3D Computer-Assisted Brain Mapping

Sonia Pujol, PhD
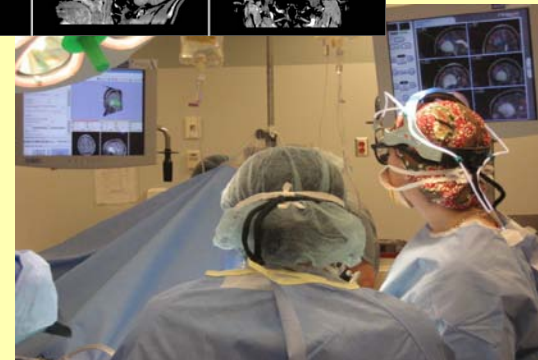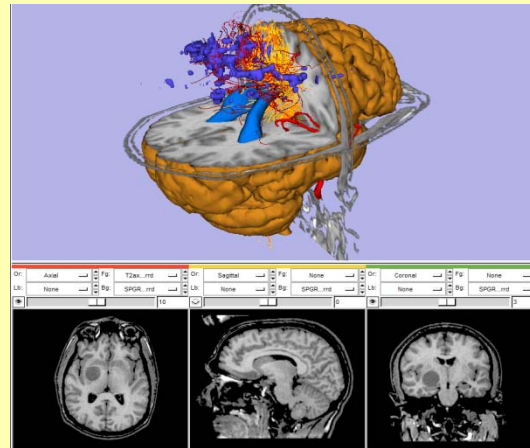
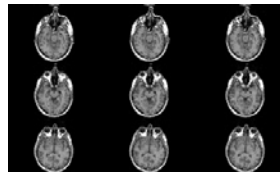Brigham and Women's Hospital,

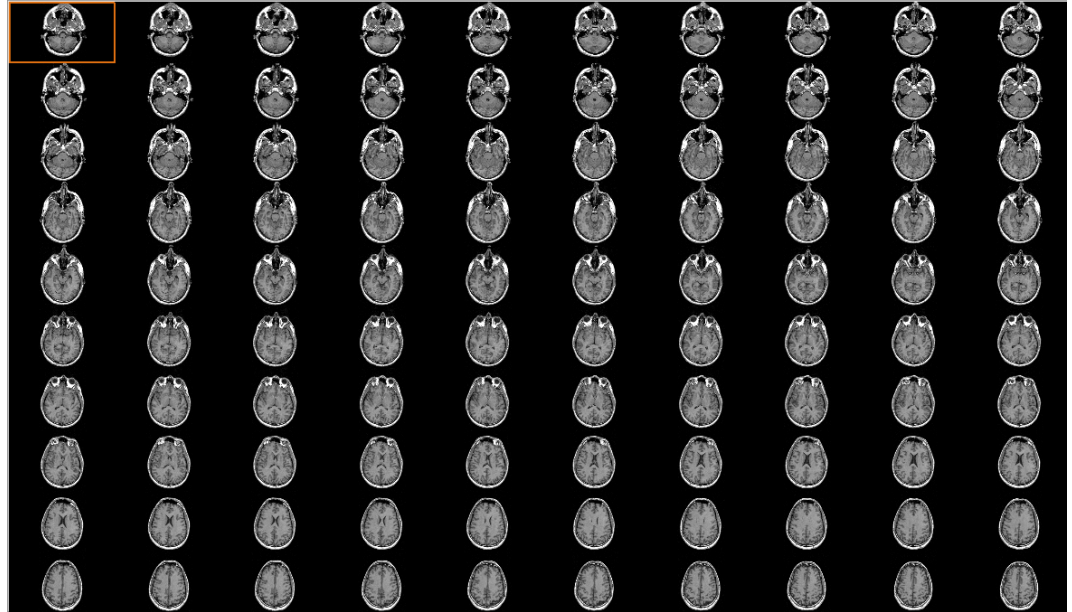Harvard University

Medical Imaging

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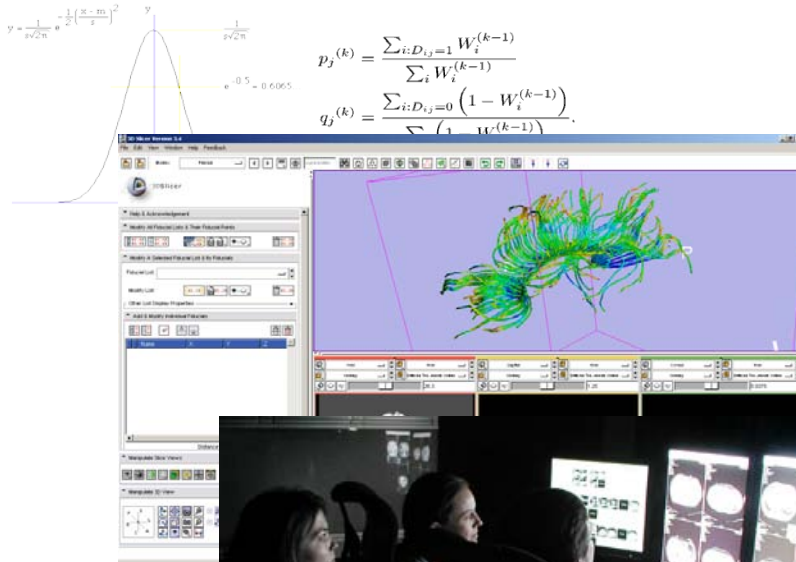Brigham and Women's Hospital

Data Explosion

75 slices, 37.5 MB

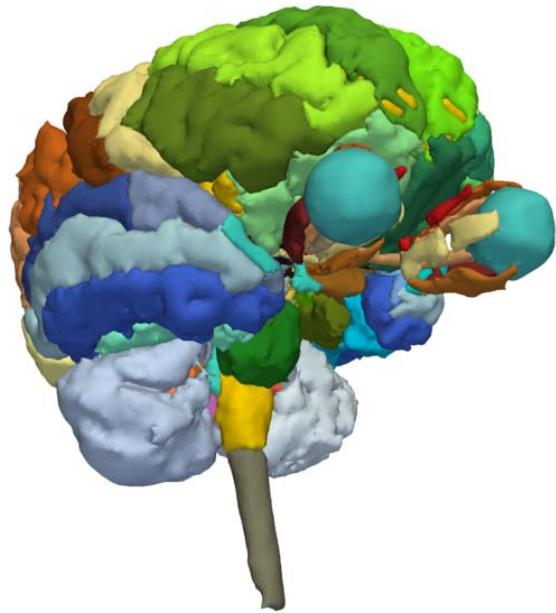1,000 slices, 0.5 GB

Challenge: how to visualize so many data ?

Computer-assisted brain mapping

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

$$p_j{}^{(k)} = \frac{\sum_{i:D_{ij}=1} W_i^{(k-1)}}{\sum_i W_i^{(k-1)}}$$

$$q_j{}^{(k)} = \frac{\sum_{i:D_{ij}=0}\left(1 - W_i^{(k-1)}\right)}{\sum_i \left(1 - W_i^{(k-1)}\right)}$$

- 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
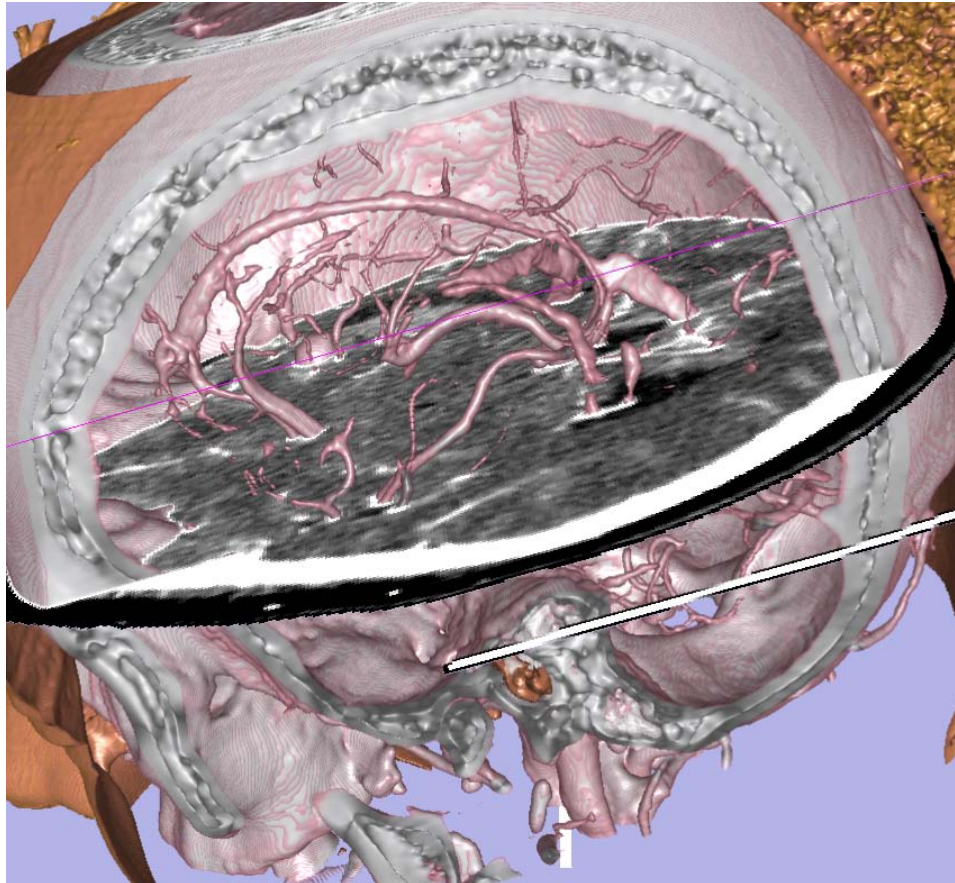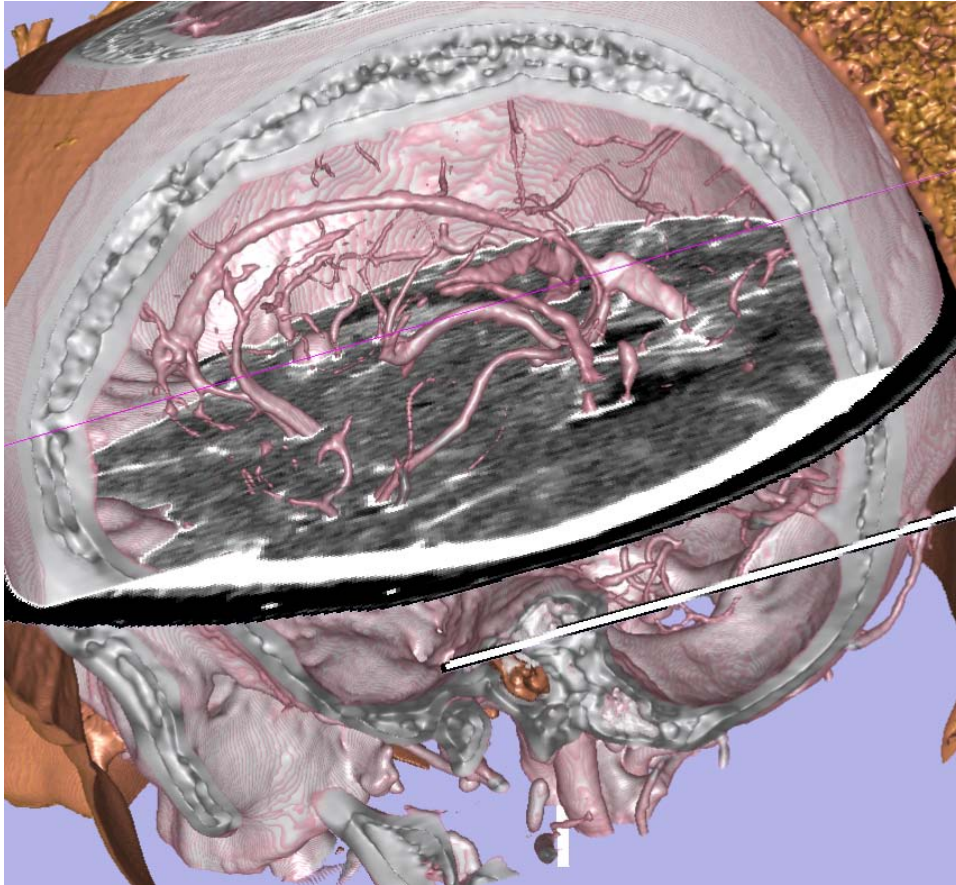Brigham and Women's Hospital, Boston

Volume Rendering

Image courtesy of Steve Pieper, Ph.D.

Volume Rendering

Image courtesy of Steve Pieper, Ph.D.
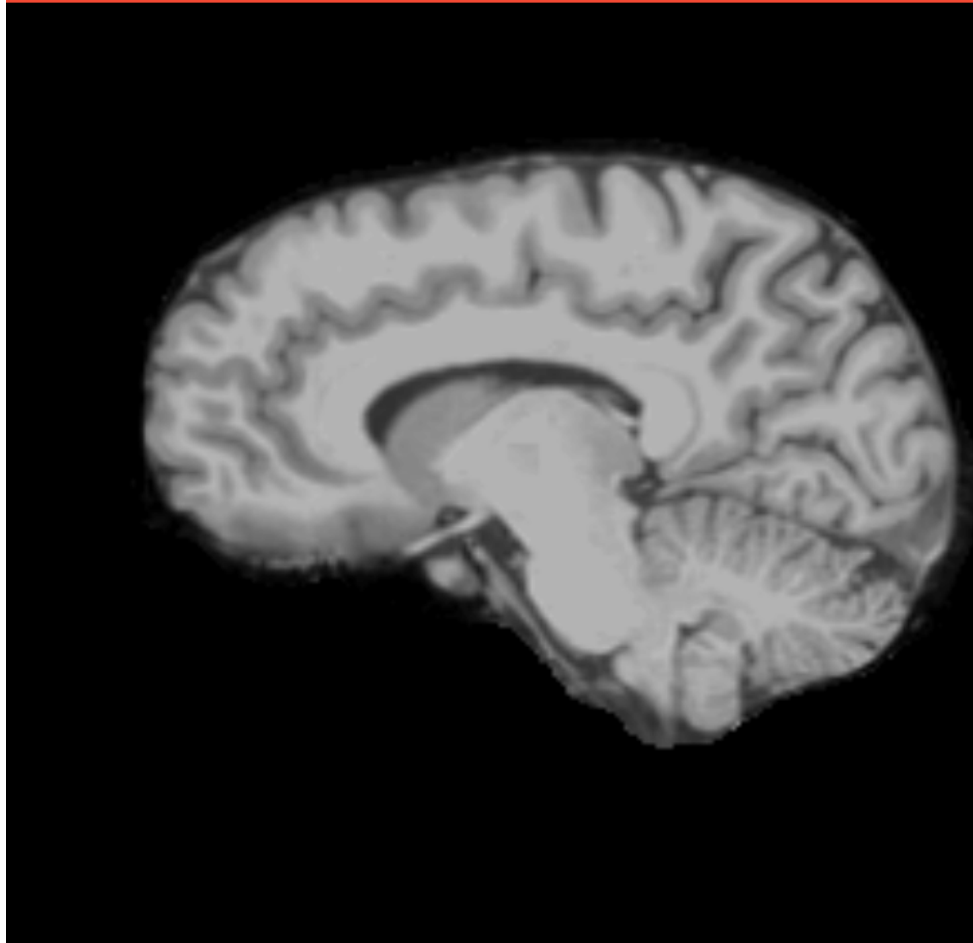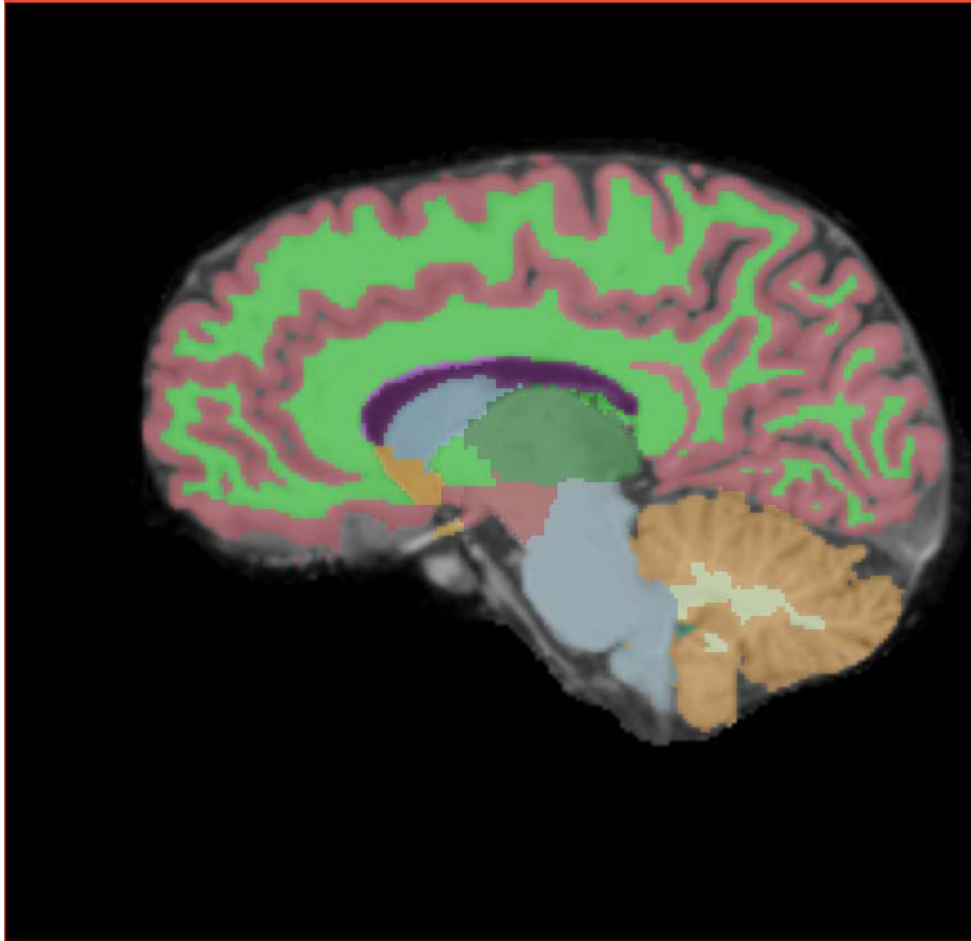
- Direct visualization
- Ray casting
- Hardware accelerated volume rendering

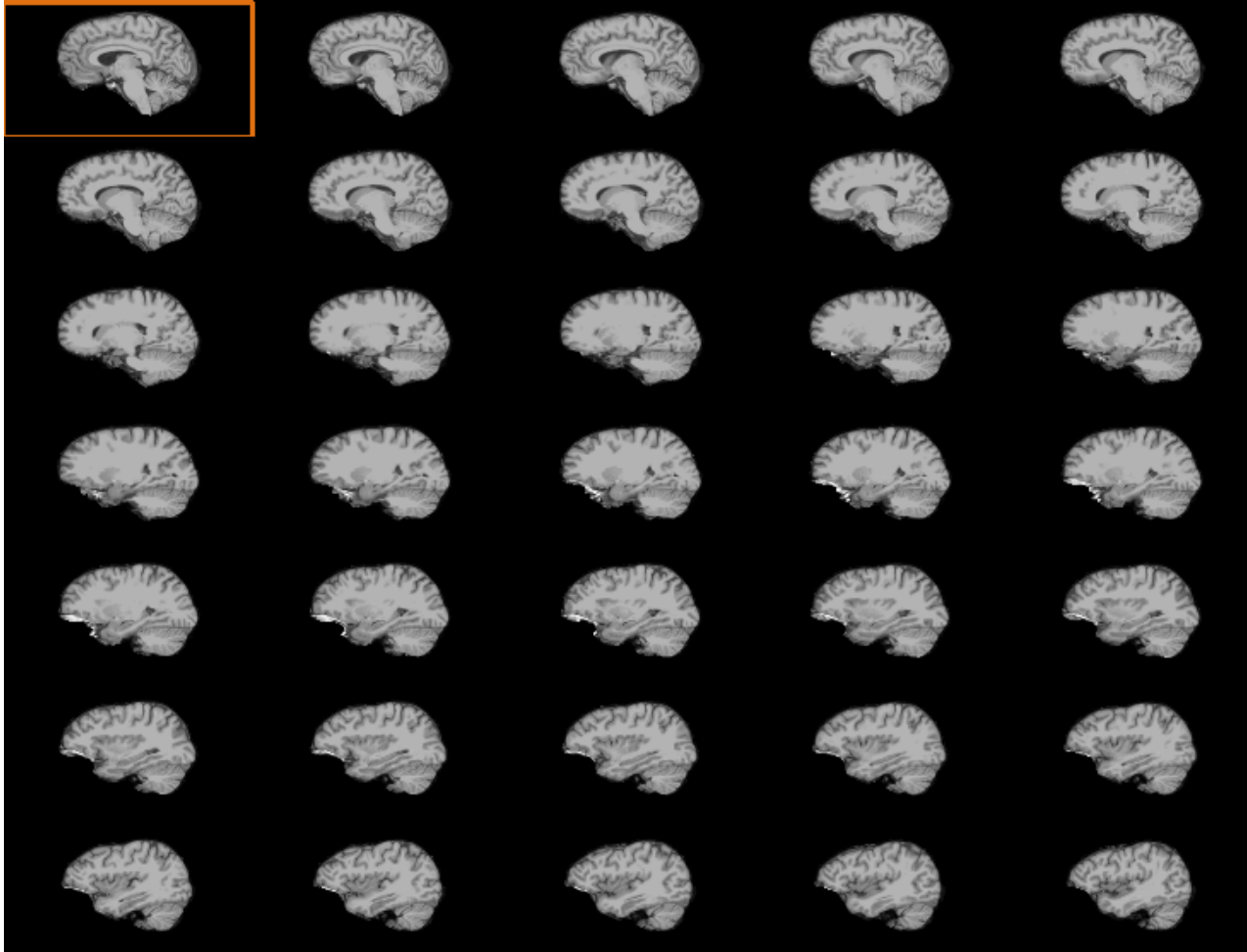# Image Segmentation

Image Segmentation

Image Segmentation
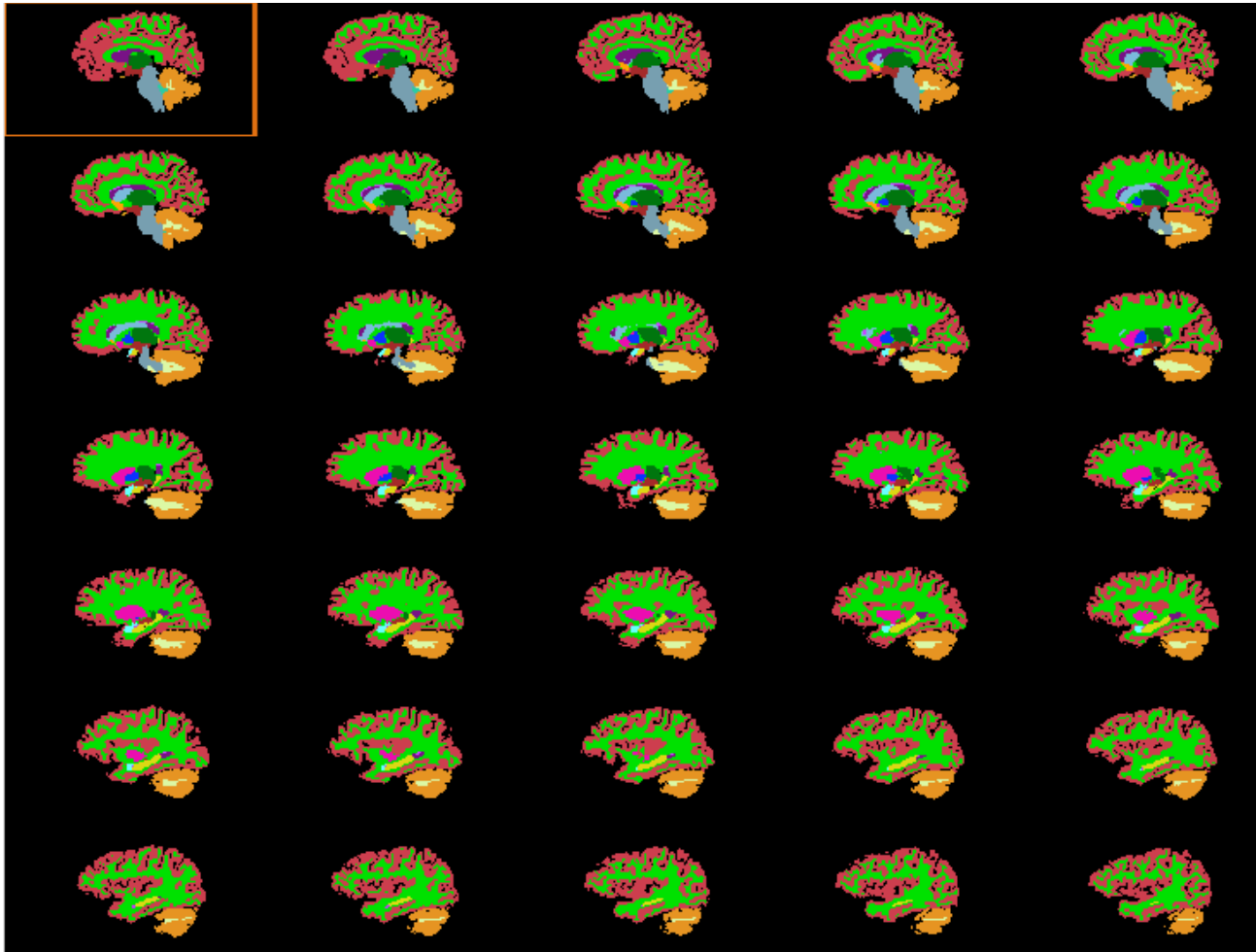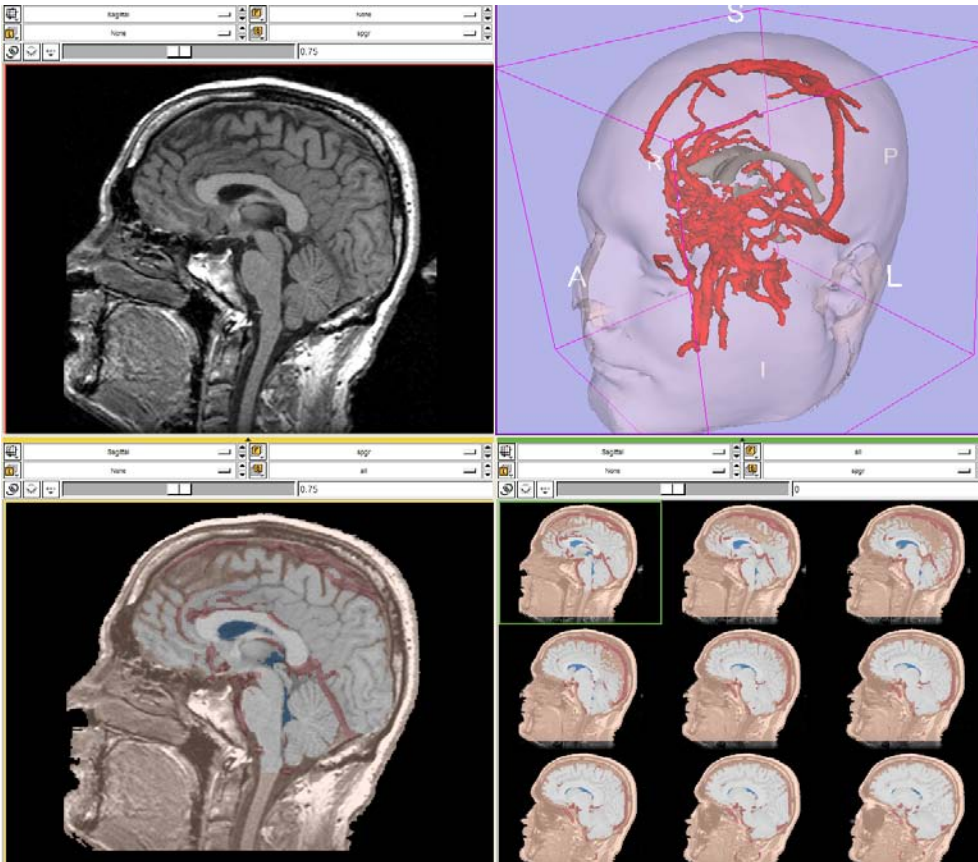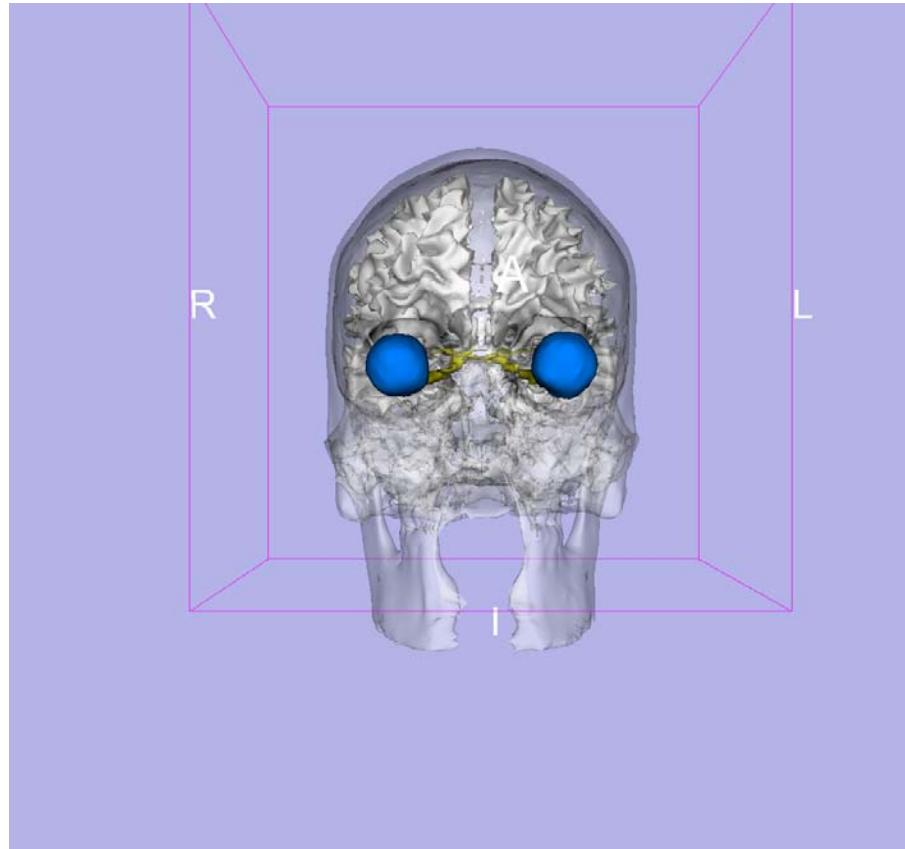
Image Segmentation

Image Segmentation

- Manual drawing & thresholding

- Semi-automated level tracing

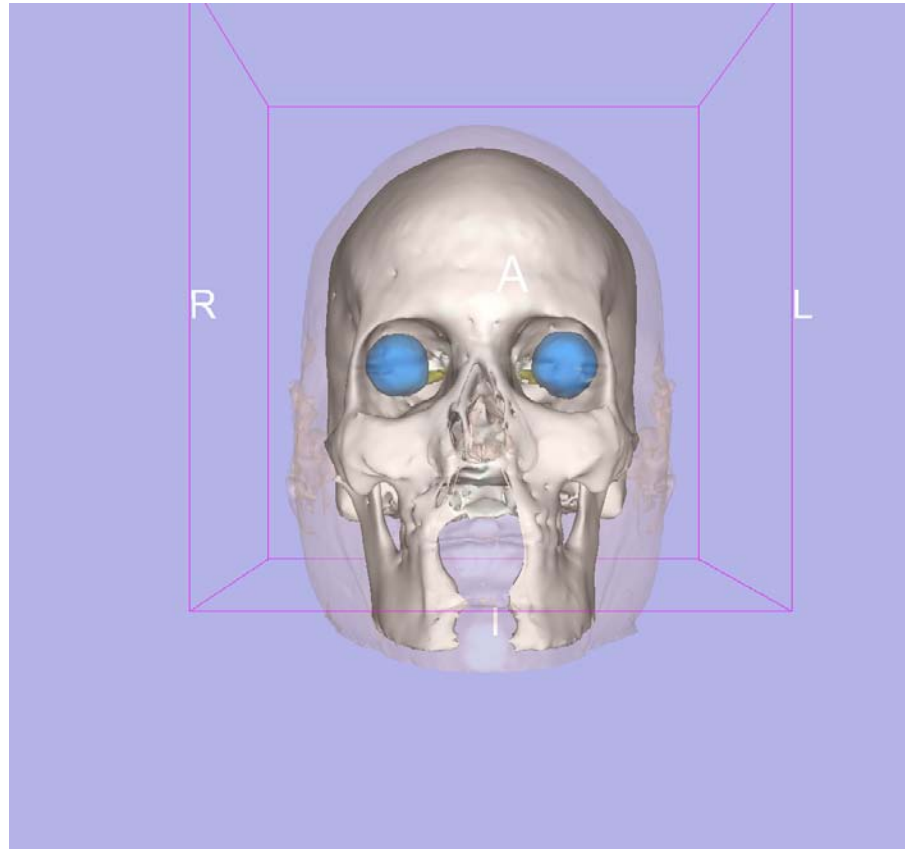- Automated segmentation algorithms
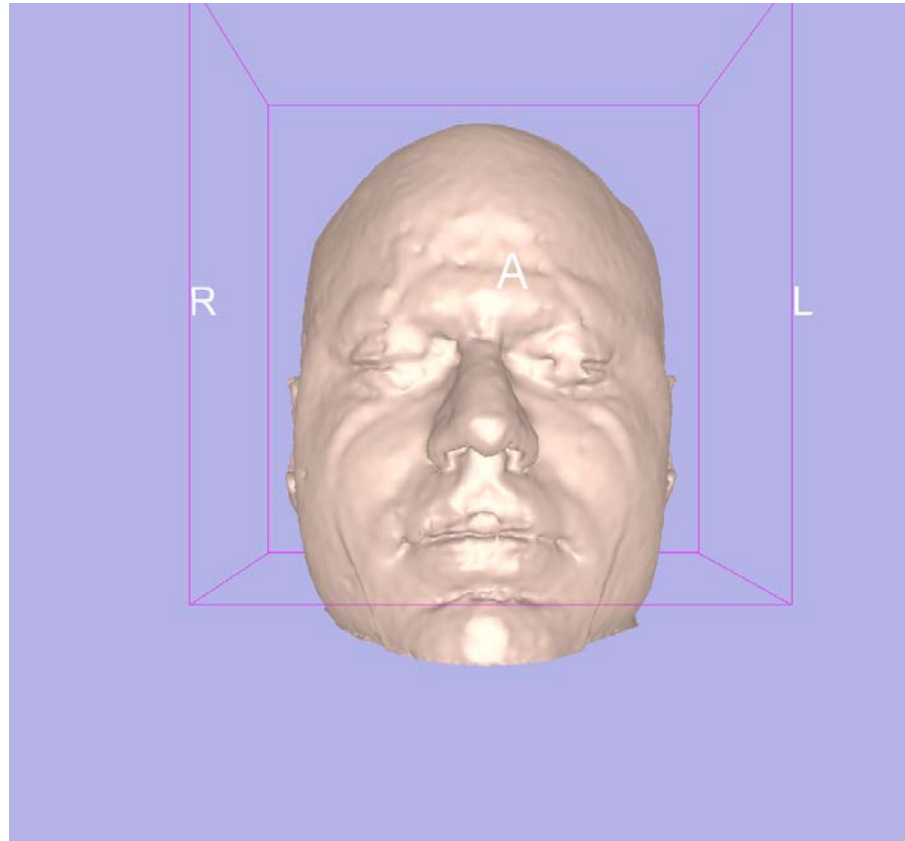
3D surface reconstruction

Marching Cube Algorithm (*)

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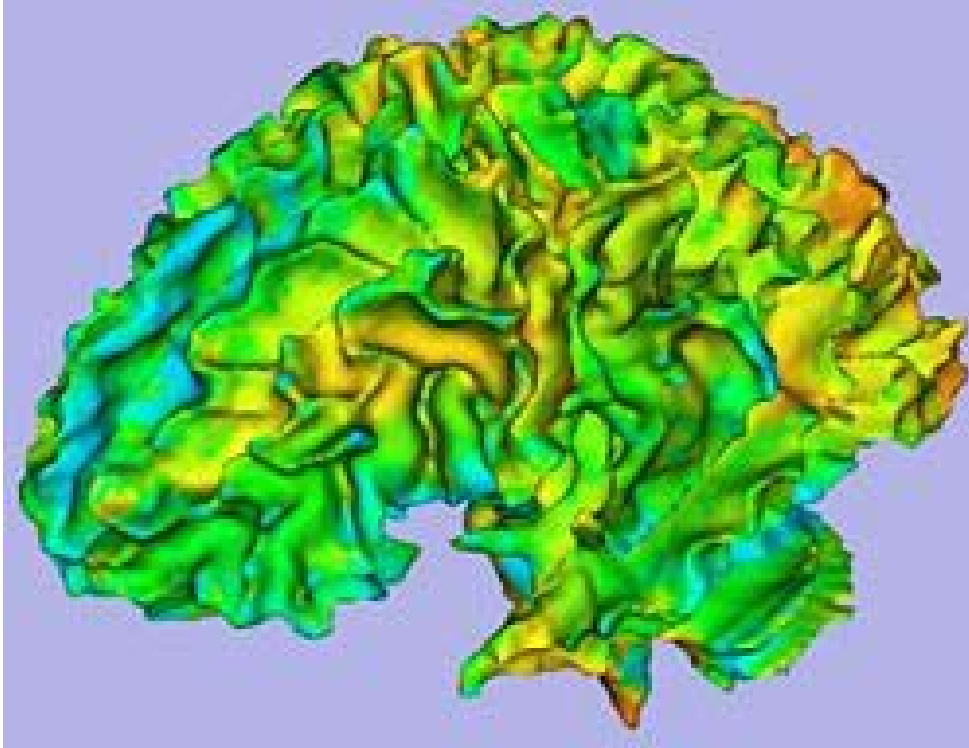
3D surface reconstruction

Marching Cube Algorithm (*)

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

3D surface reconstruction

Marching Cube Algorithm (*)

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

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
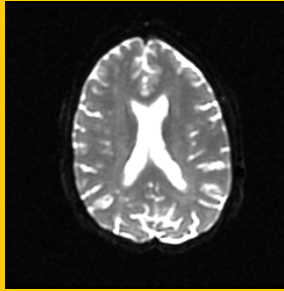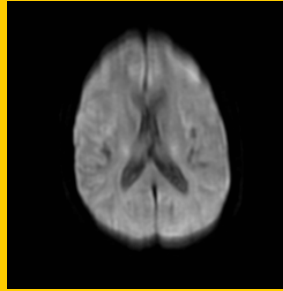
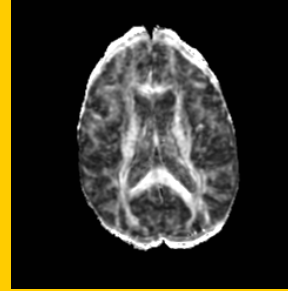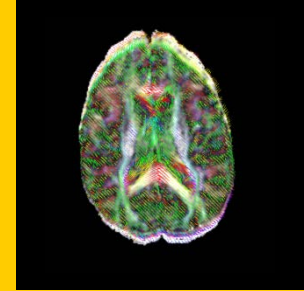# Mapping the brain with Diffusion Tensor Imaging
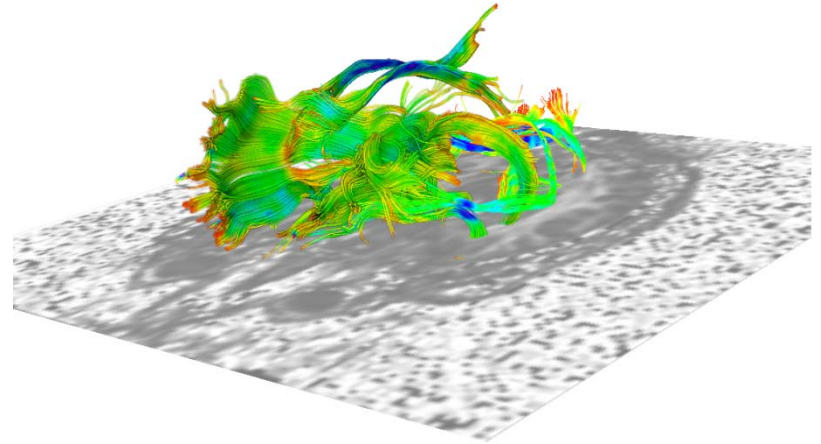
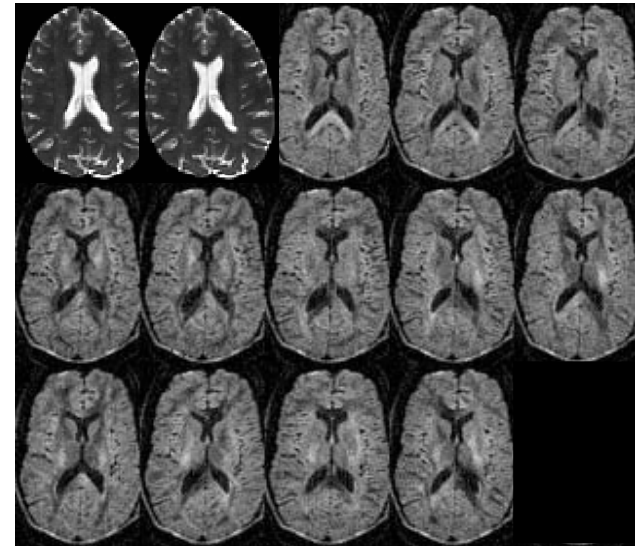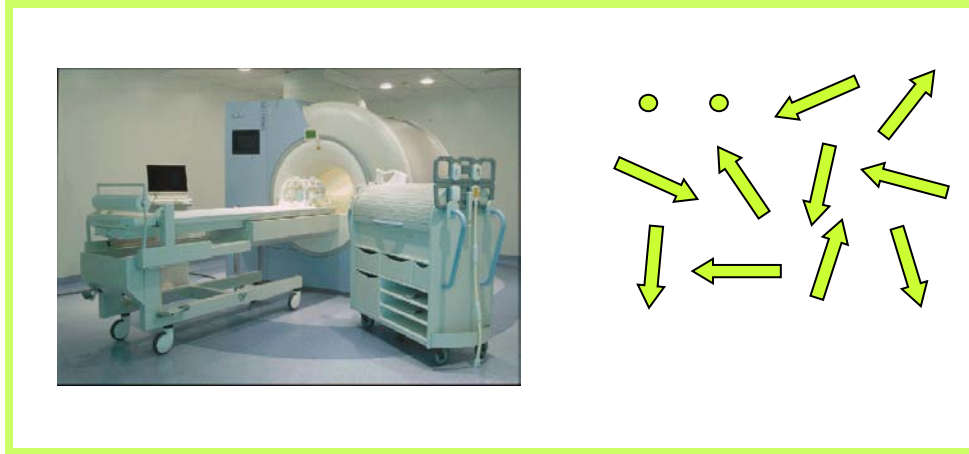# Diffusion Tensor Imaging Analysis

DWI
Acquisition

Tensor
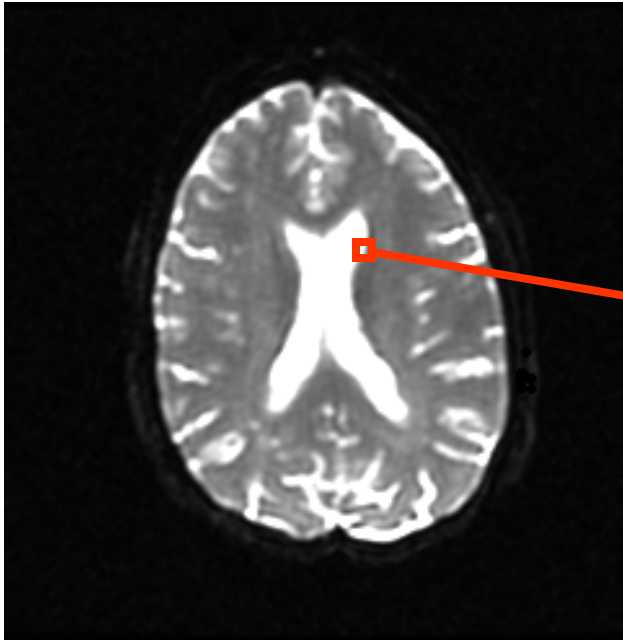Calculation

Scalar
Maps

3D
Visualization

Diffusion Weighted MR Imaging

Diffusion Tensor

Stejskal-Tanner $\quad S_i = S_0 e^{-b\hat{g}i^T \underline{D} \hat{g}_i}$
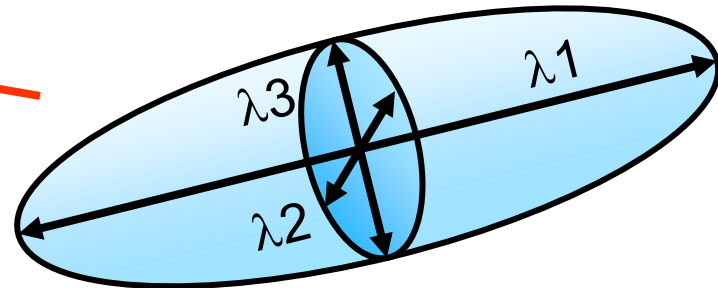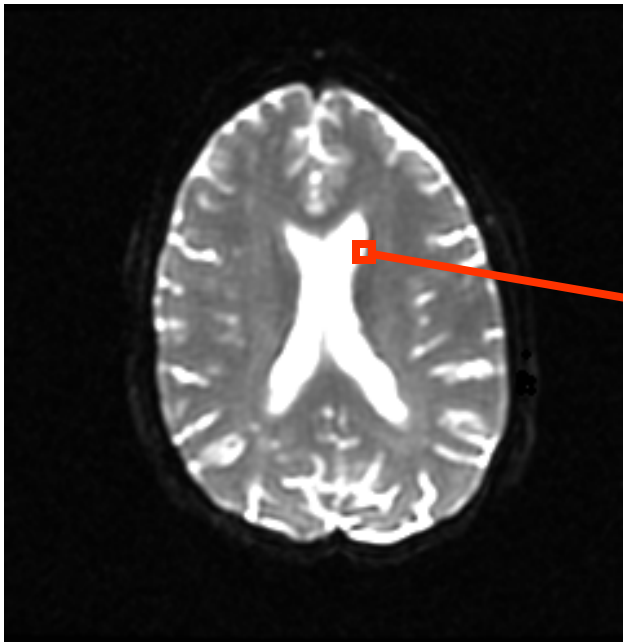

$$\underline{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$
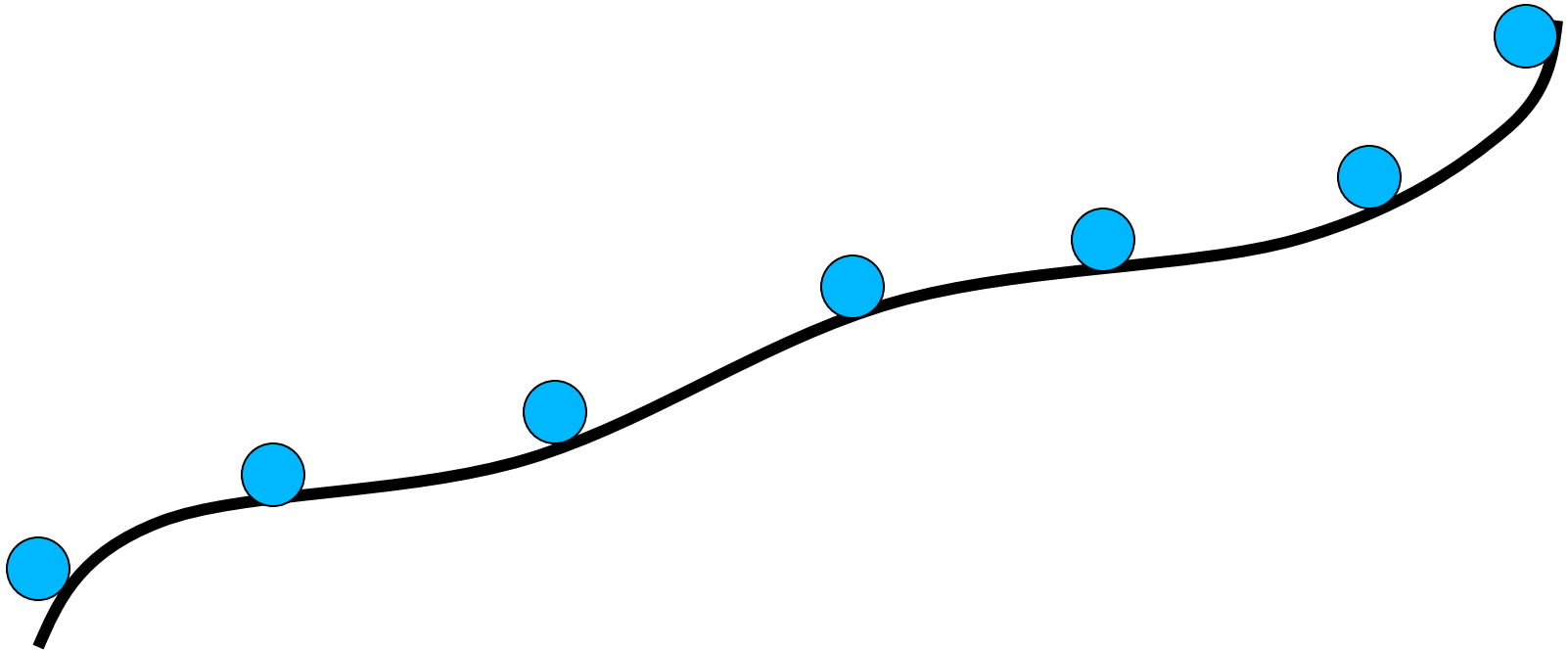
Diffusion Tensor

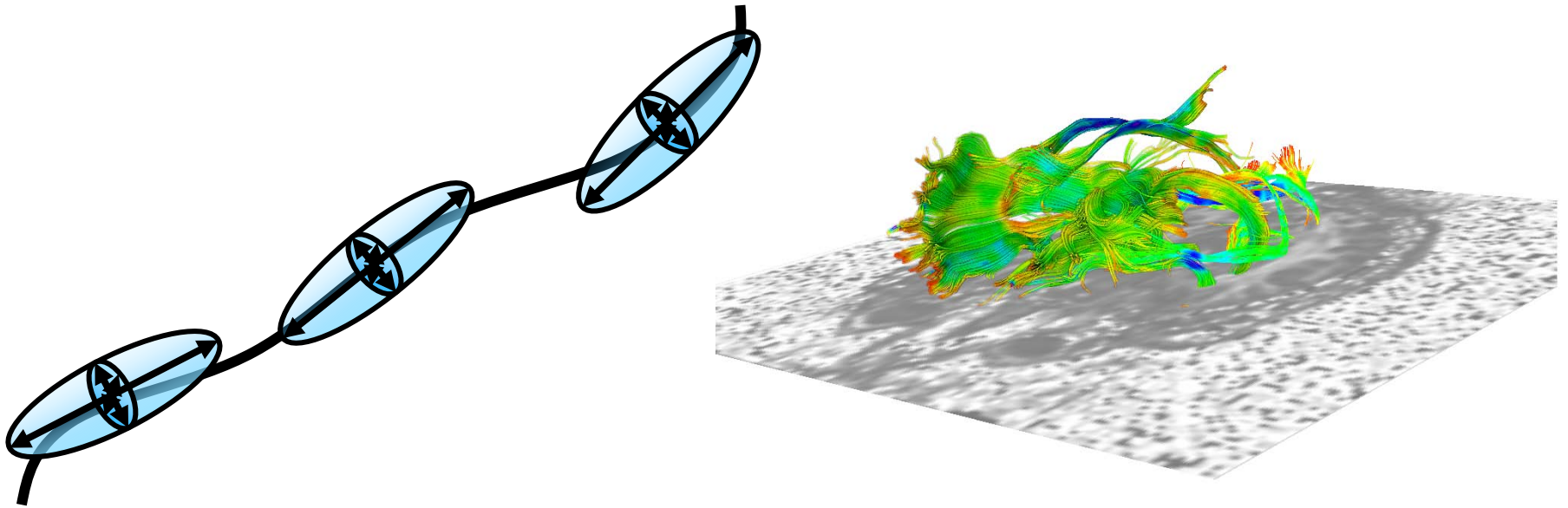Stejskal-Tanner $\qquad S_i = S_0 e^{-b\hat{g}i^T \underline{D}\hat{g}_i}$
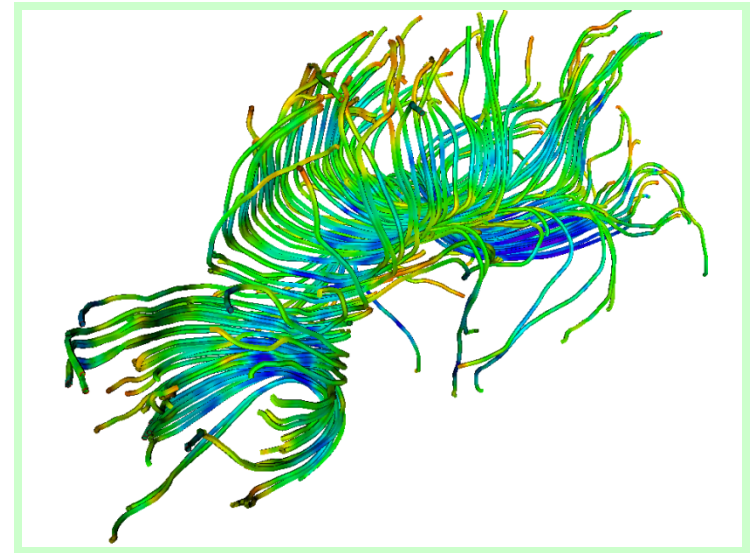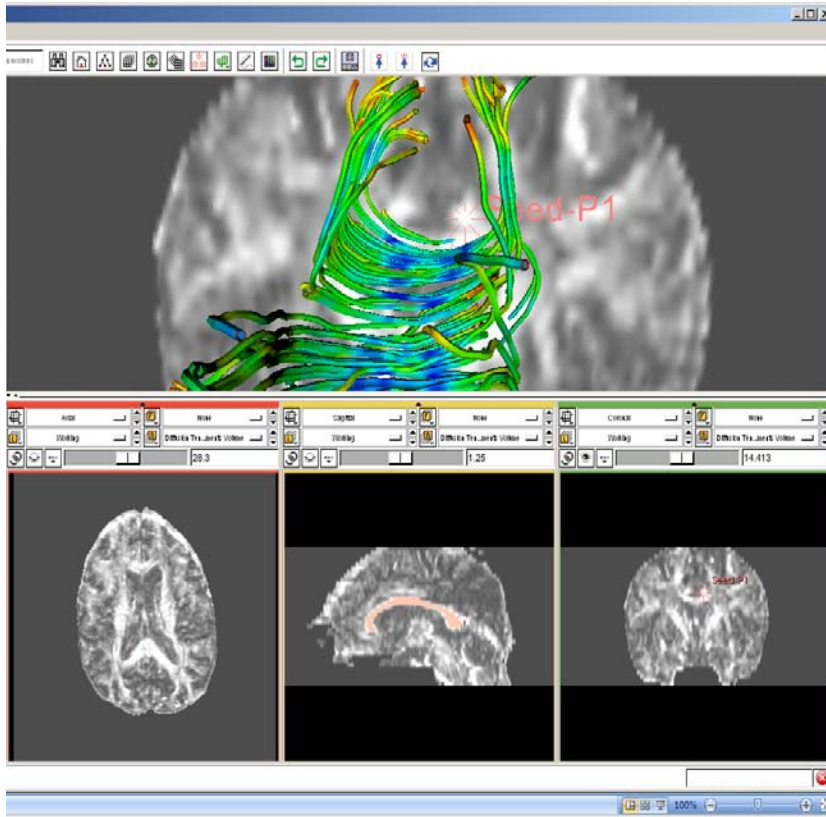
Tractography

Streamline Tractography

The goal of tractography is to determine white matter fibers' trajectory from a set of DTI voxels.

ROI Seeding
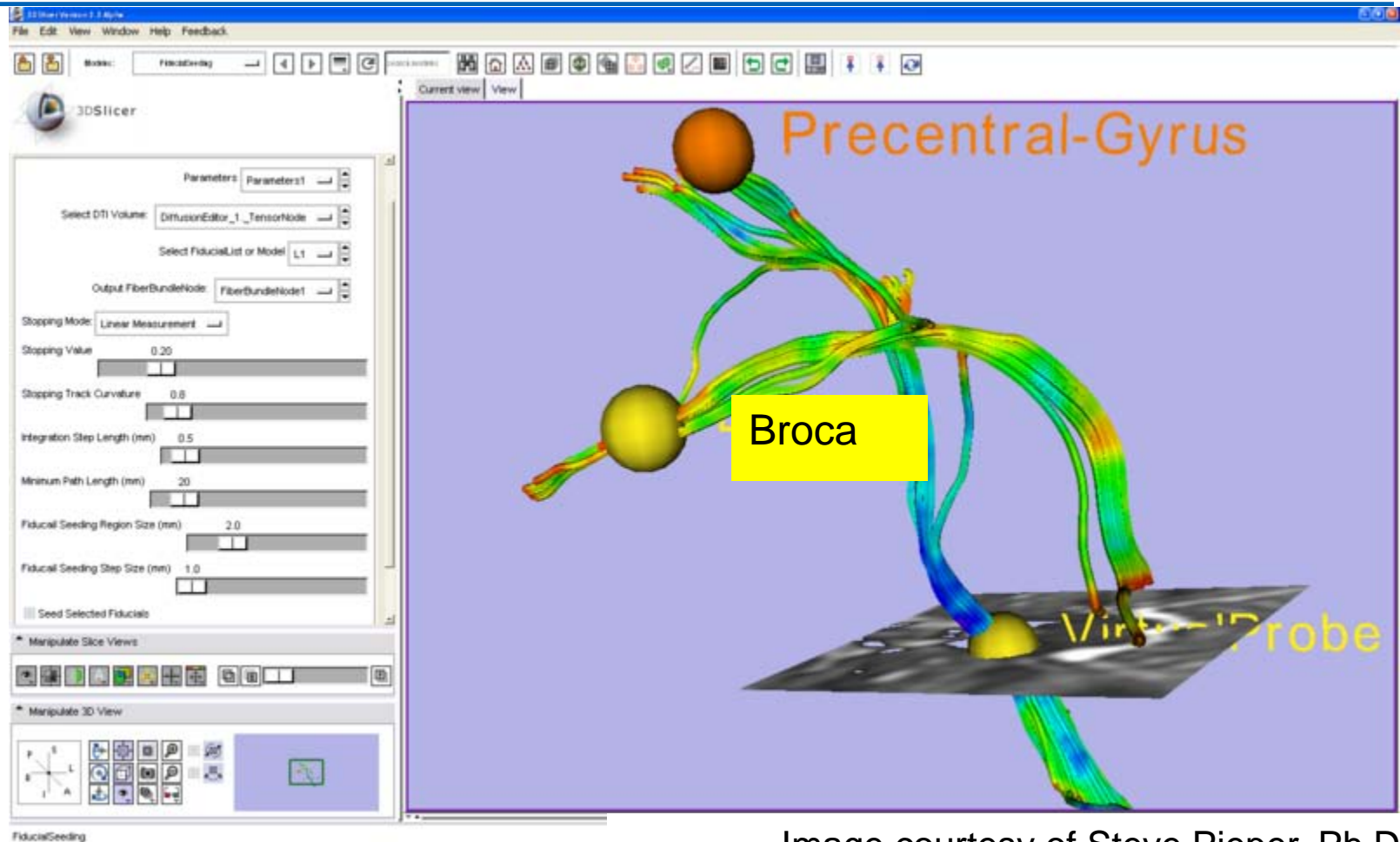
Fiducial Seeding

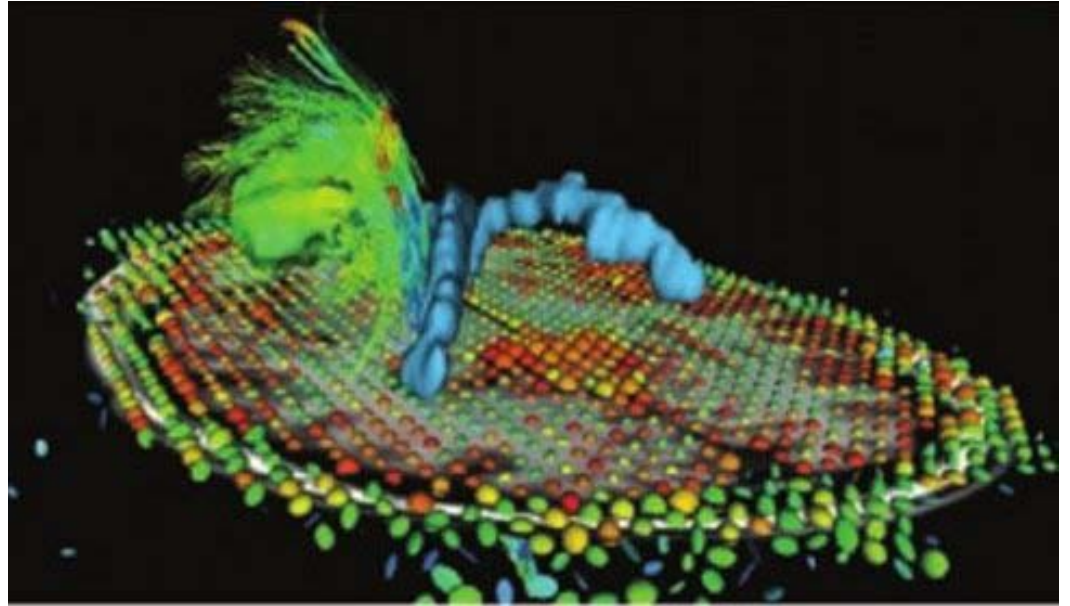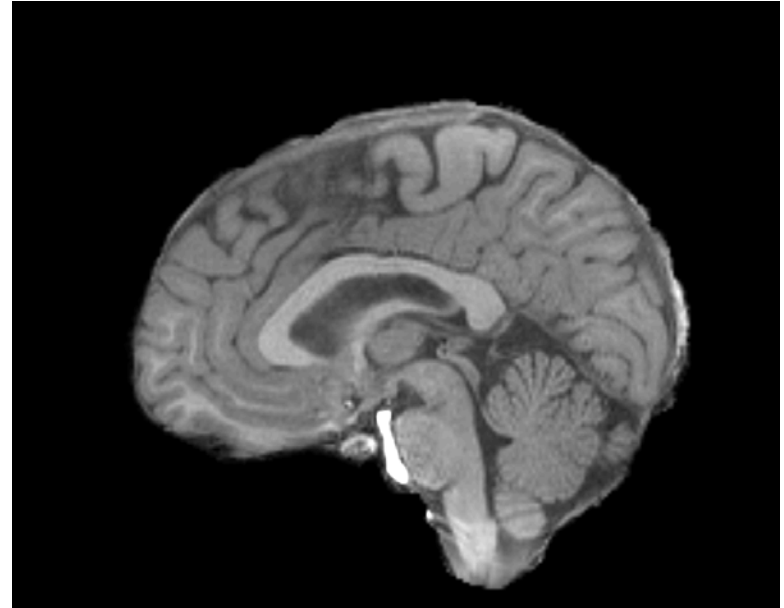Image courtesy of Steve Pieper, Ph.D.

Data Fusion

Image courtesy of Alexandra Golby, M.D., Jean-Jacques Lemaire, M.D., Ph.D., Steve Pieper, Ph.D.
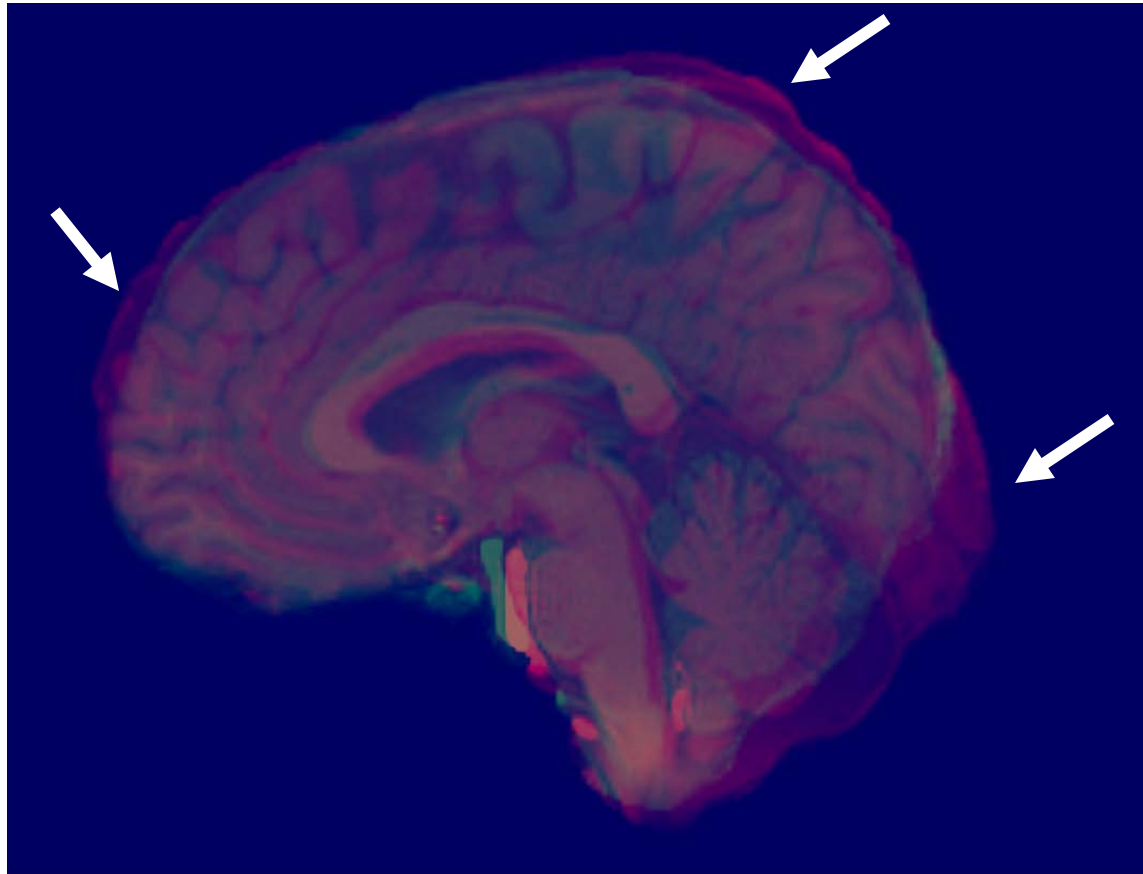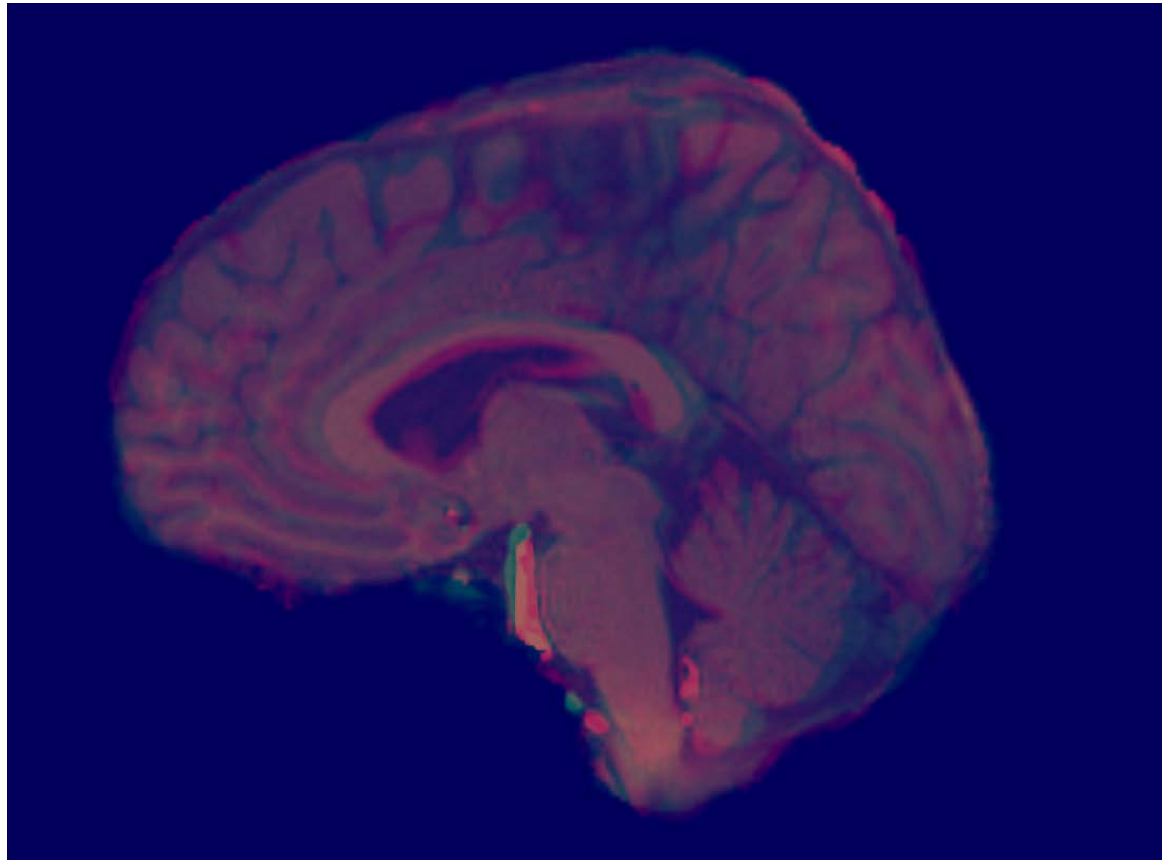
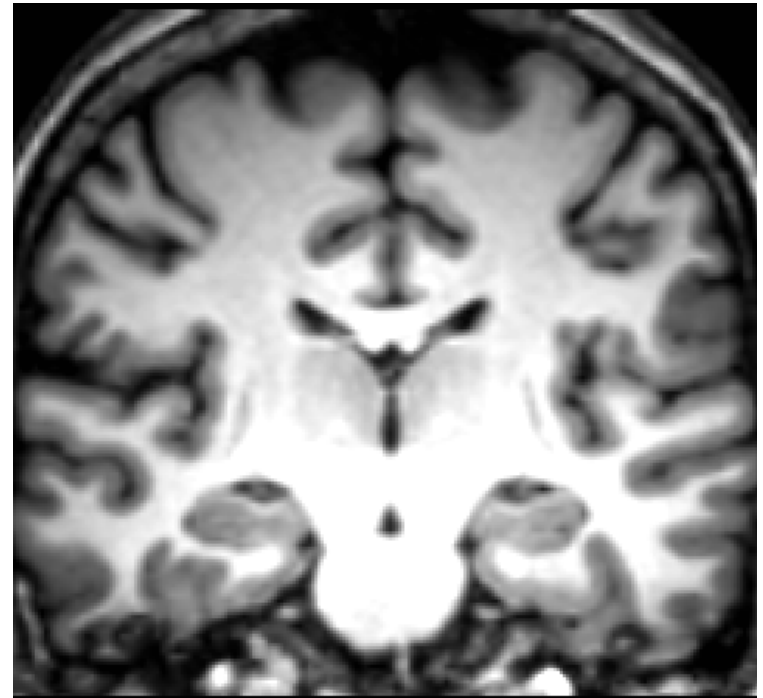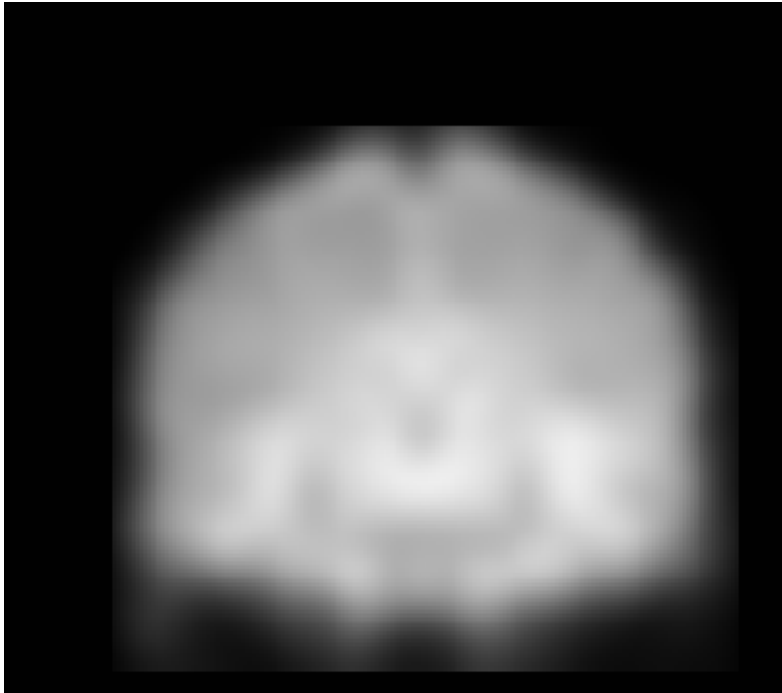# Data Fusion

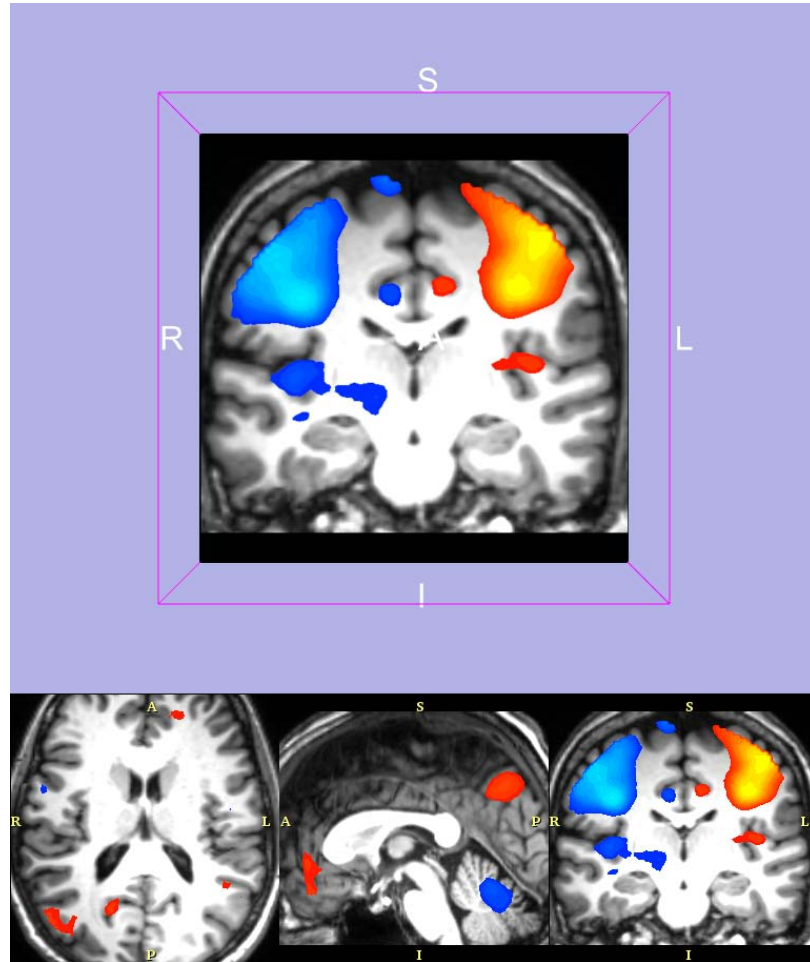# Initial mis-registration

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
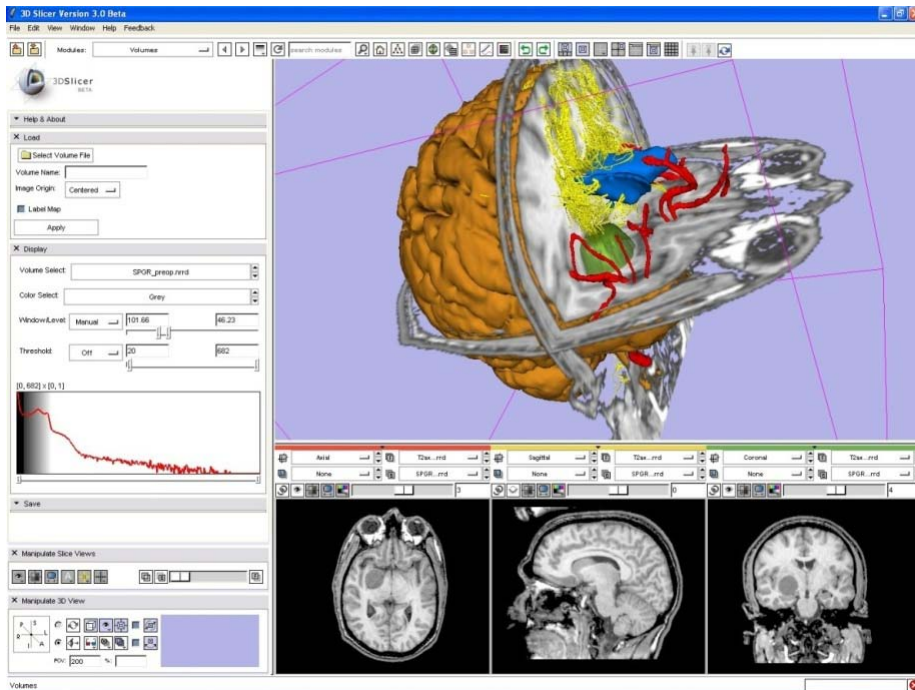
Multimodal MRI Data Fusion

Image courtesy of Steve Pieper, Ph.D.

Clinical perspectives

- Integrated visualization from various imaging modalities
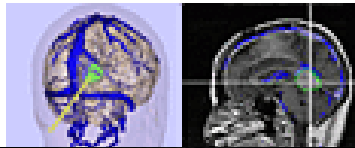
- Enhanced assessment of the clinical situation

- Better evaluation of treatment options
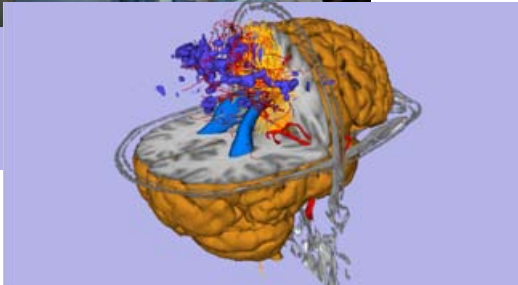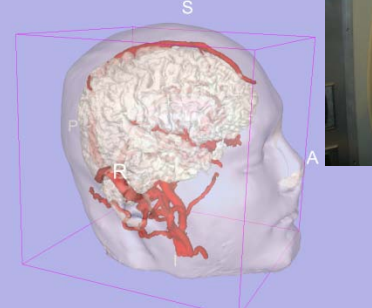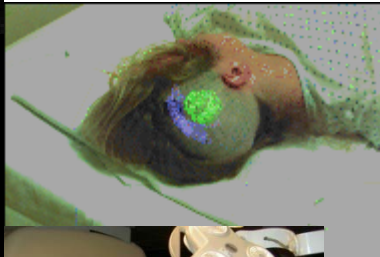
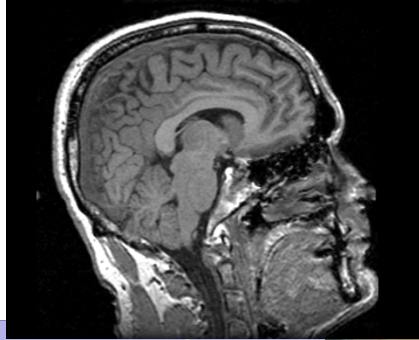# 3D Navigation in the brain

Courtesy of Ferenc Jolesz, MD, Brigham and Women's Hospital, Boston

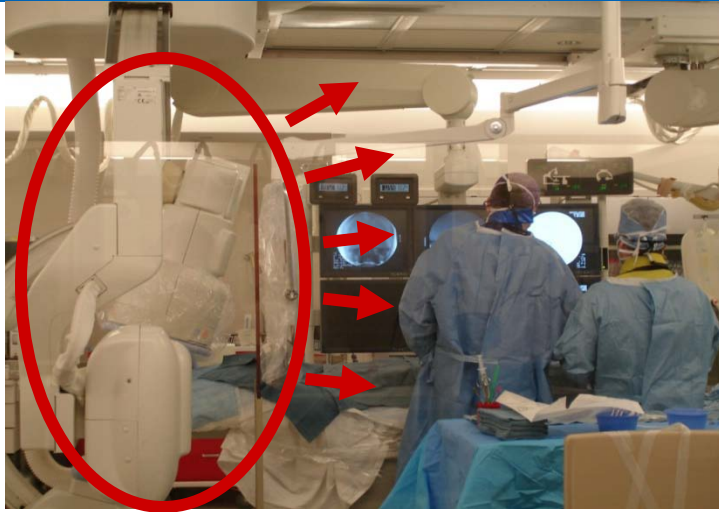# Computer-assisted navigation

Images Courtesy of CSAIL, MIT

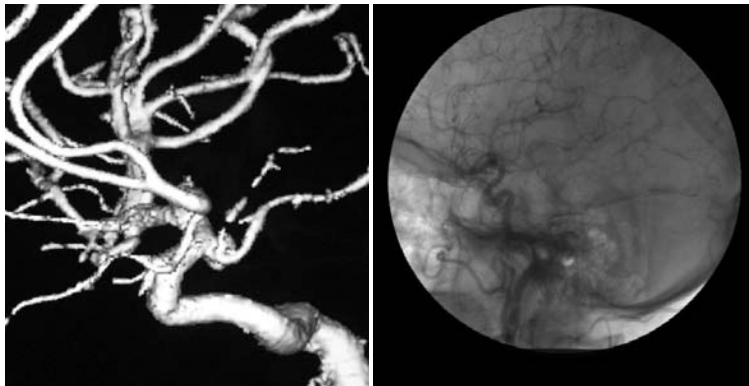Images courtesy of Ferenc Jolesz, MD, Steve Pieper, PhD, Brigham and Women's Hospital, Boston

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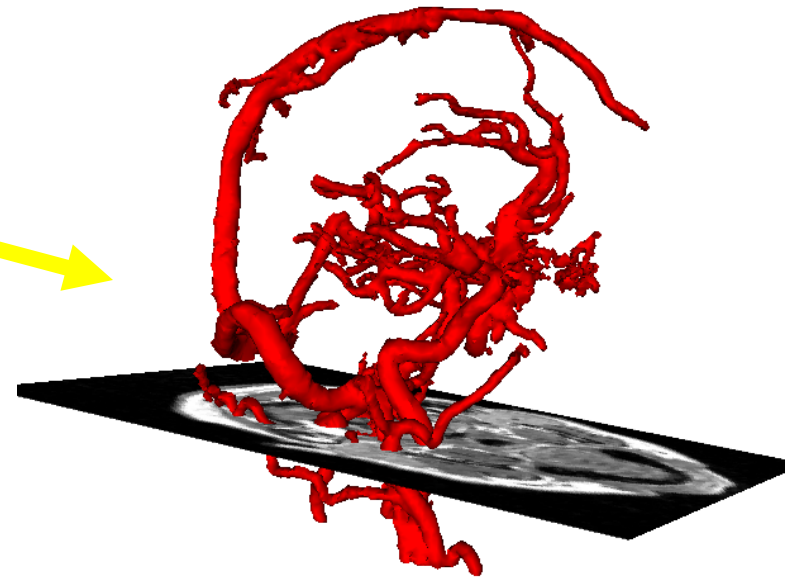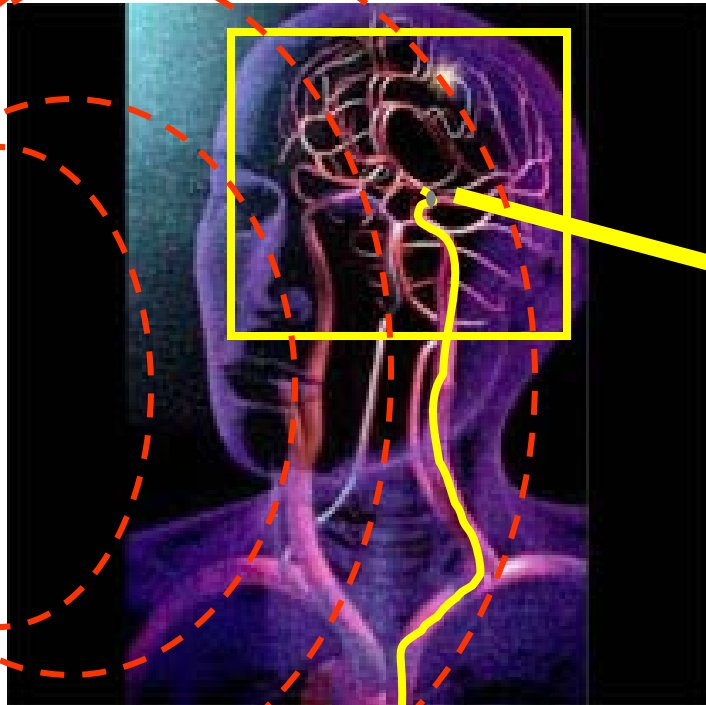
Neurointerventions

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

Kai Frerichs M.D., Sonia Pujol, Ph.D.
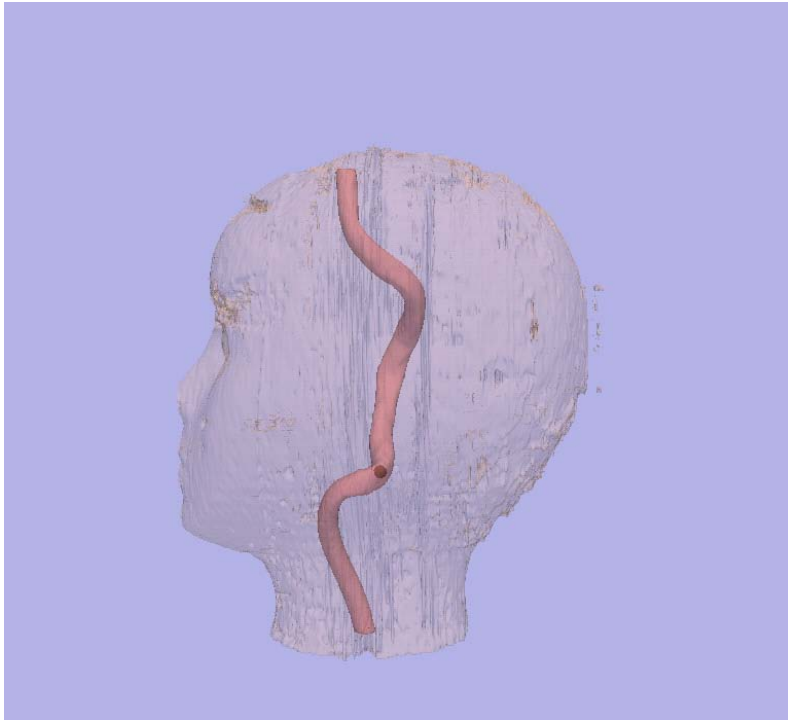Brigham and Women's Hospital

Neurovascular Navigation
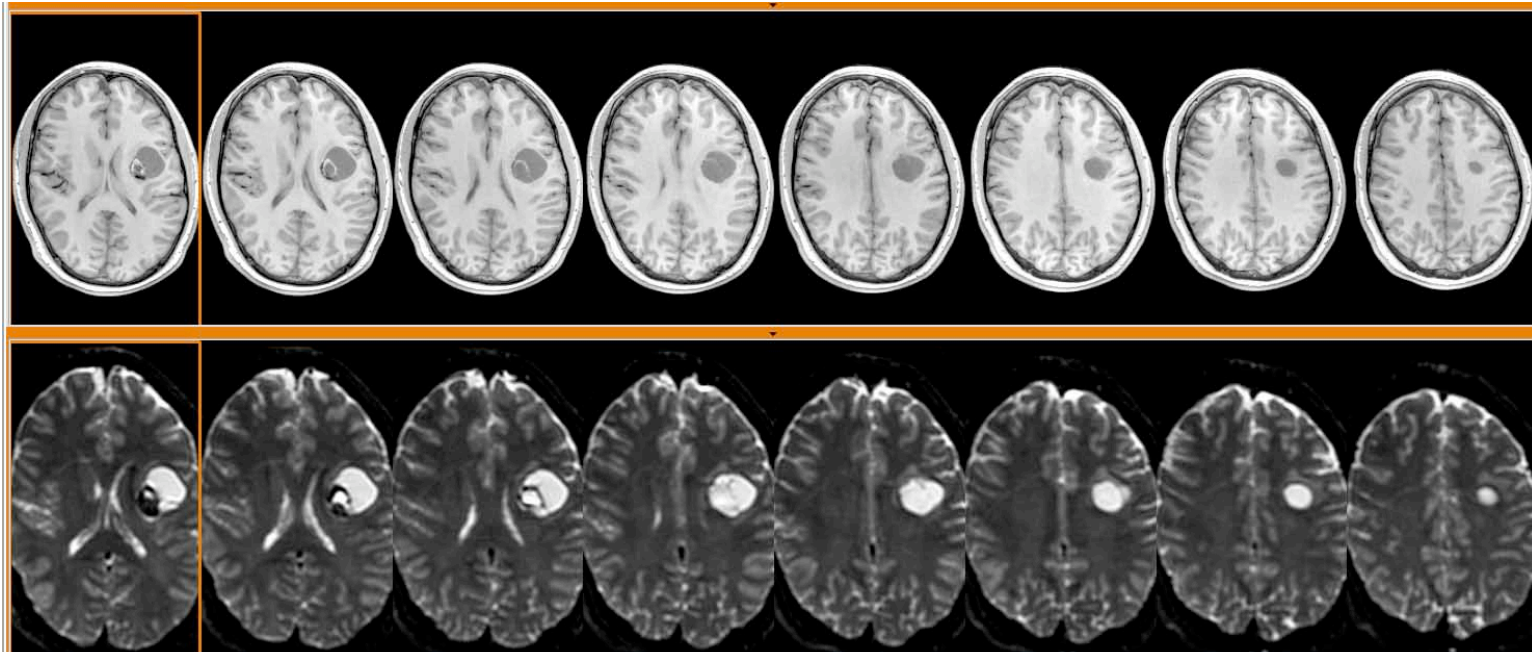
Neurovascular Navigation

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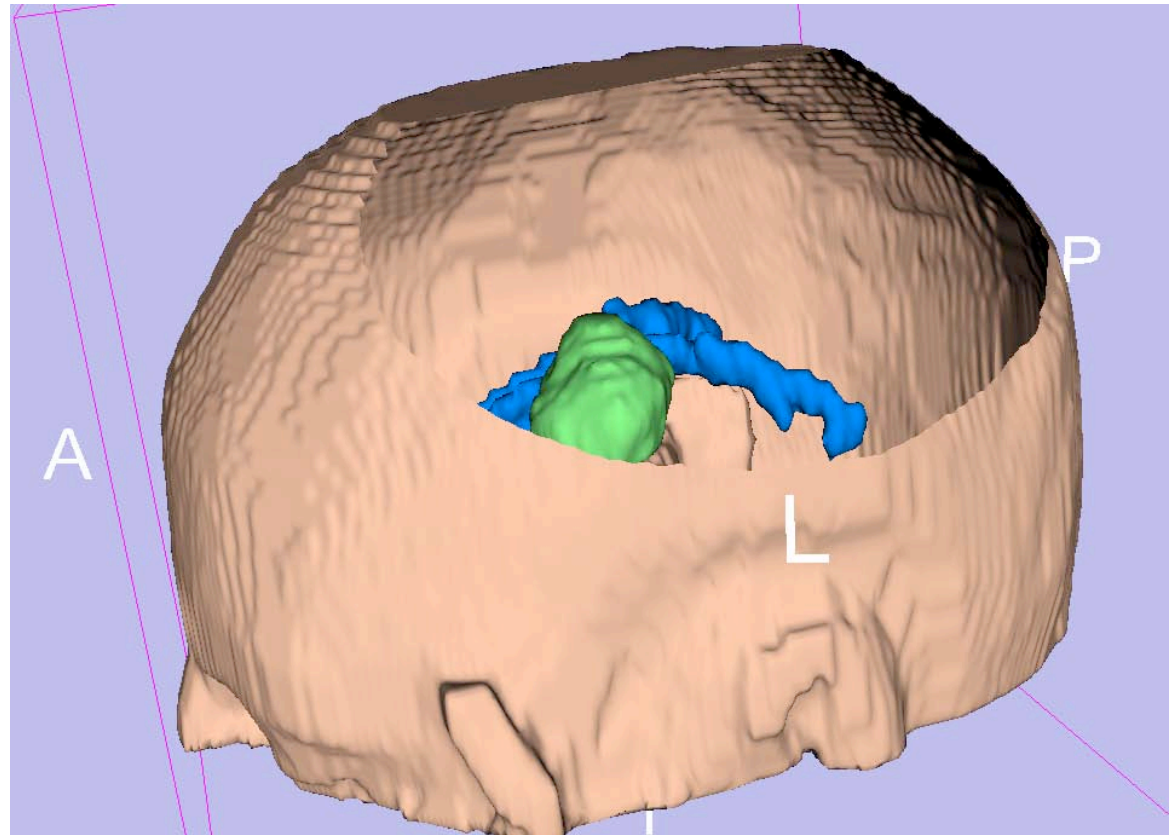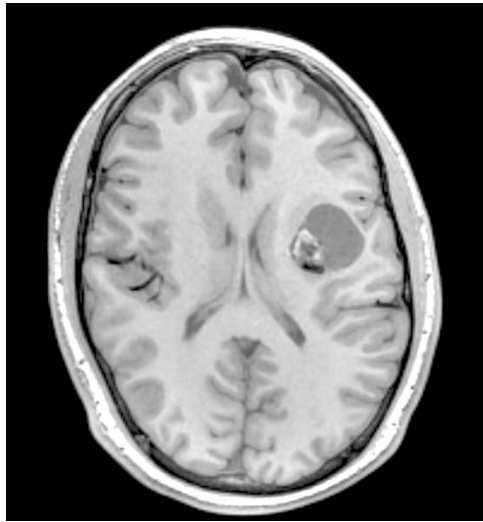
Example: A Clinical Case

- 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
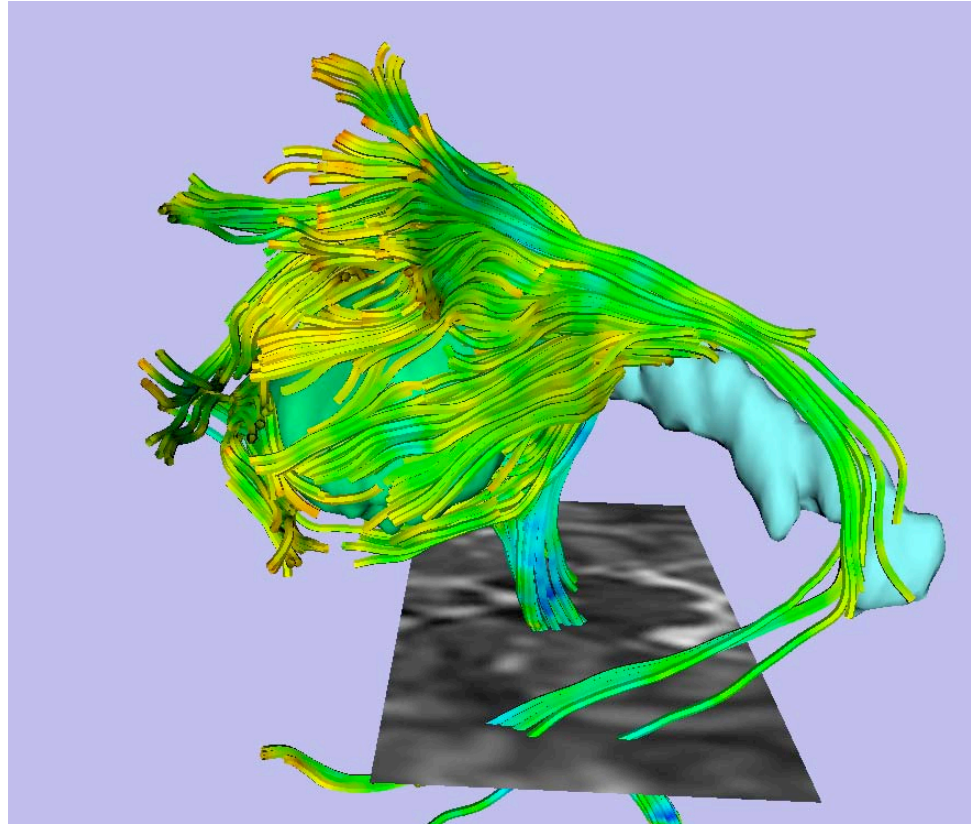Brigham and Women's Hospital, Boston, MA

A Clinical Case: Overview

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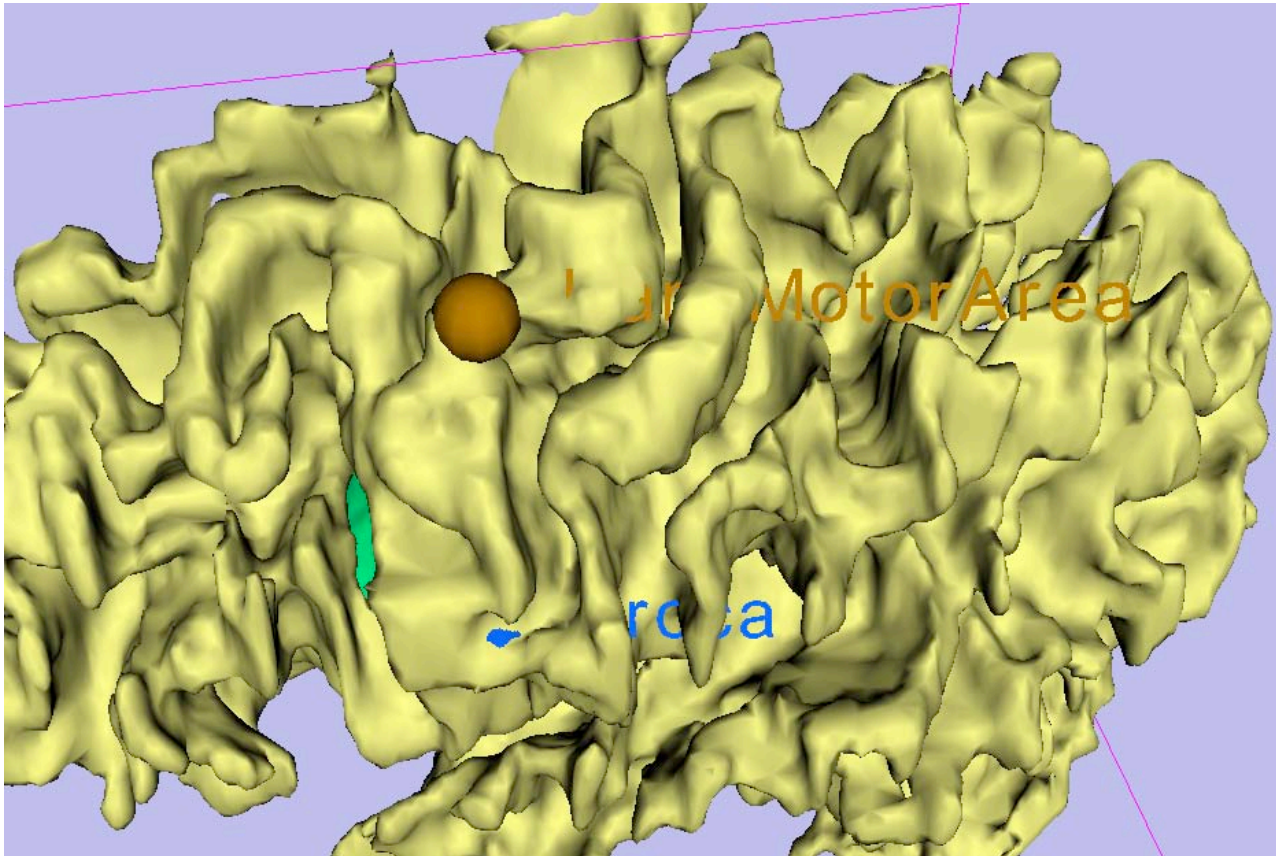Brigham and Women's Hospital, Boston, MA

Peritumoral Tracts

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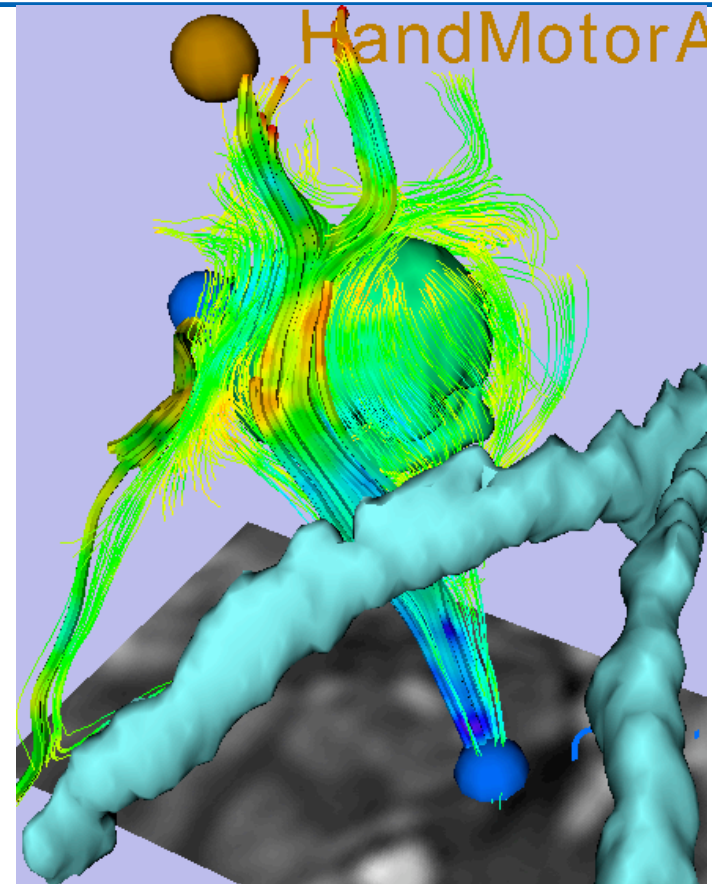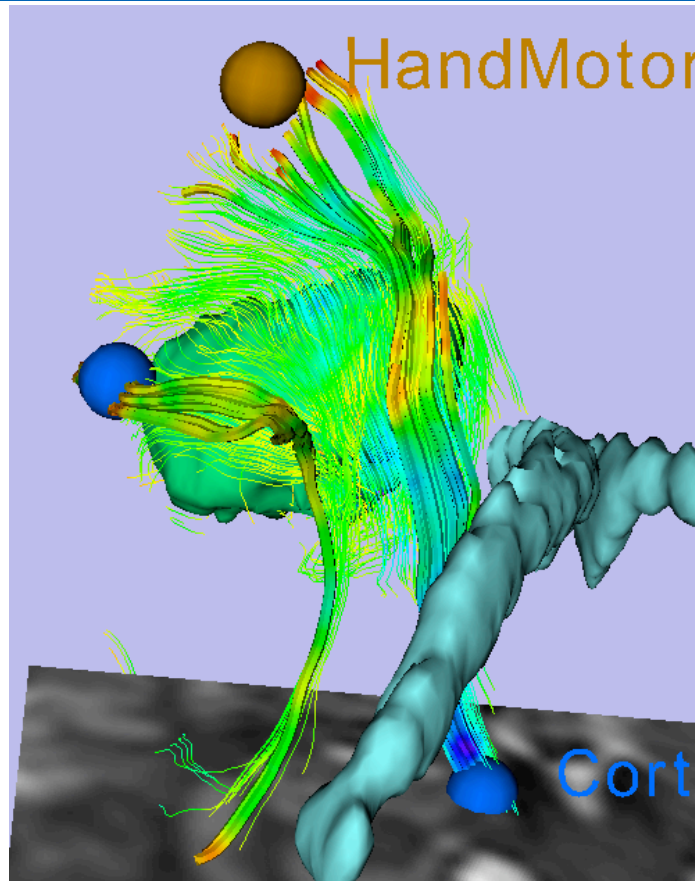
White Matter Surface

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
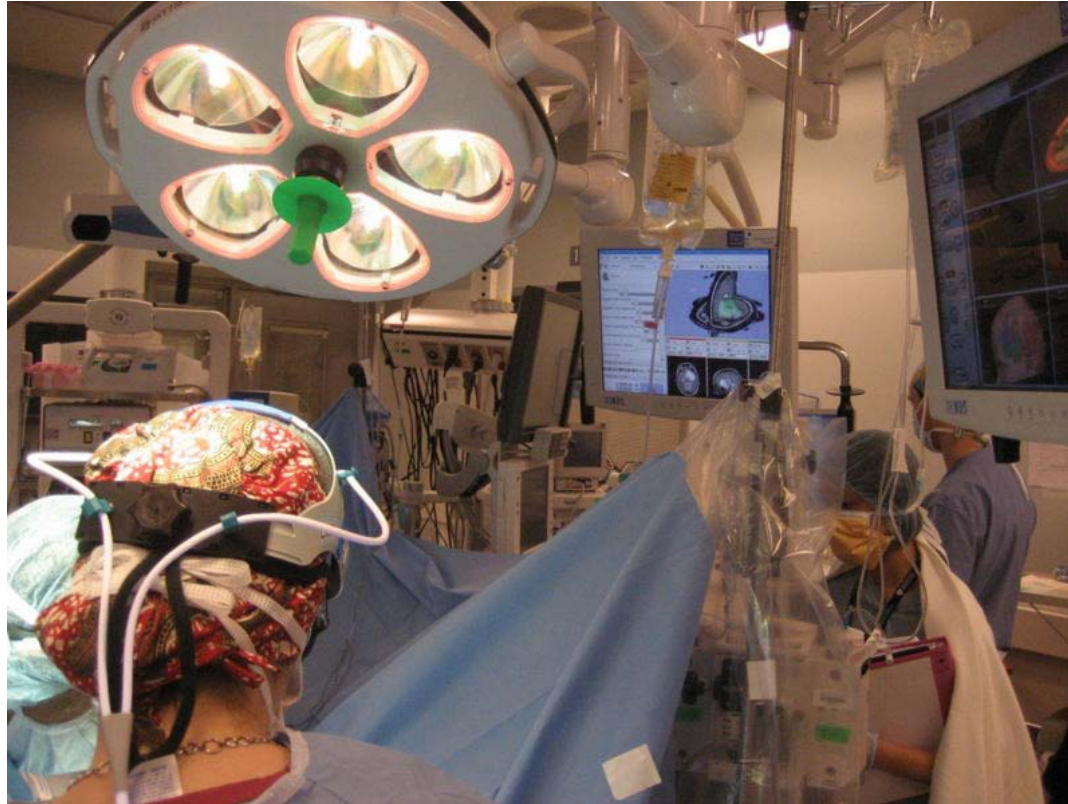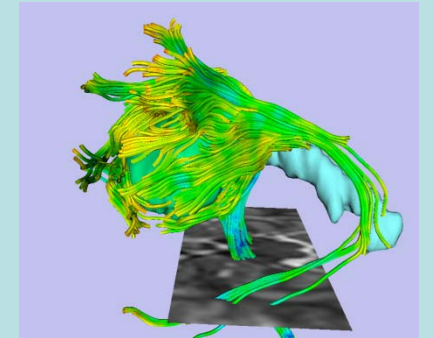
Neurosurgical Navigation

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

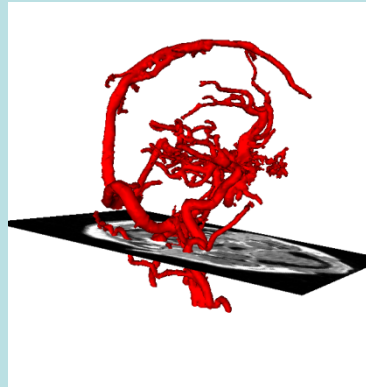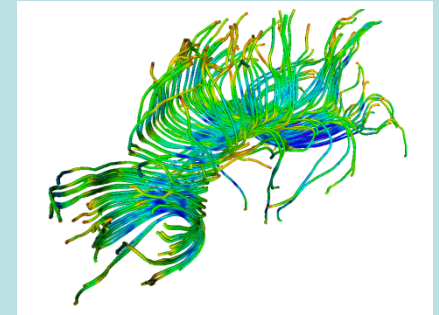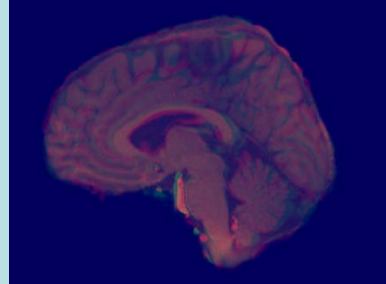Anatomic and functional brain mapping in areas surrounding brain tumors

Neurosurgical Navigation

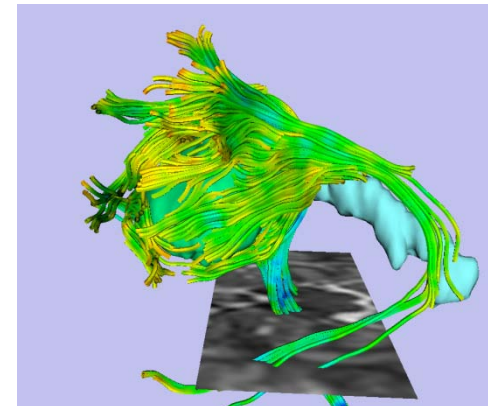Courtesy of Alexandra Golby, MD, Noby Hata, PhD, Haying Lui, MSE. Brigham and Women's Hospital, Boston, MA

Validation
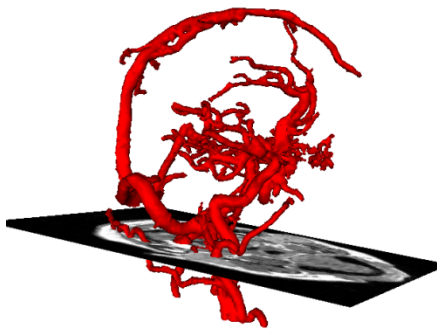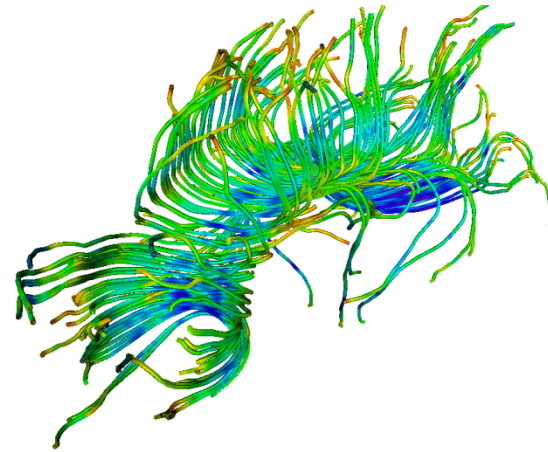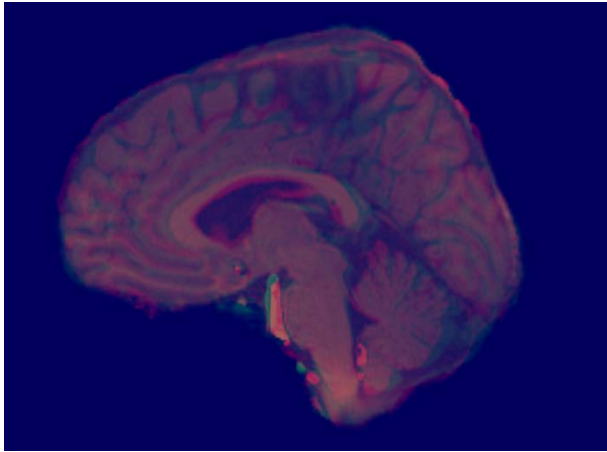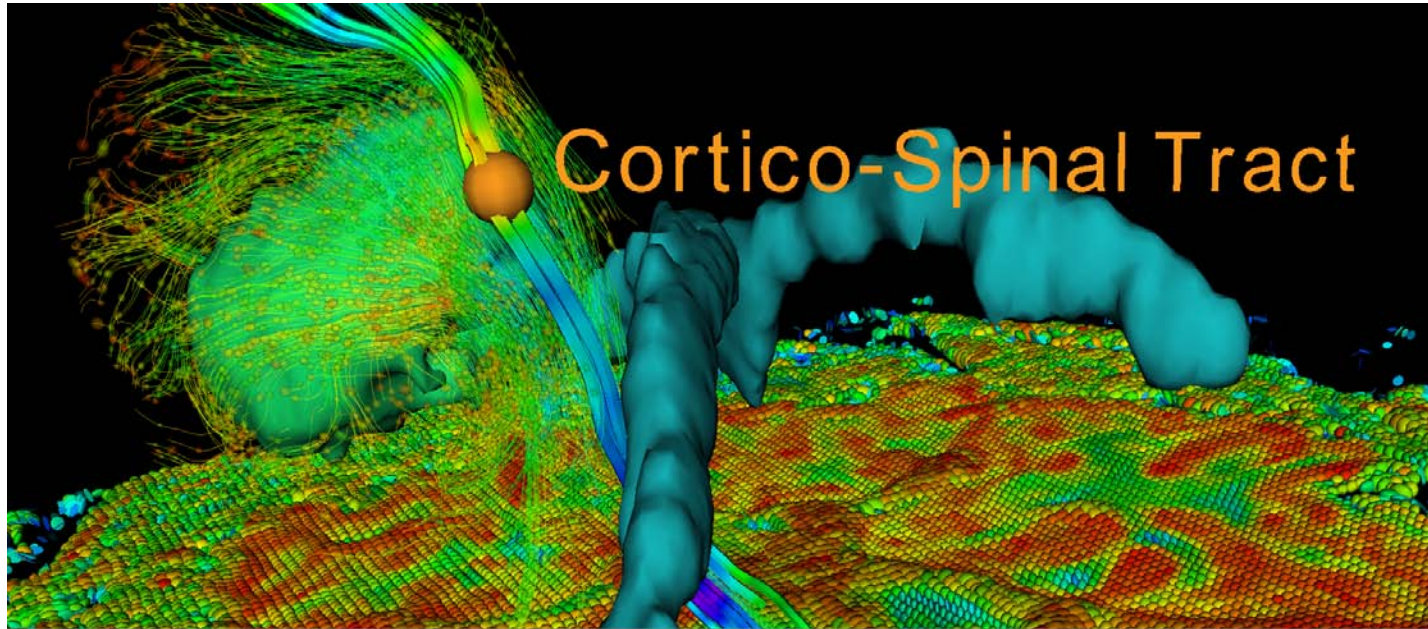
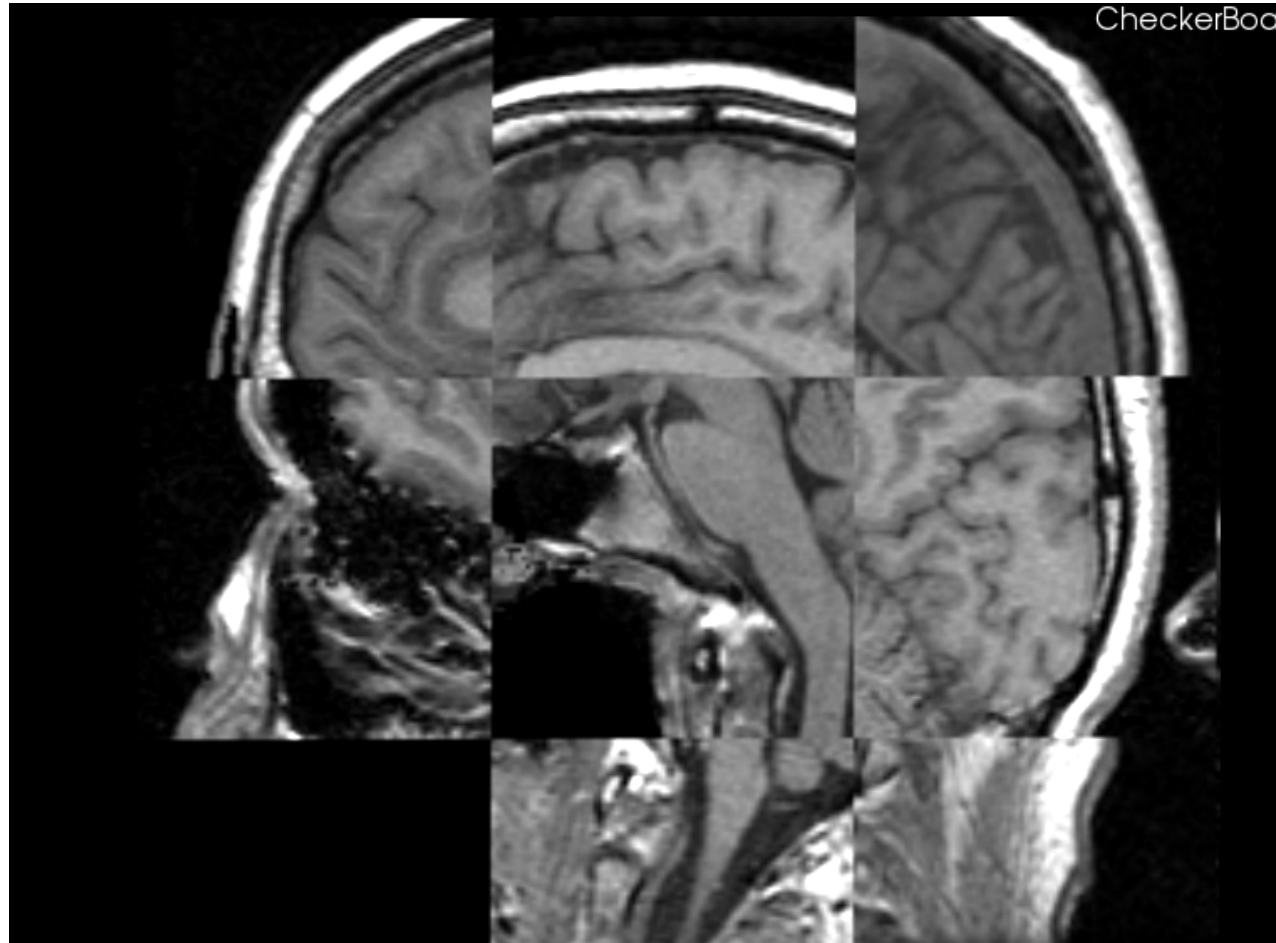# **Validation**

Golby, Black, Kikinis

Validation

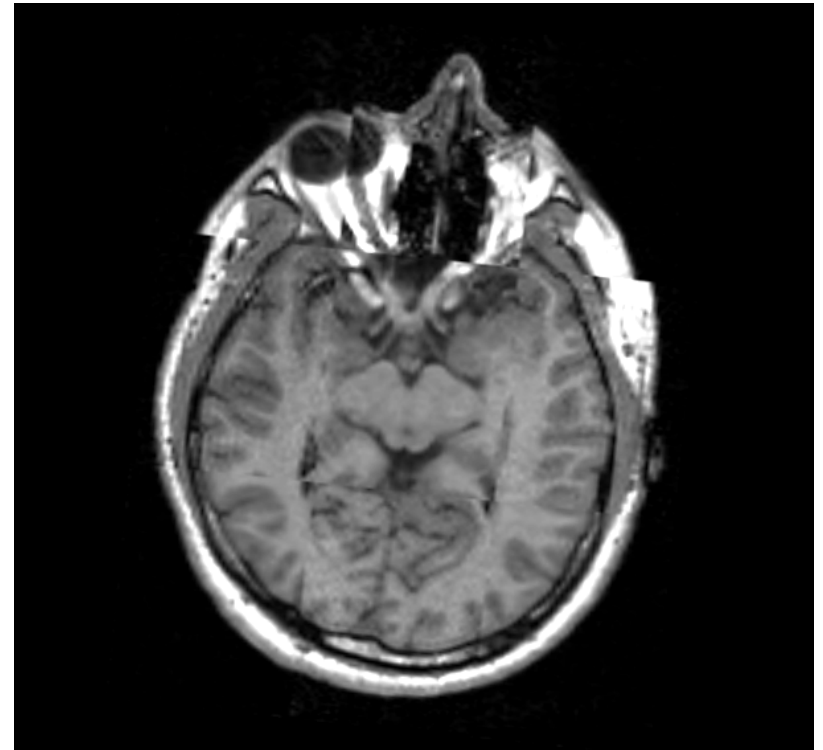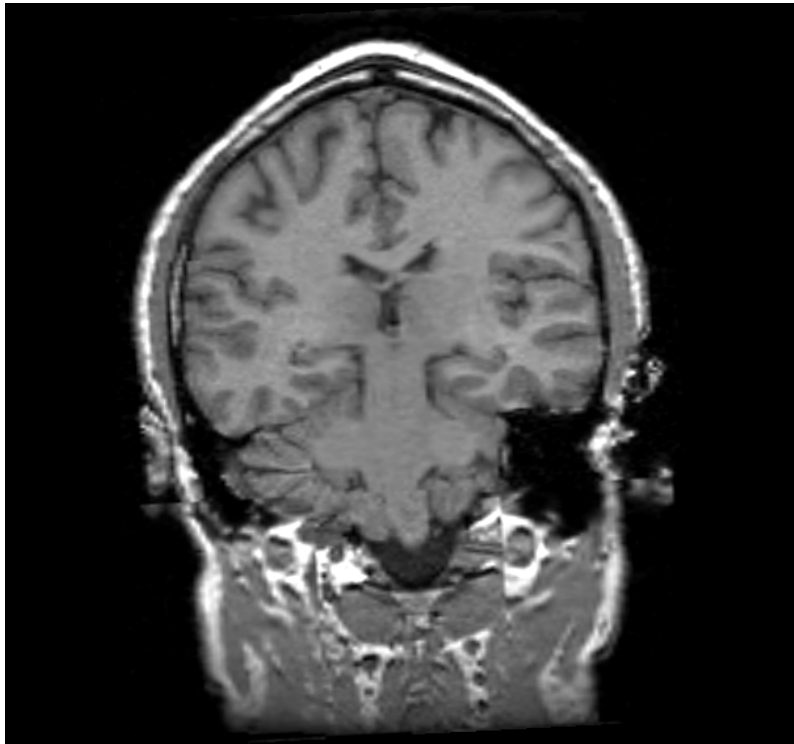Courtesy of Alexandra Golby, MD, Jean-Jacques Lemaire, MD, PhD, Steve Pieper, PhD
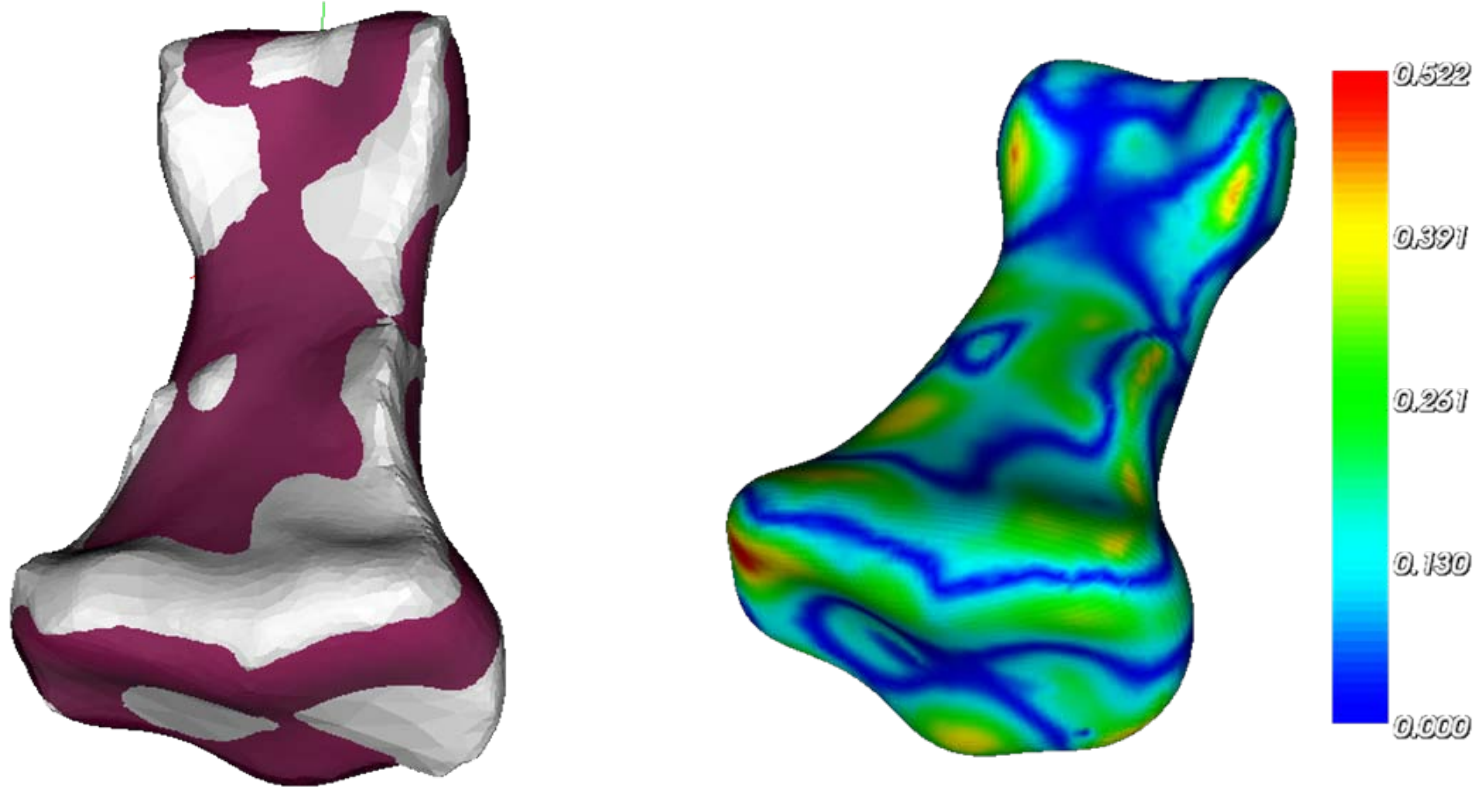
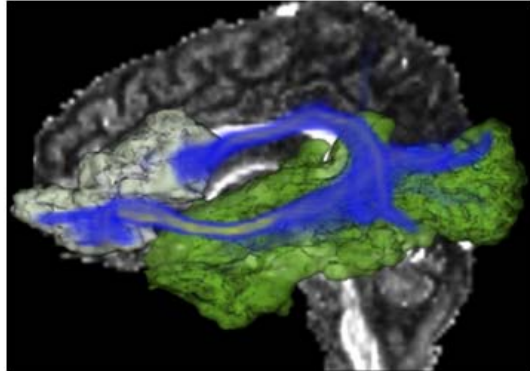# Mis-registration

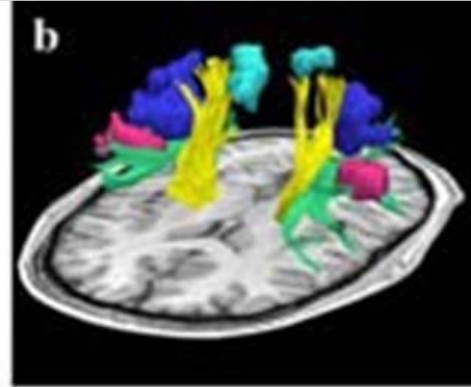# Registration Validation

Surface Reconstruction Validation

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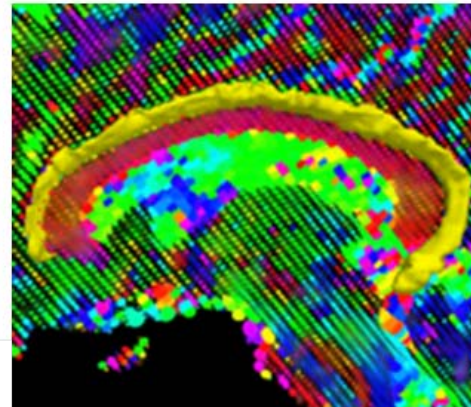The University of Iowa

Tractography Validation

Courtesy of CF Westin, PNL-LMI

Courtesy of CF Westin, BWH-LMI
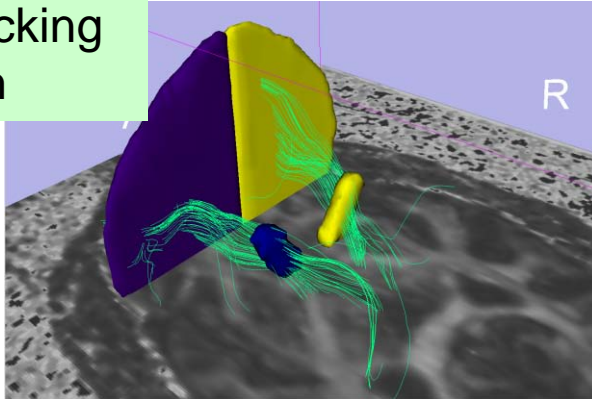
Courtesy of T.Fletcher &
R. Whitaker, SCI Utah

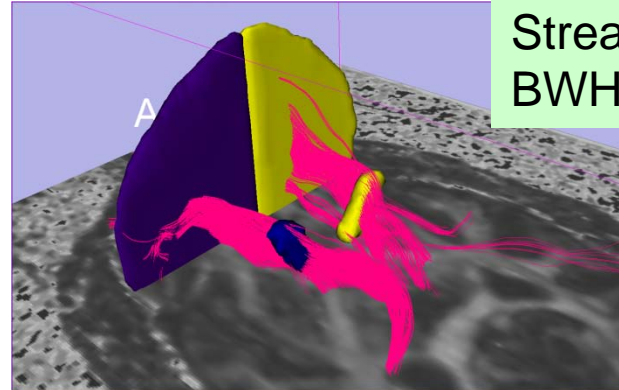Courtesy of A. Tannenbaum,
Georgia Tech.
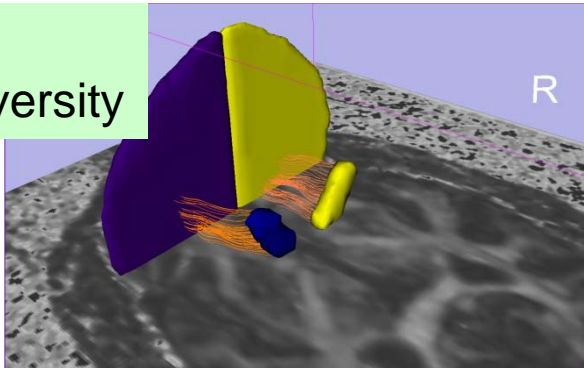
Tractography Validation
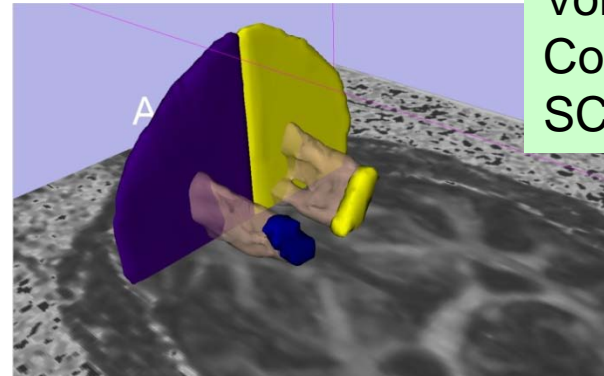

Fiber Tracking
SCI, Utah

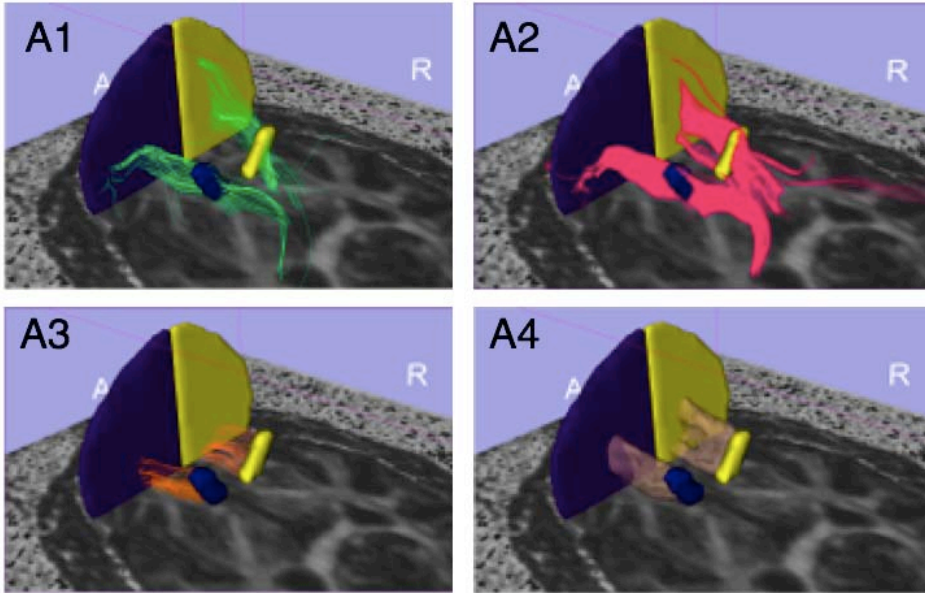Streamline
BWH, Harvard

GTRACT
Iowa University

Volumetric
Connectivity
SCI, Utah

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

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

- Evaluation of the sensitivity and specificity of tractography algorithms

- Quantitative analysis of fiber bundles

Conclusion

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

Acknowledgments

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