Deep convolutional neural networks for accelerated dynamic magnetic resonance imaging

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Purpose

- Magnetic resonance imaging (MRI) scan times are relatively slow, especially for dynamic acquisitions like in the heart
- Scan time can be accelerated by compressed sensing[1] (CS) schemes that exploit data redundancy to reconstruct undersampled MR images
- However, CS-based reconstruction times are long because they employ iterative algorithms to solve optimization problems
- Critical time between patient exam and diagnosis is extended by hours – making MRI infeasible for urgent clinical situations

Goal: Use convolutional neural networks to efficiently and accurately reconstruct *highly* undersampled dynamic MRI data

Background

- CS-based image reconstruction[1] is based on iteratively solving non-linear inverse problems of the form:

$$\underset{x}{\text{minimize}}\, ||\mathcal{F}_s x - y||_2^2 + \lambda||\phi(x)||_1$$

- CNNs are well-suited for modelling this task[2] and have previously been used to learn CT[3] and MRI[4] static CS recon pipelines

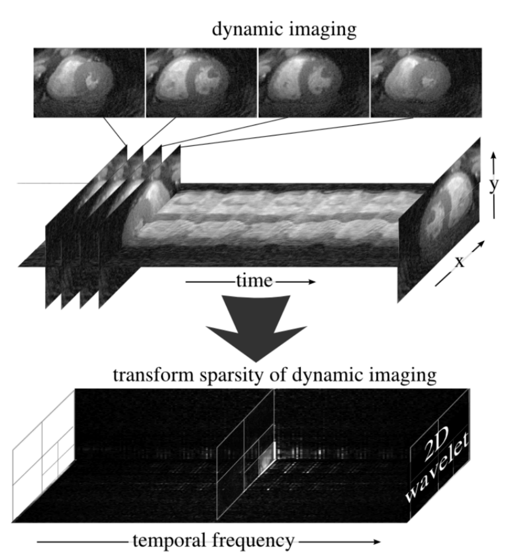
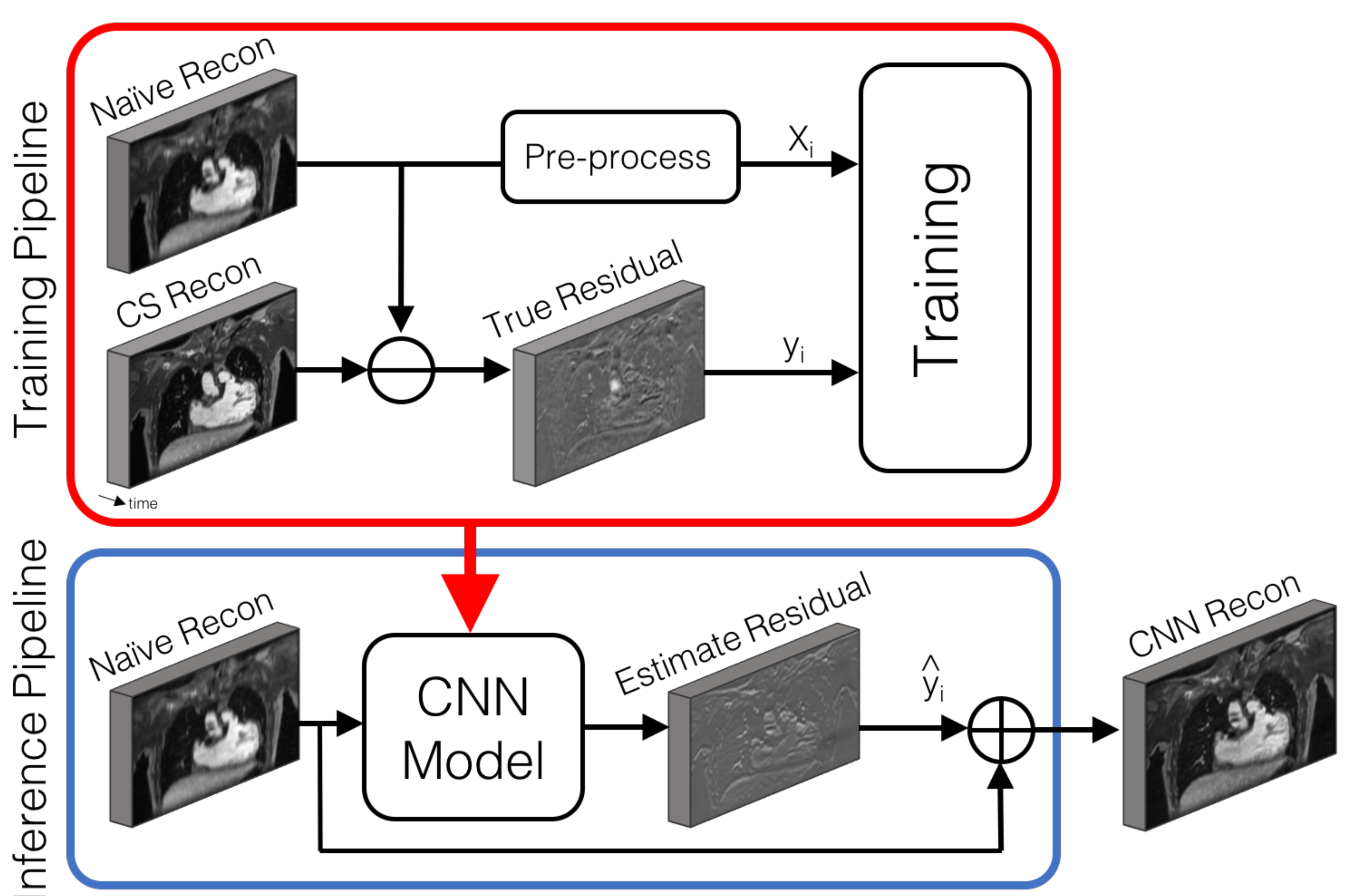


Figure from Lustig et al.[1]

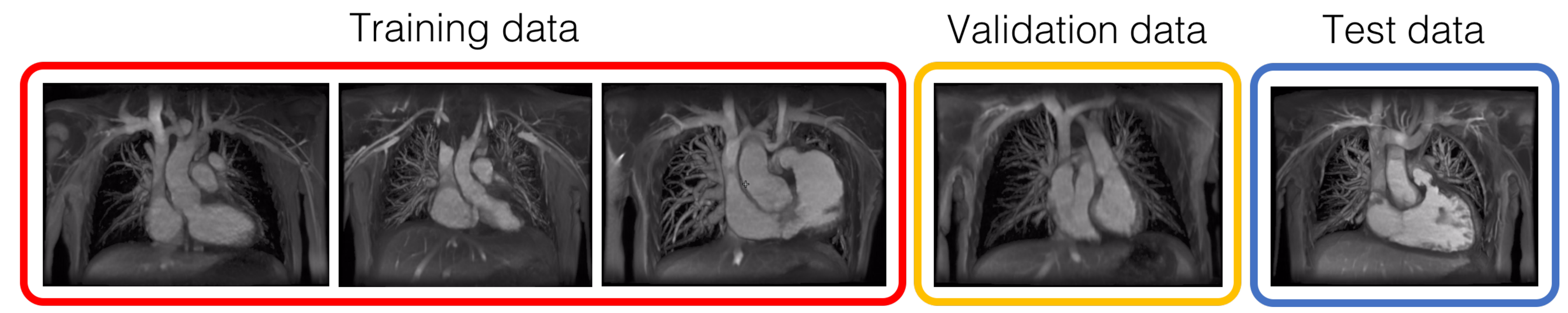
- Still many questions: Similar performance for dynamic data? Best loss function to train on? Upper limit for undersampling? How to evaluate CNN reconstructions?

Methodology

Deep Reconstruction Workflow:



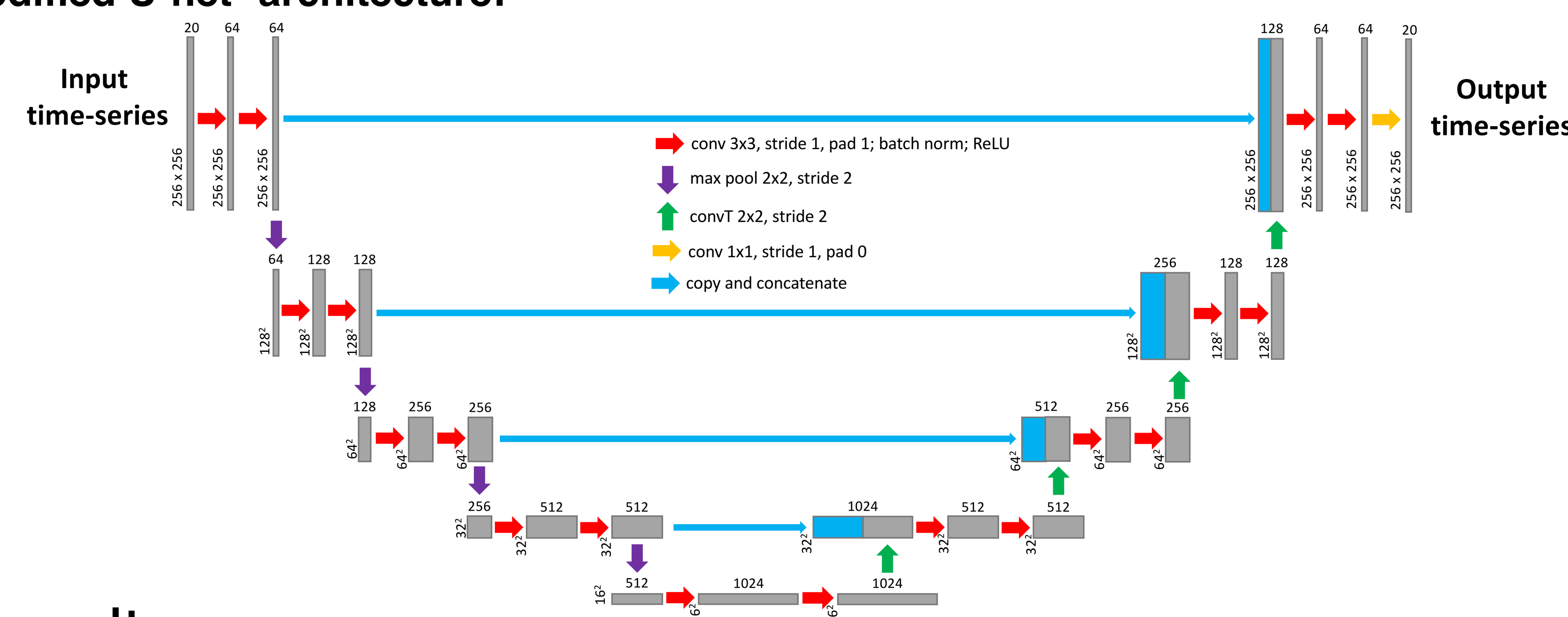
4-D cardiac MRI datasets: (Courtesy of Dr. Shreyas Vasanawala)



- Each dataset is expanded into N=896 (2D+time) examples
- Each example has 20 time frames (50 ms temporal resolution)
- Datasets are *not* fully sampled, but are diagnostic quality
- Acquisition time: ~15 min, CS reconstruction time: ~2 hours

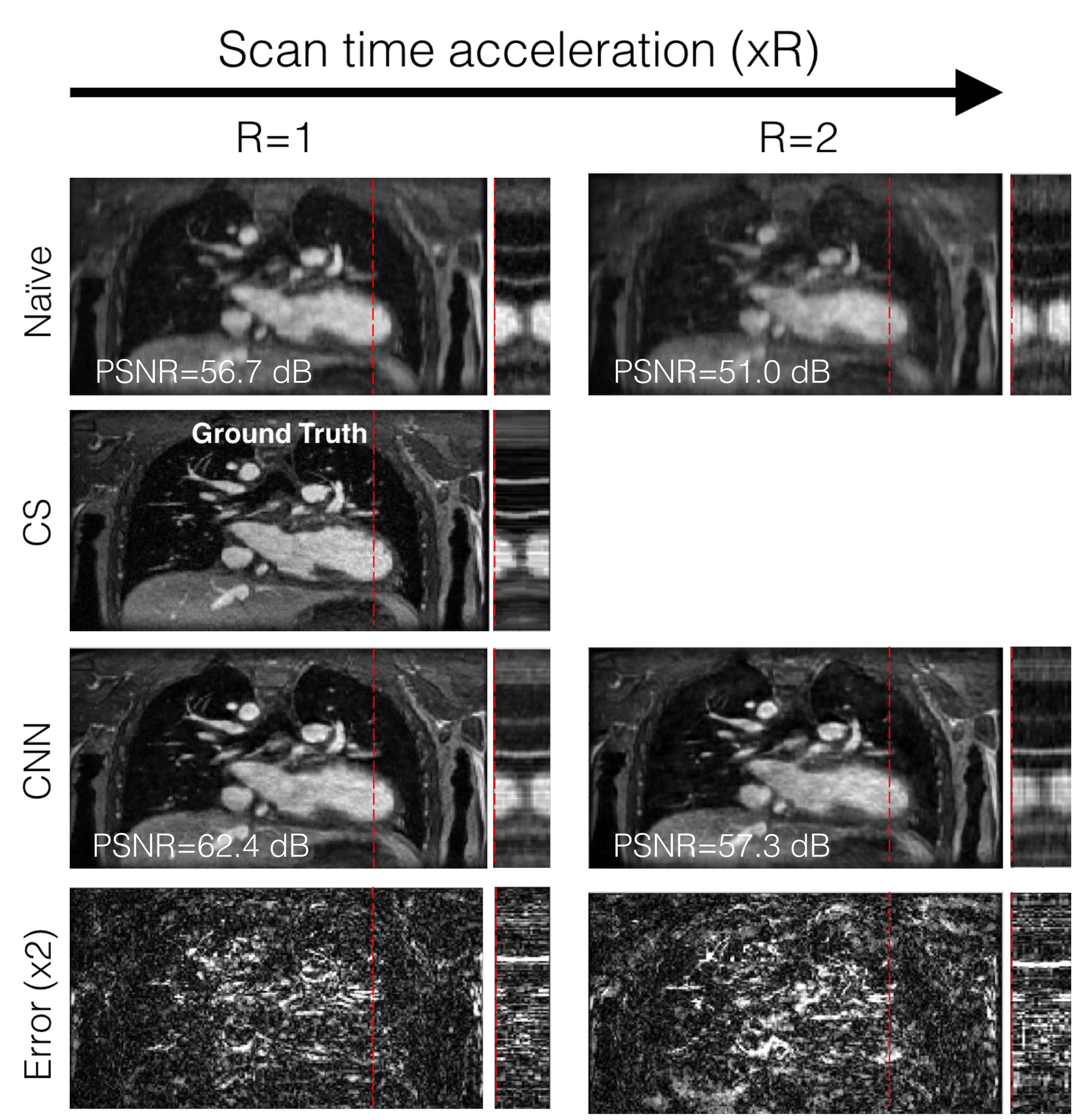
N_{train} = 2688
N_{val} = 896
N_{test} = 896

Modified U-net[5] architecture:



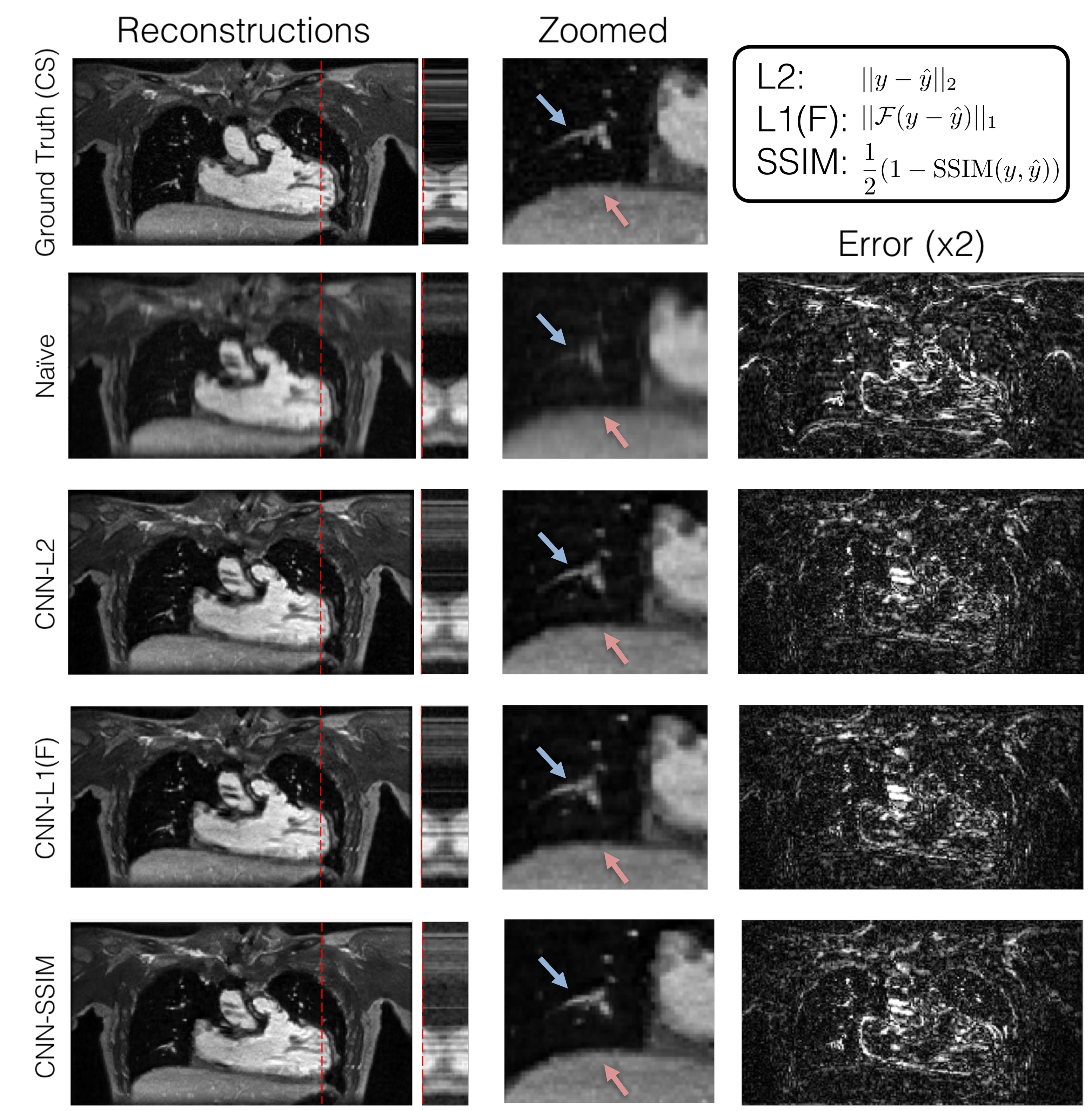
Results

Experiment #1: Can CNN reconstruct undersampled data better than CS?



- Used L2 loss
- Ground truth is diagnostic quality CS recon
- CNN outperforms Naïve recon by ~6 dB

Experiment #2: Does loss function impact image quality?



Performance Statistics:

	PSNR (dB)	SSIM	Speed
CS (Truth)	-	-	2hr19 m
Naive	57.792	0.629	3s
CNN-L2	**62.976**	0.734	57s
CNN-L1(F)	62.923	**0.743**	53s
CNN-SSIM	62.526	0.720	200s

- L1 / L2 similar performance
- SSIM better at preserving structure and edges

Discussion / Conclusions

- We present a CNN model that can reconstruct dynamic MR images comparable to standard techniques in under one minute (150x faster than CS)
- Potential to *also* accelerate scan time (2x faster than standard)
- Not able to resolve temporal dynamics well – look to RNNs?
- CNNs provide faster scan and recon times – potential to make MRI cheaper and more feasible in urgent clinical situations

References

[1] M Lustig, et al. "Compressed sensing MRI." IEEE signal processing magazine, 2008. [2] K Gregor, and Y LeCun. "Learning fast approximations of sparse coding." ICML, 2010. [3] KH Jin, et al. "Deep Convolutional Neural Network for Inverse Problems in Imaging." arXiv, 2016. [4] K Hammernik, et al. "Learning a Variational Network for Reconstruction of Accelerated MRI Data." arXiv, 2017. [5] O Ronneberger, et al. "U-net: Convolutional networks for biomedical image segmentation." International Conference on Medical Image Computing and Computer-Assisted Intervention. 2015