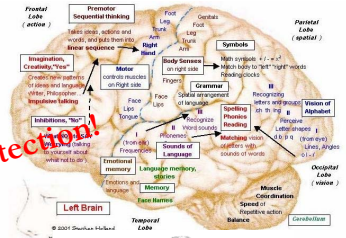
2014

An introduction to modern MRI technologies in brain studies

Ching-Po Lin Ph.D.
Brain Connectivity Lab
Inst. of Neuroscience
National Yang-Ming University
Taiwan

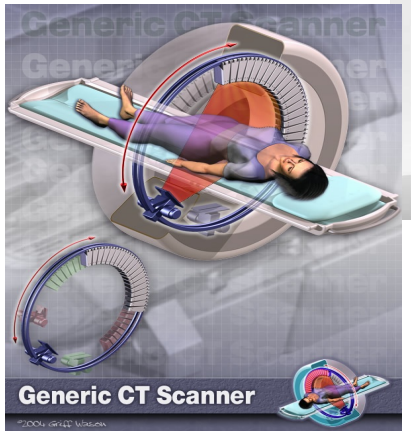
Brain Function & Structure



- **Cognitive functions**
  - What is she thinking about?
  - What is she looking for?
  - …
- **Structures underlie these functions**

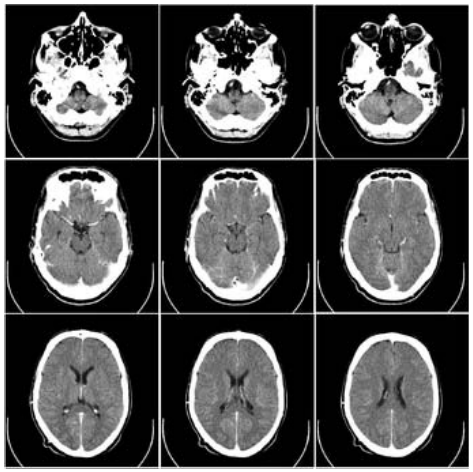
Structural Imaging

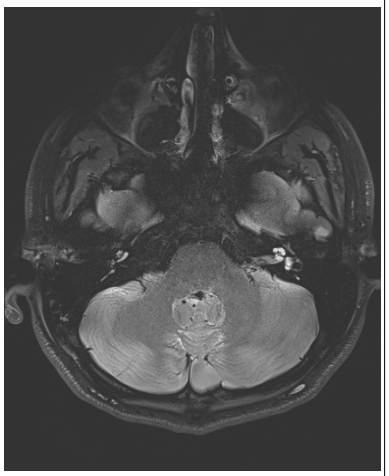
Magnetic Resonance Imaging

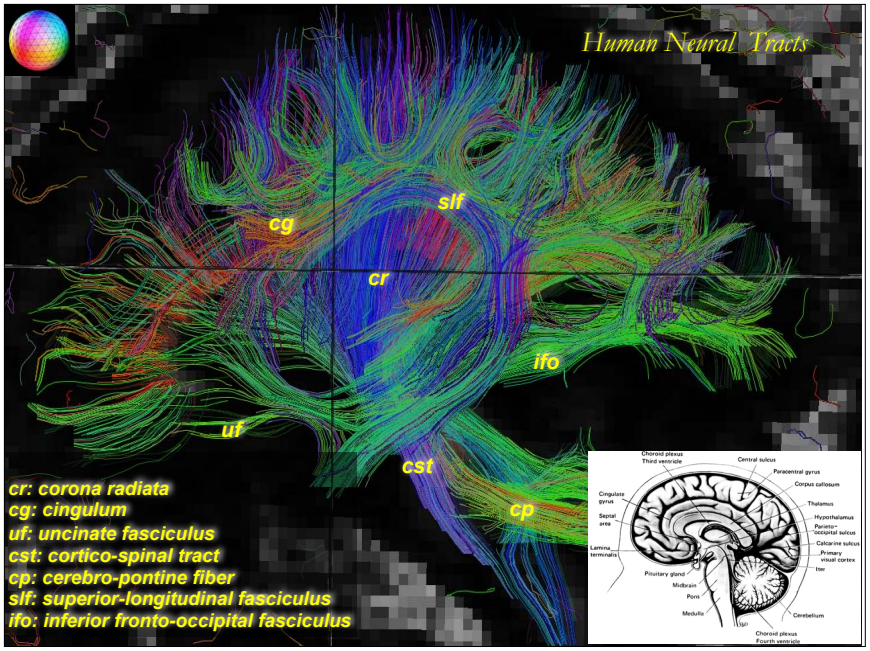


Computer Tomography (X-ray)

Structural Images

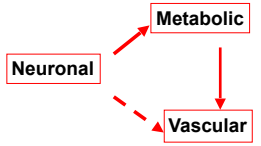




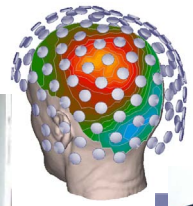


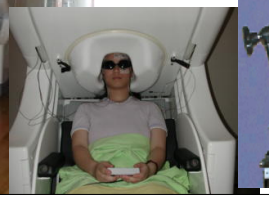
Physiology during Neural Activation

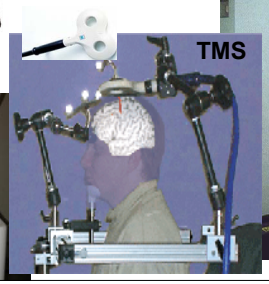
- Neuronal firing: electrical activity
  - Excitatory and inhibitory
  - Neurotransmitter: dopamine,…
  - Action potential & graded potential
    - Ion flow: Na^+, K^+, Ca^{2+}, Cl^-
- Biochemical reaction: metabolic activity
  - Active transport of ion pumps
    - Oxidative/non-oxidative glycolysis
    - Glucose…
- Vascular response: hemodynamic activity
  - Energy demand
    - Blood flow, blood volume, blood oxygenation

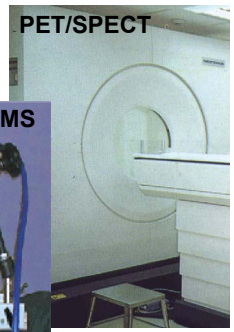


Functional Imaging

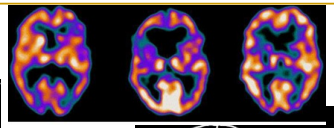


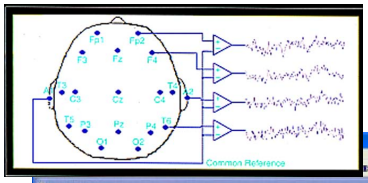


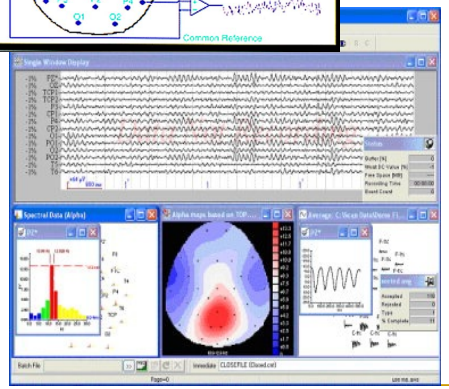


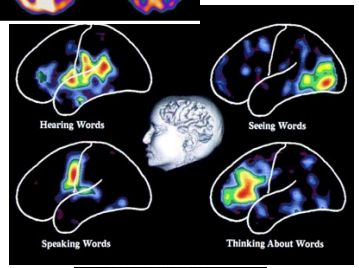


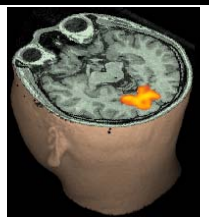
Functional Images







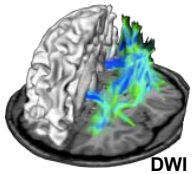




MR Images

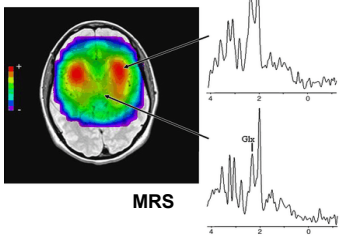

T1WI


T2WI


DWI

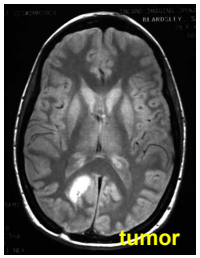

SWI

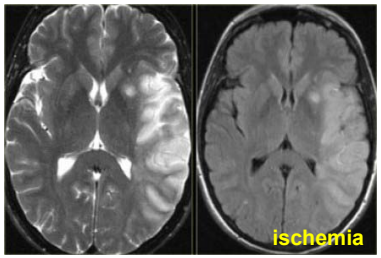

fMRI

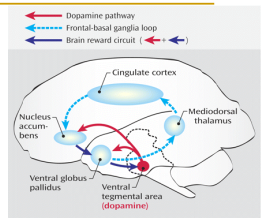

MRS


MRA

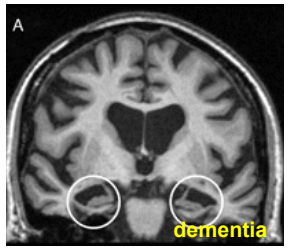
Examples


tumor

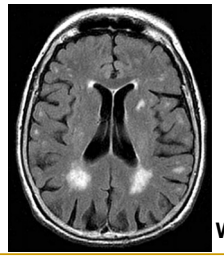

ischemia



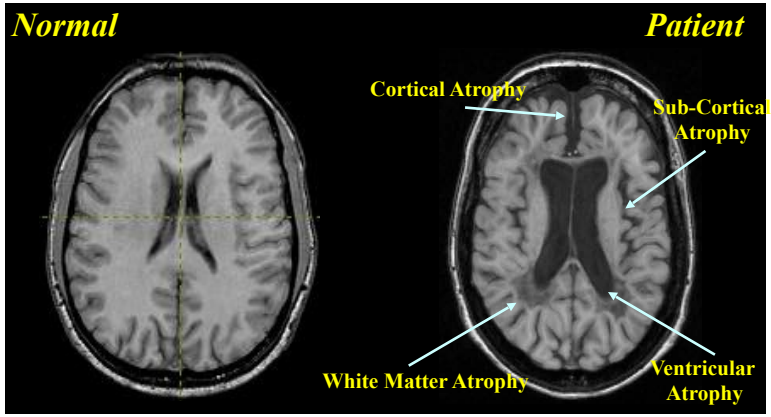

lesion in drug abuse



dementia

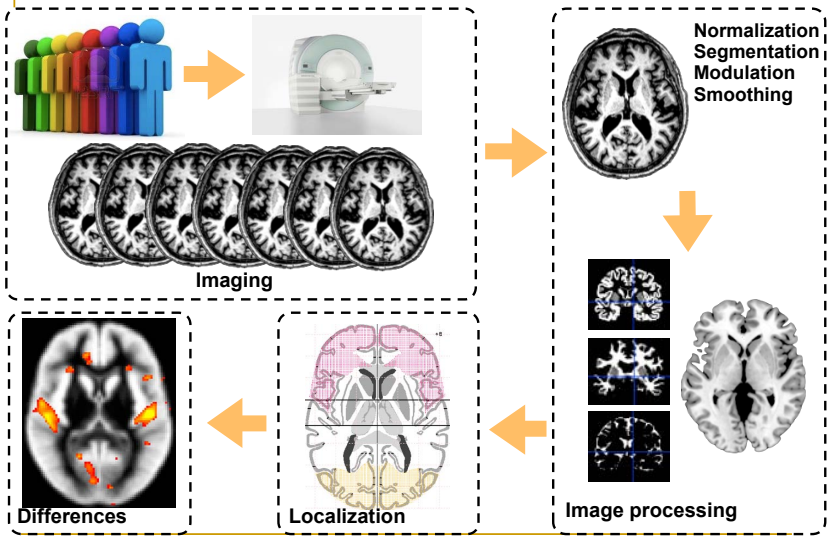

WM hyperintensity

Brain Structure



Brain Atrophy = Loss of Cerebral Tissues

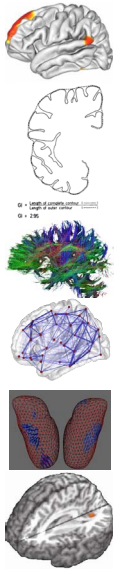
Voxel Based Analysis



MR Imaging & Post-processing

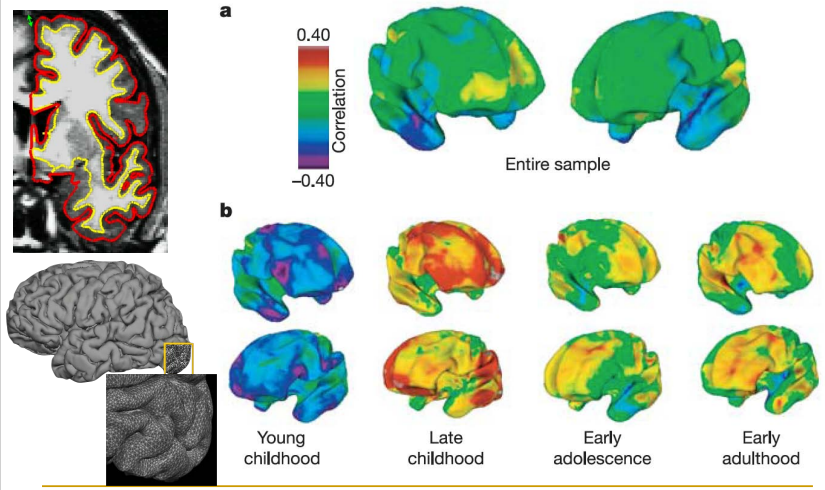
- **Anatomical MRI** (sensitive to brain structural change)
  - Brain regional contrast (T1, T2 …)
  - Regional volume (GM, hippocampus, …)
  - Other indices (gyrification, shape…)
- **Diffusion MRI** (sensitive to WM integrity & structural connectivity)
  - White matter integrity
  - White matter tractography (tract, network…)
- **Functional MRI (fMRI)** (sensitive to evoke functional activity)
  - Brain function
  - Resting state fMRI

- **To a specific physiological question**
  - Huge post-processing procedure is needed!!



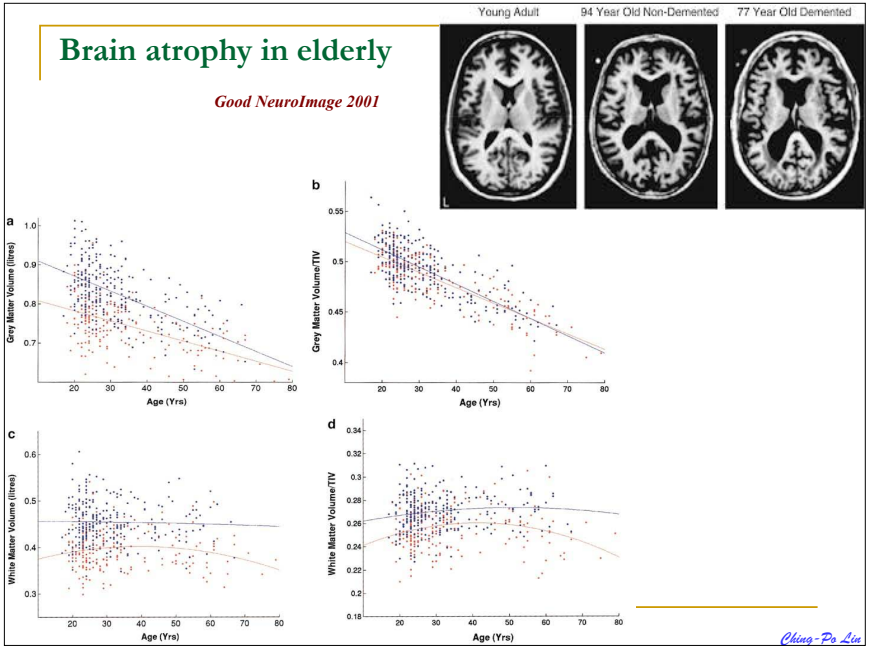
Intellectual ability and cortical development in children and adolescents

- Shaw et al., Nature 2006



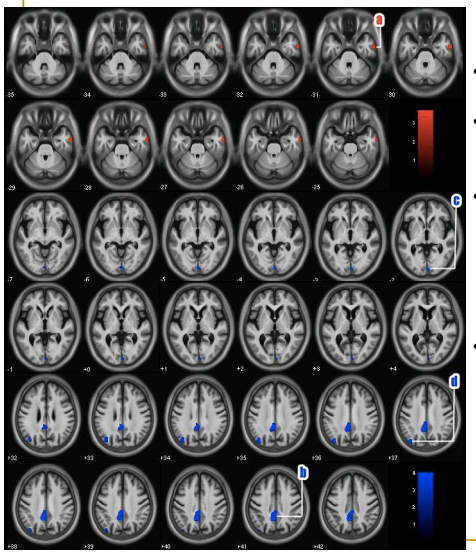
Brain atrophy in elderly

Good NeuroImage 2001



Effect of Bcl-2 SNP on GM and cognitive function

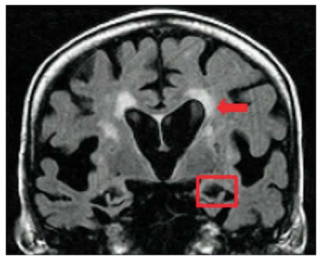
*- Liu et al., Age 2013**

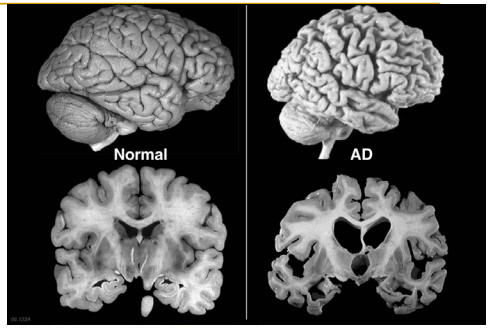


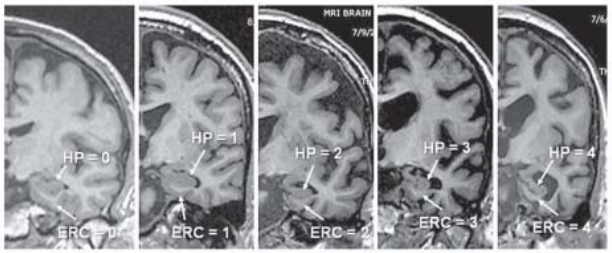
- Bcl-2 gene is a major regulator of neural plasticity and cellular resilience.
- 97 non-demented elderly men with a mean age of 80.6 ± 5.6 yrs (65-92 yrs)

- G homozygotes (compared with A allele carriers) exhibited smaller regional GM volumes in (a) right middle temporal gyrus (MTG) but larger GM in (b) left precuneus, (c) right lingual gyrus and (d) left superior occipital gyrus
- G homozygotes have worse language performance in Cognitive Abilities Screening Instrument (CASI) (P = 0.009), which is positive correlation between **right MTG** GM volume (r = 0.181; P = 0.081)

Volume atrophy in AD

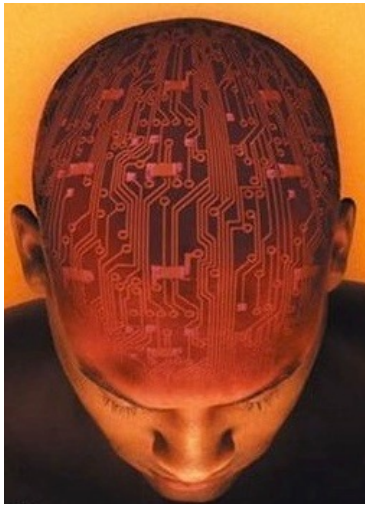






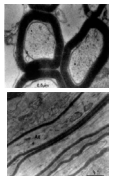
Medial temporal lob atrophy
- ranging from 0 (no atrophy) to 4 (severe atrophy)

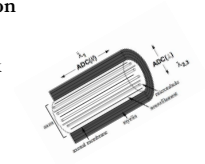
Neural Tracts



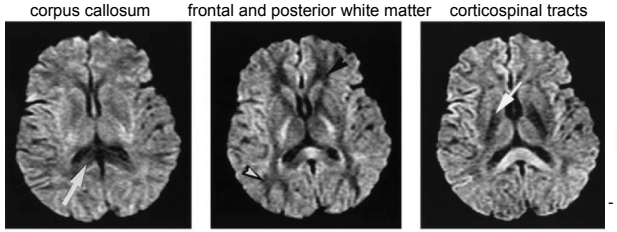
Diffusion MRI

- **In vivo mapping of microstructural tissue by** probing direction-dependent diffusivity of water molecules
  - **Microstructure**
    - Pathology
    - Neural integrity
    - …
  - **Structural connection**
    - Neural tracts
    - Anatomical network

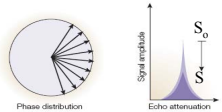




corpus callosum | frontal and posterior white matter | corticospinal tracts



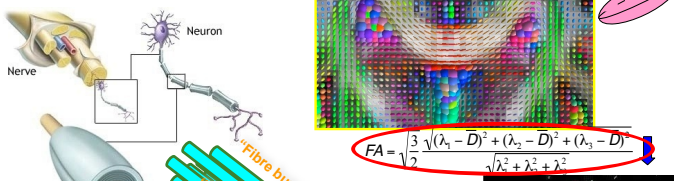
Gx Gy Gz

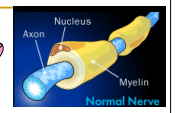


- Le Bihan, *Nat Rev Neuroscience* 2003

$$S = S_0 e^{-bD}$$

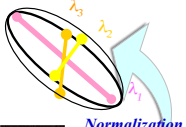
Diffusion Tensor MRI



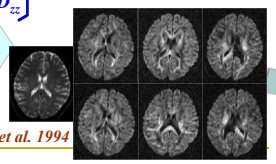


$$FA = \sqrt{\frac{3}{2}} \frac{\sqrt{(\lambda_1 - \bar{D})^2 + (\lambda_2 - \bar{D})^2 + (\lambda_3 - \bar{D})^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$

$$\begin{matrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{matrix}$$

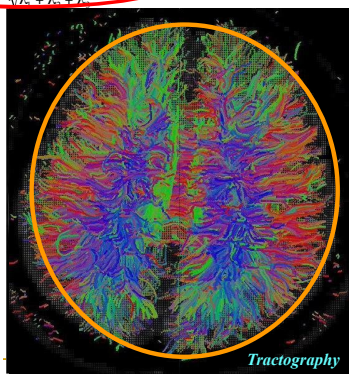


Normalization



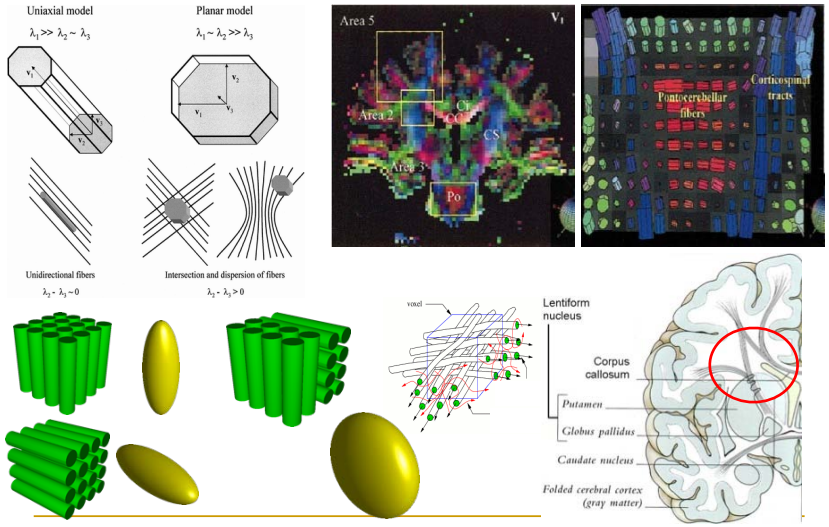
- *Basser et al. 1994*

True?

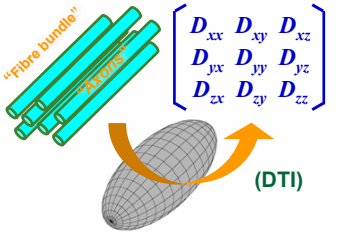


DTI @ Crossing Fibers

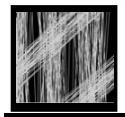
- Wiegell et al., Radiology 2000



dMRI @ Neural Mapping



$$\begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$



(DSI)

tissue I(x)

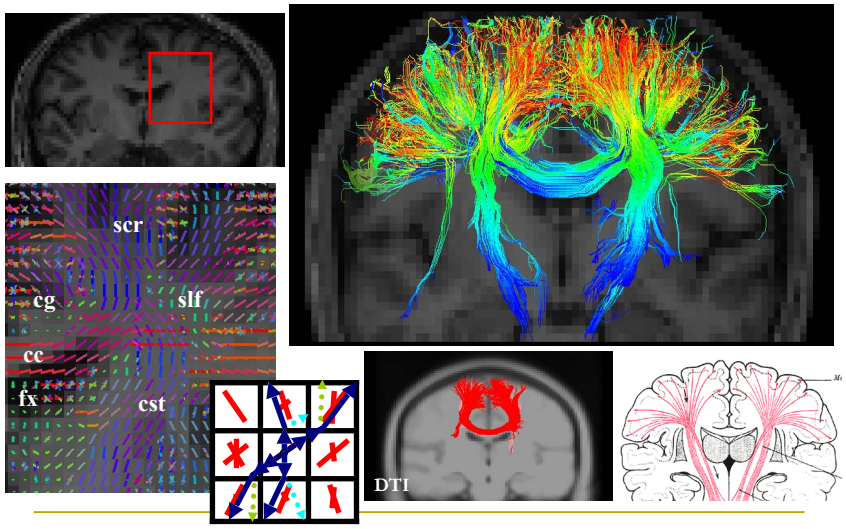
$E(q)$ $P(r) = \mathcal{F}(E)$ $ODF = \int Pr^2 dr$

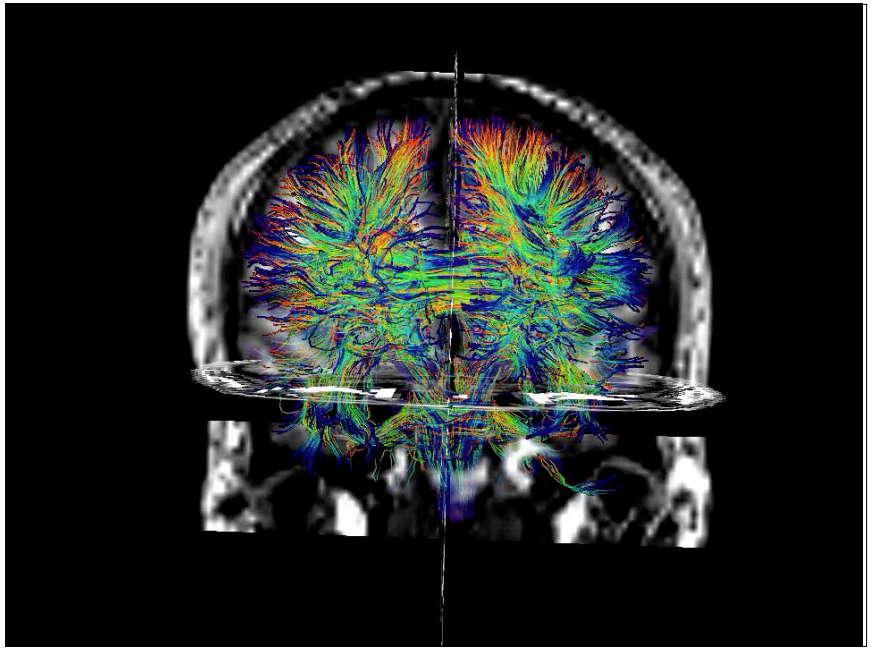
$$E(g) = \iint \rho(r) P_s(r|r', \Delta) exp^{[ir\delta g(r-r')]} dr dr'$$

- Q-space/Diffusion spectrum imaging (DSI)
  Callaghan et al. 1988; Wedeen et al., 2000
- Mixture modeling (HARDI)
  Frank et al., 2001, 2002; Tuch et al. 2002; Parker et al., 2003
- Q-ball imaging (QBI)
  Tuch, 2003 & 2004
- Persistent angular structure MRI (PAS-MRI)
  Jansons et al., 2003
- Circular spectrum imaging
  Zhan et al. 2003
- Higher order tensor imaging
  Ozarslan & Mareci 2003; Liu et al. 2004
- Spherical deconvolution
  Tournier et al, 2004
- Diffusion Orientation Transform
  Ozarslan et al, 2006
- Bayesian framework method
  Melie-Garcia et al, 2008
- Diffusion Orientation Transform revisited
  Canales-Rodríguez et al, 2009*

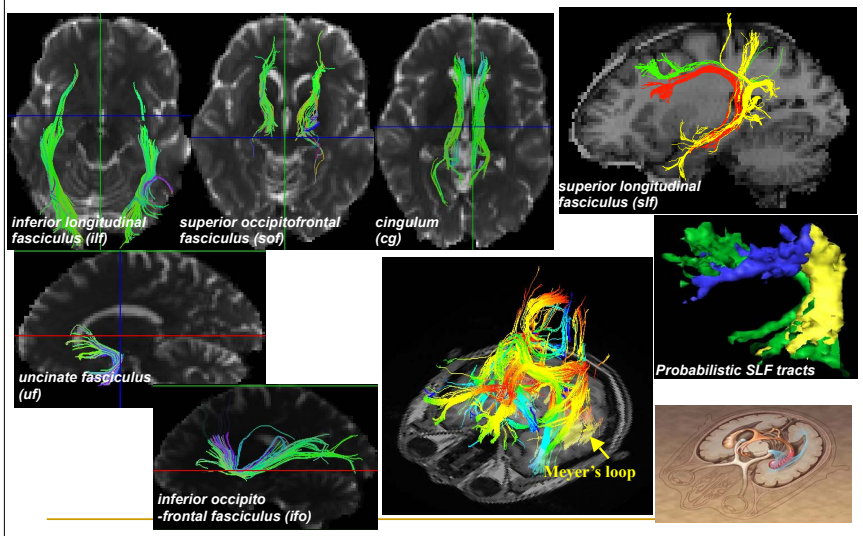
MFACT Algorithm @ Centrum Semiovale

*-Chao et al., Medical Engineering & Physics 2008**

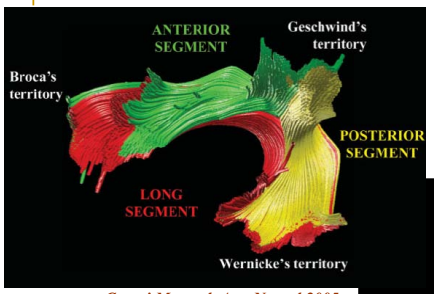




Neural Tractography



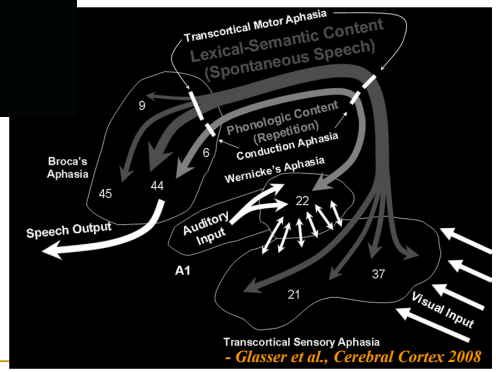
Language Pathways



- Catani M., et al. Ann Neurol 2005

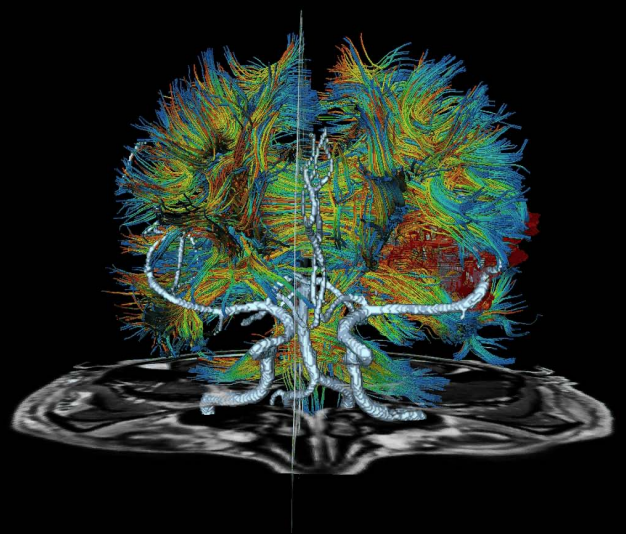
Arcuate Fasciculus:
High-frequency words,
Repeating of auditory words

Burdach's Model (1895):
Low-frequency words
Complicated process
(listen => comprehension => speech)



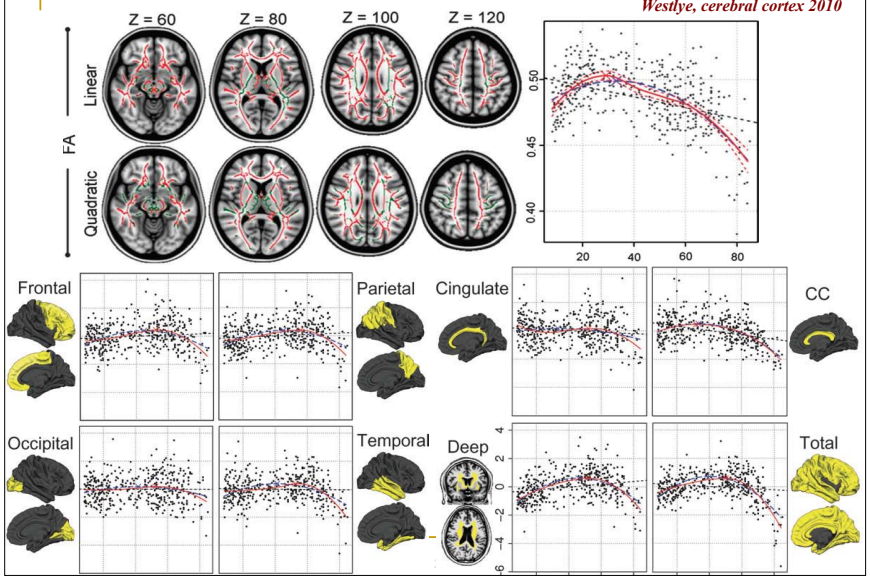
- Glasser et al., Cerebral Cortex 2008

Pre-surgery Evaluation



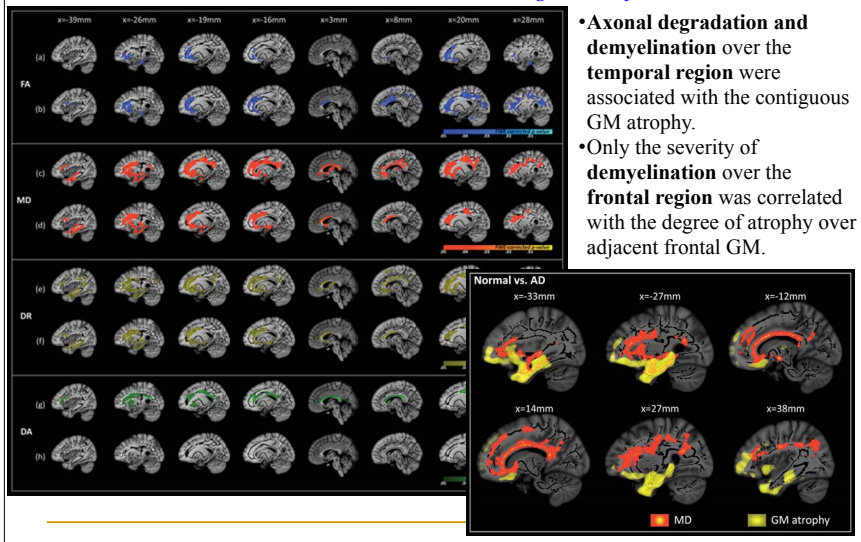
Life-span Changes of Human Brain White Matter

Westlye, cerebral cortex 2010



WM Degeneration in Amnestic MCI and AD

- Wang et al., J. of Alzheimer's Disease 2012

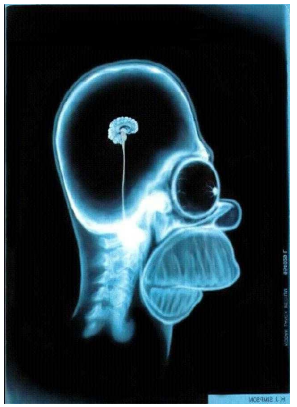


- **Axonal degradation and demyelination** over the **temporal region** were associated with the contiguous GM atrophy.
- Only the severity of **demyelination** over the **frontal region** was correlated with the degree of atrophy over adjacent frontal GM.

Functional MRI

MRI studies brain anatomy.

Functional MRI (fMRI) studies brain function.



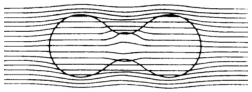
Linking Neural & Hemodynamic

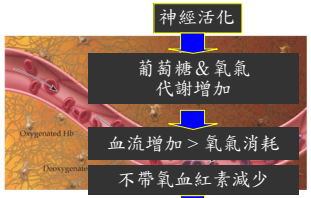
- Coupling of CBF and neural activity (Roy and Sherrington, 1890)
- Neural firing
  - glucose consumption ⇑ (cerebral metabolic rate of glucose, CMR_{Glu})
  - oxygen consumption ↗ (cerebral metabolic rate of oxygen, CMR_{O2})
  - cerebral blood flow (CBF) ⇑
  - blood oxygenation ⇑
  - cerebral blood volume (CBV) ⇑

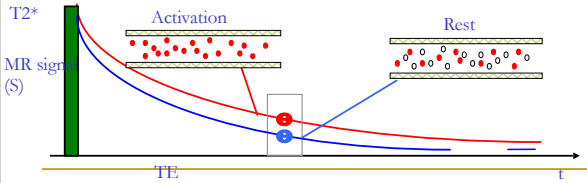
BOLD

Blood Oxygenation Level Dependent

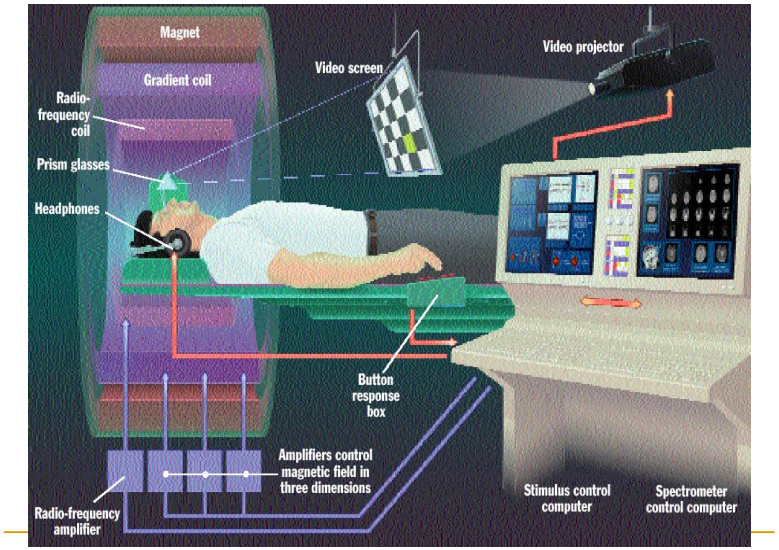
- Magnetism of red blood cell (L. Pauling PNAS 1936; S. Ogawa PNAS 1990)
  - oxy-hemoglobin: *diamagnetic* (similar to tissue)
  - deoxy-hemoglobin: *paramagnetic*
  - neural activation
    - ➔ oxy-Hgb (no ΔB effects) inflow
    - ➔ magnetic inhomogeneity ↓ (local ΔB ↓)
    - ➔ MR signal increase ↑







(Task) Functional MRI



Brain Function in Elderly

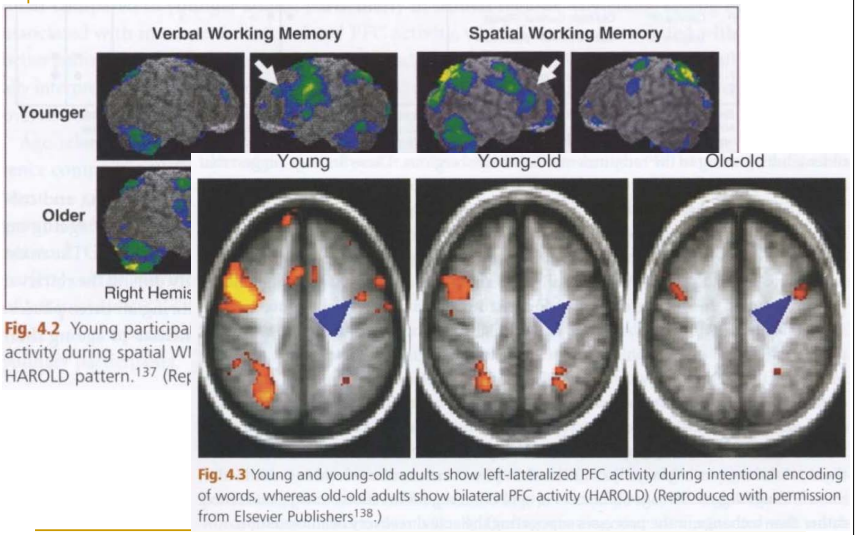
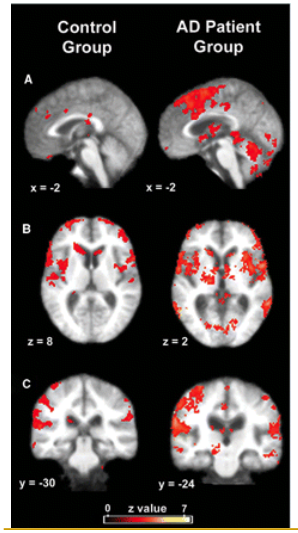
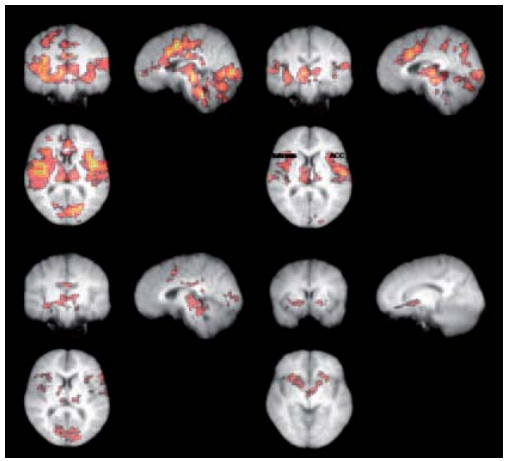


Fig. 4.2 Young participa
activity during spatial WI
HAROLD pattern.[137] (Rep

Fig. 4.3 Young and young-old adults show left-lateralized PFC activity during intentional encoding of words, whereas old-old adults show bilateral PFC activity (HAROLD) (Reproduced with permission from Elsevier Publishers[138].)

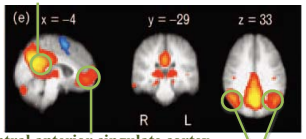
fMRI test in AD





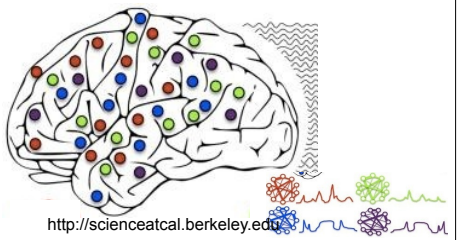
Brain Functional Connectivity in Elderly

Posterior cingulate cortex

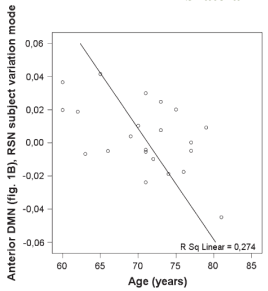


Ventral anterior cingulate cortex

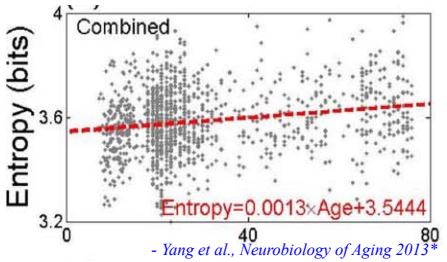
bilateral Angular gyrus



http://scienceatcal.berkeley.edu



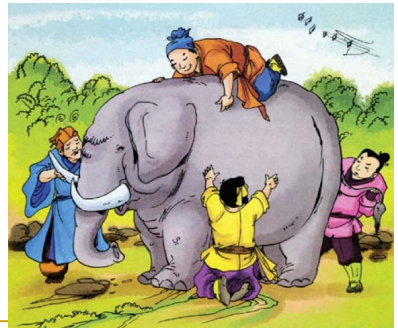
- *Damoiseaux et al., Cere Cortex 2008*



- *Yang et al., Neurobiology of Aging 2013**
- *Yao et al., Sci Rep 2013*

Overall…

- MRI can reveal multi-dimensional features
  - Anatomy
  - Neuronal pathways
  - Functional activations
  - Angiography, MRS…
- For brain study, we are drawing a conclusion from incomplete data, multi-model studies are needed



Dr. Ovid J. L. Tzeng
Dr. Daisy L. Hung
Dr. Yawei Cheng
Dr. Tung-Ping Su
Dr. Shuu-Jiun Wang
Dr. Wan-Yuo Guo
Dr. Denis Le Bihan
Dr. Cyril Poupon
Dr. Biswal Bharat
Dr. Gazi Yasargil
Dr. Donald Tournier
Dr. Lester Melie-Garcia
Dr. Ed Bullmore
Dr. Tianzi Jiang
Dr. Qi-Yong Gong
Dr. He Yong
Dr. Yihong Yang
Dr. Jean Decety

Thanks!!

NSC & NHRI & MOE project

BRAIN CONNECTIVITY LABORATORY
National Yang-Ming University

http://bclab.ym.edu.tw/