Generalized Magnetic Resonance Image Reconstruction using The Berkeley Advanced Reconstruction Toolbox

Jonathan I Tamir[1], Frank Ong[1], Joseph Y Cheng[2], Martin Uecker[3,4], and Michael Lustig[1]
[1]*Electrical Engineering and Computer Sciences, University of California, Berkeley, Berkeley, CA, United States,*
[2]*Department of Radiology, Stanford University, Stanford, United States*
[3]*Diagnostic and Interventional Radiology, University Medical Center, Göttingen, Göttingen, Germany*
[4]*German Centre for Cardiovascular Research (DZHK), Göttingen, Germany*

Target Audience: Image reconstruction researchers and developers

Introduction: There is a strong need for tools to flexibly compare, prototype, and deploy new MRI reconstruction algorithms. We present the **Berkeley Advanced Reconstruction Toolbox (BART)**[1,2], a framework for iterative image reconstruction which aims to address these needs. BART is a programming library and collection of command-line tools to simulate, analyze, and perform MR image reconstruction. Table 1 lists BART availability and resources. The library provides 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. A tool is included to perform generalized **P**arallel **I**maging and **C**ompressed **S**ensing (PICS)[3] for arbitrary sampling trajectories and regularization.

Table 1. BART availability and resources

Website	mrirecon.github.io/bart
Source Code	github.com/mrirecon/bart
Mailing List	lists.eecs.berkeley.edu/sympa/info/mrirecon
Workshop Materials	mikmini.eecs.berkeley.edu/wiki/projects/reconworkshop
License	New BSD (free for scientific and commercial use)

```
#!/bin/bash
# k-space data stored in
# ksp.cfl and ksp.hdr
bart cc -G -P 8 ksp ksp_cc
bart ecalib ksp_cc maps
bart pics -R L:7:1024:0.01 \
       ksp_cc maps recon
bart toimg recon image.dcm
```

Figure 1. BART reconstruction script.

Functionality: The use of BART is twofold: firstly, to rapidly test and prototype advanced algorithms; and secondly, to integrate these algorithms into the data acquisition and reconstruction pipeline. The programming library provides interfaces for operations on multi-dimensional arrays (e.g. to access slices of an array or to apply a transformation along an arbitrary subset of the dimensions) as well as initial support for common file types (e.g. Siemens data, ISMRMRD, DICOM). The command-line tools operate on memory-mapped input and output using a simple data format. Interoperability with Python and Matlab (Mathworks, Natick, NA) is included, as well as third-party integration with GPI Lab[4] (gpilab.com).

Demonstration: As a proof of concept, we show in Figure 1 a Bash script that was used to reconstruct a Dynamic Contrast Enhanced (DCE) MRI data. Using BART, we coil-compressed the data, estimated ESPIRiT maps[5], and applied a parallel imaging and compressed sensing reconstruction[5]. The reconstructed output was then converted to DICOM. Figure 2a shows a reformatted reconstruction from the DCE data using the PICS tool with locally low rank[6] (LLR) regularization. Figure 2b shows a GRASP[7] reconstruction of radially under-sampled data using the PICS tool.

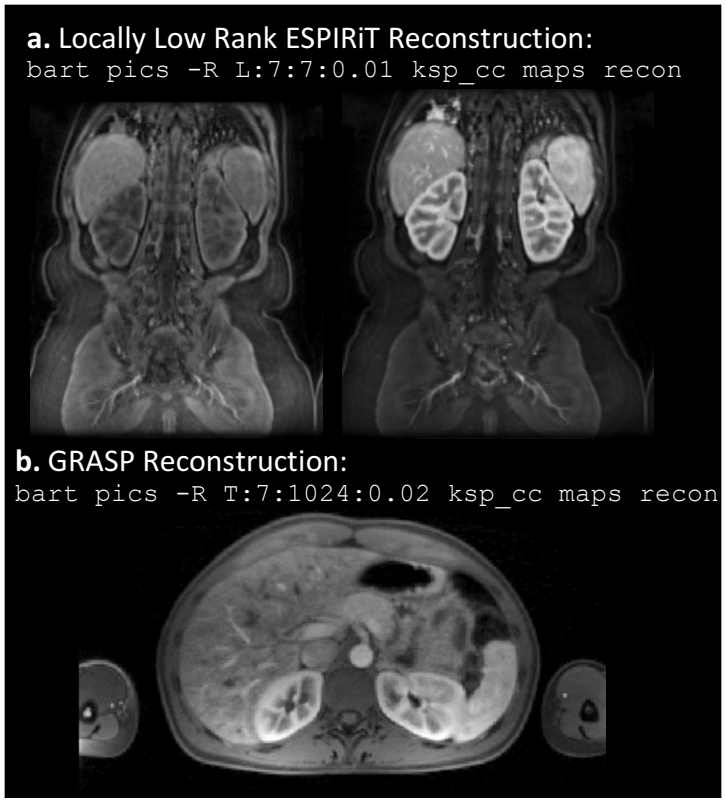

Figure 2. (a) Locally Low Rank reconstruction of Cartesian DCE MRI. (b) GRASP reconstruction of radial DCE MRI.

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.

Acknowledgement: We thank Dr. Tobias Block for the GRASP dataset, and the following funding sources: American Heart Association Grant 12BGIA9660006, NIH Grant R41RR09784 and Grant R01EB009690, UC Discovery Grant 193037, Sloan Research Fellowship, GE Healthcare, and a personal donation from David Donoho's Shaw Prize.

References: 1. BART (https://mrirecon.github.io/bart/) (2015) DOI: 10.5281/zenodo.31907 **2.** Uecker M et al., Berkeley Advanced Reconstruction Toolbox, ISMRM 23:2486 (2015) **3.** Lustig M et al., MRM 58:1182–1195 (2007) **4**. Zwart N, Pipe J, MRM 74:1449-1460 (2015) (http://gpilab.com/) **5.** Uecker M et al., MRM 2013 71(3):990-1001 **6.** Zhang T et al., MRM 69:571–582 (2013) **7.** Feng L et al., MRM 72:707-717 (2014)