Advanced Visual Medicine: Techniques for Visual Exploration & Analysis

Interactive Visualization of Multimodal Volume Data for Neurosurgical Tumor Treatment

Felix Ritter, MeVis Research Bremen

Multimodal Neurosurgical Planning

Tasks:

- Is a resection possible?
- What type of resection can be performed?
- What is an optimal access path to the lesion?
- What is the risk of the surgical intervention?

Available Data

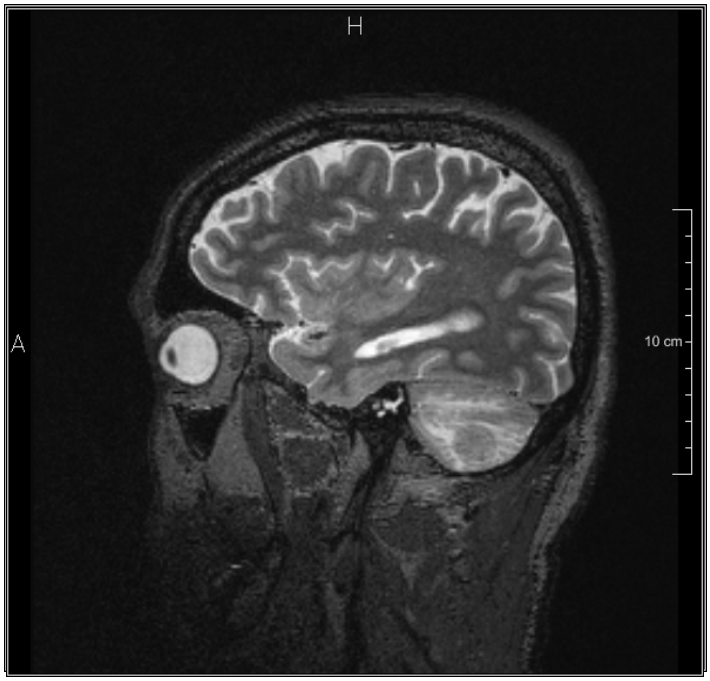
Anatomical:

- T1

Available Data

Anatomical:

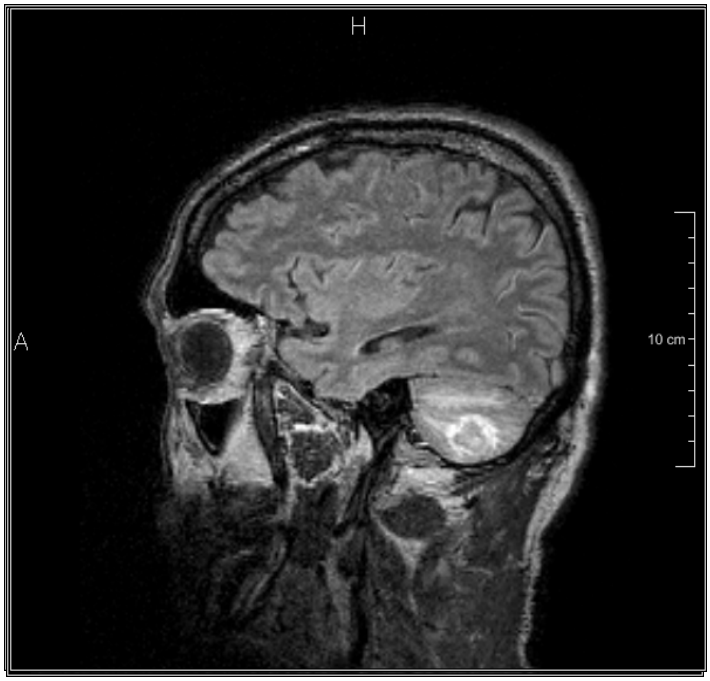
- T1
- T2



Available Data

Anatomical:

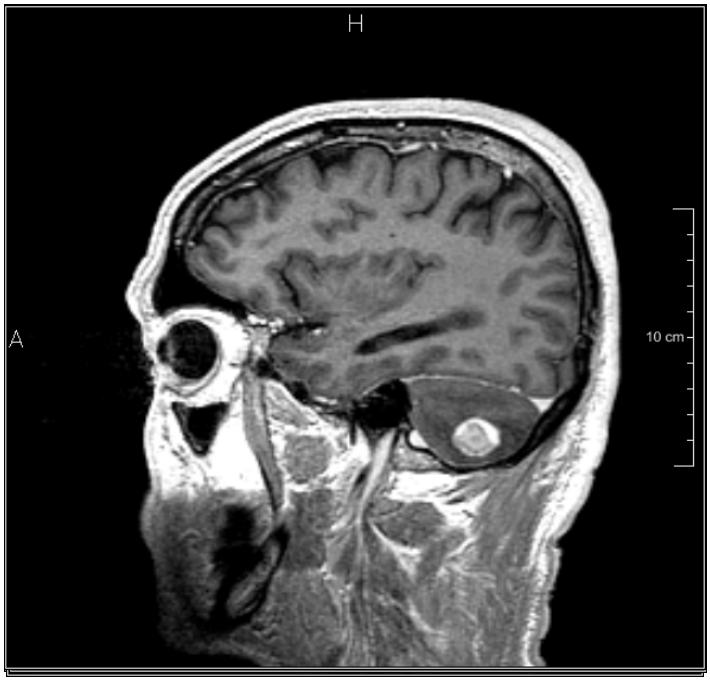
- T1
- T2
- FLAIR



Available Data

Anatomical:

- T1
- T2
- FLAIR
- contrast enhanced T1, …



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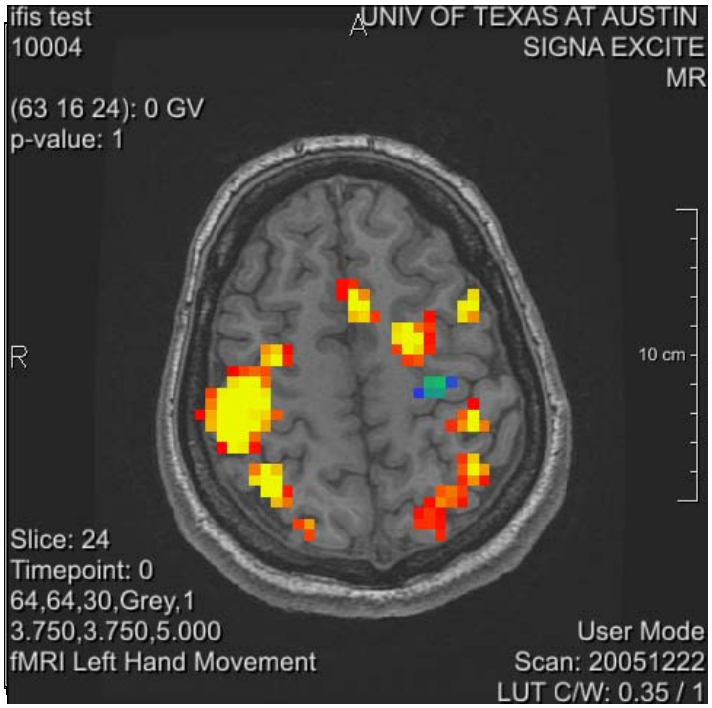
Available Data

Anatomical:

- T1
- T2
- FLAIR
- contrast enhanced T1, …

Functional

- fMRI



Available Data

Anatomical:

- T1
- T2
- FLAIR
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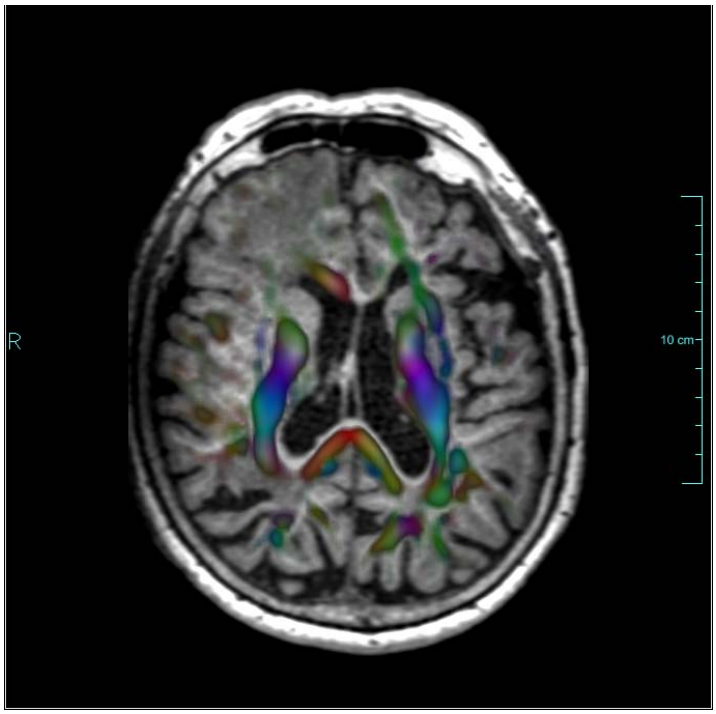
Functional

- fMRI
- DTI



Available Data

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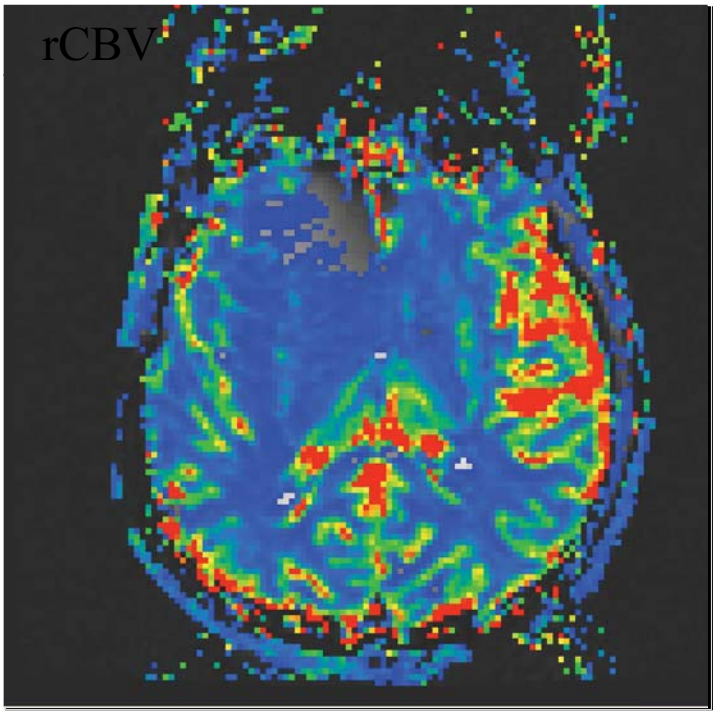
Functional

- fMRI
- DTI

Perfusion

- Cerebral Blood Volume



Available Data

Anatomical:

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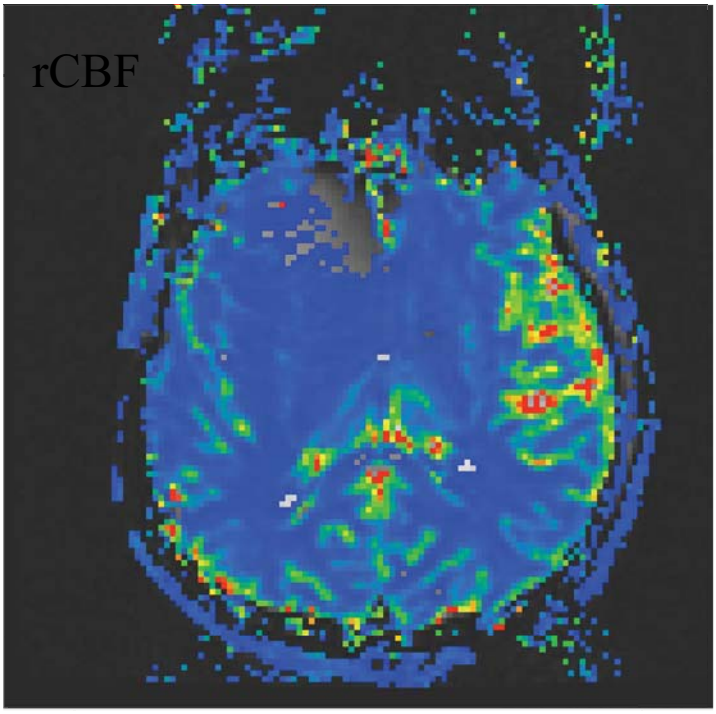
Functional

- fMRI
- DTI

Perfusion

- Cerebral Blood Volume
- Cerebral Blood Flow



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Medical Volume Data

Possible medical volume data:

- *MRI* (magnetic resonance imaging), high soft tissue contrast for visualization of anatomical details
- *fMRI* (functional magnetic resonance imaging), for detection of the brain‘s activation areas
- *DTI* (diffusion tensor imaging), for reconstruction of the brain‘s nerve tracts
- *CT* (computer tomography), just used in special cases due the high radiation exposure, e.g. skull bone infiltrated by tumor tissue
- *PET* (positron emission tomography), nuclear imaging technique to detect functional processes

Multimodal Neurosurgical Planning

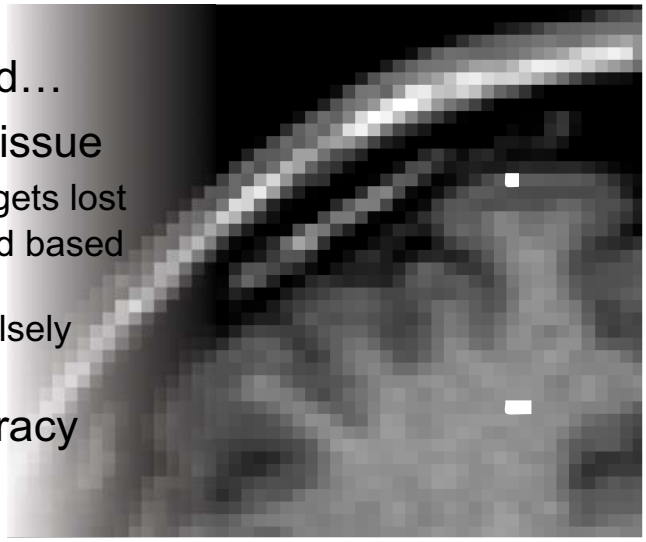
- A tempting assumption:
  - Combination of all available imaging modalities can identify all relevant structures!
- Limitations:
  - Models behind the involved techniques
    - fMRI can give hints about functional areas
    - Fiber-Tracking can give hints about axonal pathways
  - Spatial relation of relevant structures
    - Different image resolutions › Different degrees of accuracy!
    - Spatial alignment relies on registration › Rigid registration may be insufficient
- A better interpretation:
  - Combination of different images may give additional information but it also introduces additional limitations on accuracy

Neurosurgical intervention

Neurosurgical interventions are performed using an operation microscope

Dealing with Inaccuracies in Multimodal Neurosurgical Planning

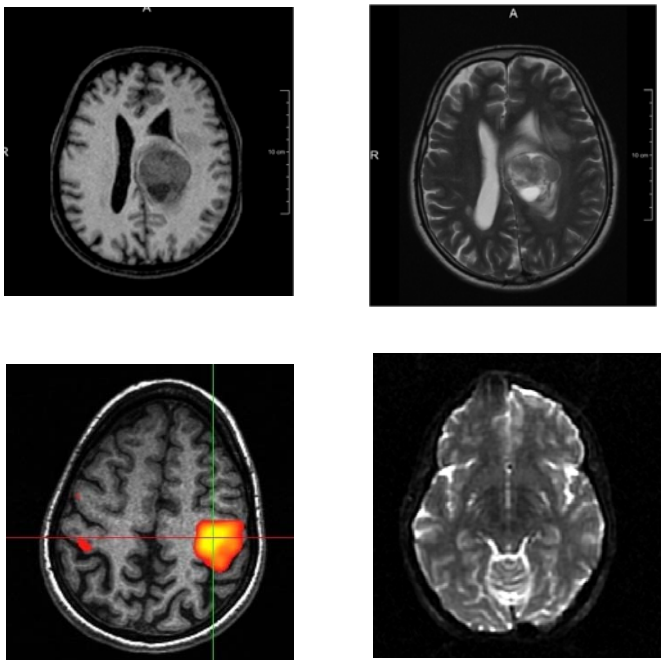
- Accuracy is limited!
- Sources for limitations are manifold…
- Limited accuracy may become an issue
  - If the awareness about the limitations gets lost
  - If decisions are made, that are not valid based on the given accuracy
  - If the impression of high accuracy is falsely created
- Limited accuracy turns into inaccuracy
- Inaccuracy is unavoidable



We must deal with it!

Sources of Inaccuracies

- Image registration
  - Spatial alignment is prerequisite for overlaying different images
  - Automatic rigid registration



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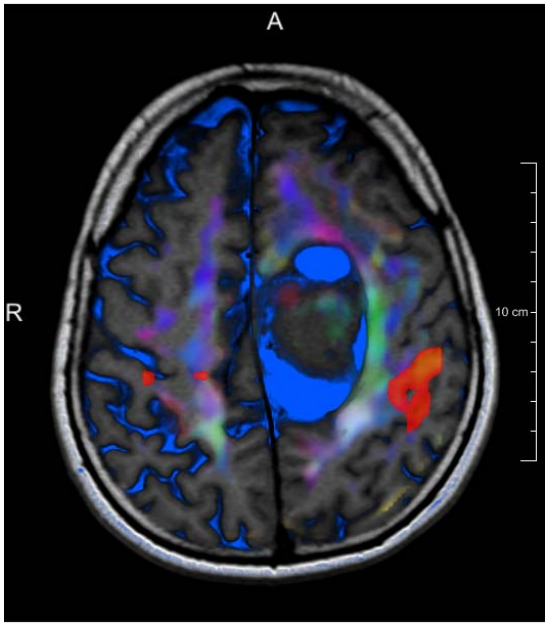

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Sources of Inaccuracies

- Image registration
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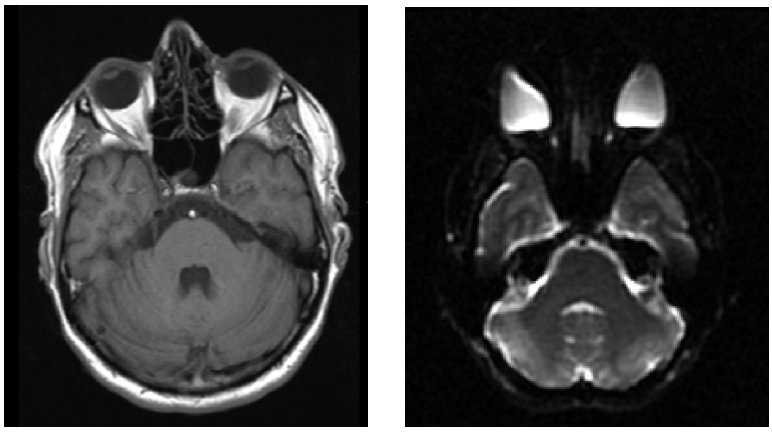
  - Automatic rigid registration
- Problem:
  - Spatial deformation



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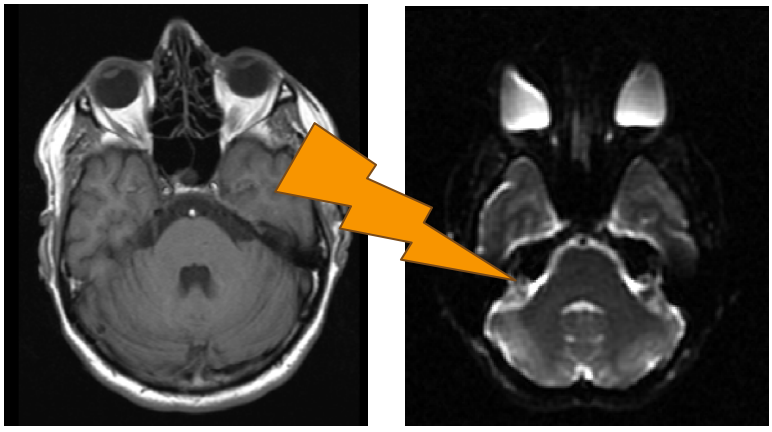

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Sources of Inaccuracies

- Image registration
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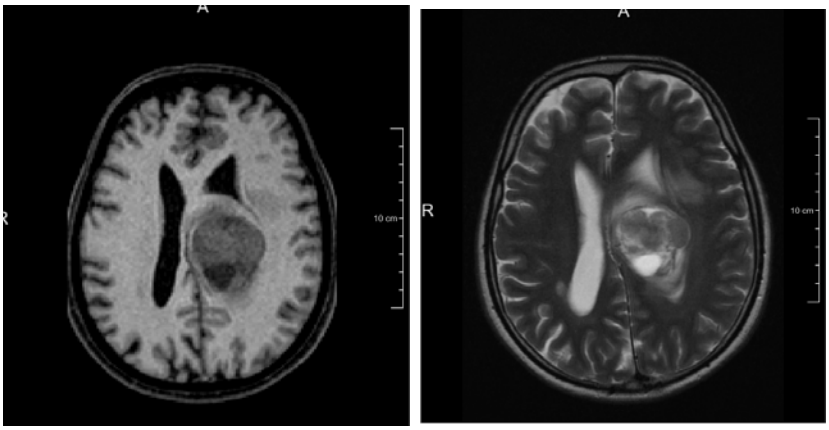
  - Automatic rigid registration
- Problem:
  - Spatial deformation
- Problem:
  - Different voxel-sizes, slice-thickness, interslice-gap



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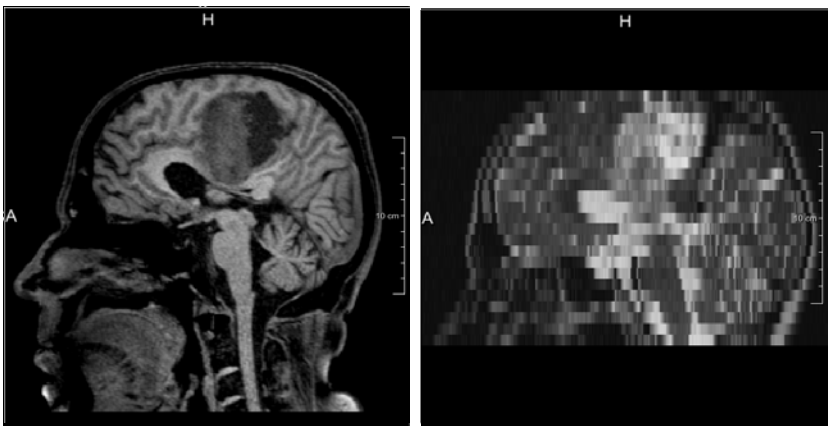

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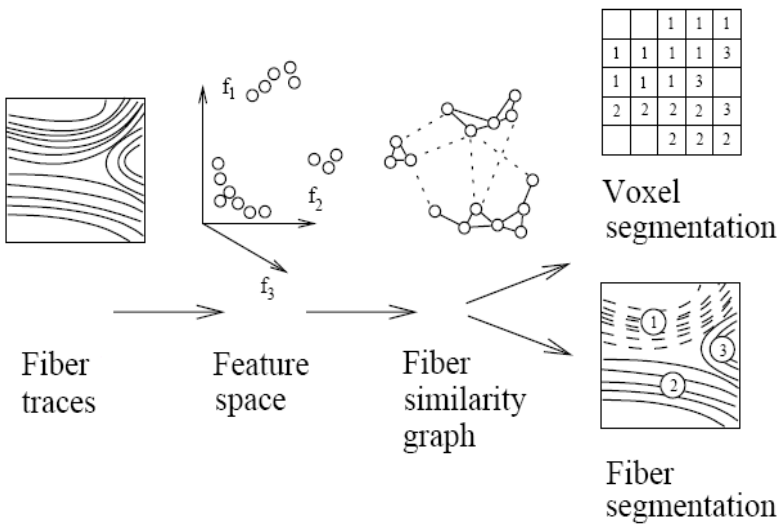
Motivation for Fiber Clustering

Group geometrically similar or related fibers acquired by DTI.

- Improve perception of fiber bundles and connectivity.
- Improve interaction with fiber bundles.
- Avoid user-biased quantification results.

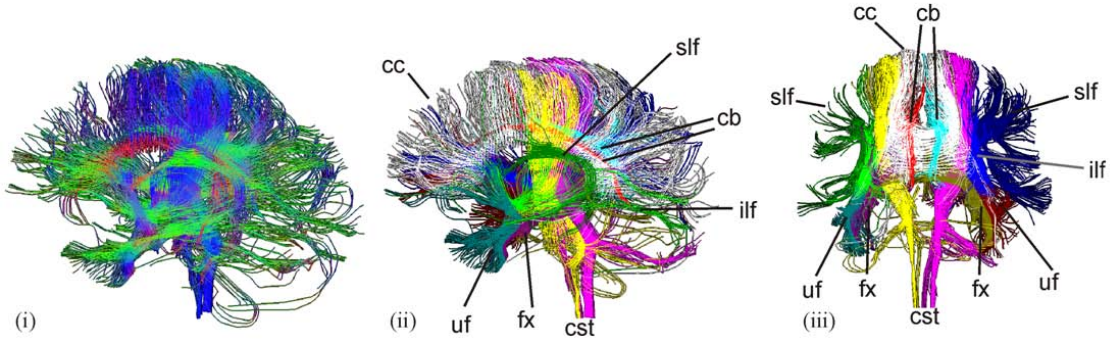
Klein et al., SPIE 2007

Fiber Clustering using Normalized Cuts

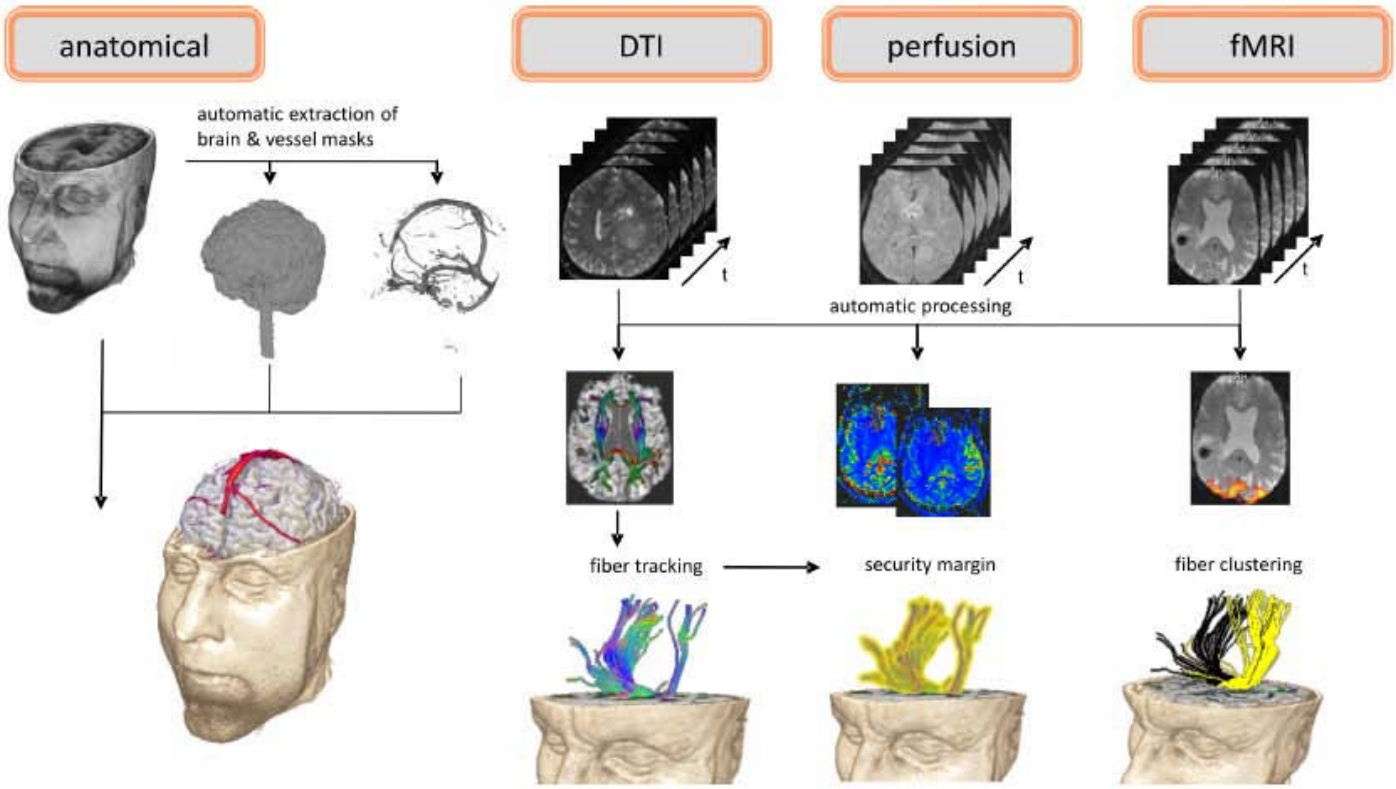


Anders Brun et al., MICCAI'04

Fiber Clustering



Multimodal Data Visualization



Combining DTI, fMRI, Vessels, Anatomy

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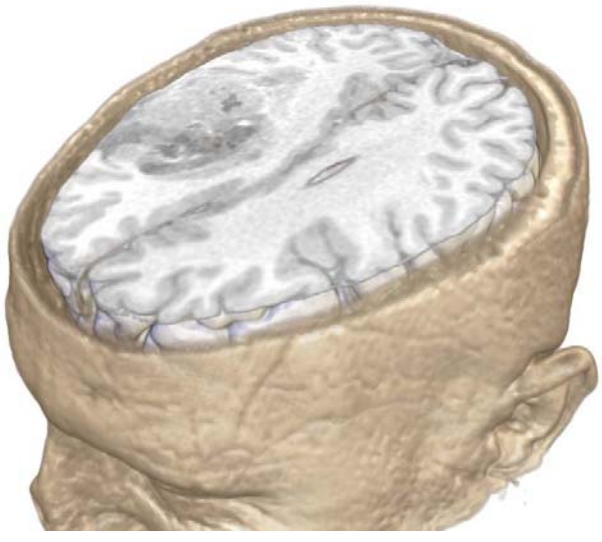

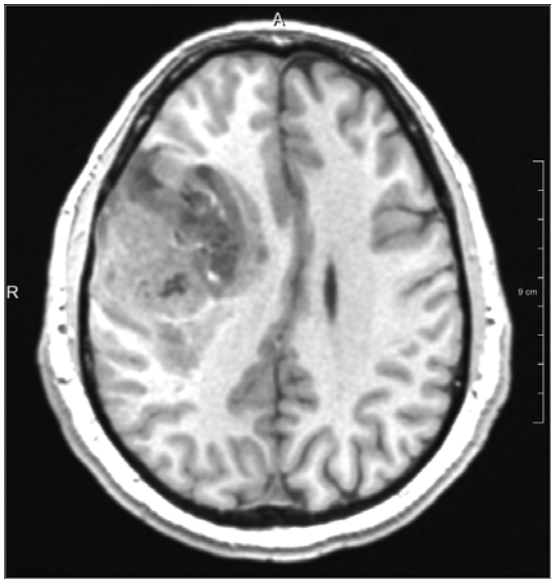

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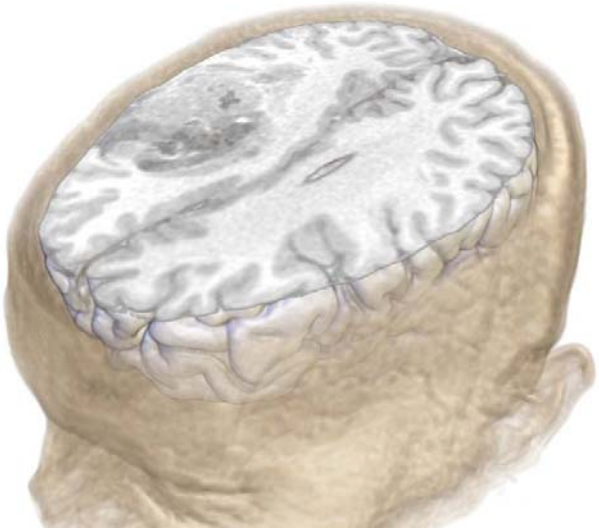
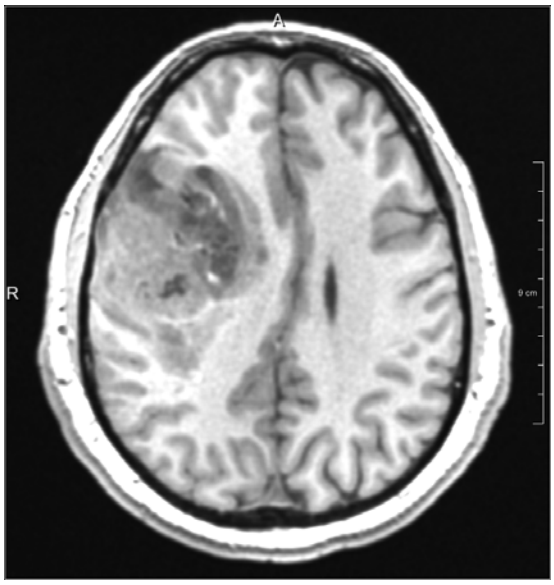
Combining DTI, fMRI, Vessels, Anatomy





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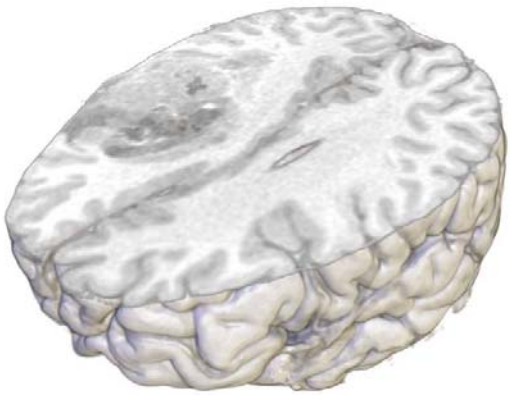

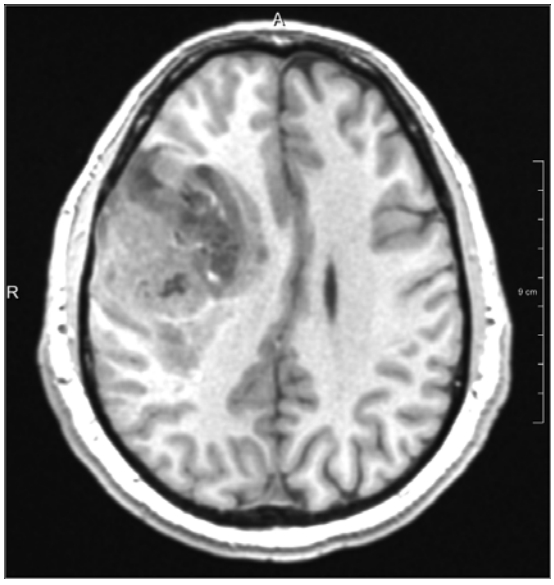

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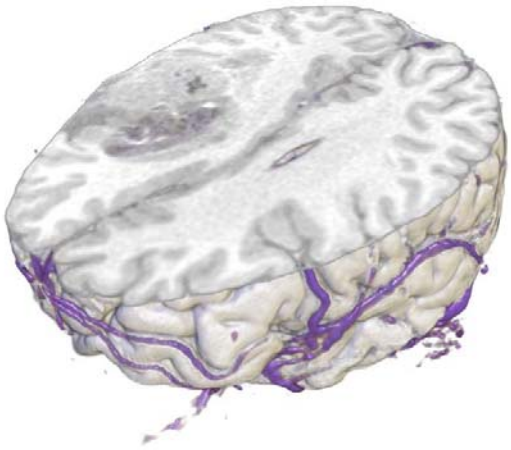

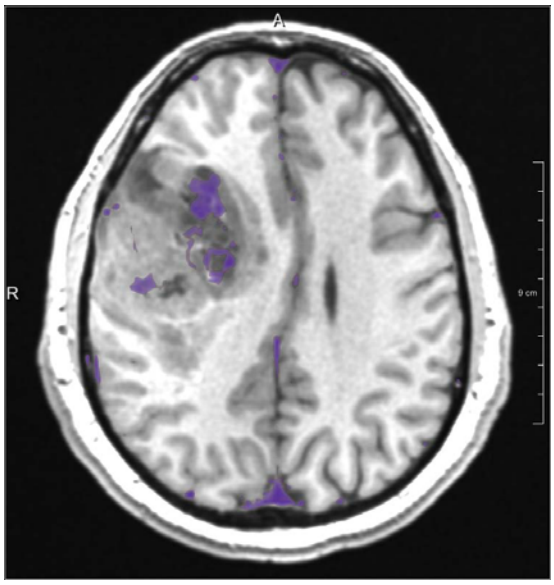

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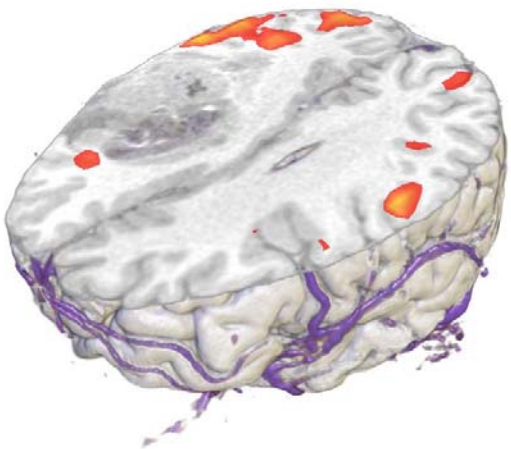

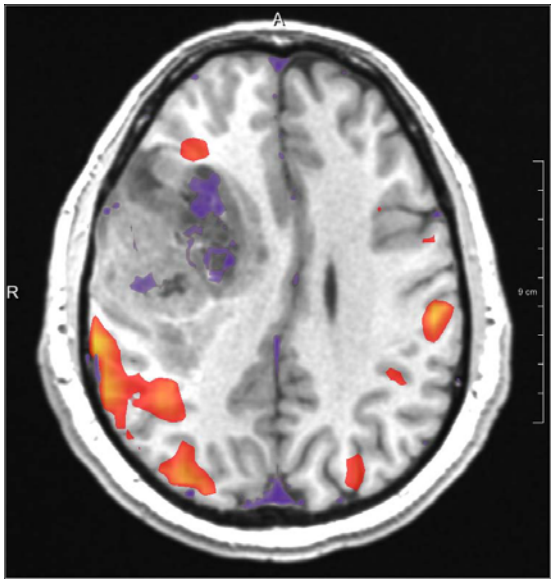

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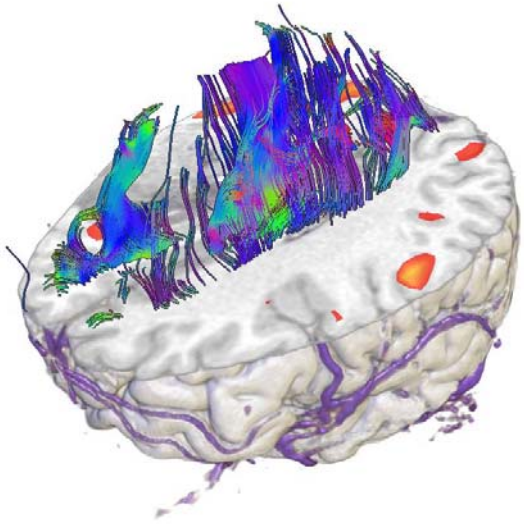

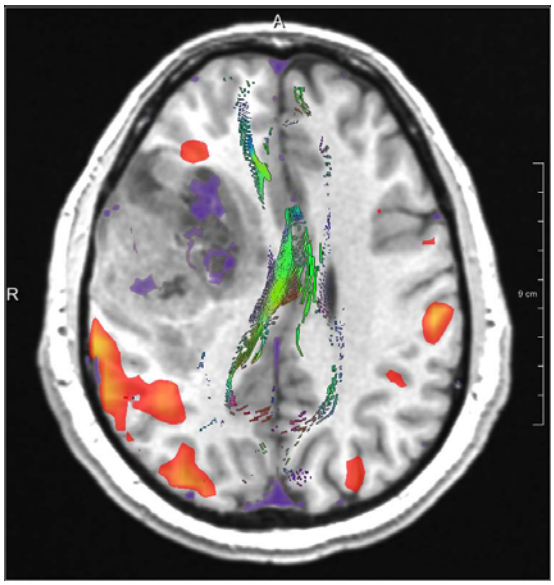

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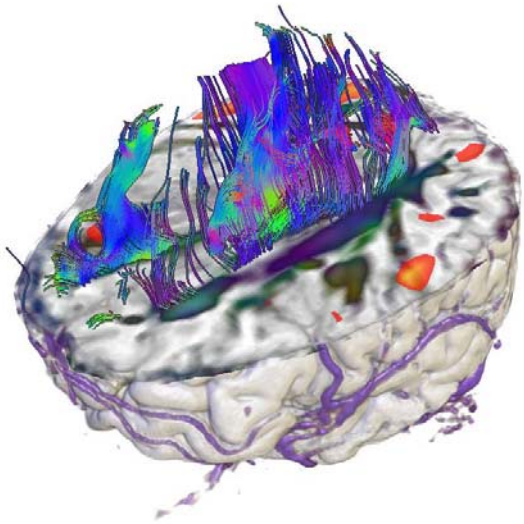

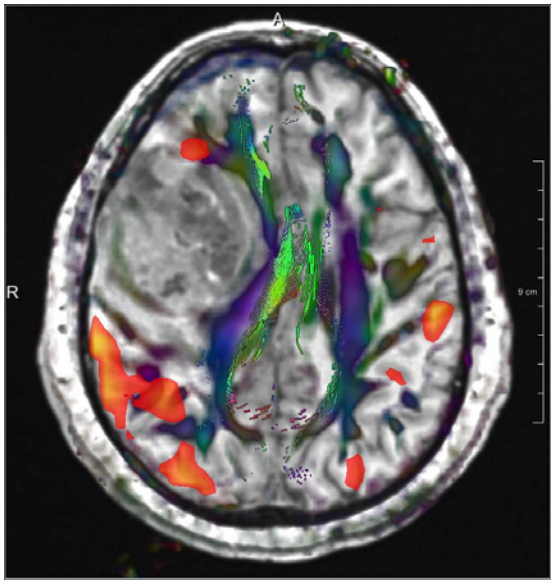

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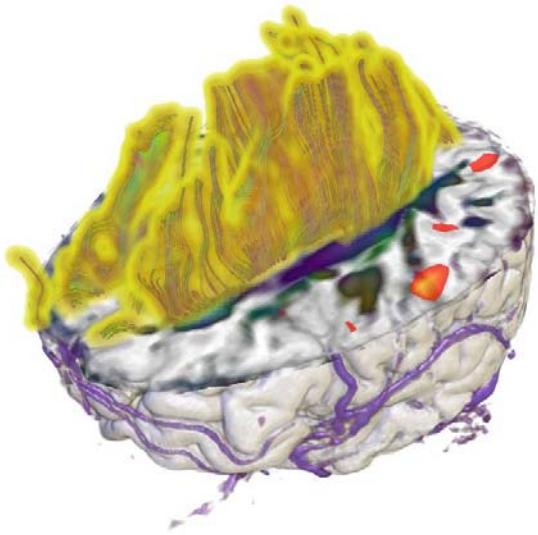
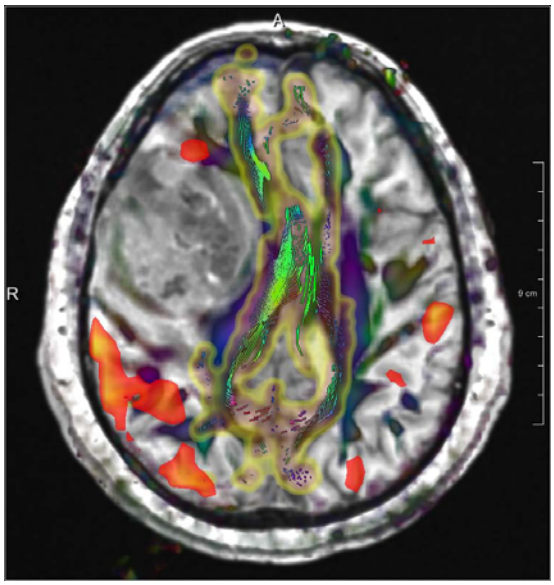
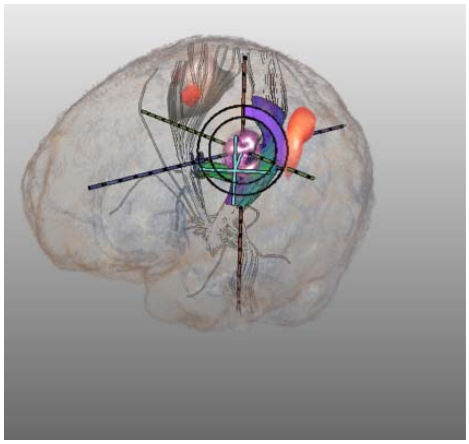
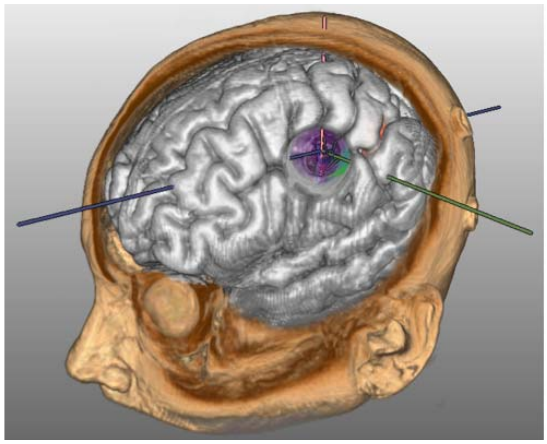
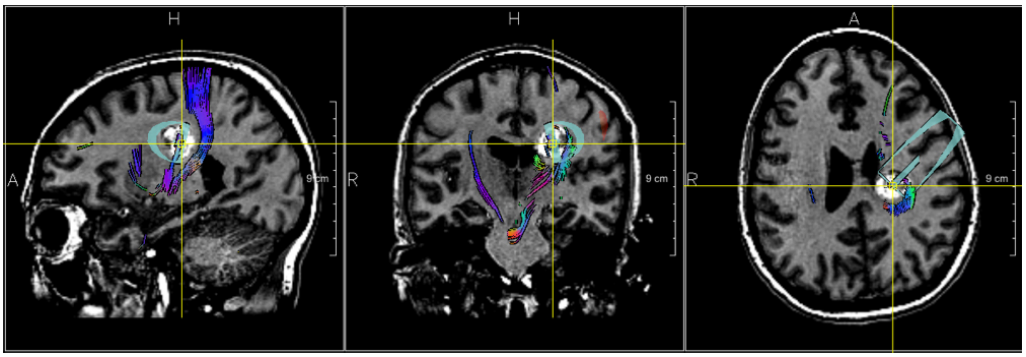




Multi Modality Visualization





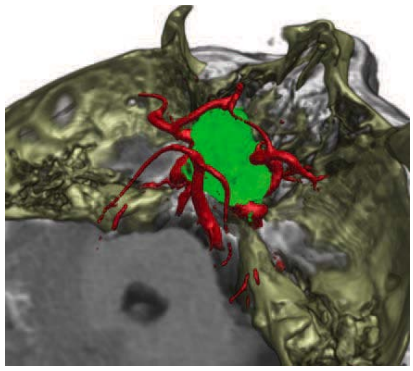


Multimodal Volume Rendering

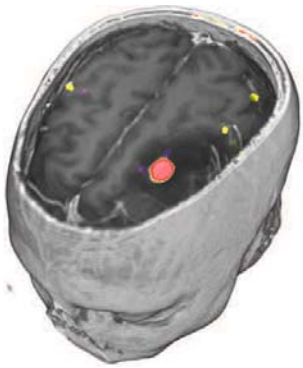
Visualization of CT and MR data for visualization of implanted electrodes for epilepsy surgery

Johanna Beyer et al., VIS 2007

CT, MR and MRA data

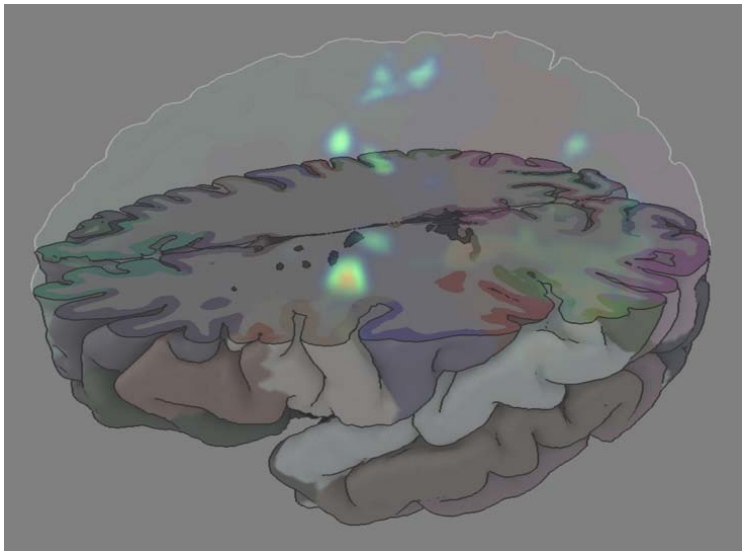


MR (black/white), PET (red) and fMR (yellow and white) data



Multimodal Volume Rendering

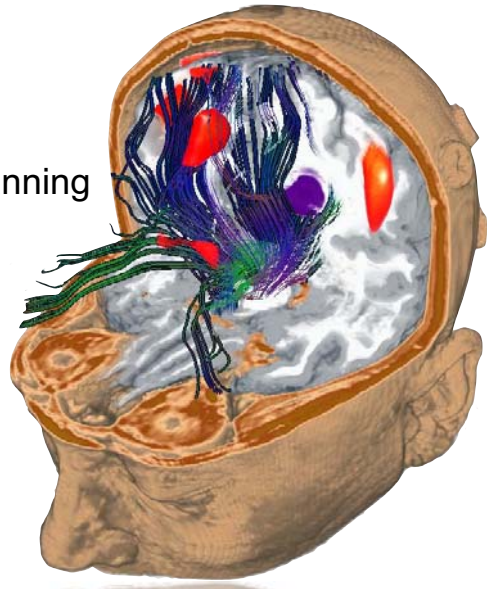
Combined MRI-fMRI visualization



Werner Jainek et al., EuroVIS 2008

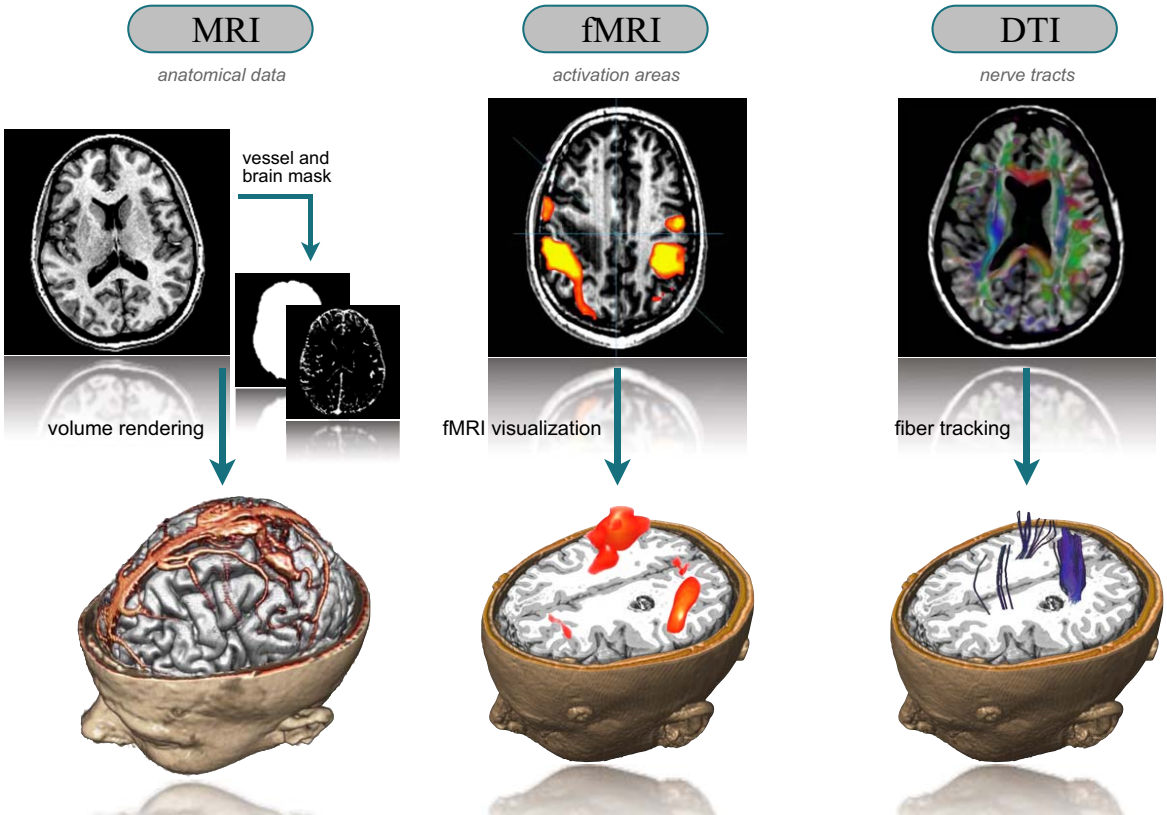
Motivation

- Visualizing risk structures is becoming standard
  - Complex visualizations
  - High amount of user interaction
- Assumption:
  - Visualization of risk structures along trajectory provide means for optimizing neurosurgical planning
- Our Prototype:
  - Combining multimodal volume data
  - Enhancement of risk structures
  - Visualization of virtual access path



Rieder et al., EuroVIS 2008

Imaging of Risk Structures



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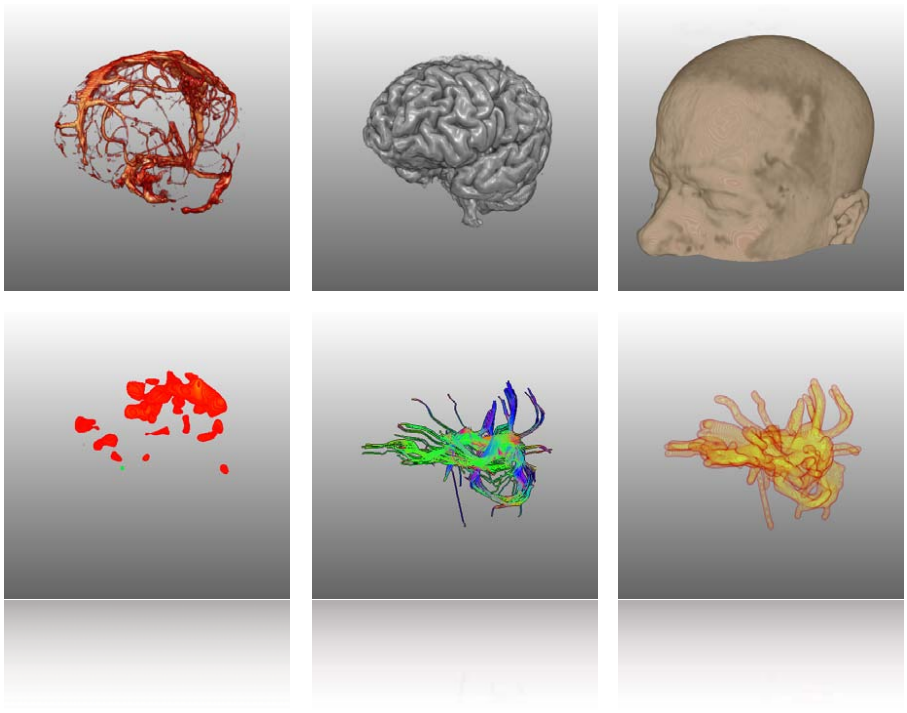

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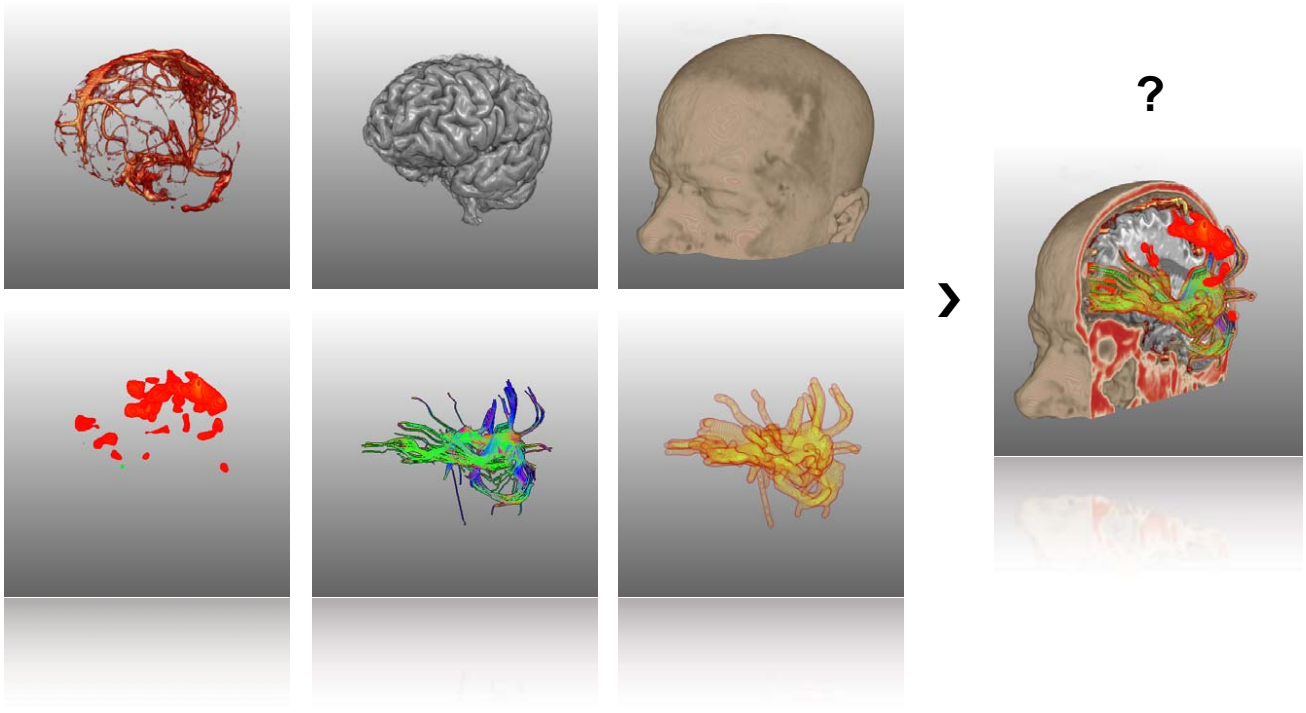

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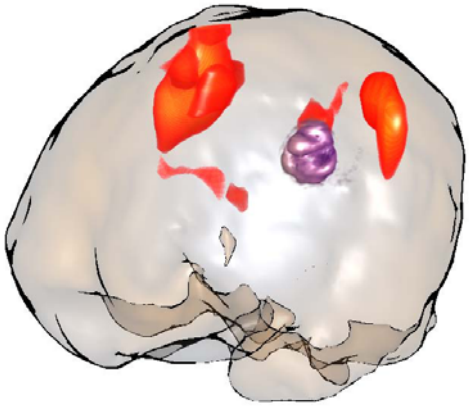
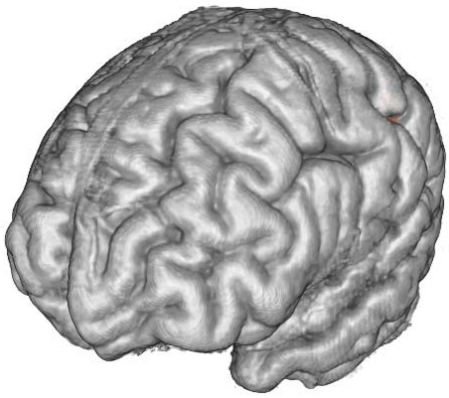
Visualization of Multimodal Volume Data

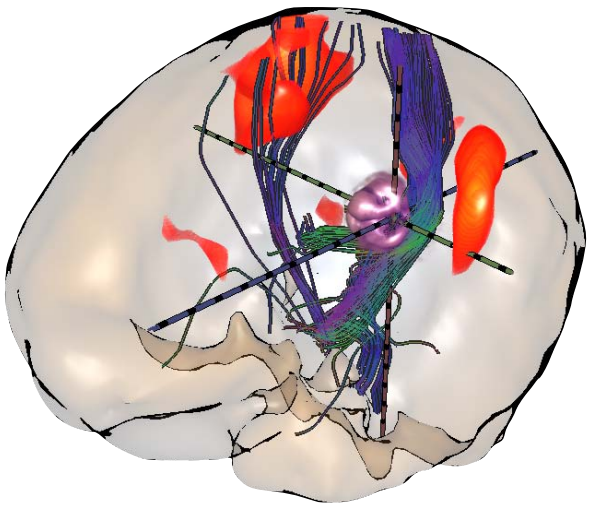
- Combined exploration of functional and anatomical data difficult
- Solution: Dual views
  - *Internal view*: visualization of internal data (Risk structures, occluded by skull and brain)
  - *External view*: visualization of opaque anatomy (skull and brain). Requires cutting tools for exploration of functional data.





Enhancement of functional data

- Not all activation areas are of interest:
  - Out-fading of *color saturation* of fMRI areas far away of the trajectory and ROI
- Not all reconstructed fibers tracts are of interest
  - Fibers far away are just visualized as *outlined silhouettes*



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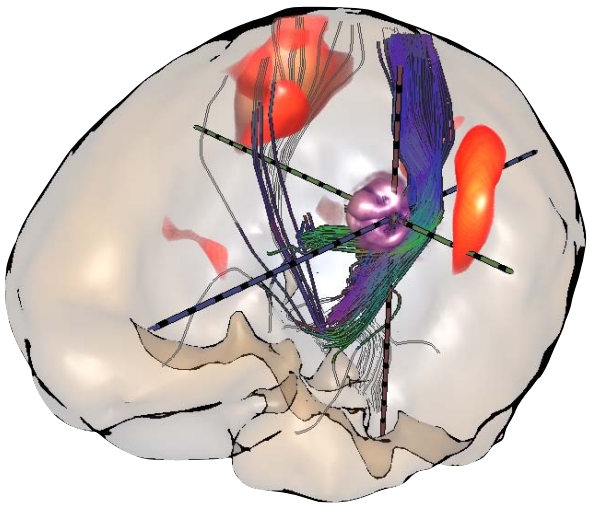

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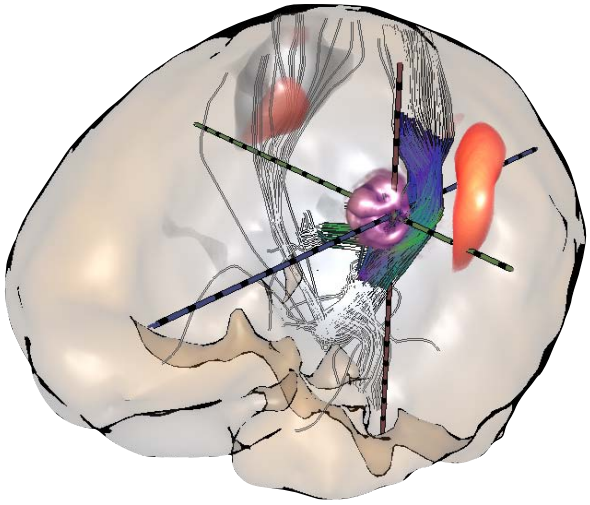
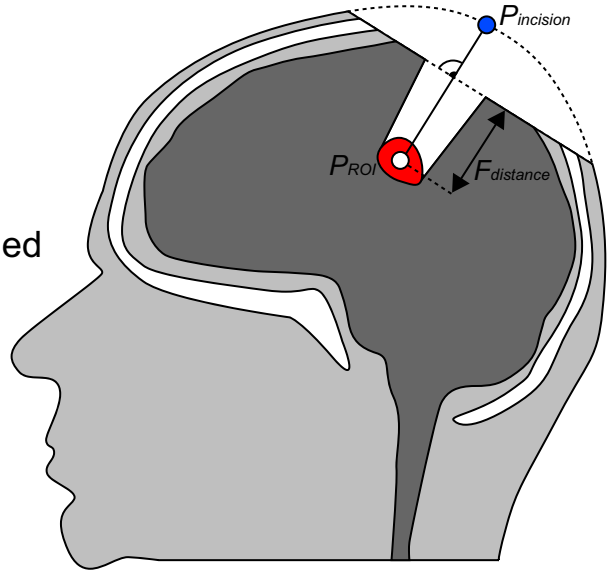


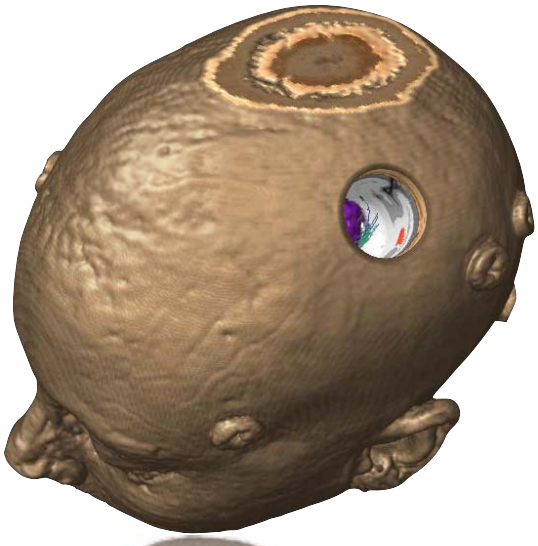
Visualization Tool: The „Access Path“

- The virtual access path: simplified cylinder geometry from virtual incision point to ROI for visualization
- Path in Internal View:
  - Visualized as thin line
  - Enhancement of functional data
- Path in External View:
  - Visualized as tubular cutting geometry
  - Exploration of anatomical data combined with functional data



Visualization of the Access Path

- Virtual access path from incision point to target
- Orthogonal cutting plane along the trajectory for detailed exploration



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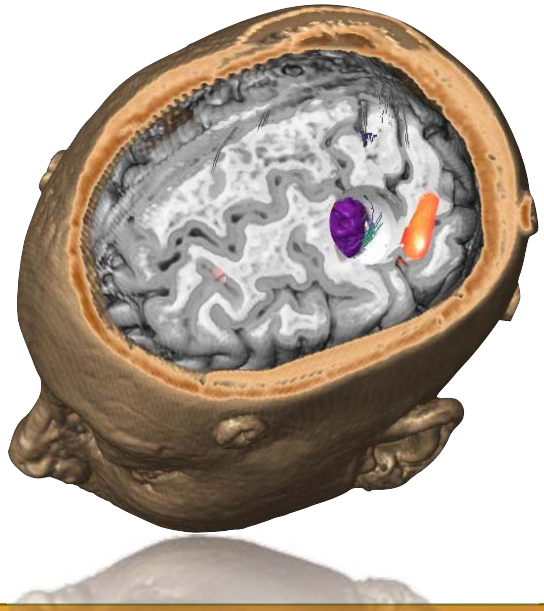

Visualization of the Access Path

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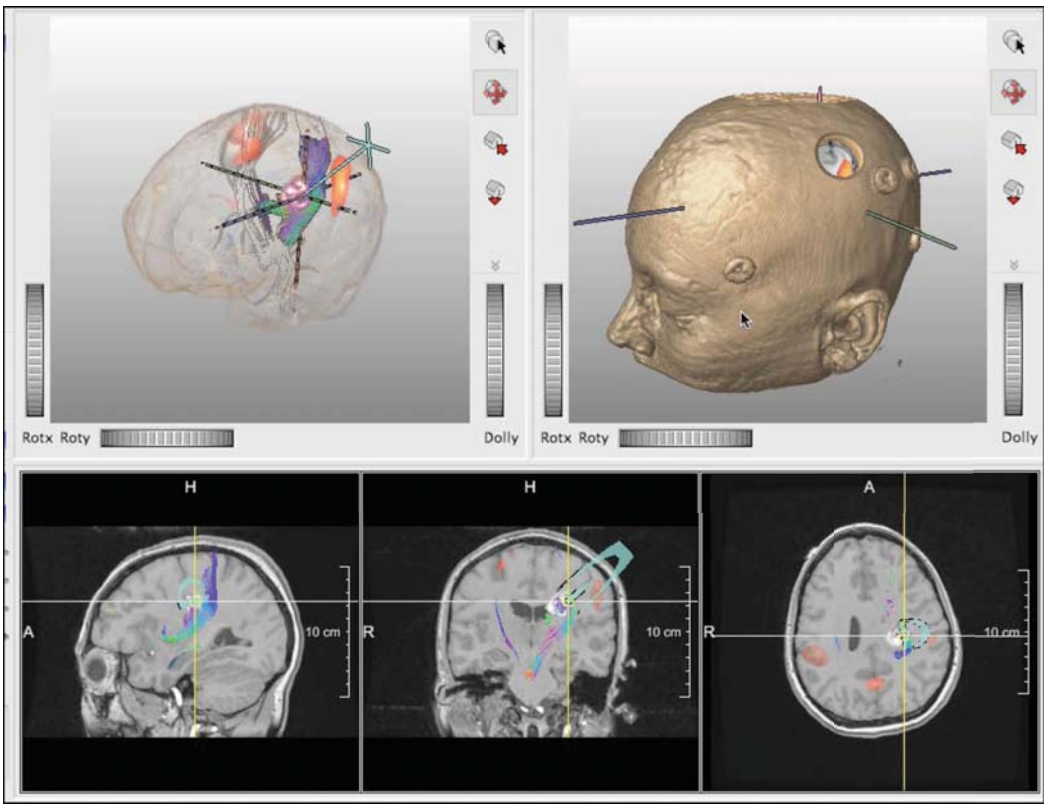
Visualization of the Access Path

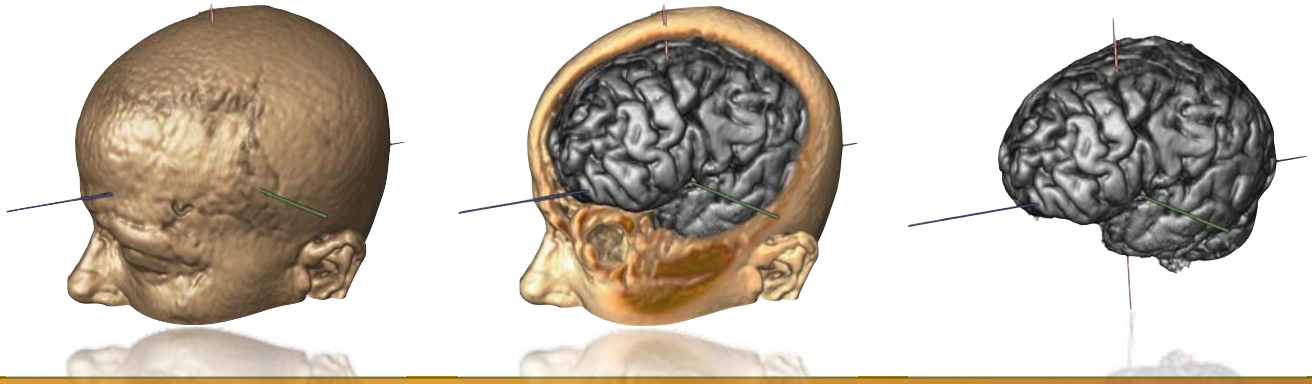
- Incorrect illumination results in homogeneous regions of the volume data (white matter, grey matter)
  - Illumination artifacts
  - Noisy visualization of anatomical details
- Solution:
  - Using consistent shading [Weiskopf et al., Trans. Vis. & Comp. 2005]

Coherent 2D Slice and 3D Volume Multimodal Visualization

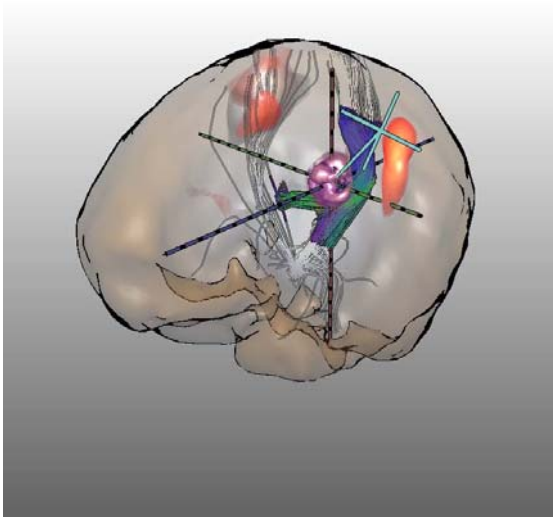


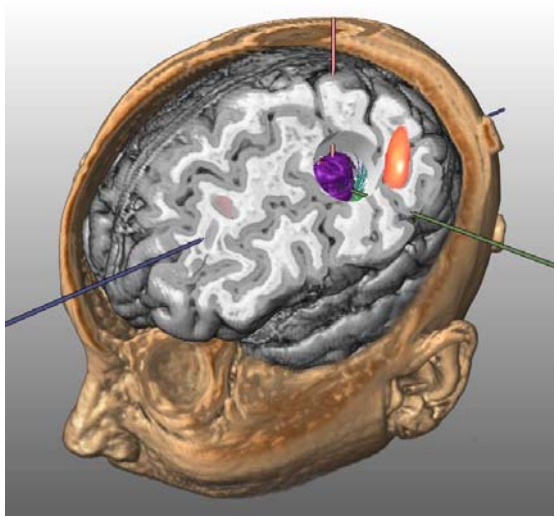
Superficial Landmarks

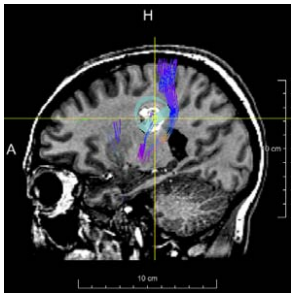
- Superficial landmarks at surface of skull and brain to support navigation:
  - Anatomical structures of head
  - Well-known brain structures after opening the skull
- Two methods:
  - Evaluating exit points of 3D coordinate system
  - Removing skull and exploration of brain‘s surface

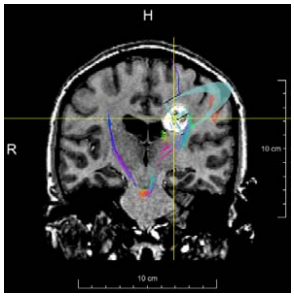


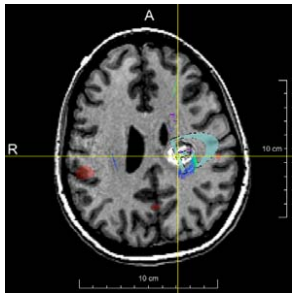
Results









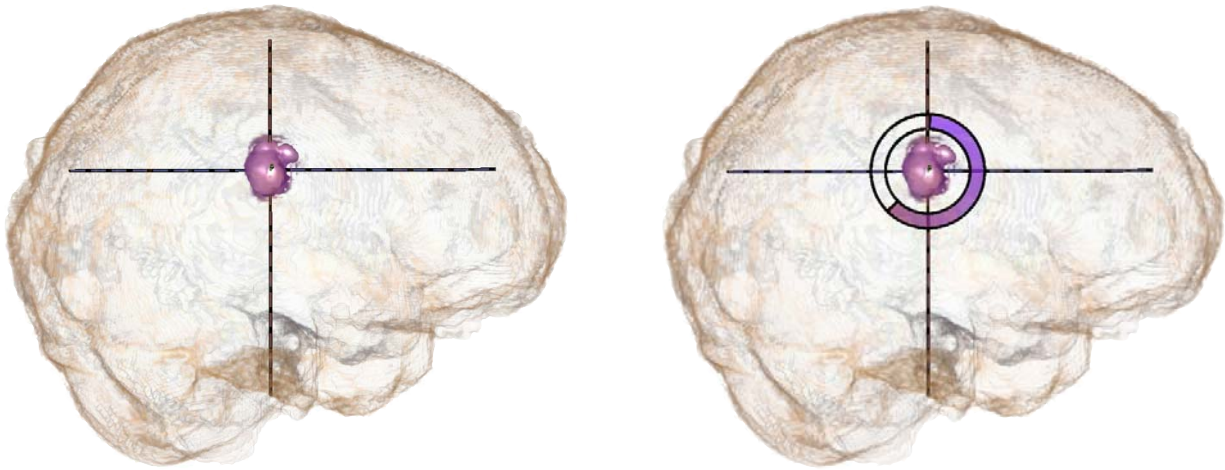


Depth Perception

- Depth perception difficult due to visualization of brain‘s contours
- Two combined techniques are used to intensify depth:
  - Distance Color Blending: color gradient from warm in the front to cool color in the back of the volume
  - Three-Dimensional Coordinate System: axes run parallel to three main directions of volume and end at brain‘s hull

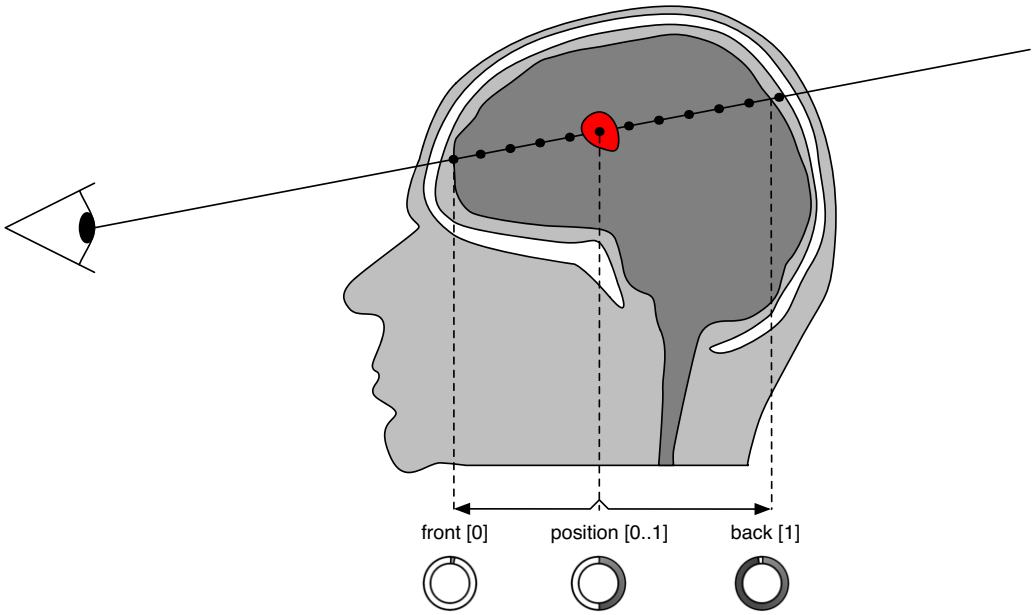
Distance Ring

- At some orientations one of the axes could be hidden by other structures or perspective distortion
- Distance Ring indicates location of ROI in view direction
  - *Minimal distance*: distance ring is completely open
  - *Maximal distance*: distance ring is completely closed

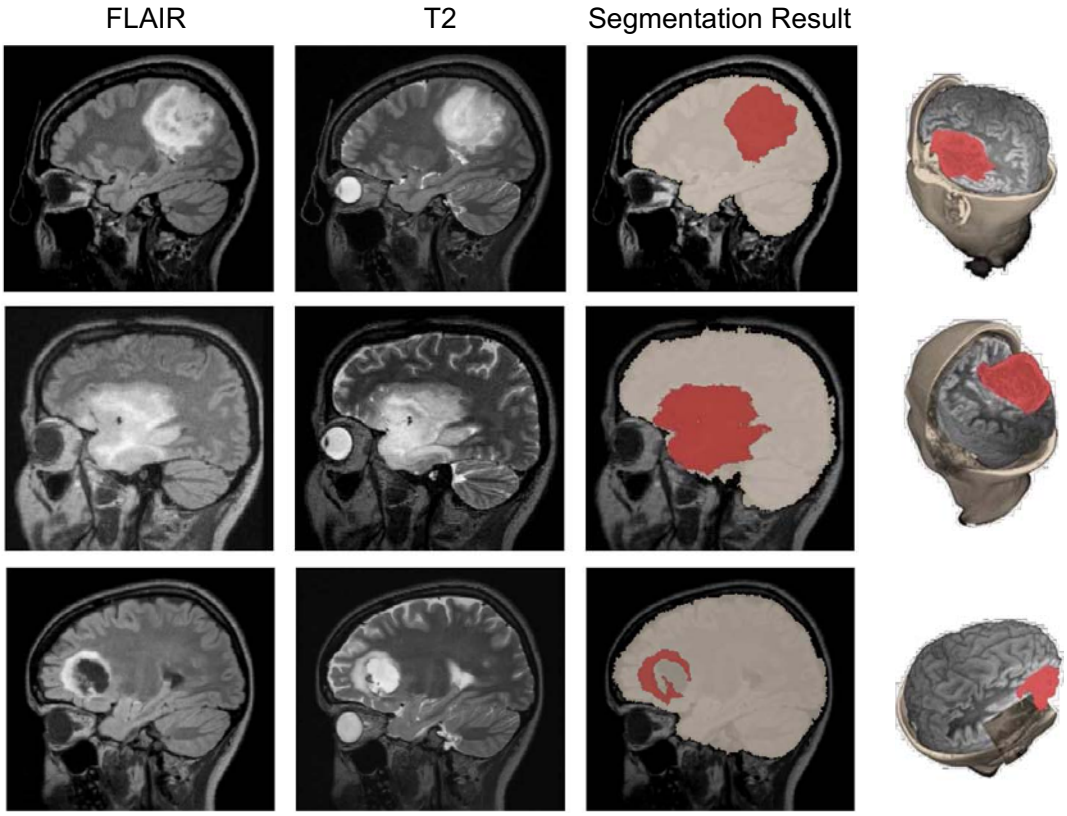


Distance Ring

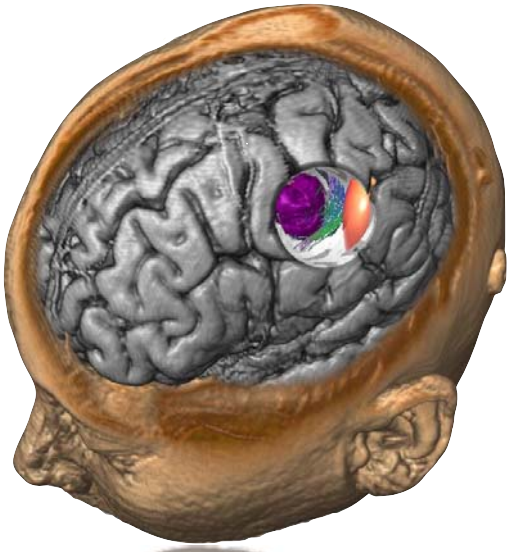
Ray tracing through brain mask

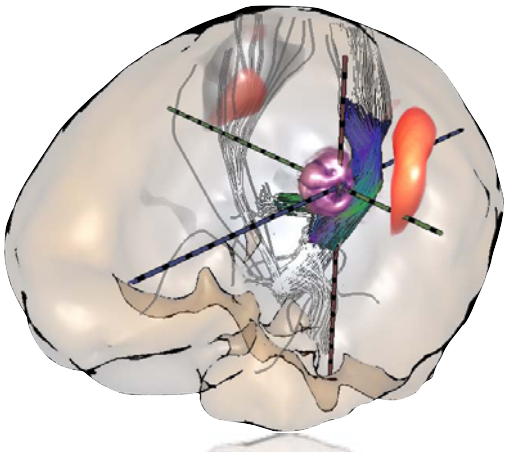


Multispectral Tumor Segmentation



Thank you!





Acknowledgments

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- Horst Hahn
- Jan Klein
- Christian Rieder
- Florian Weiler