BART Toolbox for Computational MRI

- **For research use**
- Available for Linux, MacOS X, (Windows), ...
- BSD license (free for commercial use)
- `https://mrirecon.github.io/bart/`

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Research Support
American Heart Association Grant 12BGIA9660006, NIH Grant R41RR09784 and Grant R01EB009690, UC Discovery Grant 193037, Sloan Research Fellowship, GE Healthcare, DZHK (German Centre for Cardiovascular Research), and a personal donation from David Donoho's Shaw Prize, NIH Grant U24EB029240-01

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Motivation

- Rapid prototyping
  (similar to Matlab, octave, ...)
- Reproducible research
  (i.e. scripts to reproduce experiments)
- Robustness and clinically feasible runtime
  (C/C++, OpenMP, GPU programming)
- Educational tool
- Platform for collaboration

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Programming library

- Consistent API based on multi-dimensional arrays
- Fast transforms: FFT, nuFFT, wavelet
- Generic iterative (matrix-free) algorithms
  (conjugate gradients, FISTA, IRGNM, ADMM, iPALM, . . .)
- Composable operators / algorithms
- Transparent GPU acceleration of most functions
- Neural networks

Command-line tools

- Simple file format
- Looping, parallelization, streaming
- Interoperability with Matlab, Python
- Basic operations: fft, resize, slice, . . .
- Sensitivity calibration and image reconstruction

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Generic Tools

fft	FFT
slice	extract slice
extract	extract block
resize	crop / zeropad
flip	reverse dimensions
join	merge files
zeros/ones	create files
circshift	circular shift
conv	convolution
scale	scale
conj	complex ocnjugate
fmac	fused multiply-add
saxpy	scalar mult. and add
sdot	dot product
rss	root-sum-of-squares
repmat	repmat
svd	singular-value d.

MRI Tools

cc	channel compression
walsh	Walsh method
caldir	Direct calibration
ecalib	ESPIRiT calibration
ncalib	non-linear calibration
pics	ℓ_1-SENSE/ESPIRiT
moba	model-based recon
nlinv	non-linear inversion
nufft	non-uniform FFT
pocsense	POCSENSE
fovshift	Retrospectively shift FO
pattern	extract pattern
poisson	Poisson-disc pattern
signal	create signal curves

Low field?

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pics: Parallel Imaging Compressed Sensing

> bart pics -R*A*:*B*:*C*:*D* -R ... [-t trj] [-B basis] kspace sens image

- parallel imaging and compressed sensing
- non-Cartesian k-space trajectories
- subspace reconstruction
- multiple regularization terms
- A: different types of regularization:
  ℓ_2, ℓ_1, total variation, ℓ_1-wavelet, (multi-scale) low-rank
- B: transforms along arbitrary dimensions (space, time, etc.)
- C: joint-thresholding along arbitrary dimensions
- D: regularization parameter

Note: Depending on the algorithm additional parameters (step size, number of iterations, etc.) must be set for optimal results.

moba: Model-Based Reconstruction

> bart moba - model -r ... [-t trj] kspace enc output [sens]

- signal model (T_1, T_2, $T_2^\star$, $T_2^\star + \delta B_0$, Bloch)
- parallel imaging and compressed sensing
- non-Cartesian k-space trajectories
- A, B, C, D: regularization

Note: Depending on the algorithm additional parameters (step size, number of iterations, etc.) must be set for optimal results.

Resources

1. README, doc/
2. Website: `https://mrirecon.github.io/bart`
3. Source code: `https://github.com/mrirecon/bart`
4. Mailing list with public archive (see website)
5. Workshops:
   `https://github.com/mrirecon/bart-workshop`
6. Webinars:
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7. Help: Each command has '-h' option for a very brief help.

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Educational Track 2 (ET2): Reconstruction of Images and Parameter Maps

https://github.com/mritogether/ESMRMB2024_Hardware_to_Map

Schedule

- Image Reconstruction: Compressed Sensing, Model-Based Reconstruction, Machine Learning (Efrat Shimron)

- Introduction to the BART Toolbox (Martin Uecker)
- Parameter Mapping for Low-Field MRI (Julia Pfitzer)

Literature

Model-based reconstruction for T_2 mapping:

- Block, Uecker, Frahm. Model-based Iterative Reconstruction for Radial Fast Spin-Echo MRI. IEEE TMI 2009;28:1759-1769.
- Sumpf et al. Model-based Nonlinear Inverse Reconstruction for T2 Mapping Using Highly Undersampled Spin-Echo MRI. JMRI 2011;34:420-428. MARTINI ($\Rightarrow$ GRAPPATINI)
- Sumpf, Petrovic, Uecker, Knoll, Frahm. Fast T2 Mapping with Improved Accuracy Using Undersampled Spin-echo MRI and Model-based Reconstructions with a Generating Function. IEEE Transactions on Medical Imaging 2014;33:2213-2222. stimulated echos!
- Tamir et al. T2 Shuffling: Sharp, Multicontrast, Volumetric Fast Spin-Echo Imaging. MRM 2017;77:180-195 subspace
- Wang et al. Physics-based Reconstruction Methods for Magnetic Resonance Imaging. Philosophical Transactions of the Royal Society A. 2021;379:20200196. review with BART code!
- Scholand et al. Quantitative Magnetic Resonance Imaging by Nonlinear Inversion of the Bloch Equations. Magnetic Resonance in Medicine 2023;90:520-538. generic Bloch model, BART