BrainSuite Diffusion Pipeline (BDP): Processing tools for diffusion-MRI

Presented During:

Software Demonstrations

Poster No:

1910

Submission Type:

Abstract Submission

Authors:

Divya Varadarajan[1], Chitresh Bhushan[2], Clio Gonzalez Zacarias[3], Soyoung Choi[3], Yijun Liu[3], Anand Joshi[3], David Shattuck[4], Justin Haldar[3], Richard Leahy[3]

Institutions:

[1]Athinoula A. Martinos Center for Biomedical Imaging, Harvard, Boston, MA, [2]General Electric Research, Niskayuna, NY, [3]University of Southern California, Los Angeles, CA, [4]University of California, Los Angeles, Los Angeles, CA

First Author:

Divya Varadarajan, PhD
Athinoula A. Martinos Center for Biomedical Imaging, Harvard
Boston, MA

Co-Author(s):

Chitresh Bhushan, PhD
General Electric Research
Niskayuna, NY
Clio Gonzalez Zacarias
University of Southern California
Los Angeles, CA

Soyoung Choi
University of Southern California
Los Angeles, CA
Yijun Liu
University of Southern California
Los Angeles, CA
Anand Joshi
University of Southern California
Los Angeles, CA
David Shattuck, PhD
University of California, Los Angeles
Los Angeles, CA
Justin Haldar, PhD
University of Southern California
Los Angeles, CA
Richard Leahy
University of Southern California
Los Angeles, CA

Introduction:

Diffusion weighted MRI has uniquely enabled the study of *in vivo* brain micro-architecture. However, accurate inferences from diffusion weighted images (DWI) require specialized processing. BrainSuite Diffusion Pipeline (BDP) offers an end-to-end processing pipeline for diffusion MRI that includes implementations of established as well as novel processing methods. It allows essential processing steps to correct localized susceptibility-induced geometric distortions, co-register DWI and T1 weighted MRI (T1w-MRI), estimate white matter orientations for tractography and estimate microstructure related quantitative maps. It also includes novel methods including registration-based distortion correction, INVERSION (Inverse contrast Normalization for Very Simple Registration)[2] based T1w-MRI/DWI co-registration and orientation distribution function (ODF) estimators called Funk-Radon and cosine transform (FRACT)[3] and EAP response function optimized (ERFO)[8] ODF, for improved tracking. In addition, BDP seamlessly integrates with BrainSuite's anatomical processing and image analysis tools, namely, Cortical Surface Extraction (CSE), Surface and Volume Registration (SVReg), BrainSuite Statistics toolbox in R (bssr) and graphical interface for visualization. BDP is available as an opensource software for Windows, Linux, MacOS, and is included as part of the BrainSuite BIDS App.[5] An interface is also provided for NiPype.[4]

Methods:

1) T1 and DWI co-registration and distortion correction: BDP performs rigid registration between DWI and T1w-MRI using INVERSION technique, which exploits the inverted contrast relationship between T1- and T2-weighted brain images to define a robust similarity measure.[2] Users may optionally correct susceptibility-induced distortion using B0 fieldmaps or registration-based distortion correction that uses bias-field corrected T1w-MRI (generated by BrainSuite[7]) as a template, and constrains the registration

using spatial regularization and physics-based characteristics of distortion in EPI sequences.[1]
2) Diffusion tensor and ODF estimation:BDP has implemented two novel ODF estimators that are advantageous for tractography namely 1) FRACT[3] that generates ODFs with high angular resolution from single shell data; 2) ERFO[8] that uses machine learning and linear estimation theory to optimize ODF accuracy for arbitrary q-space sampling schemes. Other single shell methods implemented include diffusion tensor imaging (DTI) and Funk-Radon transform, and other multi-shell and cartesian sampling methods implemented include 3D simple harmonic oscillator based reconstruction and estimation[6] and generalized q-sampling imaging.[9] Additionally, diffusivity and anisotropy based quantitative maps are calculated in BDP from DTI and ODF estimations.
3) Tractography and connectivity analysis: Diffusion tensors and ODFs estimated by BDP can be visualized using BrainSuite graphical interface. Particularly, the diffusion toolbox allows real-time fiber tracking and interactive visualization of fiber tracks of whole brain or customized ROIs. Furthermore, BDP can interoperate with DSI Studio (http://dsi-studio.labsolver.org) tractography.[10]
4) Statistical Analysis: ROI-wise statistics of diffusion measures can be computed in BDP, using the SVReg labelled ROIs. Additionally, ROI- or voxel-wise group statistics can be computed using bssr.

Results:

Fig. 1 shows a simplified diagram of the steps performed by BDP command line tool and the options to visualize the constructed tracts. Fig. 2 shows the integration between the anatomical and diffusion processing pipelines.

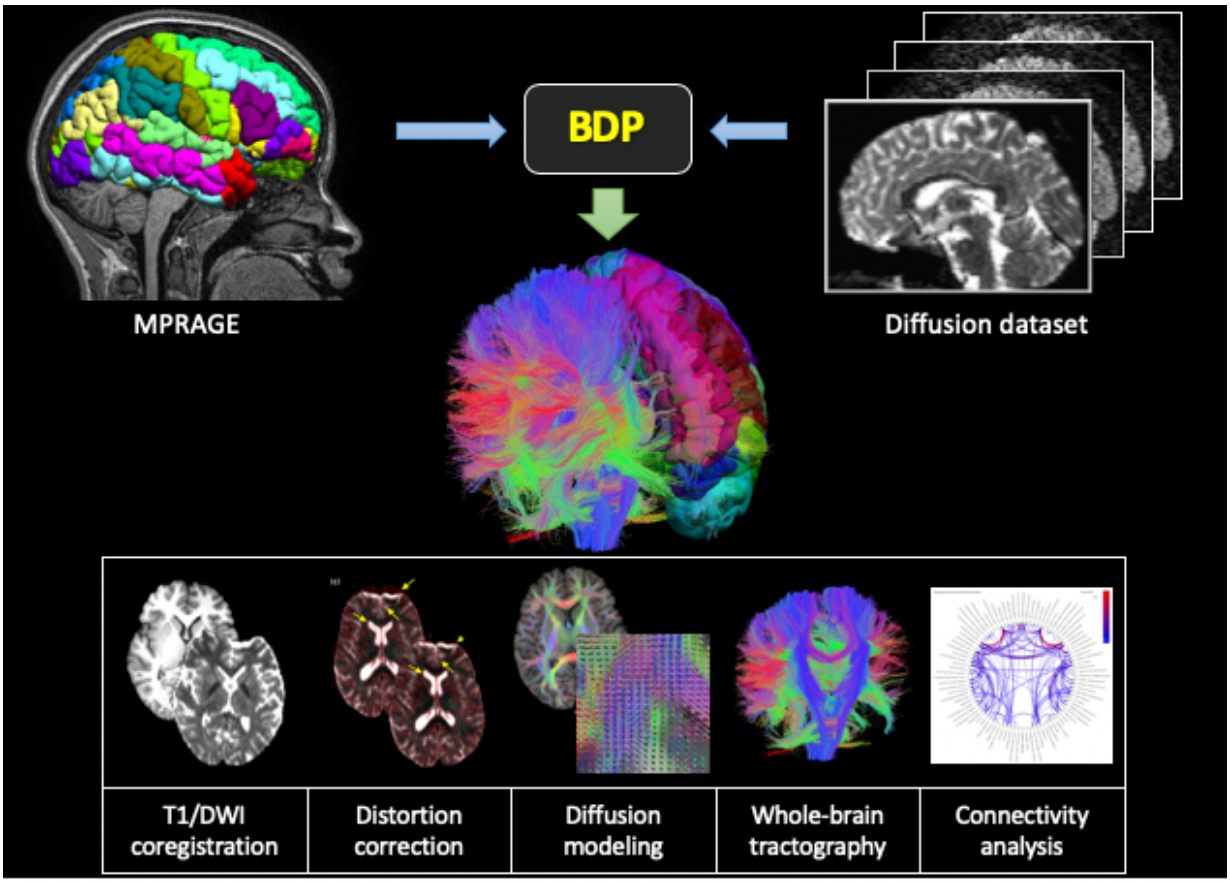

Figure 1. BDP schematic workflow. In particular, the coregistration between the T1/DWI images, distortion correction and diffusion modeling (tensors and ODFs), can be set as flags when running BDP. By default, all the outputs of BDP can be visualized in BrainSuite. BDP also optionally outputs ODFs compatible with DSI studio.

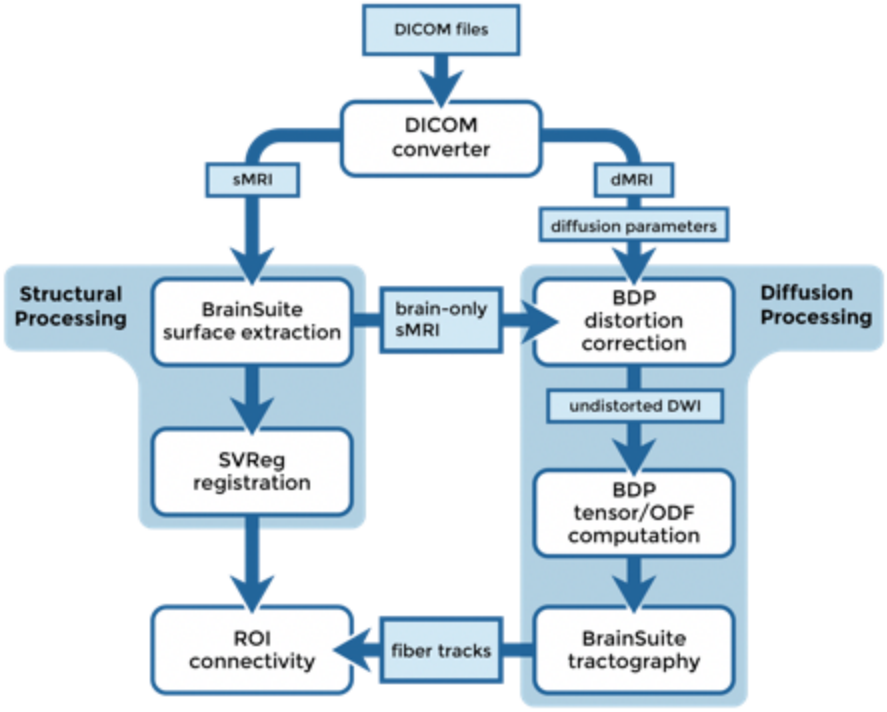

Figure 2. BrainSuite workflow diagram that shows the processing steps for structural MRI (CSE, SVReg), diffusion MRI (BDP) and the relation between them.

Conclusions:

BDP enables the integration of diffusion and structural MRI data for advanced connectivity analysis. It provides several methods for distortion correction, co-registration, modeling of DTI and ODFs, and ROI-wise statistics. Documentations and download packages are provided online (brainsuite.org).

Modeling and Analysis Methods:

Connectivity (eg. functional, effective, structural)
Diffusion MRI Modeling and Analysis [2]

Neuroinformatics and Data Sharing:

Workflows [1]

Novel Imaging Acquisition Methods:

Diffusion MRI

Keywords:

Computational Neuroscience
Data analysis
Design and Analysis
Modeling
MRI
STRUCTURAL MRI
Tractography
WHITE MATTER IMAGING - DTI, HARDI, DSI, ETC
Workflows
Other - BDP, BrainSuite, bssr, CSE, dMRI, DTI, ODF, pipeline, sMRI, SVReg

[1|2]Indicates the priority used for review

My abstract is being submitted as a Software Demonstration.

Yes

Please indicate below if your study was a "resting state" or "task-activation" study.

Other

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Are you Internal Review Board (IRB) certified? Please note: Failure to have IRB, if applicable will lead to automatic rejection of abstract.

No

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Not applicable

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

Diffusion MRI

For human MRI, what field strength scanner do you use?

1T
1.5T
2.0T
3.0T
4.0T
7T

Which processing packages did you use for your study?

Other, Please list - BrainSuite

Provide references using author date format

1. Bhushan, C., et. al. (2012). CORRECTING SUSCEPTIBILITY-INDUCED DISTORTION IN DIFFUSION-WEIGHTED MRI USING CONSTRAINED NONRIGID REGISTRATION. Proceedings of The Asia Pacific Signal and Information Processing Association Annual Summit and Conference, Hollywood, CA, 2012, 1-9.

2. Bhushan, C., et. al. (2015). CO-REGISTRATION AND DISTORTION CORRECTION OF DIFFUSION AND ANATOMICAL IMAGES BASED ON INVERSE CONTRAST NORMALIZATION. Neuroimage, 115, 269-280.

3. Haldar J. P., et. al. (2013). LINEAR TRANSFORMS FOR FOURIER DATA ON THE SPHERE: APPLICATION TO HIGH ANGULAR RESOLUTION DIFFUSION MRI OF THE BRAIN. NeuroImage, Volume 71, 2013, Pages 233-247.

4. https://github.com/nipy/nipype/tree/master/nipype/interfaces/brainsuite

5. Kim, Y., et. al. (2018). BRAINSUITE BIDS-APP: A CONTAINERIZED VERSION OF THE BRAINSUITE PROCESSING PIPELINES. 23rd Annual Meeting of the Organization for Human Brain Mapping Singapore, June 2018.

6. Özarslan, E., et. al. (2008). SIMPLE HARMONIC OSCILLATOR BASED ESTIMATION AND RECONSTRUCTION FOR ONE-DIMENSIONAL Q-SPACE MR. Proceedings of the International Society for Magnetic Resonance in Medicine (Toronto, ON), 16: 35.

7. Shattuck, D. W., et. al. (2002). BRAINSUITE: AN AUTOMATED CORTICAL SURFACE IDENTIFICATION TOOL. Med Image Anal. 6:129–142.

8. Varadarajan, D., et. al. (2018). TOWARDS OPTIMAL LINEAR ESTIMATION OF ORIENTATION DISTRIBUTION FUNCTIONS WITH ARBITRARILY SAMPLED DIFFUSION MRI DATA. Proceedings. IEEE International Symposium on Biomedical Imaging, 743–746.

9. Yeh, F. C., et. al. (2010). Generalized Q-sampling imaging. Medical Imaging, IEEE Transactions, 1626-1635.

10. Yeh, F. C., et al. (2013). DETERMINISTIC DIFFUSION FIBER TRACKING IMPROVED BY QUANTITATIVE ANISOTROPY. PLoS ONE, 8 (11).