

Diffusion Tensor Imaging in Humans: Practical Implications for Neuroanatomy

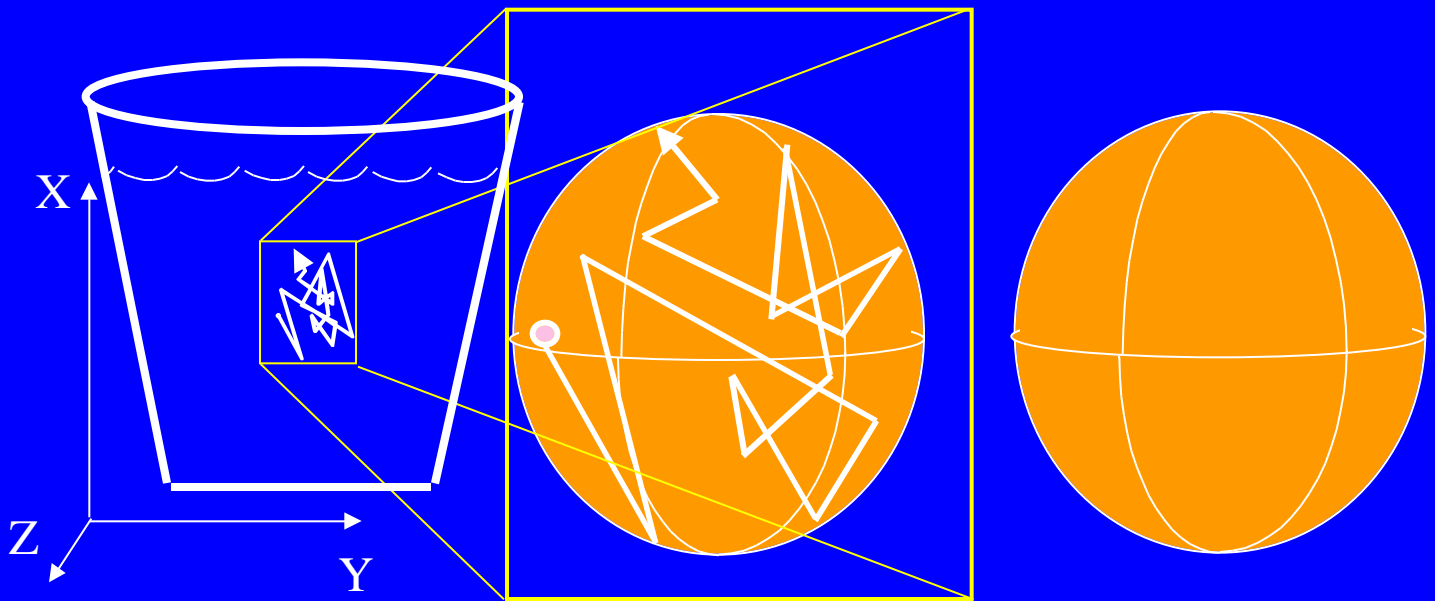
Collaborators

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 - Andy Worth
 - Verne S. Caviness
 - George Papadimitriou
- **MGH-NMR Center**
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 - Dee Pandya

Overview

- What is the Diffusion Tensor
- The Diffusion Tensor and Brain Anatomy
- The Diffusion Tensor and Brain Pathology
- Issues and Limitations

Water Diffusion in a Homogeneous Medium

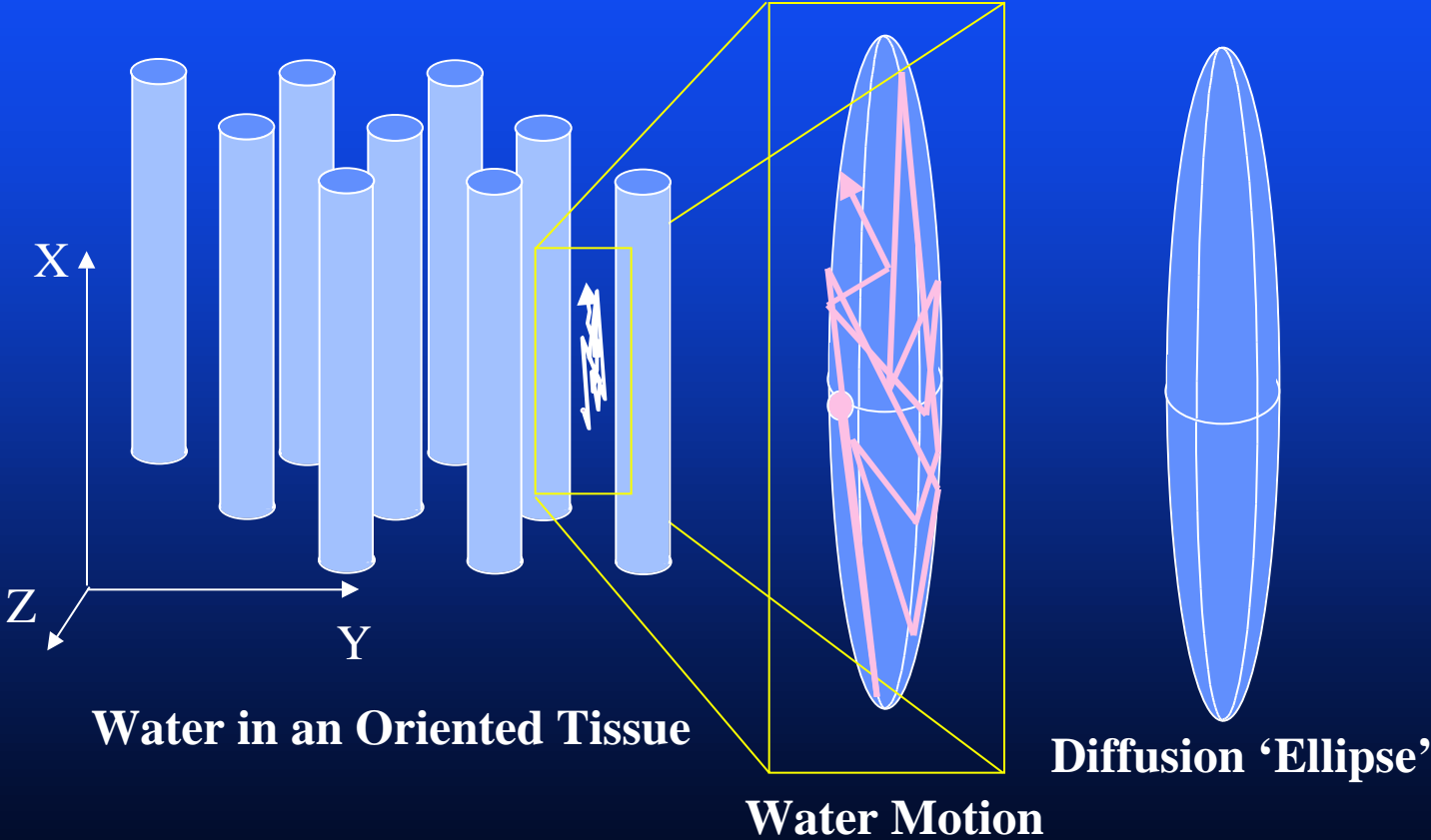


Water in a
Homogeneous Medium

Water Motion

Diffusion 'Sphere'

Water Diffusion in White Matter

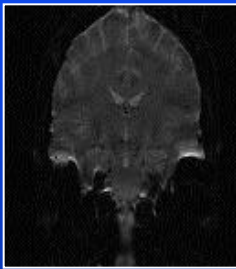


Diffusion Imaging - Principles

- Water diffusion (ie. incoherent motion) in the presence of a magnetic field gradient will dephase MR signal.
- Water in oriented tissues (such as WM fibers) prefers to diffuse along the fibers as opposed to against.
- The signal decrease is related to the diffusivity of water along the direction of the applied gradient (as well as the strength and duration of the gradient).

The 'Anatomy' of a Diffusion Image

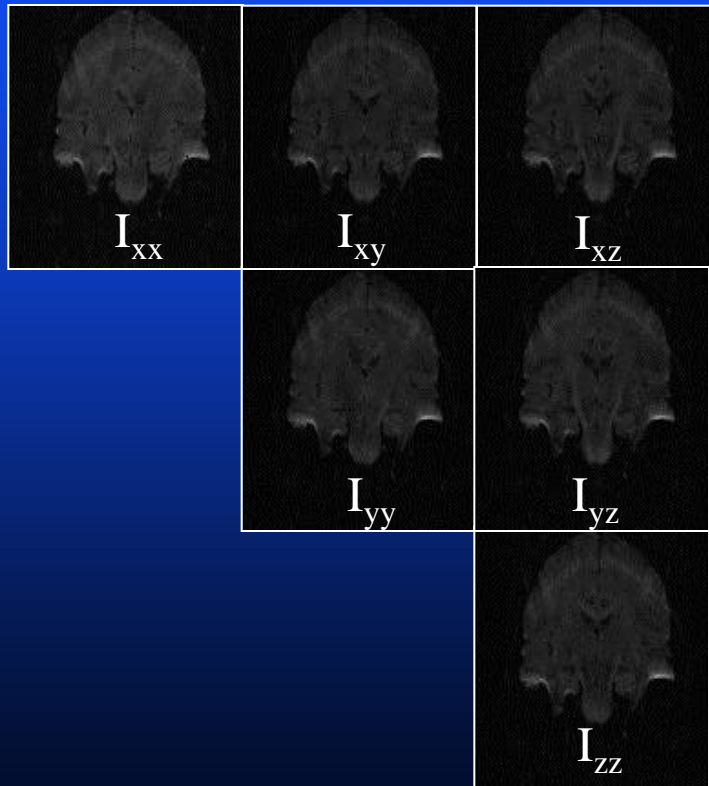
- Seven Images / Slice



I_0

$$D_{ij} = I_{ij} / I_0$$

$$\vec{\mathbf{D}} = \begin{matrix} D_{xx} & D_{xy} & D_{xz} \\ D_{xy} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{matrix}$$



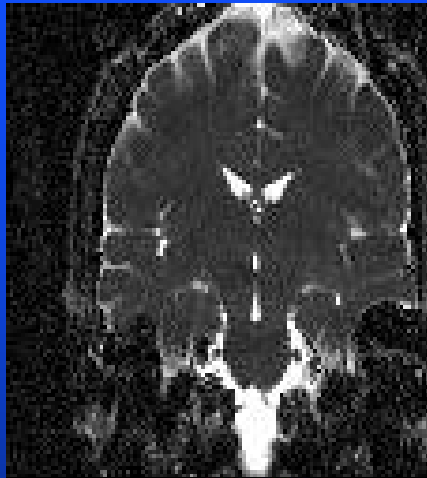
Diffusion Imaging - General Concepts

- The Diffusion Tensor:
- Apparent Diffusion Constant (ADC)
- Seven-shot Imaging
- Eigen-decomposition and Reordering
- Anisotropy Measures
 - Lattice
 - Fractional
 - others
- Visualization

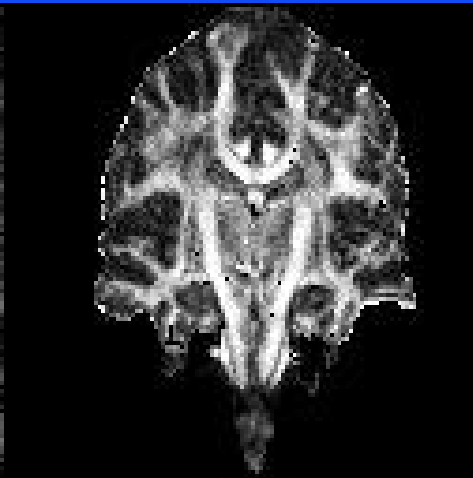
$$\vec{\mathbf{D}} = \begin{matrix} D_{xx} & D_{xy} & D_{xz} \\ D_{xy} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{matrix}$$

The 'Anatomy' of a Diffusion Image (con't.)

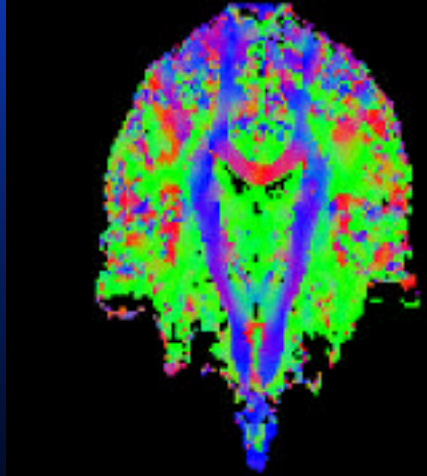
Diffusion
Magnitude
(ADC)



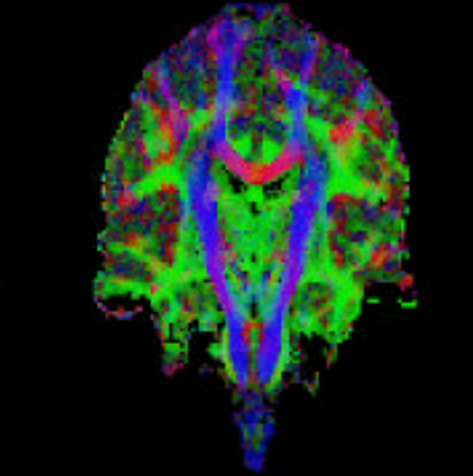
Diffusion
Anisotropy



Tensor
Orientation
Maps



(including
anisotropy
modulation)

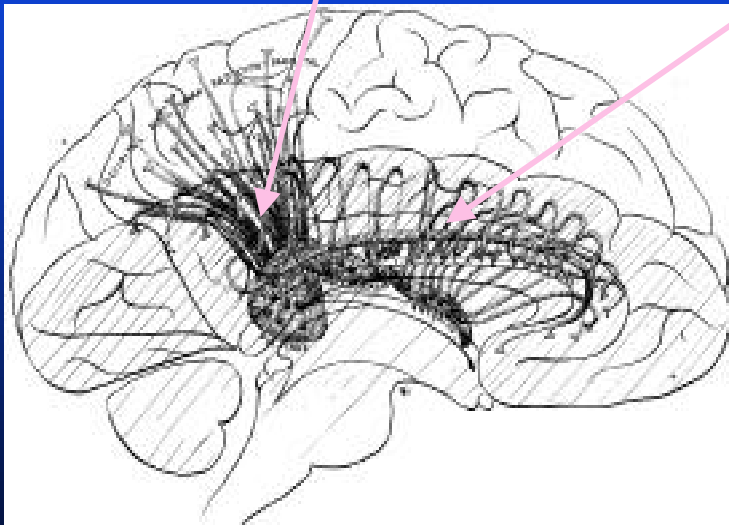


Diffusion Tensor Imaging: Normal Brain

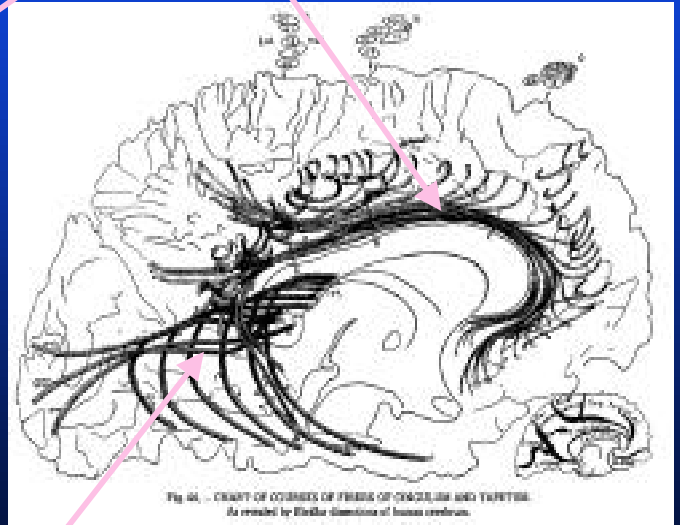
- White Matter Anatomy
- Pathway 'Validation'

Overview of WM - Macrostructure

**Parietal-Thalamic (Pulvinar) Projections
(Projectional)**



Cingulum Bundle (Associational)



Tapetum (Commissural)

W. Krieg, 1973

Overview of WM

Classes of Connections

• **Associational** - intrahemispheric cortico-cortical connections

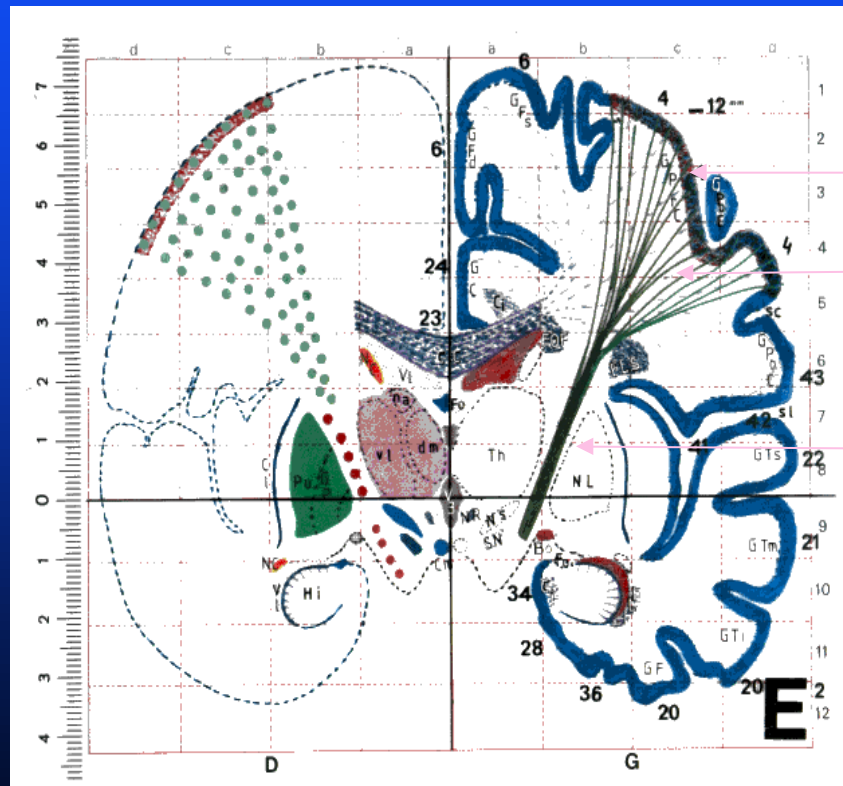
• **Commissural** - interhemispheric cortico-cortical connections

• **Projectional** - intrahemispheric cortico-subcortical connections

Principles of Organization

Fiber Pathways tend to fasciculate into “stems”, converging from origin into compact bundles, from which they ultimately diverge to termination.

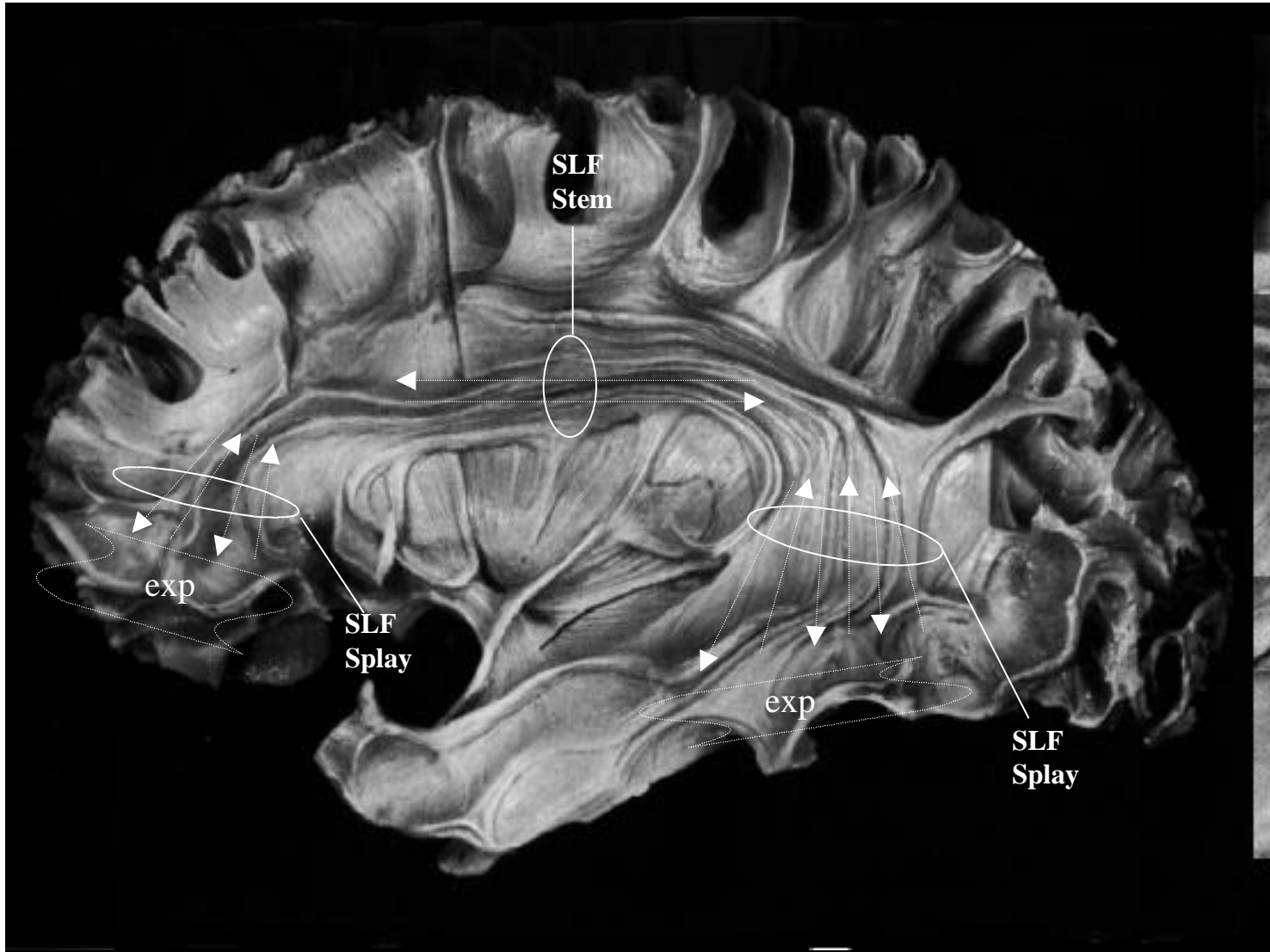
Overview of WM



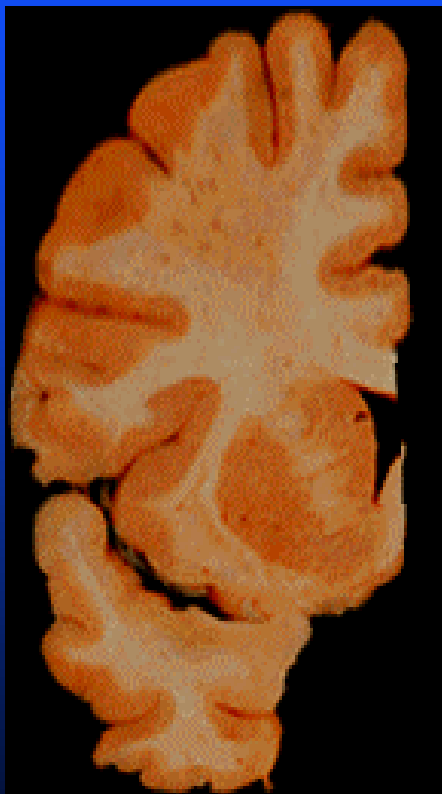
ExP

Spray ↓

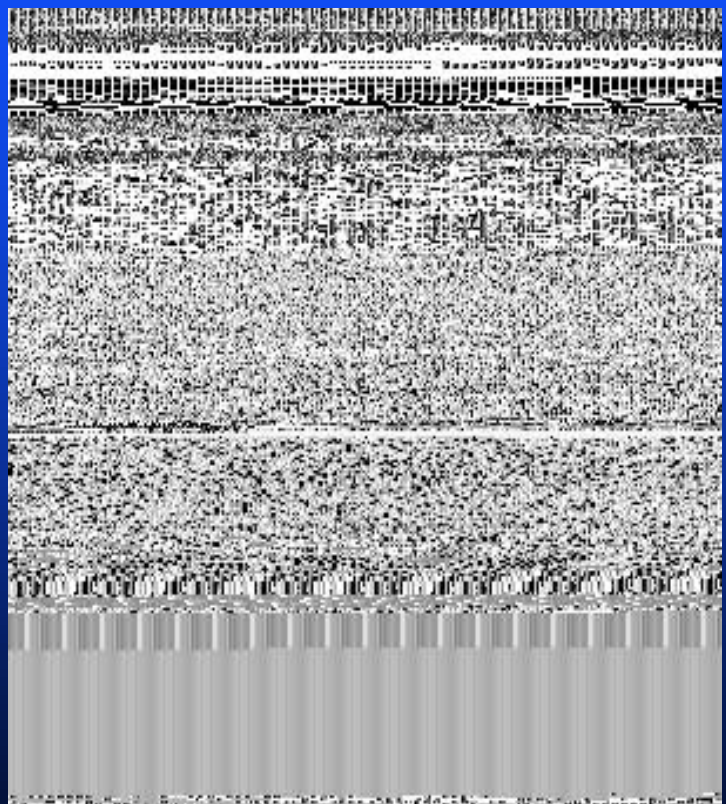
Stem



Where's the Beef?

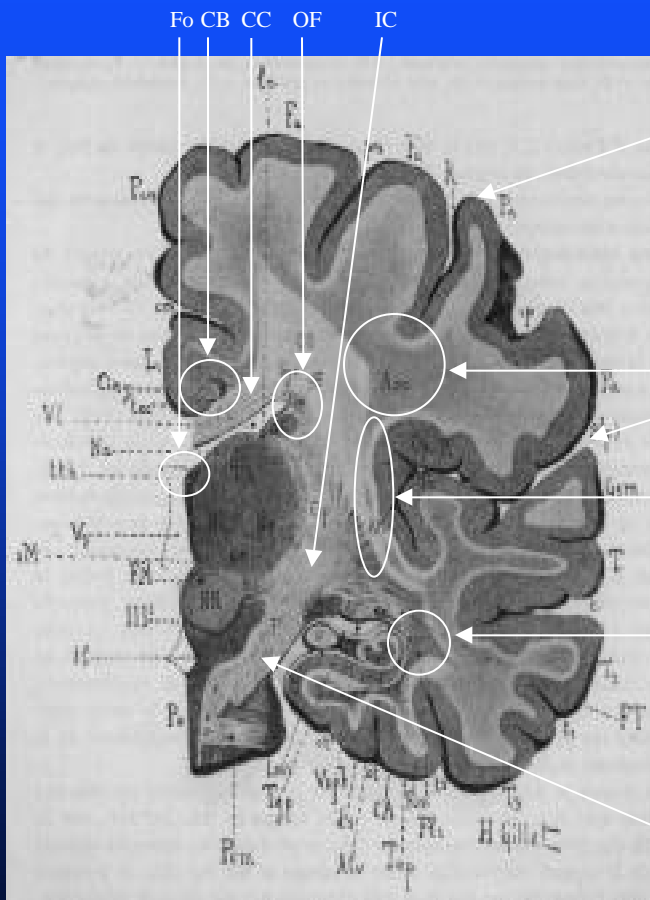


Postmortem

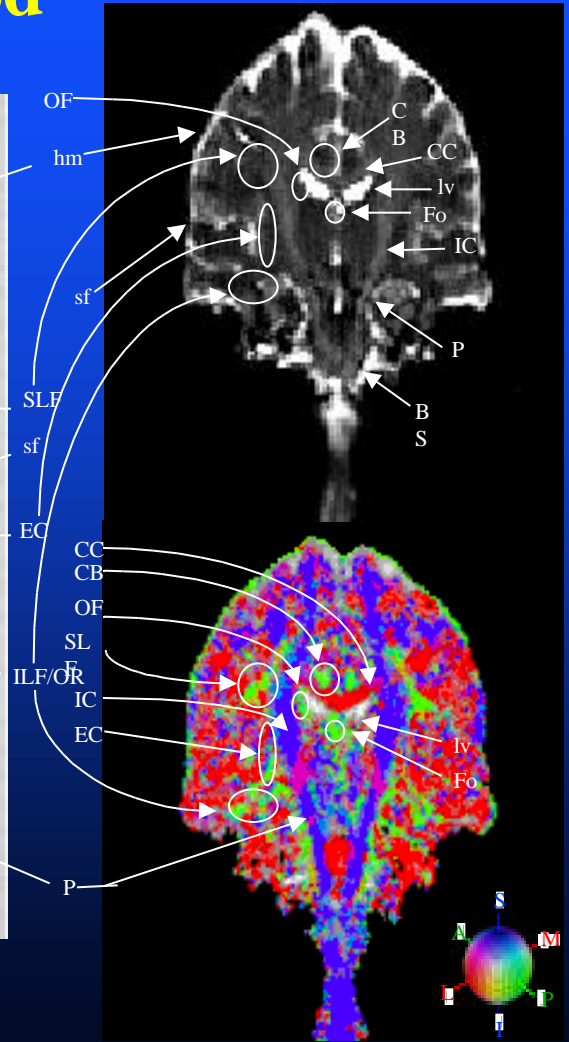


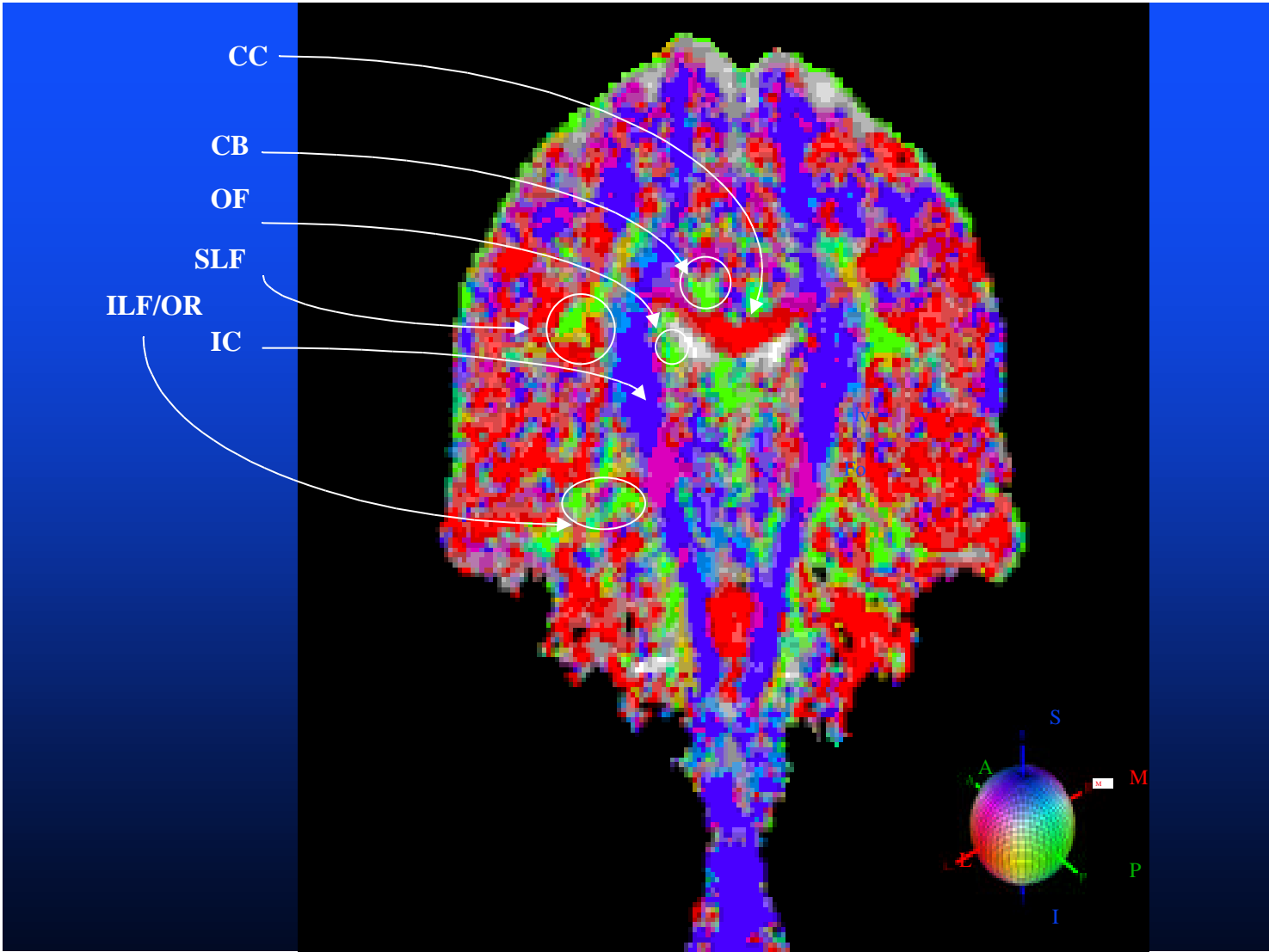
MRI Scan

Pathway Analysis Method



Dejarine Atlas

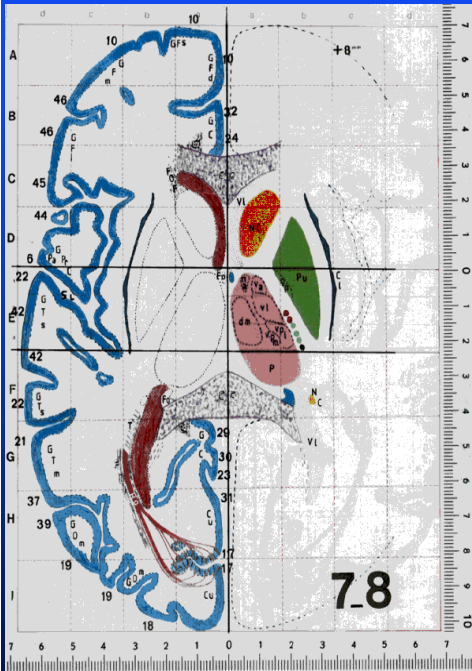




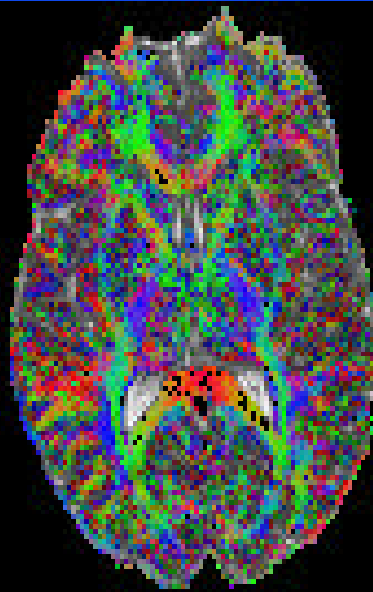
Observed Pathway Table

White Matter Pathway	Extent on Dejerine Map	Approximate Size Range in Cross Section (mm)	Orientation (major axis)
Superior Longitudinal Fasciculus (SLF) (longitudinal portion)	37 - 92	6-10	AP
Cingulum Bundle (CB)	30 - 105	5-8	AP
Inferior Longitudinal Fasciculus and Optic Radiation Complex (ILF/OR)	75 - 137	5-7	AP
Occipitofrontal Fasciculus (OF)	30 - 88	4-6	AP
Uncinate Fasciculus (UF)	40 - 63	3-5	AP
Extreme Capsule (EC)	55 - 83	2-6	AP
Fornix (Fo) (longitudinal part)	66 - 92	2-8	AP
Corpus Callosum (CC)	33 - 105	5-15	ML
Anterior Commissure (AC)	55 - 69	2-5	ML
Internal Capsule (IC)	43 - 86	5-12	SI
Cerebral Peduncle (P)	75 - 86	7-12	SI

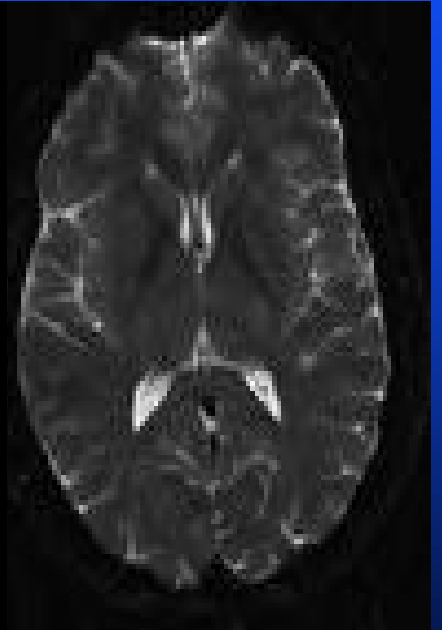
Diffusion Imaging



Talairach Atlas



Tensor Orientation Map



T2-weighted

Topographic White Matter Parcellation

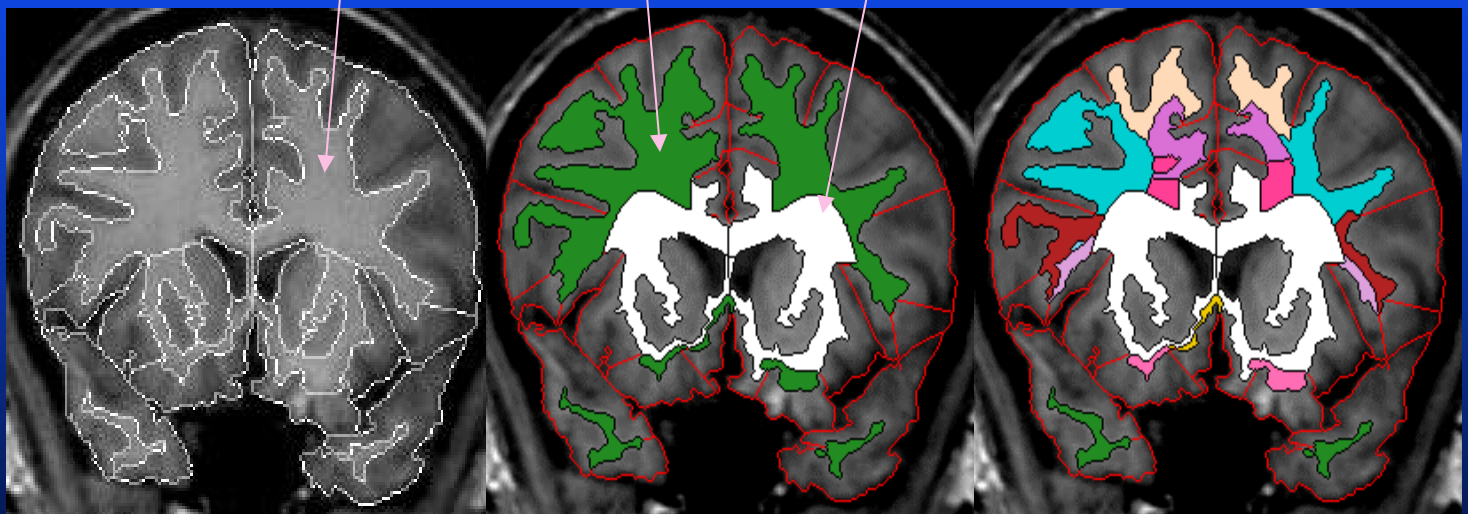
- Two Principal Zones
 - Peripheral (Radiate)
 - Deep and ‘Bridging’
- Parcellation of Zones
 - Radiate
 - Proximity regions to overlying cortical parcellation units
 - Deep and Bridging
 - Geometric constructs for:
 - Sagittal Strata (superior, inferior, temporal, cingulum)
 - Corpus Callosum
 - Internal Capsule, Fimbrial-Fornix, Amygdalofugal

Topographic White Matter Parcellation

White Matter

Radiate

Deep & Bridging

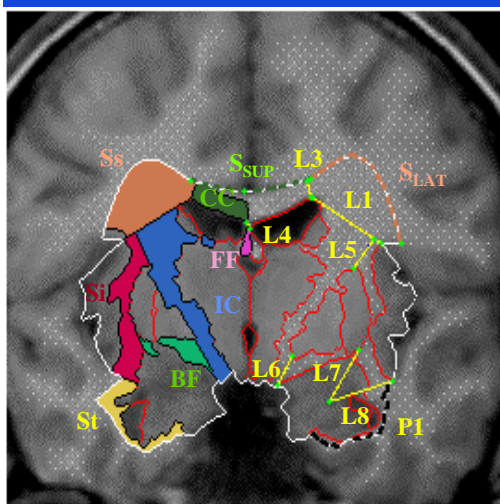


General Segmentation

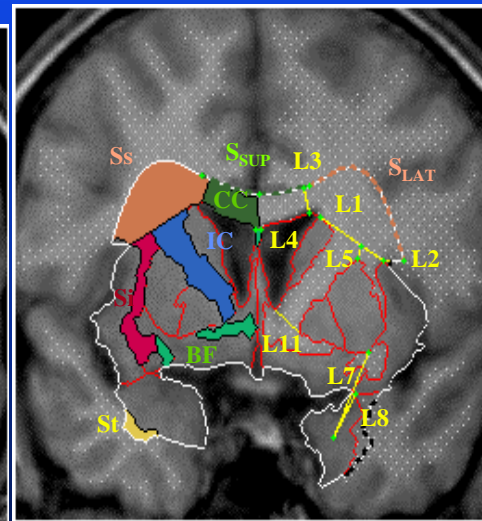
Zones

Radiate Parcellation

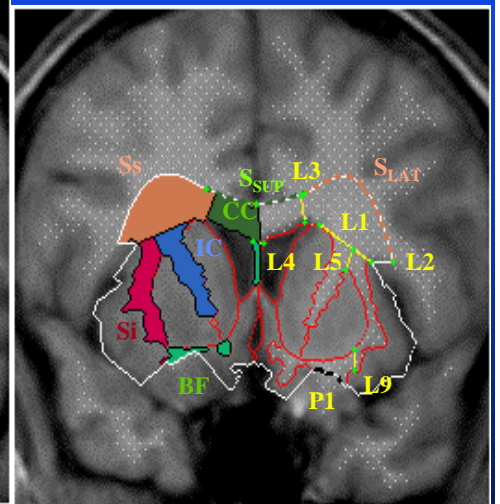
White Matter Parcellation - Deep and Bridging Systems



-10mm



+0mm



+10mm