

Challenges in Functional Brain Science from the Perspective of Inverse Problem

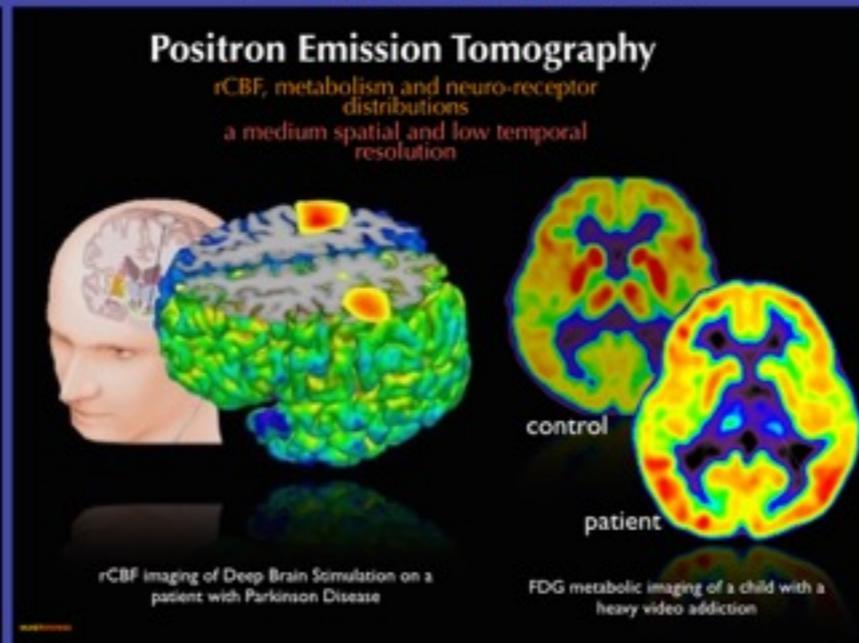
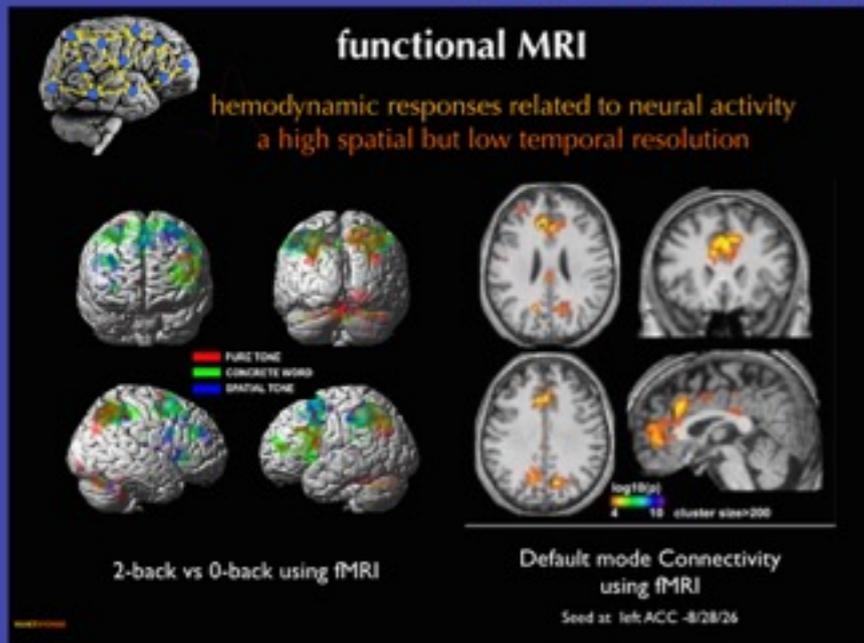
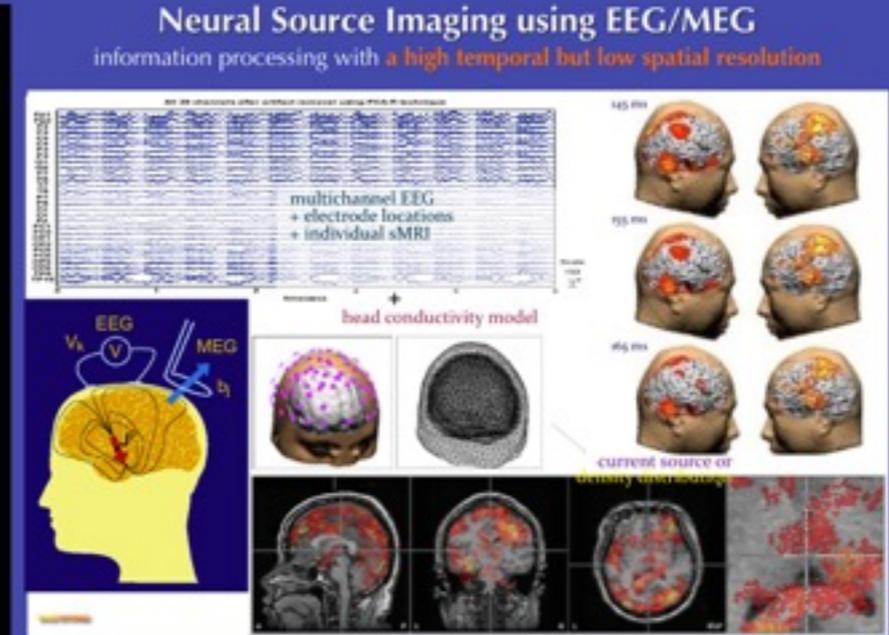
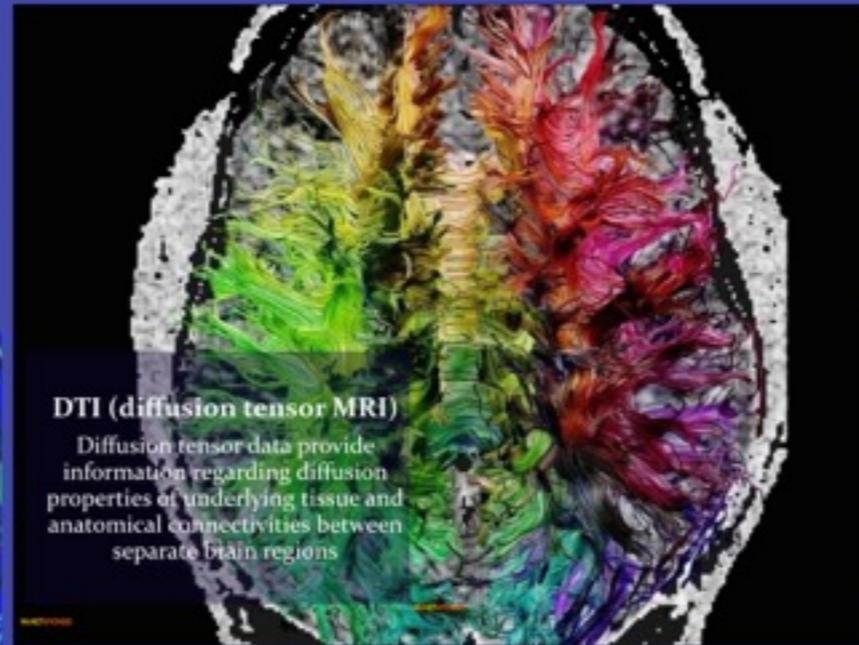
Hae-Jeong Park, Ph.D.

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Yonsei Neuroscience Institute

<http://neuroimage.yonsei.ac.kr>

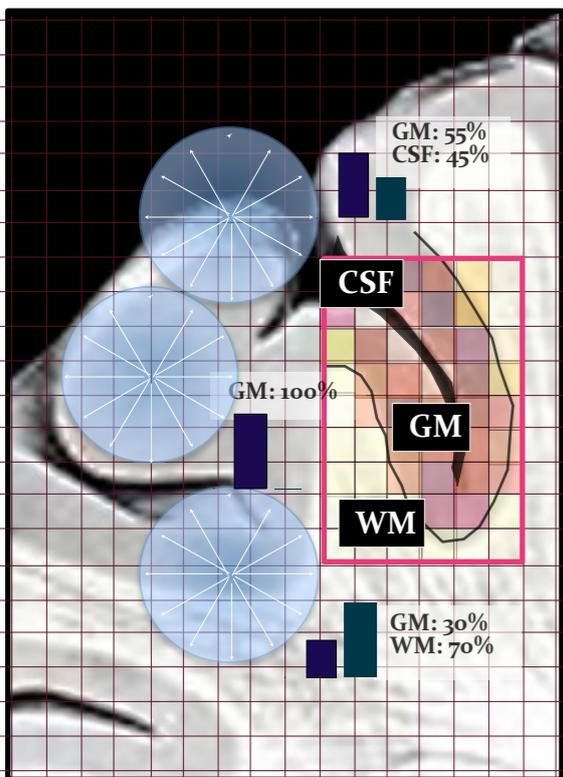
Inverse Problems :
Decoding Brain Mechanisms
from Observations using Generative Models

Neuroimaging Methods : Observations For Inverse Problem



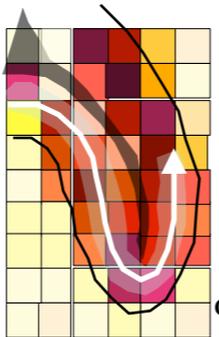
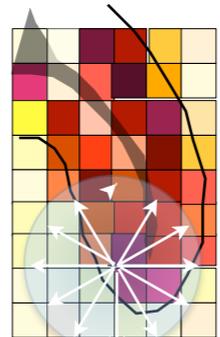
Anisotropic Smoothing of fMRI activation

- Isotropic smoothing effects differ according to brain regions.
- Smoothing leads to additional partial volume effects.



Isotropic smoothing over 3D volume includes activities at neighboring WM & CSF for GM measurements

Anisotropic smoothing along the GM surface includes activities only at neighboring GM for GM measurements



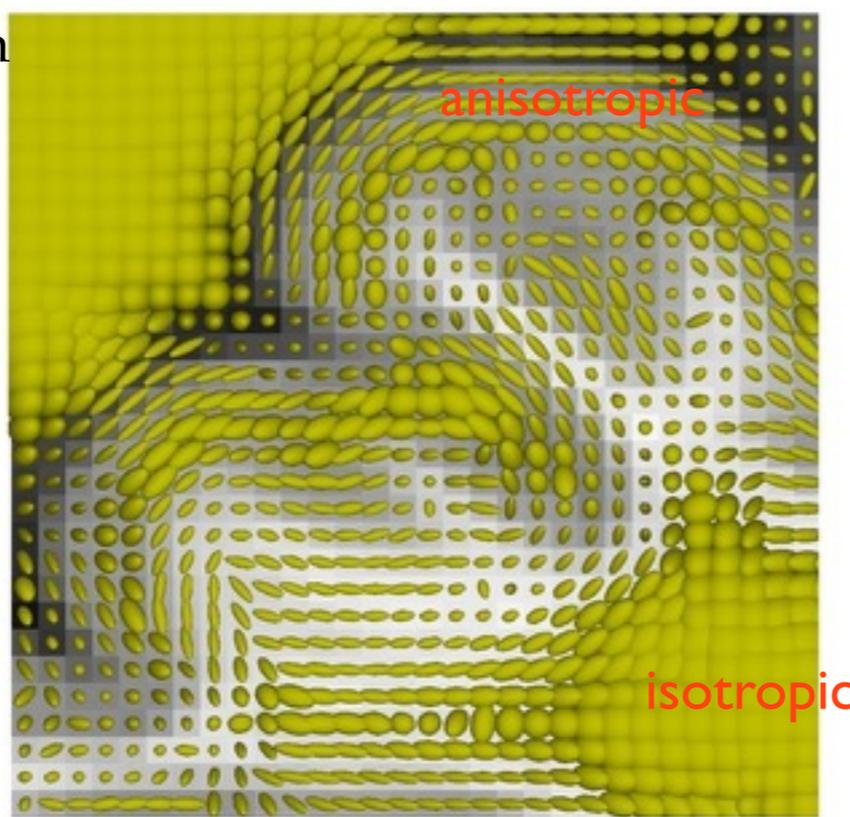
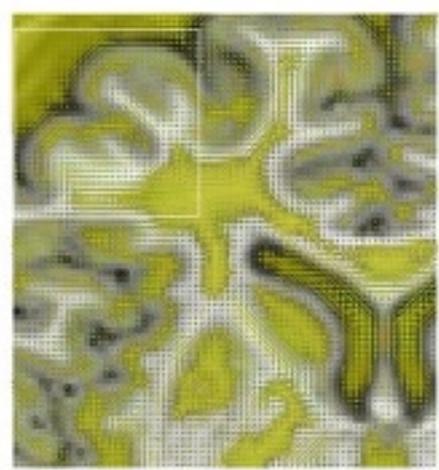
GM: 30%
WM: 65%
CSF: 5%

GM: 100%

Smoothing on the GM surface can minimize additional partial volume effects and localization errors caused by isotropic smoothing over the volume !!

$$D_p = K_p * (\nabla S_d \nabla S_d^T)$$

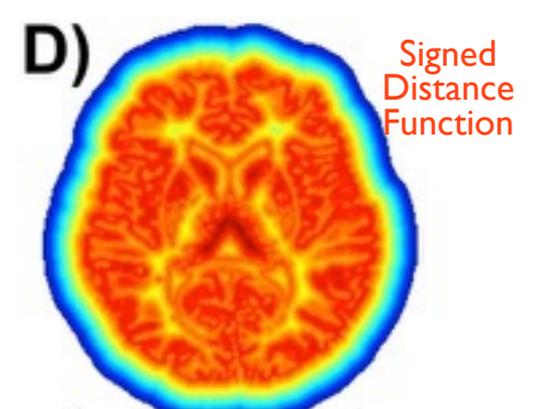
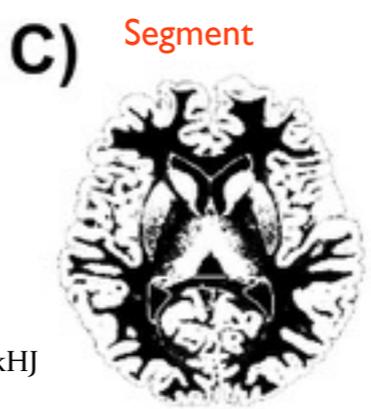
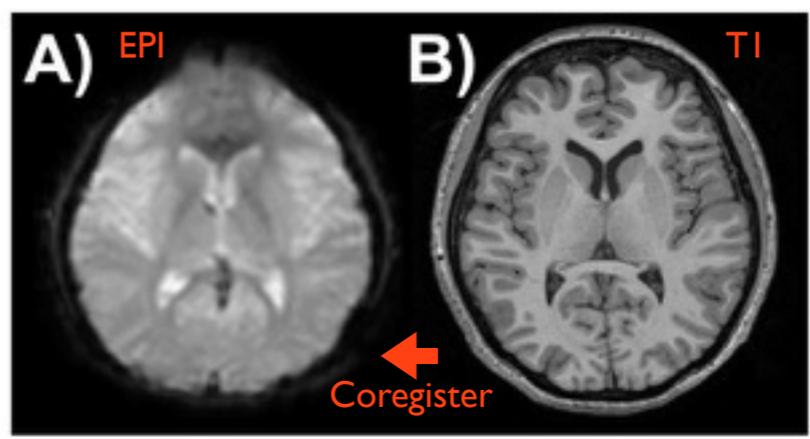
Structural tensor from the signed distance function



NamHW, & ParkHJ 2011, PMB.

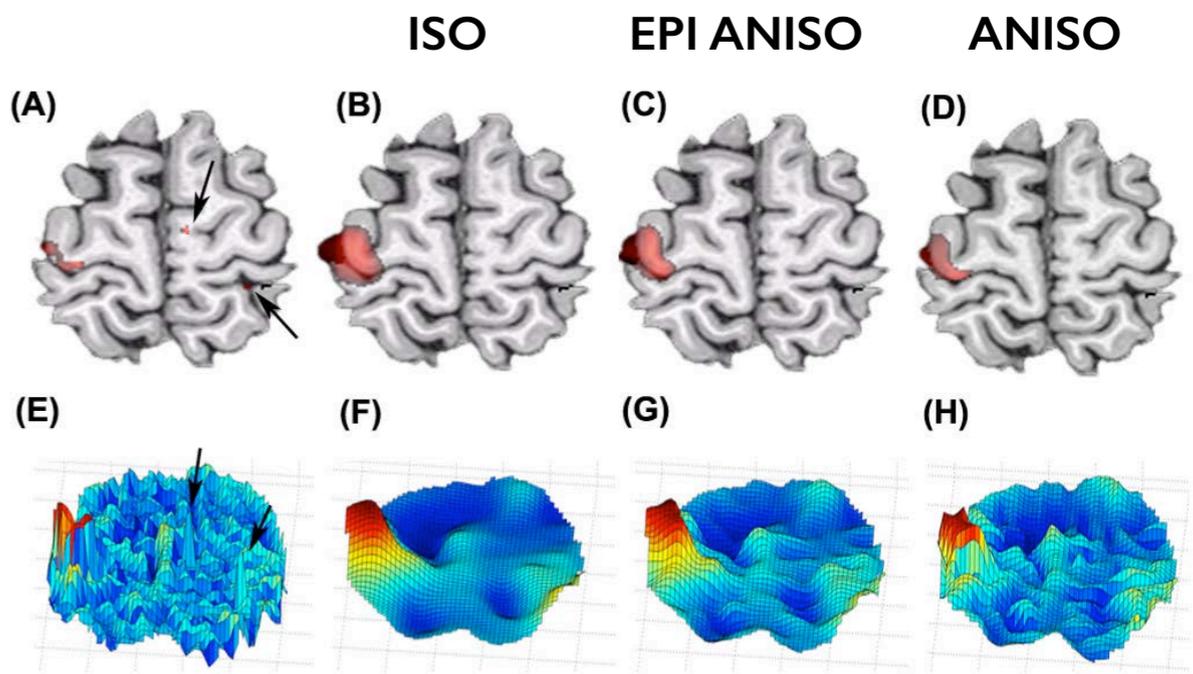
$$\alpha(x) = 1 - \exp\left(\frac{-d(x)^2}{N}\right) * (1 - \epsilon)$$

Diffusion tensor from a signed distance transformation



NamHW, & ParkHJ 2011, PMB.

Example for motor function

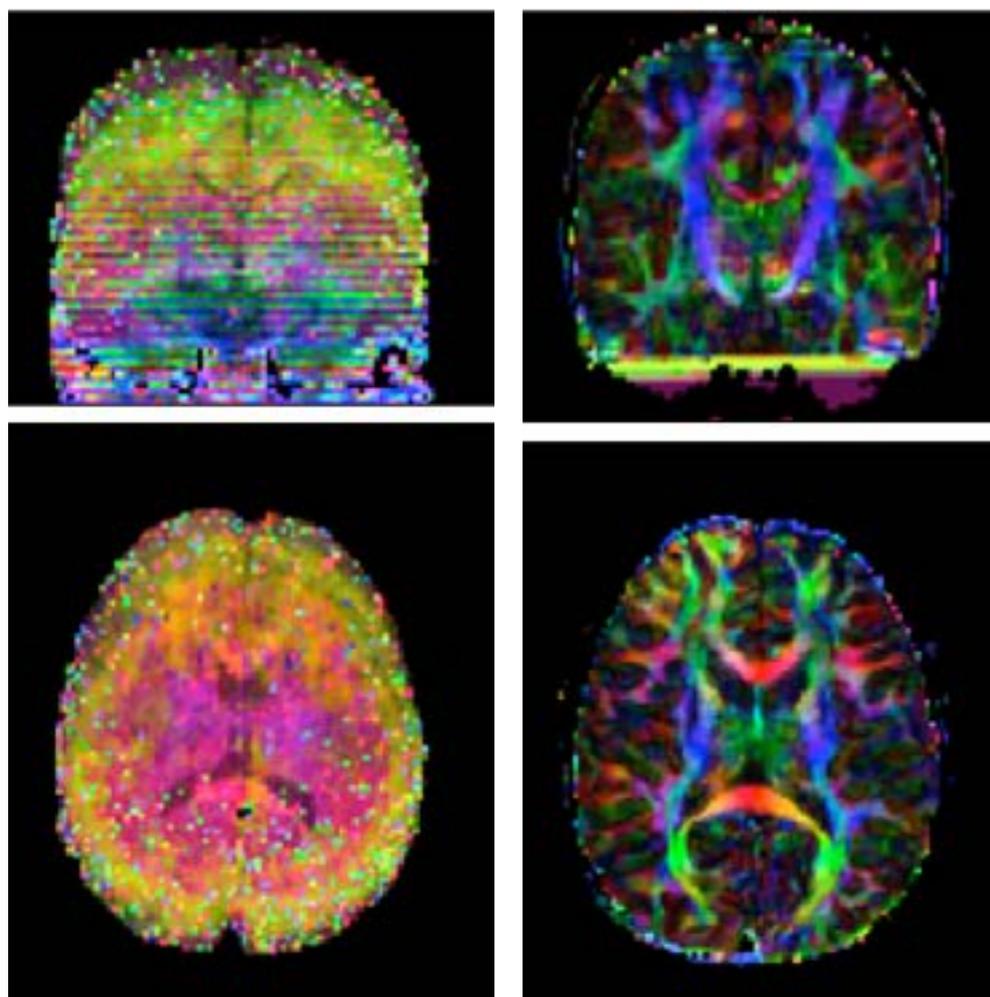


Motor Test results. Comparison of results from w/o smoothing (A, E) with isotropic smoothing (B, F), classical EPI anisotropic(C, G), and anisotropic smoothing (right) Note that the anisotropic has the largest pick and the most localized.

Motion correction in DTI

NamHW, & ParkHJ, 2011, NeuroImage.

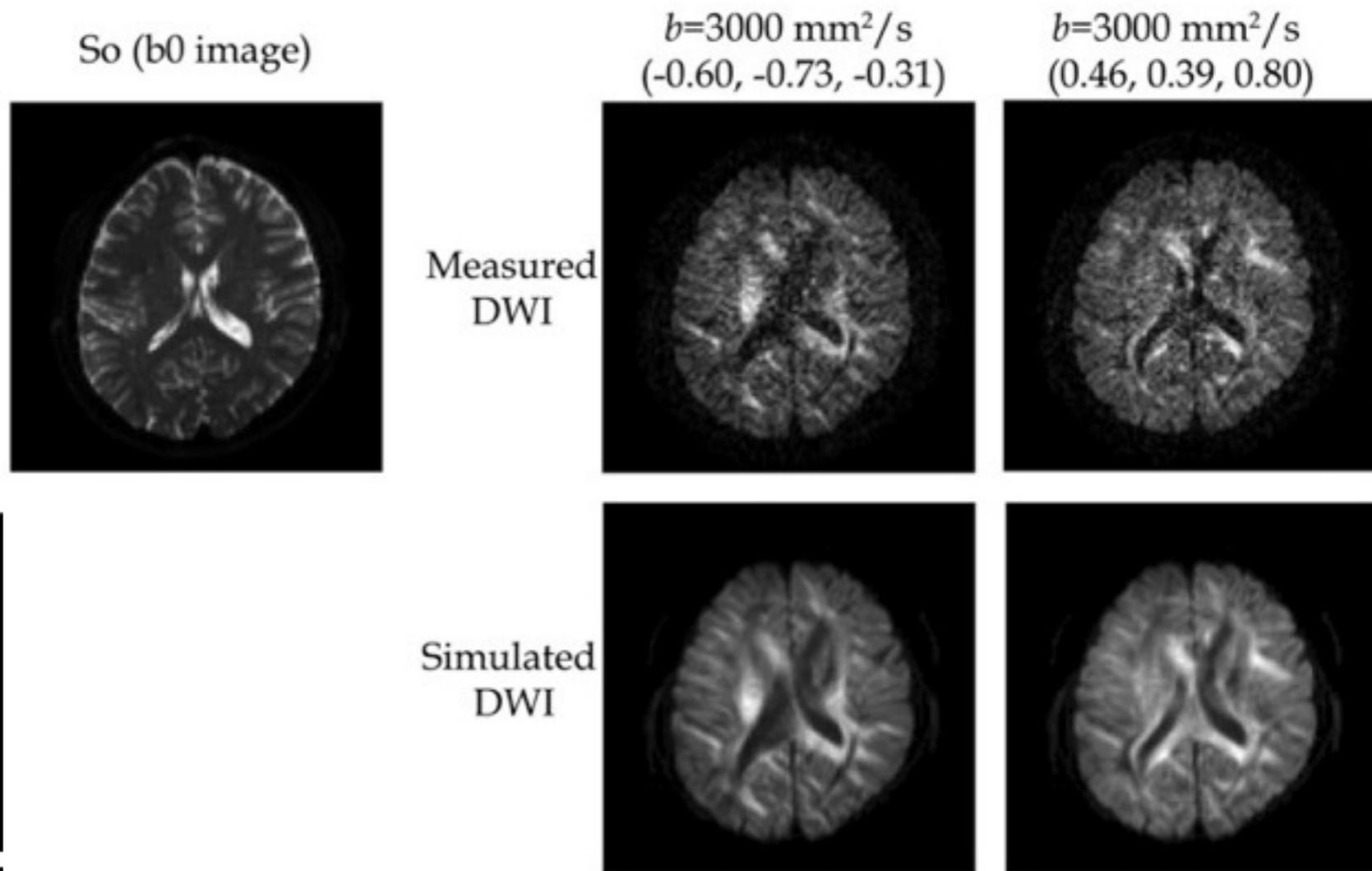
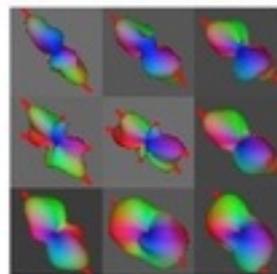
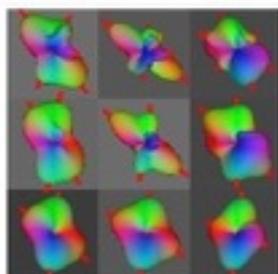
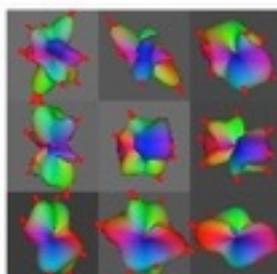
Motion artifacted DTI Motion corrected DTI



(a) ORIG

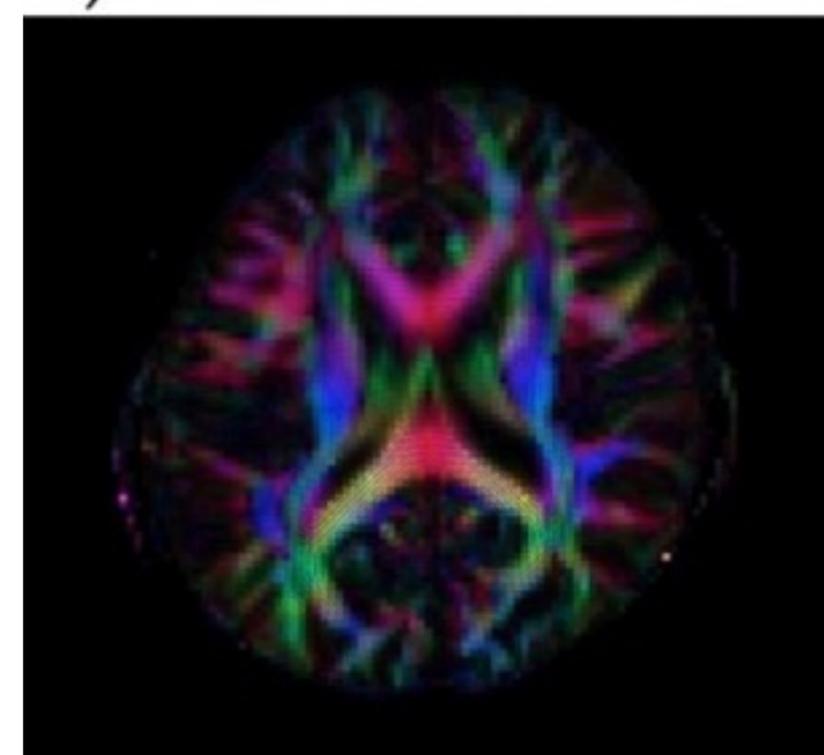
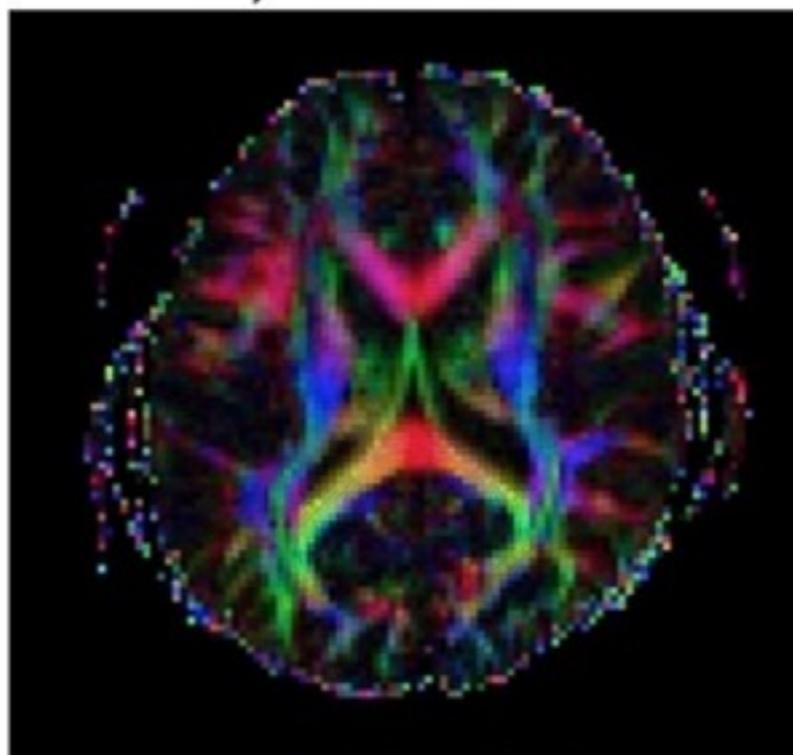
(b) AFFb₀

(c) NLsDWI



a) ORIG

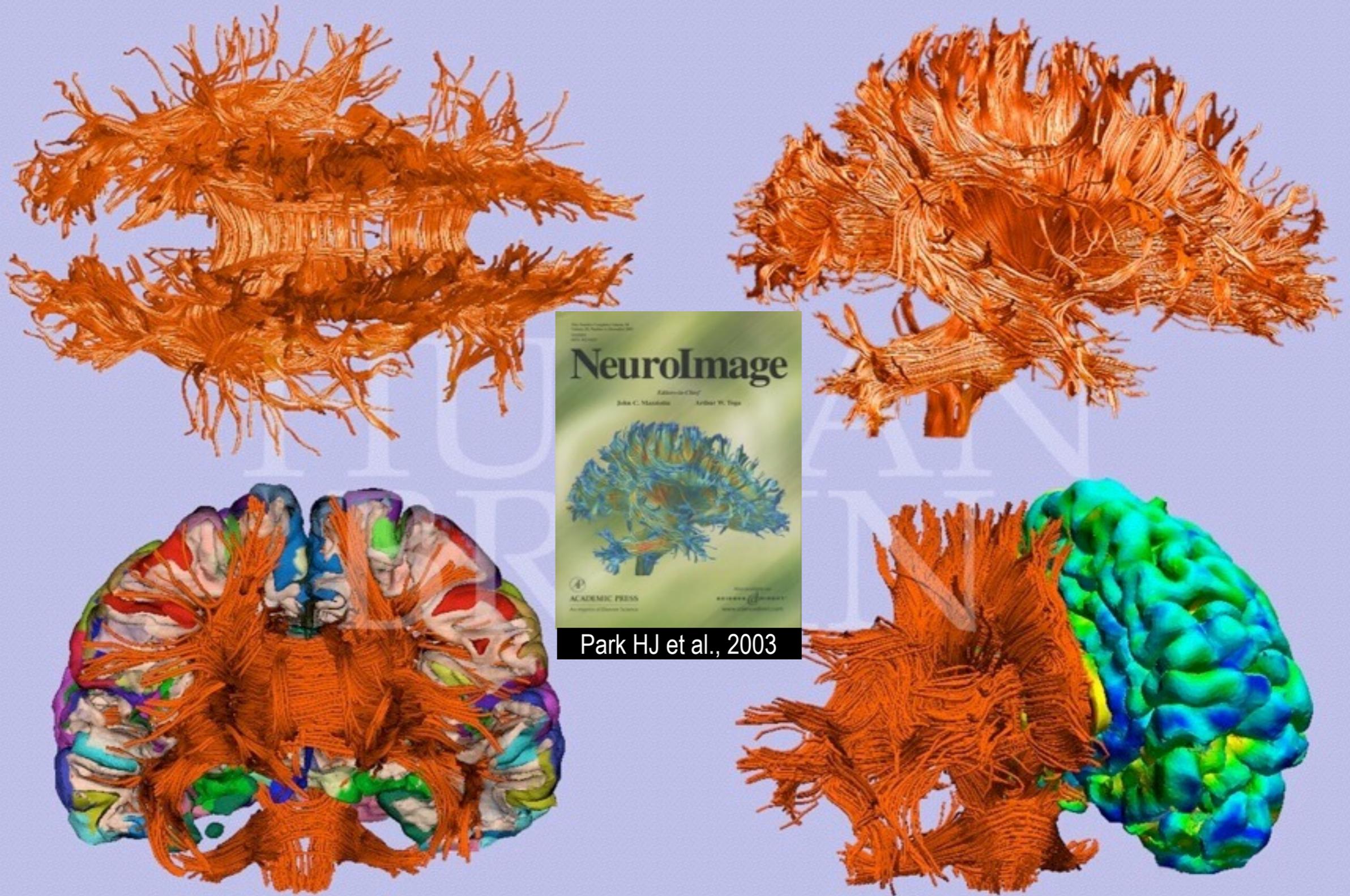
d) Nonlinear to sDWI



Anatomical Connectivity using Diffusion tensor imaging

NEUROIMAGING PROJECT

Hae-jeong Park, Ph.D. 2003



Park HJ et al., 2003

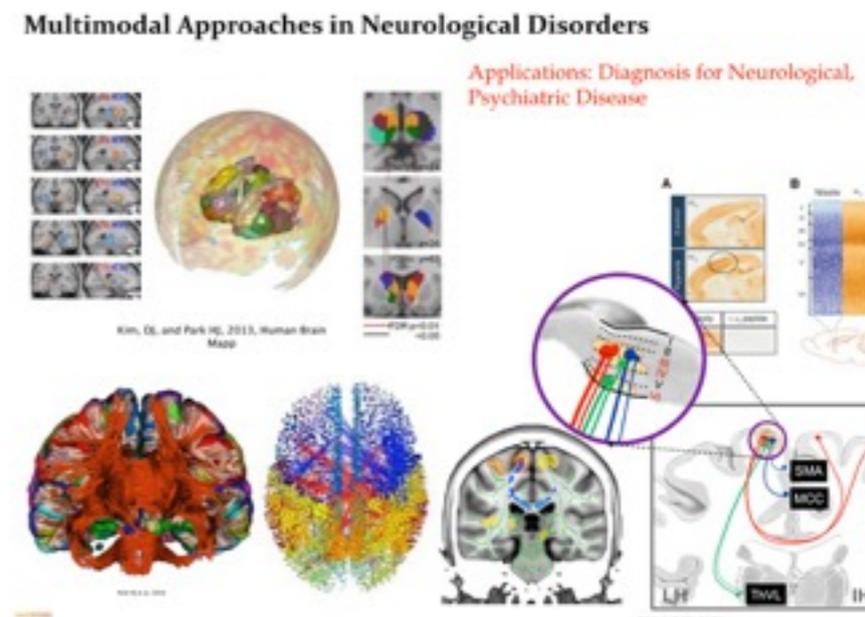
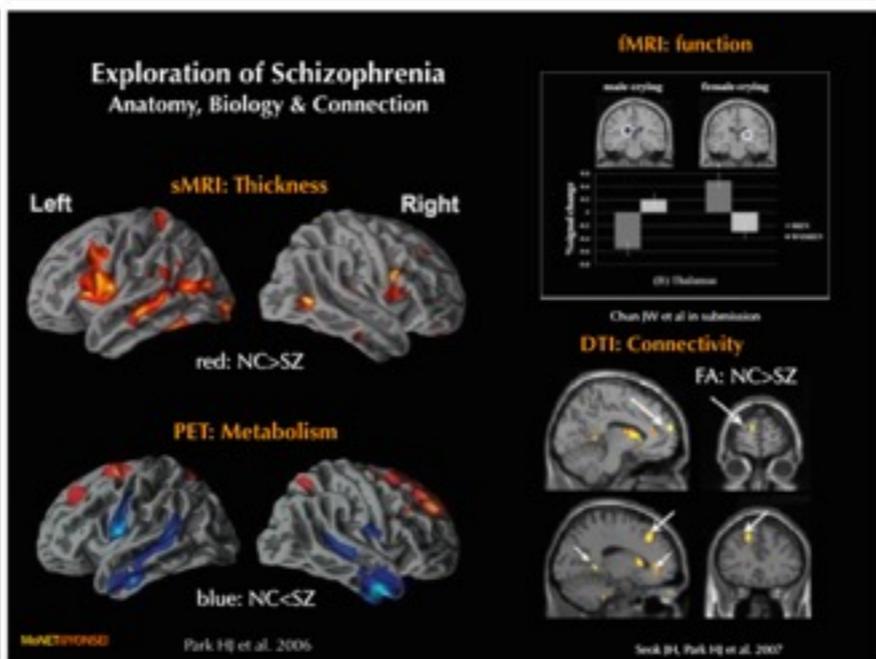
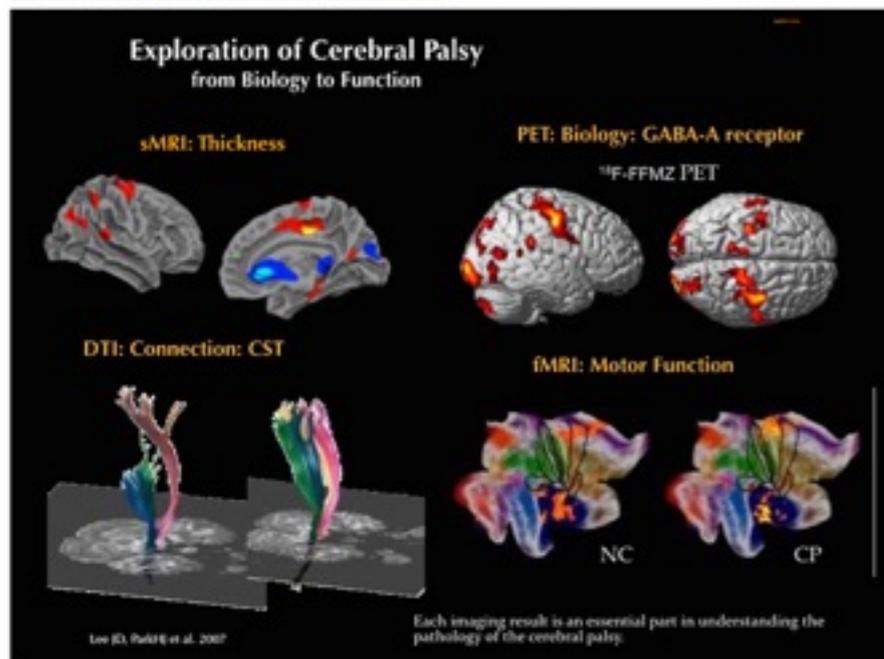
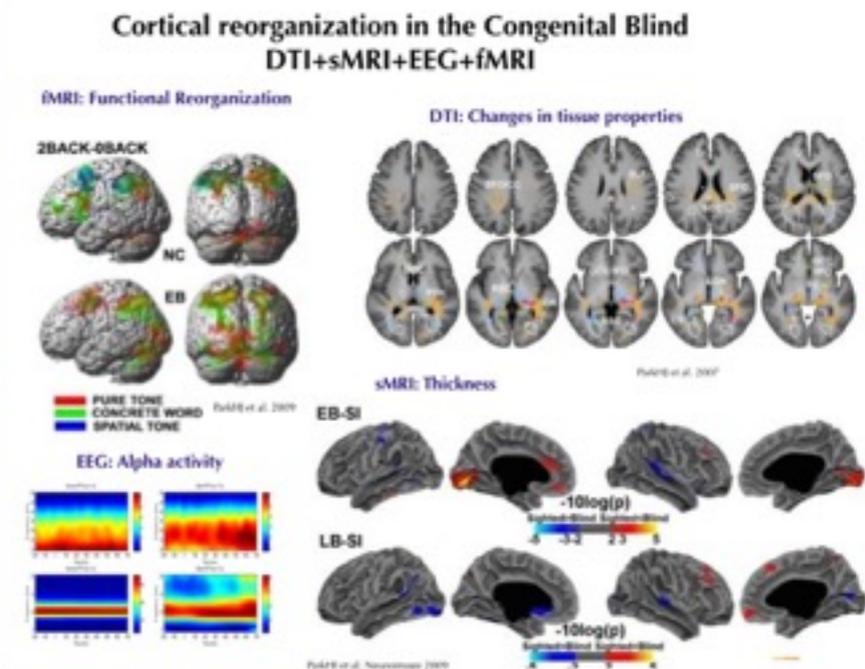
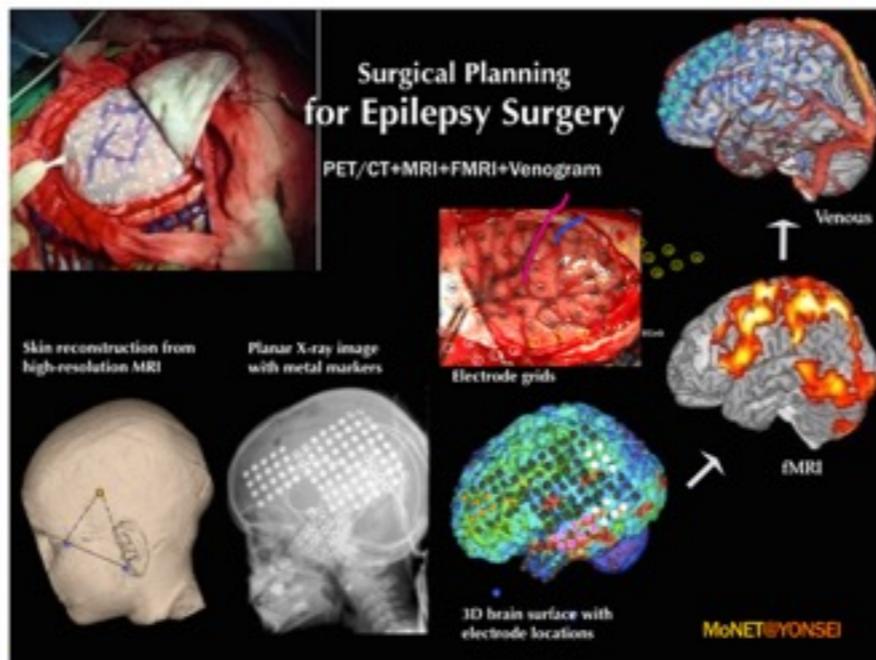
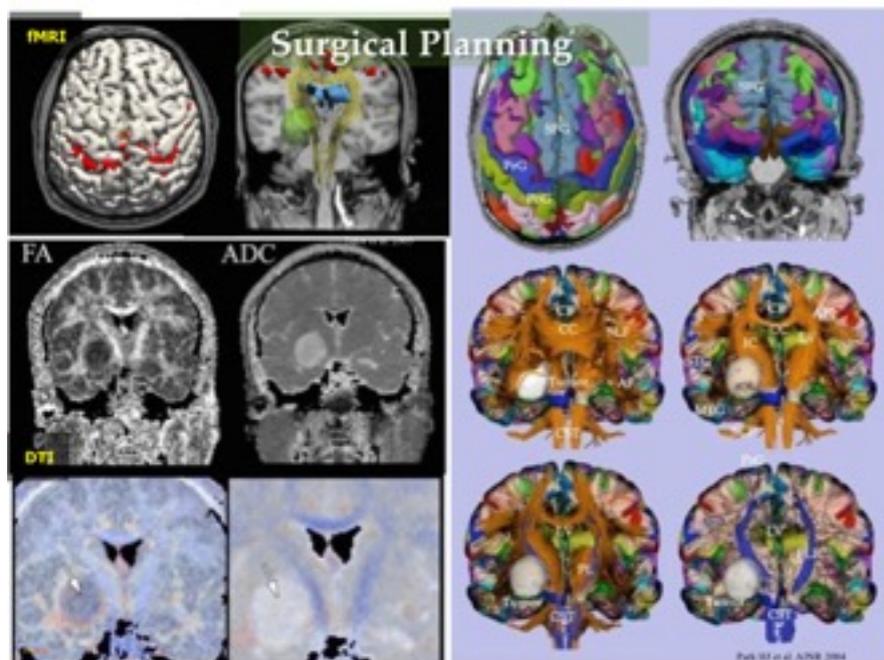


Surgical Planning Laboratory, MRI Division, Dept. of Radiology, Brigham and Women's Hospital, Harvard Medical School



The world's first whole brain fiber tractography since 2002

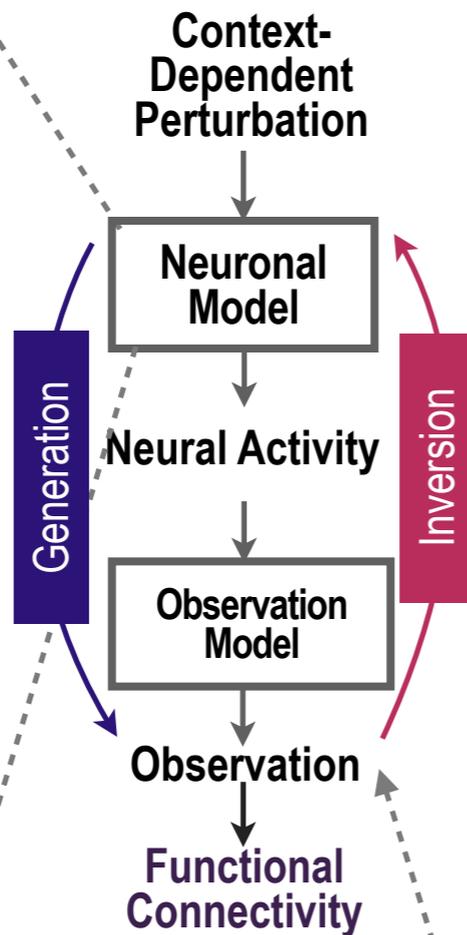
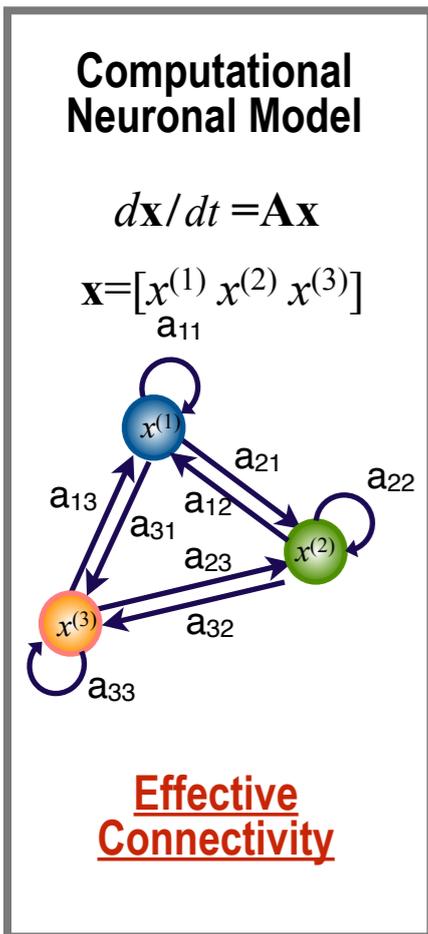
Challenges: Inverse Problems For Brain Diseases



Computational Model and Measurements

using models of probabilities with variables y (observed) and parameters θ (hidden)

Neuronal Model



Forward model (measurement)

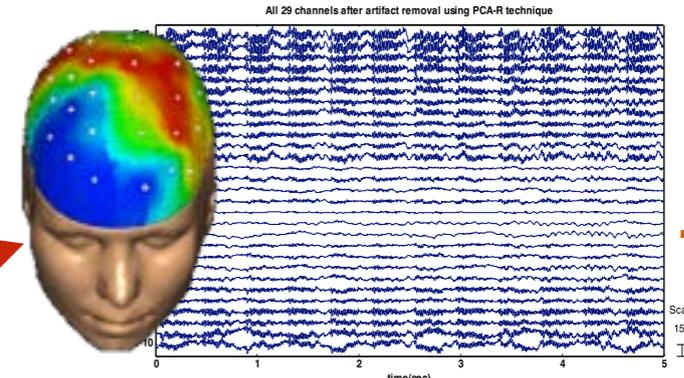
$$y = g(x, \theta) + \epsilon$$

$$p(y | x, \theta, u, m)$$

likelihood

Forward model (neuronal)

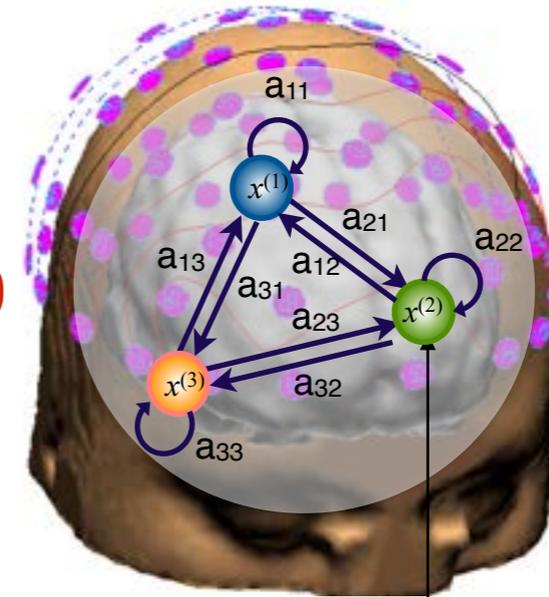
$$\dot{x} = f(x, u, \theta) + \omega$$



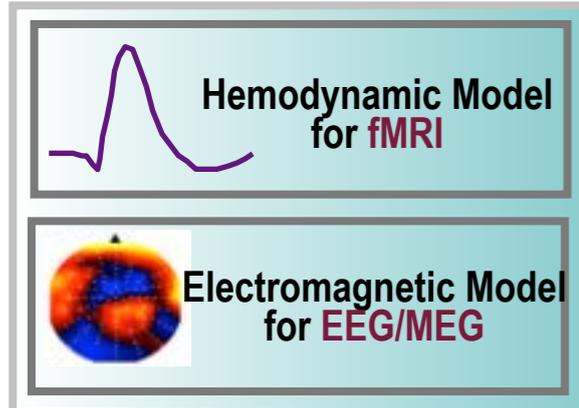
Observed data at sensors

$$p(x, \theta | y, u, m)$$

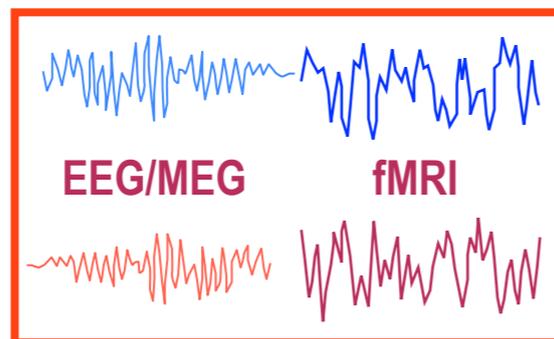
posterior distribution



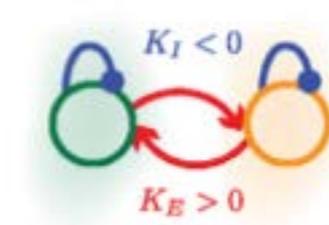
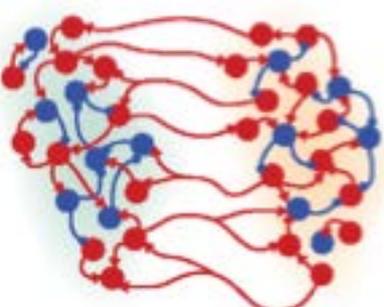
Observation Model



Observed Data

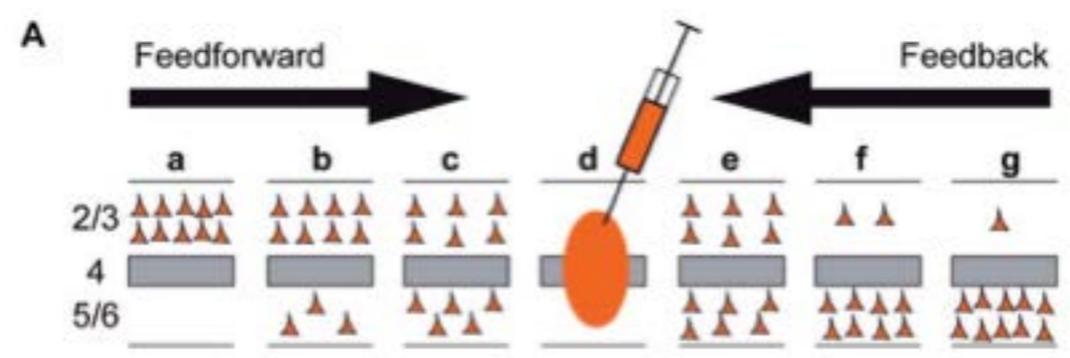


$$F = -\log p(y) + \text{KL}[q(x) \parallel p(x | y)] \quad \text{using an approximate posterior } q(x)$$



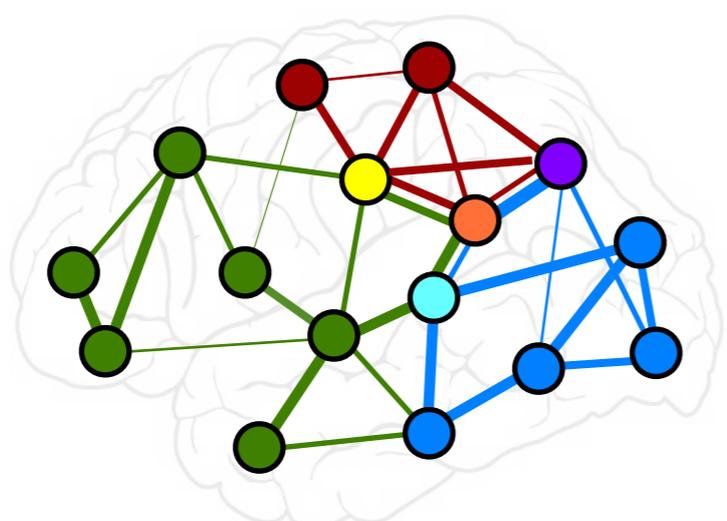
Battaglia D et al. 2012

Inter-regional long-range
extrinsic effective connectivity

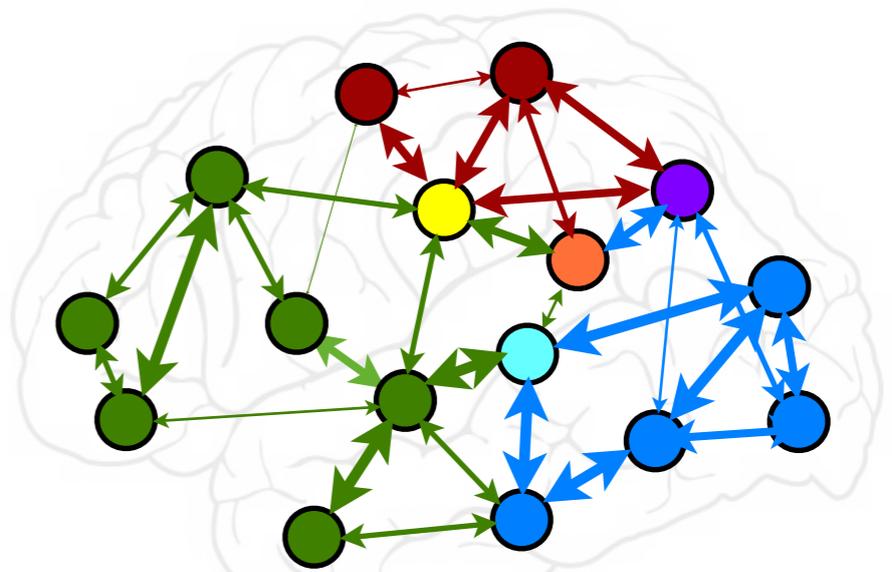
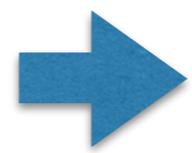


Morkov et al. 2014

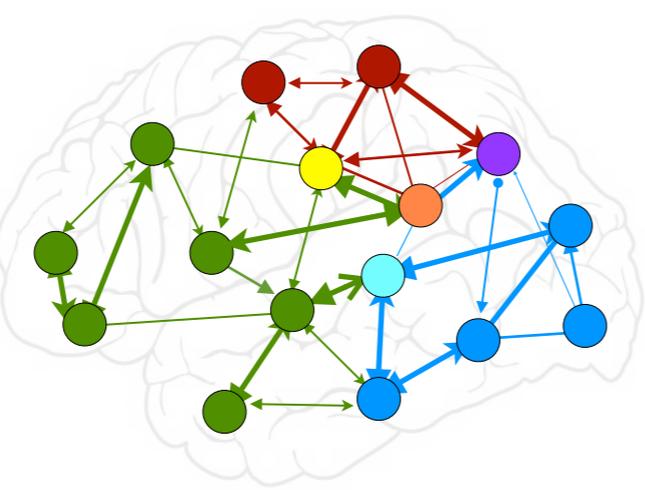
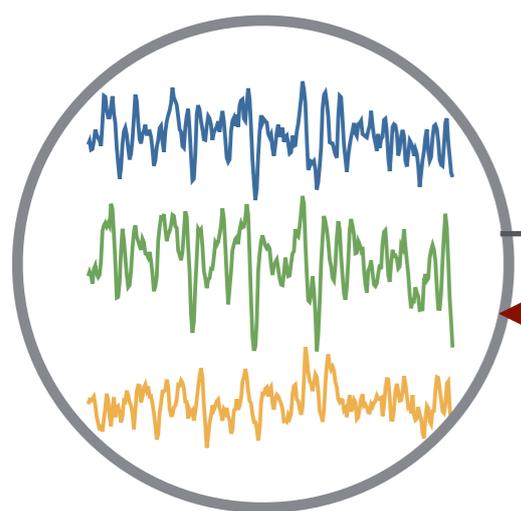
Challenges for **prediction.**



Symmetric Network

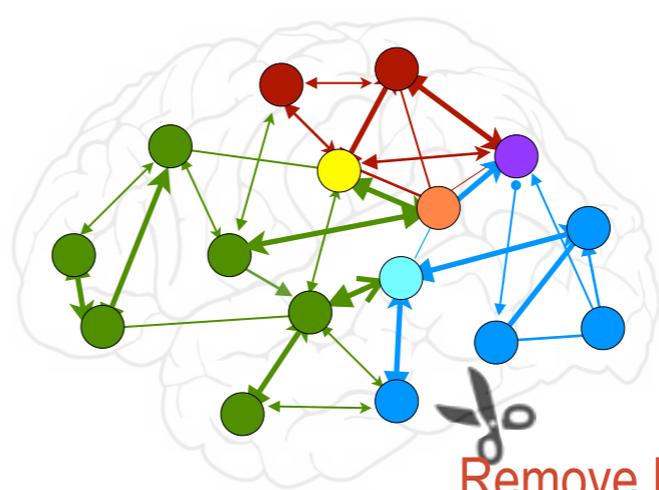


Asymmetric Effective Network

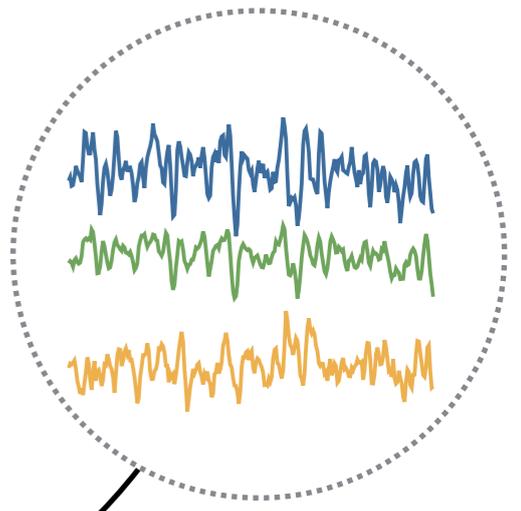


$$y = g(x, \theta) + \varepsilon$$

$$\dot{x} = f(x, u, \theta) + \omega$$



Remove Edge



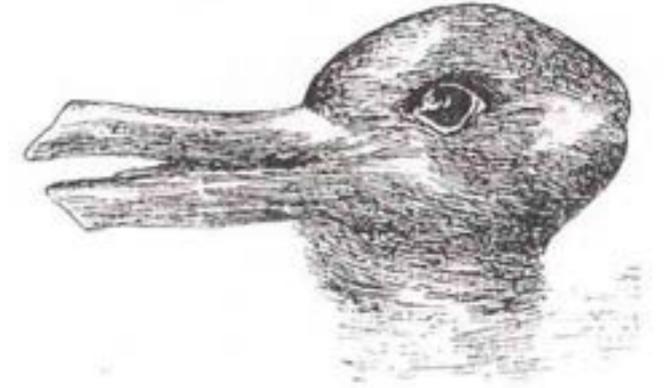
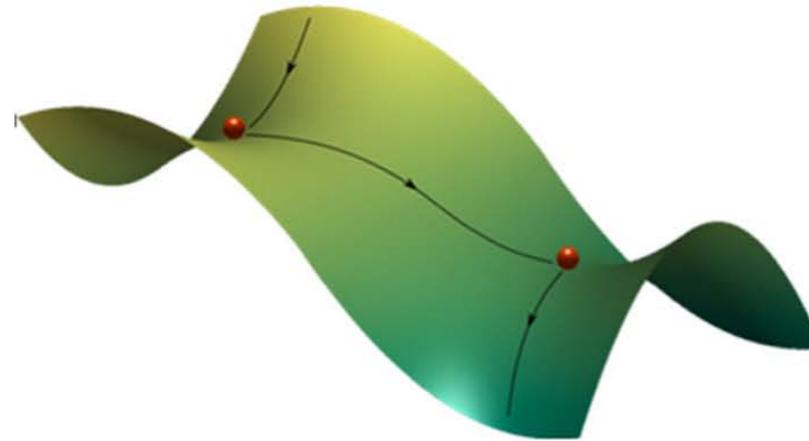
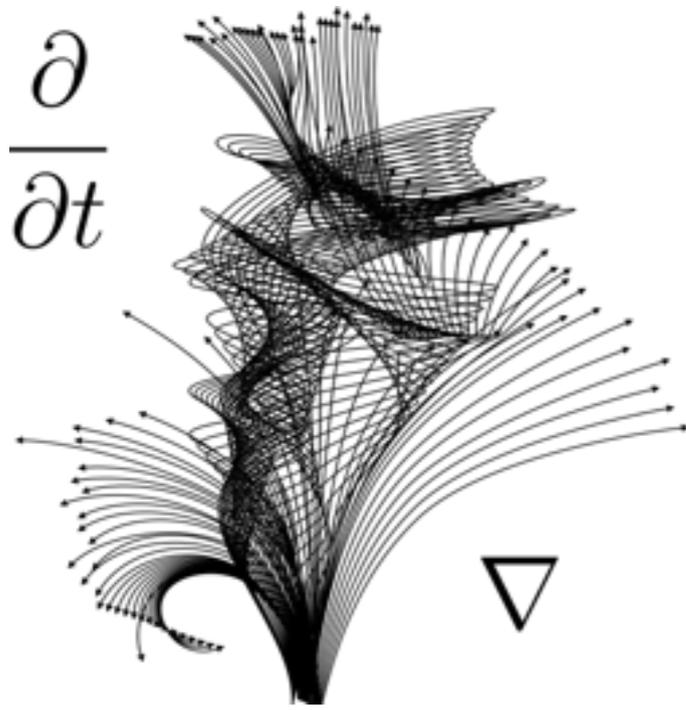
Update underlying connectivity model

....

Fundamental questions:

How many dimension is needed for the brain function?

Is there a simple/finite dimensional manifold and working principle that governs the complex BRAIN system leads MIND to the awareness of MATHEMATICAL world?



Interdisciplinary Approaches

To solve one of the most complex inverse problem..
at least, to get some mathematical equations for brain
function.

Thank you....