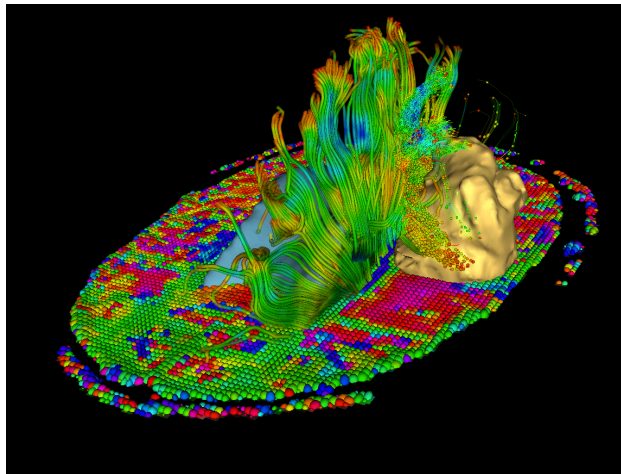




# Challenges in clinical transfer of DT-MRI: Towards Validation of DTI Tractography

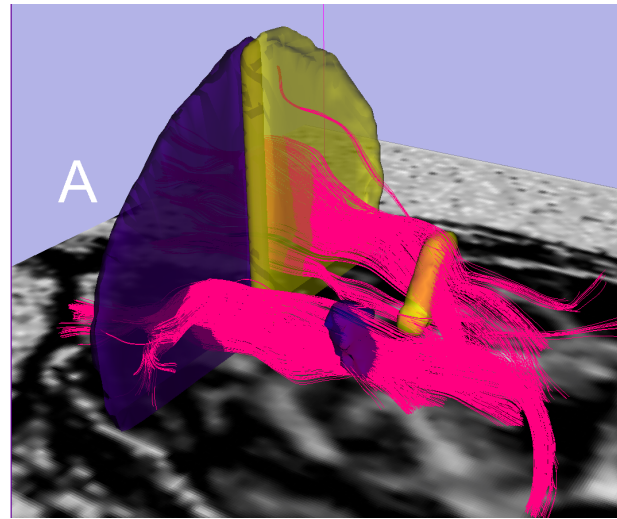
**Sonia Pujol, Ph.D.**

*Surgical Planning Laboratory  
Harvard University*

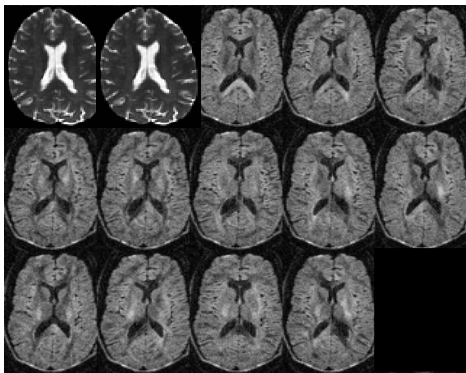




# White Matter architecture



- 100 billions of neurons
- Complex neuronal networks
- Diffusion MRI is the first non-invasive window on the organization of the brain white matter pathways
- Tractography provides 3D visualization of the trajectory of major white matter bundles





# DTI as a Neuroimaging marker

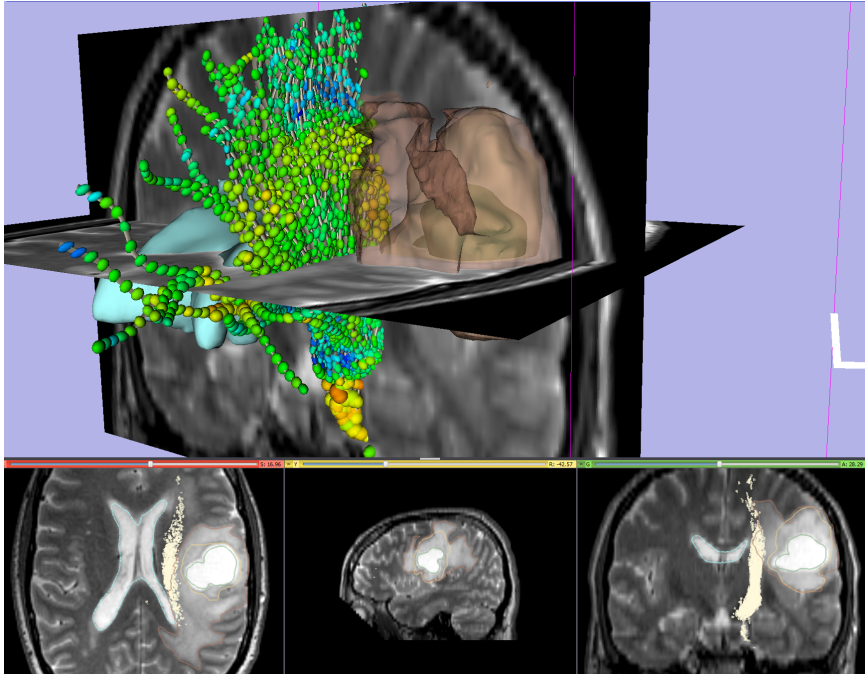
---

- Visualization of *in-vivo* normal and pathological anatomy
- Insights into white matter abnormalities which may include changes in *direction*, *radial displacement* or *diameter* of white matter fiber bundles



# Tractography for neurosurgical planning

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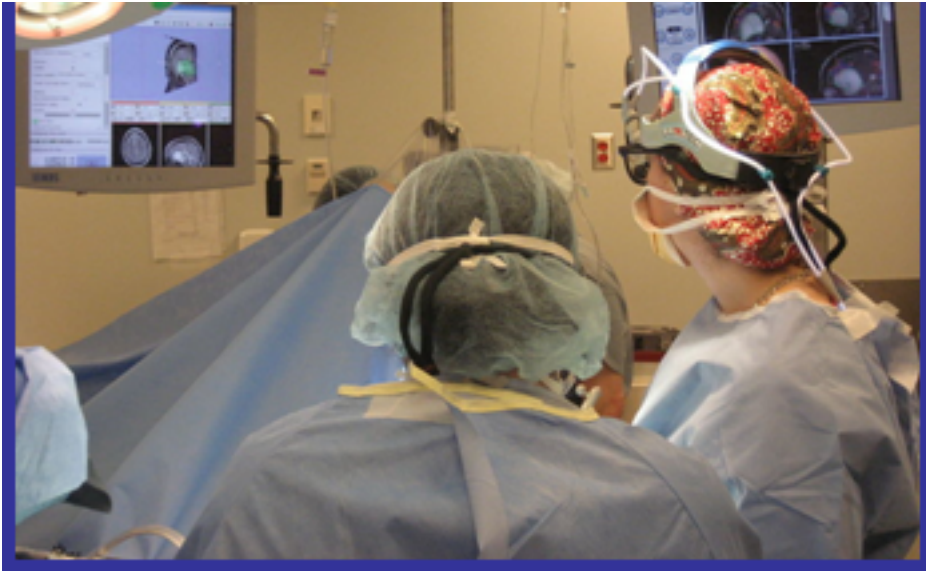
The **location** and **integrity** of eloquent white matter pathways is of major importance during neurosurgical planning

Courtesy of Ron Kikinis, MD



# Tractography for neurosurgical planning

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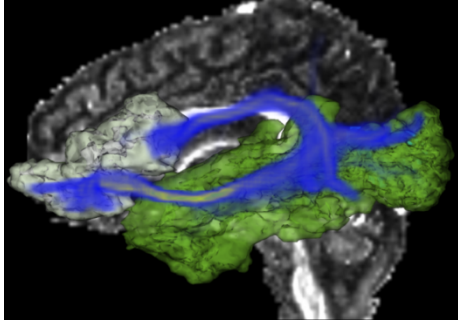
The location and integrity of eloquent white matter pathways is of major importance during neurosurgical planning

Tractography **has the potentiel** to bring valuable information to the neurosurgeon

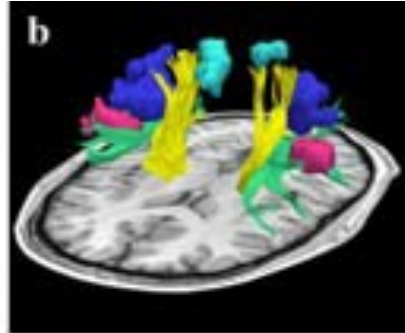


# Tractography

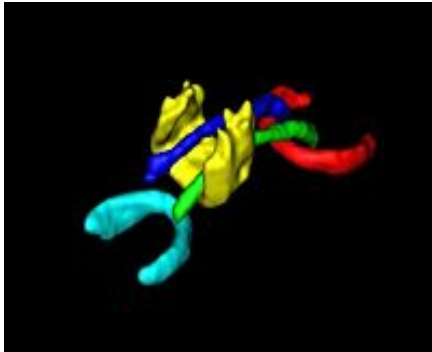
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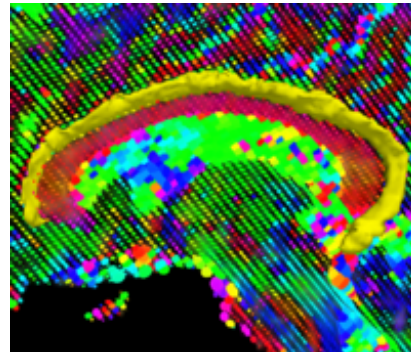
Courtesy of J De Siebenthal & CF Westin



Courtesy of A. Areza & CF Westin



Courtesy of T.Fletcher & R. Whitaker



Courtesy of A. Tannenbaum

A wide variety of tractography techniques has been developed over the past decade (streamline, stochastic, volumetric, two-tensors...)

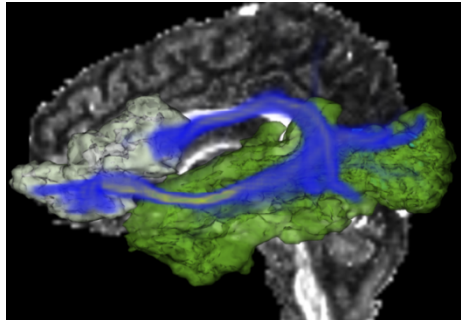


# Tractography

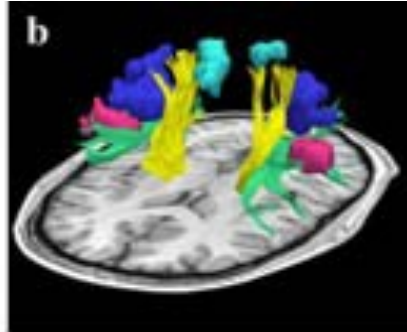
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Current achievements include:

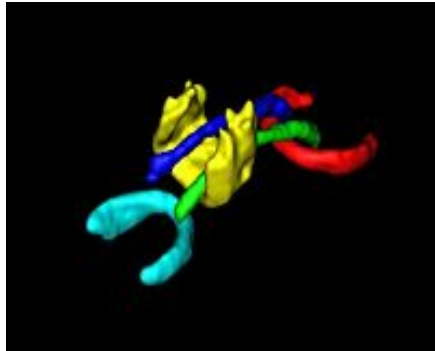
- 3D visualization of healthy & pathological anatomy
- Assessment of group differences (e.g Schizophrenia, Alzheimer's disease)



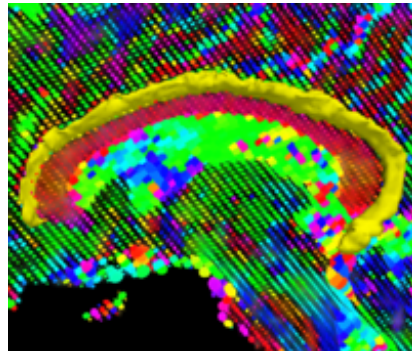
Courtesy of J De Siebenthal & CF Westin



Courtesy of A. Areza & CF Westin



Courtesy of T.Fletcher & R. Whitaker



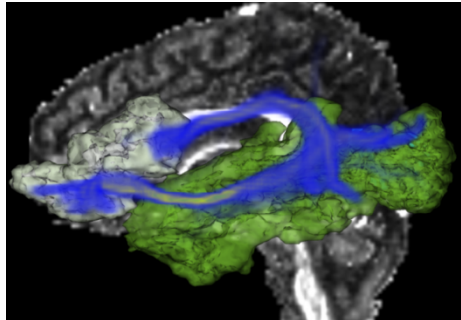
Courtesy of A. Tannenbaum



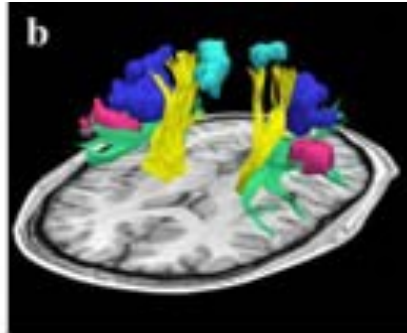
# Tractography

Current Challenge:

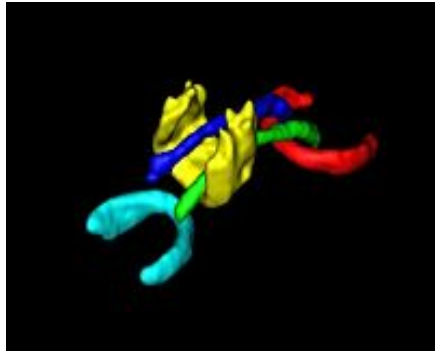
Characterization of  
different tractography  
approaches



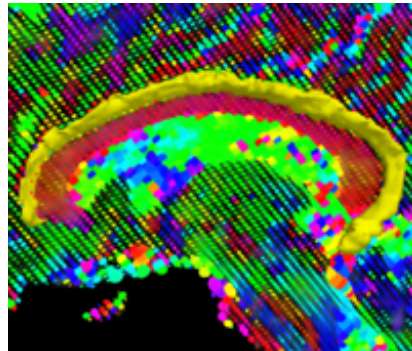
Courtesy of J De Siebenthal,  
CF Westin



Courtesy of A. Areza CF  
Westin



Courtesy of T.Fletcher & Ross  
Whitaker

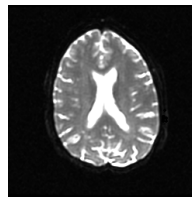


Courtesy of A. Tannenbaum





# Sources of variability

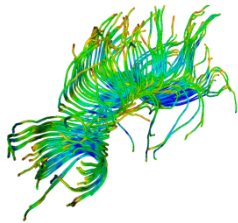


patient

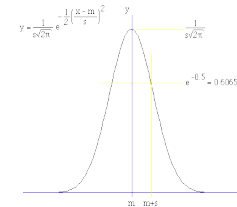


acquisition

fascicle



algorithm/models

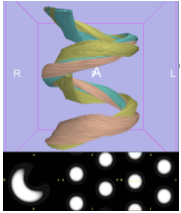


$$\ln p(X | \pi, \mu, \Sigma) = \sum_{n=1}^N \ln \left\{ \sum_{k=1}^K \pi_k N(x_n | \mu_k, \Sigma_k) \right\}$$

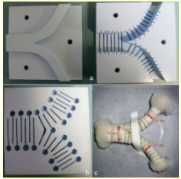


# Validation Approaches

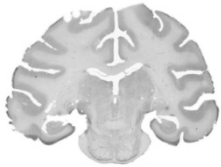
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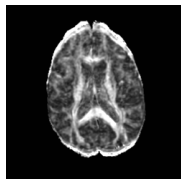
Mathematical Phantoms



Physical Phantoms



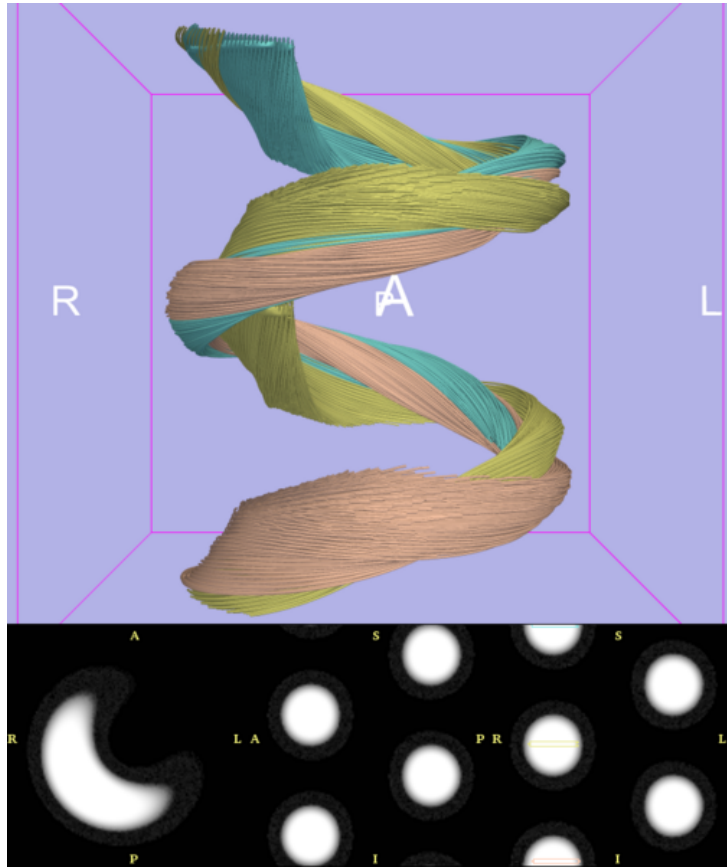
Histological Studies



Real Subject Data



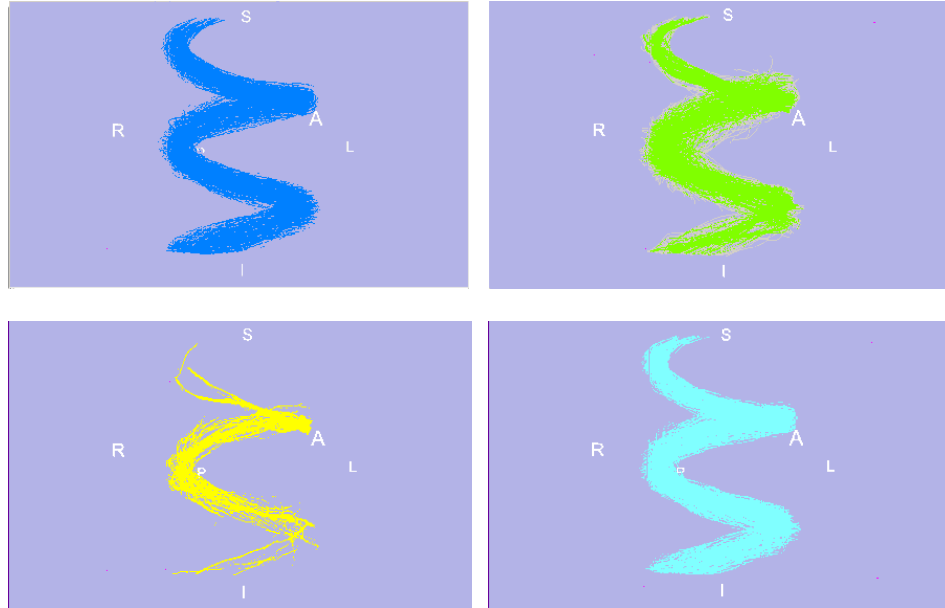
# Mathematical Phantoms



- Known absolute ground truth
- Freedom of shape design



# Mathematical Phantoms

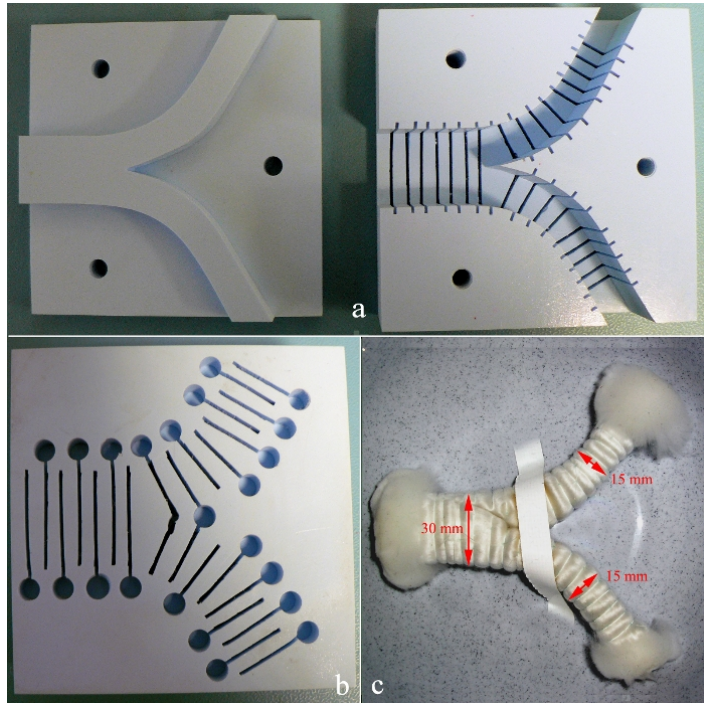


- Known absolute ground truth
- Freedom of shape design
- Freedom of parameter selection

Performance evaluation



# Physical Phantom



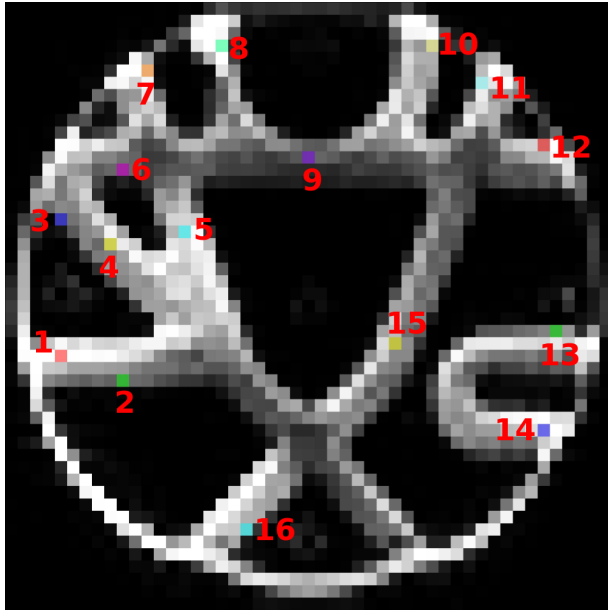
- Simple/complex tract configurations

**Poupon et al. Magn Reson Med.  
2008 Dec;60(6):1276-83.**



# Physical Phantom

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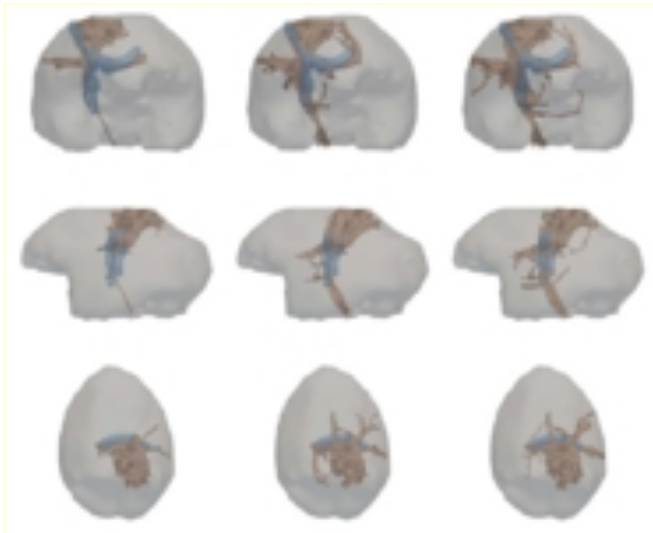
- Simple/complex tract configurations
- Real MR images
- Variations in voxel size, B-value and SNR

**Courtesy of C.Poupon and P.Fillard,  
LNAO**



# Histological studies

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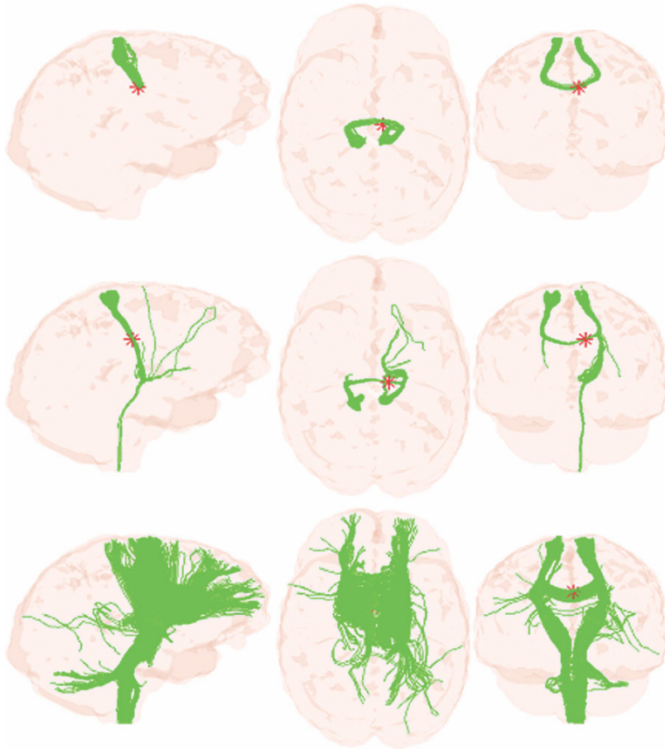
- Real anatomical structures
- Correlation with ground truth white matter anatomy

Dauguet et al, Neuroimage 2007



# Boostrapping

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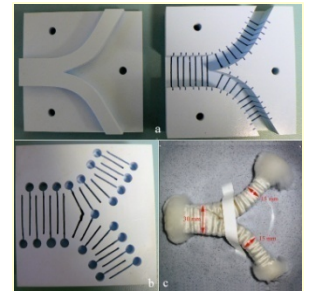
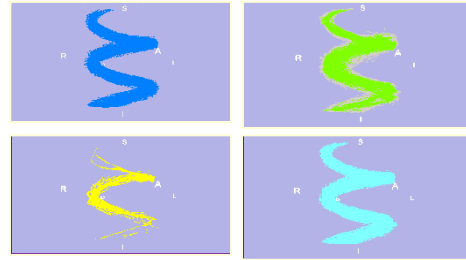
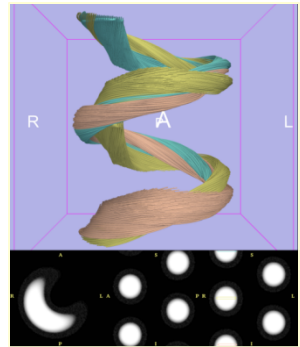
- Non parametric statistical approach
- Assessment of the precision of DTI tractography

Jones and Pierpaoli, MRM 2007

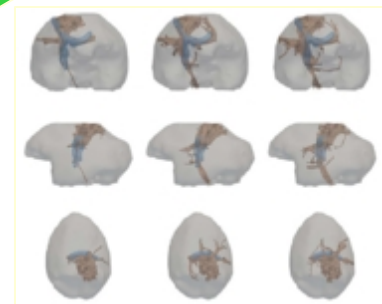
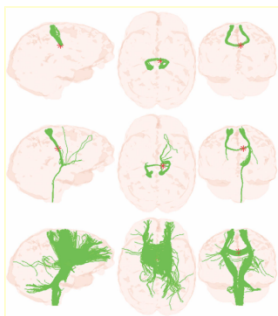




# Complementary approaches



Ground truth

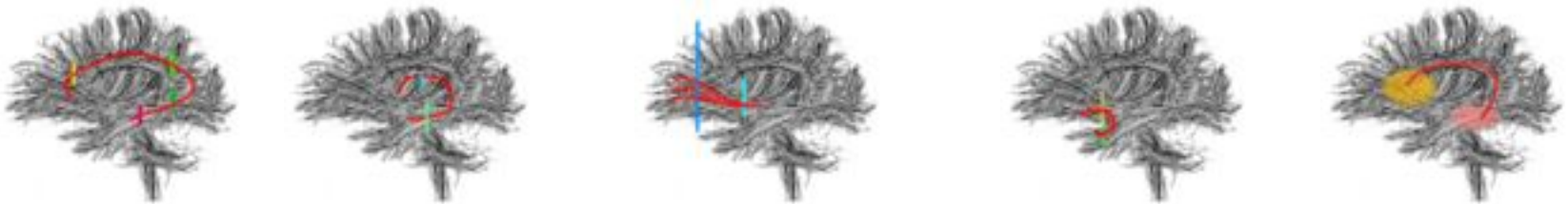




# NA-MIC pilot initiative

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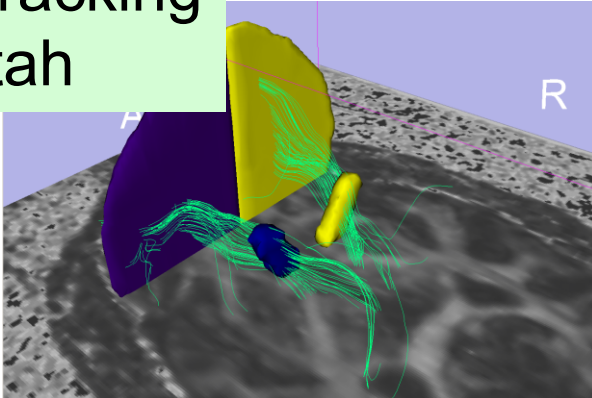
- Exploratory work initiated by the National Alliance for Medical Image Computing
- 7 major research centers across the US
- Cross-comparison of tractography algorithms on major white matter fascicles



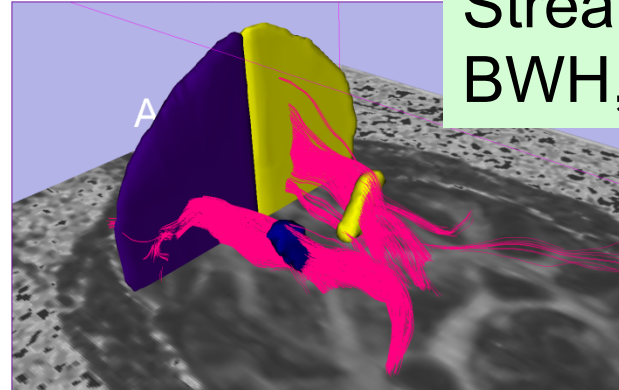


# Early Implementation

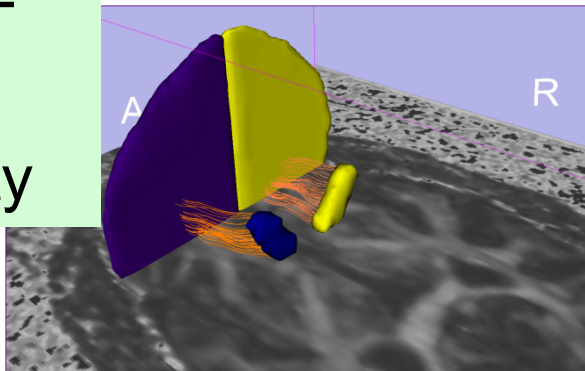
Fiber Tracking  
SCI, Utah



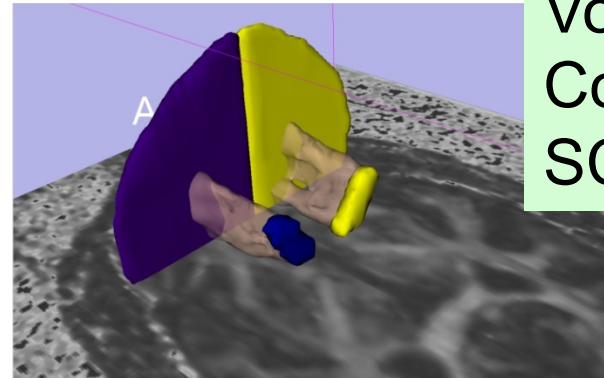
Streamline  
BWH, Harvard



GTRACT  
Iowa  
University



Volumetric  
Connectivity  
SCI, Utah



Pujol et al. ISMRM 2009

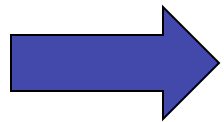


# Our approach

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- Comparison of segmentation of structural images in the absence of ground truth: STAPLE

*Warfield SK, Zou KH, Wells WM. STAPLE. Simultaneous Truth and Performance Level Estimation (STAPLE): An algorithm for the Validation of Image Segmentation. IEEE Trans Med Imaging. 23(7):903-21.*



## Application to DTI Segmentation

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# STAPLE

(Simultaneous Truth and Performance Level Evaluation)

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- Expectation-Maximization algorithm (EM) to maximize the incomplete data log likelihood function

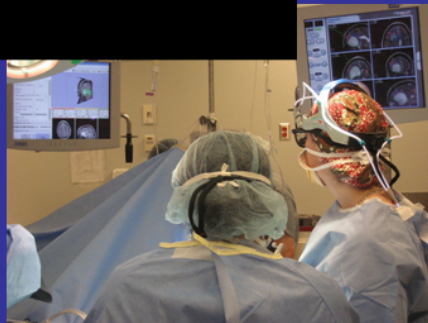
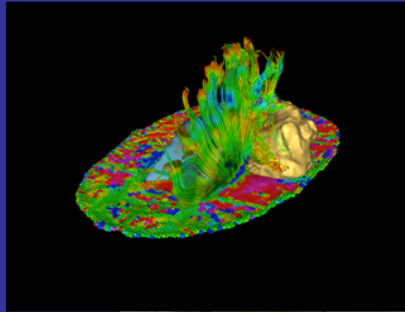
$$\ln f(D | p, q)$$

*Warfield SK, Zou KH, **Wells WM.** STAPLE. Simultaneous Truth and Performance Level Estimation (STAPLE): An algorithm for the Validation of Image Segmentation. IEEE Trans Med Imaging. 23(7):903-21.*



# MICCAI 2011 DTI Challenge

14<sup>th</sup> International Conference on Medical Image Computing and Computer Assisted Intervention



## DTI Tractography for Neurosurgical Planning: A Grand Challenge

Sunday September 18, 2011  
Westin Harbor Hotel  
Toronto, Canada

### Workshop Faculty

*Sonia Pujol, PhD, Brigham and Women's Hospital, Harvard Medical School*  
*Ron Kikinis, MD, Brigham and Women's Hospital, Harvard Medical School*  
*Alexandra Golby, MD, Brigham and Women's Hospital, Harvard Medical School*  
*Guido Gerig, PhD, The Scientific Computing and Imaging Institute, University of Utah*  
*Martin Styner, PhD, Neuroimage Research and Analysis Laboratory, University of North Carolina*  
*William Wells, PhD, Brigham and Women's Hospital, Harvard Medical School*  
*Carl-Fredrik Westin, PhD, Brigham and Women's Hospital, Harvard Medical School*  
*Sylvain Gouttard, MSc, The Scientific Computing and Imaging Institute, University of Utah*

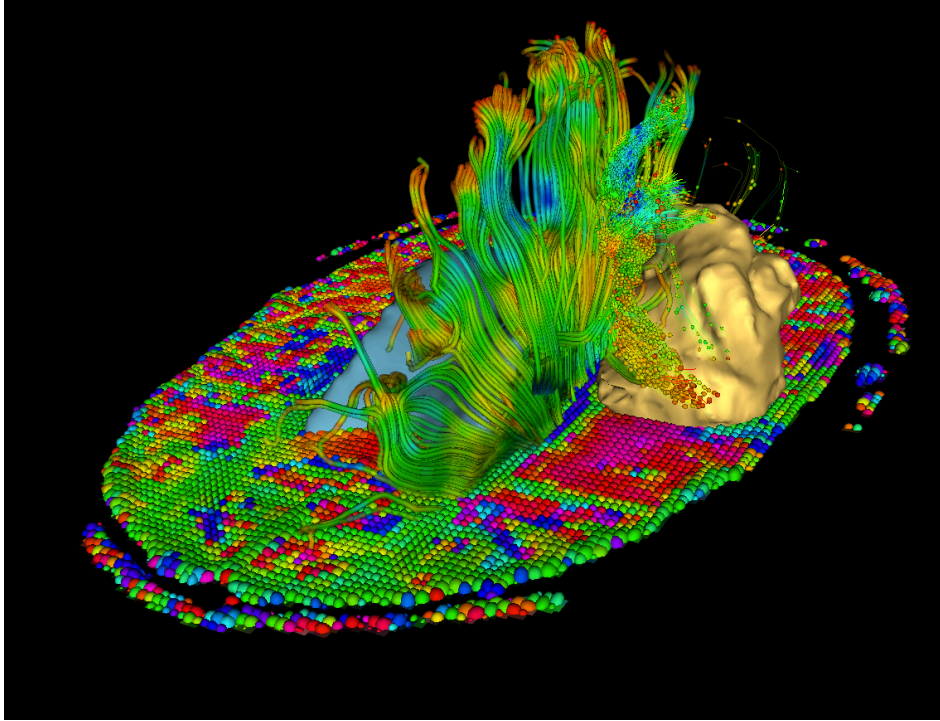
MICCAI 2011 workshop  
National Alliance for Medical Image Computing

[http://www.na-mic.org/Wiki/index.php/Events\\_DTI\\_Tractography\\_Challenge\\_MICCAI\\_2011](http://www.na-mic.org/Wiki/index.php/Events_DTI_Tractography_Challenge_MICCAI_2011)



# MICCAI 2011 DTI Tractography Challenge

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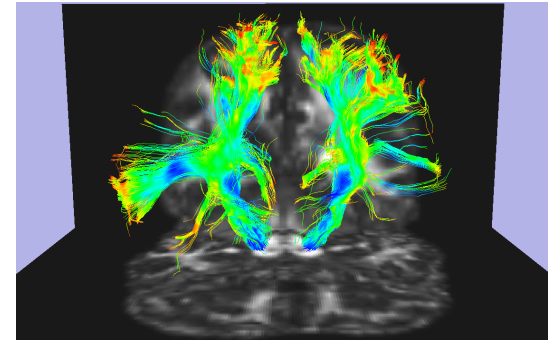


- Four clinical cases with
  - T1, T2 anatomical scans
  - DWI acquisitions
  - Segmentation of tumor and edema
- Two healthy subject scans with repeated acquisitions of T1, T2, and DWI images
- Qualitative evaluation and quantitative assessment



# MICCAI 2011 DTI Challenge

Study of the variability of algorithms  
in healthy subjects



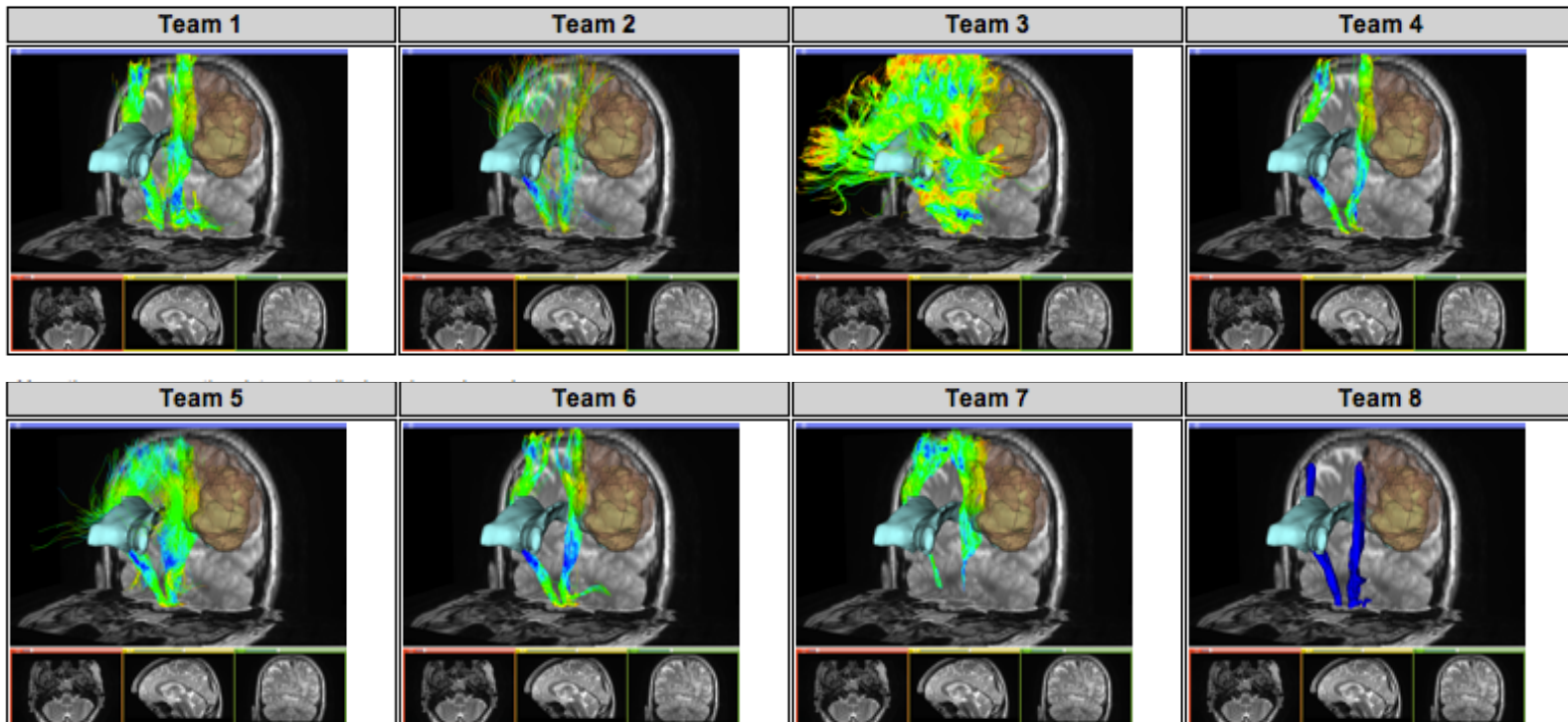
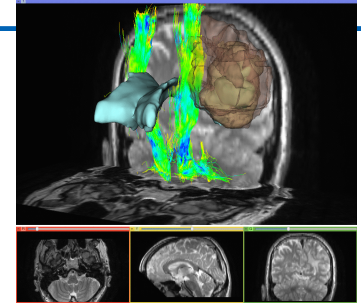
-	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10
Team 1										
Team 2										
Team 3										
Team 4										
Team 5										
Team 6										
Team 7										
Team 8										





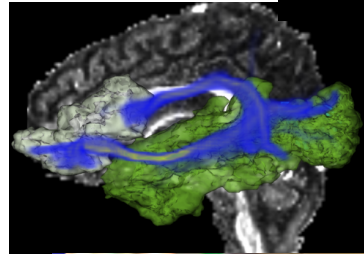
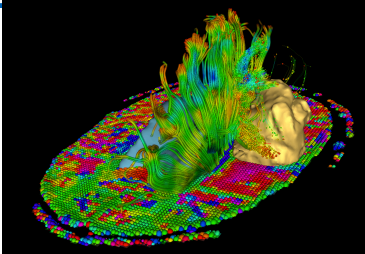
# MICCAI 2011 DTI Challenge

Study of the variability of algorithms  
in neurosurgical cases





# How to choose ?



Neurosurgeons face the challenge of selecting the appropriate tractography method and tract selection strategy

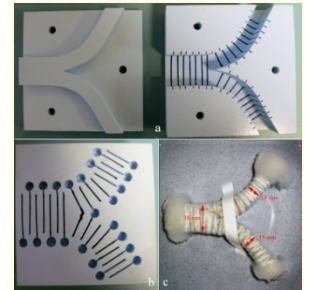
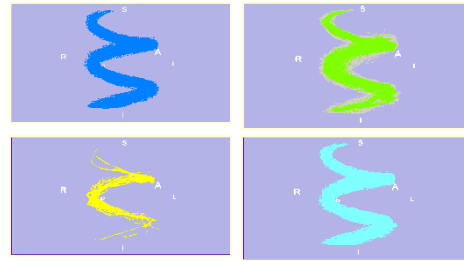
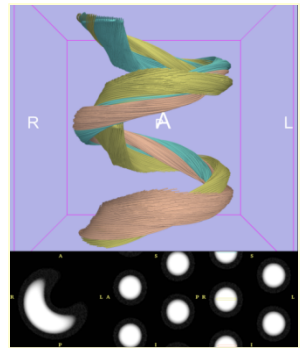


Need for validation to accelerate clinical use of DT-MRI findings

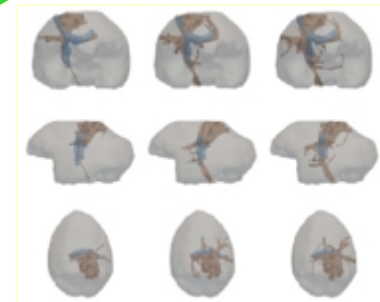
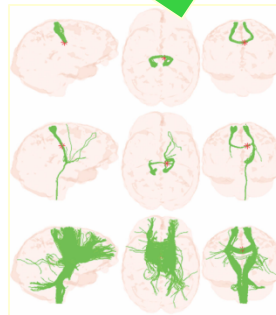
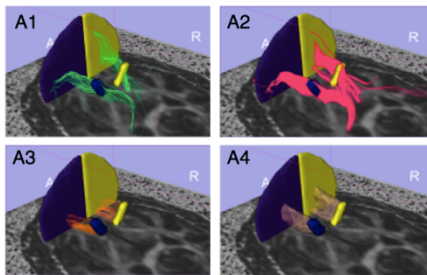




# Complementary approaches



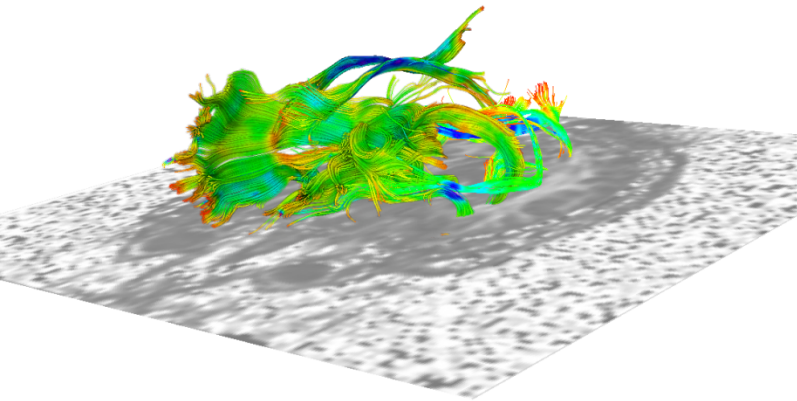
Ground truth





# Conclusion

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- Evaluation of various tractography approaches in the absence of ground truth
- Validation is key to the transfer from bench to bedside
- DTI tractography as an *in-vivo* neuroimaging marker



# Acknowledgements

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National Alliance for Medical Image Computing (NA-MIC)  
(NIH Grant U54EB005149)



Neuroimage Analysis Center (NAC)  
(NIH Grant P41 RR013218)