2010 ISMRM Recon Challenge

Wednesday Plenary Session

Recon Challenge Team: Jim Pipe[1], Donglai Huo[2], Ajit Devaraj[1], Ryan Robison[1], Nick Zwart[1], Eric Aboussouan[1], Ken Johnson[1], Payal Bhavsar[1]. **Trajectory Designs:** Ajit Devaraj[1], Brian Hargreaves[3], Miki Lustig[4], Craig Meyer[5], Jim Pipe[1], Alexey Samsonov[6], Huimin Wu[6], Nick Zwart[1]. **ISMRM Web Support:** Sally Moran. **Preliminary Judges:** Margaret Hall-Craggs[7], Leland Hu[8], Shreyas Vasanawala[3]. **Final Judges:** Kim Amrami[8], Bob Edelman[9], John Karis[1], Andrea Rockall[10], Stefan Schoenberg[11], Jeff Weinreb[12]

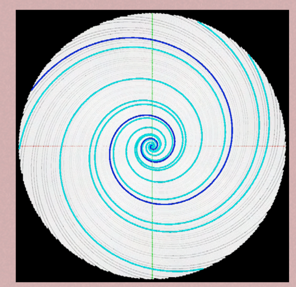
1. Barrow Neurological Institute, 2. GE Healthcare, 3. Stanford University, 4. UC-Berkeley, 5. University of Virginia, 6. University of Wisconsin - Madison, 7. University College Hospital, London, 8. Mayo Clinic, 9. NorthShore University HealthSystem, 10. Barts and the London, 11. Heidelberg University, 12. Yale University

Challenge 1. NEED FOR SPEED

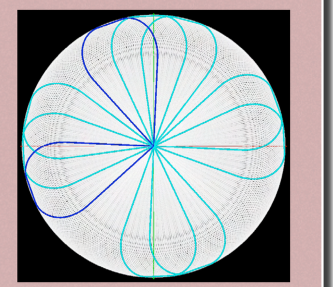
Truth = Projection X-ray turned MRA, 512x512 mtx

- Used 8-coil PA B_1 maps to simulate PA collection
- Linearly interpolated 37 X-rays to 200 temporal frames
- Synthesized data on trajectories, added noise
- Each trajectory 200 shots (1 shot/temporal frame), 2000 points each
- Contestants must reconstruct 37 time points (every 5 shots)

Trajectories: Shot 1 is blue, shots 2-5 are cyan

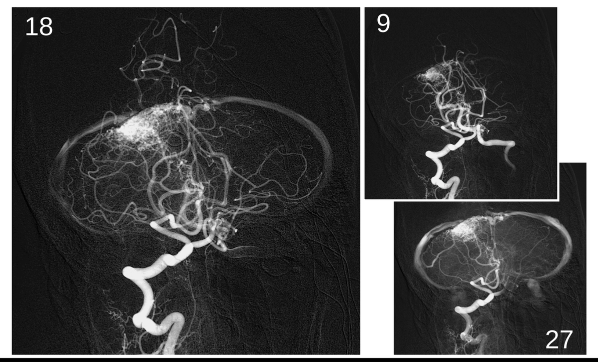


Spiral: Nick Zwart



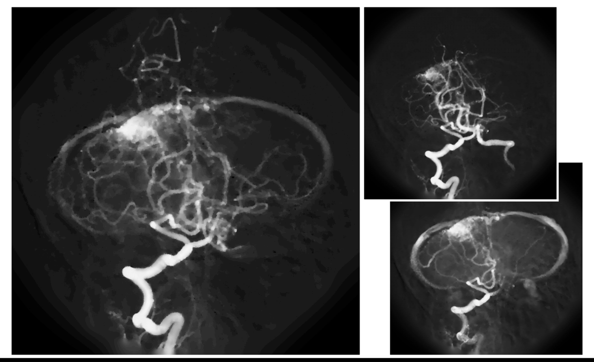
Bowtie: Alexey Samsonov

TRUTH
(Frames 9, 18, and 27 of 37)



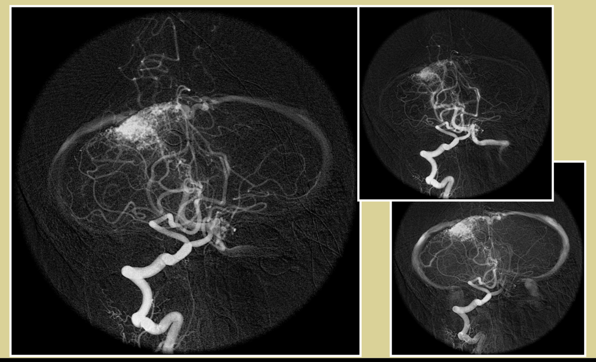
NS1, RMS Error = 1.00, Spiral Trajectory
NFFT model, CG/PD hybrid minimization algorithm, higher-order tensor total-variation regularization. 30 hours, C/CUDA code on Quad-Core CPU + GTX 280

NS2, RMS Error = 1.12, Bowtie Trajectory
NFFT model, CG/PD hybrid minimization algorithm, higher-order tensor total-variation regularization. 30 hours, C/CUDA code on Quad-Core CPU + GTX 280

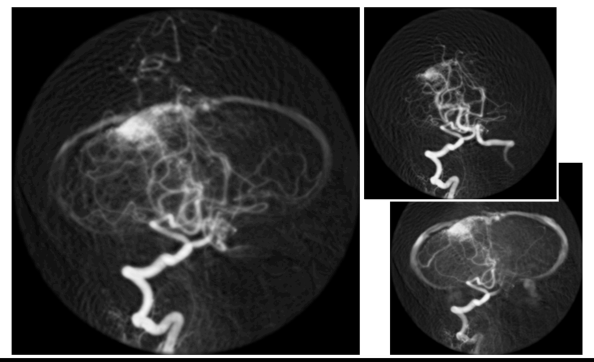


NS3, RMS Error = 1.43, Bowtie Trajectory
Gradient descent with sparsification (GRADES) minimizing the temporal differences between frames and abs image magnitude. Used 9th order polynomial fit as starting guess. Calculated multiple (6x) in the forward and backward directions with a very slight smoothing filter. Fessler toolbox for gridding. About 7 hours using 1 core 3.2 GHZ PC, 32 GB RAM.

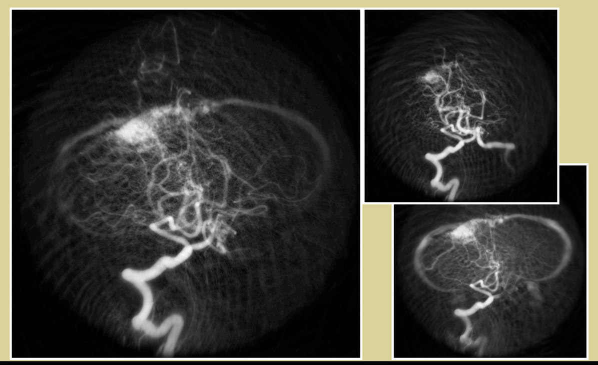
NS4, RMS Error = 1.47, Bowtie Trajectory
Reweighted L2 minimization, PCA along temporal direction, Upsampling. 200 hours, Matlab code on a Xeon 3GHz and 4GB memory Linux machine with 1 CPU's



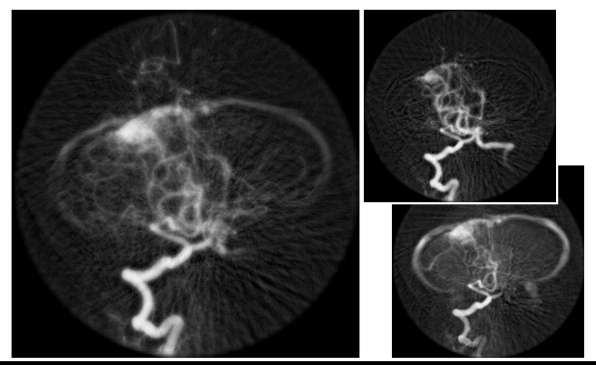
NS5, RMS Error = 1.50, Spiral Trajectory
Regularized least squares solution with the conjugated gradient algorithm. Regularisation simultanuous in spatial and time domain. 8hrs, MATLAB + GPUmat, on a NVidia Tesla GPU



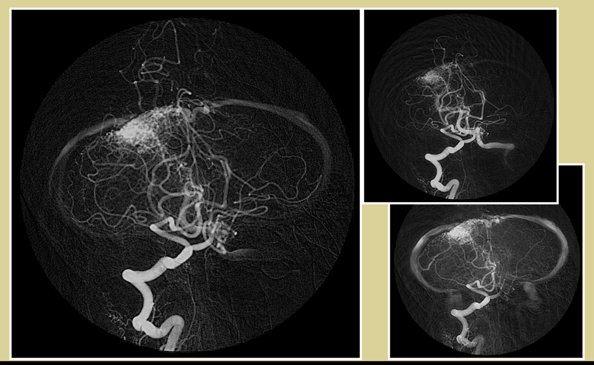
NS6, RMS Error = 1.53, Spiral Trajectory
Gridding with different kernel size k-space and image space combination. 12 minutes on a laptop with a Core 2 Dual CPU



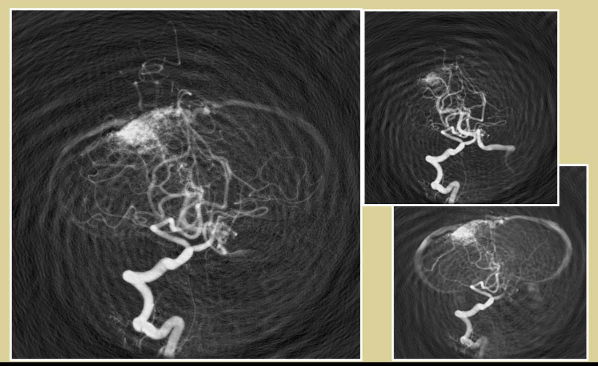
NS7, RMS Error = 1.58, Bowtie Trajectory
Regularized least squares solution of the ASAM data with the conjugated gradient algorithm. Regularisation in the spatial and temporal domain. 8hrs, MATLAB + GPUmat, on a NVidia Tesla GPU



NS8, RMS Error = 1.74, Spiral Trajectory
Sliding temporal Hanning window combined with Pretty Easy Parallel Imaging. 16.5min, c-code, Mac Pro 8-core 3.2GHz (but mostly not threaded)



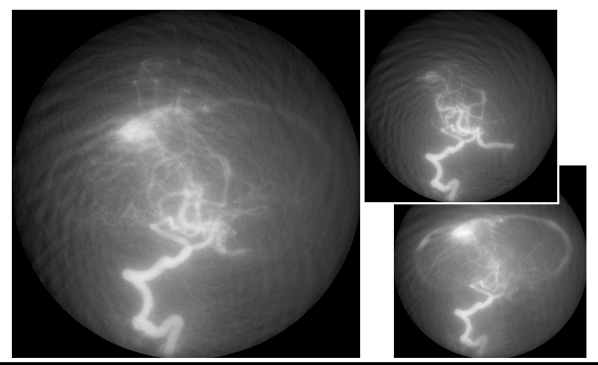
NS9, RMS Error = 1.86, Spiral Trajectory
Implemented by 3-D sampling density compensation and gridding with temporal averaging. 30 min, C/CPP on LinuxMacPro using 1 CPU



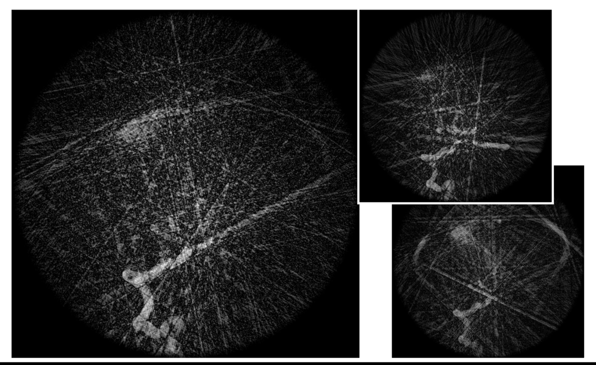
NS10, RMS Error = 1.89, Requested to withrdraw completely after preliminary judging.

NS11, RMS Error = 2.10, Bowtie Trajectory
Compressed sensing in temporal dimension minimizing l1 norm of the second temporal derivative combined with iterative SENSE. 3 hours, Matlab code on a Linux box, 1CPU

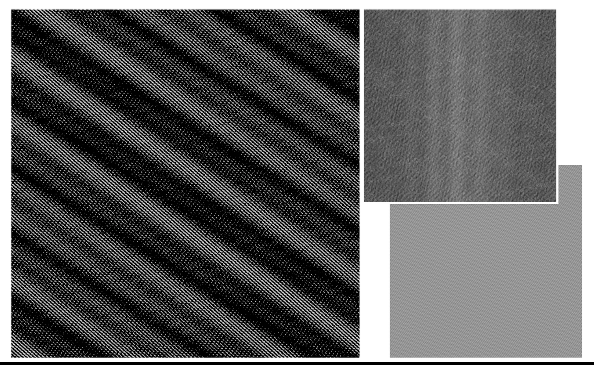
NS12, RMS Error = 2.60, Spiral Trajectory
Sliding window, Voronoi weights, Kaiser-Bessel regridding, maximum-ratio combination. 13 minutes, matlab code on a PC with 1 AMD ATHLON 64-bit CPU



NS13, RMS Error = 3.04, Bowtie Trajectory
Gridding with calculation of voroni weights. 9th order polynomial fit through data. All in Matlab using the Fessler toolbox. 400 seconds including Voroni calculation, 111 sec without this. 3GHz 4 core (using only 1) 32 GB RAM



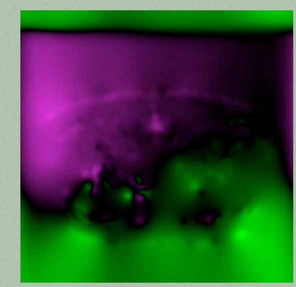
NS14, RMS Error = 5.13, Spiral Trajectory
SMASH reconstruction in polar coordinates, regridding with Kaiser-Bessel convolution kernel. 700 sec, DELL Latitude E6400, 2-core CPU



Challenge 2. DOUBLE VISION

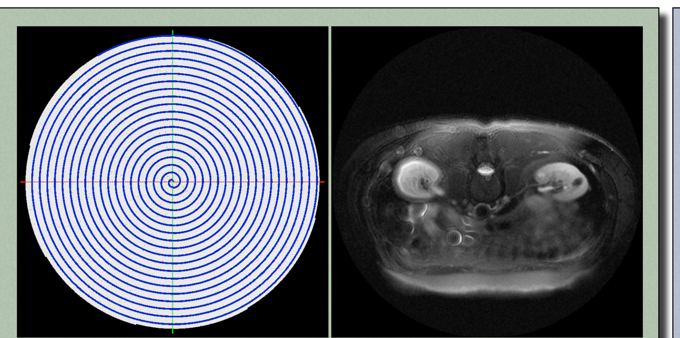
Truth = Long breath-hold FSE (320x320 mtx), 8 coil PA

- Collected B_0 off-resonance maps (3T) & doubled them
- Synthesized phase-corrupted data onto trajectories, added noise
- Each trajectory 8 shots, 20 msec ADC time
- 12 slices to reconstruct
- B_0 map provided

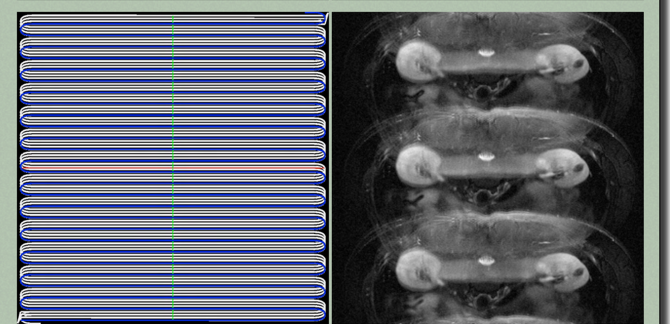


Example B_0 Map
(-215 Hz to 260 Hz)

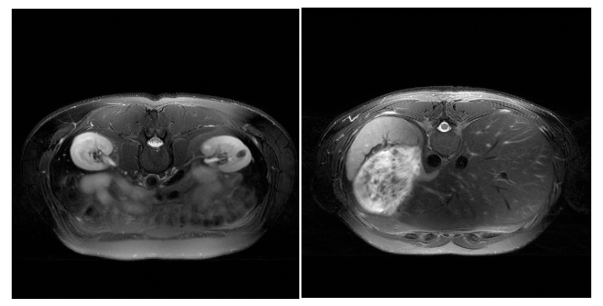
Spiral: Craig Meyer



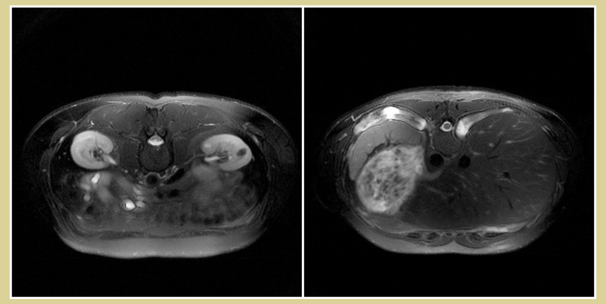
EPI (dual-direction: 4 up, 4 down, R≈3): Jim Pipe



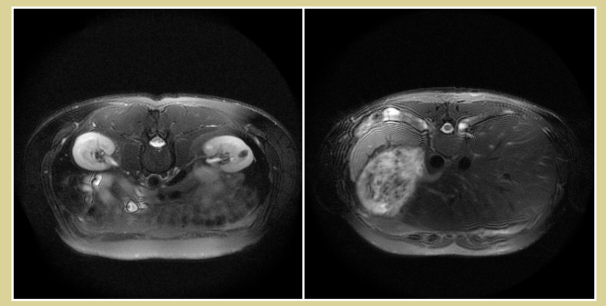
TRUTH
(2 slices of 12)



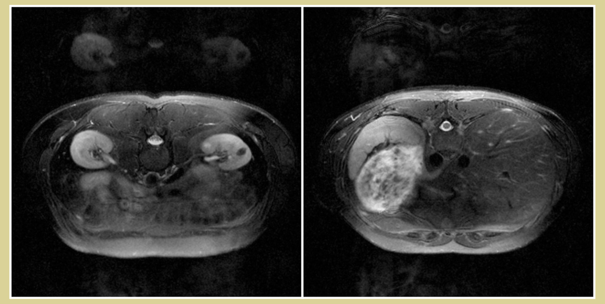
DV1, Spiral Trajectory, RMS Error = 1.00
Iterative solution of the reconstruction problem by stating it in an encoding matrix and inverting this iteratively with conjugate gradient (same algorithm as ISMRM Kyoto, Barmet; only with more efficient gridding by Beatty). 1hr20m, matlab on Dell D630 laptop with 1 CPU (not very fast computer)



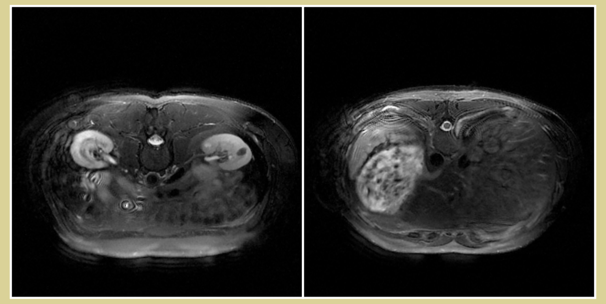
DV2, Spiral Trajectory, RMS Error = 1.02
Standard gridding with sampling density correction (sdc) followed by de-blurring via convolution with separable 2D kernels. The resulting coil data was then combined using the sum-of-squares technique. 88s on a Dual Intel Xeon 3.2 GHz processors, each with 4 cores.



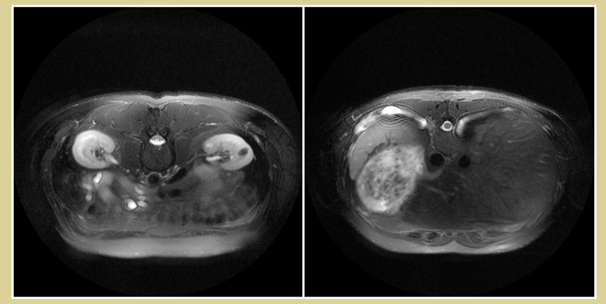
DV3, EPI Trajectory, RMS Error = 1.03
Regularized least squares solution with the conjugate gradient algorithm. Regularisation in the spatial domain. 8hrs, MATLAB +GPUmat on a NVIDIA Tesla GPU



DV4, Spiral Trajectory RMS, Error = 1.09
Iterative SENSE using penalized least-squares with convex non-quadratic regularization (huber) and time-segmented Non-Uniform Fast Fourier Transfrom (NUFFT) for B0 correction. 156 minutes matlab code on an Intel Xeon X5472 @ 3.00 GHz



DV5, Spiral Trajectory, RMS Error = 2.36
Time-segmented conjugate phase, field map correction, sum of squares for combining multi-coils. 6.8 minutes, matlab on 2 Duo Intel CPUs



INTRODUCTION and METHODS:

Data were synthesized from true images and corrupted via (Challenge 1) dynamic processes, (Challenge 2) off-resonance phase, or (Challenge 3) reduction of data by factors of 5 or more. These data were provided to contestants, who used their best algorithms to produce the images shown here. An initial ranking of image quality was performed by a panel of Radiologists in February, and the finalists for each challenge were judged early this week by a 2nd panel of 6 Radiologists. This panel will discuss their findings in the Wednesday Plenary session.

OBJECTIVES:

1. Explore objective, realistic infrastructures to compare methods, i.e. move toward the next generation of Shepp-Logan phantom. It is important to note that this is a very controlled but artificial test, and is not intended to determine the "best" trajectory or reconstruction, which involves many aspects not explored in this challenge.
2. Create a forum for dialogue between the engineers, physicsists, and clinicians. We hope to discuss things such as "What makes a good image", and "What kind of artifacts might one expect from this reconstruction".
3. A panel of expert Radiologists will also pick winners! - Just for Fun

ENTRIES:

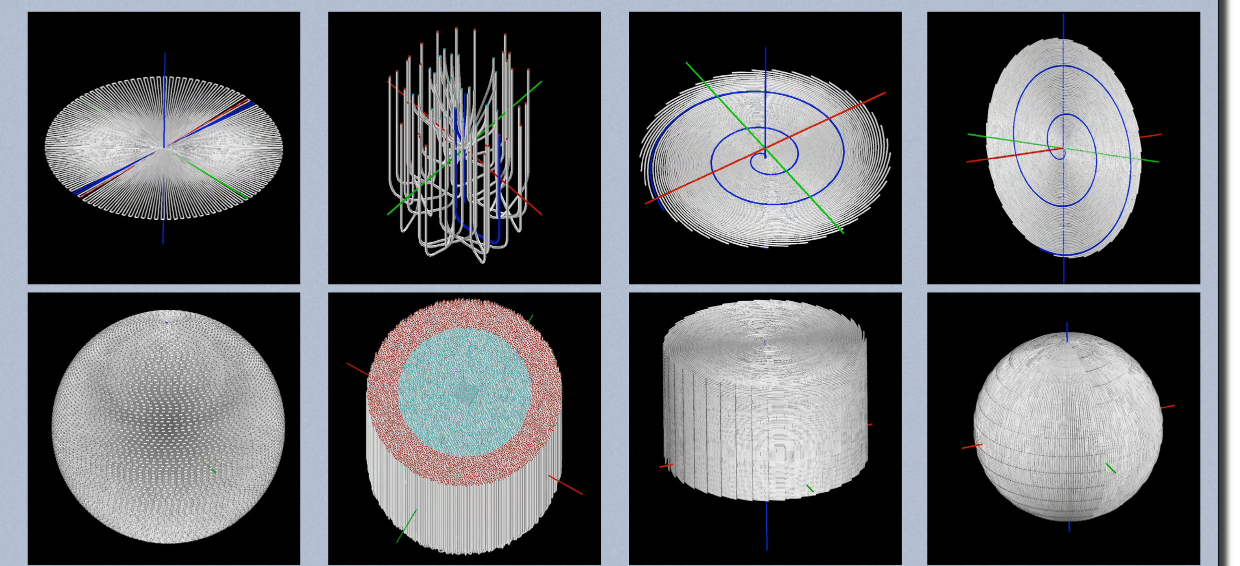
1. Each box indicates entry ID, trajectory used, relative RMS error, recon method, and approximate recon time (with hardware and software used)
2. For each challenge, entries are ordered by RMS error wrt truth, normalized by that of the best entry. RMS error was calculated after shifting and scaling each entry to minimize this error.
3. Gold Squares indicate finalists for the Wednesday Plenary.

Challenge 3. PIECE OF THE PUZZLE

Truth = 3D GRE of knee, 320x320x220 MTX, $(0.5mm)^3$ voxels (20' scan)

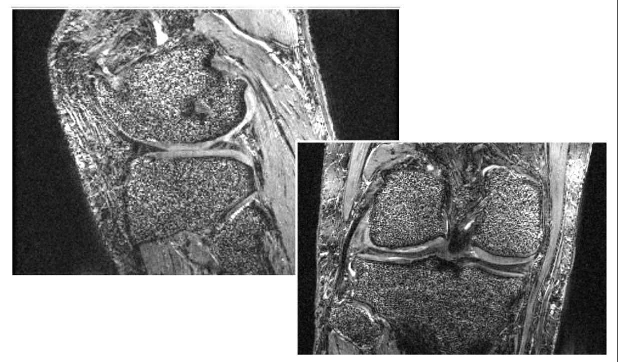
- Synthesized 8-coil data on trajectories, added noise
- Each trajectory 4000 shots, 2000 points each
- Maximum of ~20% of data (R=5) depending on trajectory

Trajectories: top image = initial shots, shot 1 is blue.



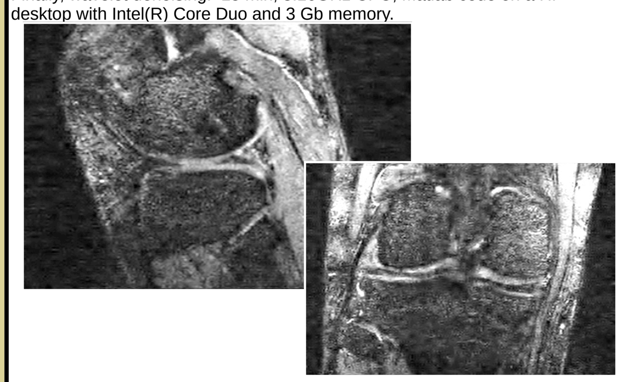
VIPR: Huimin Wu
Random, Poisson Disk: Miki Lustig
Stack of Spirals: Brian Hargreaves
SPI: Ajit Devaraj

TRUTH
(showing meniscal tear)



PP1, VIPR Trajectory, RMS Error = 1.00
3d radial VIPR trajectory. 1D regridding, self-calibrated (B1 map not used) GRAPPA operator for wider radial bands (GROWL), Jim Pipe's weight for final regridding. 20 min, 2.66GHz CPU, 16 Gb memory

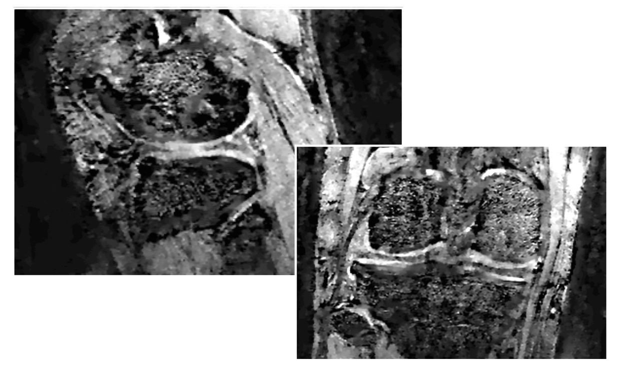
PP2, Random Poisson Disk Trajectory, RMS Error = 1.07
First, estimate correlation between k-space samples. Second, use the correlation to interpolate the missing k-space samples in the Poisson disk. Finally, wavelet denoising. 15 min, 3.16GHz CPU, Matlab code on a HP desktop with Intel(R) Core Duo and 3 Gb memory.



PP3, Random Poisson Disk Trajectory, RMS Error = 1.10
Efficient L1SPIRiT: using an Eigenvector-based approach to utilize coil sensitivity and Compressed Sensing to pursue min L1-norm in 3D image space. 60 min, xxGHz CPU, Matlab code.

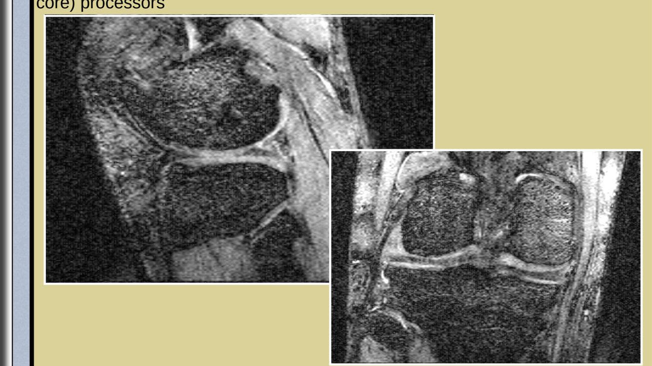
PP4, Random Poisson Disk Trajectory, RMS Error = 1.25
Iteration: 1. TV denoising for the previous reconstruction. Iteration 2. Prior information (result of step 1) regularized SENSE. 8 min, 2.6 GHz CPU, 16 G RAM

PP5, Random Poisson Disk Trajectory, RMS Error = 1.29
Cartesian FFT model, Low-frequency B1 estimation, PD minimization algorithm, higher-order tensor total-variation regularization. 100 min, 1 CPU + Tesla C1060, C/CUDA code

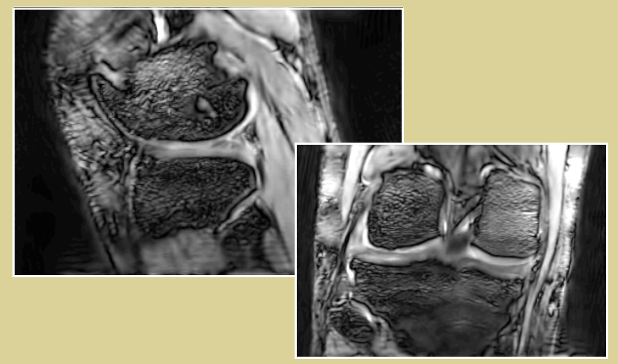


PP6, Spiral Projection Imaging Trajectory, RMS Error = 1.29
Iterative LS-NUFFT with DT-CWT regularization, then linear fusion, then 3D deconvolution. 70 min, 2.83GHz CPU, Matlab code on Intel Q9550 (quad core)

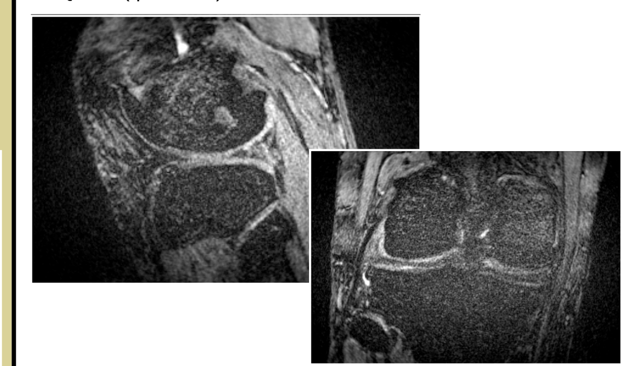
PP7, Random Poisson Disk Trajectory, RMS Error = 1.29
Compressed sensing reconstruction combined with SENSE using a data-driven iterative soft-thresholding approach with no free external parameters to be tuned. 9.3 min, 2.66GHz CPU, MATLAB R2009b, Intel Xeon X-5355 (quad core) processors



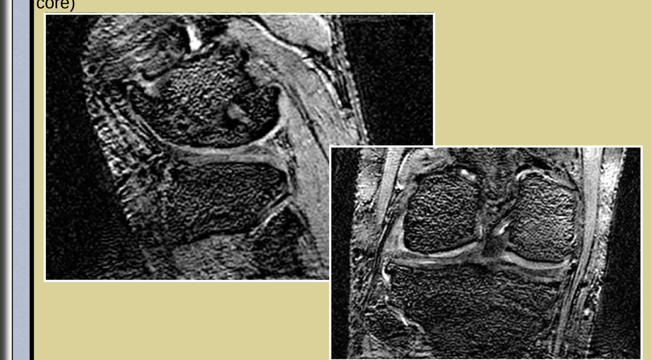
PP8, Stack of Spirals Trajectory, RMS Error = 1.39
Iterative LS-NUFFT with DT-CWT regularization, then linear fusion, then 3D deconvolution. 70 min, 2.83GHz CPU, Matlab code on Intel Q9550 (quad core)



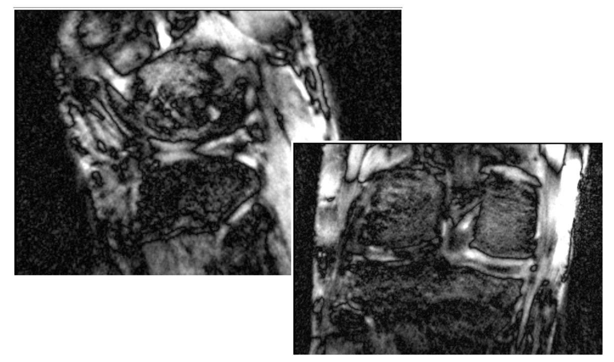
PP9, Trajectory Not Specified, RMS Error = 1.40
Gridding with multi-width kernels and the combine data of 8 coils by calculating square root of their square sum. 116 sec, 2.33 GHz CPU, intel Q8200 (quad core)



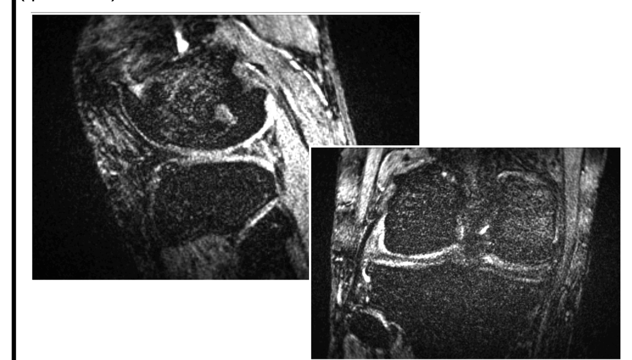
PP10, Stack of Spirals Trajectory, RMS Error = 1.41
3-D gridding, homodyne, coil combination using a low-resolution reconstruction, gentle noise reduction using Haar transform and soft-thresholding. 40 sec, 2.9GHz CPU, single threaded, AMD Athlon II X2 245 processor (2.9Ghz dual core)



PP11, Trajectory Not Specified, RMS Error = 1.75
Gridding with small kernel, and combine data of 8 coil using the B1 Map. 3.8 min, 2.33 GHz CPU, intel Q8200 (quad core)



PP12, Trajectory Not Specified, RMS Error = 1.96
Gridding with small kernel, and combine data of 8 coil by calculating the square root of their square sum. 4 min, 2.33 GHz CPU intel Q8200 (quad core)



Vote!

Go online to www.ismrmforms.org/forms2/recon.html, and vote for your choice of best entry for each challenge. Voting ends Tuesday at 12:00.
The (nonbinding) popular vote will be shown alongside the Radiologists' choice during the plenary. (One vote per attendee!)

Vote!