

Berkeley Advanced Reconstruction Toolbox

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Target Audience: Image reconstruction researchers and developers

Introduction: The high complexity of advanced algorithms presents challenges for development as well as clinical application of new MRI reconstruction methods. While basic research requires flexible and interactive tools, clinical application demands robust and highly efficient implementations. Here, we present the Berkeley Advanced Reconstruction Toolbox (BART),¹ a framework for iterative image reconstruction which aims to address these disparate requirements. It consists of a programming library and a toolbox of command-line programs. The library provides common operations including generic implementations of several iterative optimization algorithms and supports parallel computation using multiple CPUs and GPUs. The command-line tools provide direct access to a wide range of functionality from basic operations to complete implementations of advanced calibration and reconstruction algorithms.

Requirements: The library is built for Linux and Mac OS X using the C programming languages and OpenMP. It makes use of the FFTW, the GNU Scientific Library, and optionally CUDA (NVIDIA, Santa Clara, CA) and ACML (AMD, Sunnyvale, CA).

Availability and Resources: The BART source code is available at <https://www.eecs.berkeley.edu/~mlustig/Software.html> and [Github](#). Starting with version 0.2.04, releases are also permanently archived in CERN data centers using ZENODO (<https://zenodo.org>) and assigned a digital object identifier (DOI). The software is released under the new BSD (Berkeley Software Distribution) license, which allows integration into other open source projects as well as commercial products. An educational workshop with talks and exercises was offered to users from California and similar workshops are planned for the future for a larger audience. A public discussion list is available: <https://lists.eecs.berkeley.edu/sympa/info/mrirecon>

Table 1: Overview of the currently available algorithms.

Basic transforms	SVD, FFT, nuFFT ² , (divergence-free ¹⁷) wavelets, convolution
Calibration	direct ⁶ , Walsh's method ⁴ , NLINV ⁹ , ESPIRiT ¹⁴
Reconstruction	Homodyne ³ , SENSE ⁵ , POCSense ⁷ , NLINV, ESPIRiT, SAKE ¹⁵
Coil compression	SVD ¹¹ , GCC (geometric) ¹³ , ECC (ESPIRiT-based) ¹⁶
Optimization	CG, IST, POCS, FISTA, ADMM, Landweber, IRGNM
Regularization	L2, L1 (wavelet), total variation, low-rank
Simulation	Shepp-Logan (k-space, non-Cartesian, multi-channel)

Functionality: The library offers simple but powerful interfaces for many operations on multi-dimensional arrays (e.g. to access slices of an array or to apply an FFT or wavelet transform along an arbitrary subset of the dimensions). Most operations offer transparent acceleration using multiple CPUs or GPUs. The command-line tools operate on files representing multi-dimensional arrays, whereas the use of memory-mapped input/output allows the efficient processing of extremely large data sets. The file format is very simple and functions for reading and writing with C/C++, Python, and Matlab (MathWorks, Natick, NA) are included. Initial support for importing files using the ISMRMRD data format is also available. Efficient implementations of many calibration and reconstruction algorithms for MRI are provided (Table 1). As an example, a reconstructed image and computation times for I1-ESPIRiT are shown in Figure 1 and Table 2, respectively.

Summary: We present BART, a toolbox for image reconstruction which includes many advanced algorithms and is freely available to the MRI community. State-of-the-art reconstruction methods can be developed using BART and integrated into a clinical reconstruction environment.

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Figure 1: I1-ESPIRiT reconstruction of a human abdomen (variable-density Poisson-disc sampling, $R=7$, RF-spoiled 3D-FLASH, $B_0 = 3$ T $TR/TE = 4.3/1.0$ ms, partial echo .6, matrix: $320 \times 256 \times 184$, 32 channels.).

Table 2: Computation time for all steps of the 3D I1-ESPIRiT reconstruction shown above. The implementation uses parallel programming (here: 20 CPU Cores and 4 GPUs).

Reconstruction Task	Time
ECC compression	14 s
ESPIRiT calibration	9 s
ESPIRiT reconstruction	12 s
Others (homodyne, coil combination, padding, ...)	16 s