



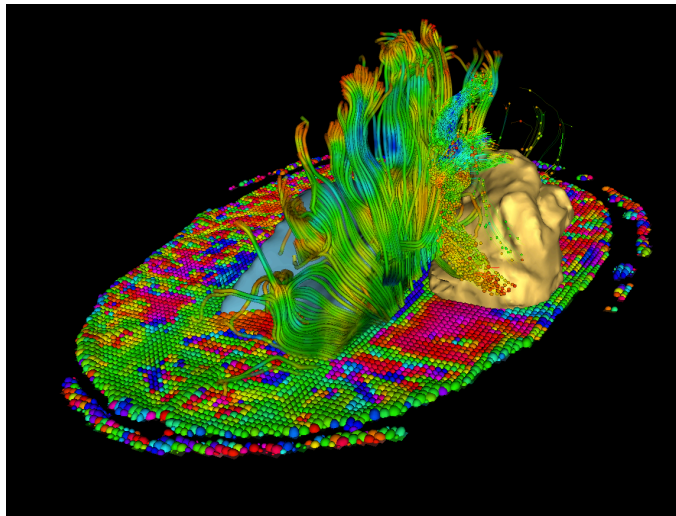
NAC



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

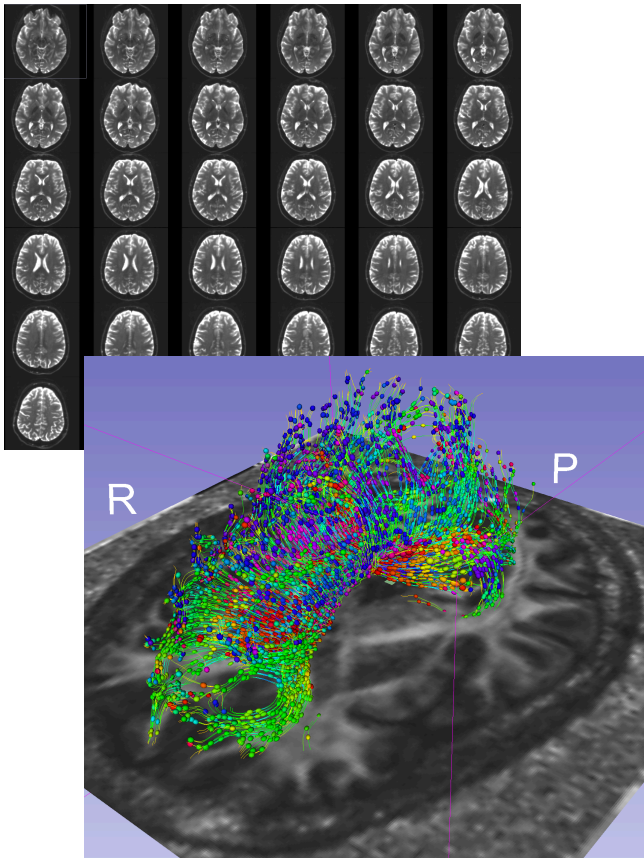
Sonia Pujol, Ph.D.

*Surgical Planning Laboratory
Harvard University*





White Matter architecture



- 100 billions of neurons in 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

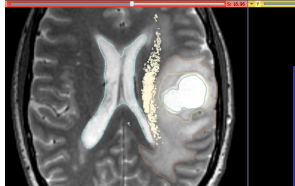
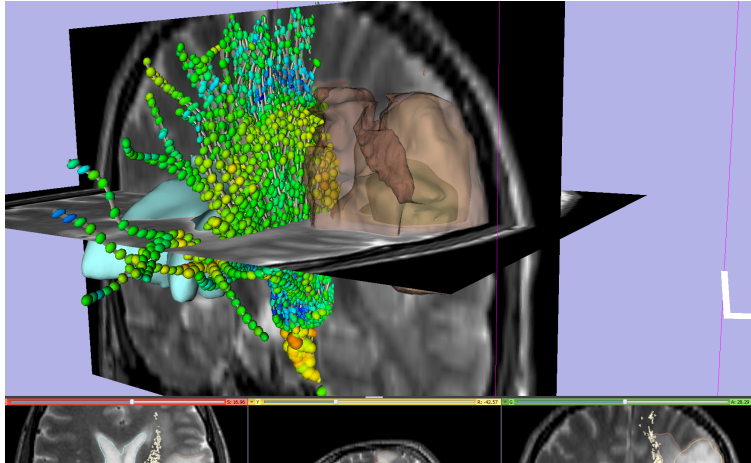


DTI as a Neuroimaging marker

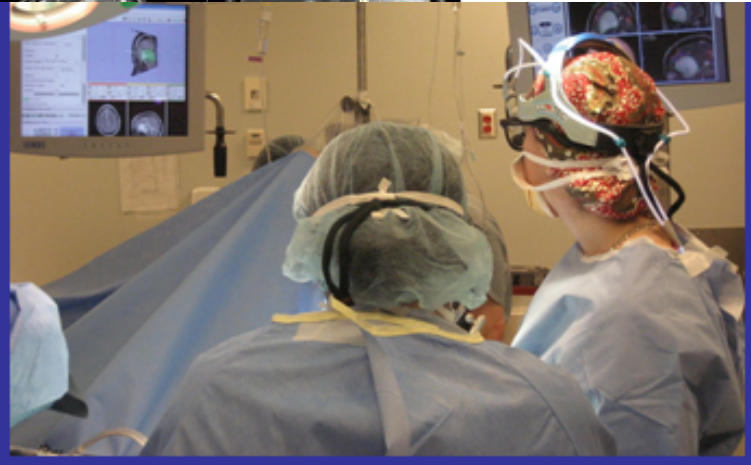
- Visualization of *in-vivo* normal and pathological anatomy
- Insights into white matter abnormalities which may include changes in *direction*, *radial displacement* or *diameter* of white matter fiber bundles



Tractography for neurosurgery



Ron Kikinis, MD
Alex Golby, MD

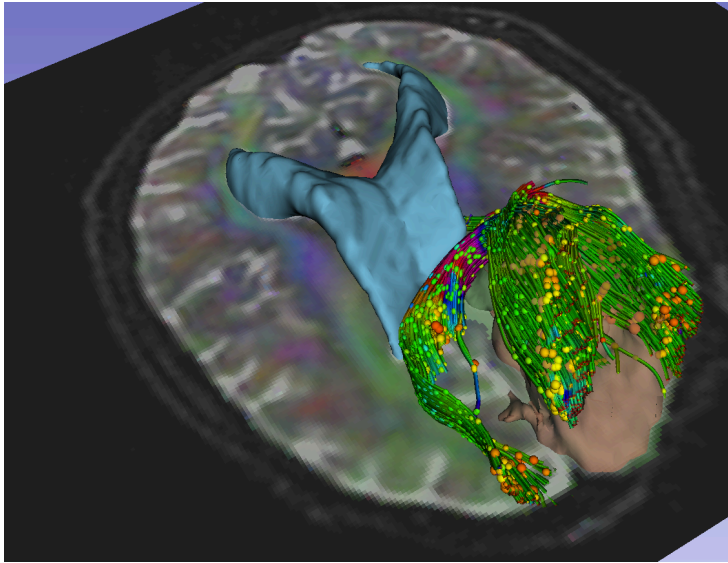


The location and integrity of eloquent white matter pathways is of major importance during neurosurgical planning

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



Tractography for neurosurgery

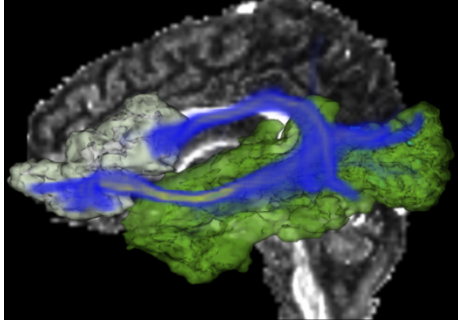


Tractography has the potential to bring valuable information to the neurosurgeon

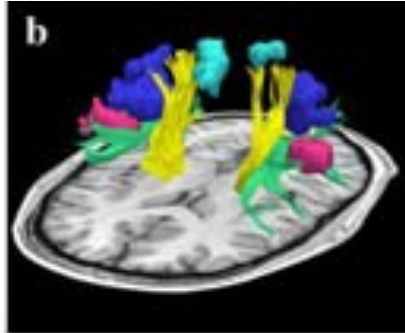
- Spatial relationship between the tract and the tumor
- Demonstration of tract displacement
- Assessment of tumor infiltration



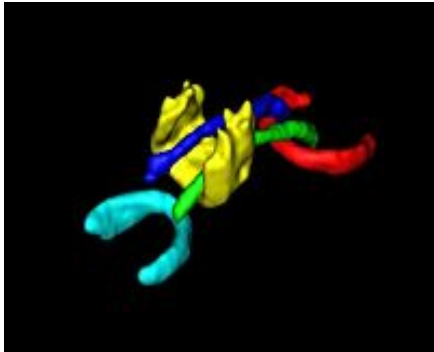
Tractography



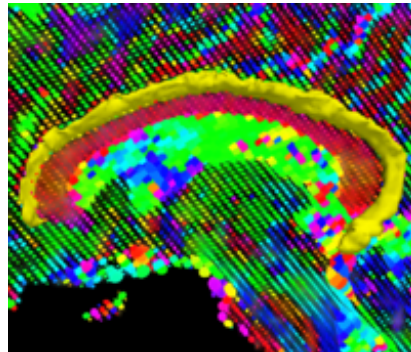
Courtesy of J De Siebenthal & CF Westin



Courtesy of A. Areza & CF Westin



Courtesy of T.Fletcher & R. Whitaker



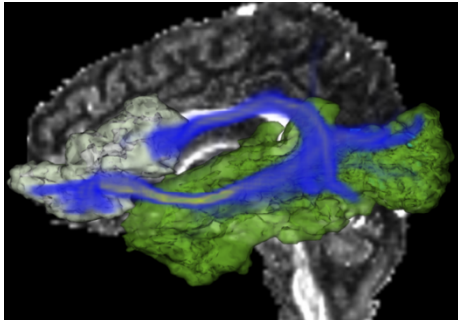
Courtesy of A. Tannenbaum

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

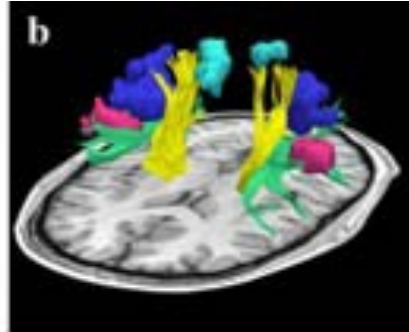


Tractography

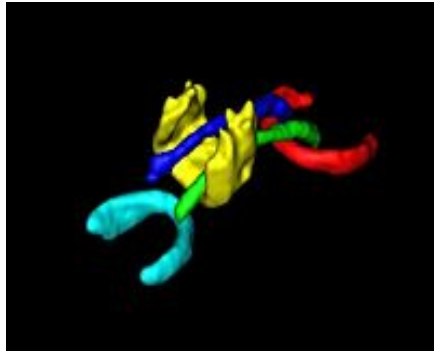
Current achievements include:



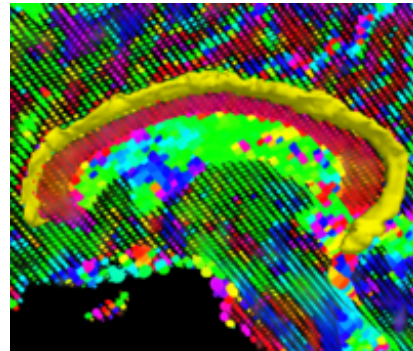
Courtesy of J De Siebenthal & CF Westin



Courtesy of A. Areza & CF Westin



Courtesy of T.Fletcher & R. Whitaker

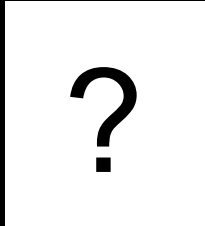
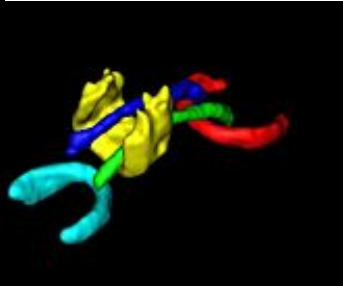
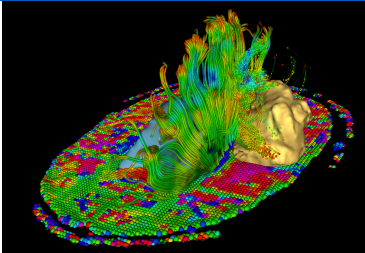


Courtesy of A. Tannenbaum

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



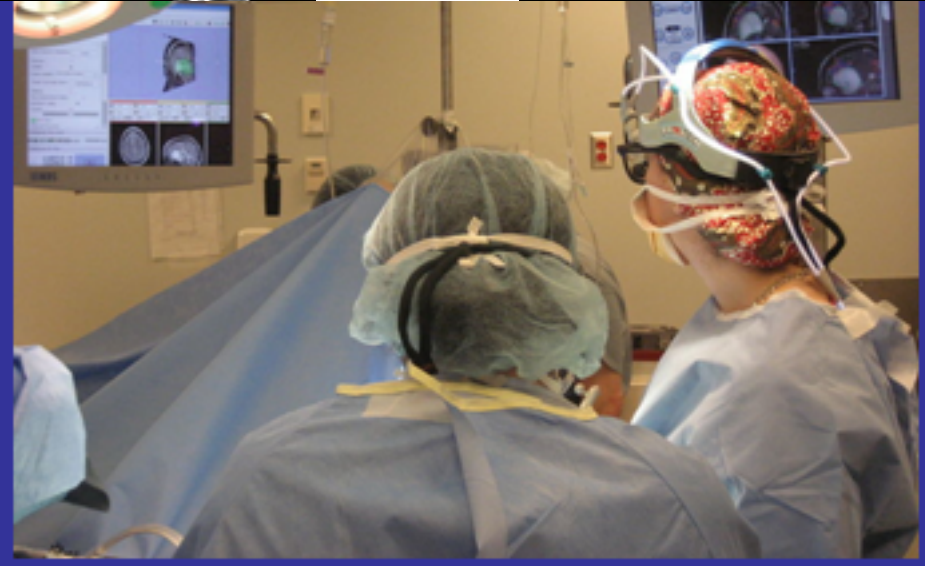
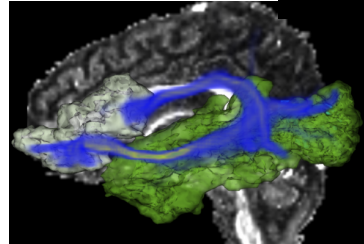
How to choose ?



Neurosurgeons face the challenge of selecting the appropriate tractography method



Need for tool comparison

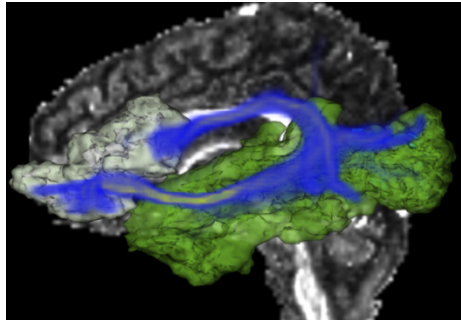




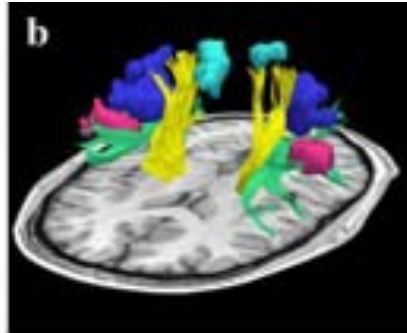
Tractography

Current Challenge:

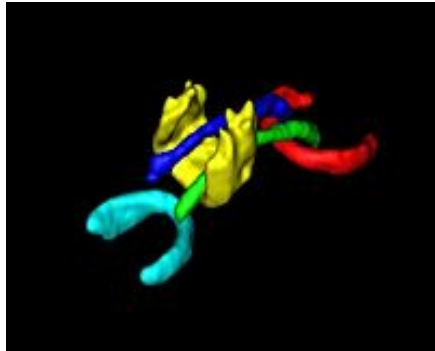
Characterization of
different tractography
approaches



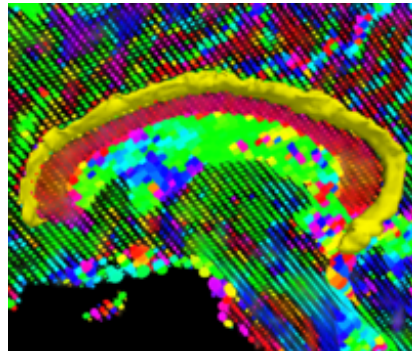
Courtesy of J De Siebenthal,
CF Westin



Courtesy of A. Areza CF
Westin



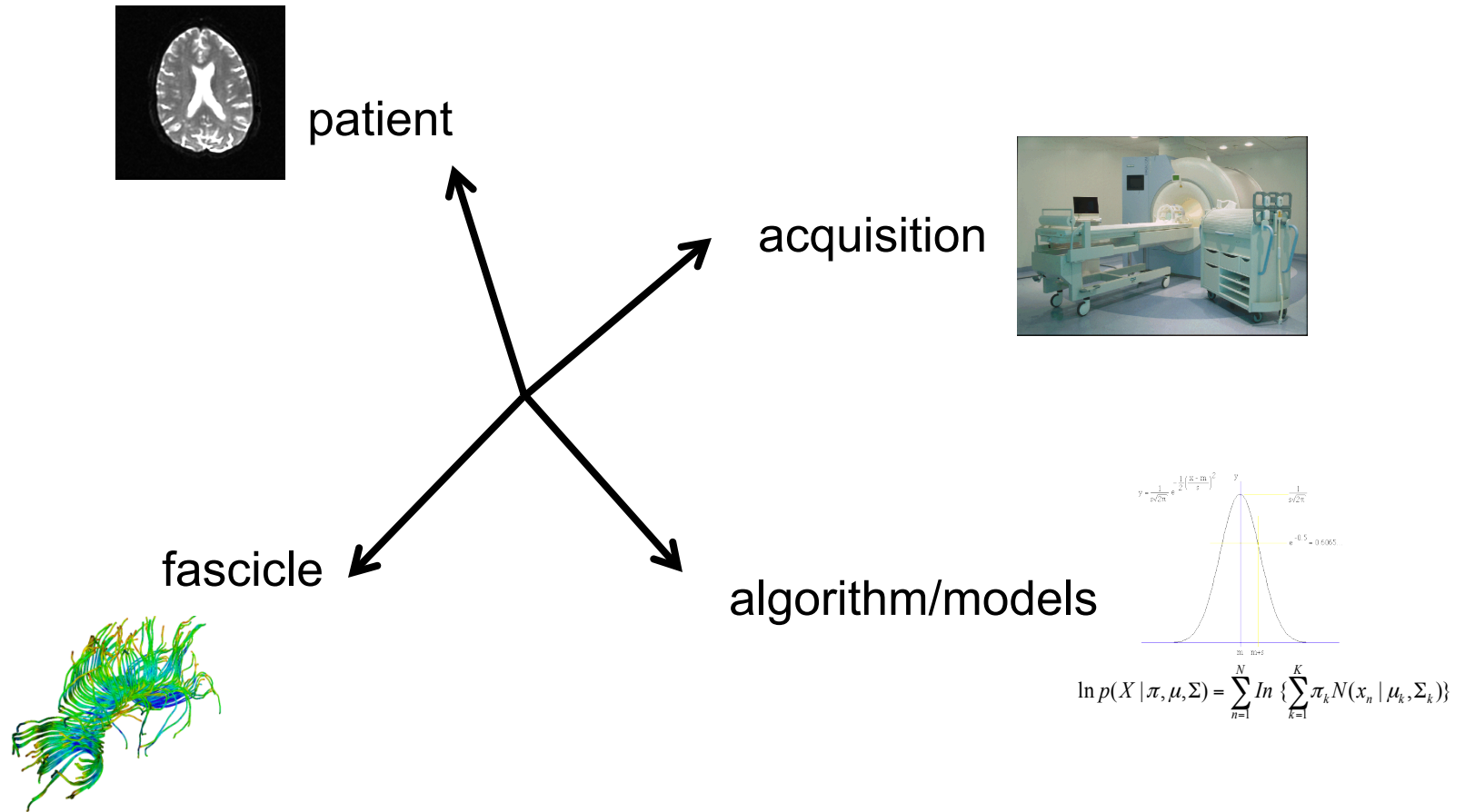
Courtesy of T.Fletcher & Ross
Whitaker



Courtesy of A. Tannenbaum

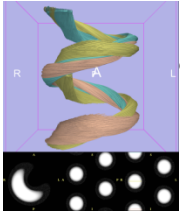


Sources of variability

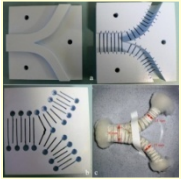




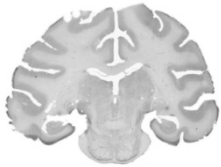
Validation Approaches



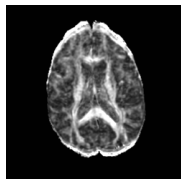
Mathematical Phantoms



Physical Phantoms



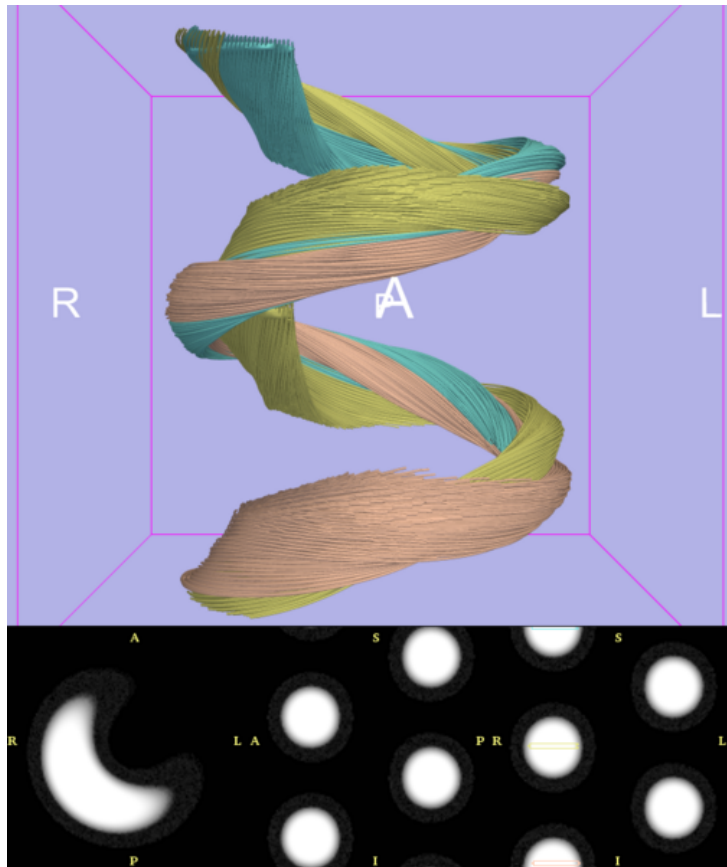
Histological Studies



Real Subject Data



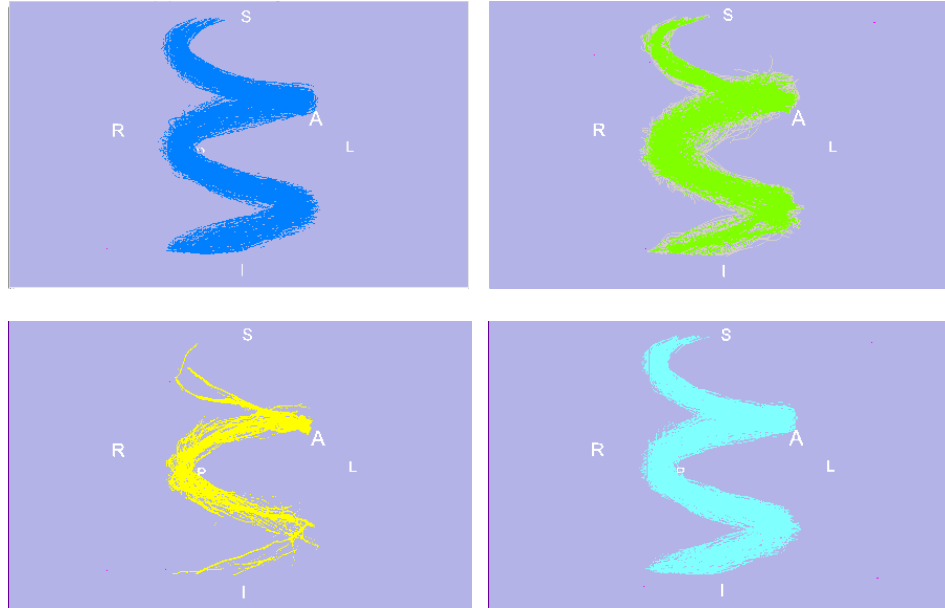
Mathematical Phantoms



- Known absolute ground truth
- Freedom of shape design



Mathematical Phantoms

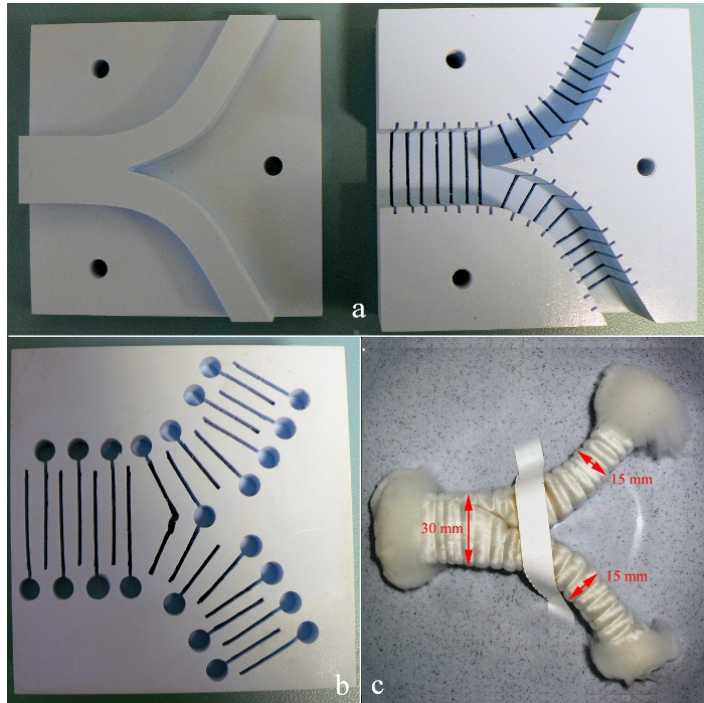


- Known absolute ground truth
- Freedom of shape design
- Freedom of parameter selection

Performance evaluation



Physical Phantom

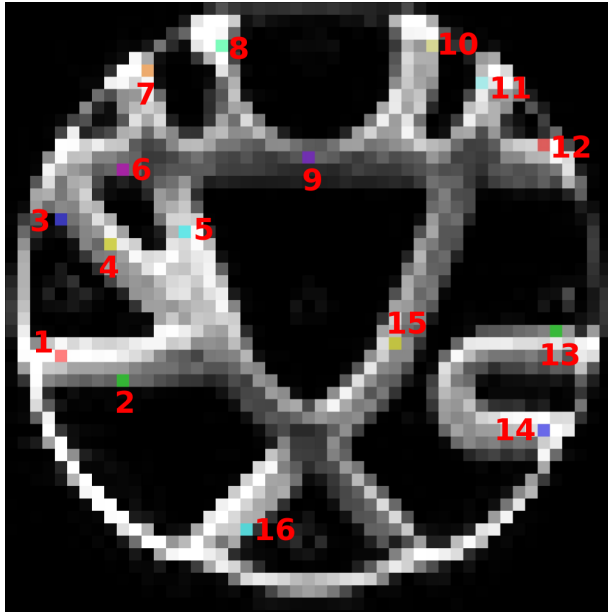


- Simple/complex tract configurations

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



Physical Phantom

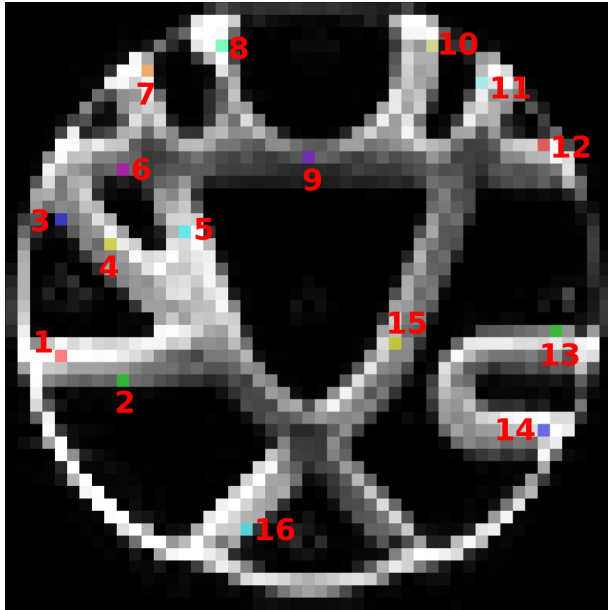


- Simple/complex tract configurations
- Real MR images

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



Physical Phantom



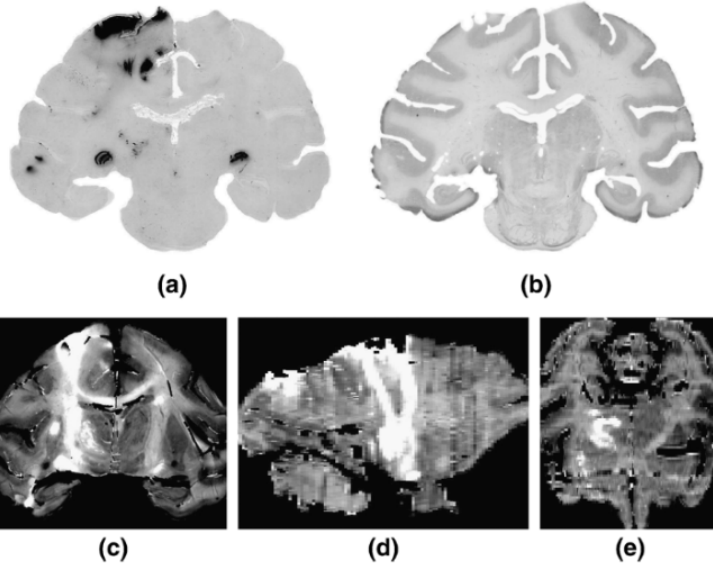
- Simple/complex tract configurations
- Real MR images
- Variations in voxel size, B-value and SNR

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



Histological studies

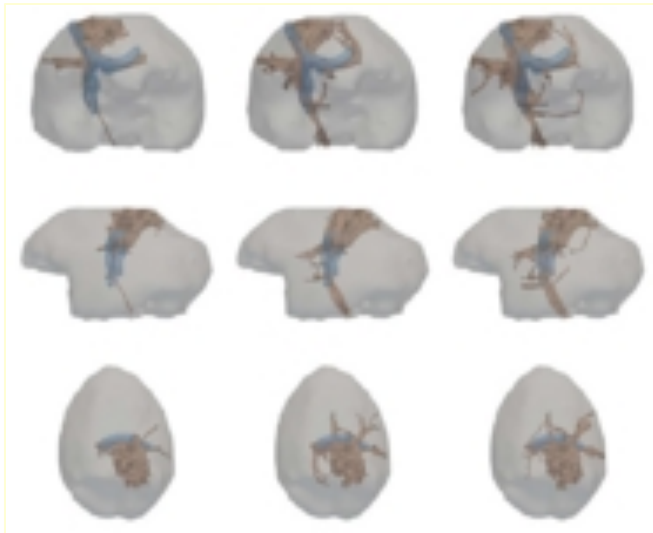
- Real anatomical structures



Dauguet et al, MICCAI 2006



Histological studies

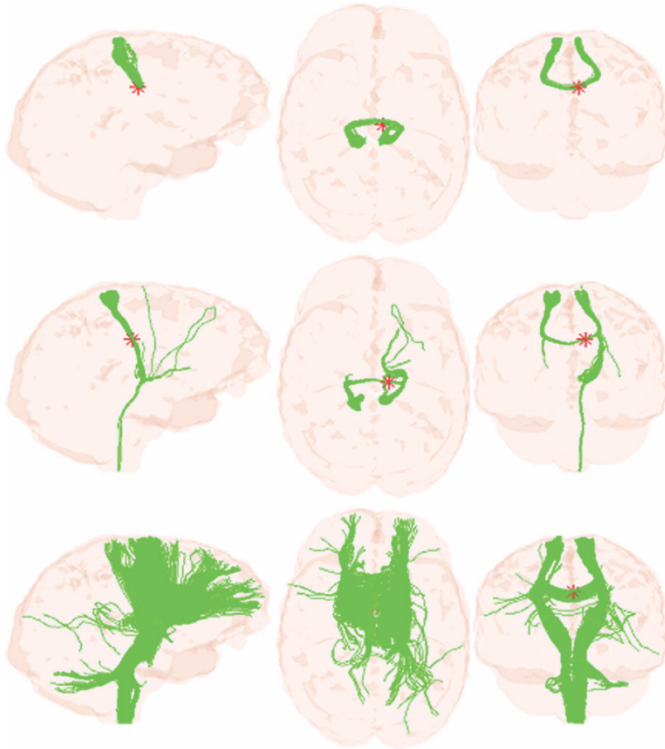


- Real anatomical structures
- Correlation with ground truth white matter anatomy

Dauguet et al, Neuroimage 2007



Boostrapping

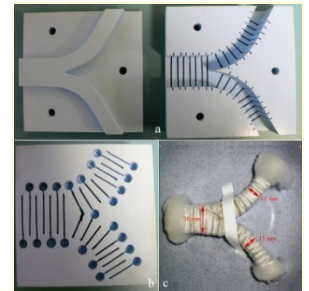
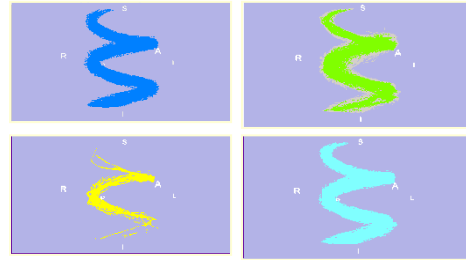
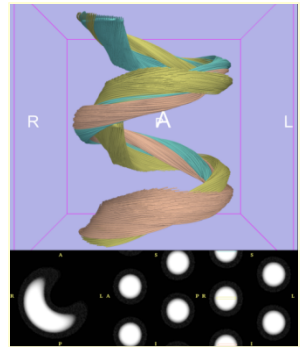


- Non parametric statistical approach
- Assessment of the precision of DTI tractography

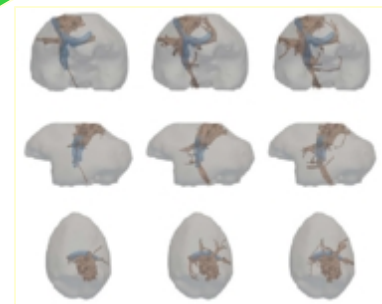
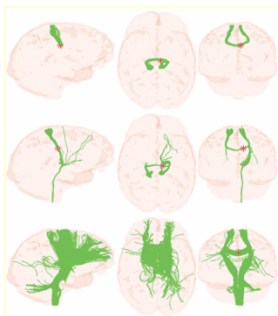
Jones and Pierpaoli, MRM 2007



Complementary approaches



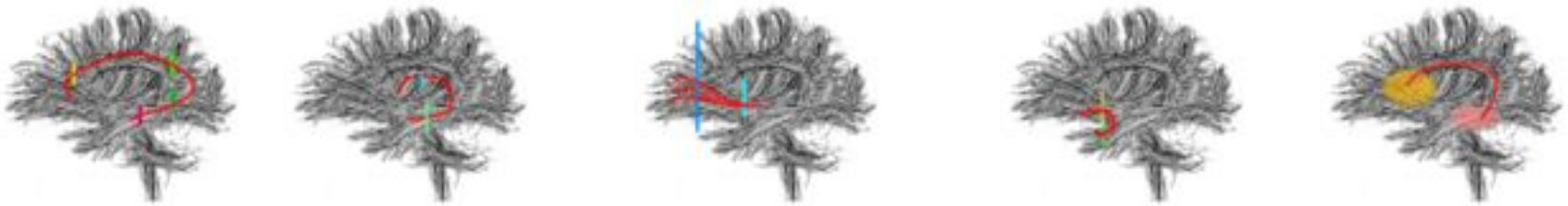
Ground truth





NA-MIC pilot initiative

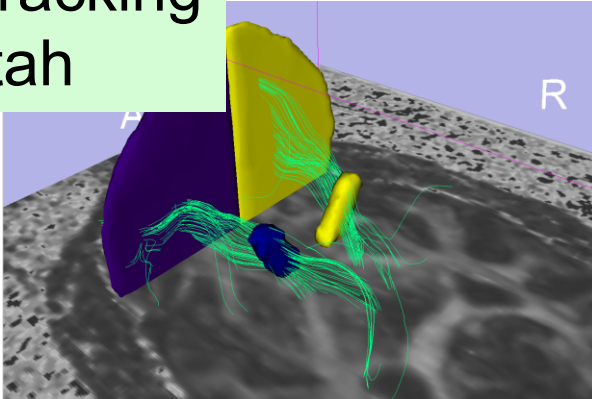
- Exploratory work initiated by the National Alliance for Medical Image Computing
- 7 major research centers across the US
- Cross-comparison of tractography algorithms on major white matter fascicles



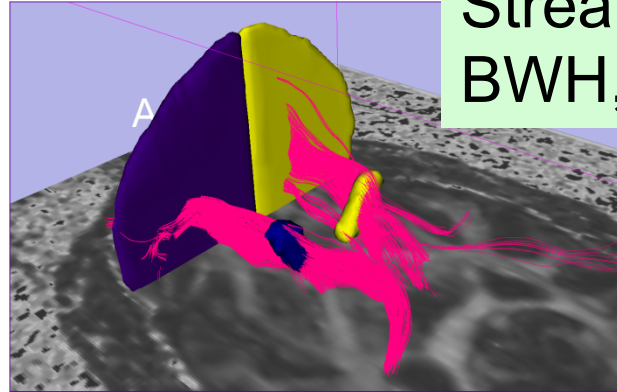


Early Implementation

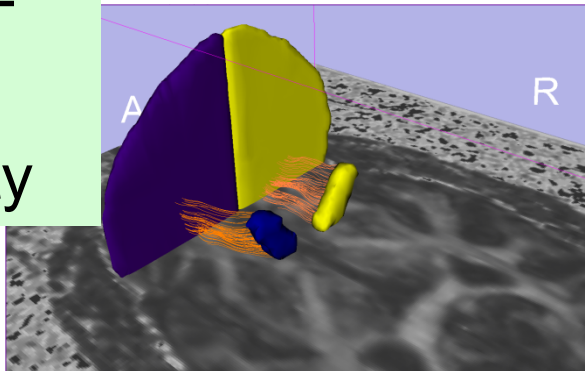
Fiber Tracking
SCI, Utah



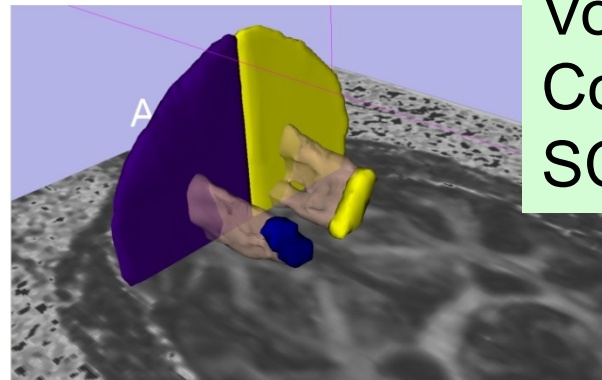
Streamline
BWH, Harvard



GTRACT
Iowa
University



Volumetric
Connectivity
SCI, Utah

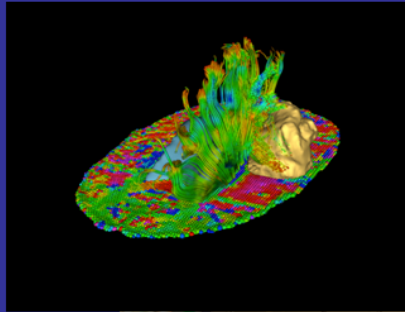


Pujol et al. ISMRM 2009



MICCAI 2011 DTI Challenge

14th 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

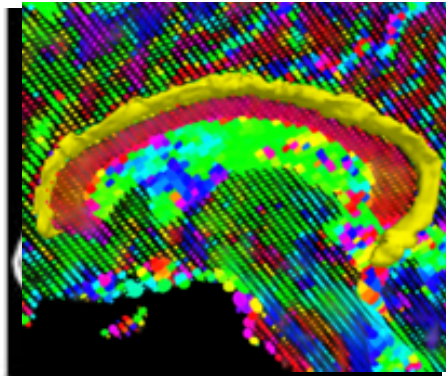
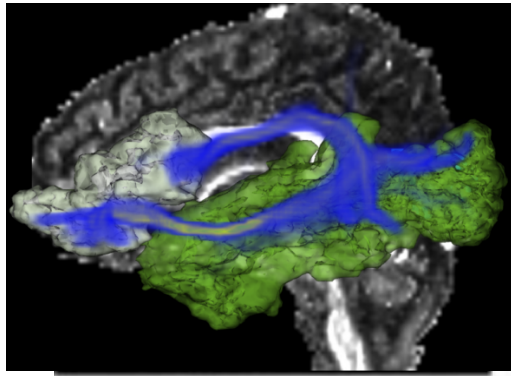
Sonia Pujol, PhD, Brigham and Women's Hospital, Harvard Medical School
Ron Kikinis, MD, Brigham and Women's Hospital, Harvard Medical School
Alexandra Golby, MD, Brigham and Women's Hospital, Harvard Medical School
Guido Gerig, PhD, The Scientific Computing and Imaging Institute, University of Utah
Martin 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

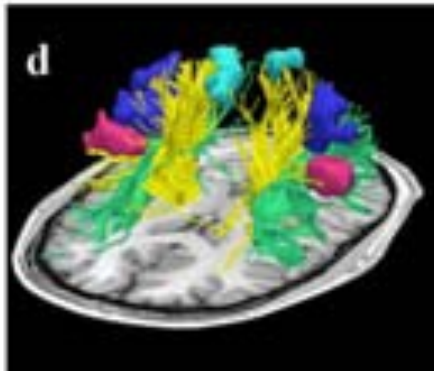
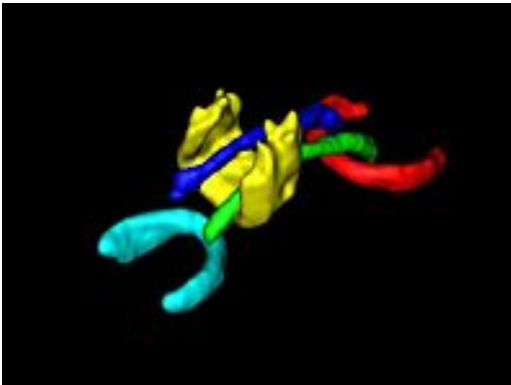
http://www.na-mic.org/Wiki/index.php/Events_DTI_Tractography_Challenge_MICCAI_2011



Goal of the workshop

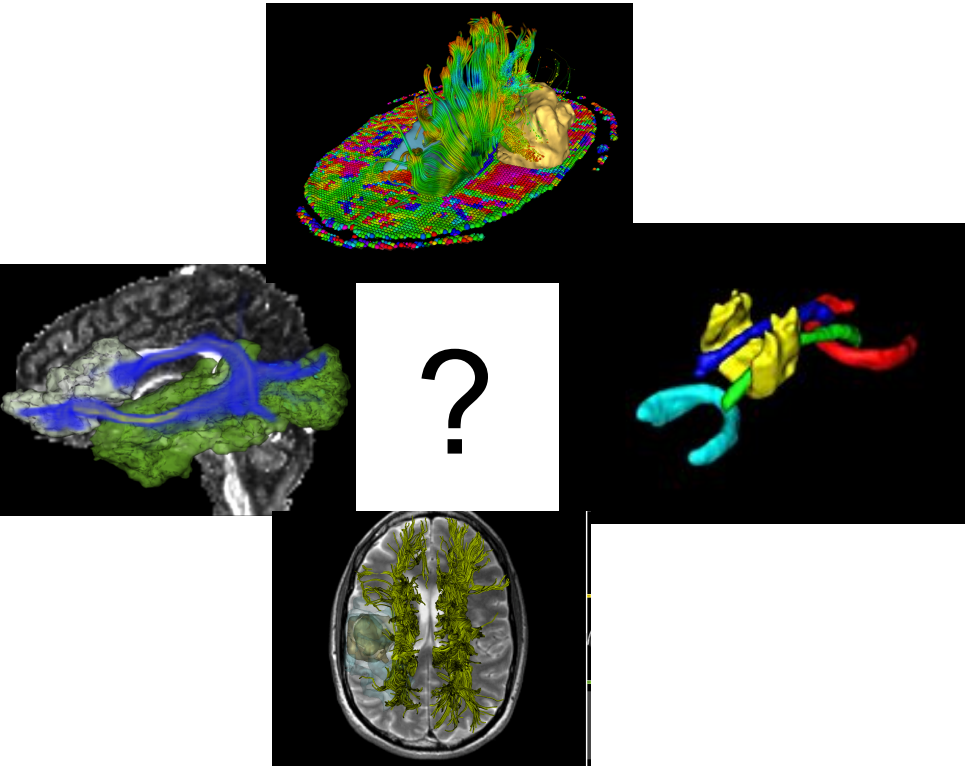


Qualitative and quantitative evaluation of multiple existing tractography algorithms





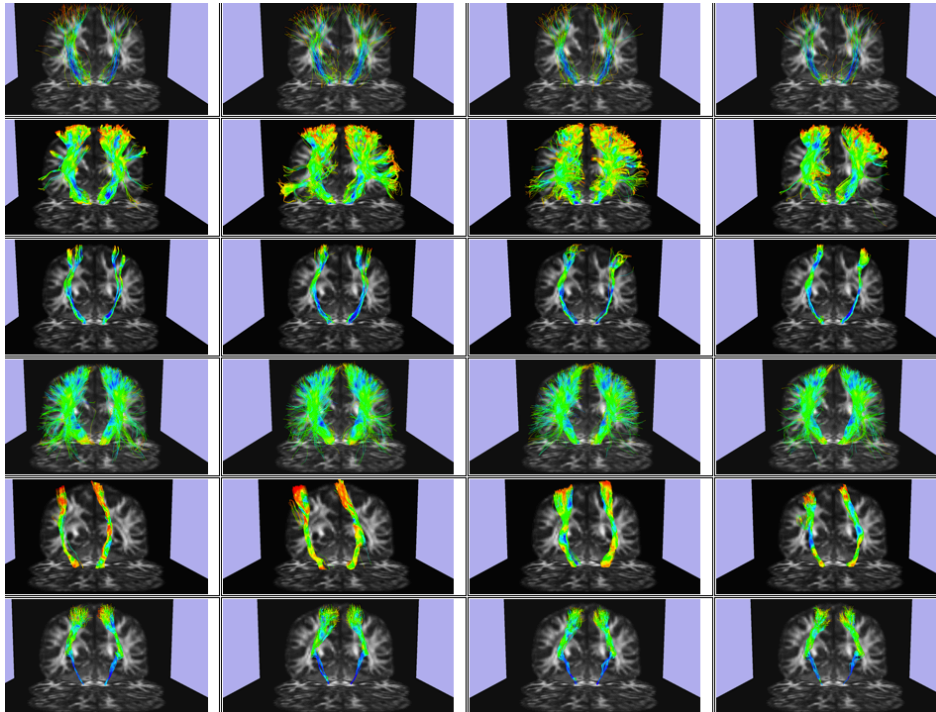
How to compare?



Many degrees of variability
(patient, MR sequence, tumor location, etc..)



How to compare?



Many degrees of variability

(patient, MR sequence, tumor location, etc..)

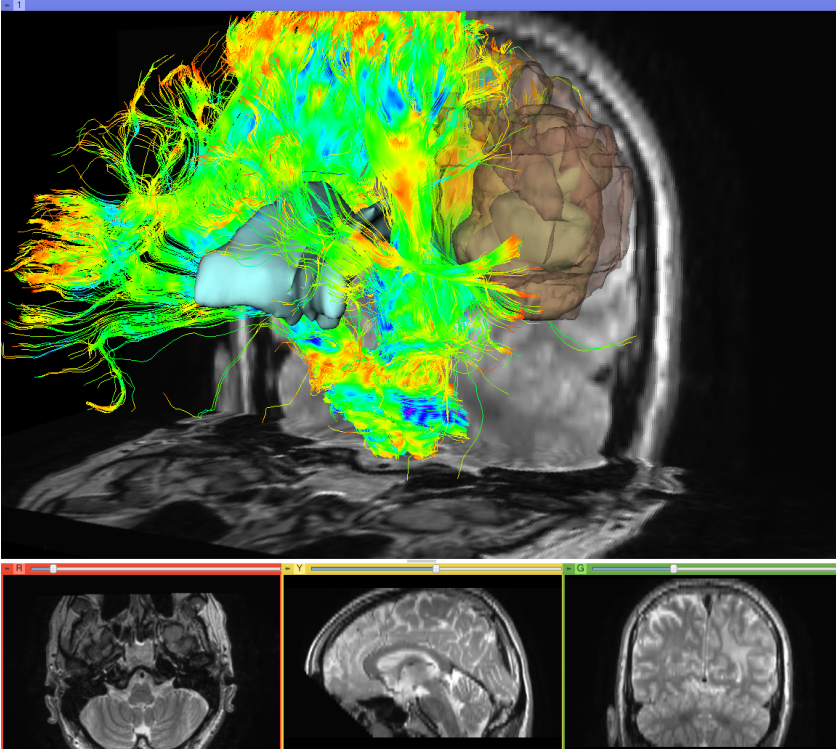


Standardized evaluation on a common set of data



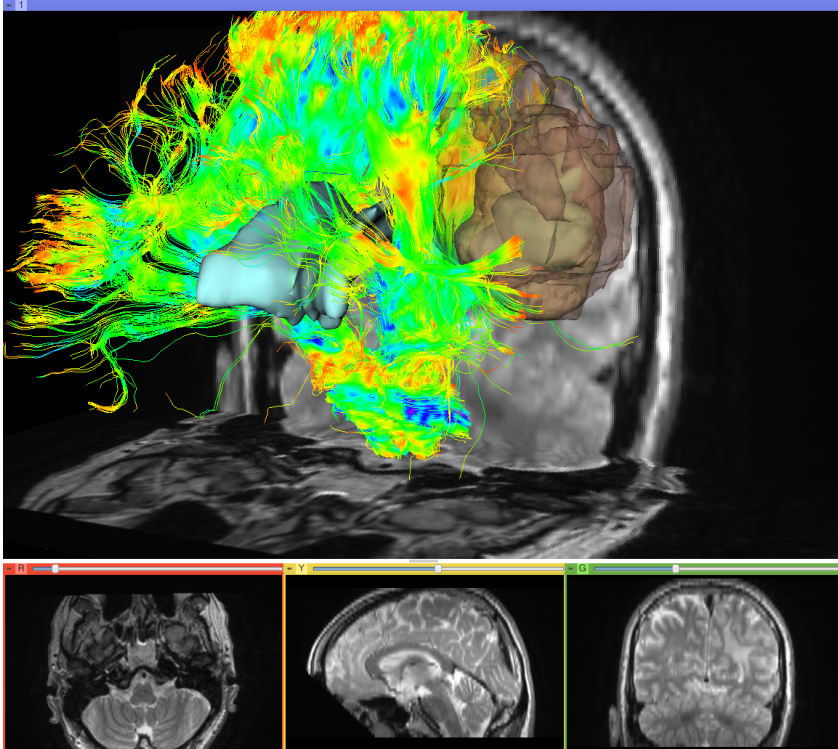
How to compare?

Absence of ground truth





How to compare?



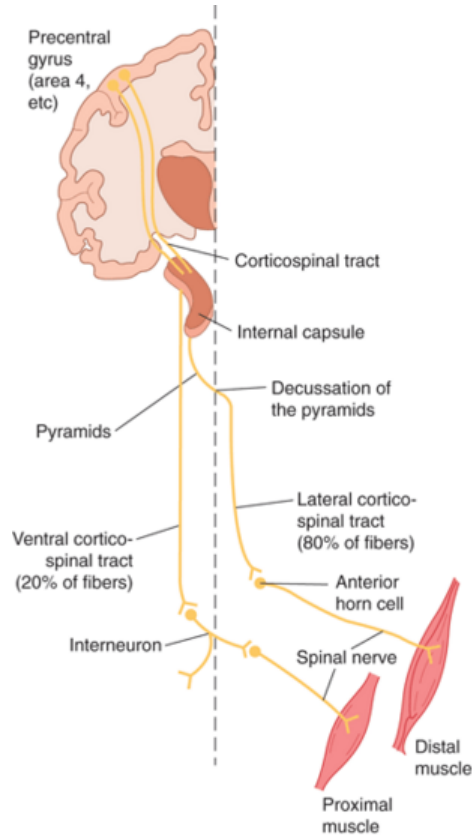
Absence of ground truth



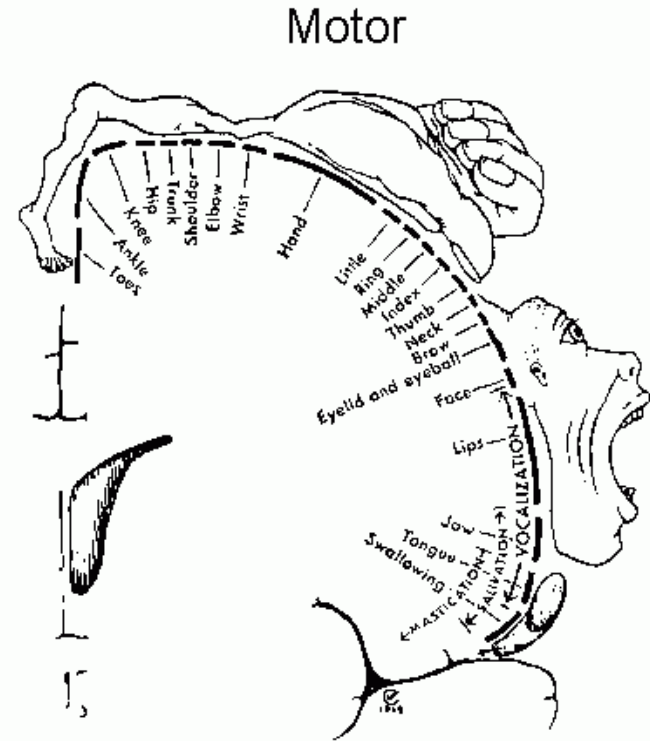
Combination of qualitative and quantitative criteria to get closer to the ground truth



Corticospinal tract



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology*, 23rd Edition: <http://www.accessmedicine.com>



(After W. Penfield and T. Rasmussen, 1950)



Workshop datasets

- Four neurosurgical cases involving the CST
 - Patient1: Residual anaplastic oligoastrocytoma
 - Patient2: Anaplastic oligoastrocytoma
 - Patient3: Anaplastic oligodendroglioma
 - Patient4: Glioblastoma grade 4

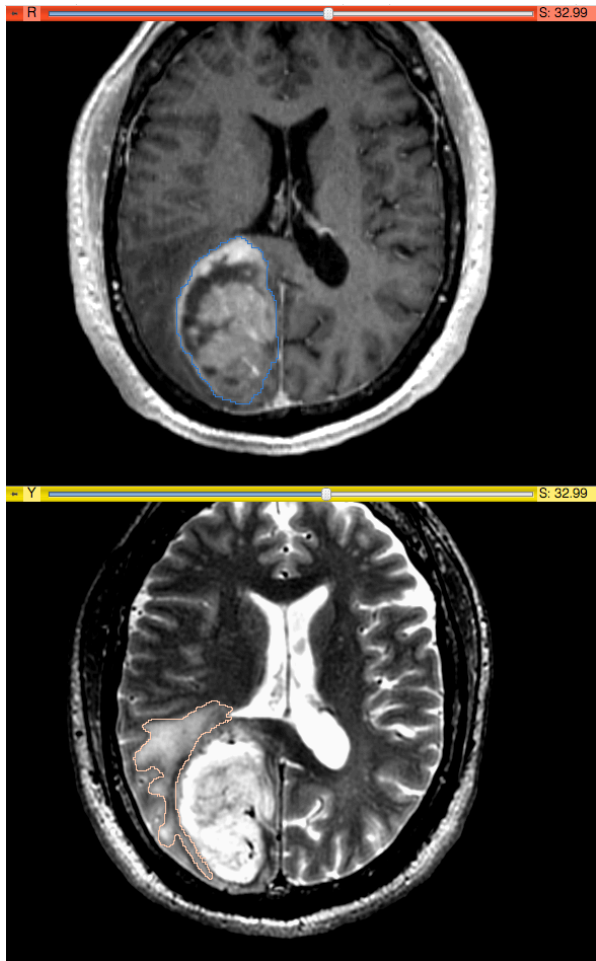
Cases provided by Dr. Alexandra Golby, neurosurgeon, BWH

- Two healthy subjects scanned twice on 5 different scanners

Datasets provided by Guido Gerig, Ph.D, SCI Utah



Workshop Datasets



- Each dataset included T1-weighted, T2-weighted, Pre-op DWI and DTI
- Manual segmentation of tumor and edema on T1 and T2 images
- Review by expert neuroradiologist



Evaluation Criteria

Two sets of metrics

- Qualitative assessment by clinicians and DTI experts
- Quantitative analysis based on five different metrics



Quantitative evaluation

Metric 1: Dice coefficient of overlap

Metric 2: Hausdorff distance

Metric 3: Fiber FA and MD profile along tract

Metric 4: STAPLE sensitivity score

Metric 5: STAPLE specificity score



Clinical Evaluation Criteria

- C1: Anatomical correctness of the tract
- C2: Presence of false positive-tracts
- C3: Presence of false negative-tracts
- C4: Distance between the tract and the lesion
- C5: Demonstration of tract displacement
- C6: Demonstration of tumor infiltration

→ critical to the neurosurgeon



MICCAI 2011 Workshop

- 8 international teams
- 10-hour long workshop
- 25 participants
- 352 corticospinal tracts generated
- 5,900 visits on challenge webpage



DTI Tractography for Neurosurgical Planning: A Grand Challenge

Welcome to the DTI Tractography for Neurosurgical Planning: A Grand Challenge workshop. The goal of the initiative is to provide neurosurgeons with an overview of the progress in the field of DTI Tractography for Neurosurgical Planning and to provide a platform for the development and validation of new DTI Tractography techniques. DTI Tractography for Neurosurgical Planning: A Grand Challenge workshop will give participants the opportunity to evaluate the performance of their Tractography Techniques and gain insights on the currently available paradigms for evaluating tractography results in the Operating Room in the absence of ground truth.

Faculty:

- Boris Poon, Ph.D., Surgical Planning Laboratory, Brigham and Women's Hospital, Harvard Medical School
- Ben Adams, M.D., Surgical Planning Laboratory, Brigham and Women's Hospital, Harvard Medical School
- Alexander Goh, M.D., Department of Neurosurgery, Brigham and Women's Hospital, Harvard Medical School
- Guohua Gao, Ph.D., The Scientific Computing and Imaging Institute, University of Utah
- Mark Spitzer, Ph.D., NeuroImage Research and Analysis Laboratory, University of North Carolina
- Wilson Velho, Ph.D., Surgical Planning Laboratory, Brigham and Women's Hospital, Harvard Medical School
- Christophoros Michos, Ph.D., Laboratory of Radiology & Imaging, Brigham and Women's Hospital, Harvard Medical School
- Frank Gantner, M.D., The Scientific Computing and Imaging Institute, University of Utah
- Paul Mallat, M.D., Department of Neurosurgery, University Hospital Schleswig-Holstein, Kiel, Germany
- Mathieu Morales, M.D., Ph.D., Department of Radiology, Brigham and Women's Hospital, Harvard Medical School

Workshop Agenda:

- 08:00-09:00: Start of the workshop
- 09:00-09:30: Welcome remarks
- 09:30-10:00: DTI Tractography and Neurosurgical Planning
- 10:00-10:30: Presentation of the challenge
- 10:30-10:45: Coffee break
- 10:45-12:00: Tractography Session
- 12:00-12:30: Lunch break
- 12:30-12:45: Inviting remarks
- 12:45-1:00: Assessment of the challenge
- 1:00-1:15: A Volunteer's Story



http://www.na-mic.org/Wiki/index.php/Events:_DTI_Tractography_Challenge_MICCAI_2011



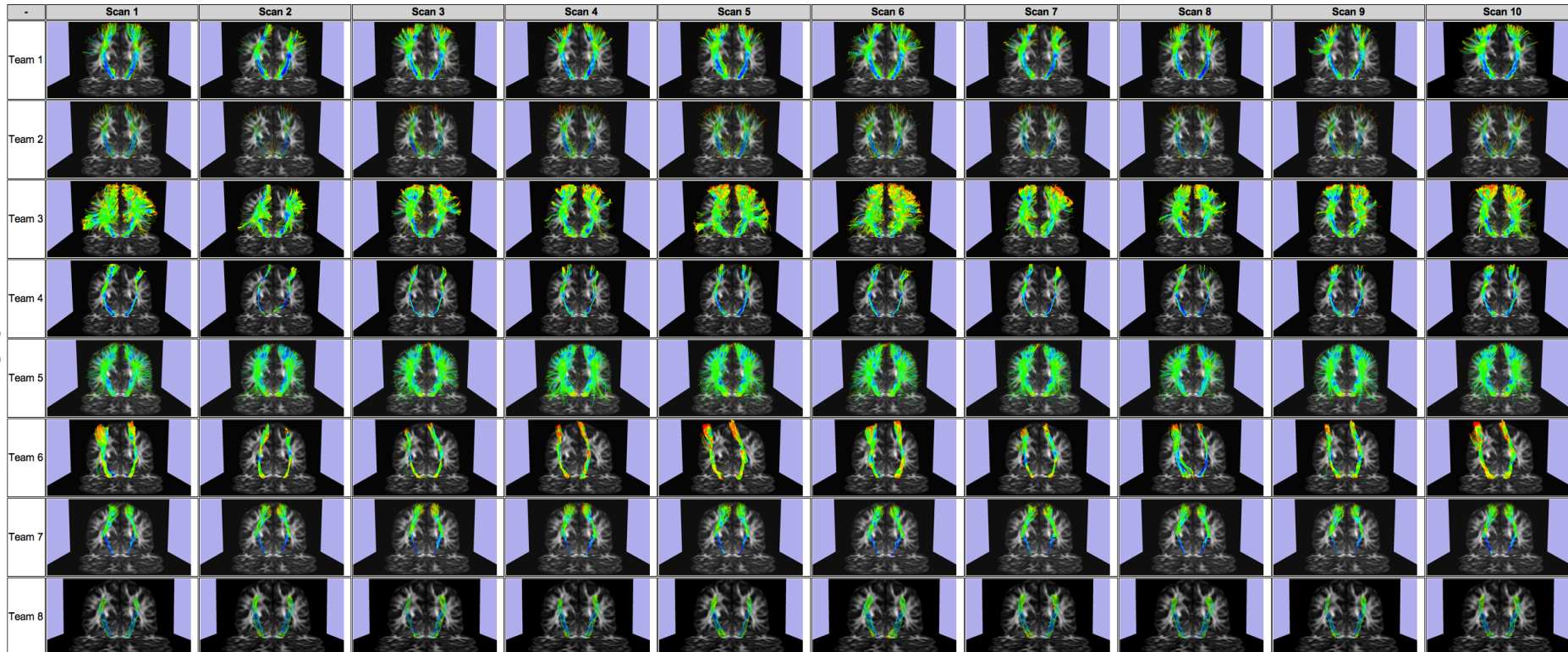
Tractography Algorithms

1. Intrinsic Unscented Kalman Filter
2. Global Fiber tracking based on Finsler Distance
3. Automated Atlas-Based Seeding
4. Machine Learning & Particle Mass based tractography
5. Streamline tractography based on a multi-compartment model
6. Filtered Multi-tensor tractography
7. Volumetric Tractography
8. MITK Global Tractography



Healthy subjects Results

Scan



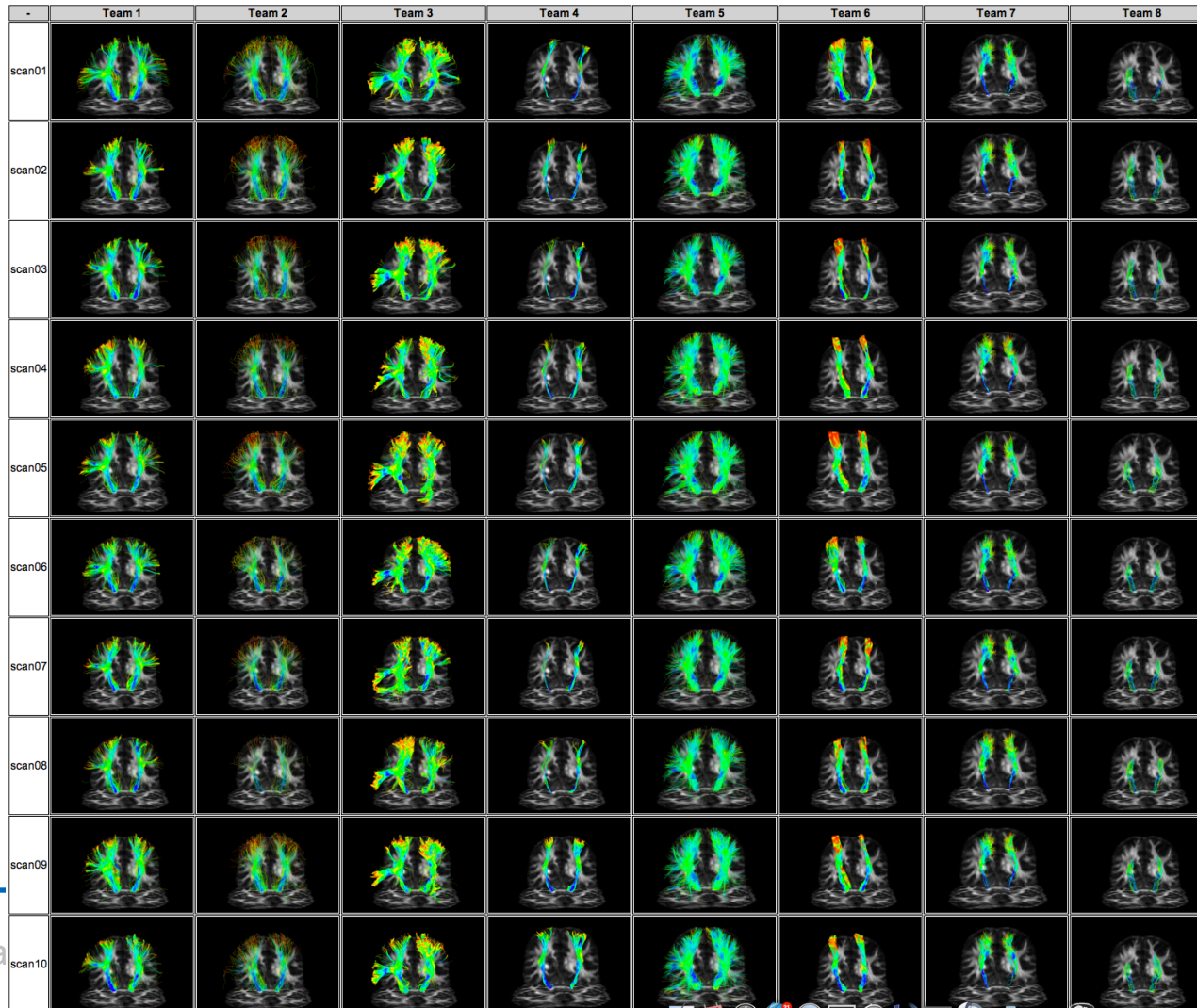


Healthy subjects Results

Team

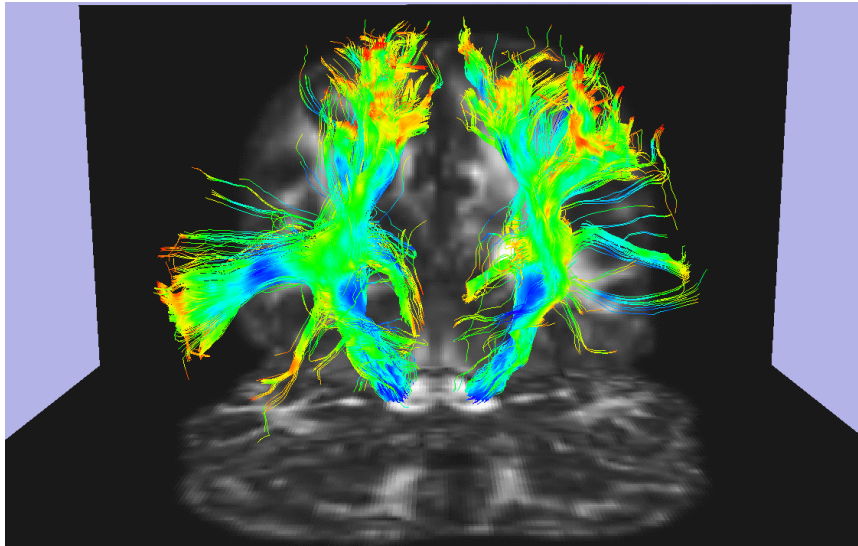
Healthy Subject 1 (For each scan, the images show the comparison across teams.)

Scan





Workshop Outcomes

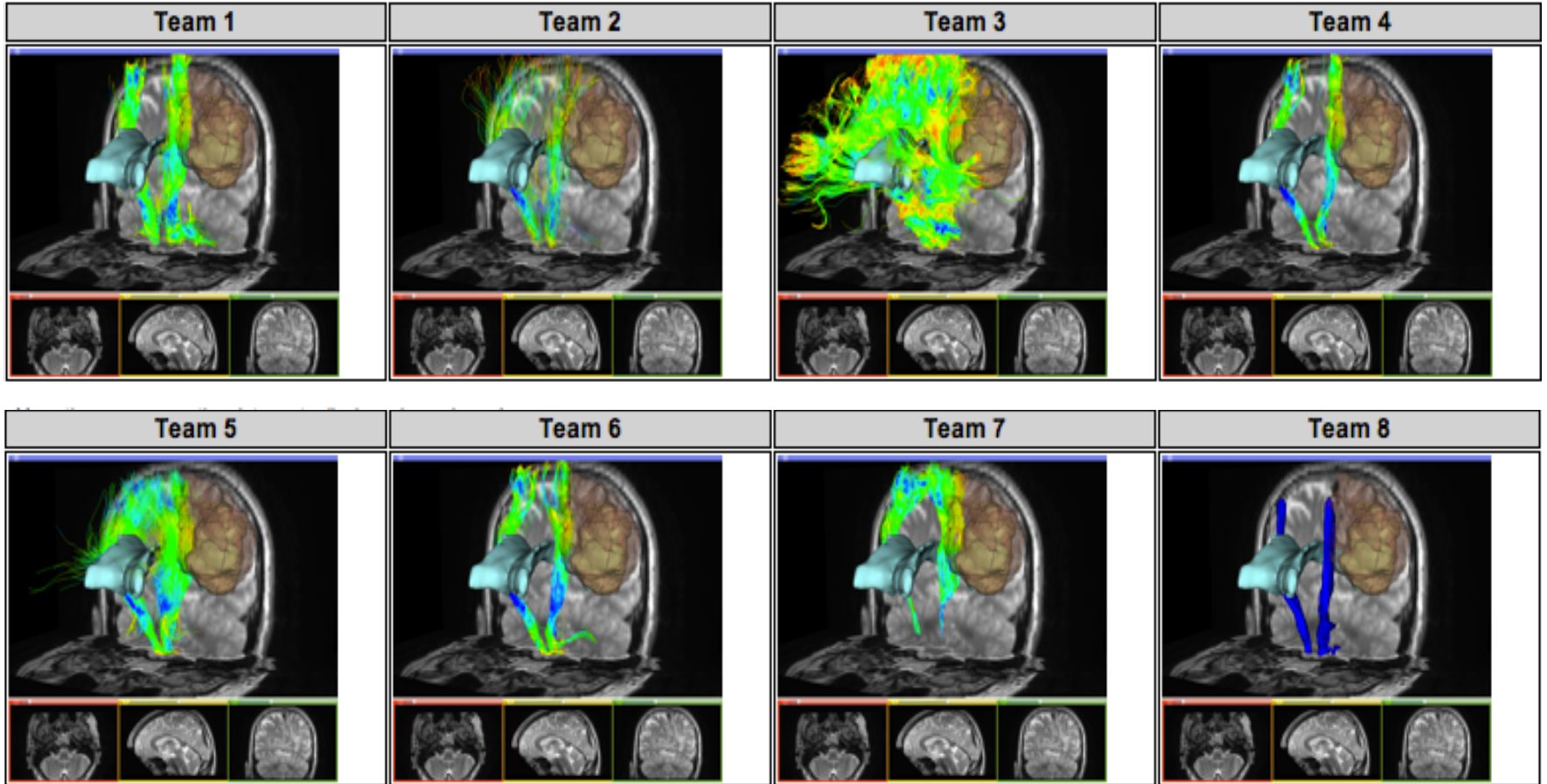


Healthy subject study

→ large **intra-
algorithm** variability

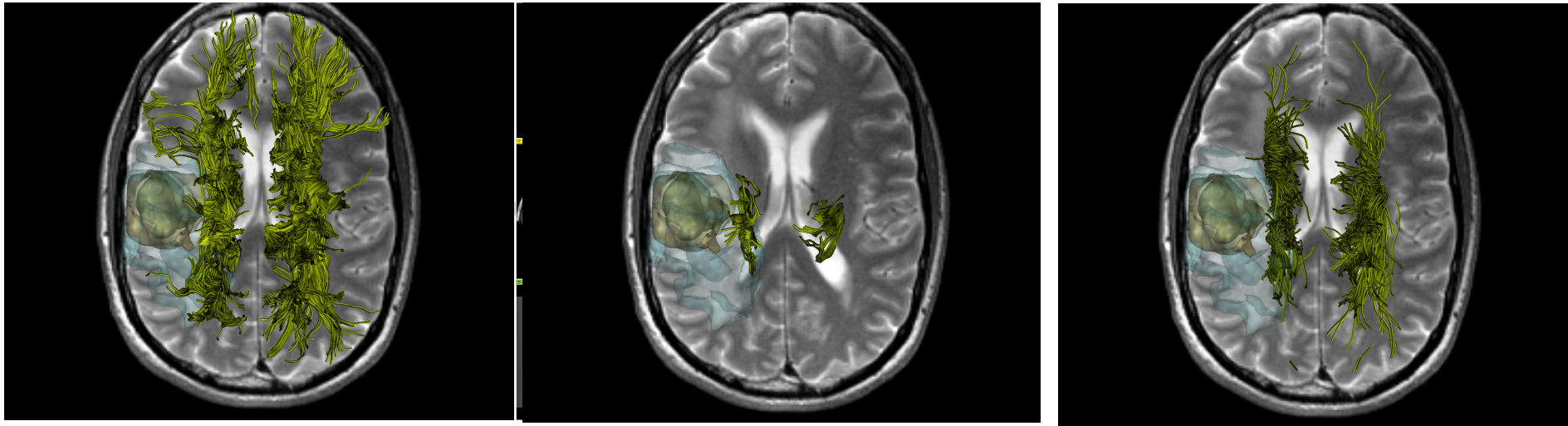


Clinical Cases Results



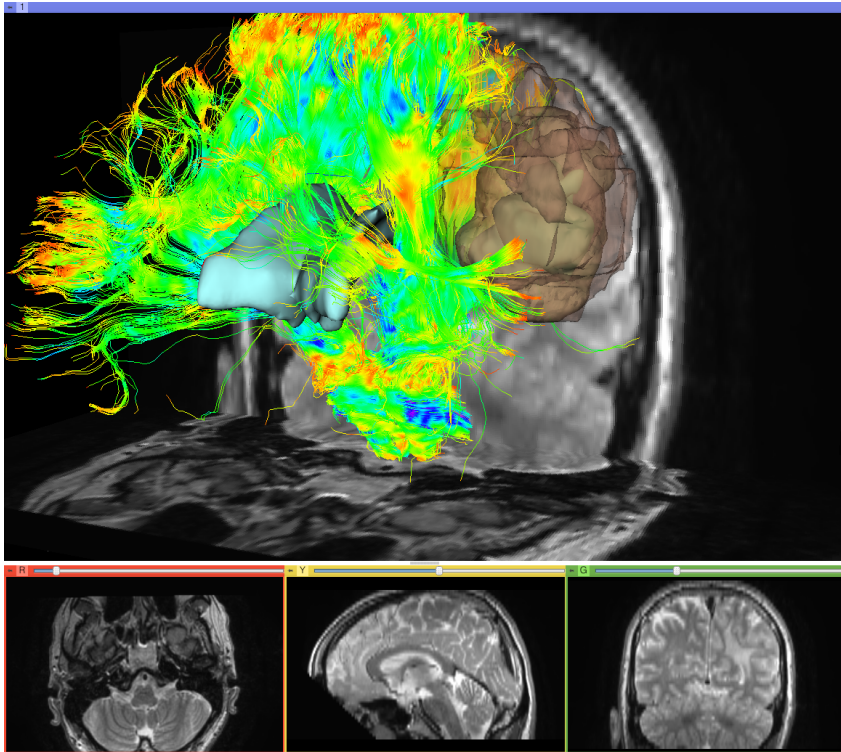


Clinical cases results

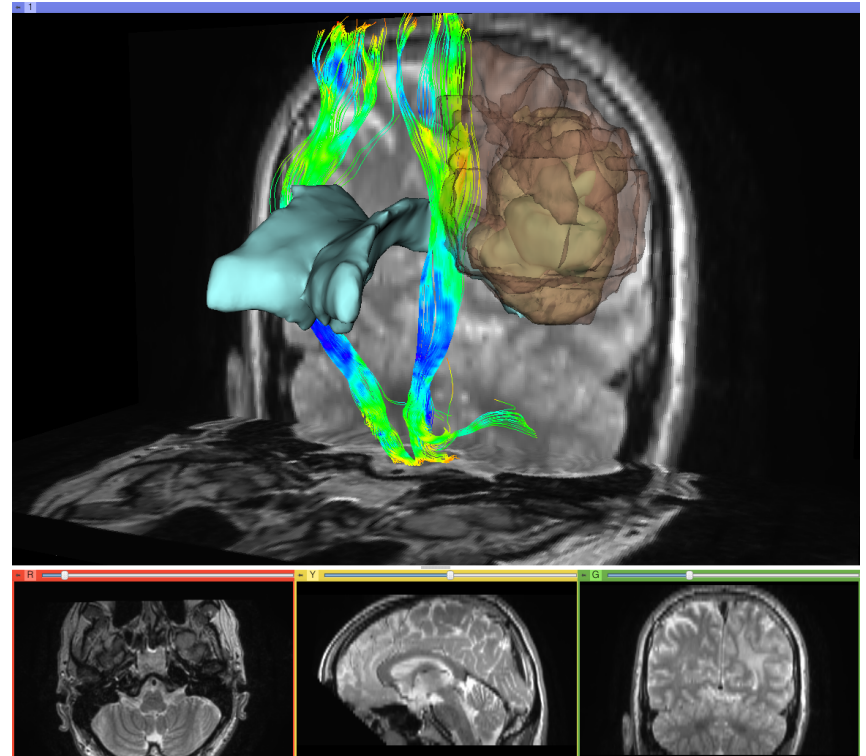




CST reconstructions



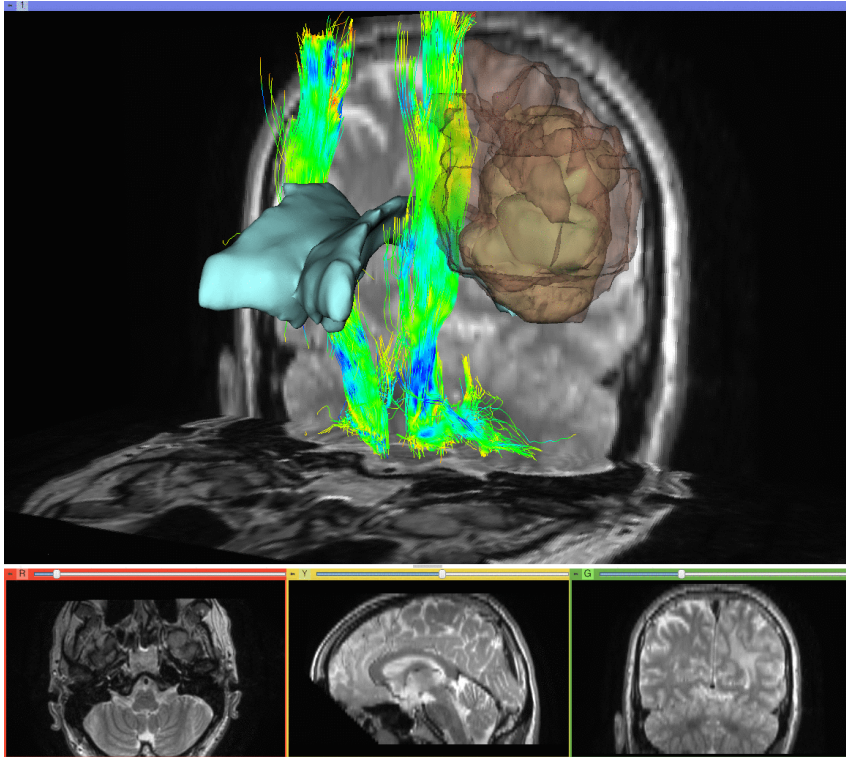
FP



FN



Clinical cases Results



Neurosurgical cases study

→ large **inter-algorithm** variability



Workshop outcomes

- Large variability among tractography methods
- Quantitative metrics selected based on hypothesis of successful targeting of CST
- Opportunity for review and feedback from leading neurosurgeons
- Positive feedback from the MICCAI community



Bridging the Gap

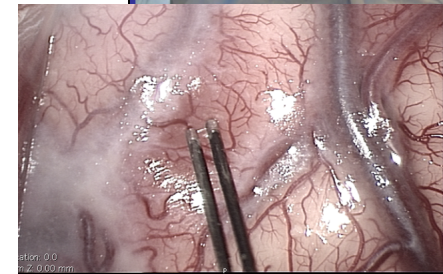
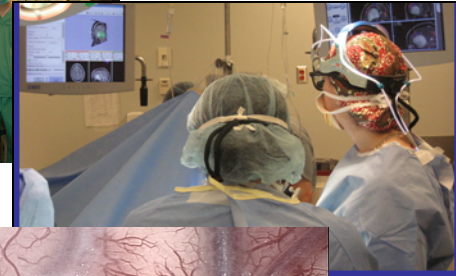


Image courtesy of Arya Nabavi, MD

$$\frac{\partial}{\partial x_i} \frac{\partial}{\partial x_k} A$$
$$\frac{\partial}{\partial x_k} \sqrt{A} + \frac{1}{c} \frac{\partial^2 A_k}{\partial t^2} + \frac{\partial}{\partial x_k} \left(\vec{\nabla} \cdot \vec{A} + \frac{1}{c} \frac{\partial \phi}{\partial t} \right) = \frac{4\pi}{c} J_k$$
$$-\nabla^2 A_k + \frac{1}{c^2} \frac{\partial^2 A_k}{\partial t^2} + \frac{\partial}{\partial x_k} \left(\vec{\nabla} \cdot \vec{A} + \frac{1}{c} \frac{\partial \phi}{\partial t} \right) = \frac{4\pi}{c} J_k$$
$$-\nabla^2 \vec{A} + \frac{1}{c^2} \frac{\partial^2 \vec{A}}{\partial t^2} + \vec{\nabla} \left(\vec{\nabla} \cdot \vec{A} + \frac{1}{c} \frac{\partial \phi}{\partial t} \right) = \frac{4\pi}{c} \vec{J}$$

```
doms::logPlus::logger::write(
  rootLogger::settings::get("dirs::
  @Application::srcDir, srcDir);
app::setOrganizationName("com");
app::setOrganizationDomain("com");
app::setAppId("comName");
app::setAppVersion("1.0.0");
}

// set up the database
if (argc > 1)
{
  @String::directory(srcDir, "database");
  settings::sync();
}

if ( ! settings::value("database:directory", "") == "" )
{
  database::directory = @String::directory(srcDir, "database");
  settings::sync();
} else
{
  database::directory = settings::value("database:directory", "");
  settings::sync();
}
```



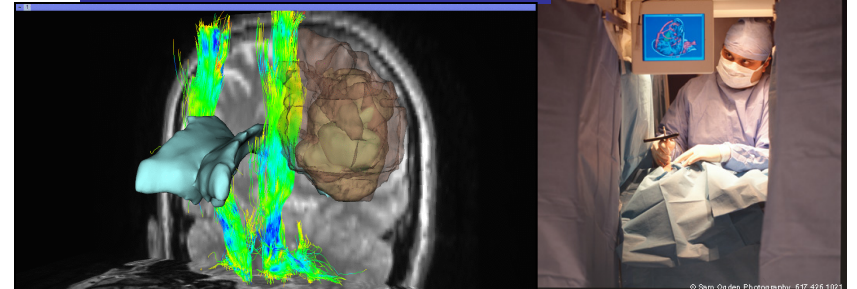
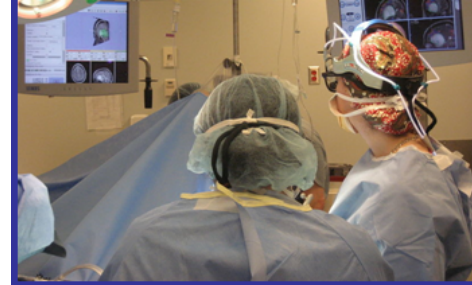
Bridging the gap

- After the challenge, each team received a 14-page document containing the qualitative evaluation by the clinical and DTI experts, and the values of the quantitative metrics
- Participants were invited to re-process the data using the reviewers' feedback



DTI Challenge: Conclusion

- Appropriate reflection of the current state of the art in the field
- Submission to MICCAI 2012
- On-going learning effort for the community





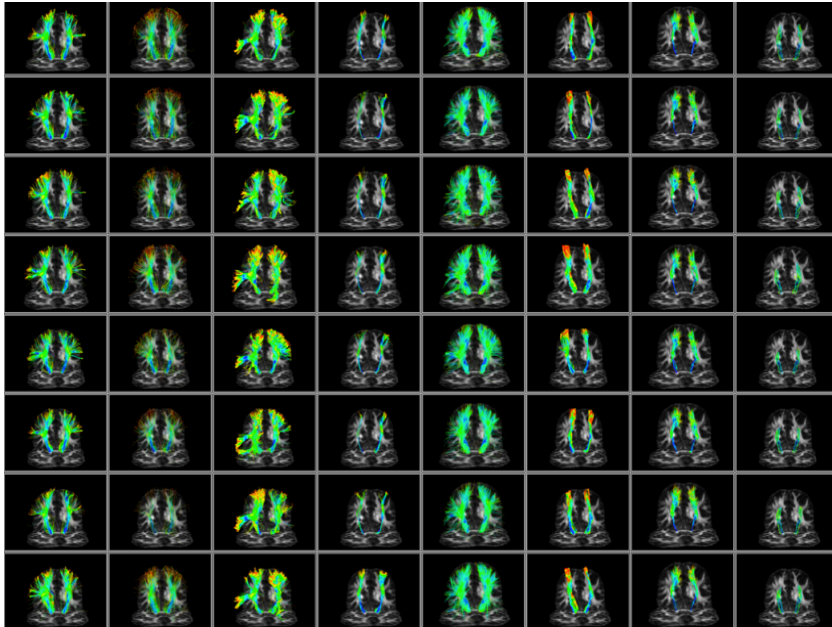
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