BDP: BrainSuite Diffusion Pipeline

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Mouse spinal chord – axial diffusivity (DTI)

BDP

T1/DWI coregistration
Distortion correction
Diffusion modeling
Whole-brain tractography
Connectivity analysis

Joong Hee Kim, MRM 2016
BrainSuite Diffusion Tools

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BrainSuite Diffusion Pipeline
Command line tool (bdp.exe / bdp.sh)

BrainSuite GUI

- Allows user interaction
- Highly flexible
BDP command line

Command line output:

```
Setting up dataset and inputs
Reading input flags...
Checking input files...
BDP could not find any mask.nii.gz file. BDP will use input bfc file itself as brain mask for registration and statistics. All voxels with intensity > 0 in bfc will be treated as voxels in brain. You can specify a custom brain mask by using flag --tl-mask <maskfile_name>. The custom mask must overlay correctly with input BFC image in BrainSuite.
Processing data with fileprefix: 2523412

Co-registration and Distortion Correction
Reading the input parameters for co-registration...
Total usable memory found: 5.98GB
Checking orientation information...Done
Extracting 0-diffusion (b=0) image from input DWIs...
DWI mask is not defined in input flags. BDP will generate (pseudo) mask from 0-diffusion (b=0) image. Automatic mask generation may not be accurate in some situations and can affect overall quality of co-registration. In case co-registration is not accurate, you can define a DWI mask by using flag --dwi-mask <maskfile_name>. The mask can be generated and hand edited in BrainSuite interface. This mask would be used only for registration purposes (and not for statistics computation).
Saved (pseudo) masks: C:\Users\User\Desktop\BDP\2523412\dwi.BA3_mask.nii.gz

Starting Registration based distortion Correction...
Loading data...
Reading input data...
Setting/generating masks...
Matching centroids (approx. align)...
Matching resolution of the images...
Normalizing intensity of images...
Running affine registration with 6 degrees of freedom...
Search-based initialization...
Iteration 1 of 6 running...
Iteration 2 of 6 running...
```
BrainSuite GUI
EPI distortion in diffusion MRI

MPRAGE  b=0 image  Field inhomogeneity

Overlay with edges

MPRAGE  b=0 image  MPRAGE  b=0 image
Distortion correction in BDP

1. Fieldmap based
   - --fieldmap-correction <fname.nii.gz>

2. Registration based (default)
   - Uses structural image to estimate distortion field
   - Does not require a field inhomogeneity map

3. --no-distortion-correction (Only Rigid) / --no-structural-registration
   - Different distortion correction method, eg. IPED.
   - No distortion e.g. ex vivo study
   - Non-brain data e.g. heart, thigh etc.
   - No MPRAGE and no fieldmap

Distortion correction in BDP

Distorted After correction

Color FA overlaid on MPRAGE image after correction
Diffusion modeling

- Low resolution sampling
- High-resolution single-shell sampling
- Arbitrary sampling
  - E.g. Multi-shell/Cartesian

Diffusion tensor

- FRACT ODFs

- FRT ODFs
  - Tuch 2004, Descoteaux 2007

- 3D-SHORE ODFs
  - Ozarslan 2009, Merlet 2013

GQI ODFs
- Yeh 2010
- Low resolution / High resolution single shell data
- Diffusion parameters
  - FA map
  - MD map
  - Useful for quantitative diffusion studies
- Bad for Crossing fibers

Color FA

MD

Diffusion tensor

FA image
• High resolution single shell data
• Diffusion parameters
  • GFA map
  • Useful in quantitative diffusion studies
• Detects Crossing fibers

FRT ODF
(min-max norm.)
Tuch 2004, Descoteaux 2007
FRACT ODF (min-max norm.)

- High resolution single shell data
- Detects Crossing fibers
  - Better angular resolution than FRT
  - Recommended for Tractography

Tractography

FA image
- High resolution data
- Arbitrary sampling scheme
  - Multi-shell sampling
  - Cartesian sampling
  - Custom sampling
- Detects Crossing fibers

3DSHORE ODF
(min-max norm.)
Ozarslan 2009, Merlet 2013
• High resolution data
• Arbitrary sampling scheme
  • Multi-shell sampling
  • Cartesian sampling
  • Custom sampling
• Detects Crossing fibers

GQI ODF
(min-max norm.)
Yeh 2010
- High resolution data
- Arbitrary sampling scheme
  - Multi-shell sampling
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  - Custom sampling
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3DSHORE ODF
- High resolution data
- Arbitrary sampling scheme
  - Multi-shell sampling
  - Cartesian sampling
  - Custom sampling
- Detects Crossing fibers
Choosing the Diffusion model

- Know your data
  - Figure out the relevant diffusion models
  - Example: Multi-shell data -> DTI, FRT, FRACf be careful!
  - BDP will warn you during sampling – modeling mismatch
Choosing the Diffusion model

- Try the relevant models on a subset
  - Look for features that your application needs.
  - Example: Tractography depends on the angular resolution of ODFs

**HCP Multi-shell Dataset**

Recommendation:
- Quantitative studies: DTI, Use b=1000 shell
- For tractography with HCP data use b=3000 shell along with FRACT ODFs.

Varadarajan & Haldar, OHBM 2017 (Poster 2999)
Running BDP

- BDP executable location
  - Mac: /Applications/BrainSuite17a/bdp/bdp.sh
  - Windows: C:\Program Files\BrainSuite17a\bdp\bdp.exe

- Typical syntax
  bdp.sh <BFC File> [Optional Flags] --nii <4D DWI NIfTI> \ 
  --bvec <Gradient file> --bval <b-value file>

- Example
  bdp.sh 2467264.bfc.nii.gz --tensor --odf \ 
  --nii 2467264.dwi.nii.gz --bvec 2467264.dwi.bvec \ 
  --bval 2467264.dwi.bval

(See next section and website for more details)
http://brainsuite.org/processing/diffusion/pipeline/
BDP: Flexible flags

- >50 optional flags
- Supports several types of diffusion data
- Works without anatomical image
Frequently used flags

- **Software support flags**
  - **--help or -h** - Prints out description of all BDP flags and BDP version.
  - **--check-for-updates** - Connects to BrainSuite server to check if a new version of BDP is available

- **Distortion correction flags**
  - **--dir=<direction>** - Define phase encoding direction
  - **--fieldmap-correction <fname.nii.gz>** - Fieldmap in rad/sec
  - **--echo-spacing=<t>** - Echo spacing in sec

- **Registration flags**
  - **--no-structural-registration** - Run BDP in diffusion space
  - **--rigid-reg-measure <measure>** - Similarity measure for rigid registration

- **Diffusion modeling flags**
  - **--frt,--fract,--tensors,--3dshore,--gqi** - DTI and ODF methods

- **I/O flags**
  - **--nii** - Input DWI file
  - **--output-subdir** - Output subdirectory
  - **--output-diffusion-coordinates** - Outputs in diffusion coordinates

Of course online documentation:  [http://brainsuite.org/processing/diffusion/](http://brainsuite.org/processing/diffusion/)
User friendly interface

- Summary
- `<fileprefix>.BDPSummary.txt`

```bash
COMMAND USED:
bdp13.exe D:\BrainReg_Git\data\BDP_test_data\6067H\5934JH.bfc.nii.gz
  --threads=4
  --dir=--
  --pdf
  --tensor
  --output-subdir windows_complied_v13p17_fieldmap
  --output-diffusion-coordinate
  --nii D:\BrainReg_Git\data\BDP_test_data\6067H\6067JH.DWI.00.nii.gz
  --bvec D:\BrainReg_Git\data\BDP_test_data\6067H\6067JH.DWI.00.bvec
  --bval D:\BrainReg_Git\data\BDP_test_data\6067H\6067JH.DWI.00.bval
  --fieldmap-correction D:\BrainReg_Git\data\BDP_test_data\6067H\6067JH.fieldmap.rad
  --echo-spacing=0.00036

Approximate processing time: 18.07 minutes
```
User friendly interface

- Command line output – Always verbose with relevant important information

Reading input flags...

Output sub-directory already exists:
D:\BrainReg_Git\data\BDP_test_data\6067JH\windows_complied_v13p17_fieldmap
The files in the output folder can be overwritten.
Checking input files...
Successfully generated b-matrices file.

BDP could not find any .mask.nii.gz file. BDP will use input bfc file itself as brain mask. You can specify a custom head mask by using flag --t1-mask <maskfile_name>. The custom mask must overlay correctly with input BFC image in BrainSuite.

Reading the input parameters for co-registration...
Checking orientation information...Done
Extracting 0-diffusion (b=0) image from input DWIs...Done

DWI mask is not defined in input flags. BDP will generate (pseudo) mask from 0-diffusion (b=0) image. Automatic mask generation may not be accurate in some situations and can affect overall quality of co-registration. In case co-registration is not accurate, you can define a DWI mask by using flag --dwi-mask <mask_filename>. The mask can be generated and hand edited in BrainSuite interface. This mask would be used only for registration purposes (and not for statistics computation).

Saved (pseudo) mask: D:\BrainReg_Git\data\BDP_test_data\6067JH\windows_complied_v13p17_fieldmap\5934JH.dwi.RAS.mask.nii.gz
User friendly interface

- Error!
BDP outputs

http://brainsuite.org/processing/diffusion/output-files/
Example study

Regional Susceptibility to Chronic Anemia in WM Microstructure Using Diffusion Tensor Imaging
S Choi, AM Bush, M Borzage, AA Joshi, TD Coates, RM Leahy, JC Wood, 58th American Society of Hematology Annual Meeting and Exposition (ASH), San Diego, 2016, 3640
BDP Documentation:
http://brainsuite.org/processing/diffusion/

Detailed flag description:
http://brainsuite.org/processing/diffusion/flags/