Cortical Thickness Analysis with Slicer

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Motivation Neuroimaging

• Morphometry ⇔ Pathology
  – Cortical Gray Matter thickness
• Schizophrenia, Autism, Alzheimer’s, Huntington’s…

• This talk:
  – Cortical thickness examples
  – Existing methods for cortical thickness
  – NA-MIC/Slicer modules
  – Future work
Neurodevelopmental Trajectories of the Human Cerebral Cortex

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Intellectual ability and cortical development in children and adolescents

P. Shaw¹, D. Greenstein¹, J. Lerch², L. Clasen¹, R. Lenroot¹, N. Gogtay¹, A. Evans², J. Rapoport¹ & J. Giedd¹
Cortical thinning and correlation with cortical thinning

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http://na-mic.org
Existing Methods

• Cortical thickness ≠ Graymatter density
  – M Chung, TMI 2007, negatively correl.

• Major methods
  – BrainVoyager, Goebel
    • Commercialized, Brain Innovation
  – CLASP, Evans et al (MNI)
  – FreeSurfer, Fischl et al (MGH)
  – CRUISE, Tosun et al (JHU,UCLA,UCSF)
• Image preprocessing & Cortical surface extraction

Native MR image → Intensity Non-uniformity Correction → Spatial Normalization to stereotaxic space

Tissue Classification → Cortical Surface Extraction (CLASP algorithm) → Cortical thickness measurement

CLASP - MNI

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CLASP Correspondence

- Nonlinear registration on 2D sphere surfaces
- Spherical surface registration with sulcal depth map

Sulcal geodesic depth

Average sulcal depth

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FreeSurfer

- Similar preprocessing
  - Different order of steps
- WM from segmentation and topology correction
- GM surface from evolution along T1 intensity gradient
FreeSurfer Correspondence

Sulcal depth

Surface registration to atlas
CRUISE Cortical Reconstruction Using Implicit Surface Evolution

Laplacian based Cortical Thickness
CRUISE Correspondence

Koenderink Shape Measures

Shape Index Measure

atlas
subject

Curvedness Measure

atlas
subject

Subject
Atlas
Central surface

Hemispherical maps

Optical Flow
Flow field
Warp

Improved sulcal alignment

$N_{\infty}$

htl, ____________
Major Differences

• Cortical topology
  – Spherical topology needed?
  – During or After WM/GM segmentation

• Thickness measurement
  – Closest point, skeleton based, deformation based and laplacian solution based

• Cortical correspondence
  – Many based on sulcal depth based or curvature
  – Template vs Group-wise? Parametrization?
NAMIC Approach for CT

• 2 separate module pipelines

1. Regional/image based CT analysis:
   – Template based registration, simple but stable, good for regional analysis

2. Local/surface based CT analysis
   – Spherical topology, but tolerance against violations
   – Group-wise correspondence
   – Extensible generic framework that easily incorporates landmarks, connectivity, vessels, functional
   – Full framework in open source, NAMIC Kit
Regional CT – Pipeline

Slicer external module (loadable via extension manager)

*ARCTIC (Automatic Regional Cortical ThICkness)*

Input: raw data (T1-w, T2-w, PD-w images)

Three steps in the pipeline:

1. Tissue segmentation
2. Regional atlas deformable registration
3. Cortical Thickness
Step 1: Tissue segmentation

- Probabilistic atlas-based automatic tissue segmentation via an Expectation-Maximization scheme
- Tool: itkEMS or ABC (Automatic Brain Classification on NITRC, UNC & UUtah)

![T1w image](image1)
![Corrected image](image2)
![Label image](image3)
Step 2. Regional atlas deformable registration

• **2.1** Skull stripping using previously computed tissue segmentation label image
  Tool: SegPostProcess (UNC Slicer3 ext module)

• **2.2** T1-weighted atlas deformable registration using a B-spline pipeline registration
  Tool: RegisterImages (Slicer3 modules)

• **2.3** Applying transformation to the parcellation map
  Tool: ResampleVolume2 (Slicer3 module)
Step 3. Cortical Thickness

- Sparse asymmetric local cortical thickness
- Uses distance map based local maxima to correct for CSF/GM errors (akin to skeleton based CT)
- Tool: CortThick (UNC Slicer3 module)

*Note:* All the tools used in the pipeline are Slicer3 modules, some of them being UNC external modules. All can be run as command line and thus are scriptable.
ARCTIC Validation

ARCTIC vs. FreeSurfer:

Freesurfer’s tutorial dataset consisting of 40 healthy subjects, ranging in age from 18 to 93, Pearson correlation of the mean lobar CT’s

• As is: Good correlation for parietal lobe, other lobes $r < 0.7$
• When using FreeSurfer’s WM/GM segmentation: all lobes $r > 0.75$
• Also using FreeSurfer’s parcellation: all lobes $r > 0.85$

Longitudinal autism study of 86 subjects aged 2-4 years.

• FreeSurfer low success: <40% without, <70% manual intervention
• ARCTIC: 98% success rate
GAMBIT: local CT analysis

Group-wise Automatic Mesh-Based Analysis of Cortical Thickness (GAMBIT)

- Tissue segmentation
- ROI segmentation
- WM cortical image creation
- Cortical thickness computation
- WM cortical image post-processing
- Genus 0 - WM image & surface creation
- Genus 0 - WM surface inflation
- Sulcal depth computation
- Particles initialization

Similar processing to other local approaches
Inflation, Sulcal Depth and Particle Initialization

Sulcal Depthmap

Particle Placement

WM surface

Inflated surface

98 Regions

98 Particles at COG
Group-wise Correspondence

- Template free
- Correspondence over all surfaces
- Minimum Description Length
  - Davies et al
  - Parametric framework
- Entropy: Oguz & Cates
  - UNC & Utah

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Particle Approach (Cates & Oguz)

- Point-based sampling of the surface
  - Same number of particles per shape
  - Very different from all other parametric approaches
- Particles are ordered $\Rightarrow$ correspondence
- Incorporates functions of position
  - Local curvature, Sulcal depth, DTI connectivity
Entropy Tradeoff

- Simultaneously maximize both the geometric accuracy and the statistical simplicity of the model

\[ Q = H(Z) - \sum_{k} H(P^k) \]

- **k**: shape id
- **P**: particle locations
- **Z**: ensemble distribution

\( Q \) = Ensemble entropy (small = simple) - Surface entropy (large = accurate)
Dealing with Cortical Geometry

• Highly convoluted surface is a problem
  – Particle correspondence computed on 3D image grid

• Solution: run correspondence on inflated brain
  – Convex move in, concave move out
Experiments

- 9 healthy subjects
- Correspondence metric: sulcal depth
- Reduction of sulcal depth variance
- Compare vs Freesurfer, same init

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<thead>
<tr>
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<th>Sulcal Depth</th>
<th>Cortical Thickness</th>
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<tr>
<td>Initial Data</td>
<td>0.227634</td>
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<td>XYZ-entropy</td>
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<td>FreeSurfer</td>
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Open Source Framework

• All BSD style open source
• Slicer external modules for all individual steps
• “Super” modules (ARCTIC and GAMBIT)
  – Generates and run BatchMake script that calls steps
  – Can be run local or on grid
Discussion & Future Work

• Cortical thickness
  – Important for neuroimaging studies
  – Many tools, NAMIC cortical thickness

• Next steps
  – Regional CT: First study papers in review on cortical thickness in Autism (DPB II)
  – Full Framework, testing, tutorials
  – Cortical thickness in rodents