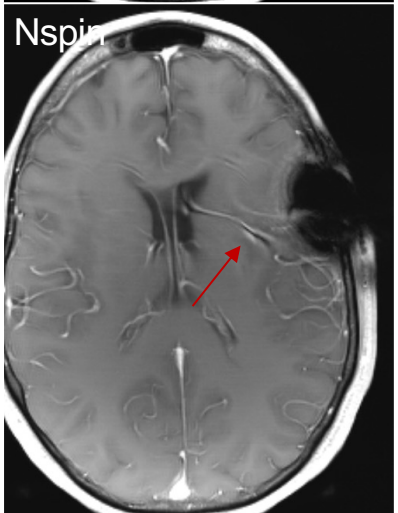
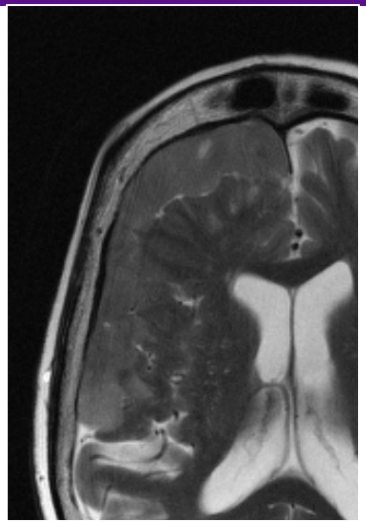
hallucinations

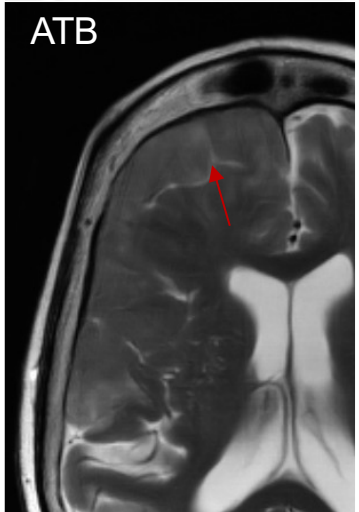






pseudo-normalization





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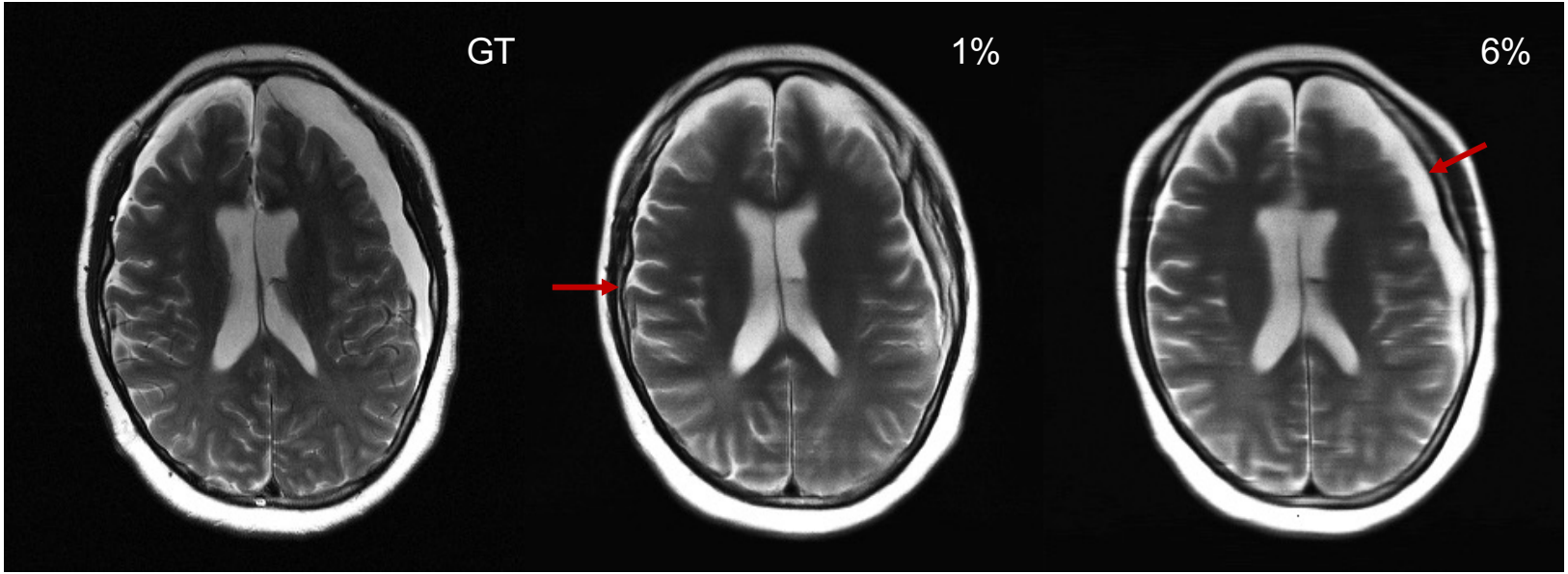
sampling and fractional representation of low frequency lines



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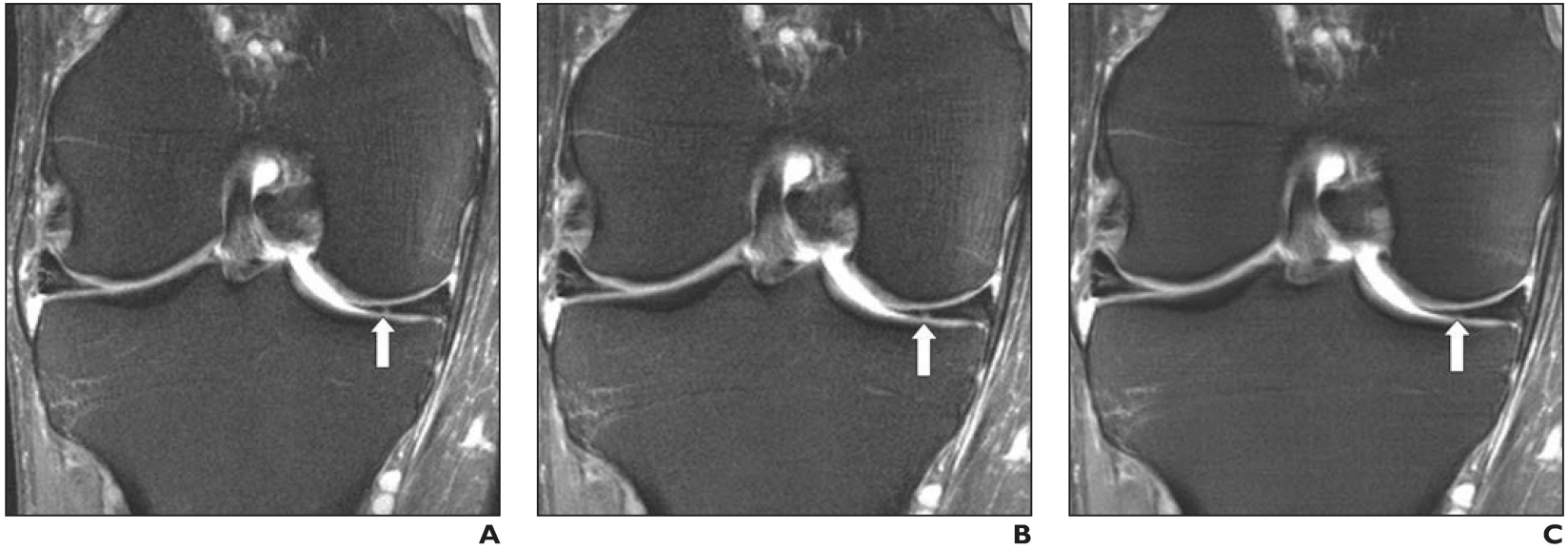
Clinical question dictates reconstruction need



Clinical

4X

8X

Recht et al, AJR 2000

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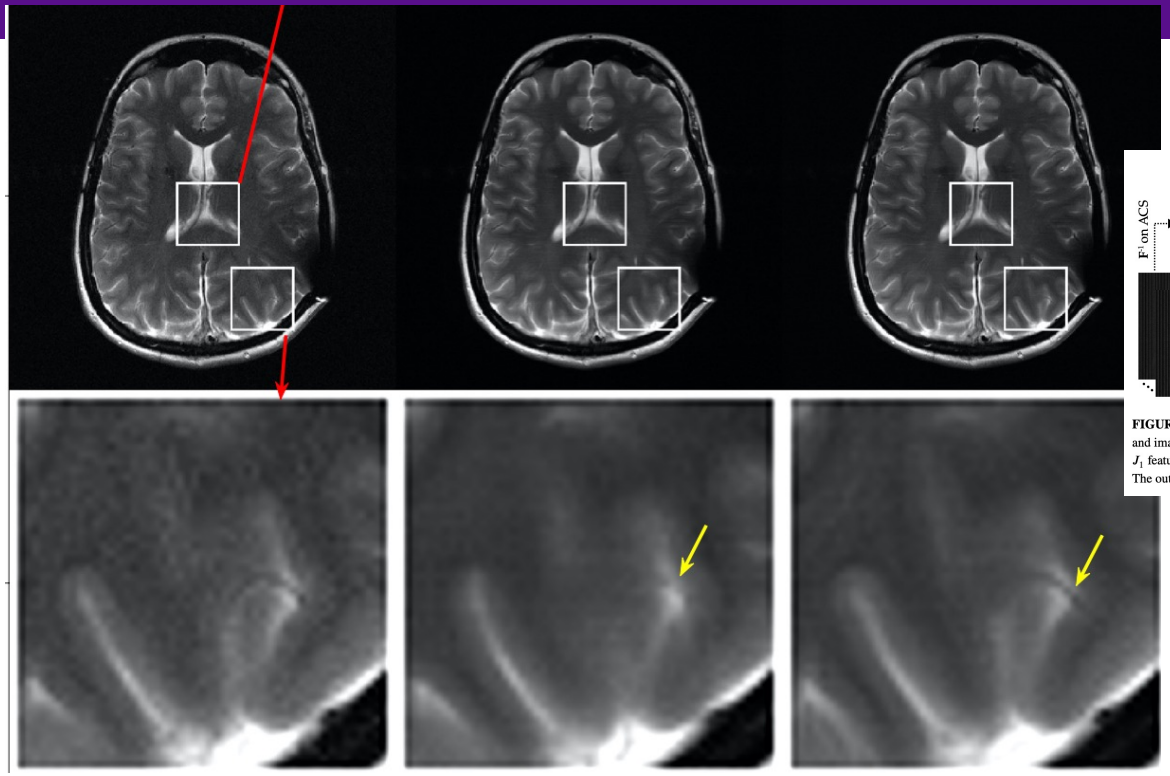

GT VarNet FI VN

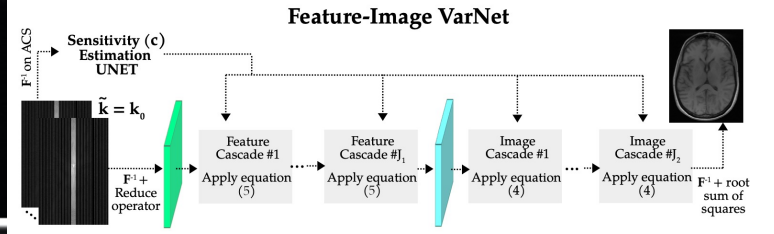

FIGURE 2 Feature-Image (FI) VarNet architecture. The sensitivities are estimated as in the E2E VarNet with a UNET and are passed to the feature and image cascades. The k-space is encoded into feature-space, and the resulting feature maps are processed by the update rule of (5) in each of the J_1 feature cascades. The last feature maps are decoded into k-space, which is further processed by the update rule of (4) in the J_2 image cascades. The output k-space is transformed to the final image. The network is trained end-to-end.

courtesy of Ilias Giannakopoulos, Riccardo Lattanzi

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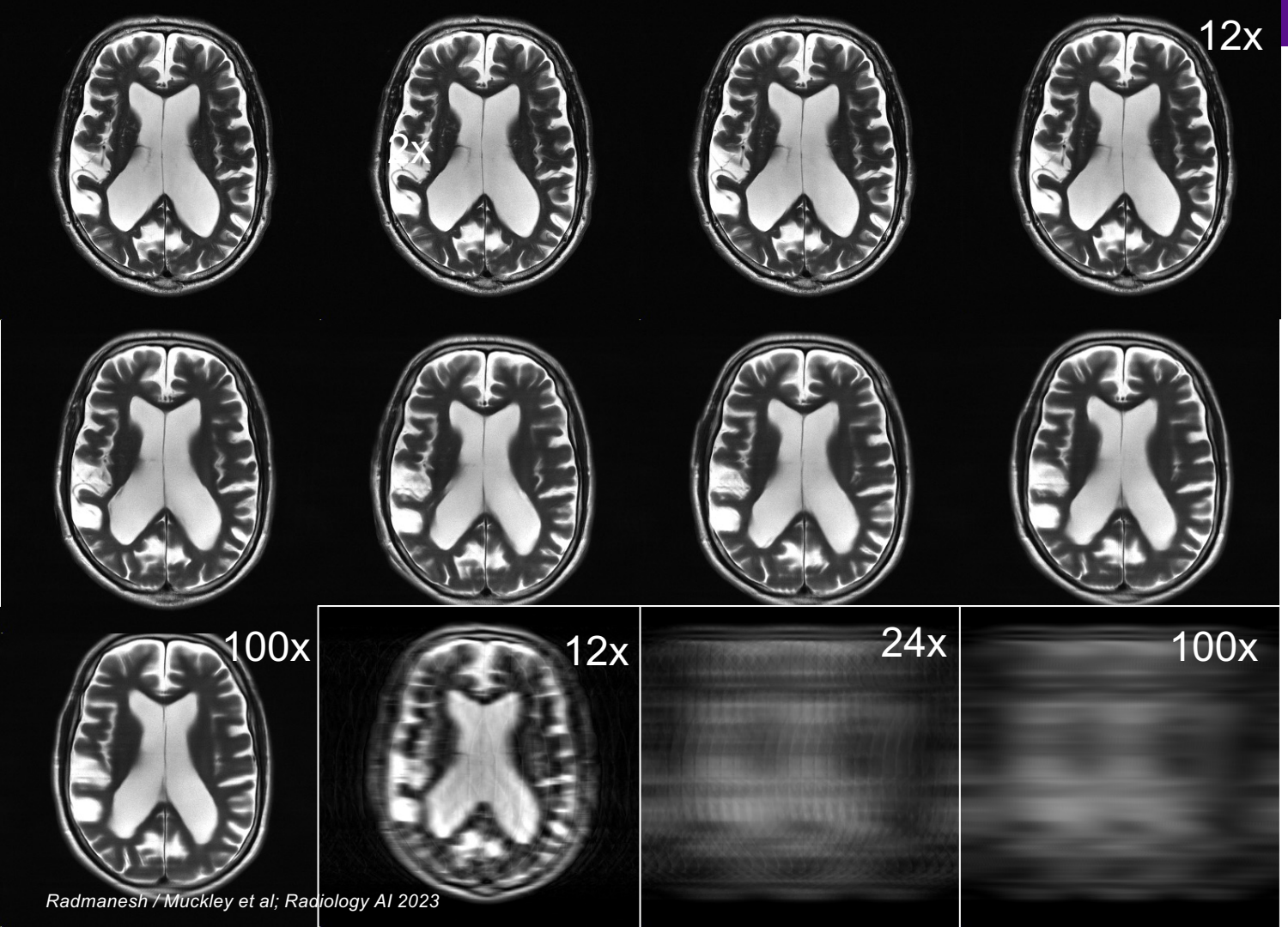

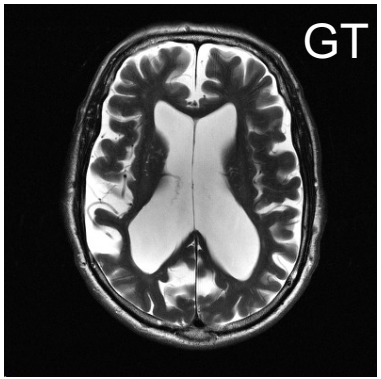

Radmanesh / Muckley et al; Radiology AI 2023

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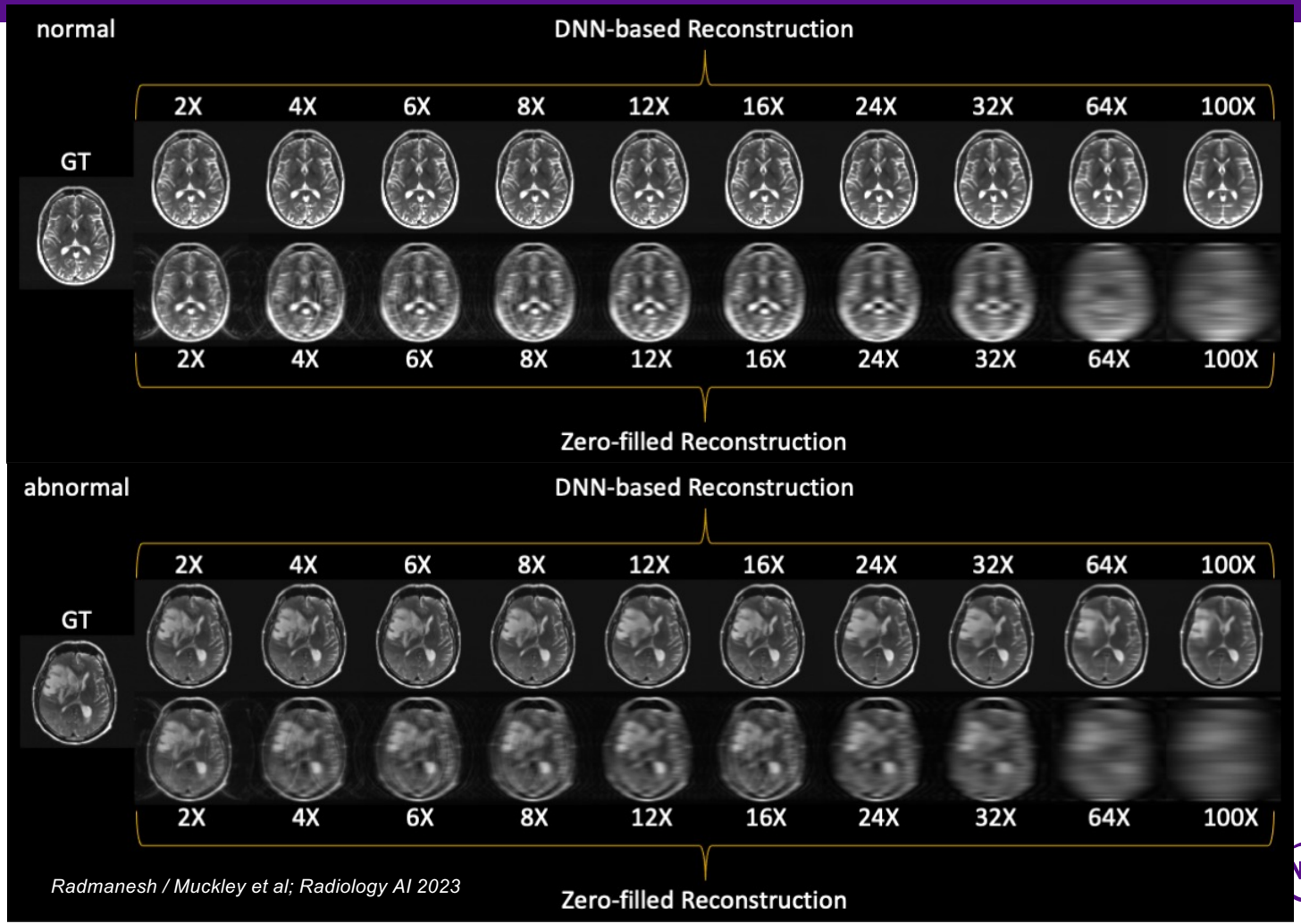

Radmanesh / Muckley et al; Radiology AI 2023

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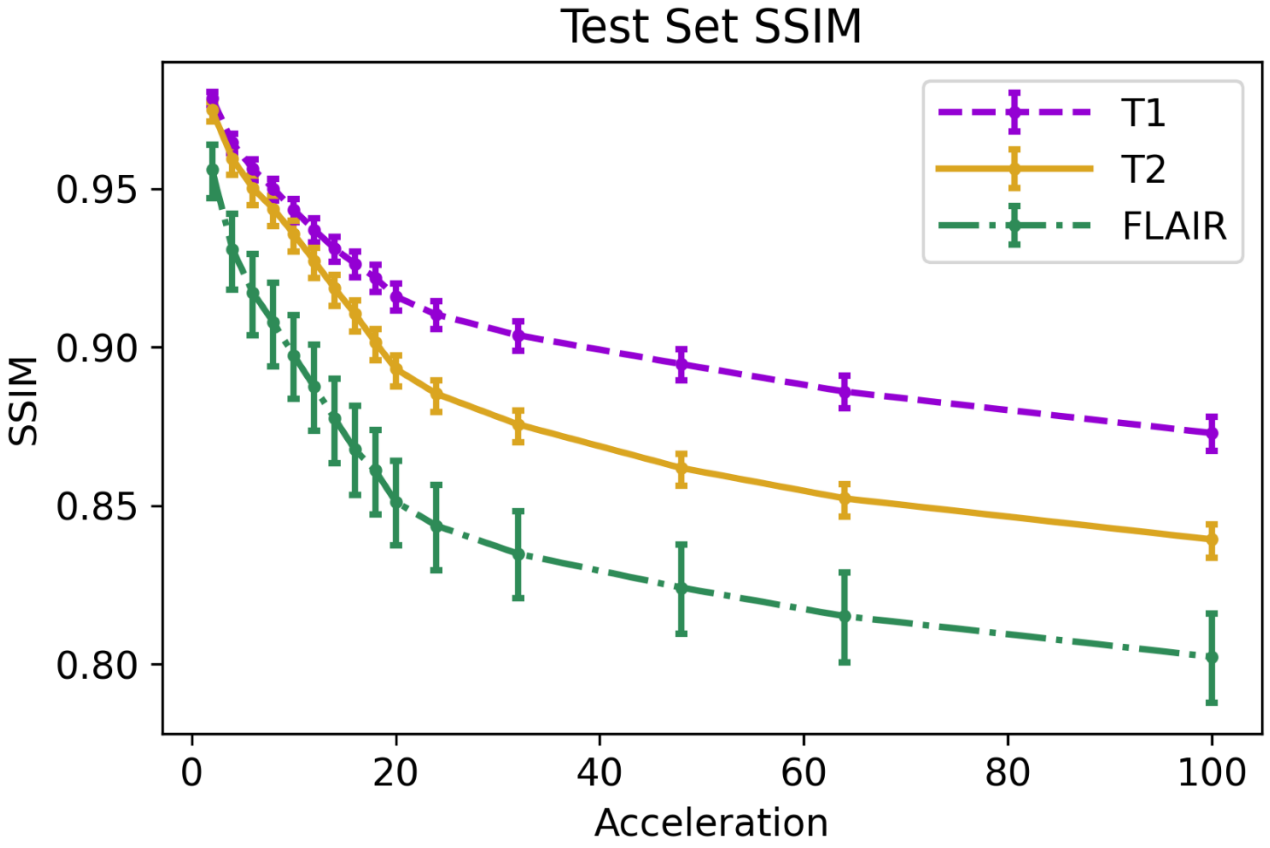

Radmanesh, Muckley et al. Radiol Artif Intell 2022 Nov 2;4(6)

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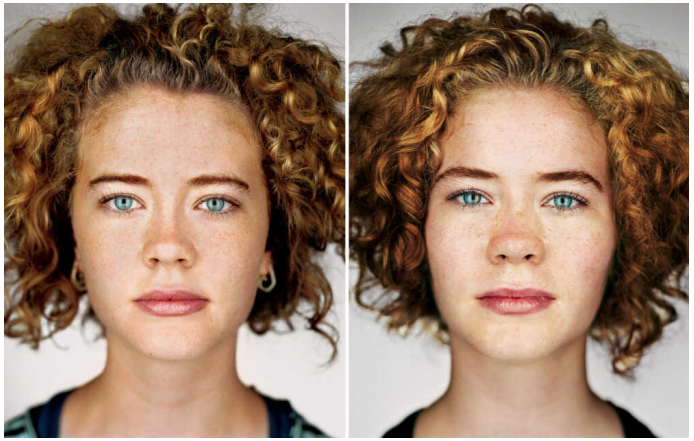

a study in *SSIM*ilarity

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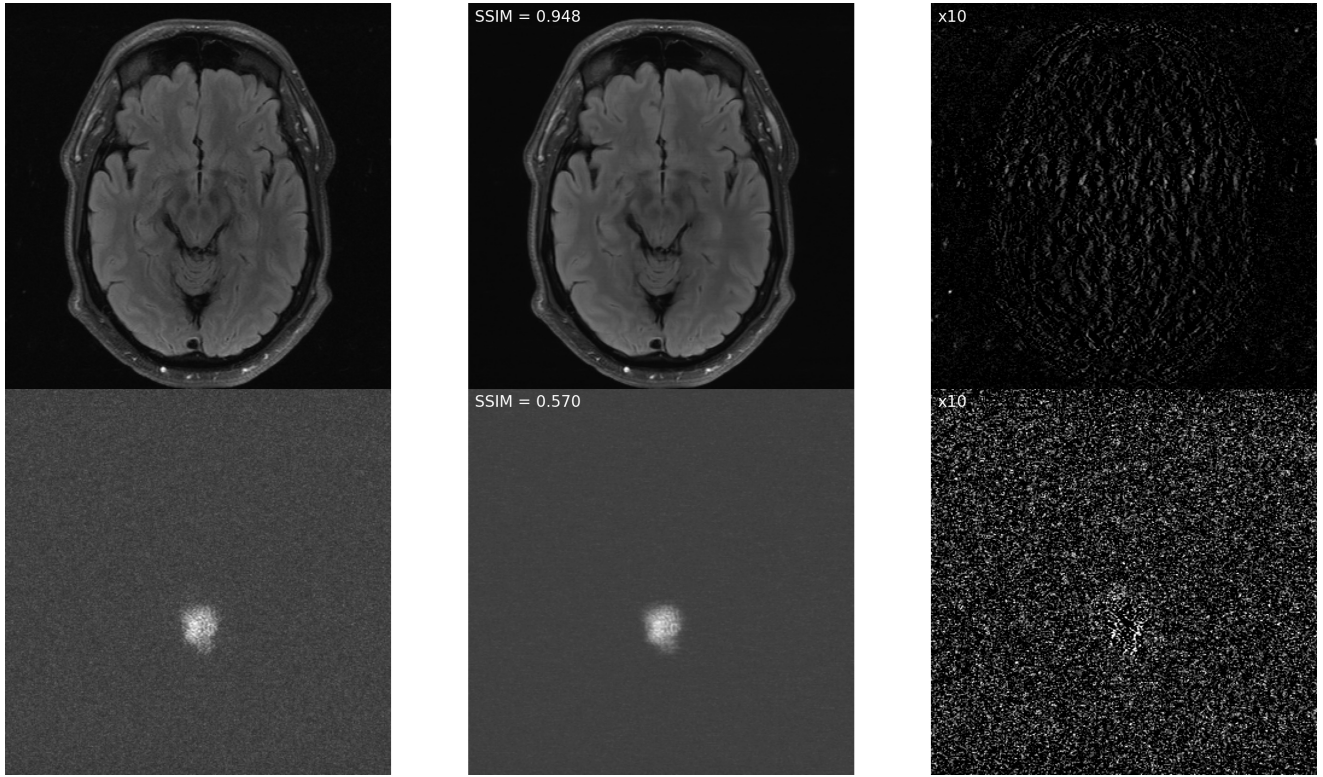
is SSIM all that?



Lin et al; AJR 2020

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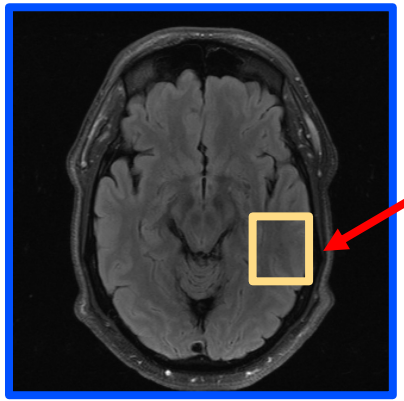

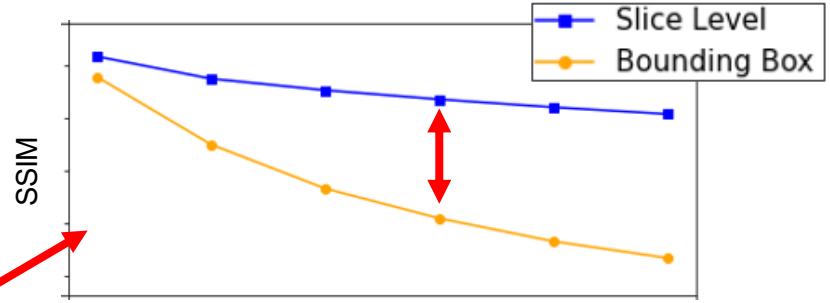

SSIM
- contrast
- luminence
- structure

Chen et al; ISMRM2023

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pathological differences

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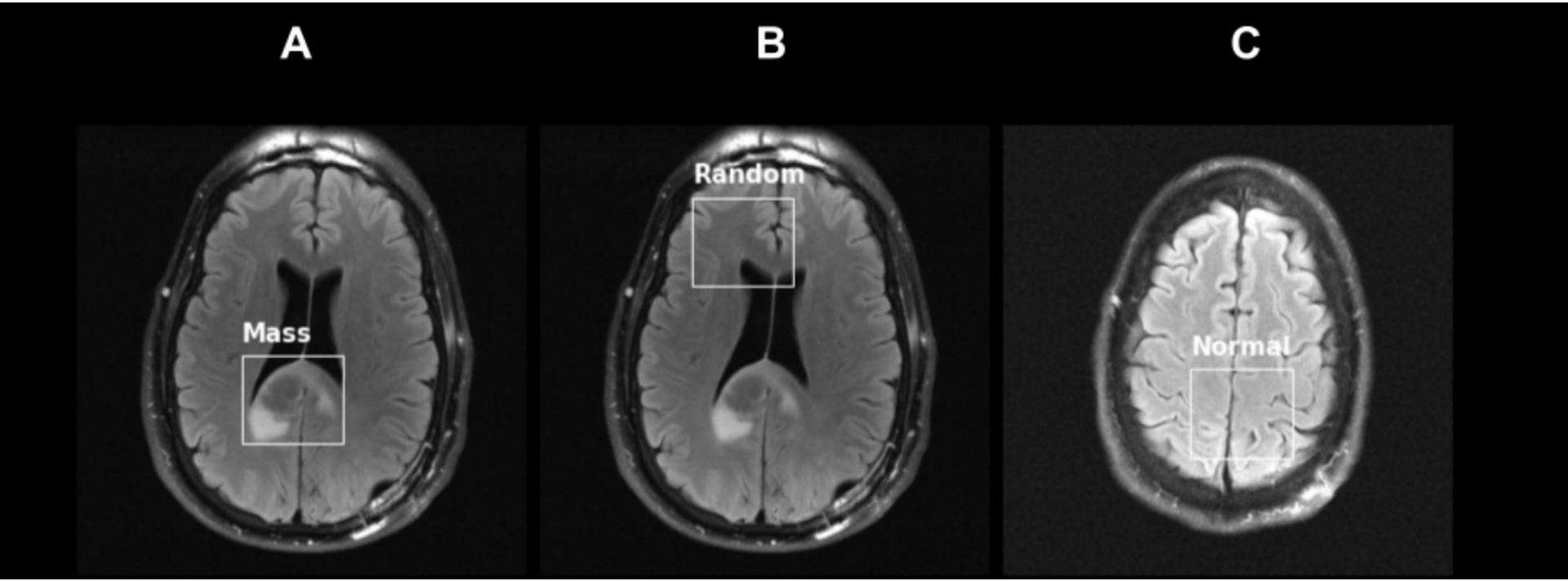

Chen et al; ISMRM23

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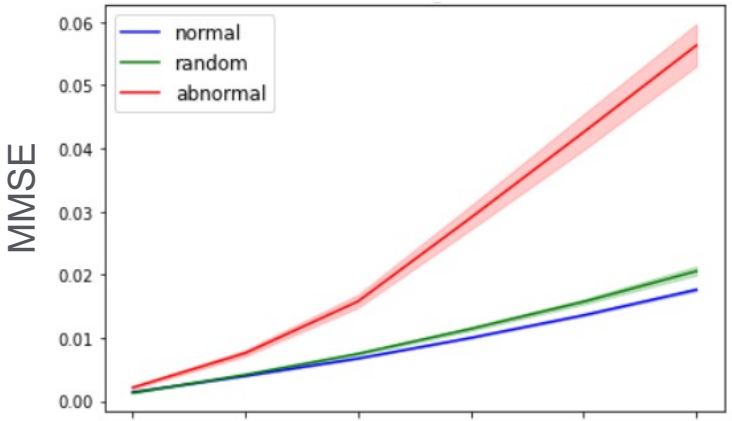
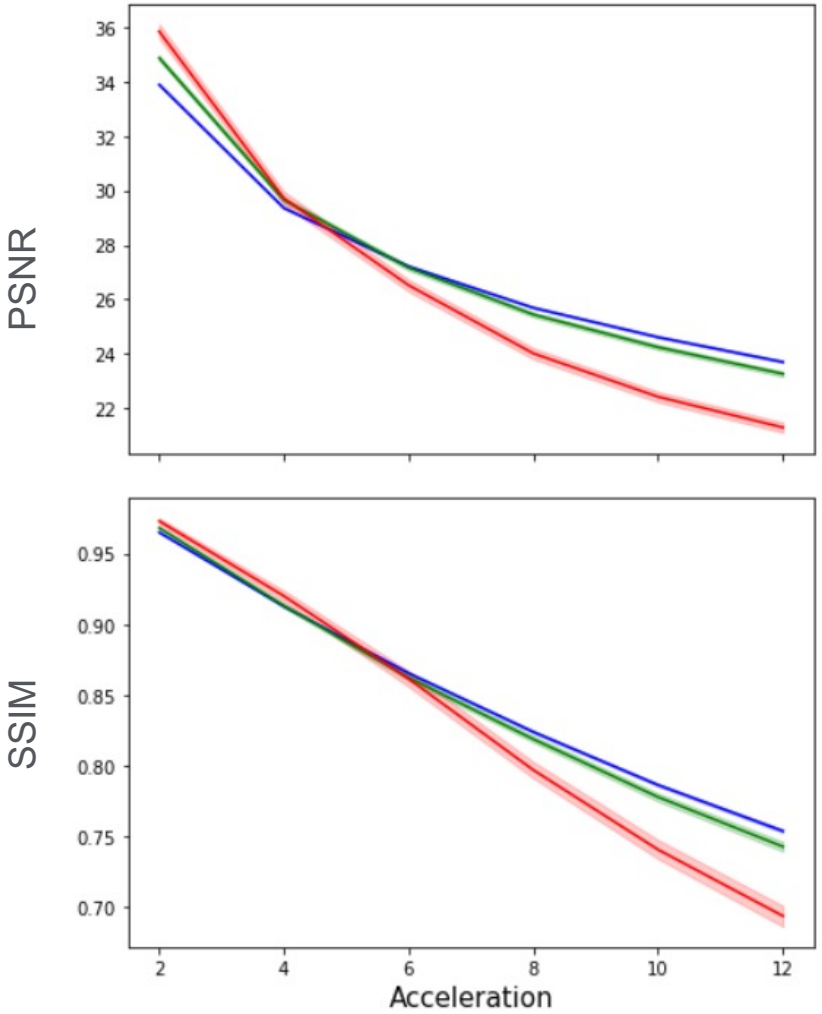
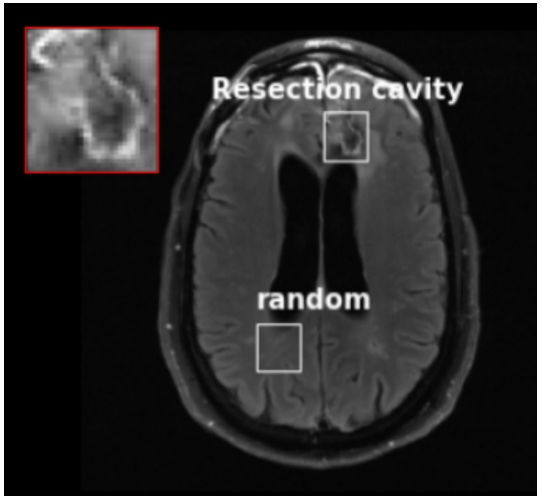
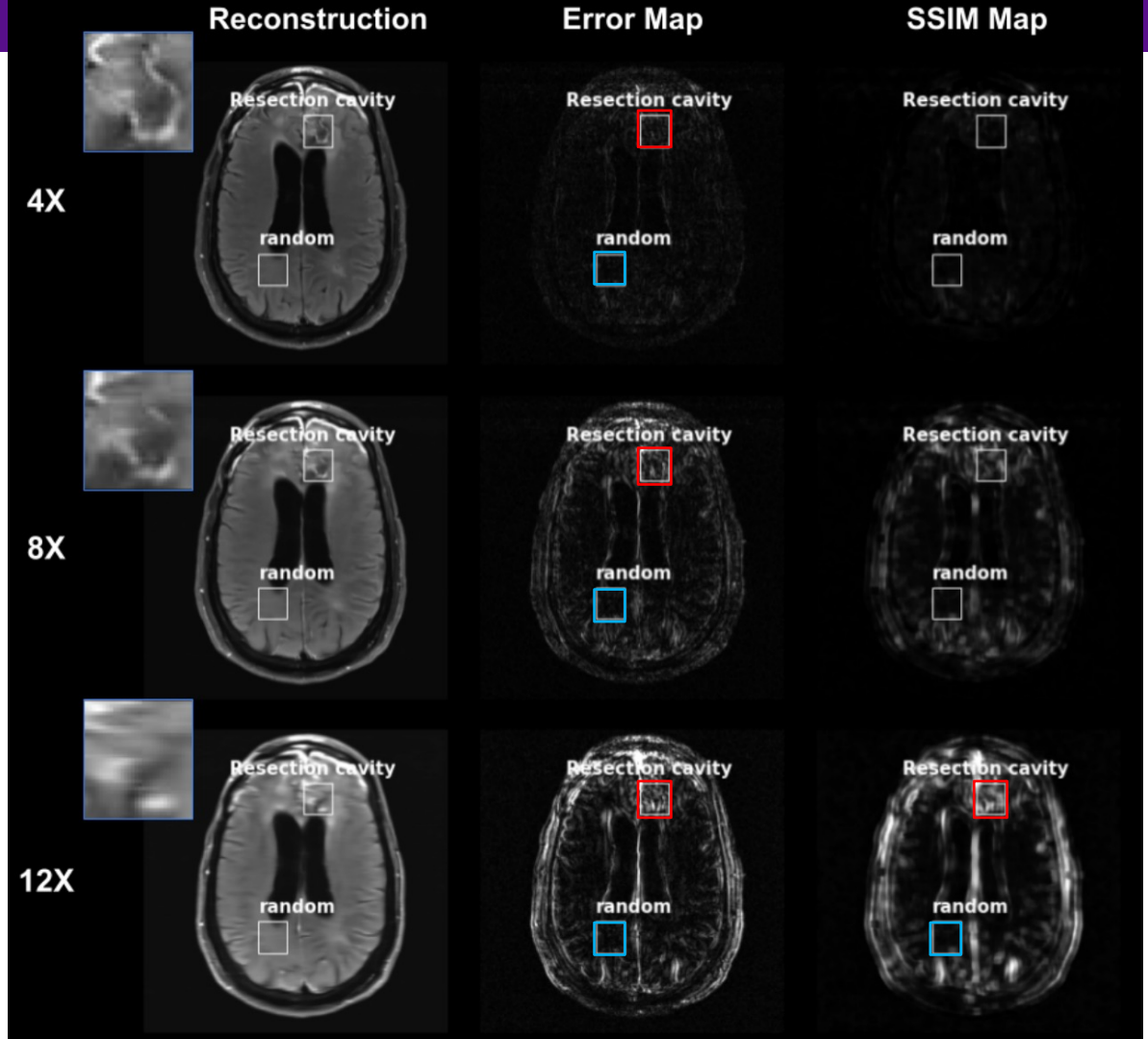




Chen et al; ISMRM23



GT



Chen et al; ISMRM23

knowing the unknowable?

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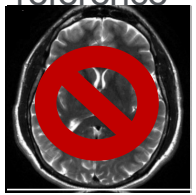
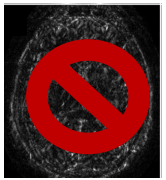
In real life:

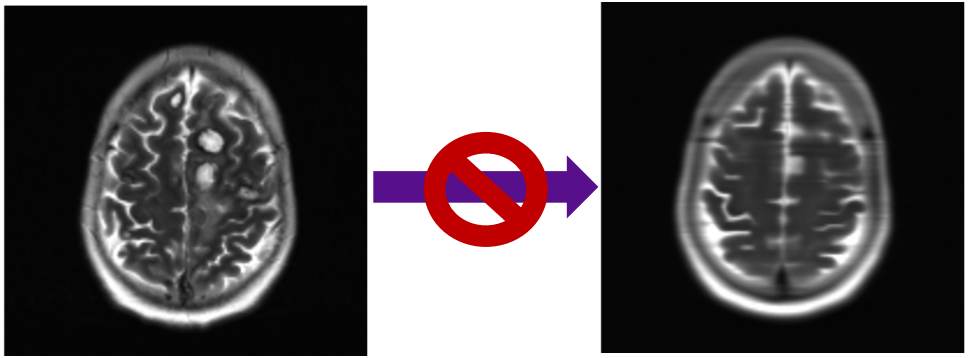
reference



reconstruction
error measure



How to guard against:



pseudonormalization
hallucinations
bad

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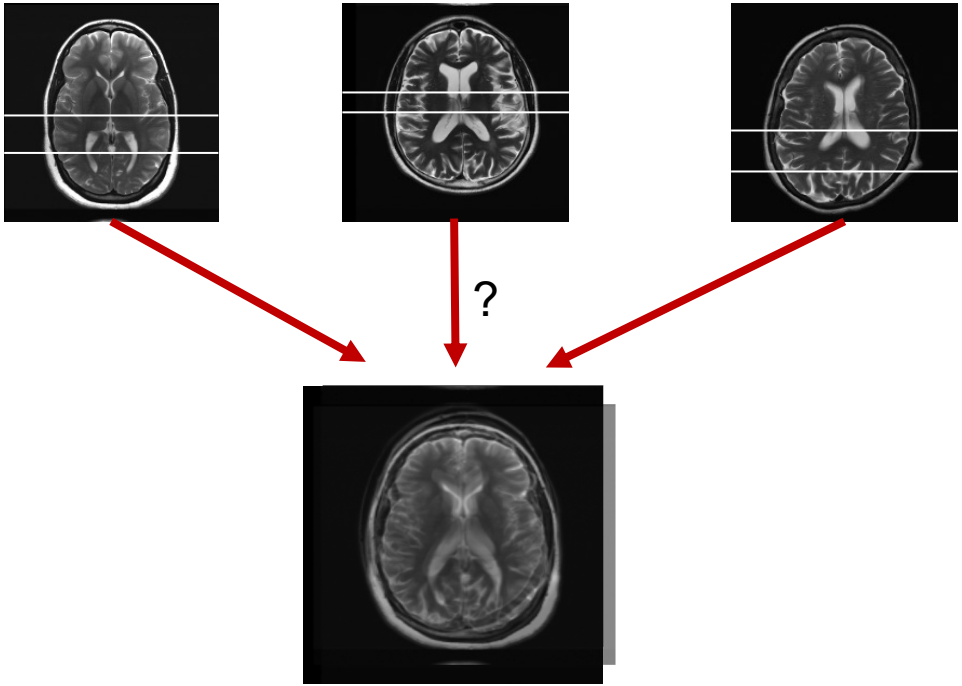
Is it mere memorization?



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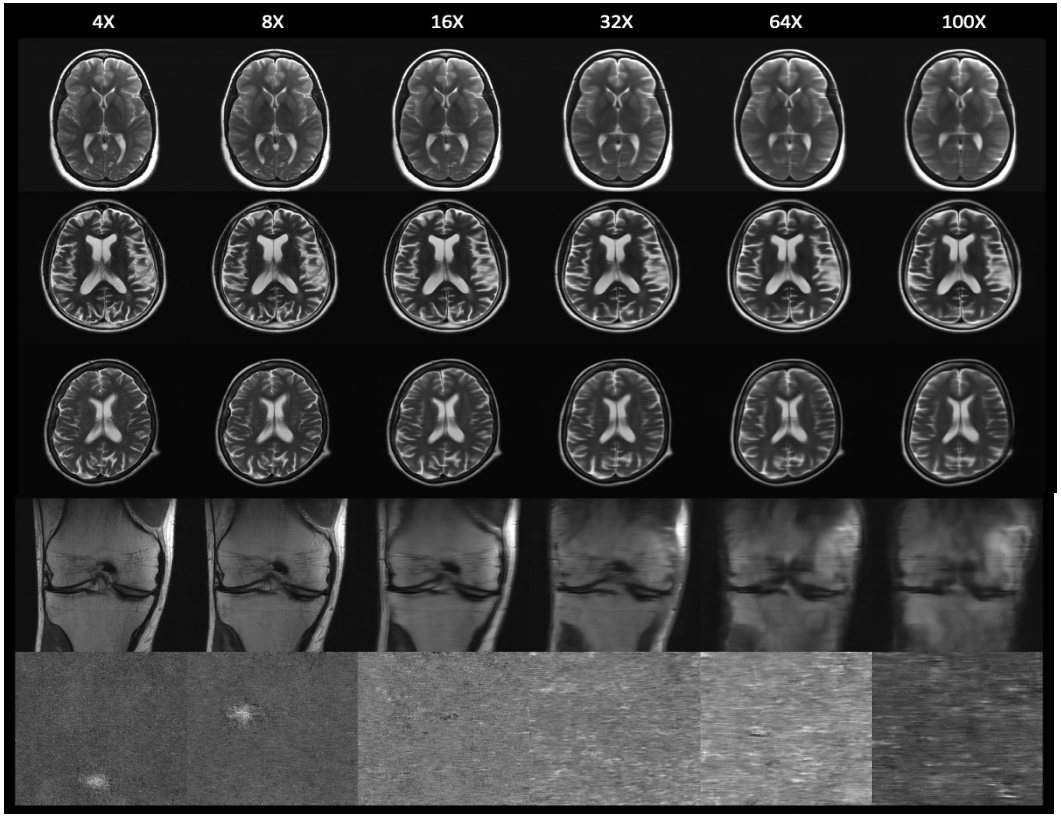
Complex projector



Muckley et al; in revision Radiology AI

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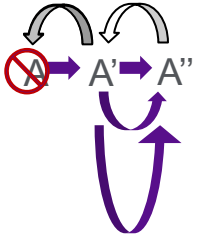
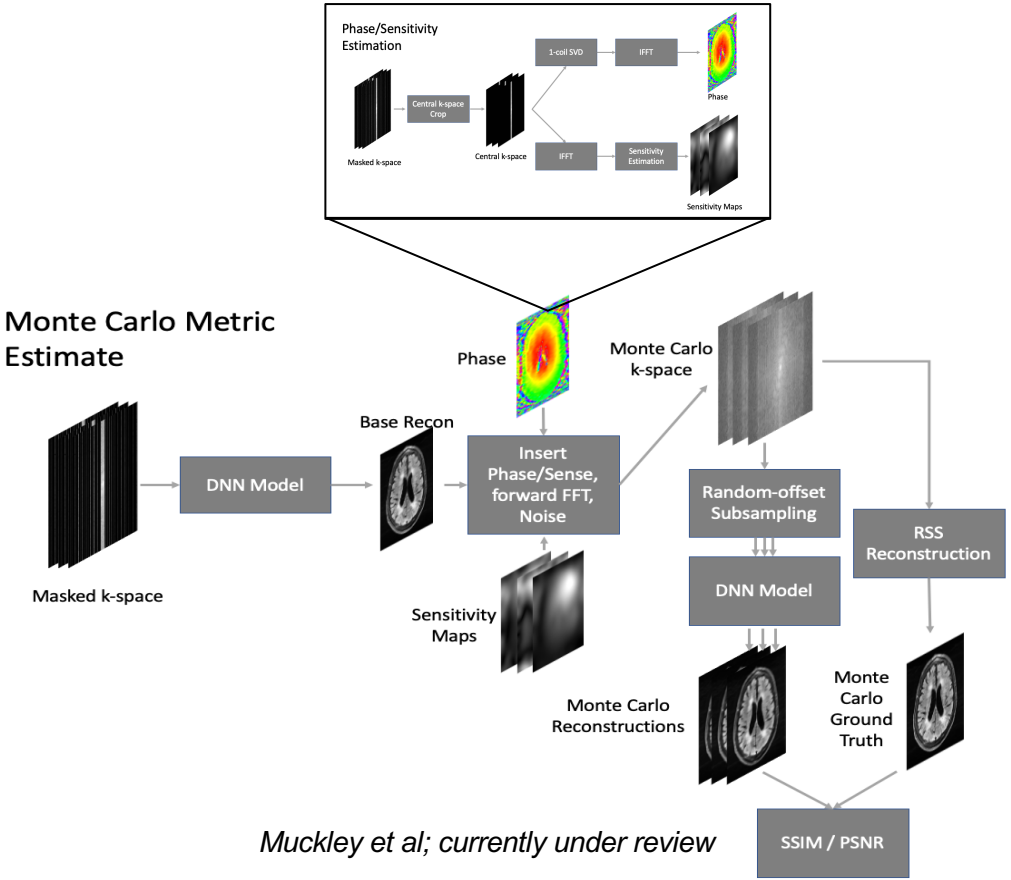
How to evaluate in the clinical environment??





Muckley et al; currently under review

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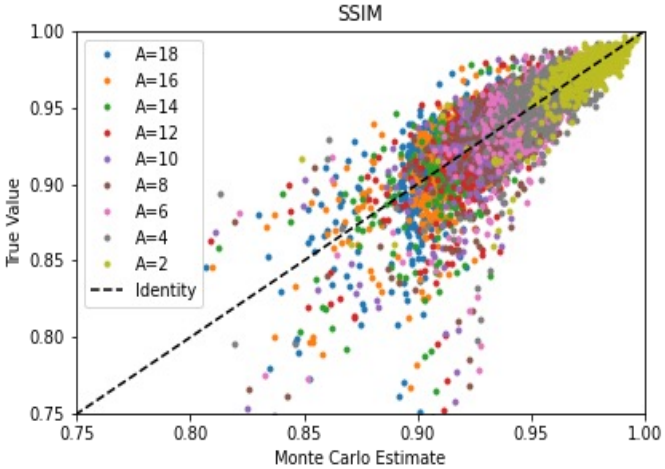
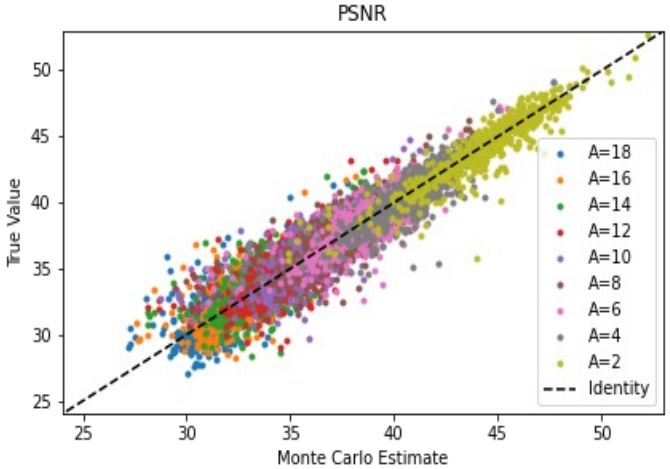
Monte Carlo estimates of error





Muckley et al; currently under review

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adaptation

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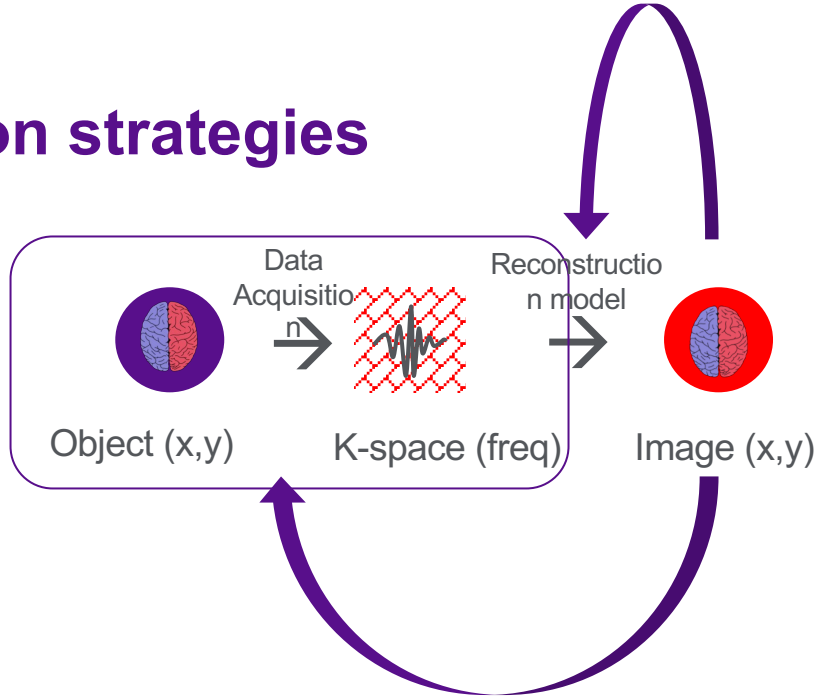
Adaptive acquisition strategies



	adaptive	non-adaptive, dataset-specific	equispaced
4×	**95.63** ± 0.27	**95.61** ± 0.55	95.38 ± 0.03
8×	**93.26** ± 0.20	91.37 ± 0.67	91.30 ± 0.06

Bakker, Muckley et al, 2022 Proceedings of ML Research

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"LOUPE"

Deep-learning-based Optimization of the Under-sampling Pattern in MRI

Cagla D. Bahadir*, Alan Q. Wang*, Adrian V. Dalca, and Mert R. Sabuncu

Alternating Learning Approach for Variational Networks and Undersampling Pattern in Parallel MRI Applications

Marcelo V W Zibetti [1], Florian Knoll [2], Ravinder R Regatte [1]

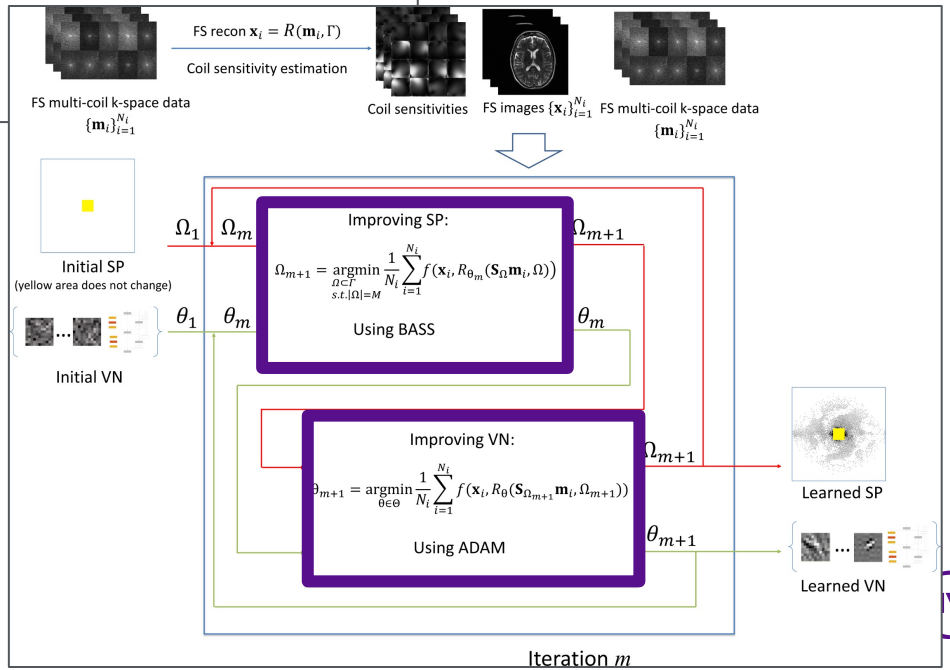

Figure courtesy of Marcelo Zibetti, PhD

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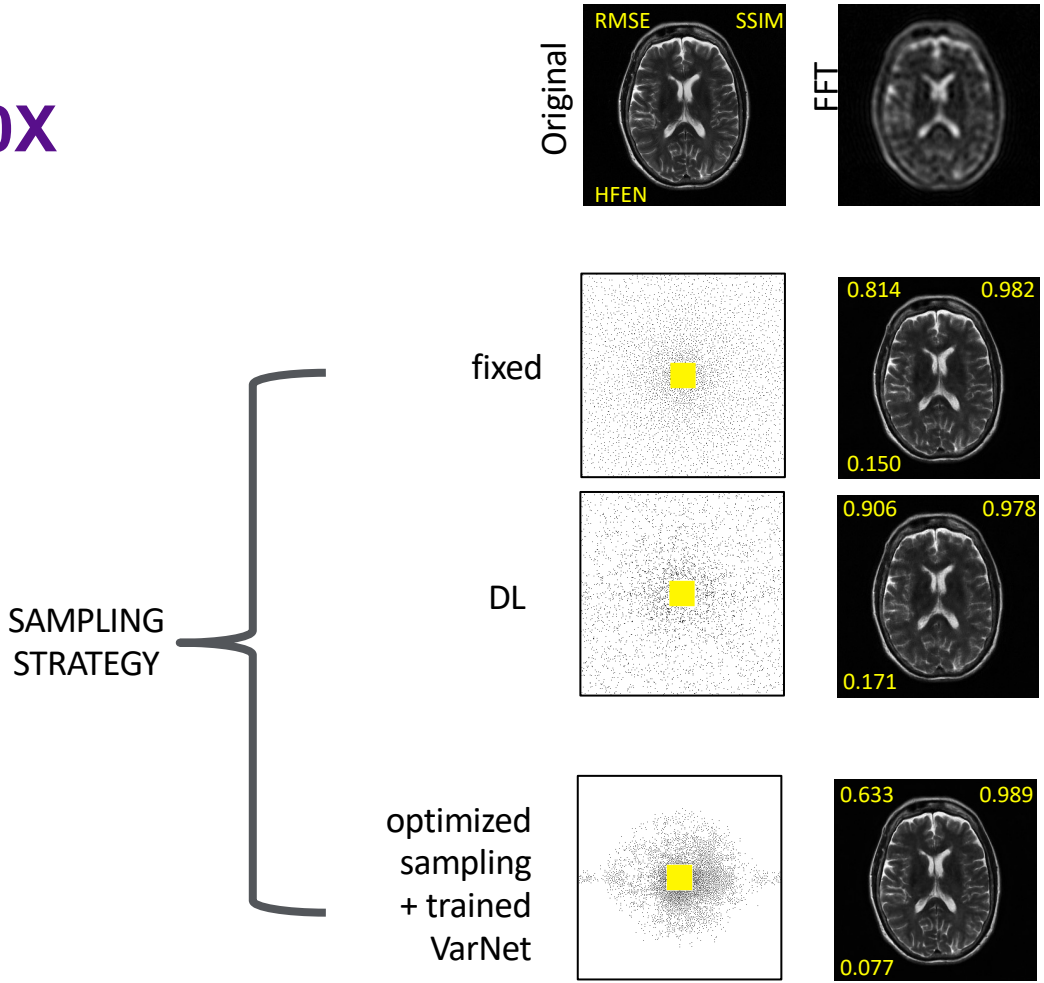
20X



courtesy of Marcelo Zibetti, PhD

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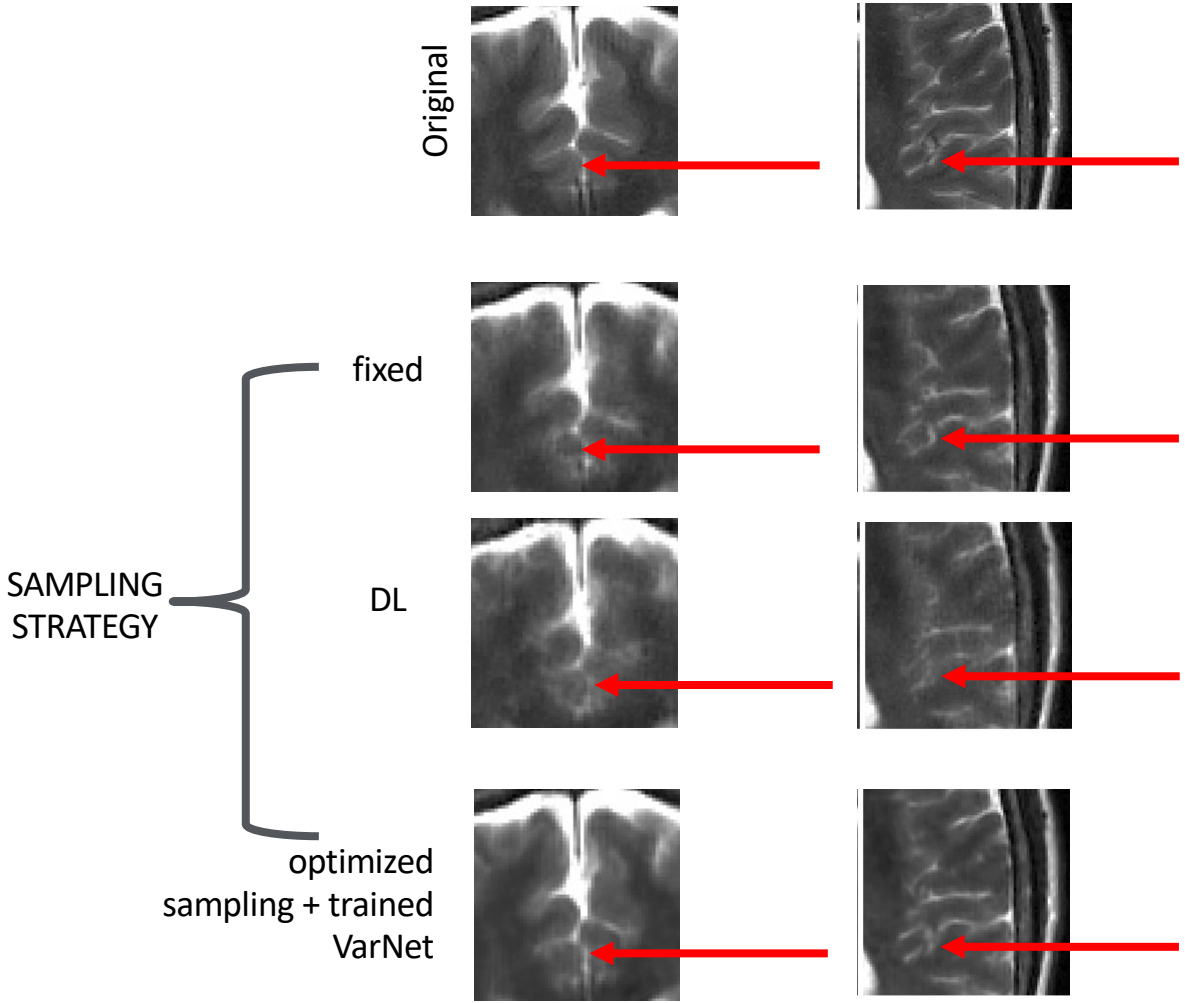
20X



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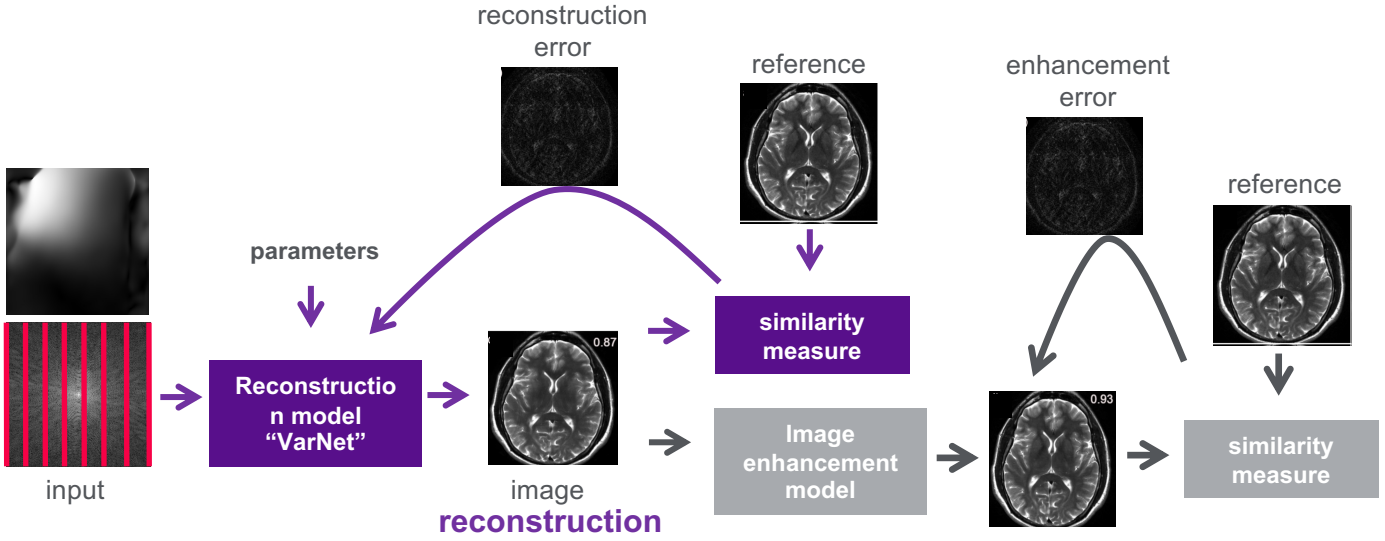
enhancing your image

Learning for acquisition strategies…

Learning for image reconstruction…

…learning for image enhancement



adapted from Hammernik MRM 2018

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Enhancing an image

- super-resolution
- low dose to high dose
- image space de-noising
- nuisance voxels
- parameter estimation

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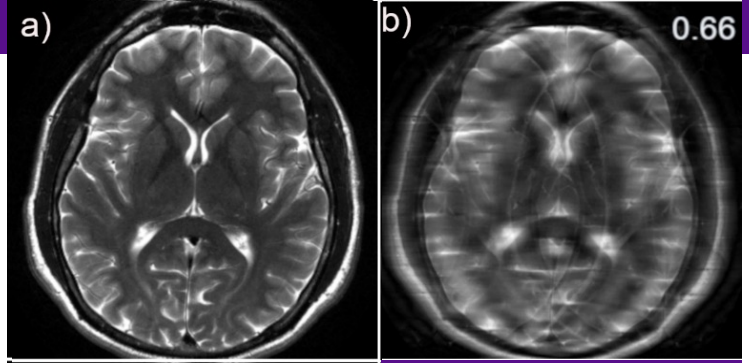
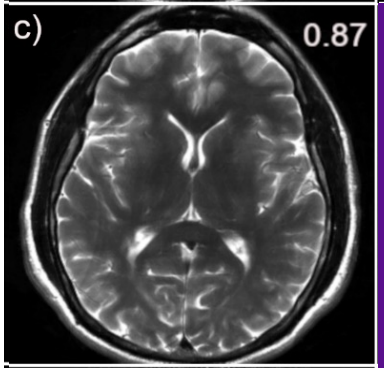
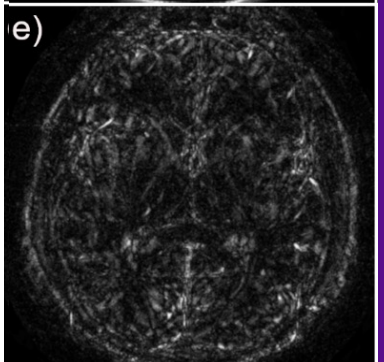
image enhancement vs image reconstruction







Lin et al, JMRI 2020

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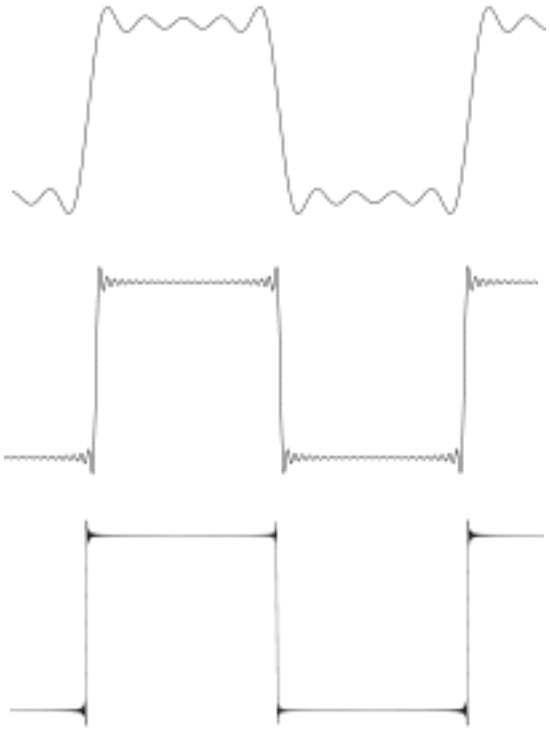
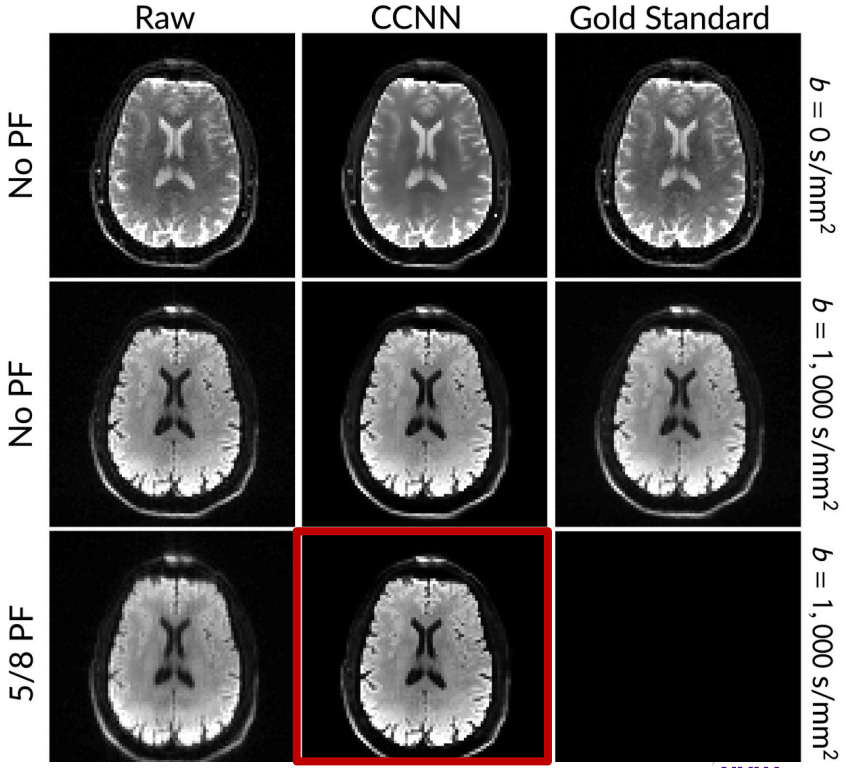
DeGibbsing, denoising





Muckley MRM, 2020

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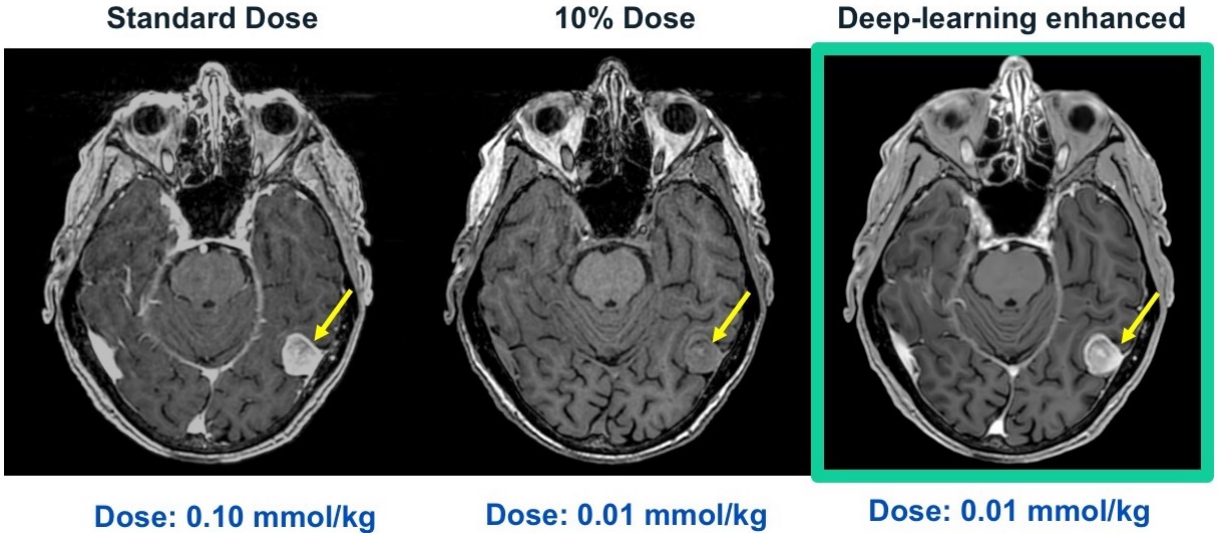
Ultra-low dose gadolinium imaging



courtesy of Greg Zaharchuk, MD PhD

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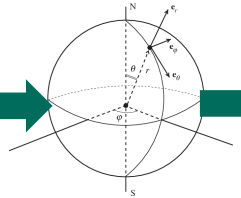
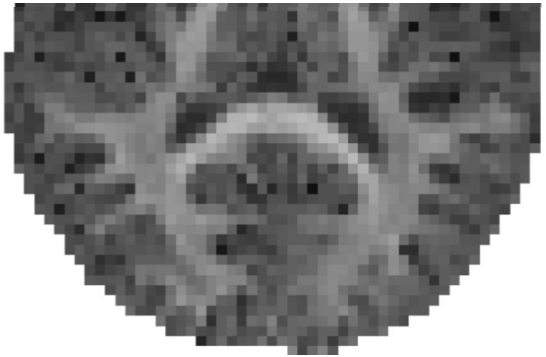
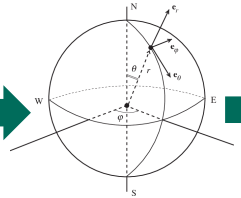
Parameter Estimation: Diffusion Kurtosis

Diffusion signal → Kurtosis calculation (Tensor) →  → Mean Kurtosis



Diffusion signal →  → Powder Kurtosis → DL Estimator Mean Kurtosis

courtesy of Jelle Veraart, PhD

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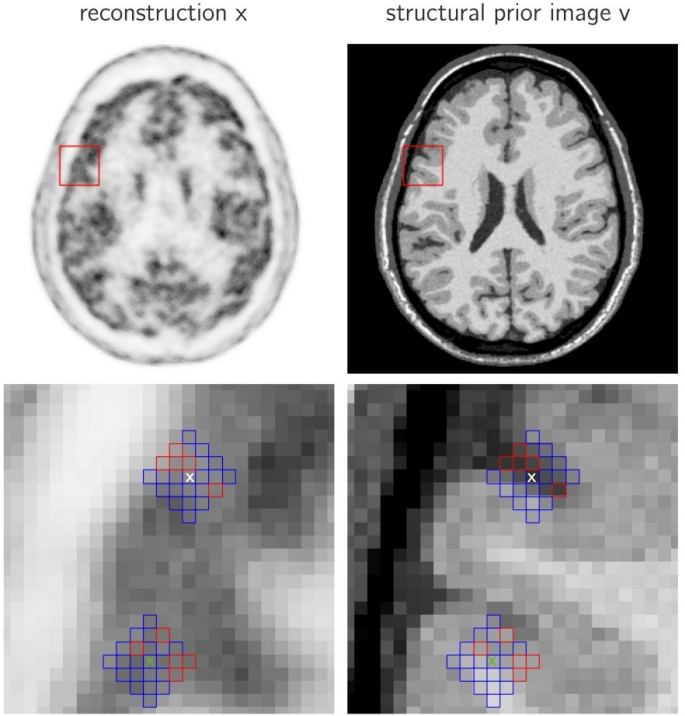
Anatomically-Guided PET reconstructions: Predicting the Bowsher Prior

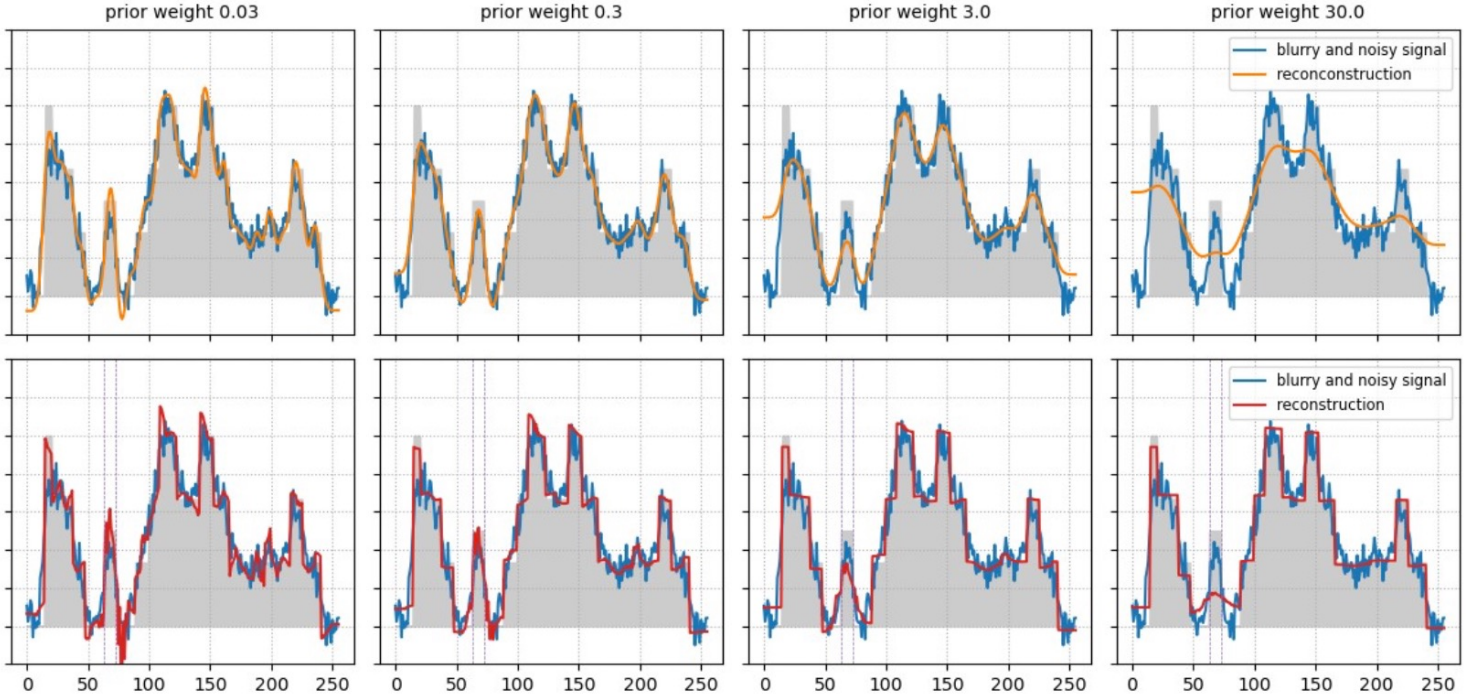
conventional smoothing prior

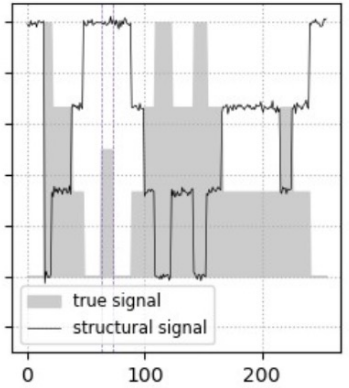
$$R(x) = \sum_i \sum_j \psi(x_i, x_j)$$

Bowsher's (structural) prior

$$R(x, v) = \sum_i \sum_j w_{ij}(v)\psi(x_i, x_j)$$

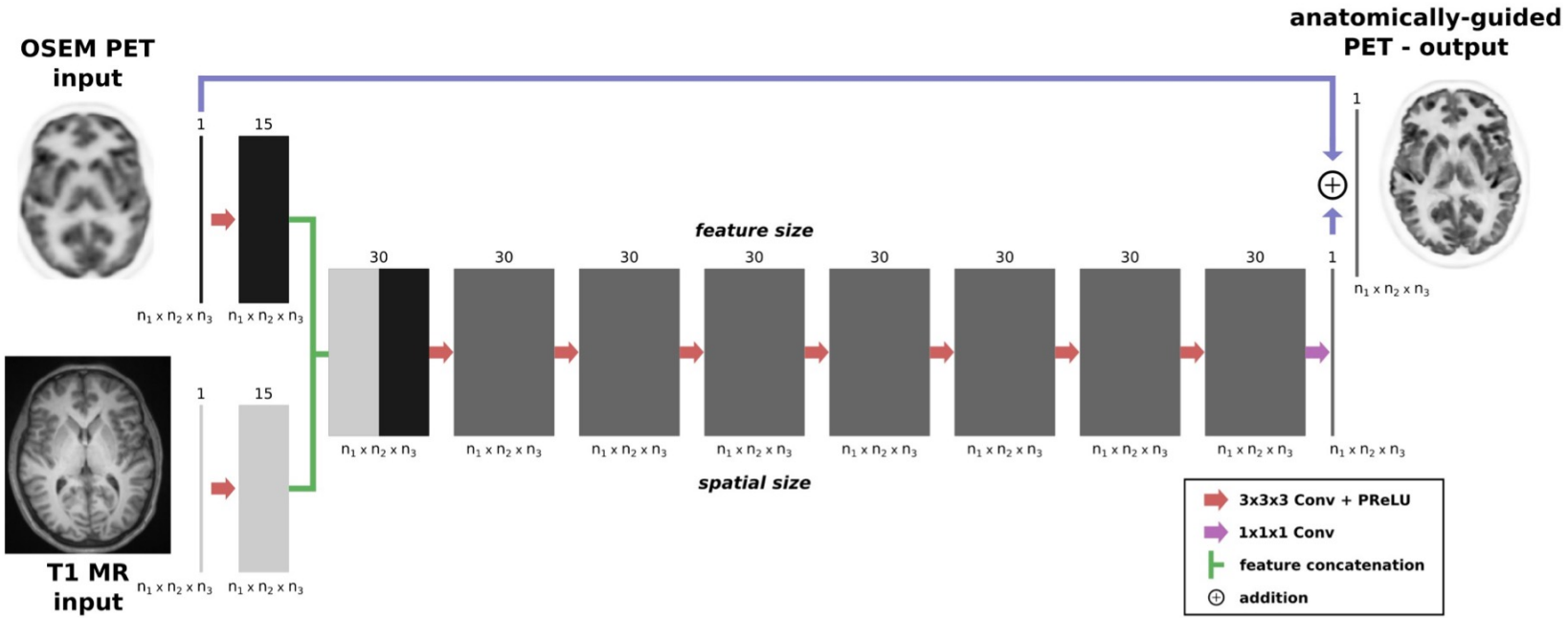


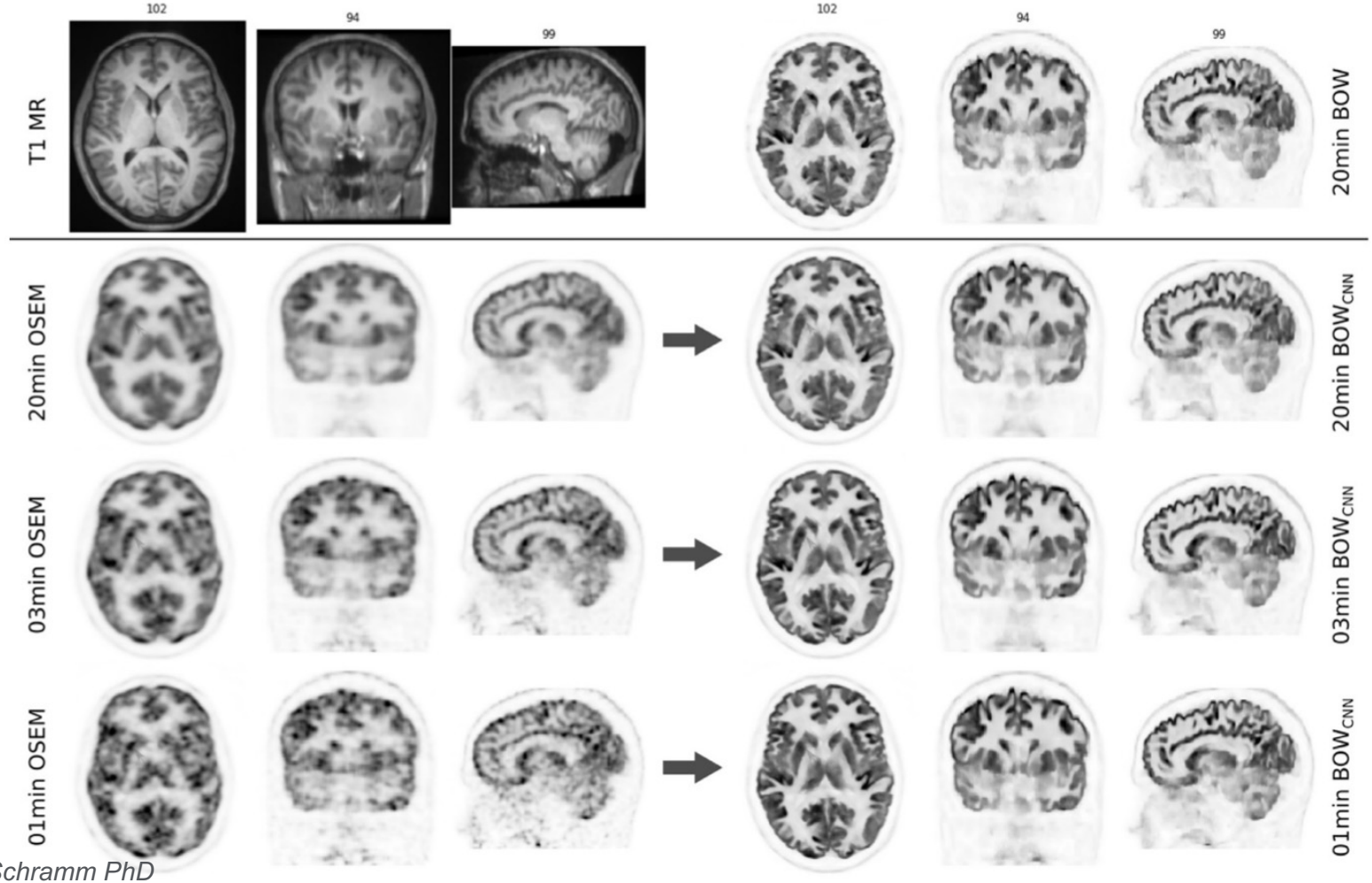

prior weight 0.03
prior weight 0.3
prior weight 3.0
prior weight 30.0
blurry and noisy signal
reconconstruction
blurry and noisy signal
reconstruction
0
50
100
150
200
250


true signal
structural signal
0
100
200

Schramm et al, NeuroImage 2021
"Approximating anatomically-guided PET reconstruction in image space using a convolutional neural network"

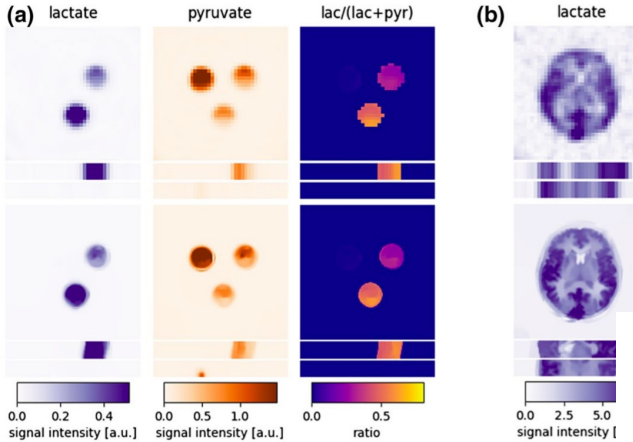
Structural priors recon in image space using a CNN



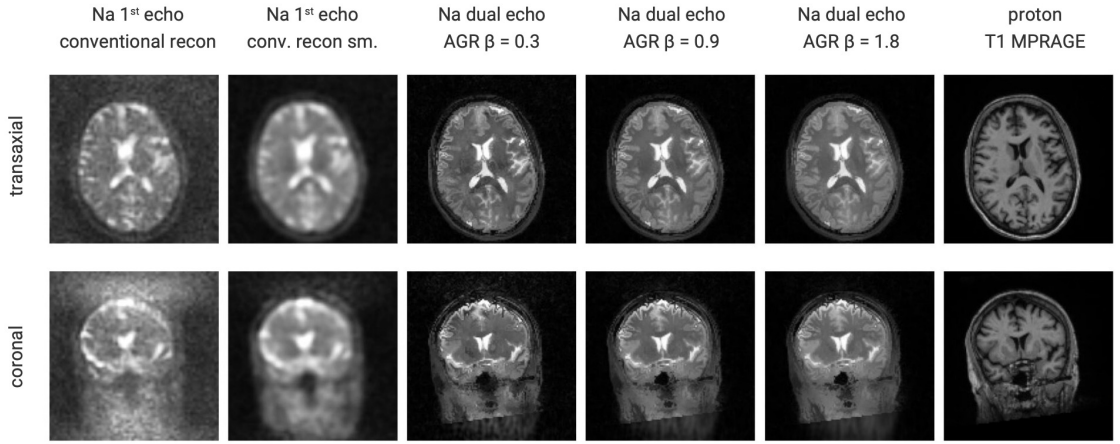

T1 MR
102
94
99
20min BOW
20min OSEM
20min BOW$_{CNN}$
03min OSEM
03min BOW$_{CNN}$
01min OSEM
01min BOW$_{CNN}$

Hyperpolarized ^{13}C MRI with structural priors

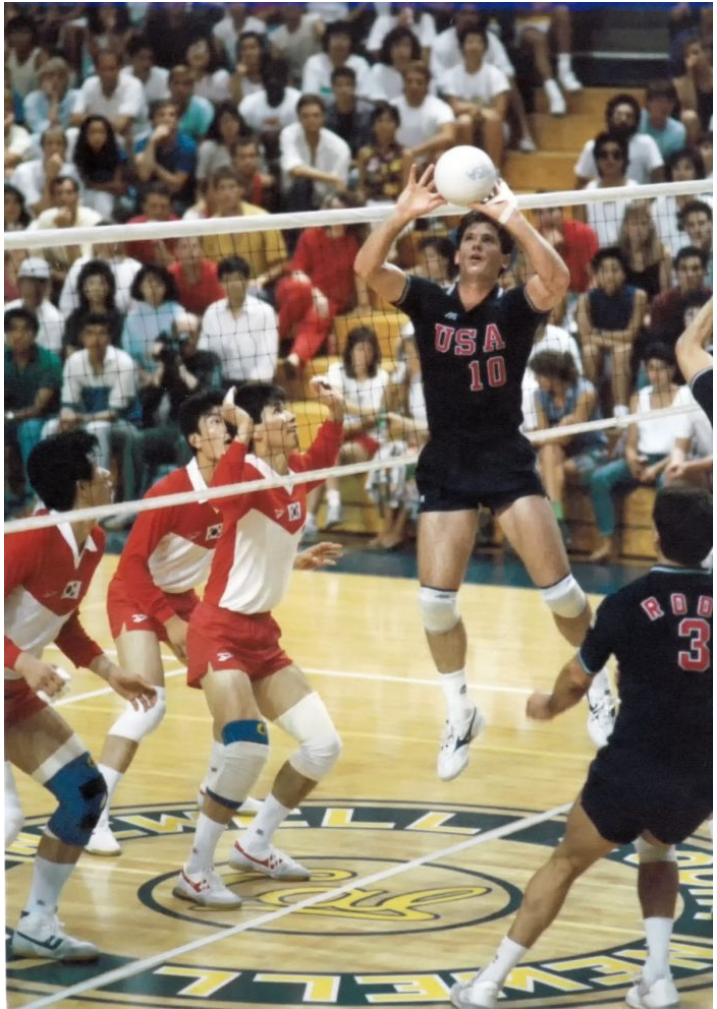
Ehrhardt et al, MRM, 87, 2022
"Enhancing the spatial resolution of hyperpolarized C-13 MRI of human brain metabolism using structure guidance"



3T sodium MRI reconstruction with structural priors



sets



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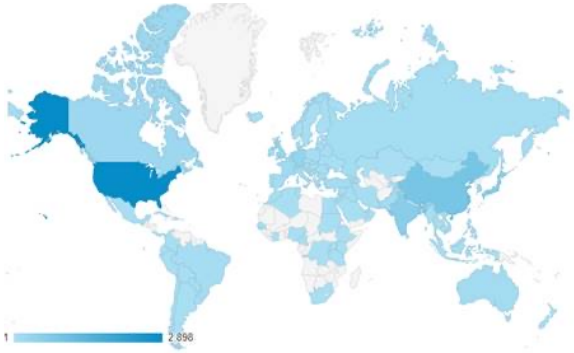
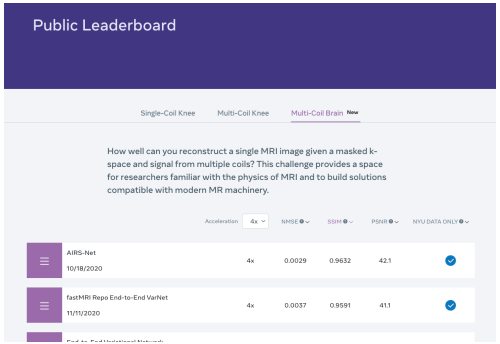
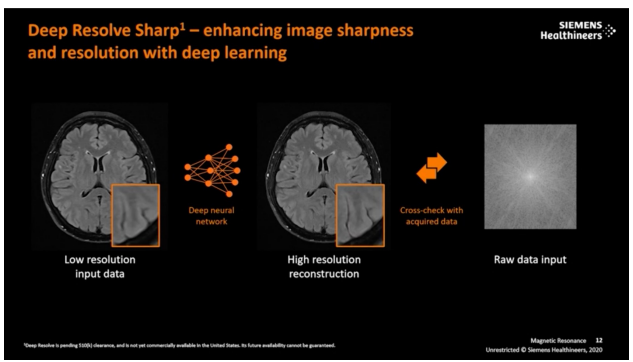
*fast*MRI

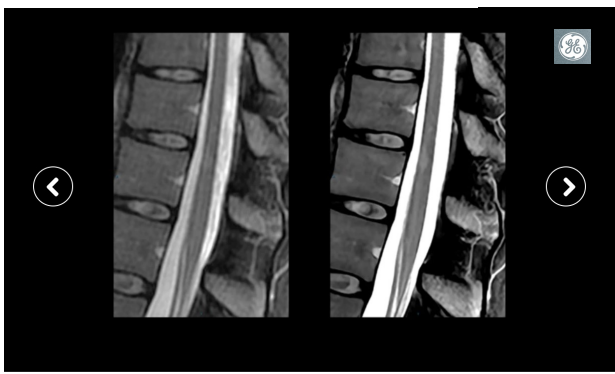
- Publicly available dataset for MR image reconstruction
- Hosted on AWS
- >10,000 users from >125 countries in past year
- also released tools / provided opportunities towards making research efficient and reproducible across research communities
  - standardized evaluation criteria
  - standaridized code
  - PyTorch data loaders on Github
  - hosting public leaderboard, challenges





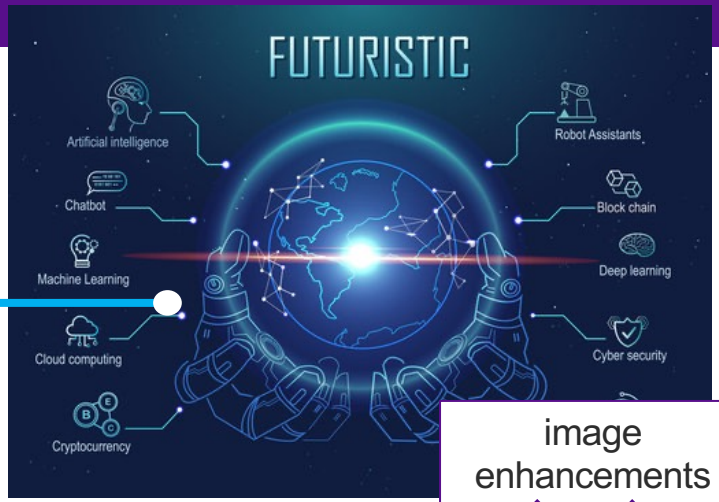
Acceleration: the pace of research





Left: Conventional, 2:50 min.
Right: AIR™ Recon DL, 1:28 min.

image reconstruction



patient specific Prior information

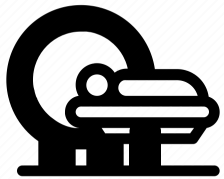
parameters

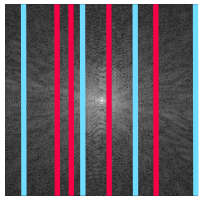
intelligent sampling strategy

better evaluation metrics; capturing pathology

image enhancements

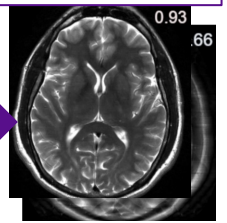
final patient image





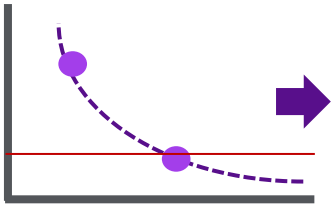
input

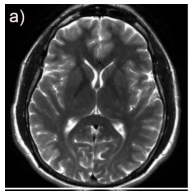
Reconstruction model



reconstruction

estimate error





end-to-end

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R01 NS119767 PI Lui
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Thank you!

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foundational models

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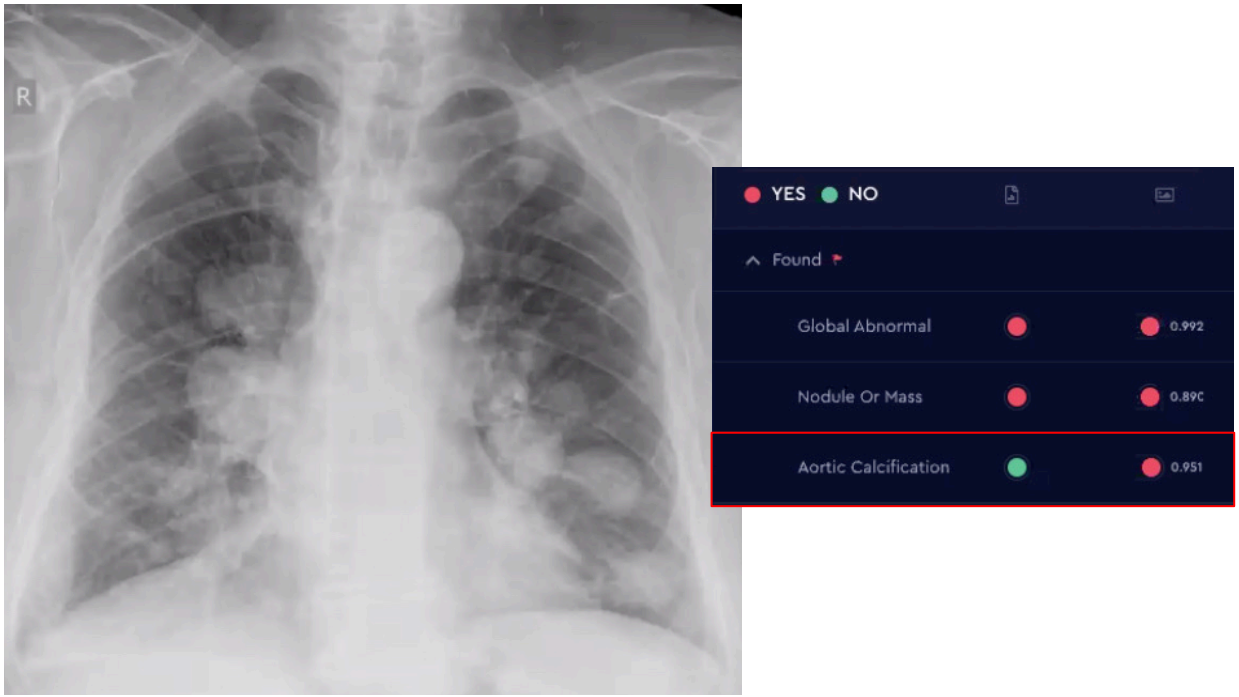
Radiology as narrative



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T

write a biblical verse in the style of the king james bible explaining how to remove a peanut butter sandwich from a VCR

And it came to pass that a man was troubled by a peanut butter sandwich, for it had been placed within his VCR, and he knew not how to remove it.

And he cried out to the Lord, saying, "Oh, Lord, how can I remove this sandwich from my VCR, for it is stuck fast and will not budge?"

And the Lord spoke unto him, saying, "Fear not, my child, for I shall guide thy hand and show thee the way. Take thy butter knife, and carefully insert it between the sandwich and the VCR, and gently pry them apart. And with patience and perseverance, the sandwich shall be removed, and thy VCR shall be saved."

And the man did as the Lord commanded, and lo and behold, the sandwich was removed from the VCR, and the man was saved.

Med SAM

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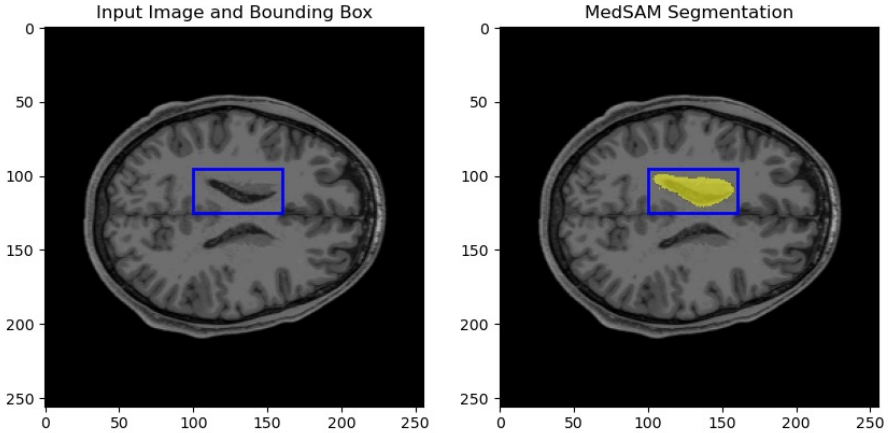

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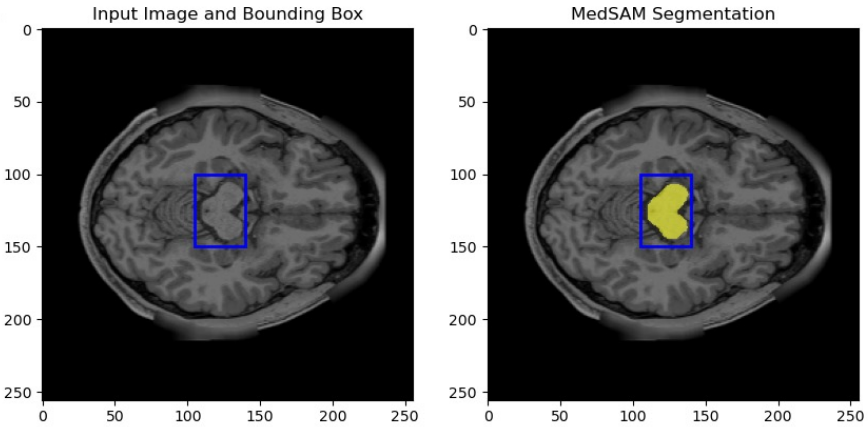

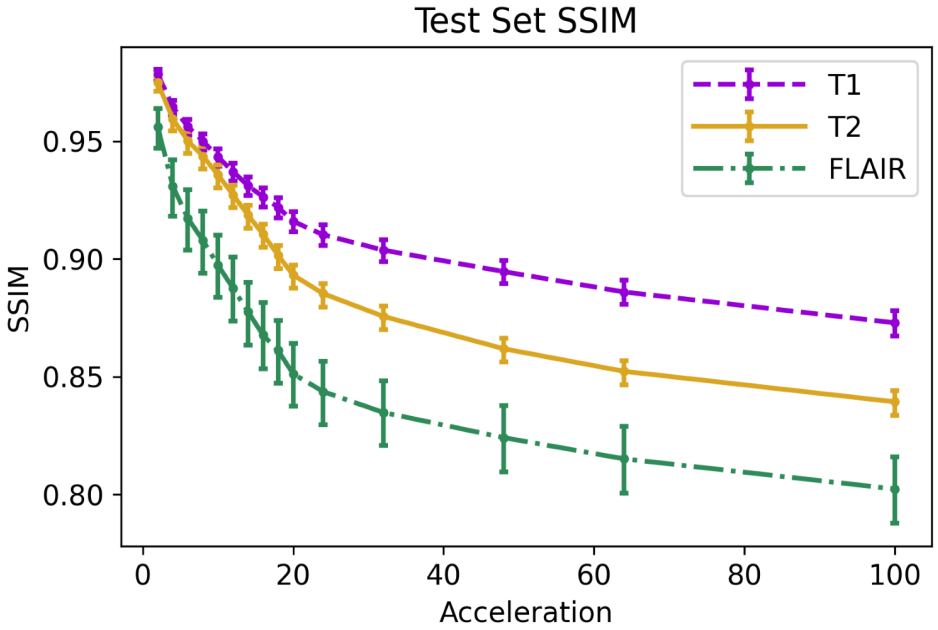

Muckley et al; currently under review

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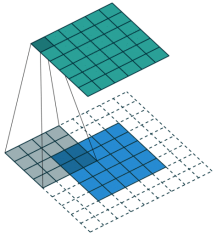
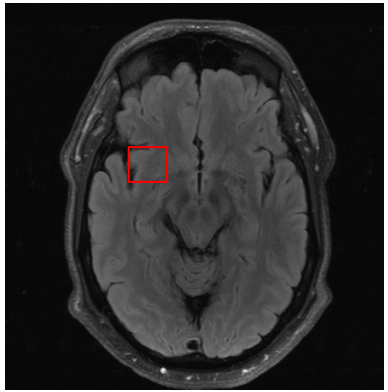
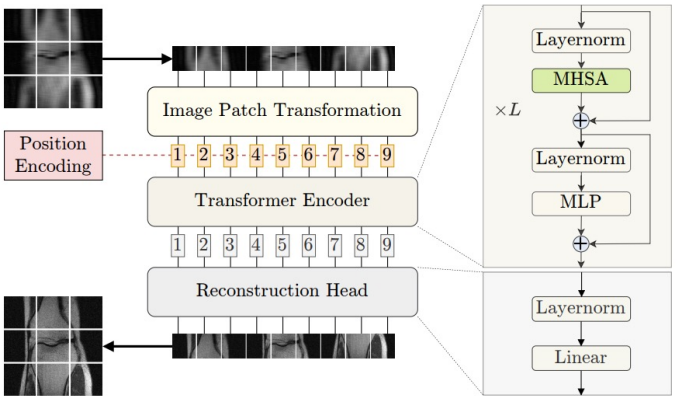
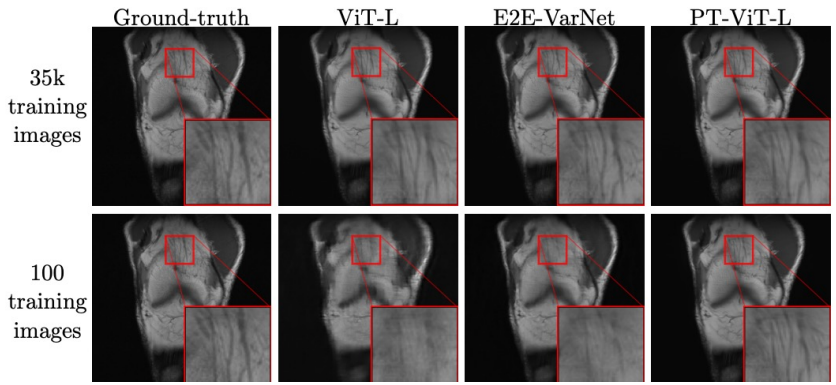
Vision Transformers; are CNNs a thing of the past?









Lin et al; MIDL 2022; Proc ML Research under review

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