USC University of Southern California

Accelerated Cardiac Cine Using Locally Low Rank and Finite Difference Constraints

Xin Miao[1], Sajan Goud Lingala[2], Yi Guo[2], Terrence Jao[1], and Krishna S. Nayak[1,2]

[1]Department of Biomedical Engineering,
[2]Department of Electrical Engineering,
University of Southern California, Los Angeles, CA, United States,

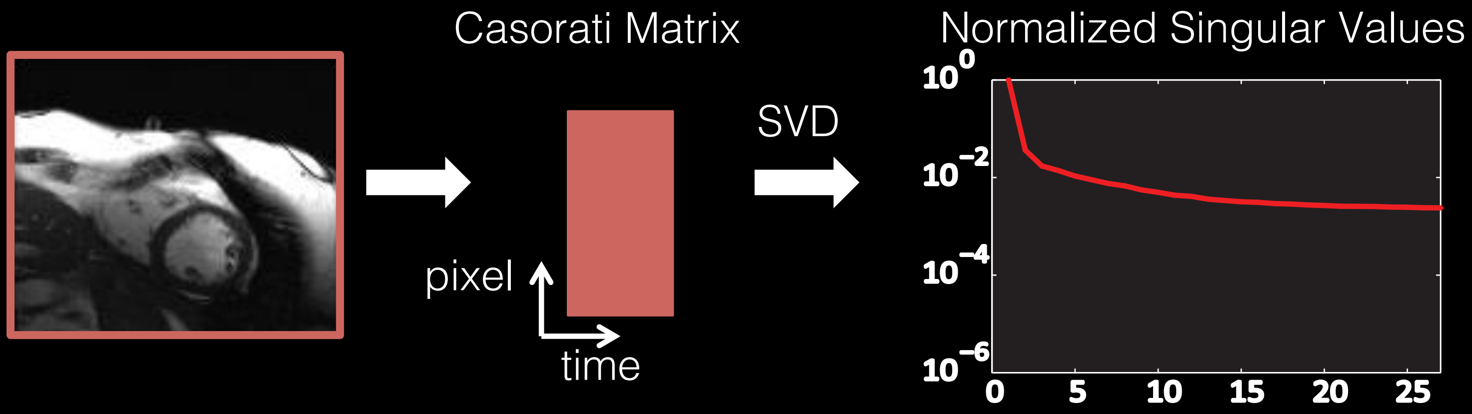
Declaration of Financial Interests or Relationships

Speaker Name: Xin Miao

I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

Background

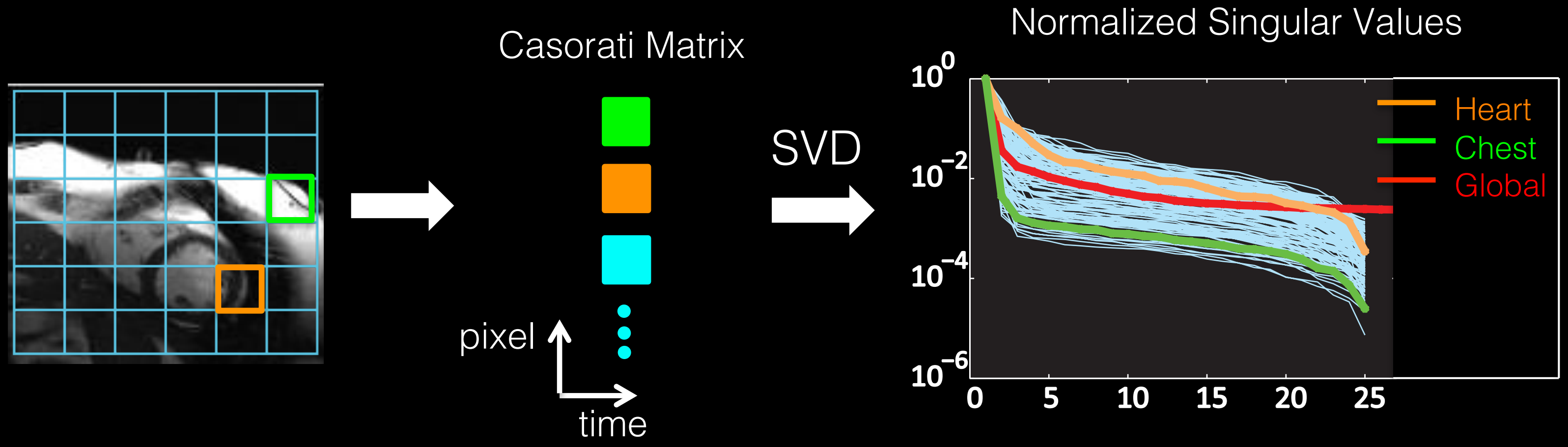
- Global Low Rank (GLR)[1-5]: PSF [1,5], k-t PCA[2], IRPF[3], k-t SLR[4]



1. Z. Liang, IEEE-ISBI, 2007 2. H. Pedersen et al. MRM, 2009 3. J. P. Haldar and Z. Liang, IEEE-ISBI, 2010
4. S. G. Lingala et al. IEEE-TMI, 2011 5. B. Zhao et al. IEEE-TMI, 2012

Background

- Locally low rank[6] (LLR), PSF with varying model order[7]



- This study: LLR + sparsity

Key Dates

- September 2015: Phase I data available
- Jan-Feb 2016: Phase II begins
- May 2016: Winner announced at ISMRM 2014

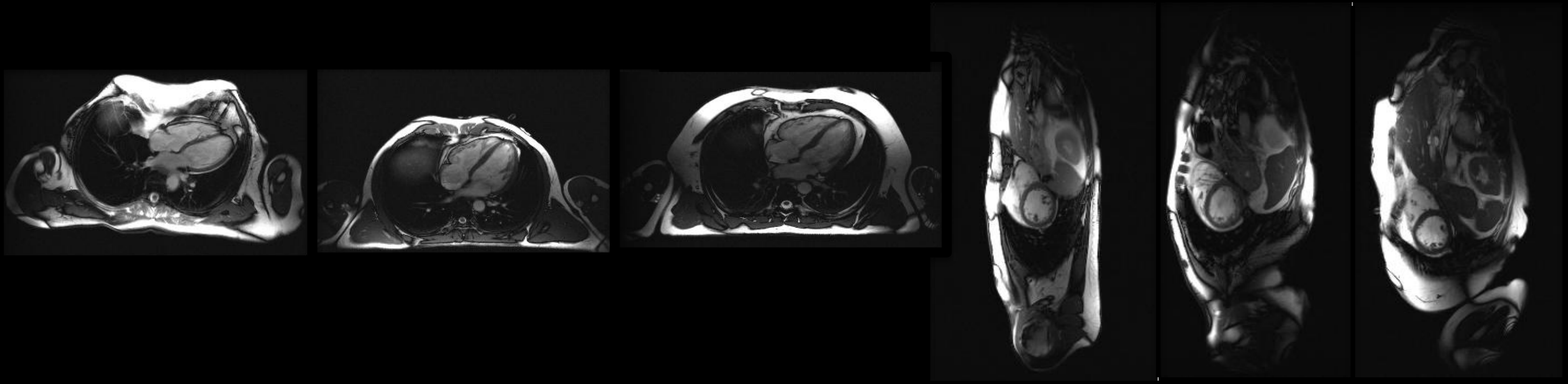
2013 Ph I Leaderboard

Team Name	Score	Case #1	Case #2	Case #3	Case #4	Case #5	Case #6	Case #7	Case #8	Case #9	Case #10	Last Updated
fastbeat	08833	08612	08922	08878	08955	08603	09018	08910	08451	08941	09049	15-Mar-2014 09:46:33 CST
SRT	08828	08576	08785	08839	09140	08514	09027	08840	08665	08977	08924	15-Mar-2014 15:22:58 CST
TinWoodman	08764	08391	08903	08777	08861	08484	08924	08880	08659	08852	08918	15-Mar-2014 21:52:07

Method: Data

Six fully-sampled 2D cine datasets

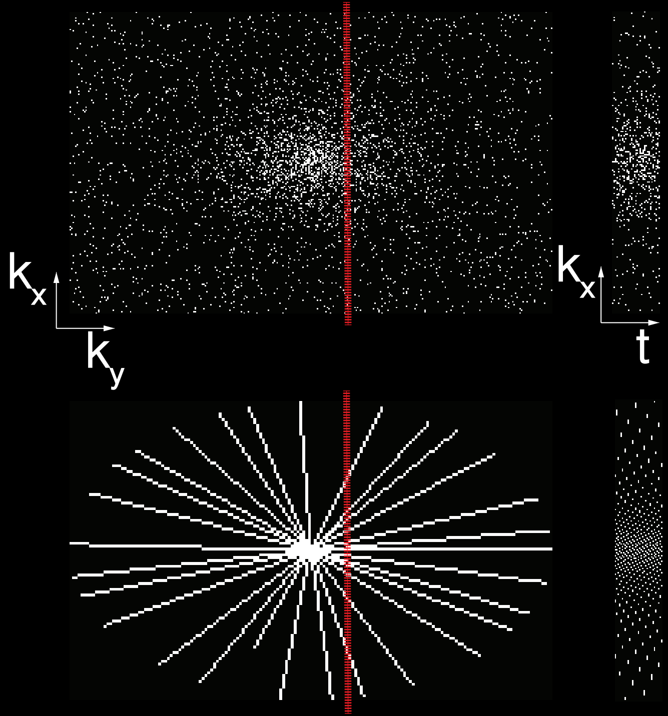
- 32 cardiac coils
- spatial resolution 1×1 mm^2, 30 timeframes per cardiac cycle.
- distributed by the 2013 ISMRM Challenge (http://www.ismrm.org/challeng



Method

- Sampling patterns:
  - Variable-density random sampling
  - Cartesian golden-angle radial sampling
- Acceleration factors (R):

10 to 50.



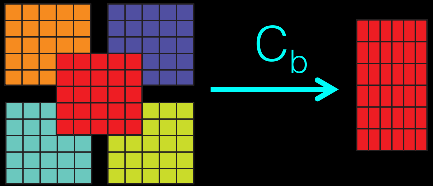
Method

- Locally low rank (LLR) + temporal finite difference (tFD)
- Algorithm: ADMM with variable splitting[8]

$$\Gamma^* = \arg\min_{\Gamma} \|F \cdot S \cdot \Gamma - m\|_2^2 + \lambda_1 \sum_{b \in patches} \|C_b(\Gamma)\|_{\text{Schatten, p}} + \lambda_2 \|\nabla_t(\Gamma)\|_1$$

Data Consistency | Locally Low Rank | Sparsity

C_b (•): operator to extract and reform the overlapping patches from Γ, patch matrix size: $5 \times 5 \times N_t$



8. S. Ramani, IEEE-TMI， 2011

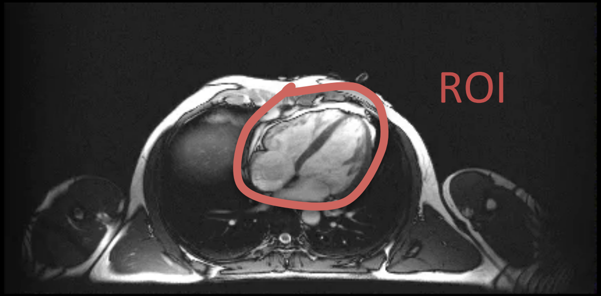
Method

- LLR+ temporal Finite Diff. compared with:

Methods	Regularization Terms
LLR	$\lambda \sum_{b \in patches} \|\|C_b(\Gamma)\|\|_{\text{Schatten, p}}$
Temp. Finite Diff.	$\lambda \|\|\nabla_t(\Gamma)\|\|_1$
kt-SLR	$\lambda_1 \|\|\Gamma\|\|_{\text{Schatten, p}} + \lambda_2 \|\|\nabla_t(\Gamma)\|\|_1$

Method

- Quantitative metrics:
  - normalized root mean square error (NRMSE)
  - structural similarity index (SSIM)[9]
  - high frequency error norm (HFEN)[10]



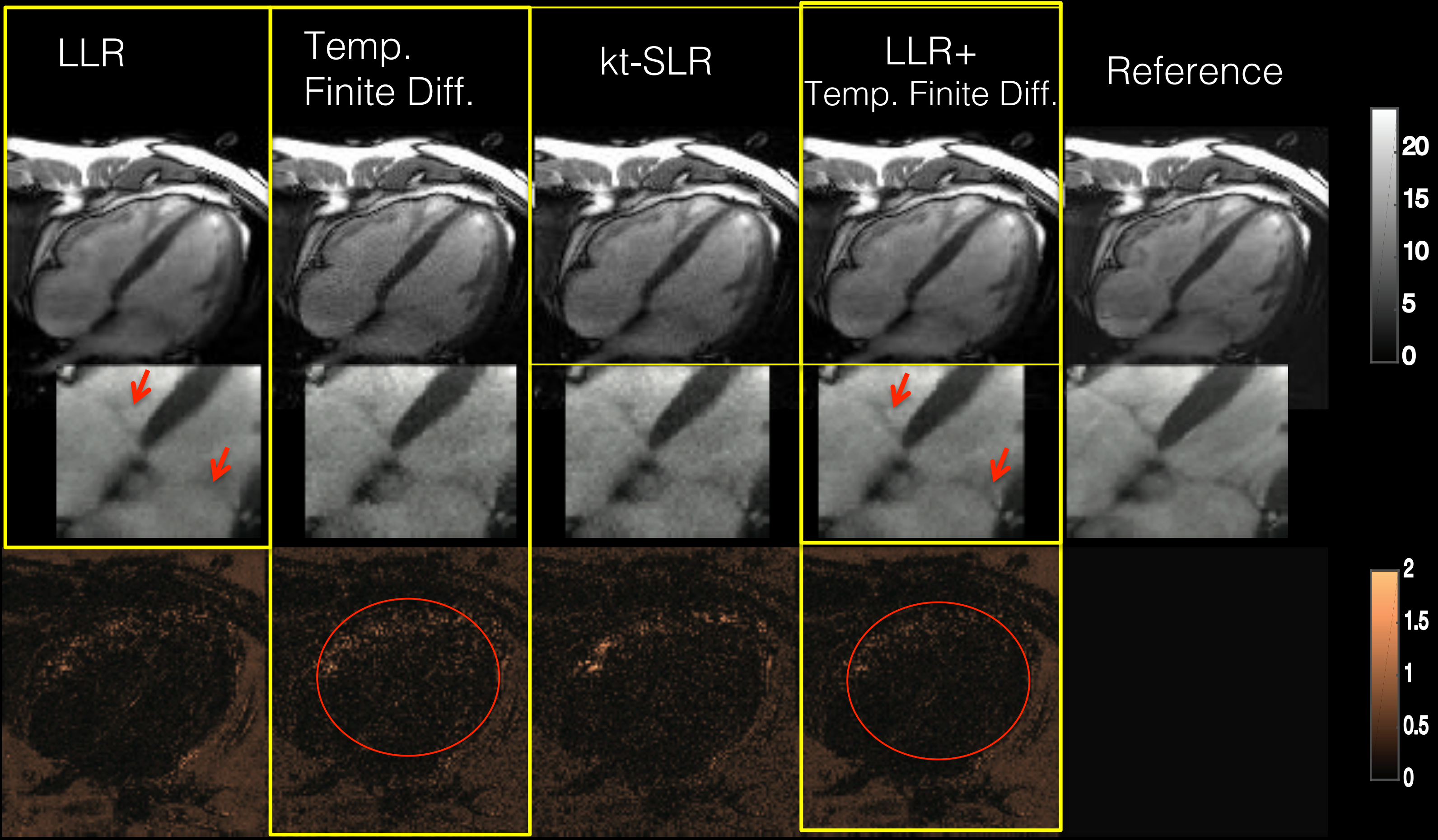
$$\text{HFEN}=\sqrt{\frac{\left\|LoG(\Gamma^{*})-LoG(\Gamma_{true})\right\|_F^2}{\left\|LoG(\Gamma_{true})\right\|_F^2}}$$

LoG(•) : Laplacian of Gaussian filter that captures the edges

9. Z. Wang et al. IEEE-TIP, 2004
10. S. Ravishankar and Y. Bresler, IEEE-TMI, 2011

RESULT

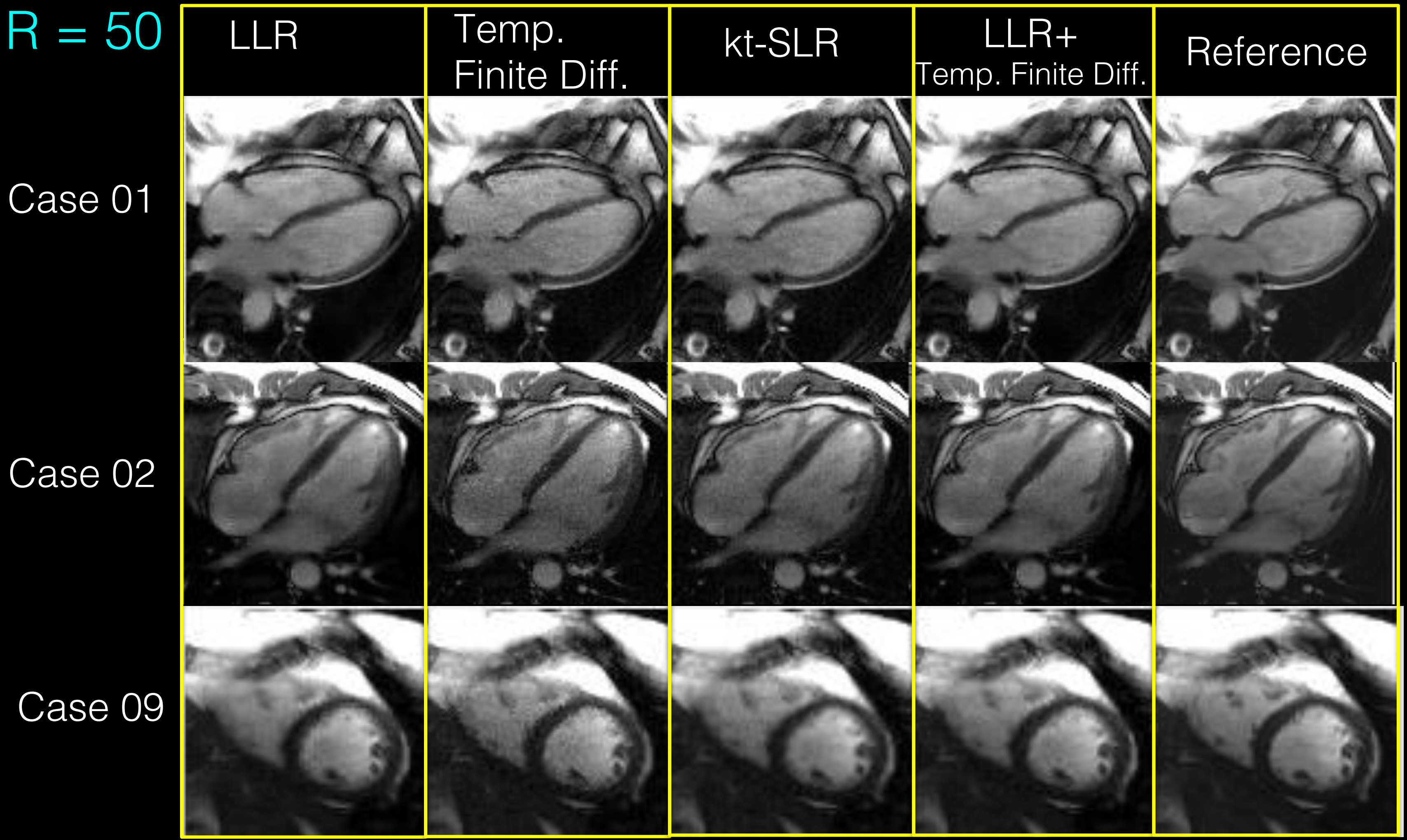
R = 30



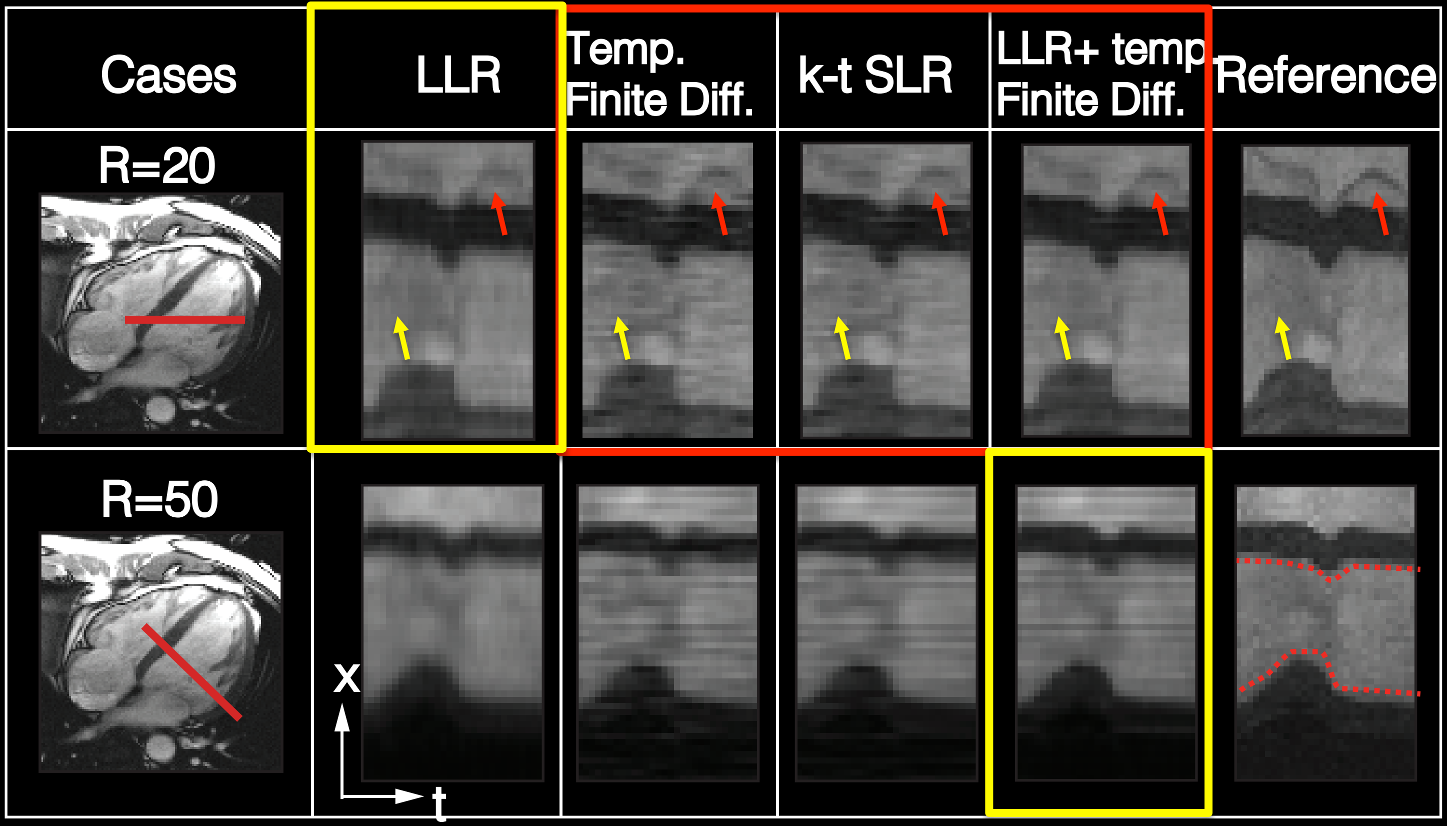
Difference Image

	LLR	Temp. Finite Diff.	kt-SLR	LLR+ Temp. Finite Diff.
NRMSE(10^{-2})	9.18	10.3	9.94	8.55
SSIM(10^{-1})	9.27	9.05	9.18	9.32

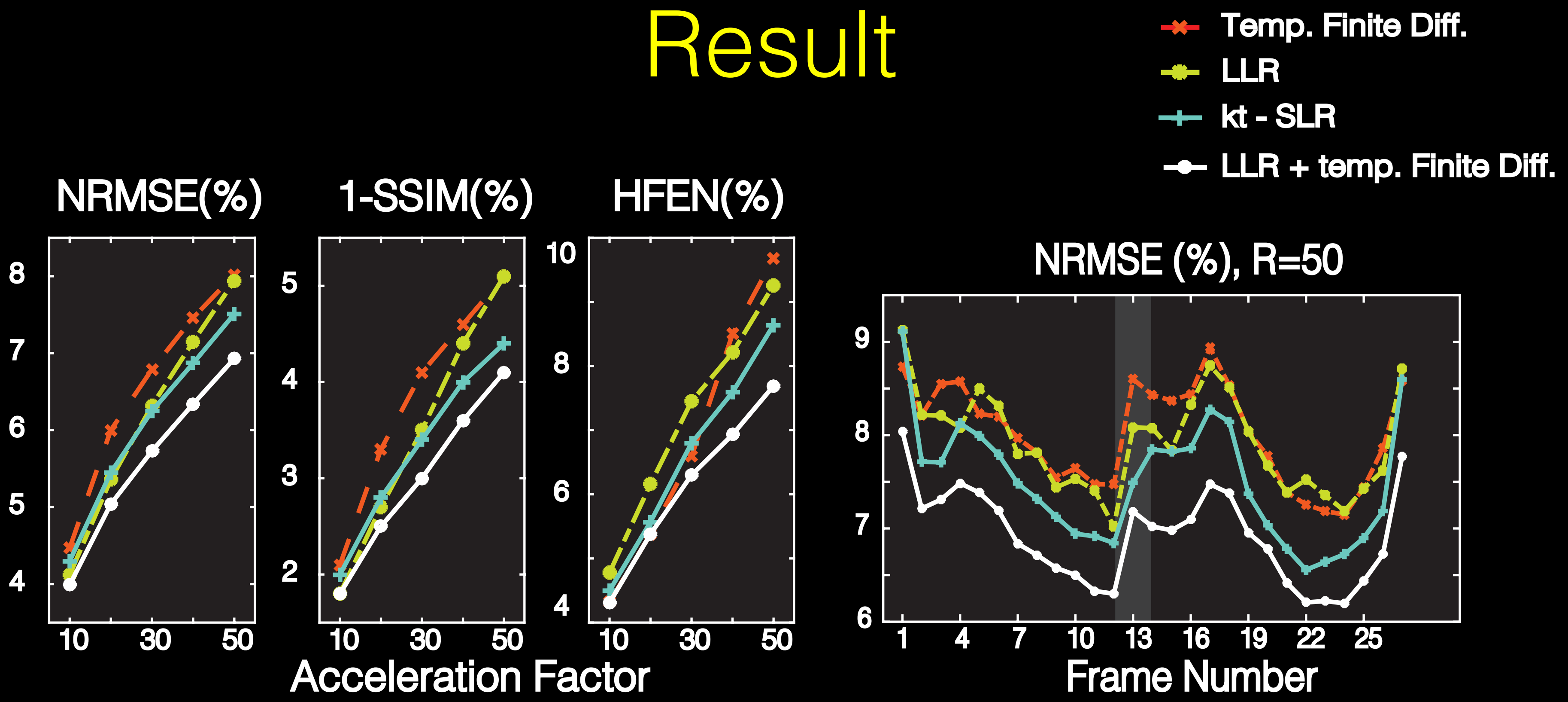
R = 50


LLR
Temp. Finite Diff.
kt-SLR
LLR+ Temp. Finite Diff.
Reference
Case 01
Case 02
Case 09

Result

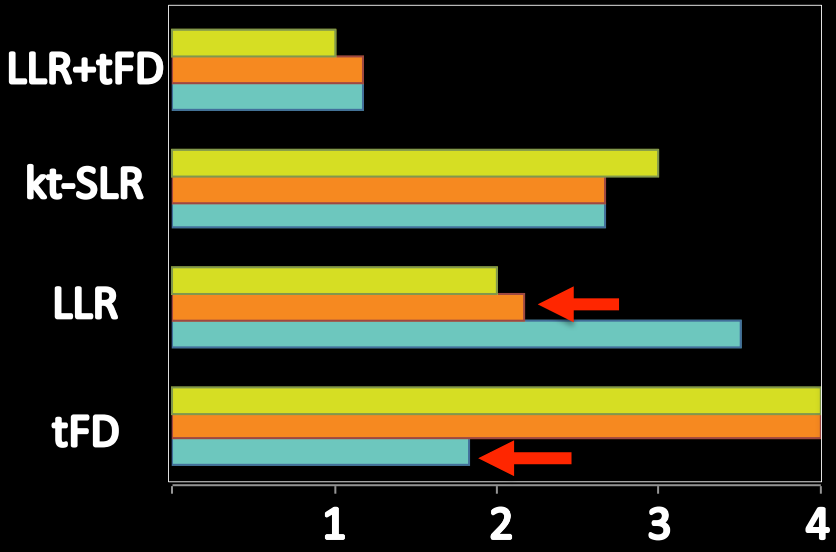

Cases
LLR
Temp.
Finite Diff.
k-t SLR
LLR+ temp.
Finite Diff.
Reference
R=20
R=50
x
t

Result

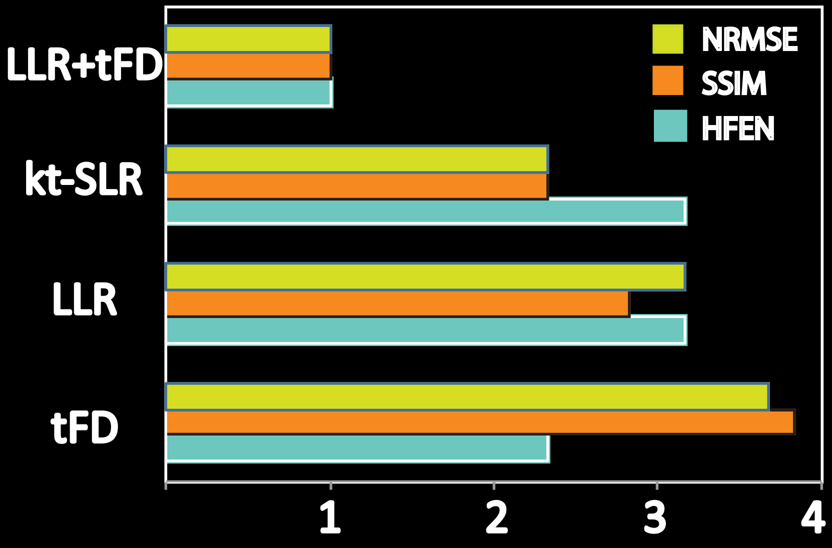

Temp. Finite Diff.
LLR
kt - SLR
LLR + temp. Finite Diff.
NRMSE(%)
1-SSIM(%)
HFEN(%)
NRMSE (%), R=50
8
7
6
5
4
10
30
50
5
4
3
2
10
8
6
4
9
6
1
4
7
10
13
16
19
22
25
Acceleration Factor
Frame Number

Result

Averaged Ranking, R=20



Averaged Ranking, R=50

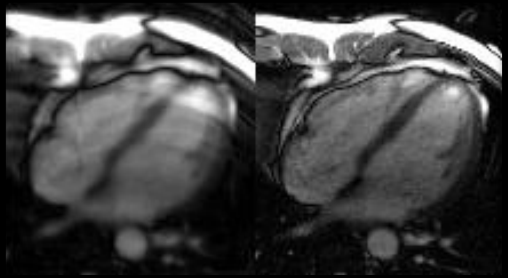


Discussion

- Retrospective → Prospective study
  - 2D random : impractical in 2D acquisition
  - Cartesian golden angle sampling

    → 2D cine with golden angle radial
    → 3D cine with Cartesian sampling
  - 1D random:

LLR Temp. Finite Diff.



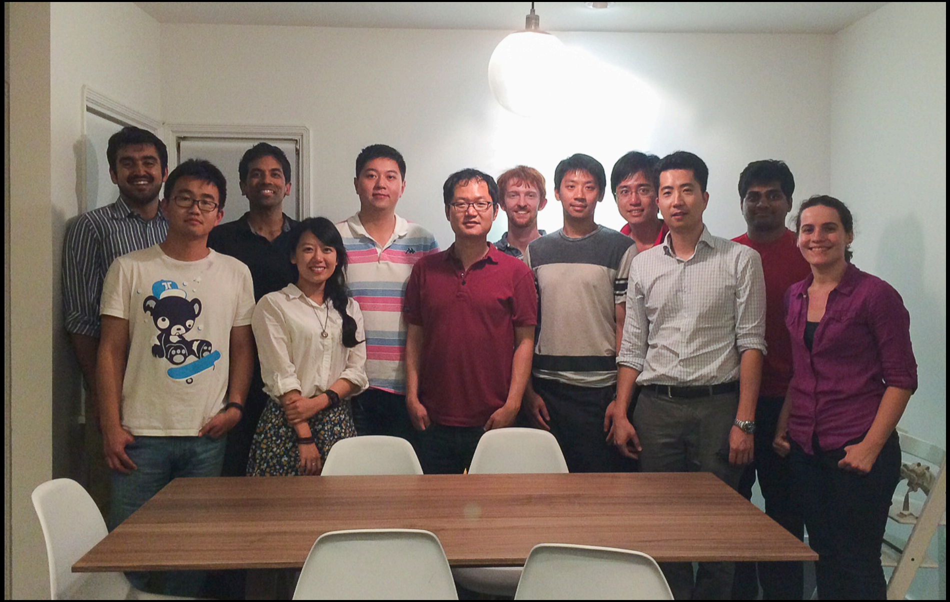
Summary

- LLR + temp. Finite Diff. provides superior image quality
  - preservation of fine structures, endo- and epicardial boundaries
  - Less model-related artifact

- The results are directly relevant to 2D cine MRI using radial sampling, and emerging 3D cine MRI methods.

Acknowledgement

- Magnetic Resonance Engineering Lab @USC



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- 2013 ISMRM Challenge