3D Computer-Assisted Brain Mapping

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Medical Imaging

Courtesy of Alexandra Golby, MD, Noby Hata, PhD, Steve Pieper, PhD
Brigham and Women’s Hospital
Data Explosion

75 slices, 37.5 MB

1,000 slices, 0.5 GB

Challenge: how to visualize so many data?
Computer-assisted brain mapping

\[
\ln p(X | \pi, \mu, \Sigma) = \sum_{n=1}^{N} \ln \left\{ \sum_{k=1}^{K} \pi_k N(x_n | \mu_k, \Sigma_k) \right\}
\]

- Increasing sophistication in computer hardware
- Scientific advances made by the biomedical imaging computing community
- Enhanced research capabilities for exploring the brain
Visualizing the brain in 3D

Image from the SPL-PNL Brain Atlas
Talos IF, Jakab M, Kikinis R, Shenton ME
Brigham and Women’s Hospital, Boston
Volume Rendering

Image courtesy of Steve Pieper, Ph.D.
Volume Rendering

- Direct visualization
- Ray casting
- Hardware accelerated volume rendering

Image courtesy of Steve Pieper, Ph.D.
Image Segmentation
Image Segmentation
Image Segmentation
Image Segmentation
Image Segmentation

- Manual drawing & thresholding
- Semi-automated level tracing
- Automated segmentation algorithms
3D surface reconstruction

Marching Cube Algorithm (*)

*Lorensen WE, Cline HE. Marching Cubes: a high resolution 3D surface construction algorithm. SIGGRAPH'87
3D surface reconstruction

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3D Surface Analysis

Cortical thickness on white matter surface

Image courtesy of Martin Styner, PhD, Clement Vacher, M.Sc., University of North Carolina Chapel Hill
Mapping the brain with Diffusion Tensor Imaging
Diffusion Tensor Imaging Analysis

- DWI Acquisition
- Tensor Calculation
- Scalar Maps
- 3D Visualization
Diffusion Weighted MR Imaging
Stejskal-Tanner

\[ S_i = S_0 e^{-b \hat{g}_i^T D \hat{g}_i} \]

\[
D = \begin{bmatrix}
D_{xx} & D_{xy} & D_{xz} \\
D_{yx} & D_{yy} & D_{yz} \\
D_{zx} & D_{zy} & D_{zz}
\end{bmatrix}
\]
Diffusion Tensor

Stejskal-Tanner

\[ S_i = S_0 e^{-b\hat{g}_i^T D \hat{g}_i} \]
Tractography

Diagram showing a path with points connected by line segments.
Streamline Tractography

The goal of tractography is to determine white matter fibers’ trajectory from a set of DTI voxels.
ROI Seeding
Fiducial Seeding

Image courtesy of Steve Pieper, Ph.D.
Data Fusion

Image courtesy of Alexandra Golby, M.D., Jean-Jacques Lemaire, M.D., Ph.D., Steve Pieper, Ph.D.
Data Fusion
Initial mis-registration
After registration
Data Fusion

Example: Registration of high-resolution anatomical and functional datasets to improve localization of findings for fMRI analysis
Mapping the brain and its function

fMRI activation map superimposed on the anatomical images
Multimodal MRI Data Fusion

Clinical perspectives

• Integrated visualization from various imaging modalities

• Enhanced assessment of the clinical situation

• Better evaluation of treatment options

Image courtesy of Steve Pieper, Ph.D.
3D Navigation in the brain

Courtesy of Ferenc Jolesz, MD, Brigham and Women’s Hospital, Boston
Computer-assisted navigation

- Computer-assisted stereotactic neurosurgery
- Improvement of surgical accuracy
- Faster & safer procedures

Images Courtesy of CSAIL, MIT

Images courtesy of Ferenc Jolesz, MD, Steve Pieper, PhD, Brigham and Women’s Hospital, Boston
Neurointerventions

- Patient radiation exposure
- Clinician radiation exposure
- Projective imaging of complex cerebral vasculature

Kai Frerichs M.D., Sonia Pujol, Ph.D.
Brigham and Women’s Hospital
Neurovascular Navigation
Neurovascular Navigation

- 3D roadmapping
- Reduced radiation exposure for patient and clinician
- Real-time 3D data fusion
Example: A Clinical Case

- Right handed male patient, 20 years old.
- Scan of the head after sport trauma

Courtesy of Alexandra Golby, MD, Peter Black, MD, Ron Kikinis, MD
Brigham and Women’s Hospital, Boston, MA
A Clinical Case: Overview

Courtesy of Alexandra Golby, MD, Peter Black, MD, Ron Kikinis, MD
Brigham and Women’s Hospital, Boston, MA
Peritumoral Tracts

Courtesy of Alexandra Golby, MD, Peter Black, MD, Ron Kikinis, MD
Brigham and Women’s Hospital, Boston, MA
White Matter Surface

Courtesy of Alexandra Golby, MD, Peter Black, MD, Ron Kikinis, MD
Brigham and Women’s Hospital, Boston
Virtual Probing

Courtesy of Alexandra Golby, MD, Peter Black, MD, Ron Kikinis, MD
Brigham and Women’s Hospital, Boston, MA
Neurosurgical Navigation

Anatomic and functional brain mapping in areas surrounding brain tumors

Courtesy of Alexandra Golby, MD, Noby Hata, PhD, and Haying Lui, MSE. Brigham and Women’s Hospital, Boston
Neurosurgical Navigation

Courtesy of Alexandra Golby, MD, Noby Hata, PhD, Haying Lui, MSE. Brigham and Women’s Hospital, Boston, MA
Validation
Validation

Golby, Black, Kikinis
Validation

Cortico-Spinal Tract

Courtesy of Alexandra Golby, MD, Jean-Jacques Lemaire, MD, PhD, Steve Pieper, PhD
Mis-registration
Registration Validation
Surface Reconstruction Validation

Courtesy of Nicole Grosland, PhD, Vincent Magnotta, PhD, Nicole DeVries, PhD, The University of Iowa
Tractography Validation

The Life Cycle of Medical Imaging Data - Sonia Pujol, Ph.D.
Preliminary results on the use of STAPLE for evaluating DT-MRI tractography in the absence of ground truth. Pujol et al. ISMRM 2009.
Tractography Validation

• Evaluation of the sensitivity and specificity of tractography algorithms

• Quantitative analysis of fiber bundles

Preliminary results on the use of STAPLE for evaluating DT-MRI tractography in the absence of ground truth. Pujol et al. ISMRM 2009.

National Alliance for Medical Image Computing
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Conclusion

• 3D Visualization of anatomy and function
• Multimodal data fusion
• Computer-assisted surgical Navigation
• Importance of validation
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