Diffusion Tensor Processing and Visualization

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NAMIC: National Alliance for Medical Image Computing
DTI Tools: Slicer 3
NAMIC activity: Analysis of DTI

From **raw data** to **analysis**:

- DICOM to NRRD conversion
- Correction for artifacts (head motion, Eddy currents): QC-ing
- Filtering, interpolation (non-Euclidean geometry)
- Calculation of tensors (lin, nonlin)
- **White matter pathways/tracts via tractography or volumetric path search methods → expert interaction**
- Characterization of tracts via parametrization of tract geometry and coding of diffusion attributes: QCing
- Linear/nonlinear registration of sets of images
- Building of population means/templates/atlases: QC-ing
- Statistical analysis, Hypothesis testing
From Modules to Systems / Workflows
Eddy Current Correction

Eddy current, head motion, geometric distortion correction comparison

before

after
Rician Filtering of Tensor Fields

Noisy Data

Rician Filtered
Dream: Connectivity?

Forebrain Fiber Bundles: General idea of where various fiber bundles are and regions they interconnect or project to.

Source: Duke NeuroAnatomy
Web Resources (Ch. Hulette)

Tractography: Coronal view
Clinical Uses: Tractography

Catani, Cortex
2008
(Adult DTI)

splenium
genu
mid-cc
uncinate
ilf
motor
sensory
etc.
DTI Tractography: Principle

Seed point(s)

Move marker in discrete steps and find next direction

Direction of principle eigen value
Alternative methods for tractography

- Tracking in tensor field
- Keep history along track: e.g. Kalman filtering
- Probabilistic tractography
- Optimal path analysis
- Fiber tract by volumetric diffusion
- ...
- Variety of methods developed by NAMIC developers
Volumetric White Matter Pathways

- Region-to-region analysis
- Volumetric representation of pathway
- Integral of a local cost function $\psi(T, M)$ over the path $c$
Stochastic Tractography


Courtesy Carl-Fredrik Westin, MICCAI 2008 workshop
Stochastic Tractography

Fractional anisotropy

A probability density function of the fiber orientation in each point.

In every step, draw a step direction from the pdf of the underlying fiber orientation.

Friman, Westin MICCAI 2005, TMI 2006

Courtesy Carl-Fredrik Westin
Probability of Connection

Courtesy Carl-Fredrik Westin, MICCAI 2008 workshop
Ron Kikinis:
• Visual assessment of multi-modality imaging with 3D tracts and objects.
• Potential identification of specific functions for neurological testing, -> deploy tests based on hypothesis from imaging.
• Future: More principled approach, leads to quantitative assessments.
Quantitative Tractography

- Tractography for ROI definition
- Tensor analysis for statistics along tracts
- Corouge, Gouttard, Gerig, MedIA’06
Example Uncinate Fasciculus

FA distributions in cross-sections: Kernel Regression
Coming soon: Population-based analysis
Population Analysis of DTI: Computational Anatomy Approach

  - Available in sandbox MultimodalImageRegistration
  - Tensor processing tools – DTIprocess (NeuroLib), Teem, Slicer 3
Population based DTI analysis
Unbiased Atlas Building: Population Average of Images

[Goodlett et al 2006]
[Joshi et al 2004]

Balci, Golland, Wells. Non-rigid Groupwise Registration using B-Spline Deformation Model: →NITRC

Dinggang Shen, HAMMER

Important: Fully diffeomorphic/invertible registration
Group-wise Atlas Building

A) Choice of template: Analysis is biased by choice of template.

B) Unbiased atlas building: Minimize total distance between population and template
   (Gee & Avants, Joshi & Fletcher)
Population-based analysis of DTI

Map DTI into unbiased atlas

Tractography in atlas space

Map tracts to original images

Functional data analysis

DTI: Estimation of coordinate transformations

- Structural Operator
- Transformation (Affine, Fluid)
- Structural Average
- Deformation Fields (1:N)
- $H^{-1}$-fields (1:N)
Computation of tensor means

DTI Images

Rotate Tensors based on $J_{H}^{-1}$

Tensor Averaging

H-fields (1:N)

Riemannian Symmetric Space

DTI Atlas
Pediatric Example – Genu 1 to 2yrs

Population analysis of fiber tracts:
Goodlett et al., MICCAI 08, NeuroImage 2009
Tract Profile Group Statistics
Controls - Left Internal Capsule Tracts

Krabbe’s - Left Internal Capsule Tracts

FA = 0 \quad \text{FA = 1}

Worst motor development
FA Statistics along Fibers

Statistics over 6 Krabbe, 53 Healthy neonate babies
Babies of drug-addicted mothers: Population based tract analysis of DTI

### Cocaine vs Control

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Population based analysis of DTI

Motor tract NC vs. CO

Left motor tract (FA color coded)
Brain Morphometry

Humans
- Large Variability

Monkey
- Reduced complexity and variability

Mouse, Rat
- Genetic control, small variability

Translational Research
Mouse Brain Analysis

- Structural & DTI analysis analogous to human & primate analysis
- Light-reared vs dark-reared mice
  - Prelim: 6 (3 vs 3)
Mouse: Voxel Wise DTI Analysis
Mouse: FiberTracking

- Major tracts successfully extracted:
  - CC, fornix, AC
- FA along tracts
  - Same as in humans
- Example on fetal alcohol syndrome
Monkey DTI

• With Marc Niethammer
• DTI atlas method adapted for primate data
• First MRI scan batch acquired
  – DTI atlas and sMRI atlas at 2w, 3m, 6m are built
Conclusions

• Slicer 3 Platform provides comprehensive set of tools

• Whole processing from DICOM to output results in one computational environment

• New tools added as new technologies and methodologies emerge