



NA-MIC

National Alliance for Medical Image Computing

<http://na-mic.org>

Diffusion Tensor Processing and Visualization

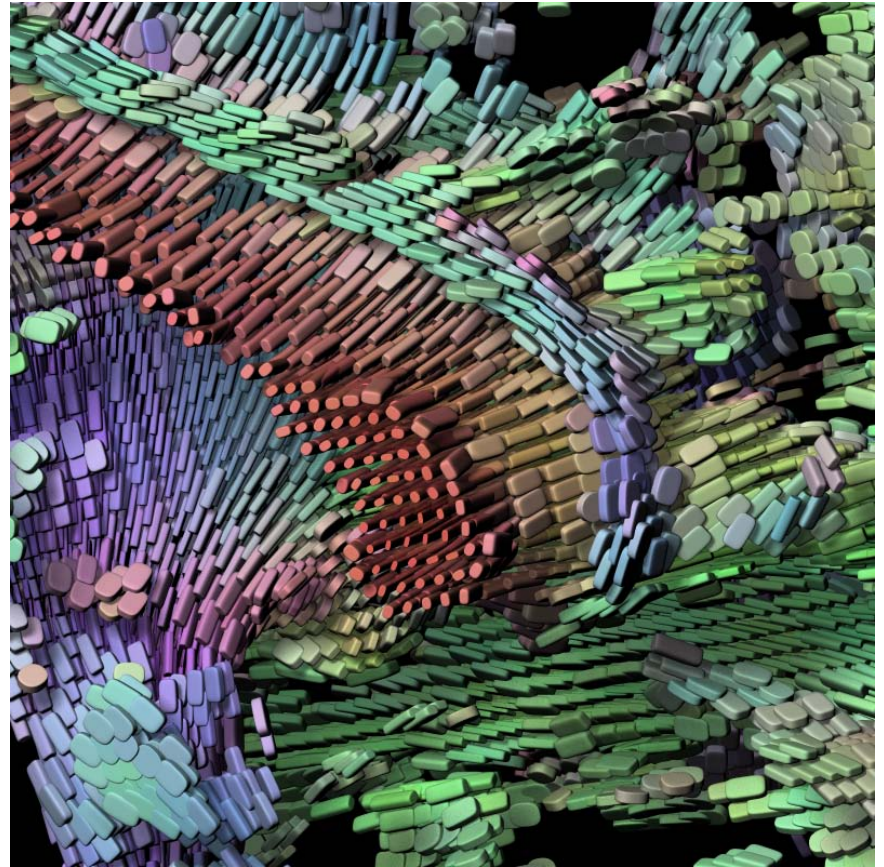
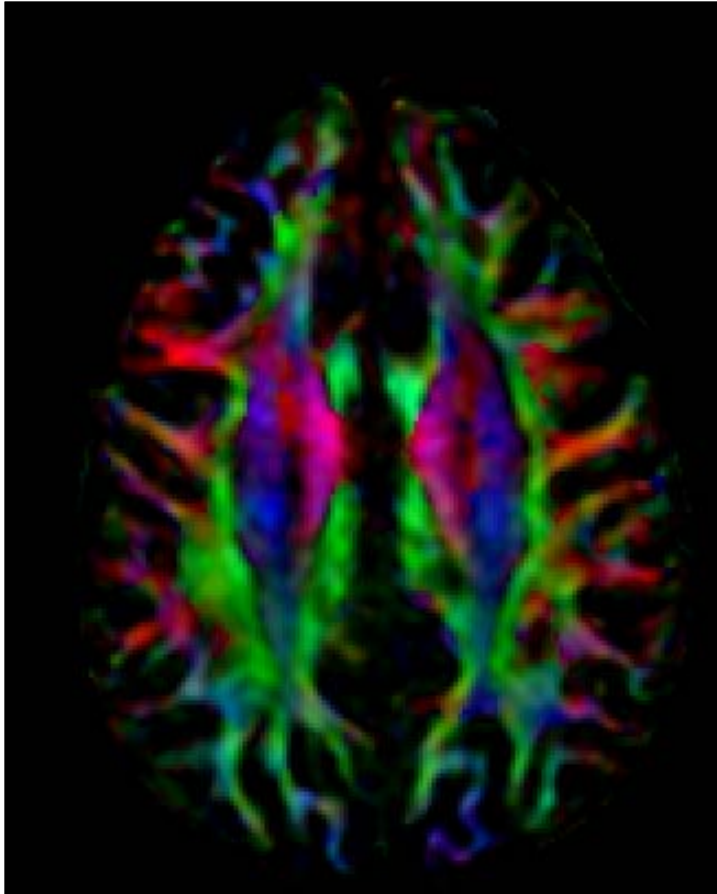
Guido Gerig

University of Utah

Martin Styner, UNC

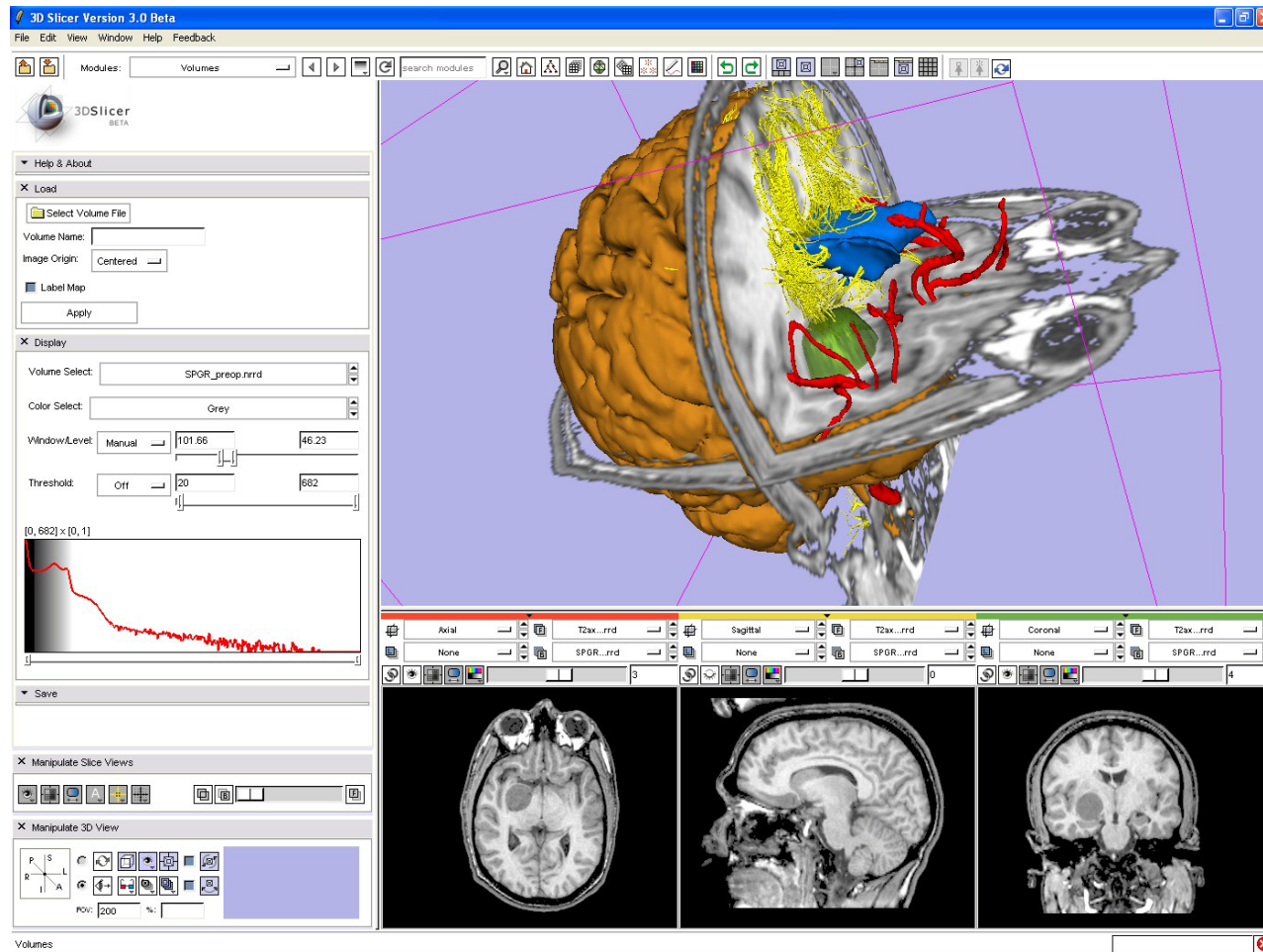
NAMIC: National Alliance for
Medical Image Computing







DTI Tools: Slicer 3





NAMIC activity: Analysis of DTI

From raw data to analysis:

- DICOM to NRRD conversion
- Correction for artifacts (head motion, Eddy currents): [QC-ing](#)
- Filtering, interpolation (non-Euclidean geometry)
- Calculation of tensors (lin, nonlin)
- [White matter pathways/tracts via tractography or volumetric path search methods](#) → expert interaction
- Characterization of tracts via parametrization of tract geometry and coding of diffusion attributes: [QCing](#)
- Linear/nonlinear registration of sets of images
- Building of population means/templates/atlasses: [QC-ing](#)
- Statistical analysis, Hypothesis testing

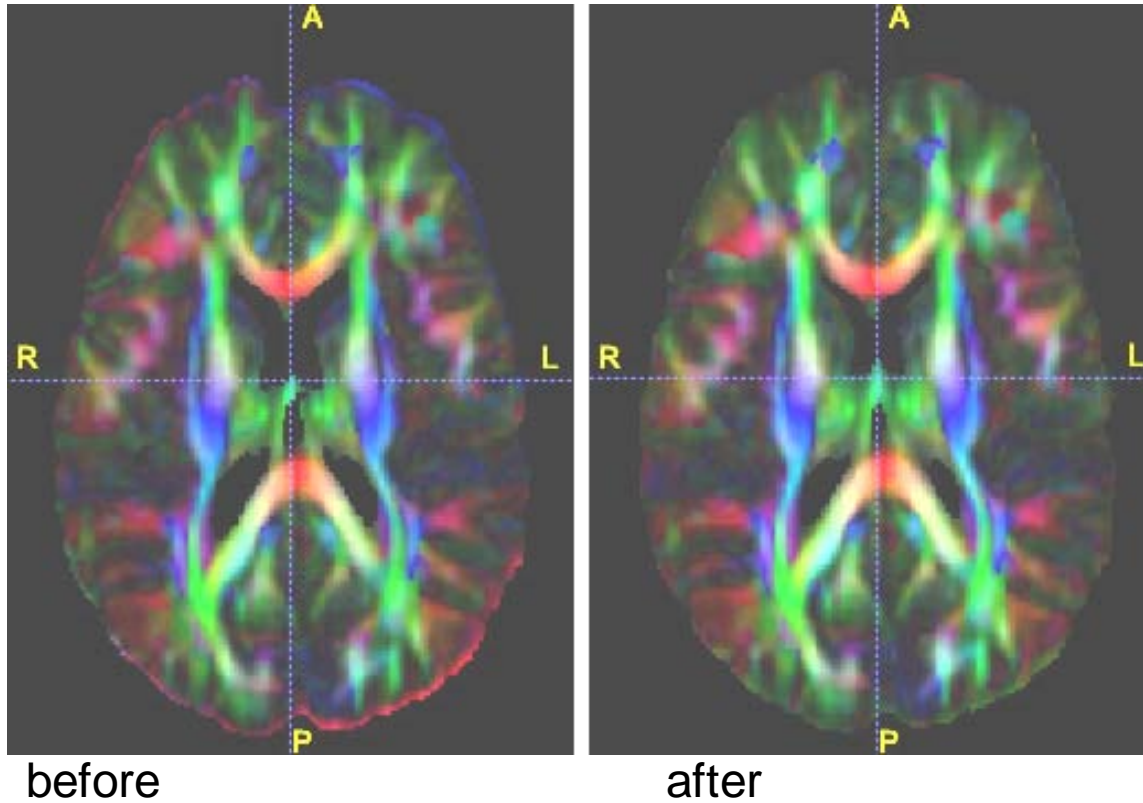


From Modules to Systems / Workflows





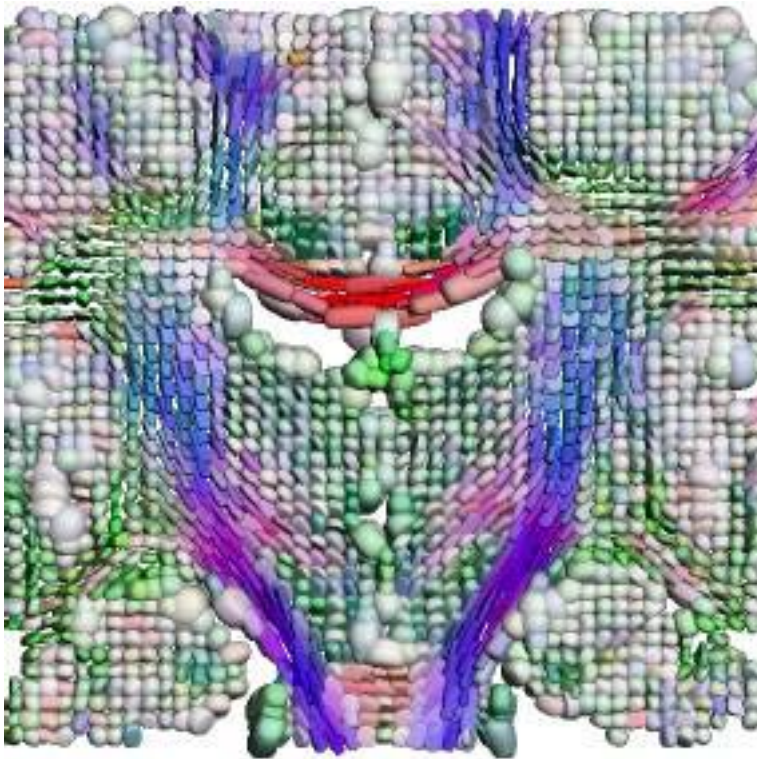
Eddy Current Correction



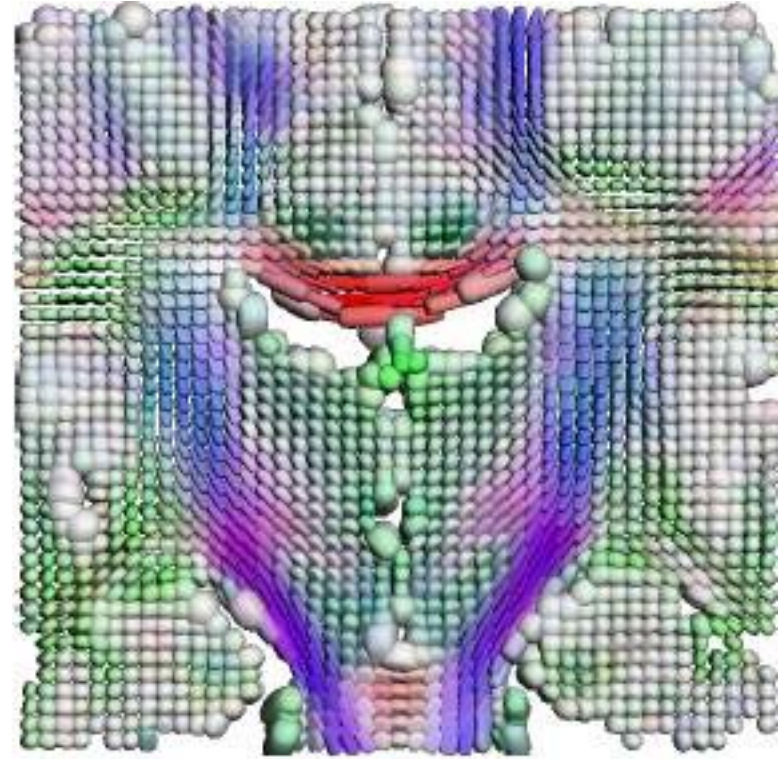
Eddy current , head motion, geometric distortion correction comparison



Rician Filtering of Tensor Fields



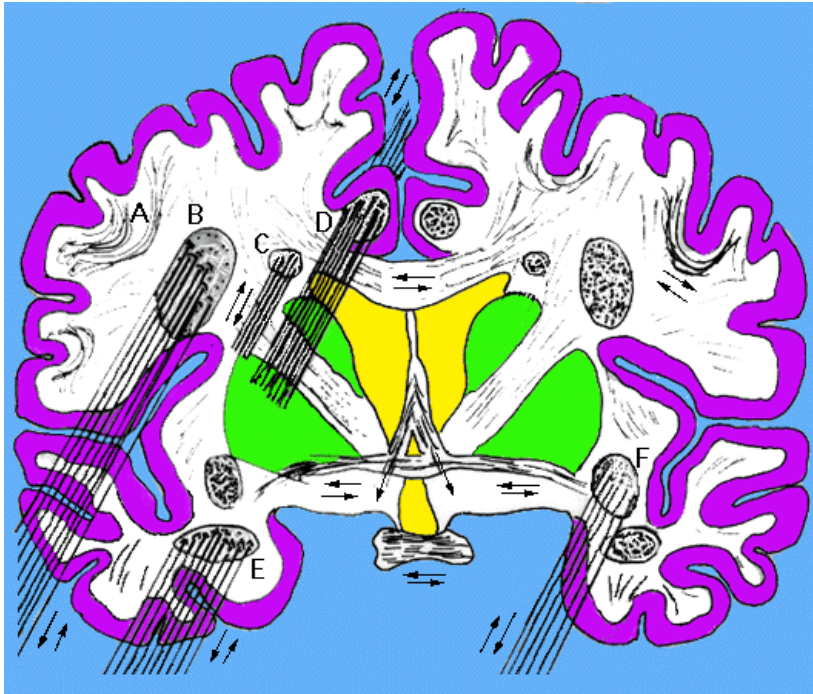
Noisy Data



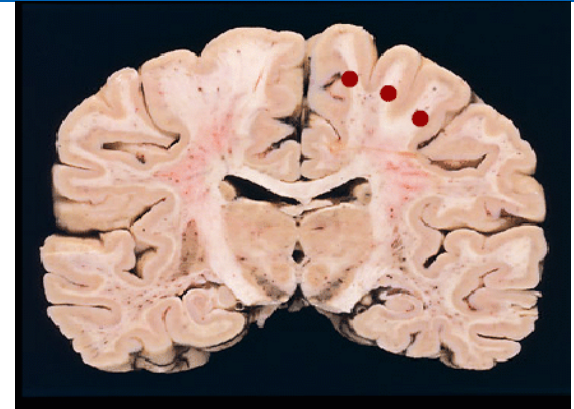
Rician Filtered



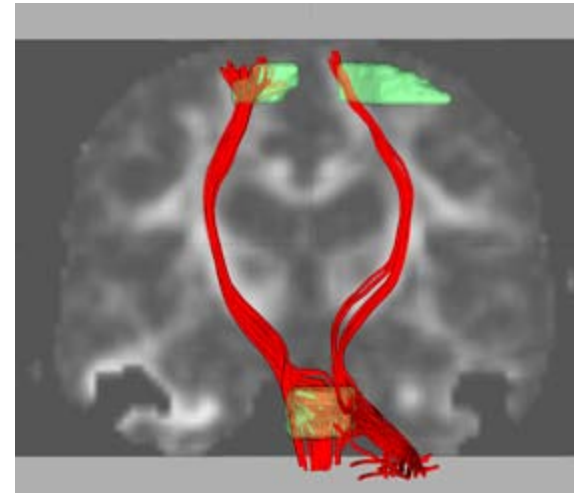
Dream: Connectivity?



Forebrain Fiber Bundles: General idea of where various fiber bundles are and regions they interconnect or project to.



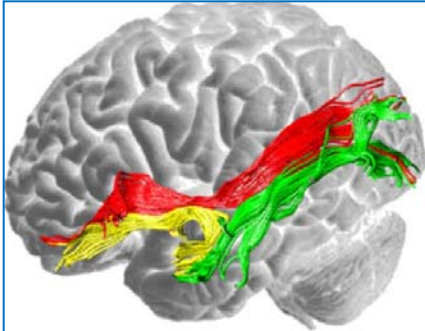
Source: Duke NeuroAnatomy Web Resources (Ch. Hulette)



Tractography: Coronal view

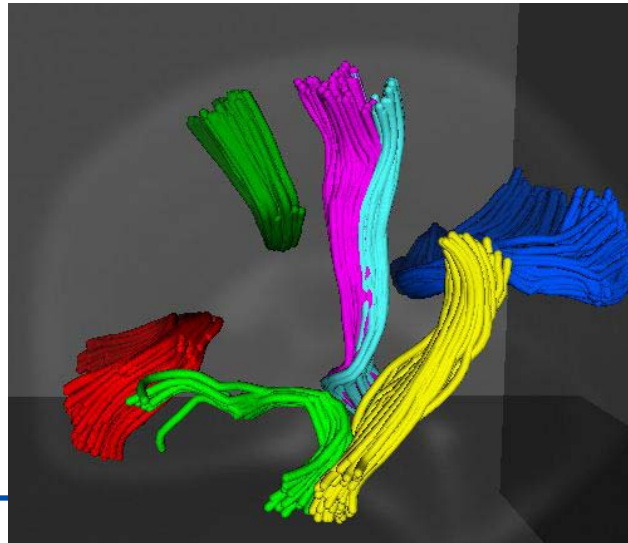
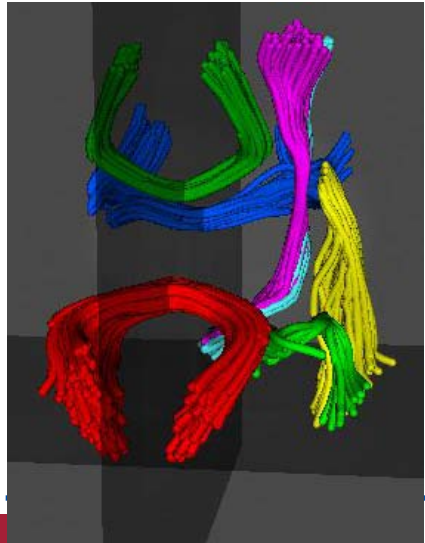


Clinical Uses: Tractography



Catani, Cortex
2008
(Adult DTI)

-  Inferior Fronto-Occipital Fasciculus
-  Inferior Longitudinal Fasciculus
-  Uncinate Fasciculus



splenium

genu

mid-cc

uncinate

ilf

motor

sensory

etc.

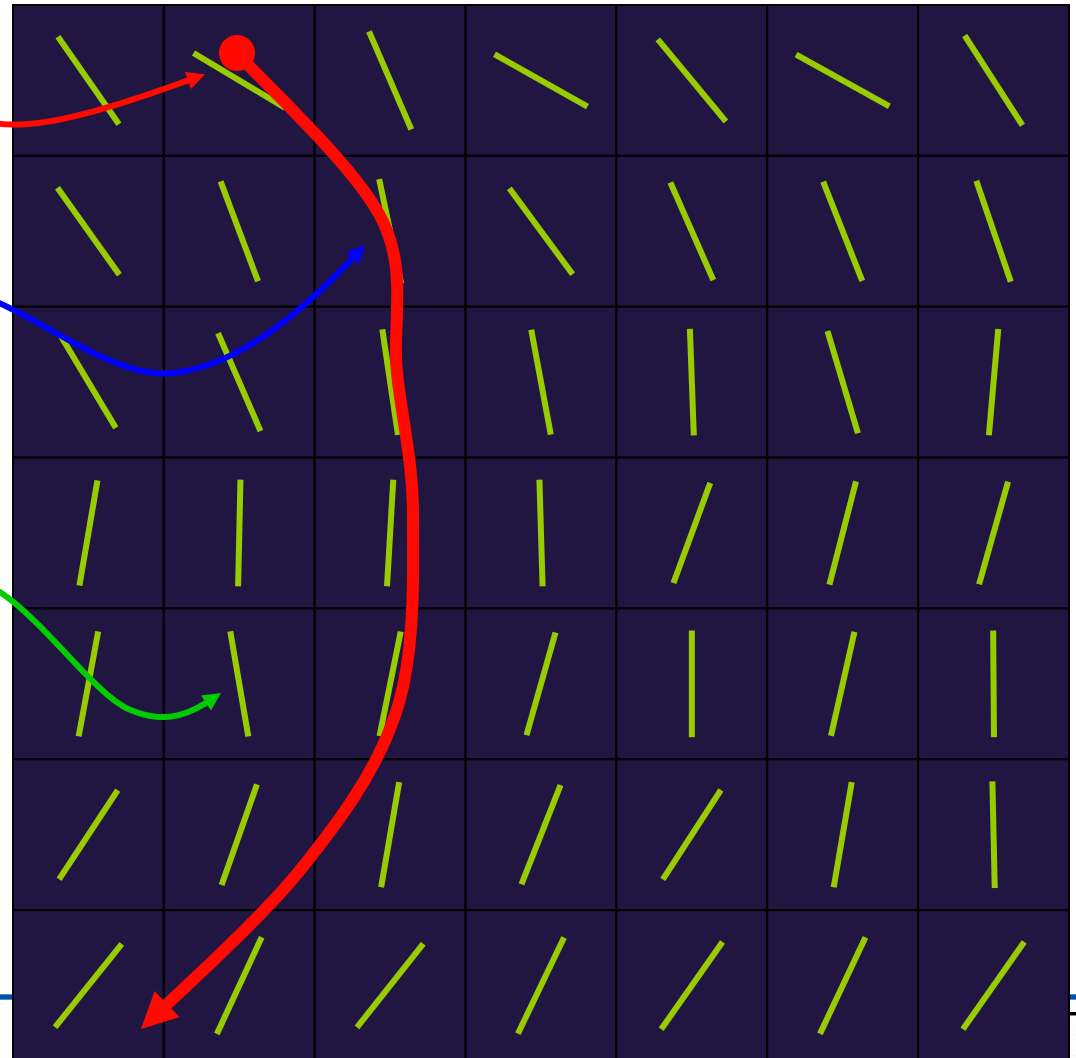


DTI Tractography: Principle

Seed point(s)

Move marker in discrete steps and find next direction

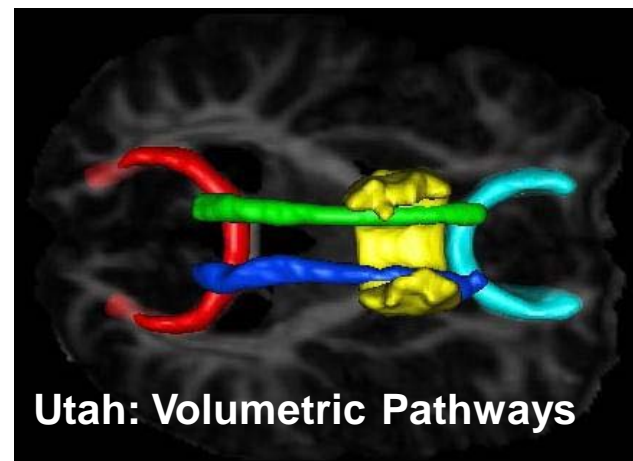
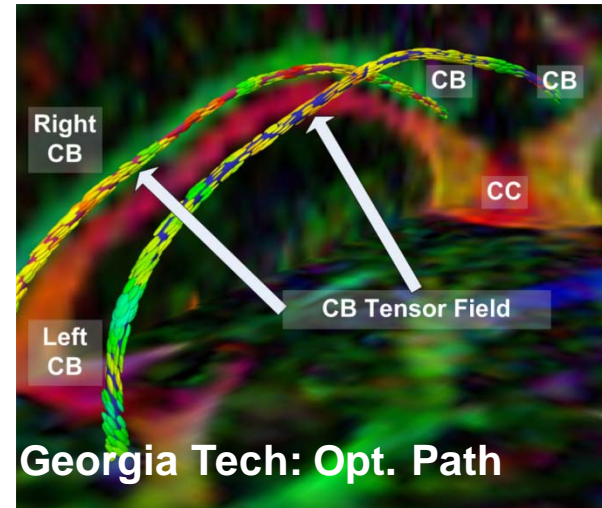
Direction of principle eigen value





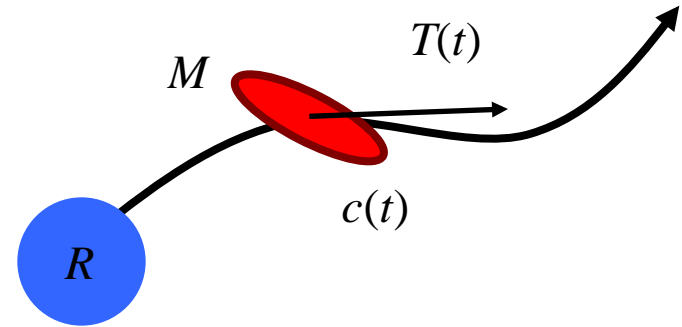
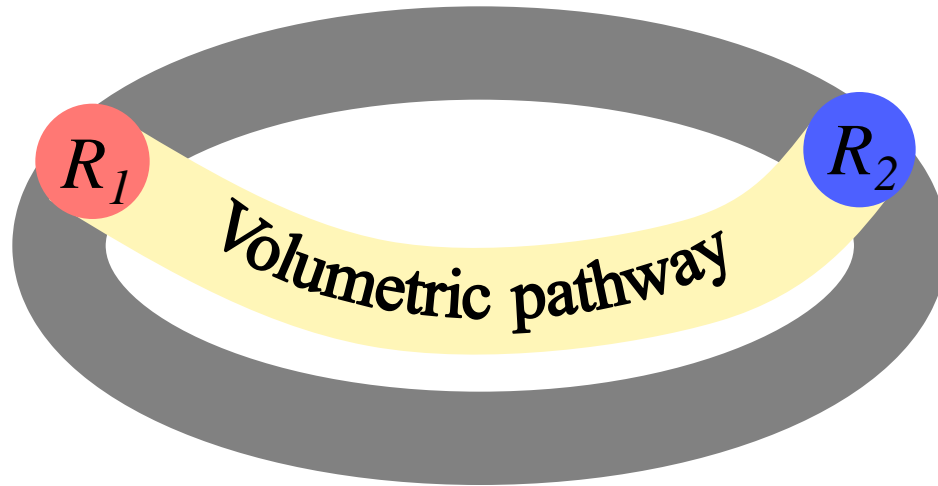
Alternative methods for tractography

- Tracking in tensor field
- Keep history along track: e.g. Kalman filtering
- Probabilistic tractography
- Optimal path analysis
- Fiber tract by volumetric diffusion
-
- Variety of methods developed by NAMIC developers

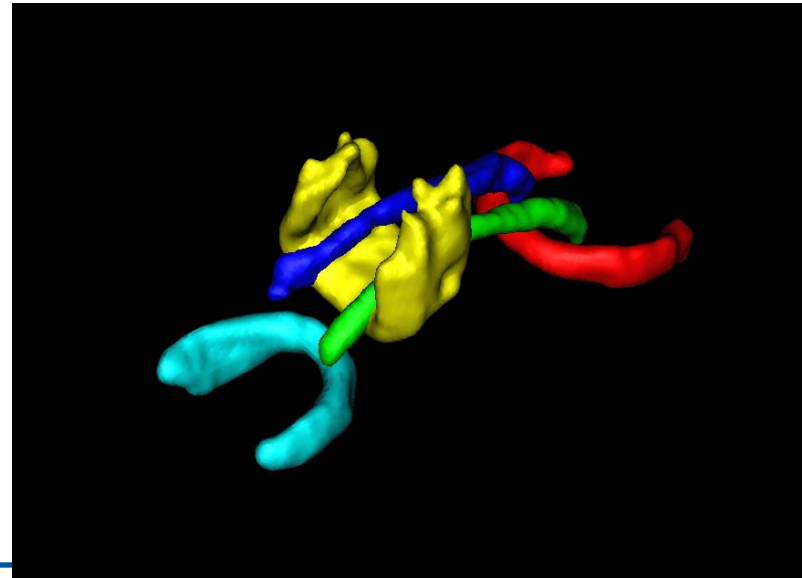
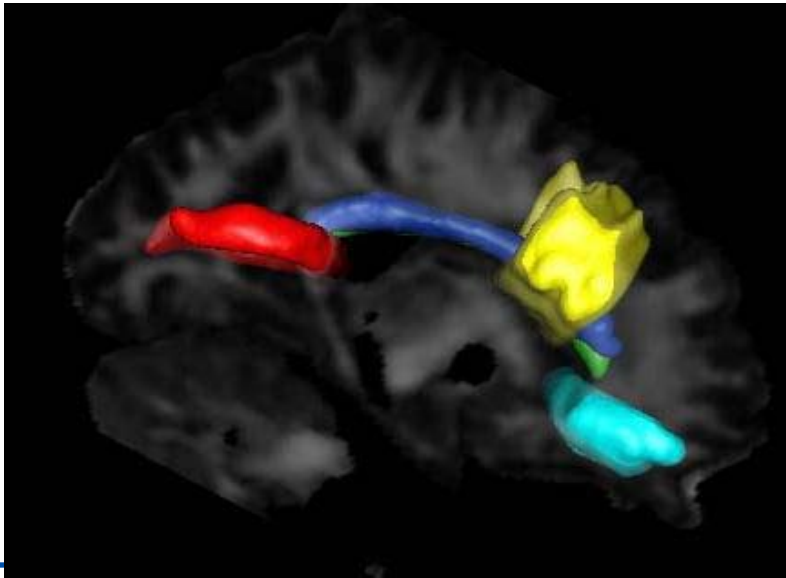
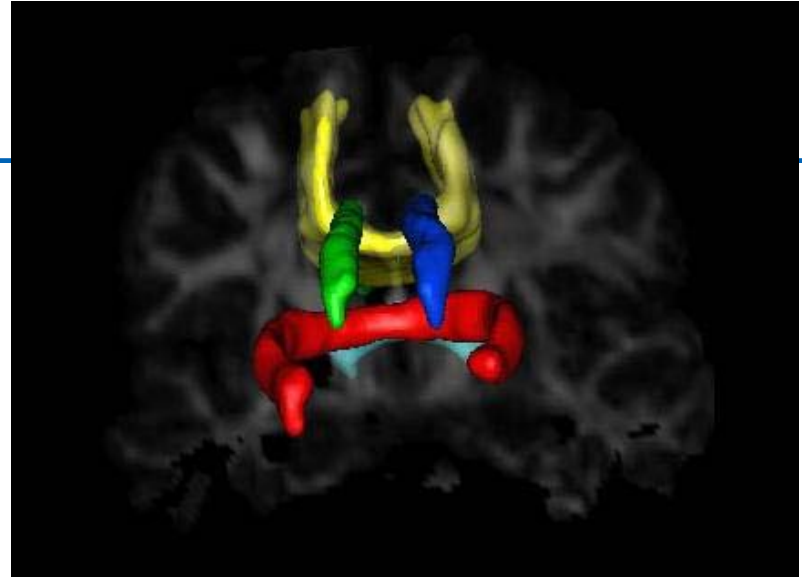
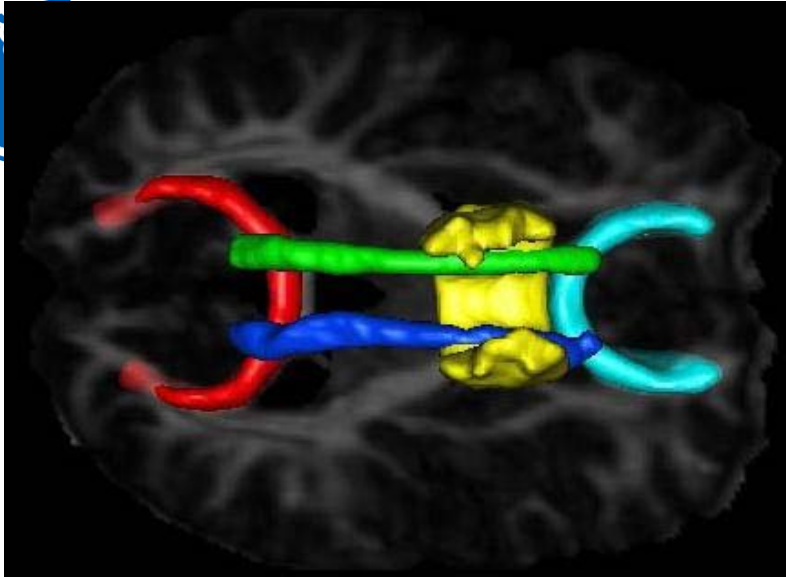




Volumetric White Matter Pathways



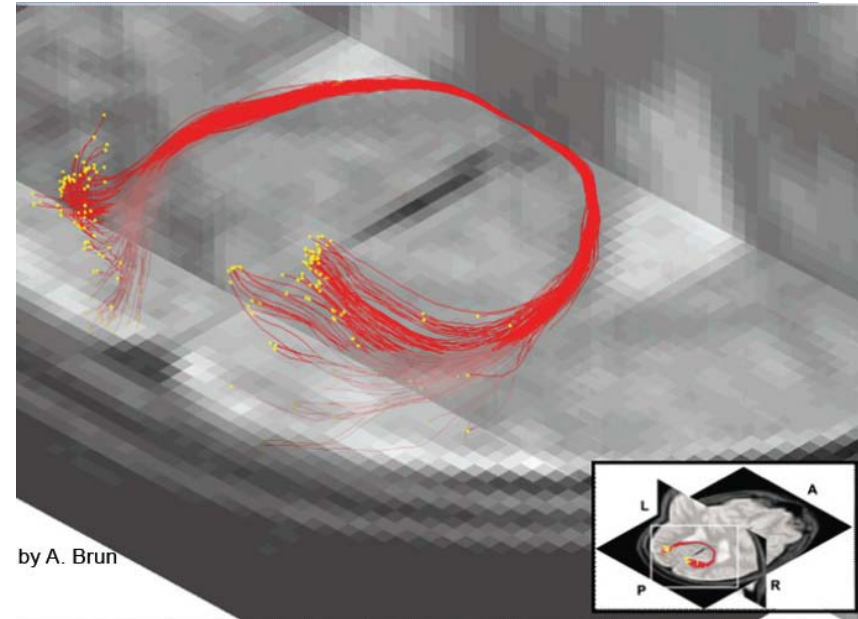
- Region-to-region analysis
- Volumetric representation of pathway
- Integral of a local cost function $\psi(T, M)$ over the path c





Stochastic Tractography

- Lazar, Alexander, **White Matter Tractography using Random Vector (RAVE) Perturbation**, ISMRM 2002
- D. Tuch, Diffusion MRI of complex tissue structure, Ph.D. dissertation, Harvard-MIT, 2002
- Brun, Westin, **Regularized Stochastic White Matter Tractography Using Diffusion Tensor MRI: Monte Carlo, Sequential Importance Sampling and Resampling**. MICCAI 2002.
- Zhang, Hancock, Goodlett and Gerig, **Probabilistic White Matter Fiber Tracking using, Particle Filtering and von Mises-Fisher Sampling**, Med Image Anal. 2009 Feb;13(1):5-18



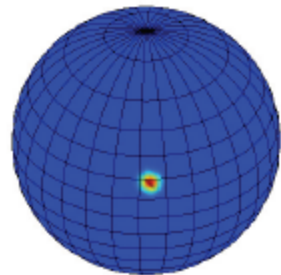
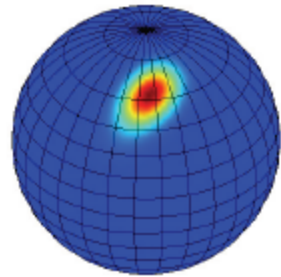
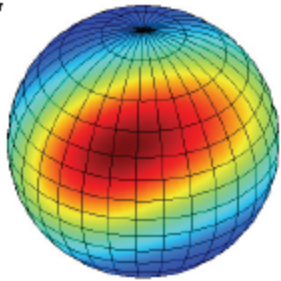
Courtesy Carl-Fredrik Westin,
MICCAI 2008 workshop



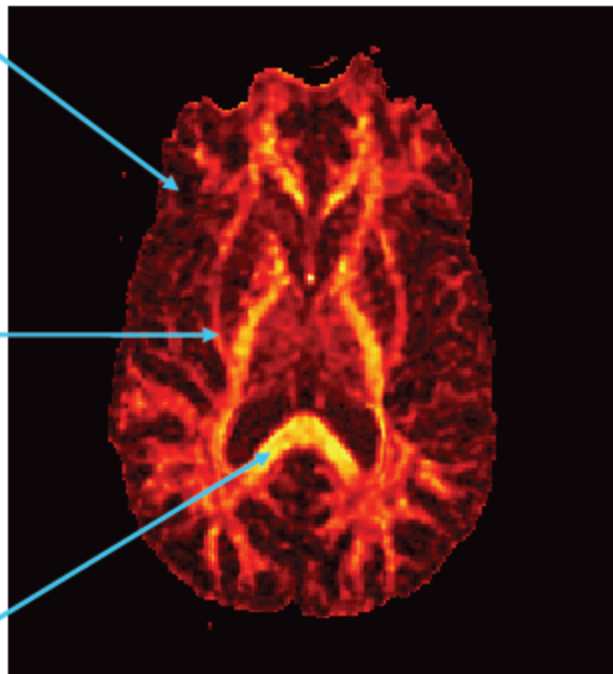
Stochastic Tractography

laboratory of
imaging

Friman, Westin MICCAI 2005, TMI 2006



Fractional anisotropy



A probability density function of the fiber orientation in each point.

Start point



In every step, draw a step direction from the pdf of the underlying fiber orientation.

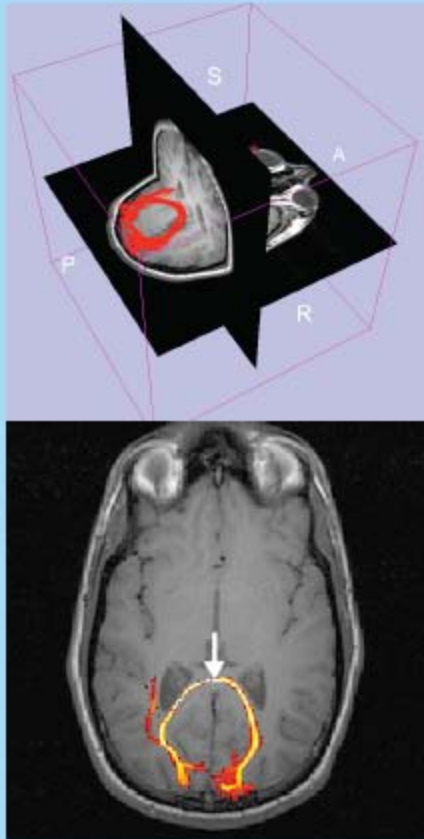
Rickman and Westin, Hospital, Harvard Medical School

Courtesy Carl-Fredrik Westin

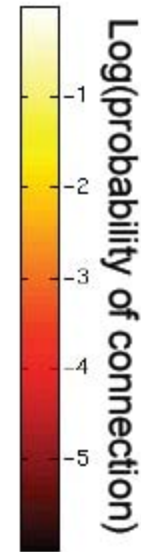


Probability of Connection

Corpus callosum

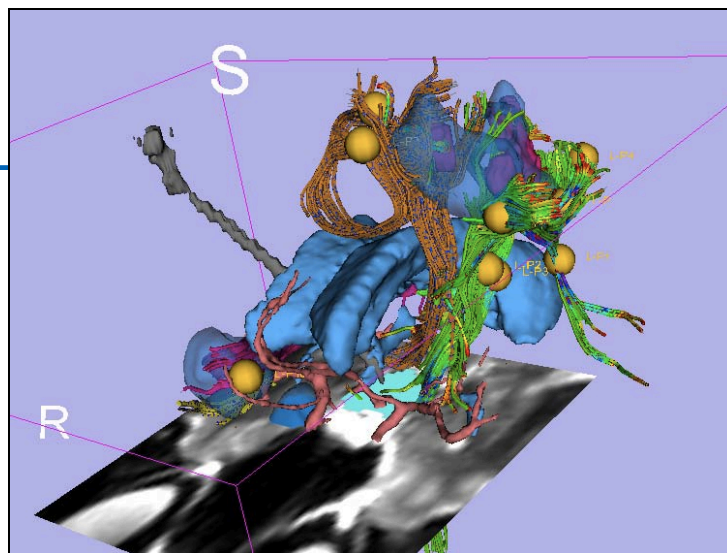
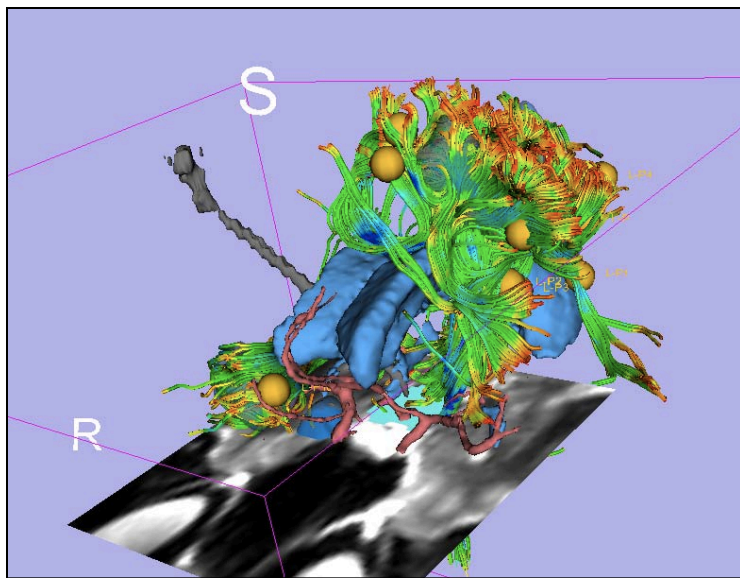


Inferior occipitofrontal fasciculi



Courtesy Carl-Fredrik Westin,
MICCAI 2008
workshop

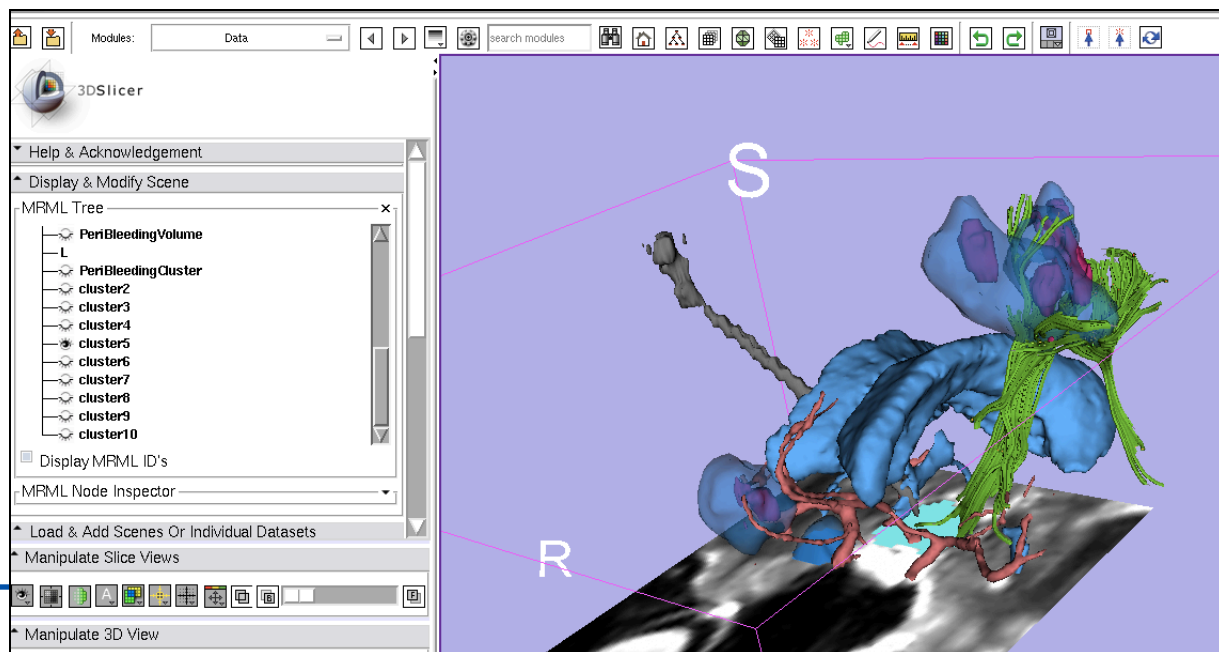
Work with O. Friman



Peri-bleed tract, fiducials for the sub-clusters/tracts, result fiber clustering in relation to lesion.

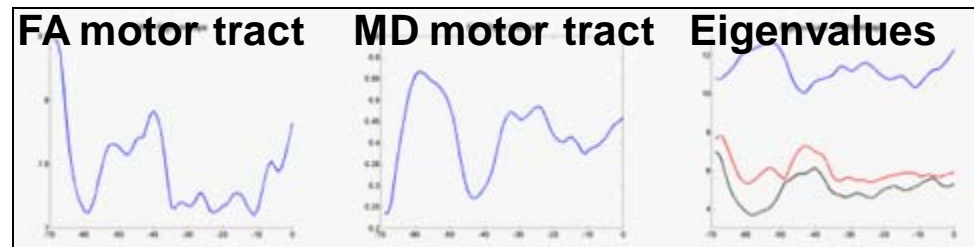
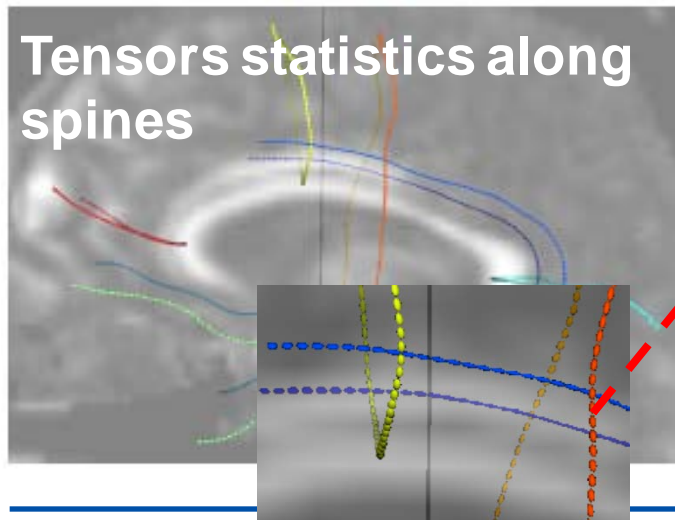
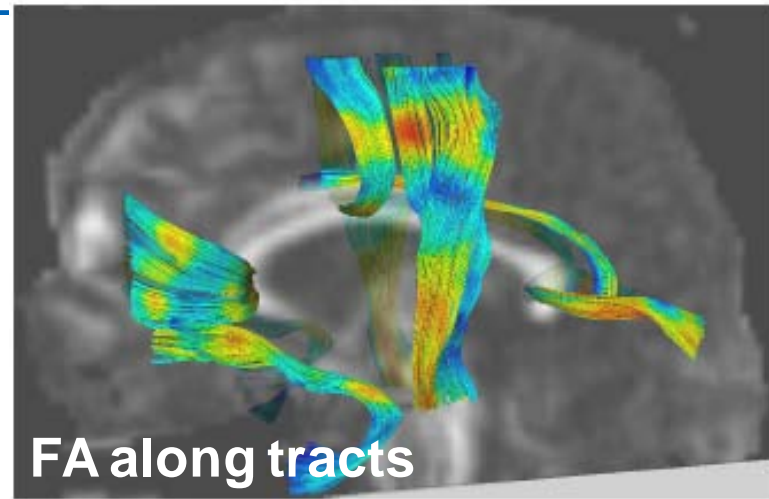
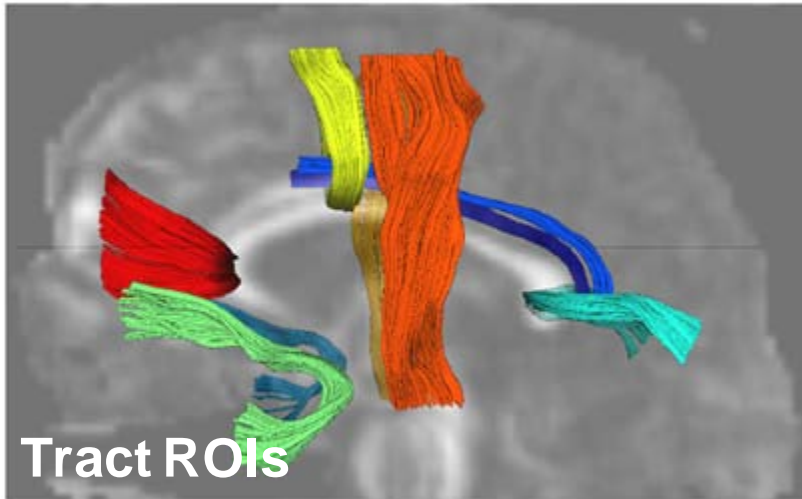
Ron Kikinis:

- Visual assessment of multi-modality imaging with 3D tracts and objects.
- Potential identification of specific functions for neurological testing, -> deploy tests based on hypothesis from imaging.
- Future: More principled approach, leads to quantitative assessments.





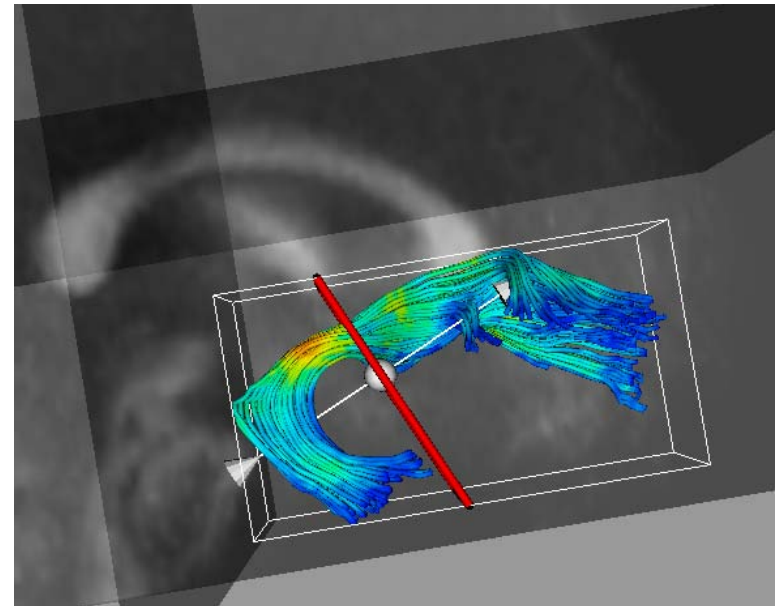
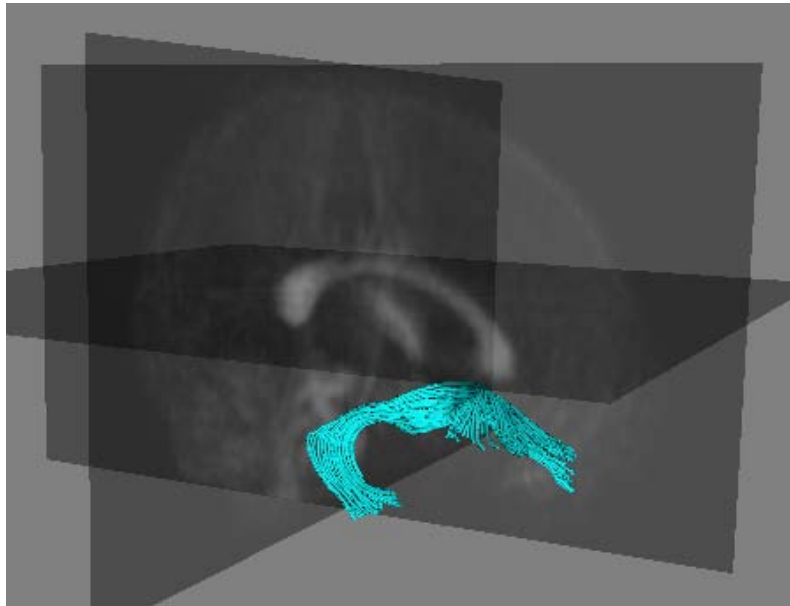
Quantitative Tractography



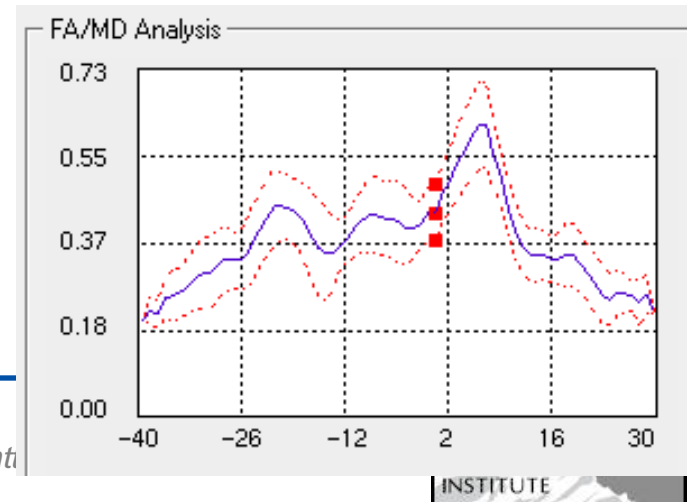
- Tractography for ROI definition
- Tensor analysis for statistics along tracts
- [Corouge, Gouttard, Gerig, MedIA'06](#)



Example Uncinate Fasciculus

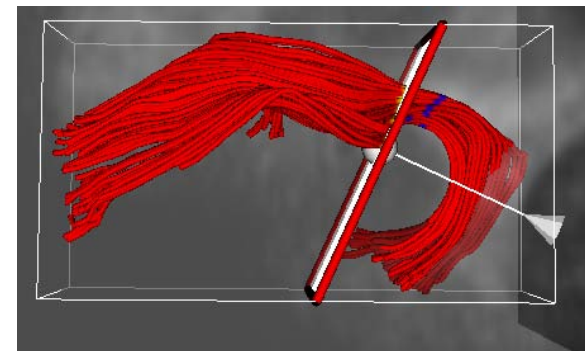
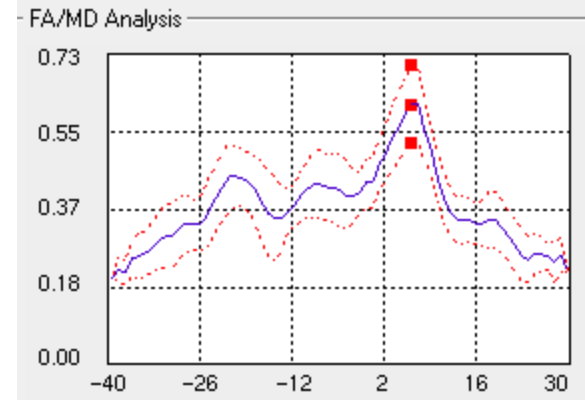
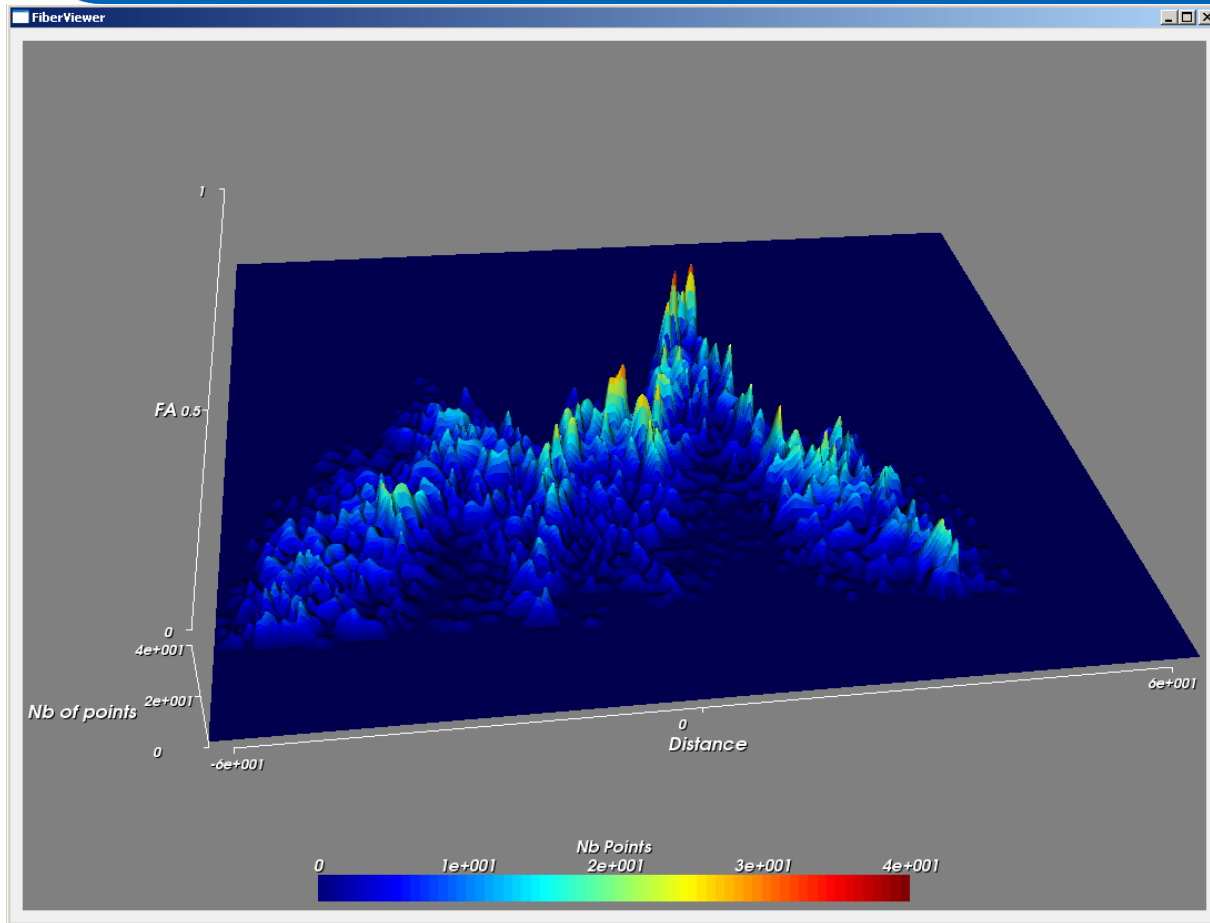


Corouge et al. *Fiber tract-oriented statistics for quantitative diffusion tensor MRI analysis*. Medical Image Analysis 2006.
FiberViewer software - <http://www.ia.unc.edu/dev/>





FA distributions in cross-sections: Kernel Regression





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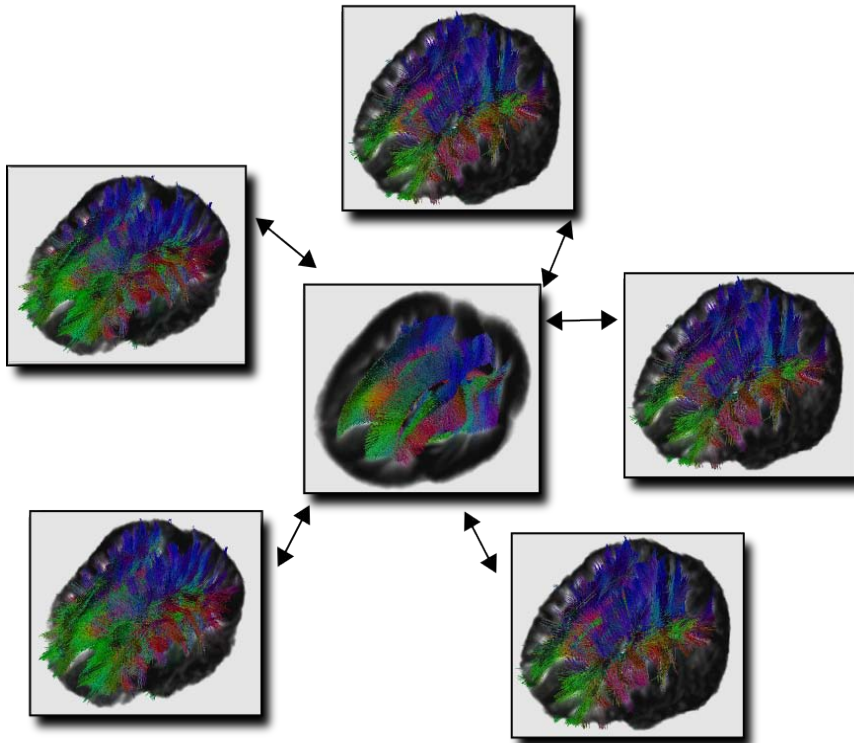
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**Coming soon: Population-
based analysis**



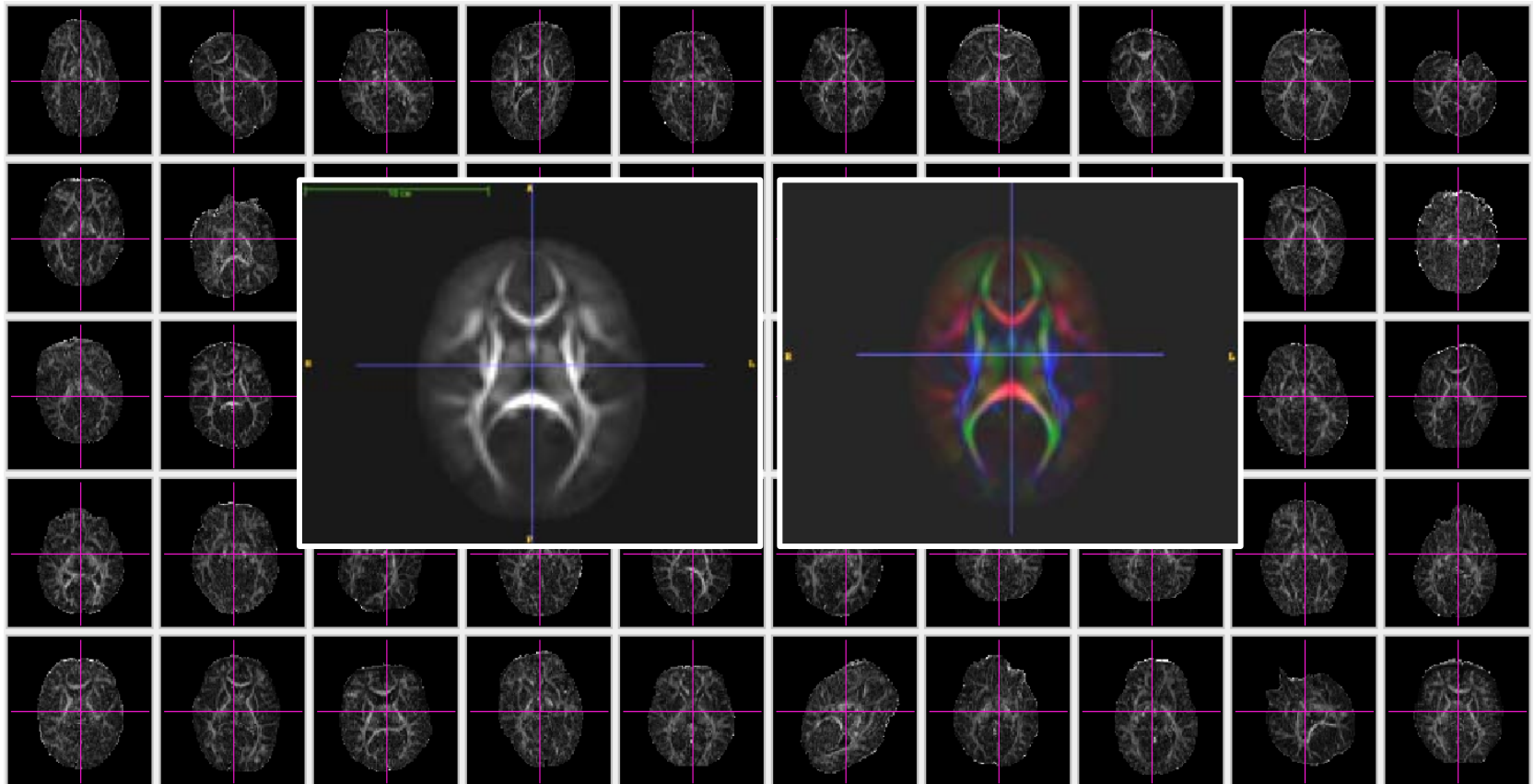
Population Analysis of DTI: Computational Anatomy Approach



- Balci, Golland, Wells. *Non-rigid Groupwise Registration using B-Spline Deformation Model*. ITK Workshop 2007.
 - Available in sandbox
MultImageRegistration
- Goodlett et al. *Improved correspondence for DTI population studies via unbiased atlas building*. MICCAI 2006, Neuroimage 2009.
 - Tensor processing tools –
DTIprocess (NeuroLib),
Teem, Slicer 3



Population based DTI analysis





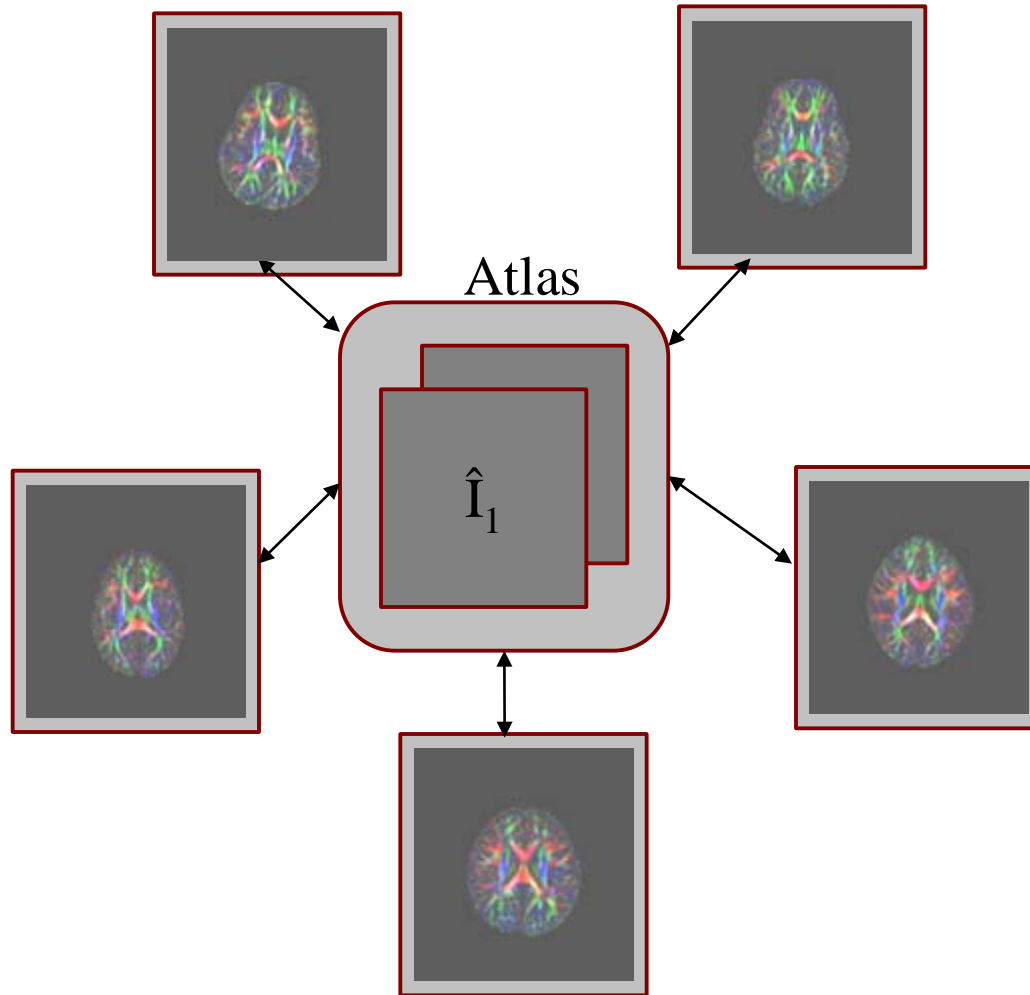
Unbiased Atlas Building: Population Average of Images

[Goodlett et al 2006]
[Joshi et al 2004]

Balci, Golland, Wells.
*Non-rigid Groupwise
Registration using
B-Spline Deformation
Model: →NITRC*

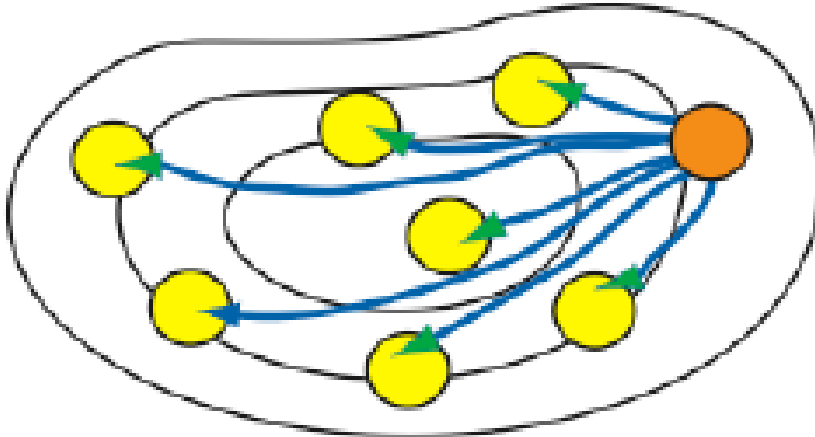
*Dinggang Shen,
HAMMER*

*Important: Fully
diffeomorphic/invertible
registration*

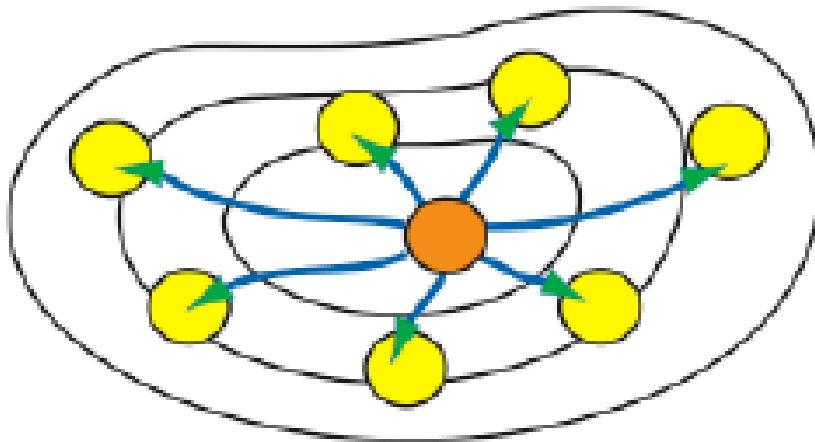




Group-wise Atlas Building



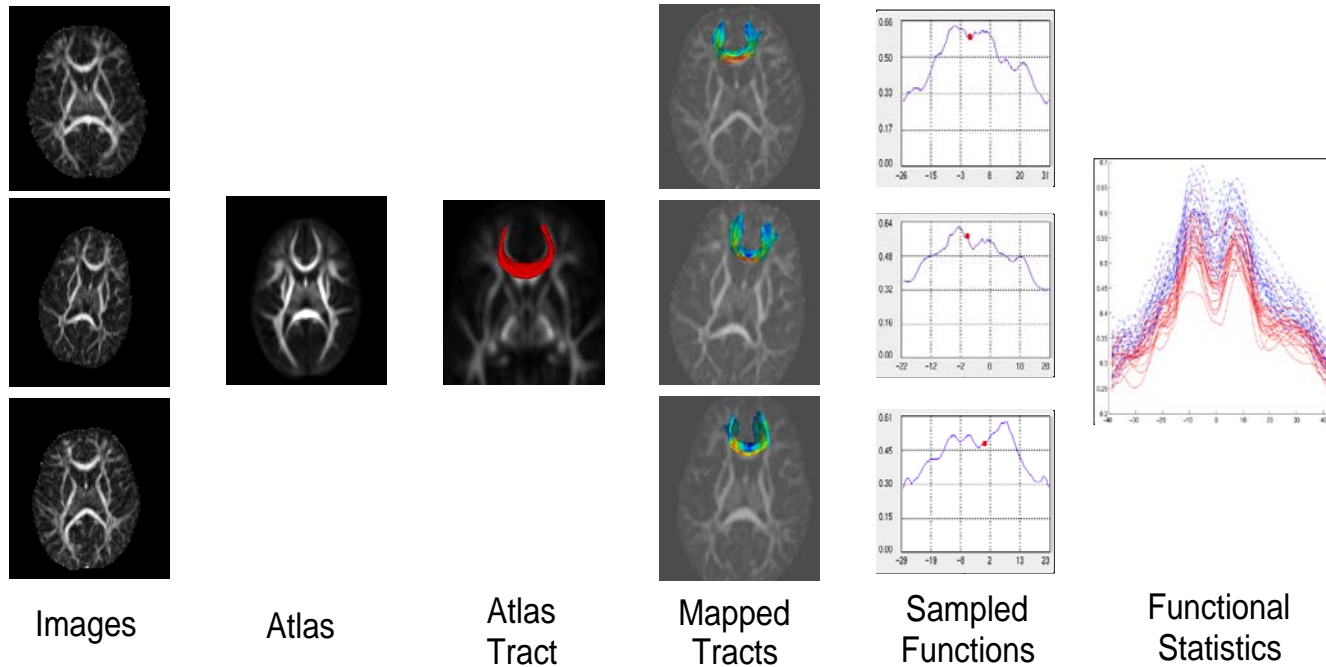
A) Choice of template:
Analysis is biased by choice
of template.



B) Unbiased atlas building:
Minimize total distance
between population and
template
(Gee & Avants,
Joshi&Fletcher)



Population-based analysis of DTI



Map DTI into unbiased atlas

Tractography in atlas space

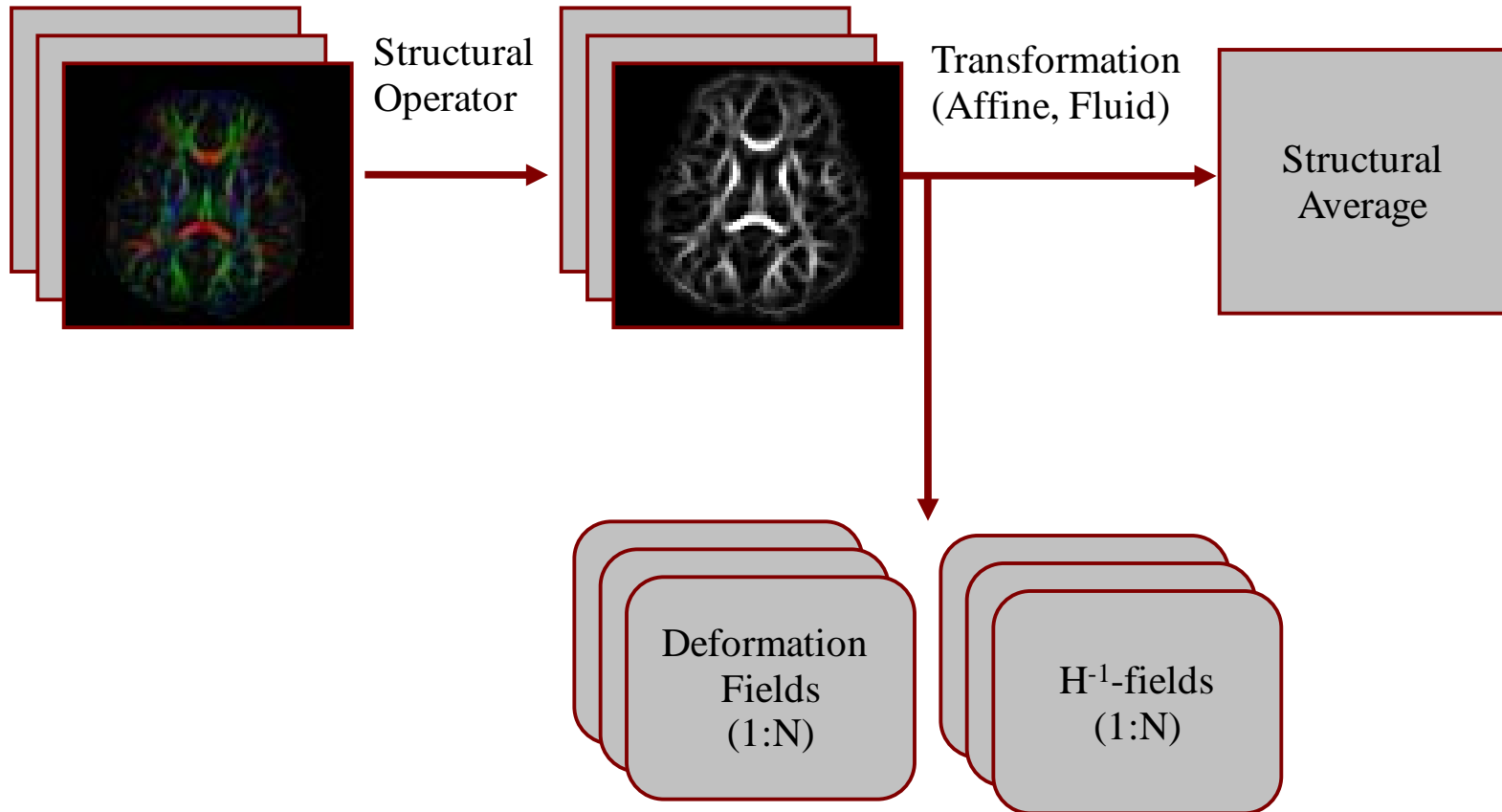
Map tracts to original images

Functional data analysis

Goodlett, et al., Group Analysis of DTI Fiber Tract Statistics with Application to Neurodevelopment, NeuroImage 45 (1) Supp. 1, 2009.p. S133-S142

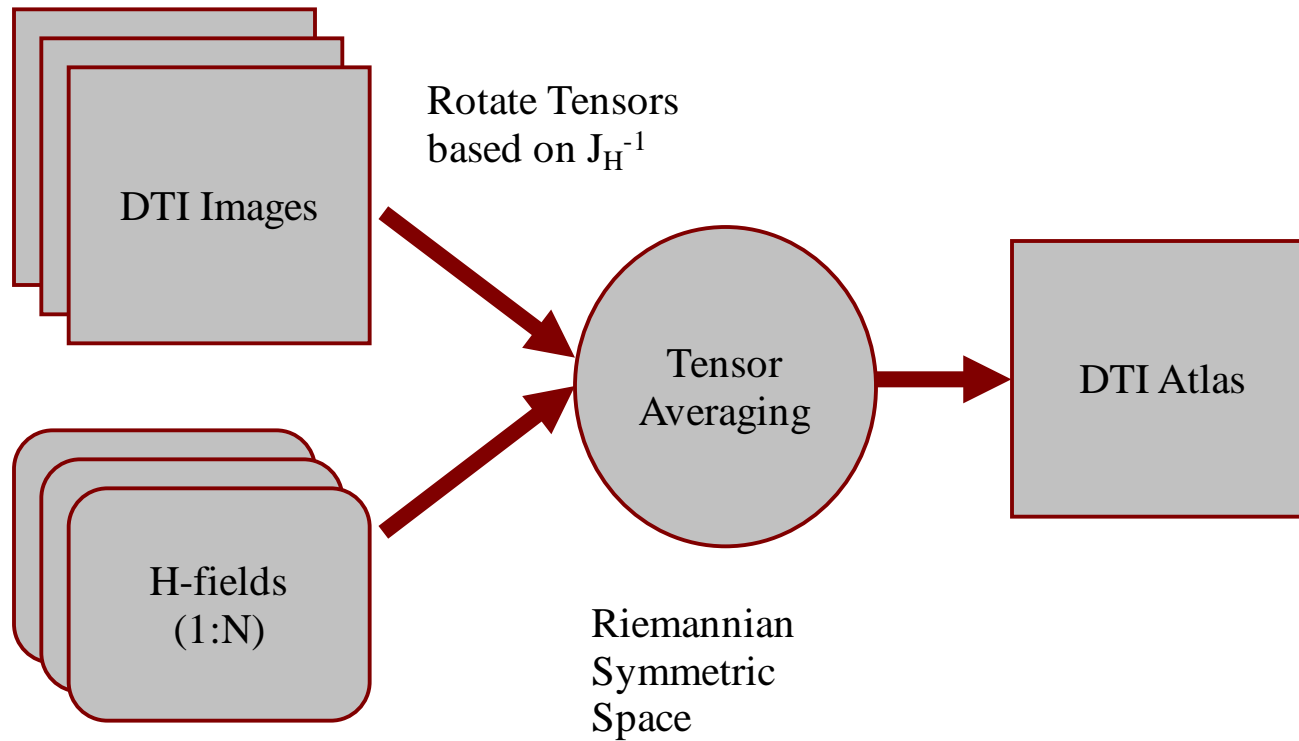


DTI: Estimation of coordinate transformations





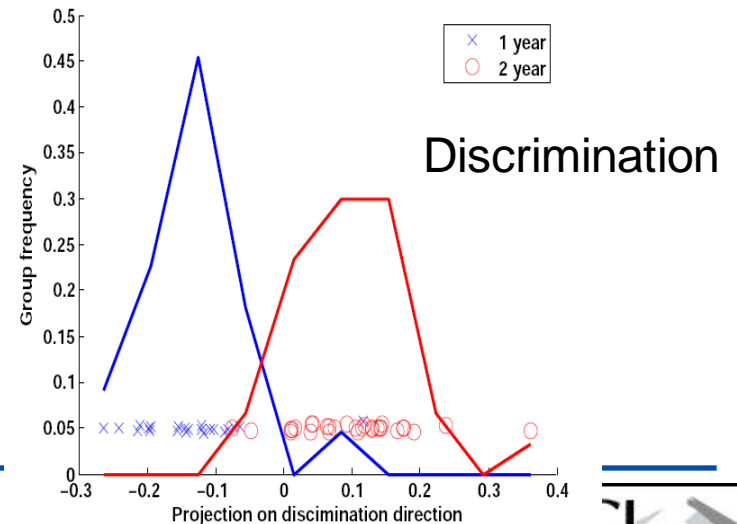
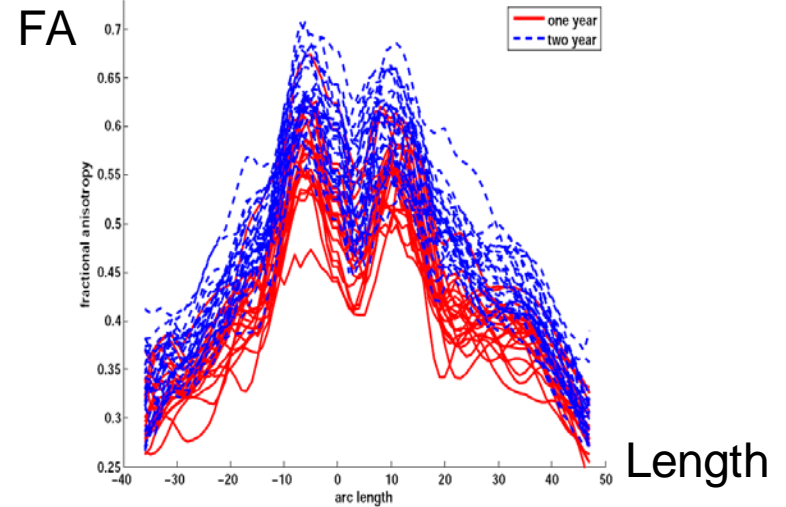
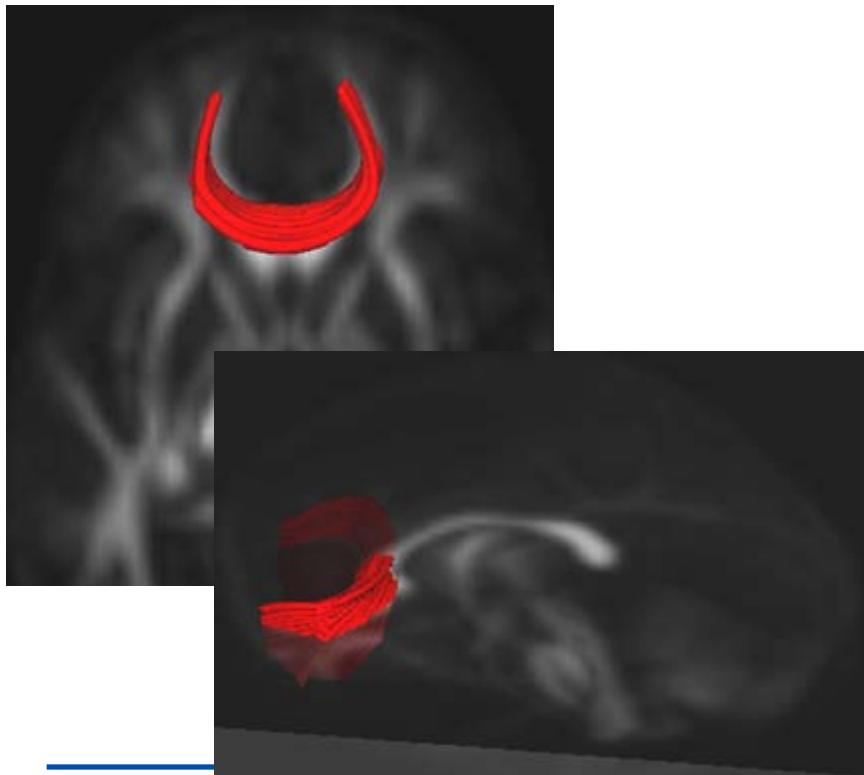
Computation of tensor means





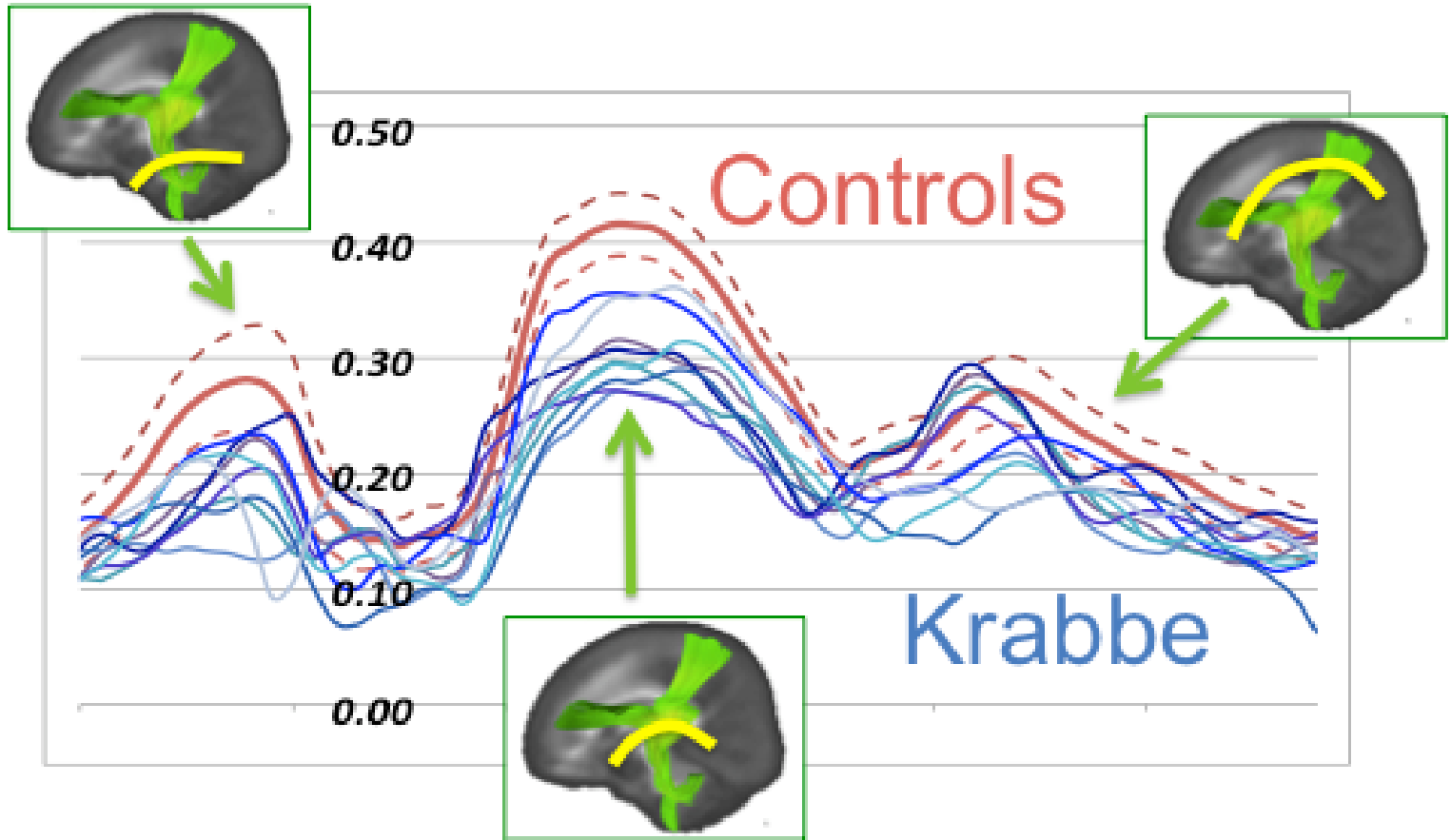
Pediatric Example – Genu 1 to 2yrs

Population analysis of fiber tracts:
Goodlett et al., MICCAI 08,
NeuroImage 2009



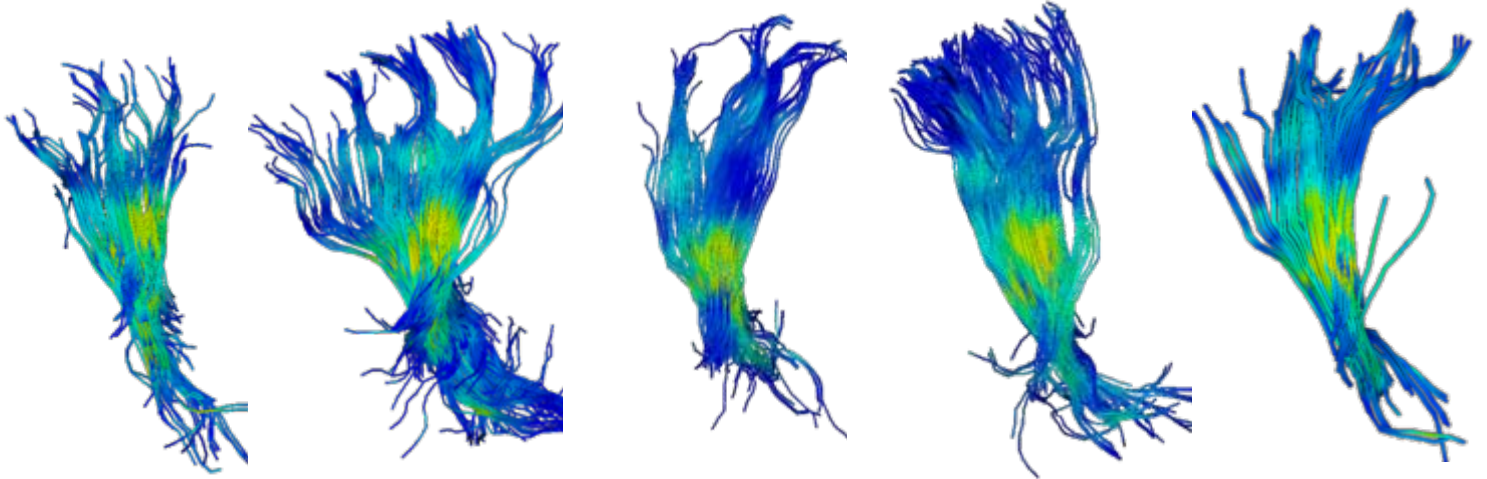


Tract Profile Group Statistics

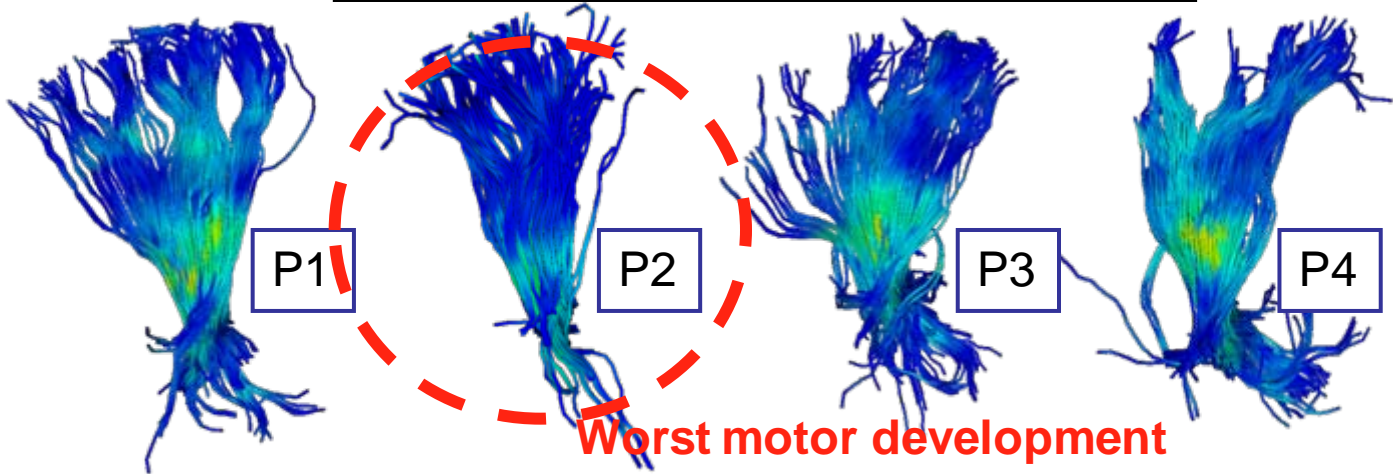




Controls - Left Internal Capsule Tracts



Krabbe's - Left Internal Capsule Tracts



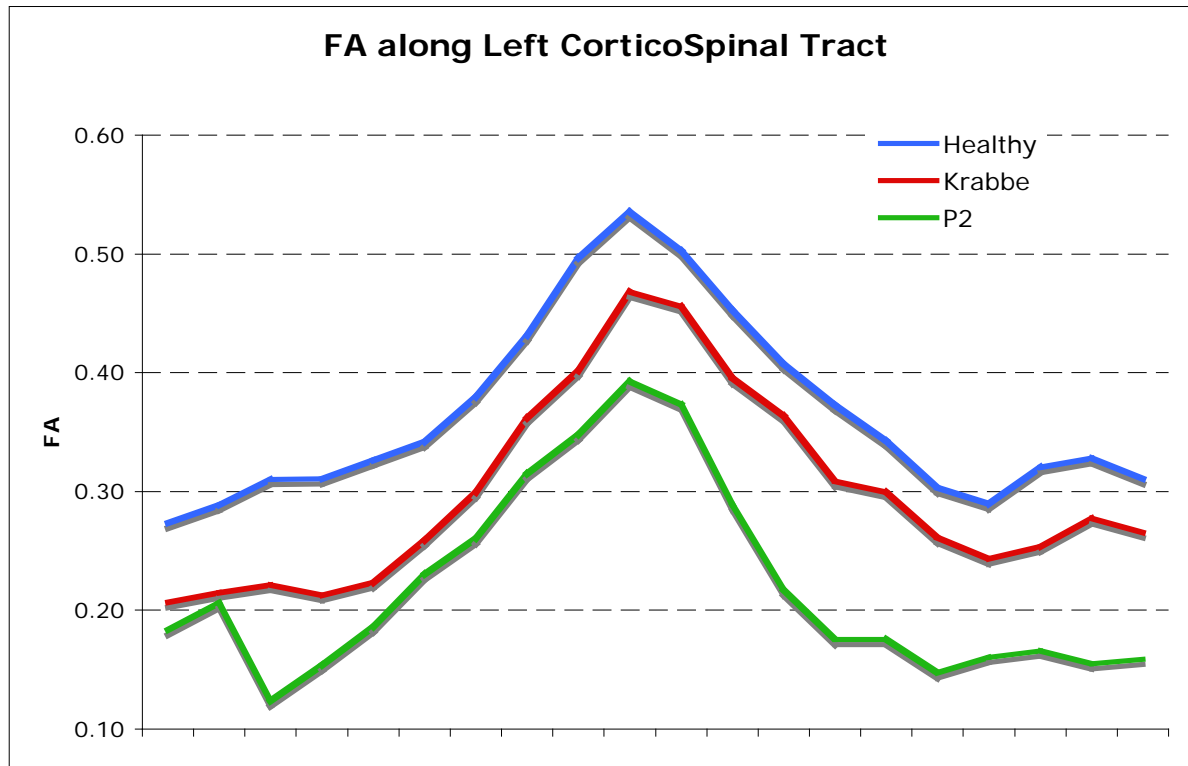
FA = 0



FA = 1



FA Statistics along Fibers



Statistics over 6 Krabbe, 53 Healthy neonate babies



Babies of drug-addicted mothers: Population based tract analysis of DTI

Cocaine vs control

	FA_FRO		AD_RD	
	p-value	% misclass	p-value	% misclass
cc	< 0.0541	9.09%	< 0.0537	9.09 %
splenium	NS		NS	
genu	NS		NS	
motor_L	NS		NS	
motor_R	NS		NS	

Cocaine vs NonCoc

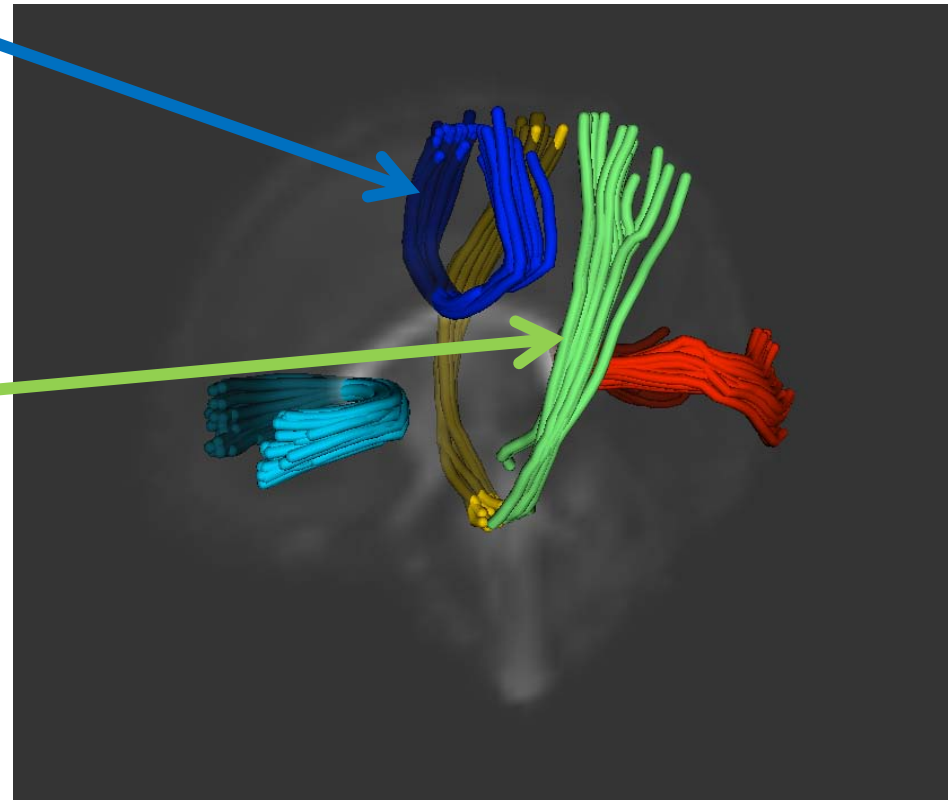
	FA_FRO		AD_RD	
	p-value	% misclass	p-value	% misclass
cc	NS		NS	
splenium	NS		NS	
genu	NS		NS	
motor_L	< 0.0497	5.55 %	< 0.0484	%5.55
motor_R	NS		NS	

Control vs Coc NonCoc

	FA_FRO		AD_RD	
	p-value	% misclass	p-value	% misclass
cc	NS		NS	
splenium	NS		NS	
genu	NS		NS	
motor_L	NS		NS	
motor_R	NS		NS	

NonCoc vs Control

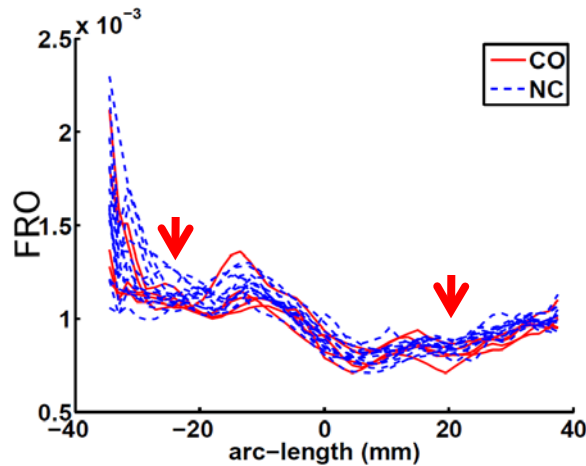
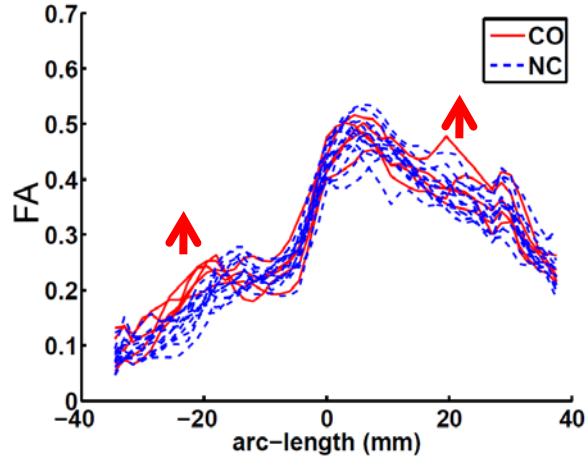
	FA_FRO		AD_RD	
	p-value	% misclass	p-value	% misclass
cc	NS		NS	
splenium	NS		NS	
genu	NS		NS	
motor_L	NS		NS	
motor_R	NS		NS	



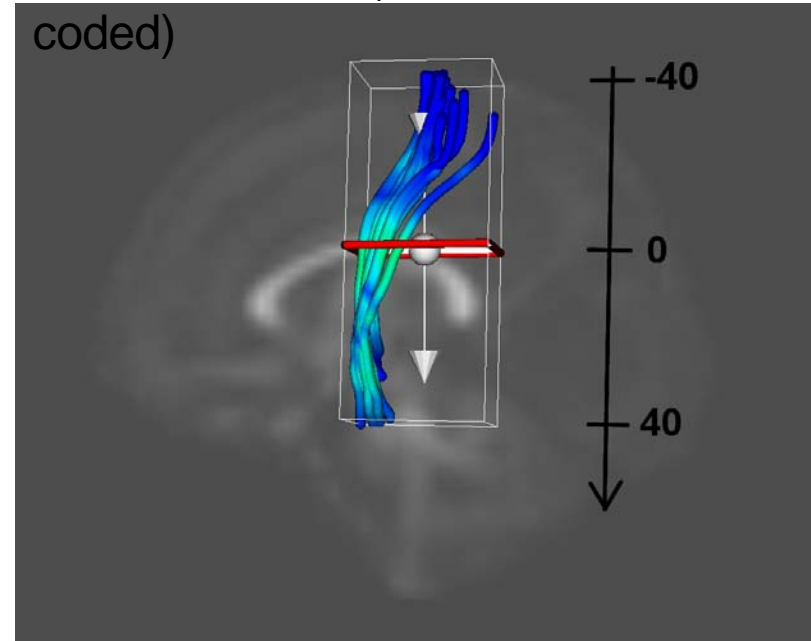


Population based analysis of DTI

Motor tract NC vs. CO

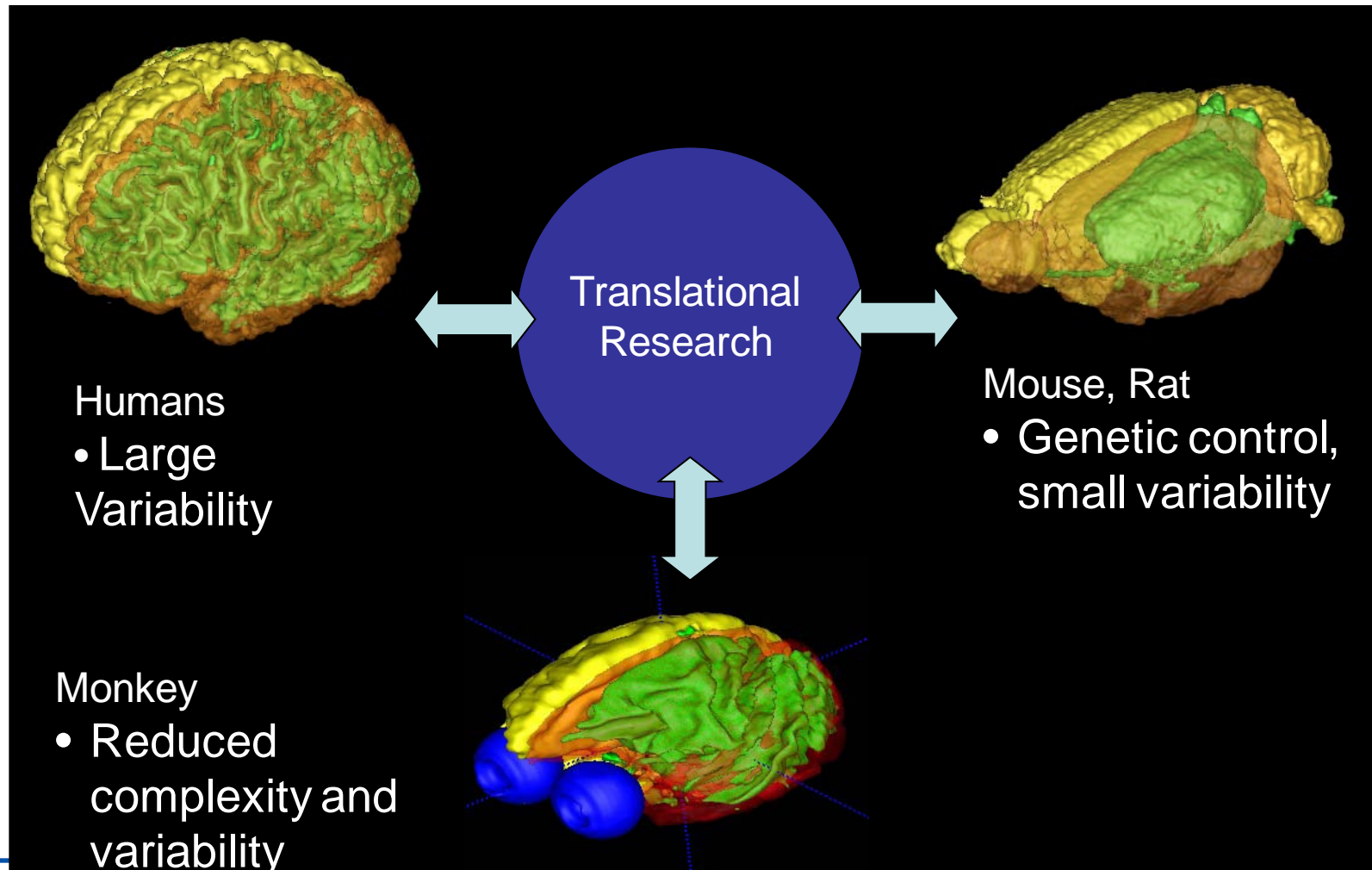


Left motor tract (FA color coded)





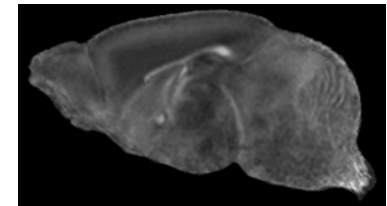
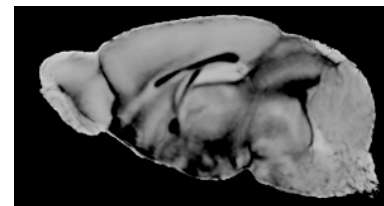
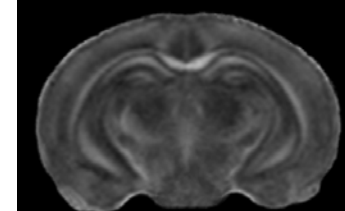
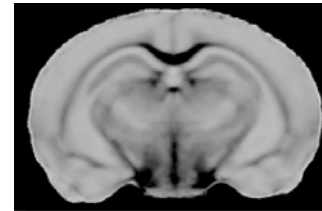
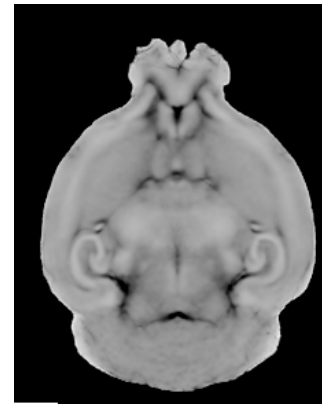
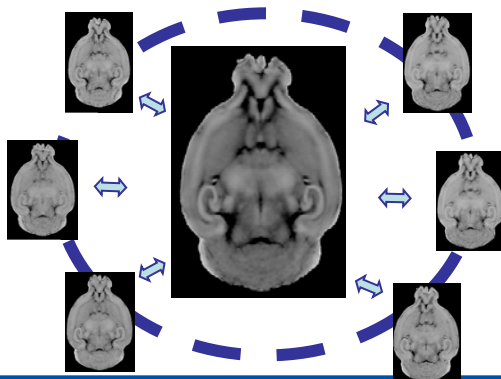
Brain Morphometry





Mouse Brain Analysis

- Structural & DTI analysis analogous to human & primate analysis
- Light-reared vs dark-reared mice
 - Prelim: 6 (3 vs 3)

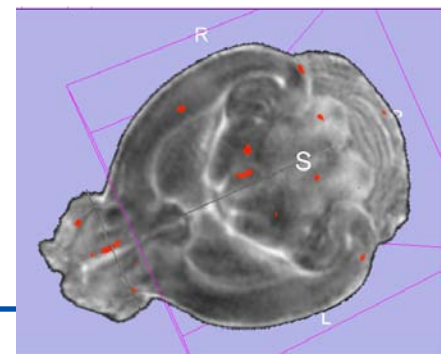
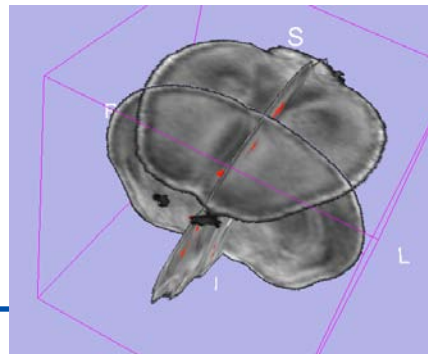
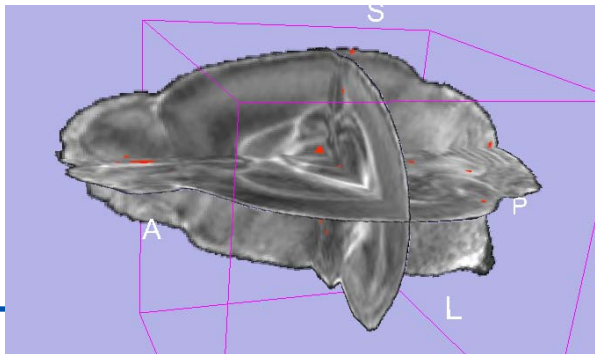
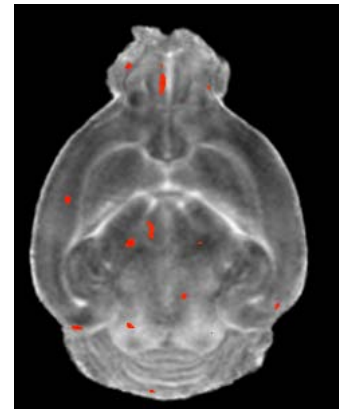
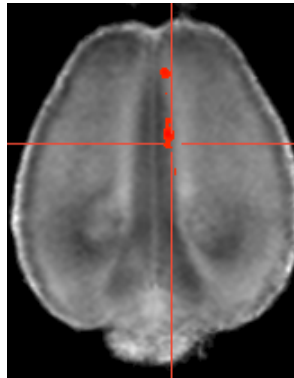
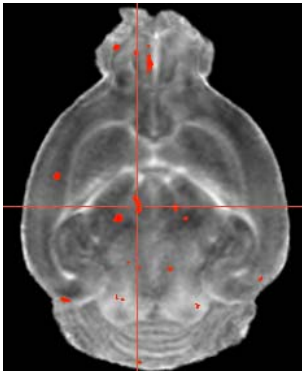
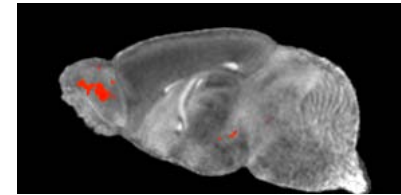
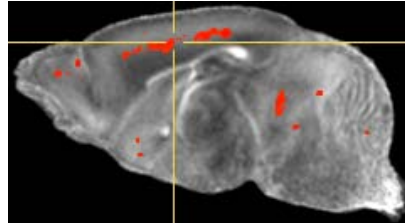
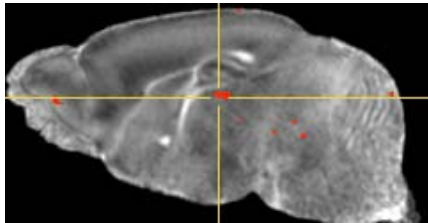


MD

FA



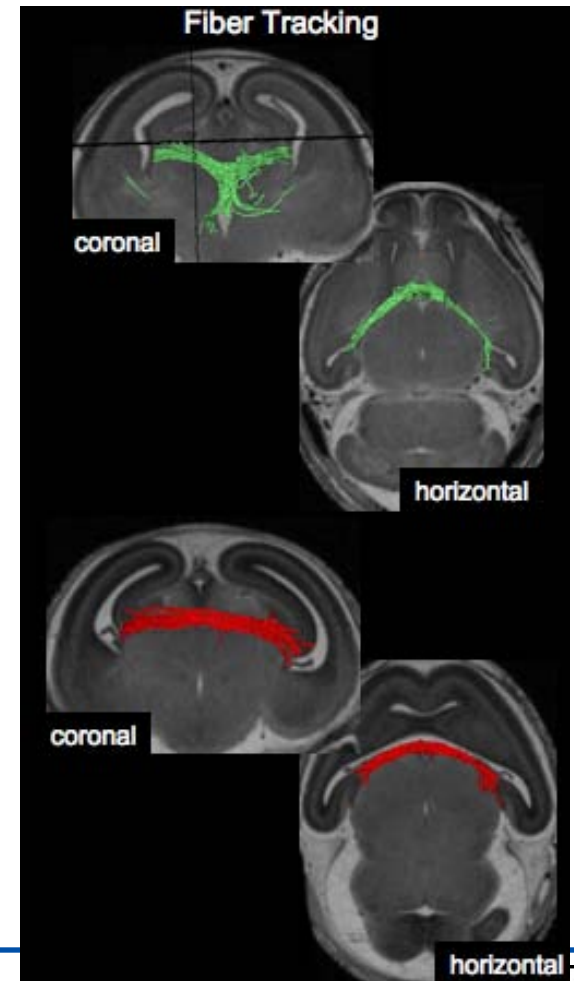
Mouse: Voxel Wise DTI Analysis





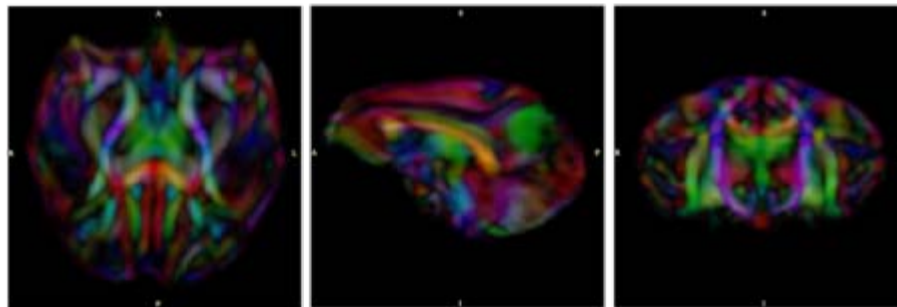
Mouse: FiberTracking

- Major tracts successfully extracted:
 - CC, fornix, AC
- FA along tracts
 - Same as in humans
- Example on fetal alcohol syndrome

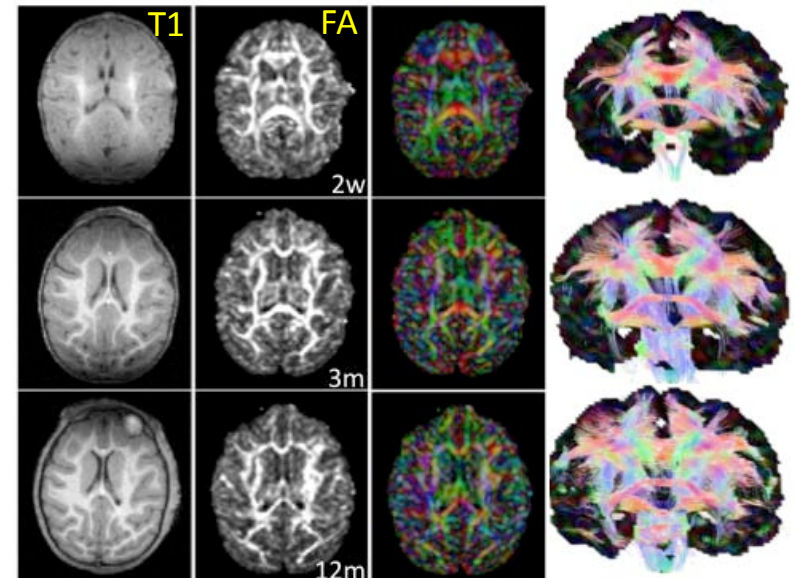
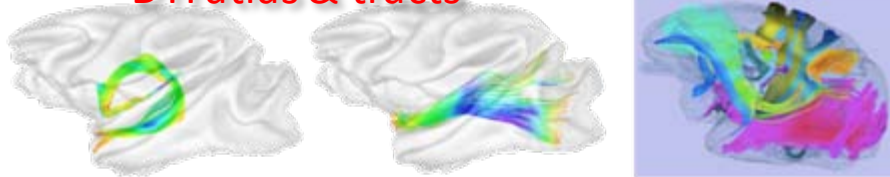


Monkey DTI

- With Marc Niethammer
- DTI atlas method adapted for primate data
- First MRI scan batch acquired
 - DTI atlas and sMRI atlas at 2w, 3m, 6m are built



DTI atlas & tracts



Conclusions

- Slicer 3 Platform provides comprehensive set of tools
- Whole processing from DICOM to output results in one computational environment
- New tools added as new technologies and methodologies emerge