

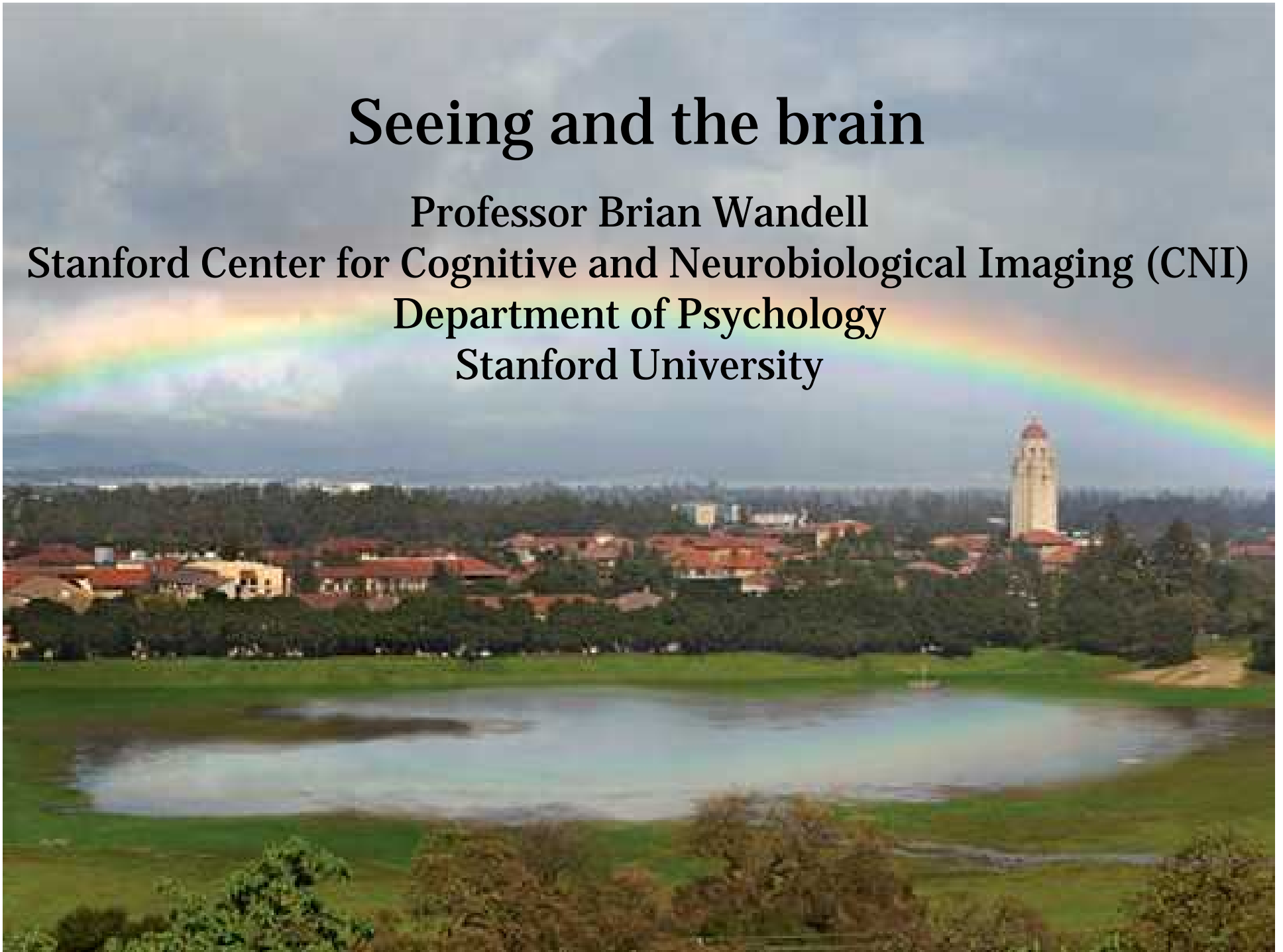
Seeing and the brain

Professor Brian Wandell

Stanford Center for Cognitive and Neurobiological Imaging (CNI)

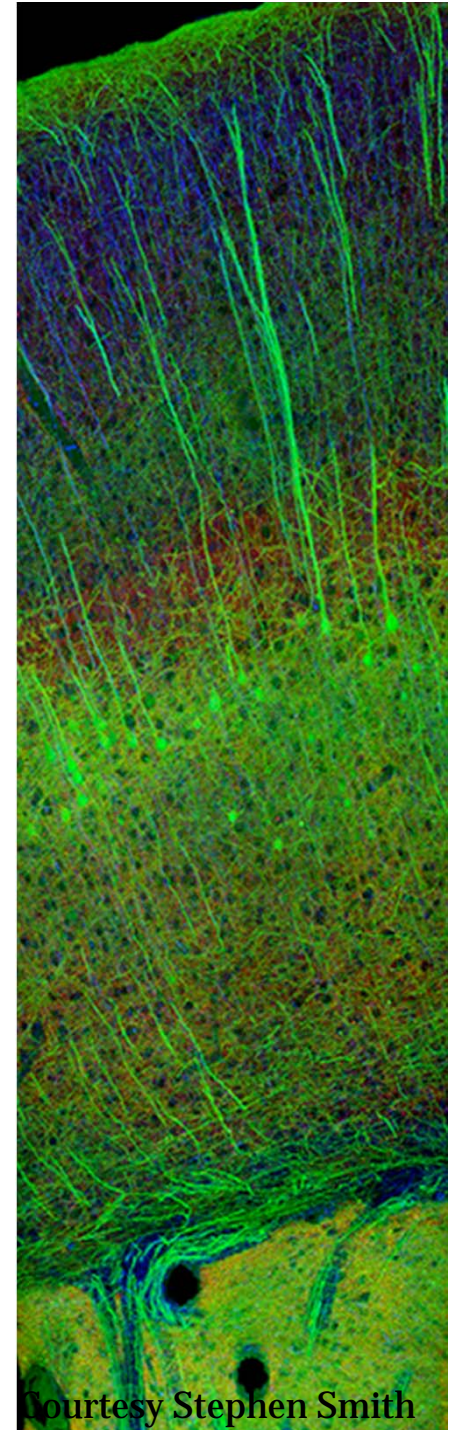
Department of Psychology

Stanford University



Preview

- Computation and the brain
- Functional MRI
 - Maps
 - Population receptive fields
 - Curing blindness
- Diffusion MRI
 - White matter tracts
 - Reading
- Neuroscience for Society



Lightness Perception (Lotto and Purves)

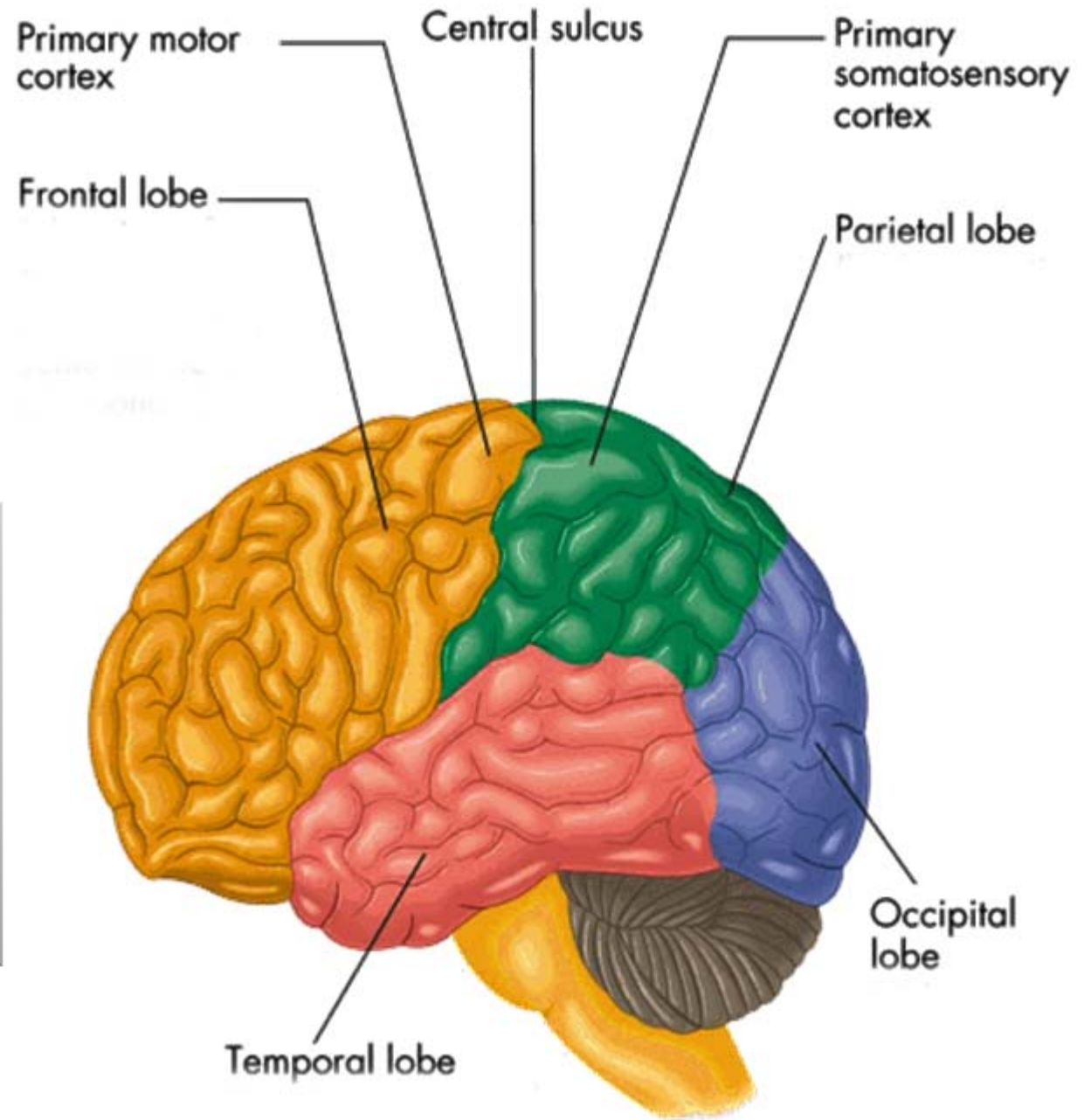


Lobes and functions

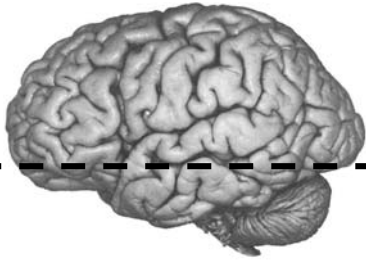
Vision – Occipital and temporal

Reading – Temporal, parietal, Frontal

Hearing – Temporal

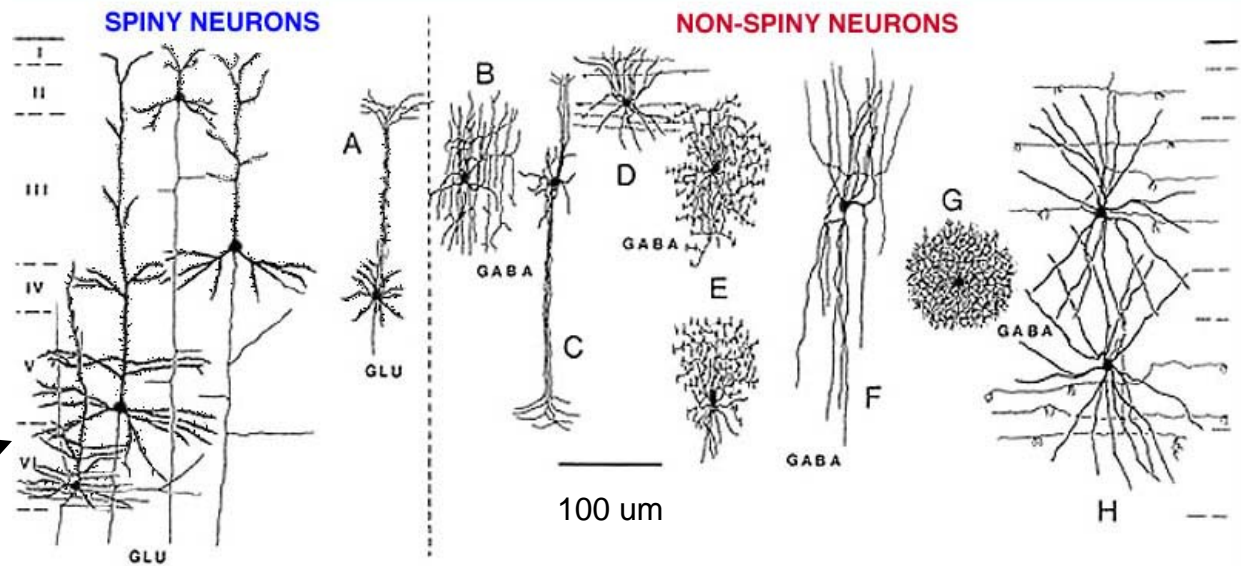
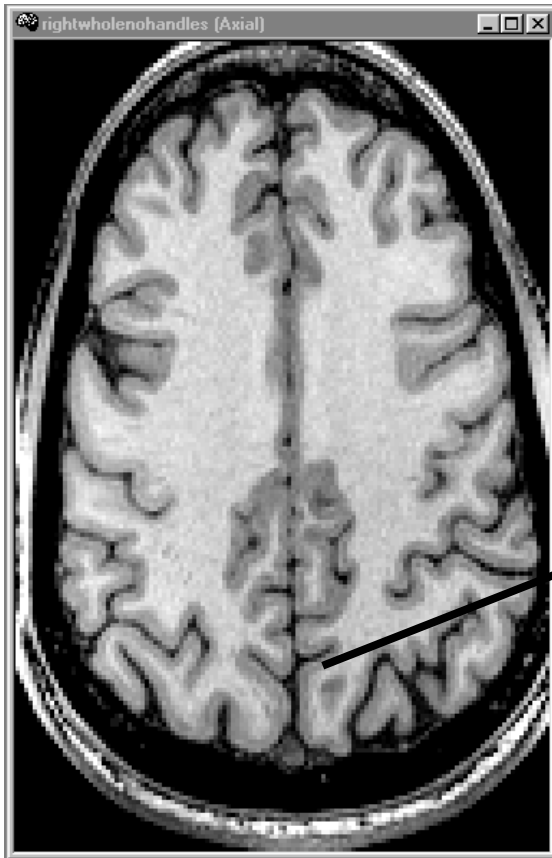


Many types of neurons



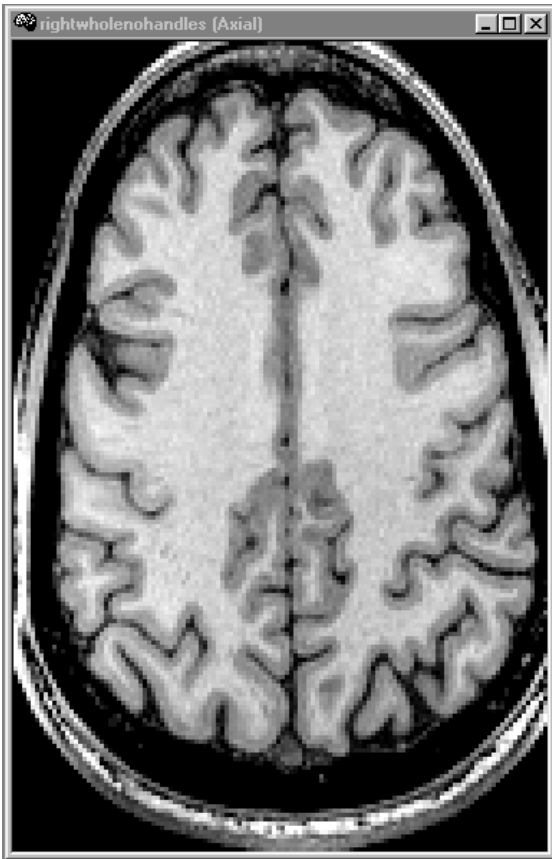
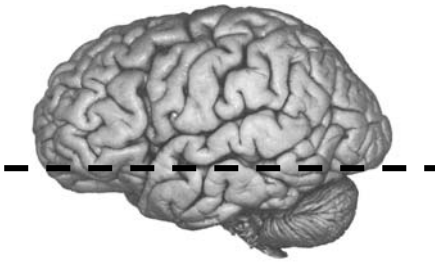
Primary visual cortex

- Spiny pyramidal – excitatory
- Spiny stellate – excitatory
- Smooth or sparsely spiny - inhibitory



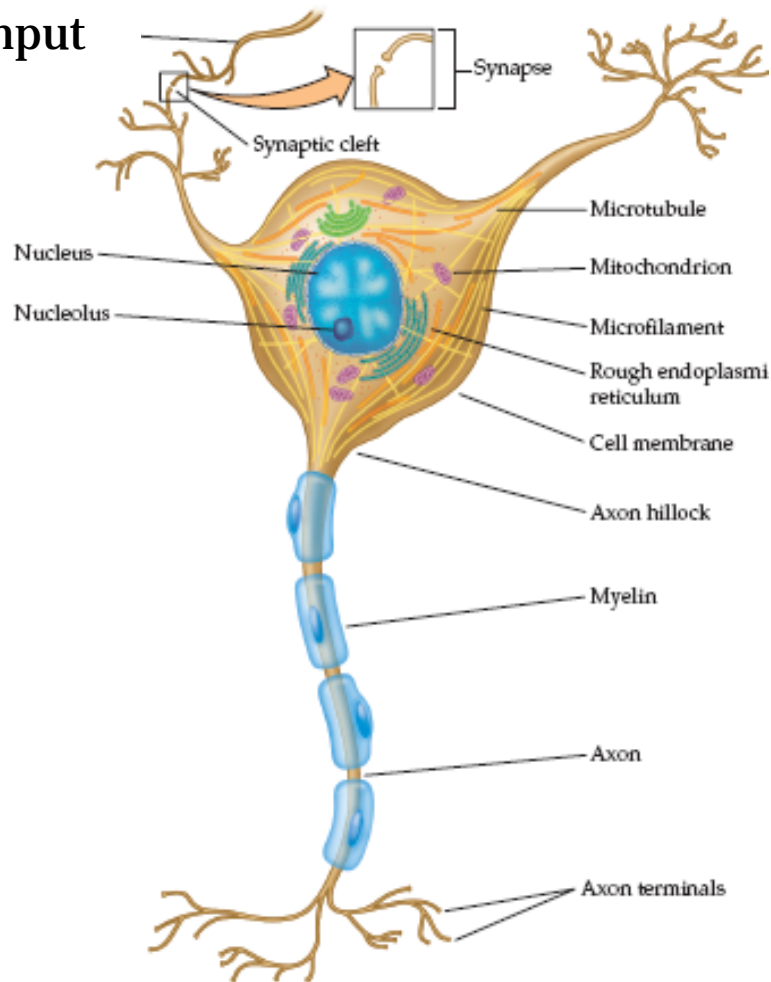
Structures

Neuron: The parts



Structures

Axon
input



Dendrites

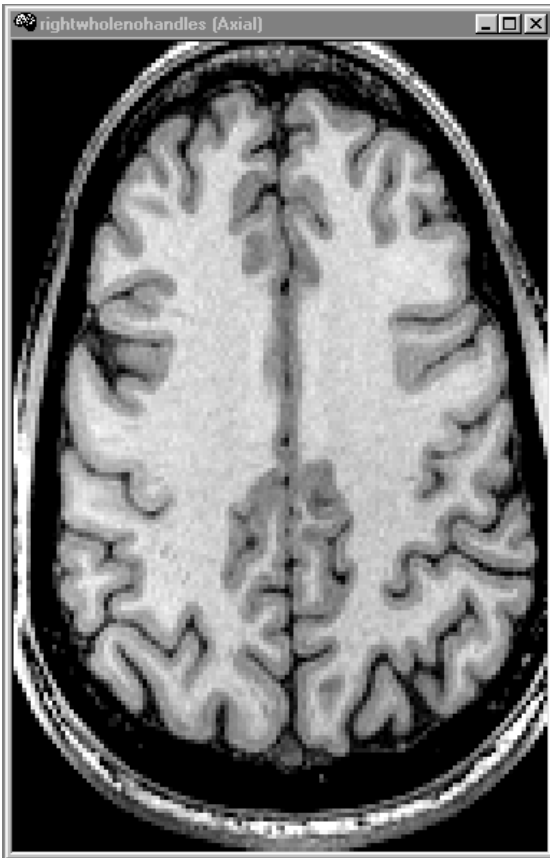
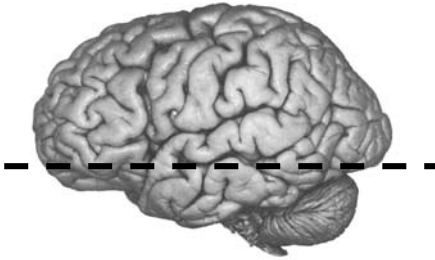
Soma

Axons

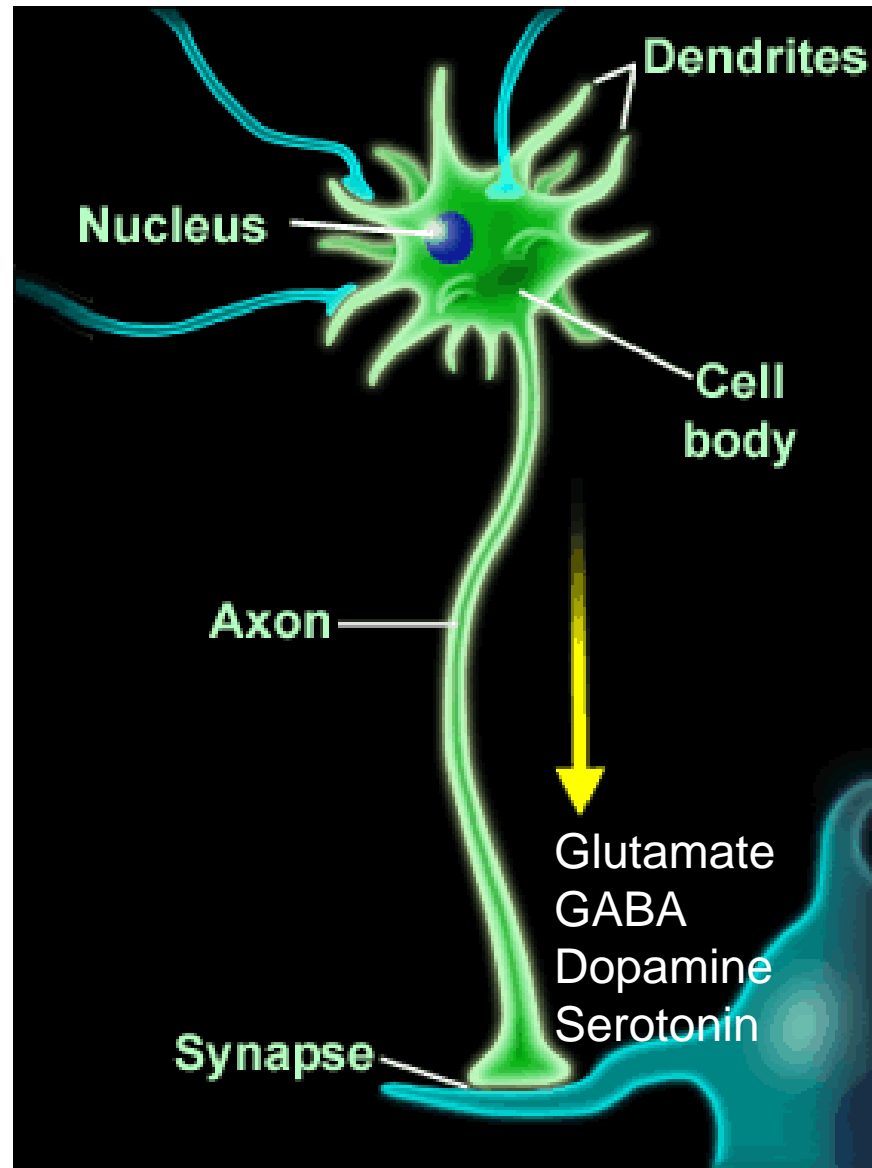
Axon
terminals



Axons and transmitters



Structures



- Brain computations takes place in the gray matter (also called cerebral cortex), a thin (2-4 mm) sheet of neural tissue that cover the surface of the brain



Neuron: impulse-conducting cell; bodies are in the cerebral cortex

Axon: a thin fiber that carries the output impulses from a neuron

Dendrite: a branching process of a neuron that receives impulses from other neurons

Synapse: The point of connection between neurons

Francis Crick; Braitenberg and Schutz
Synapse image from Graham Johnson

Brain computations takes place in the gray matter (also called cerebral cortex), a thin (2-4 mm) sheet of neural tissue that cover the surface of the brain



Neurons/mm³: 10^4 - 10^6

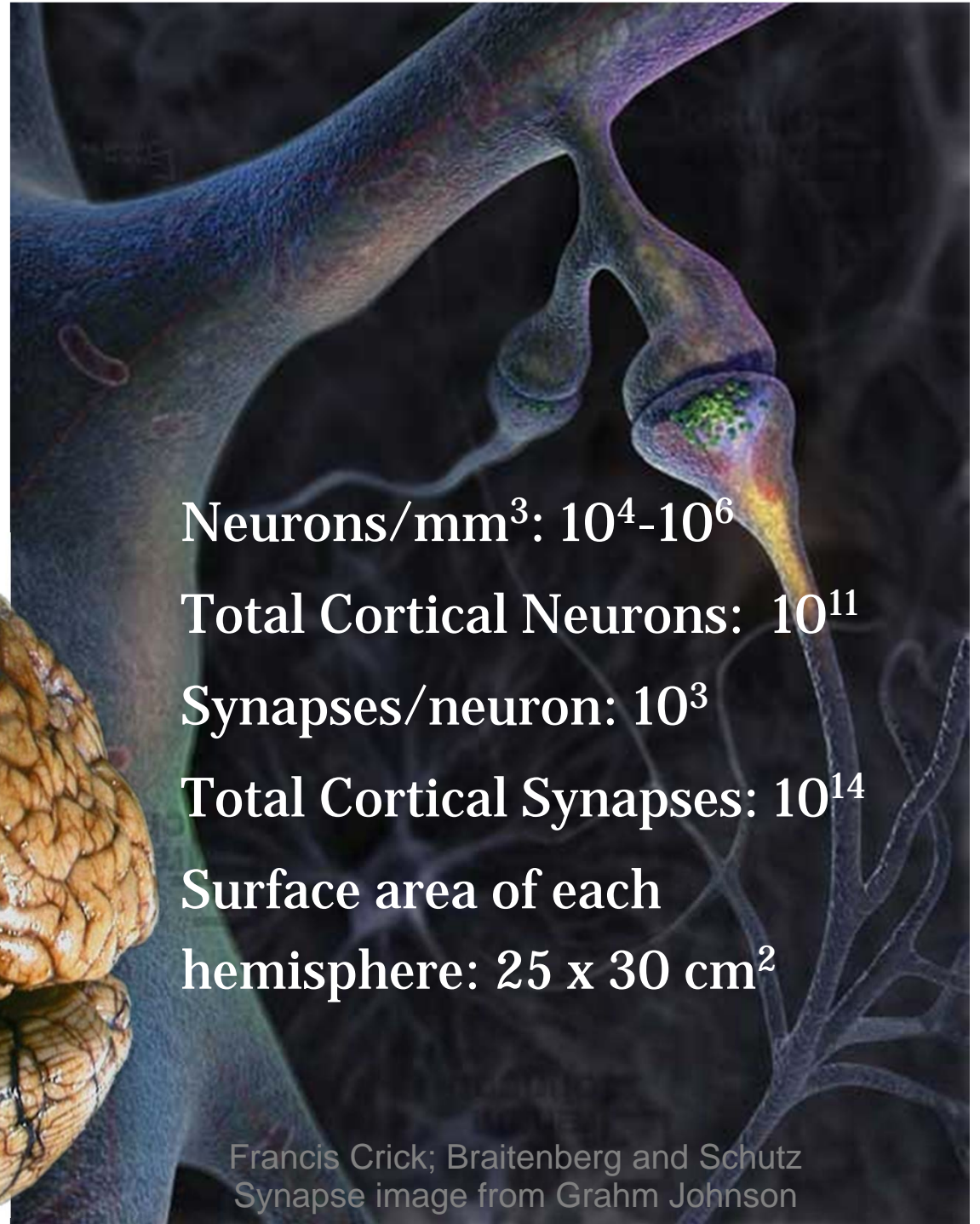
Total Cortical Neurons: 10^{11}

Synapses/neuron: 10^3

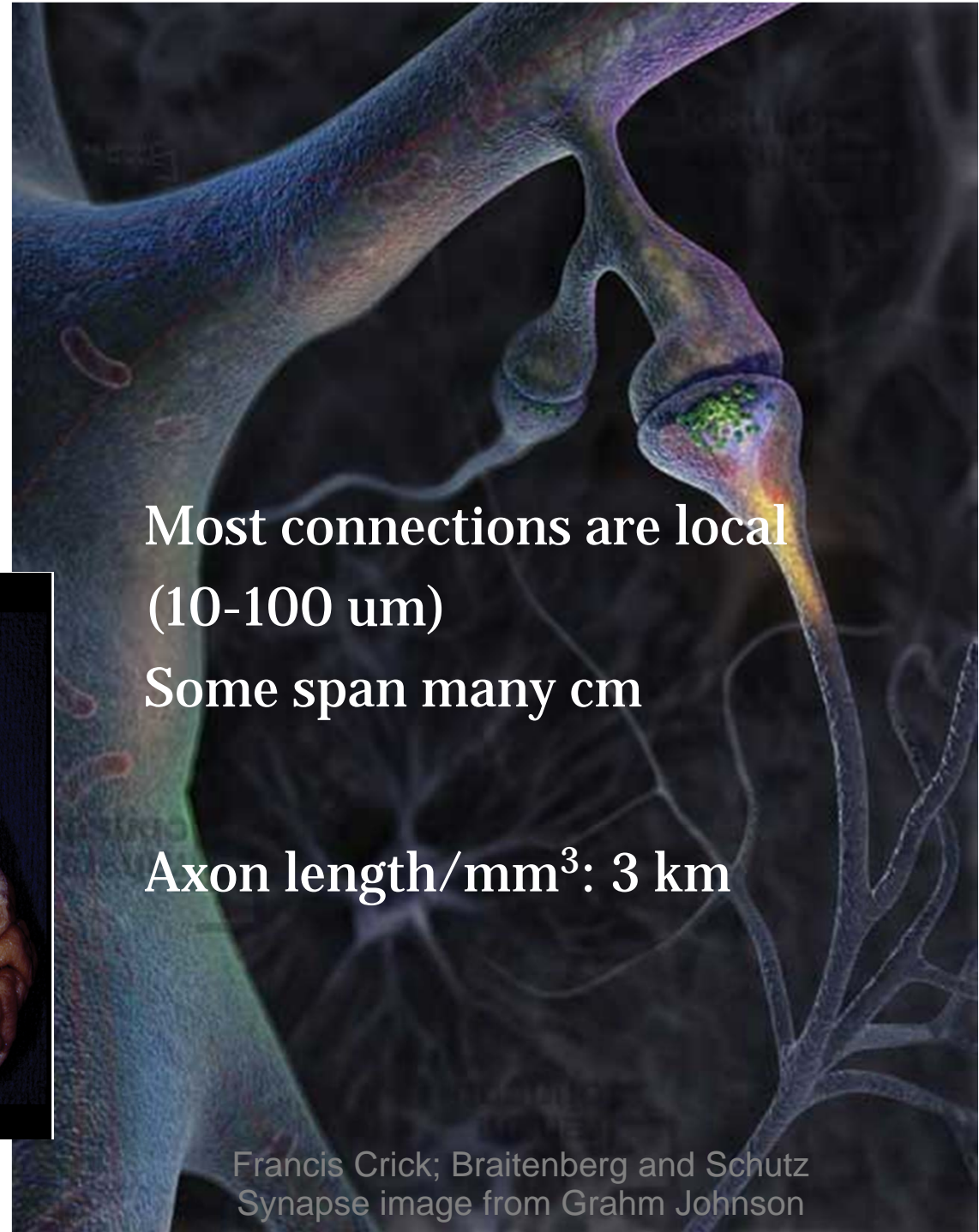
Total Cortical Synapses: 10^{14}

Surface area of each hemisphere: $25 \times 30 \text{ cm}^2$

Francis Crick; Braitenberg and Schutz
Synapse image from Graham Johnson



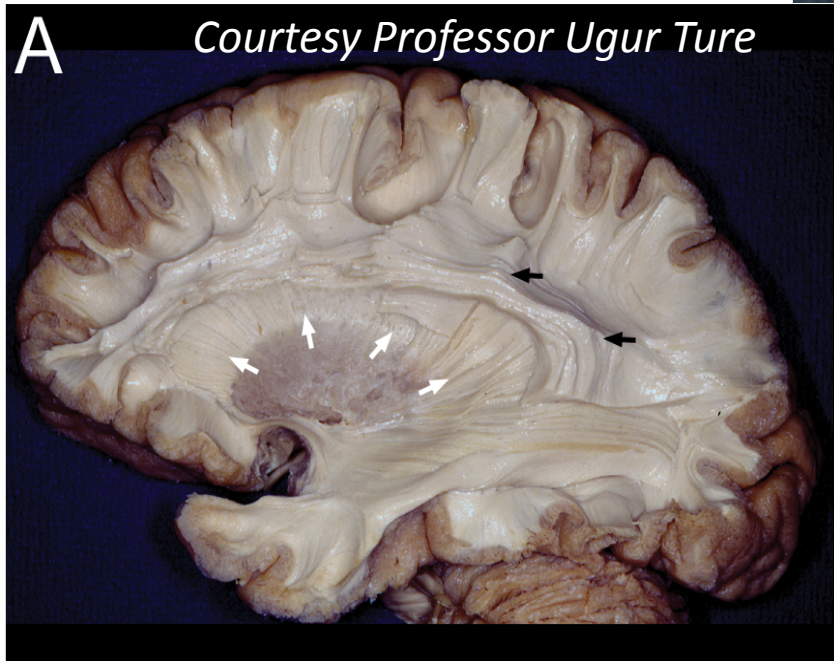
Long-range brain communications take place via axon bundles, (also called cerebral white matter). This is the wiring.



Most connections are local (10-100 μm)

Some span many cm

Axon length/ mm^3 : 3 km



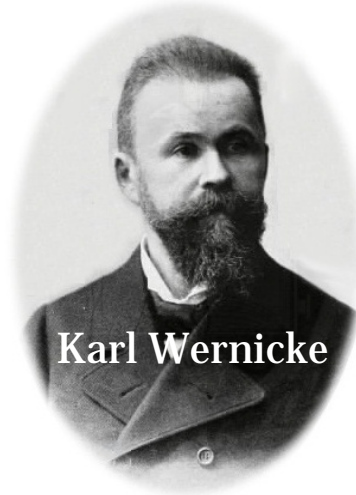
Francis Crick; Braitenberg and Schutz
Synapse image from Graham Johnson

Neurology

Theory of function at coarse scale

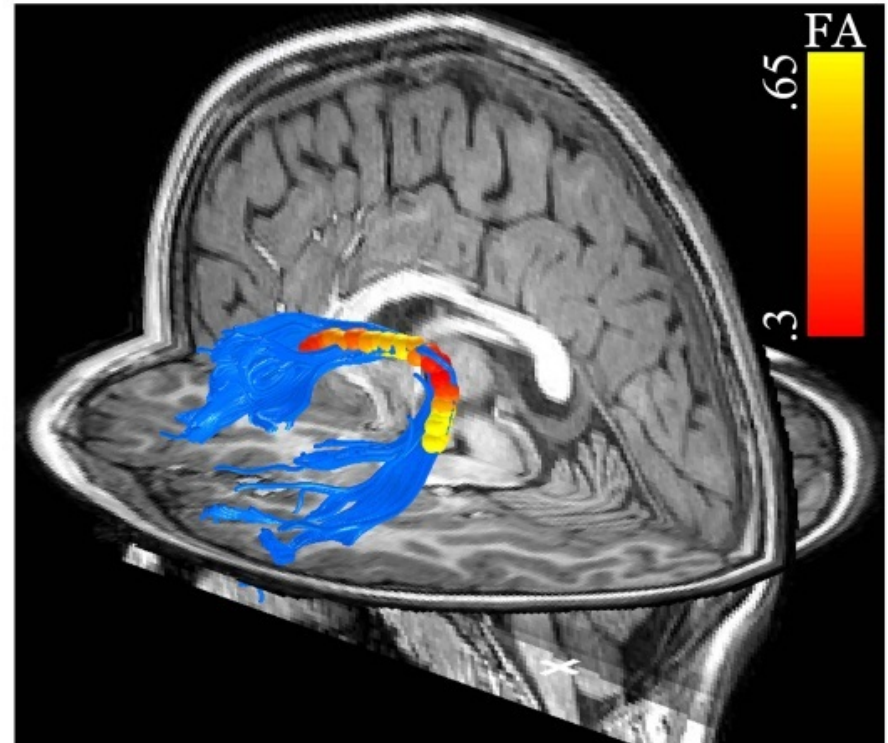
Neurology

Wernicke, Dejerine,
Geschwind, others



Karl Wernicke

- Connectionist - cognitive functions explained by **white matter** connections between sensory and motor regions



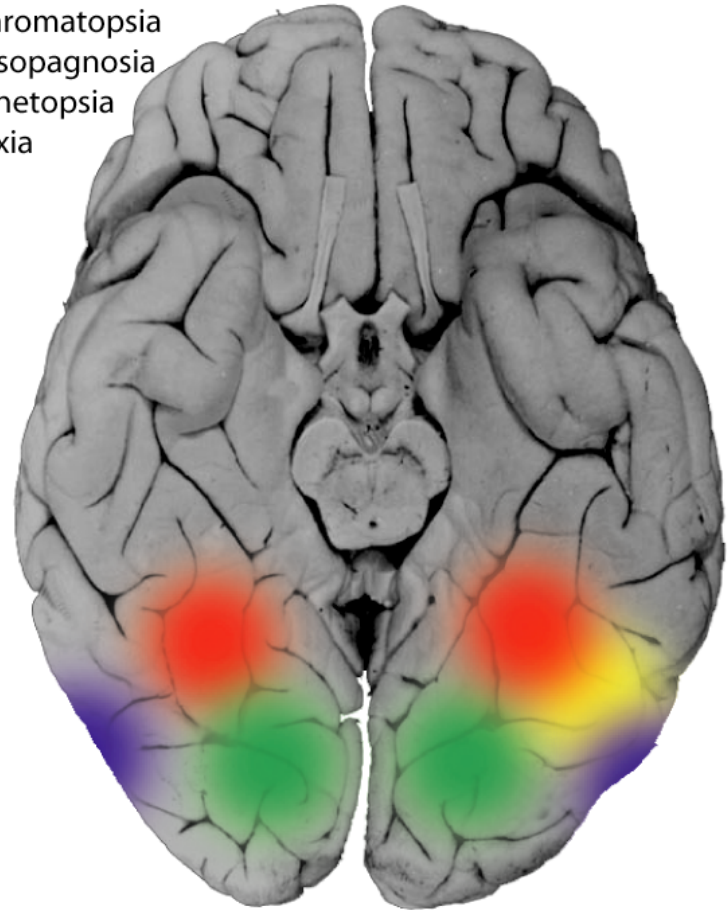
Neurology

Kinsbourne, Warrington,
Shallice, others



- Achromatopsia
- Prosopagnosia
- Akinetopsia
- Alexia

- Functional analysis focused on neural information processing in the **gray matter**



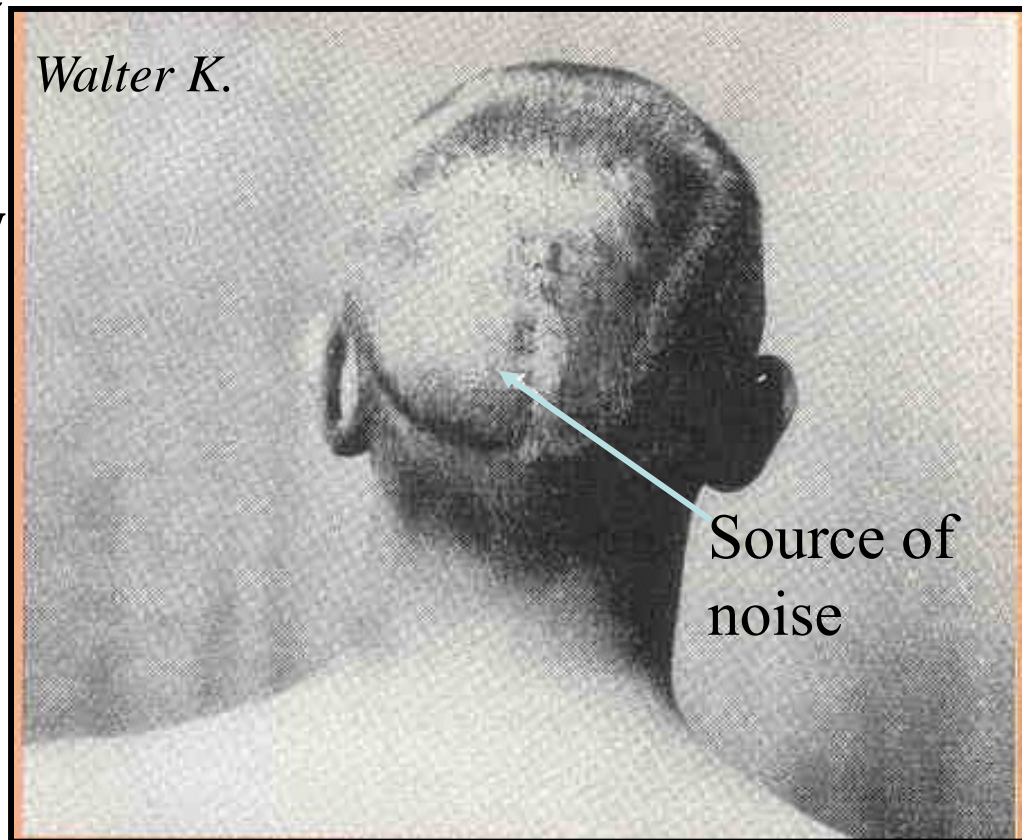
The rise of functional Magnetic Resonance Imaging (fMRI)

Blood oxygen level dependent (BOLD) imaging is an fMRI methodology

Neural and vascular activity are coupled

Observations Upon the Vascularity of the
Human Occipital Lobe During Visual Activity
J.F. Fulton, M.D. (1928)

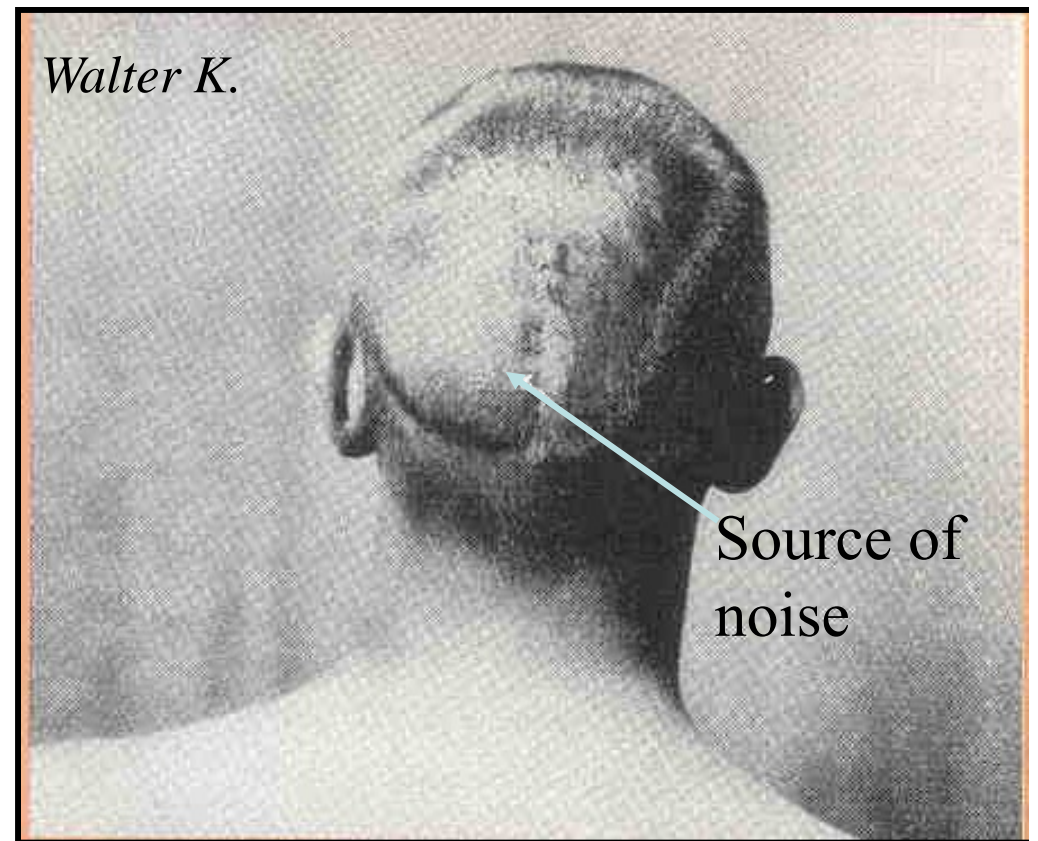
On turning down a left occipital bone flap, a large angry-looking angioma arteriale racemosum of the left occ. Lobe was disclosed which extensively involved the visual cortex. The haemorrhage occasioned by the bone flap was so excessive that the operation had to be abandoned without touching the tumour. A decompression, however, was made. The patient was discharged ... with greatly improved vision.



Neural and vascular activity are coupled

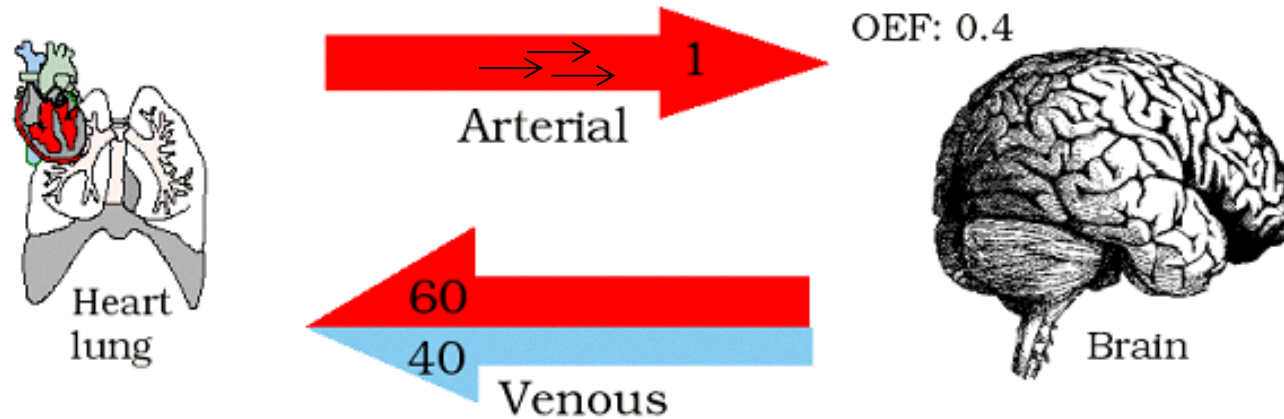
Observations Upon the Vascularity of the
Human Occipital Lobe During Visual Activity
J.F. Fulton, M.D. (1928)

- Subject noted that ‘the noise in the back of his head increased in intensity when he was using his eyes.’
- No increase for hearing, touch or smell
- Increased more when he tried harder



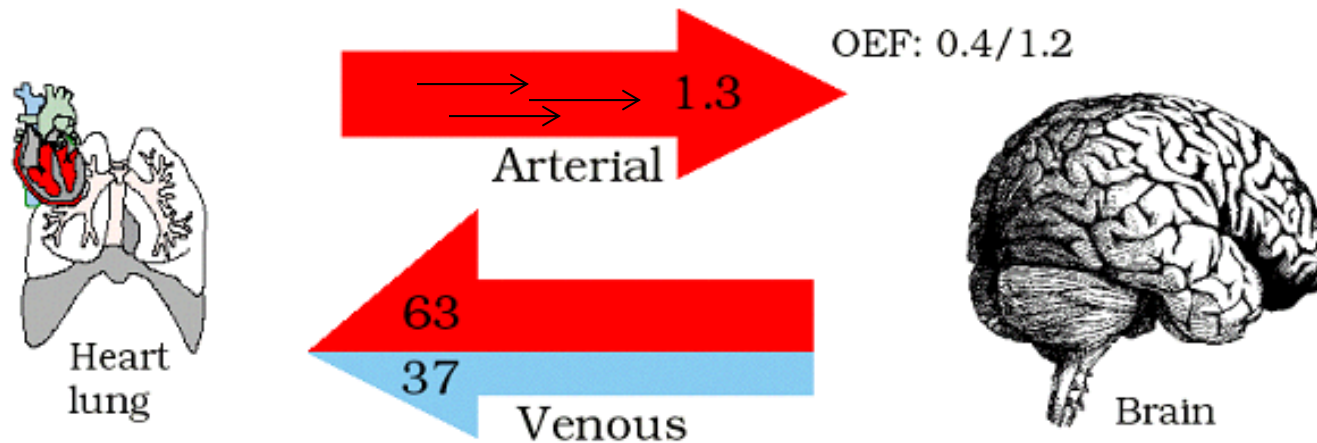
Blood oxygenation increase is localized

Control state



**Sokolow
Raichle
Fox**

Active state

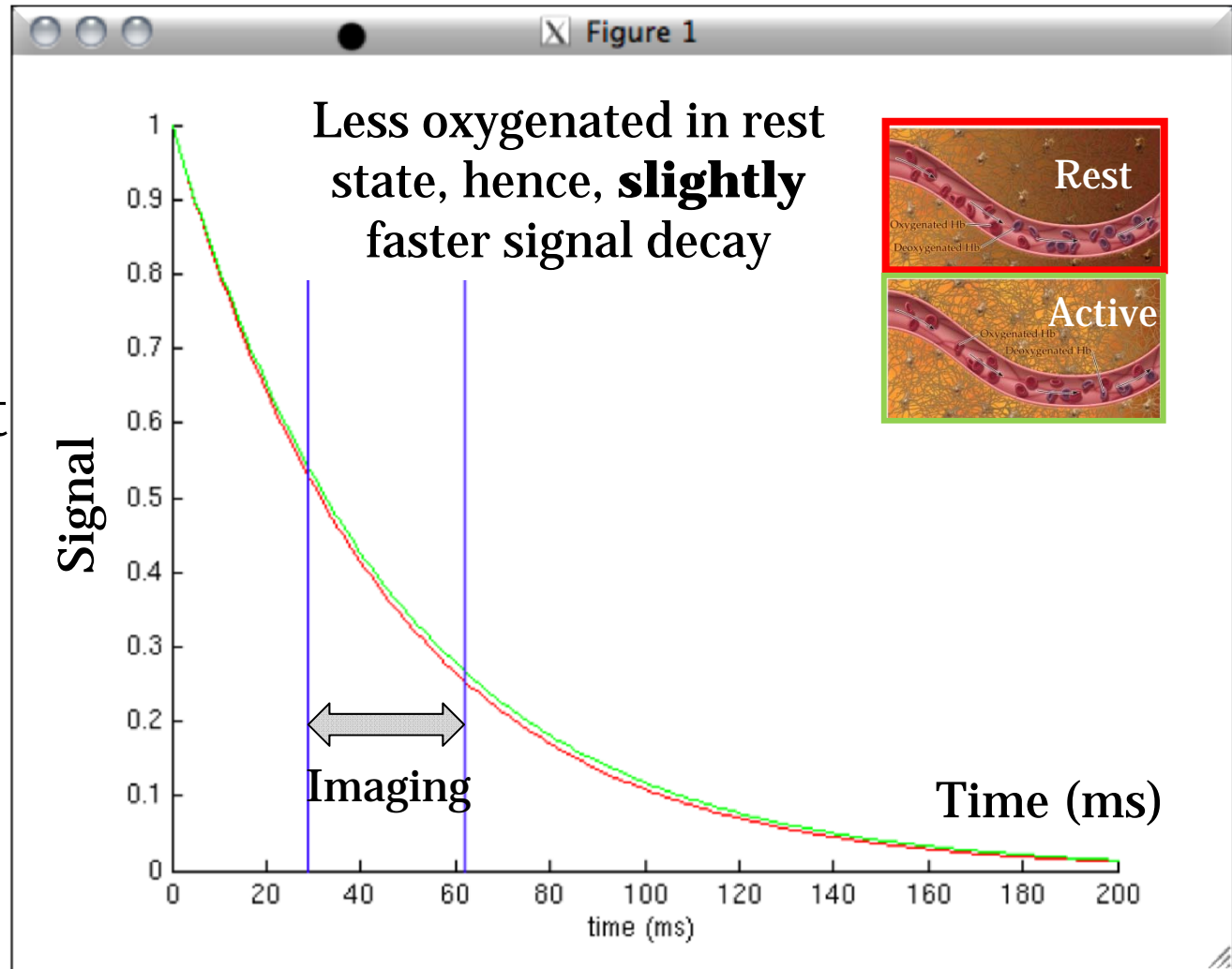


MRI scanners measure the blood oxygen level



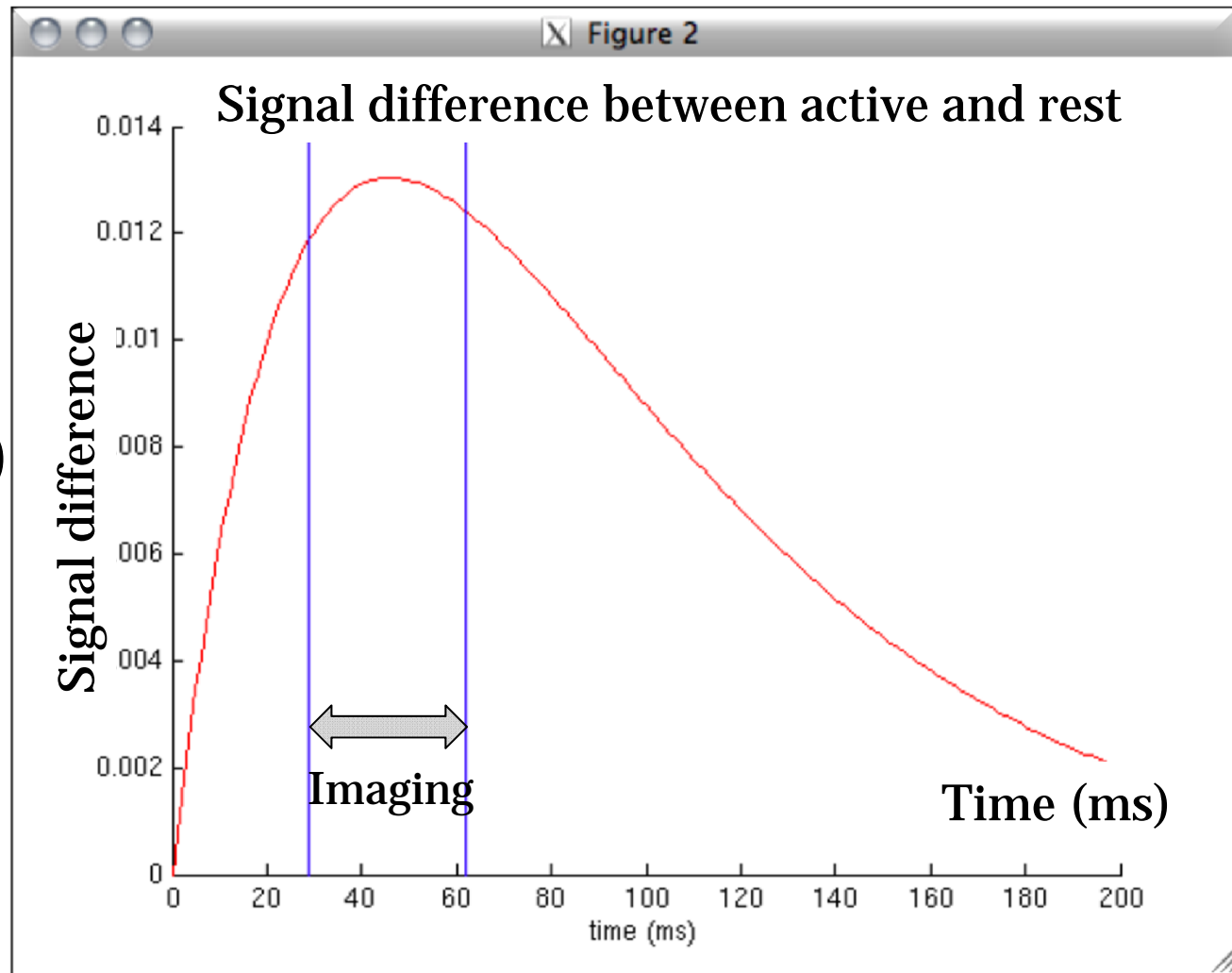
How will BOLD imaging work?

fMRI signal
decay for rest
and active



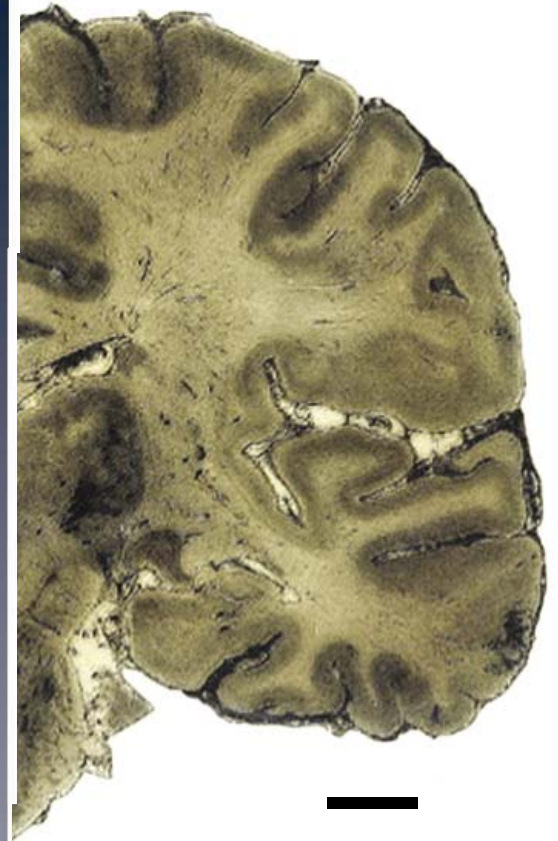
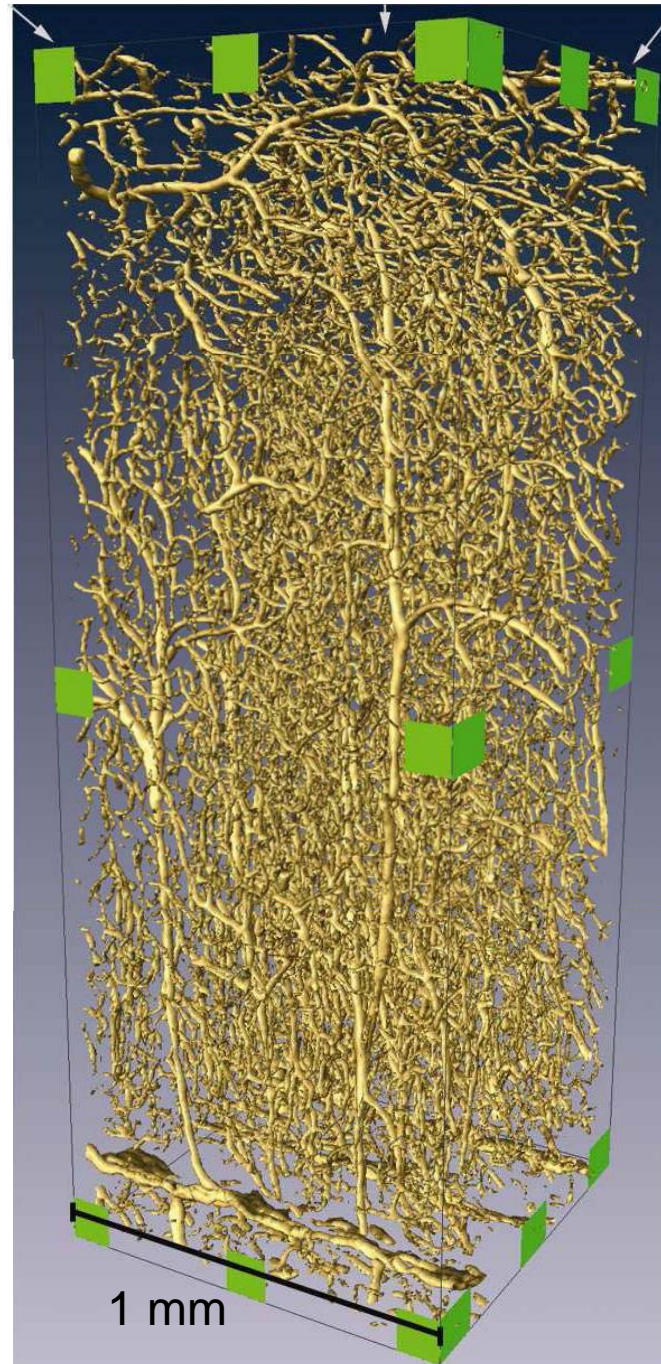
How will BOLD imaging work?

fMRI signal
decay
difference
(active – rest)



The cortical vasculature is dense

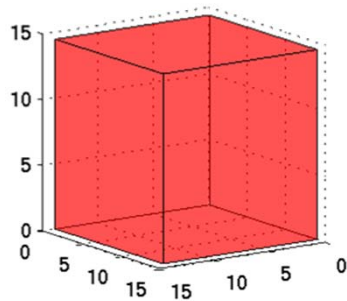
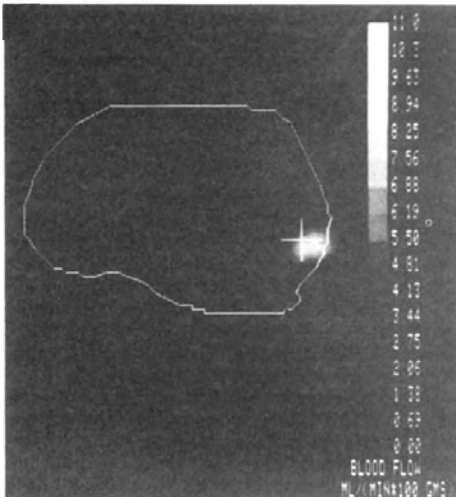
(Lauwersa et al.,
Neuroimage, 2007)



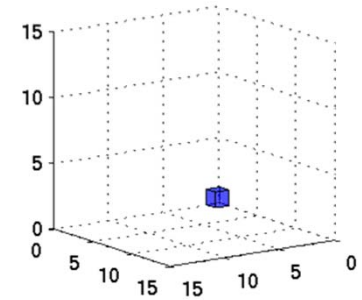
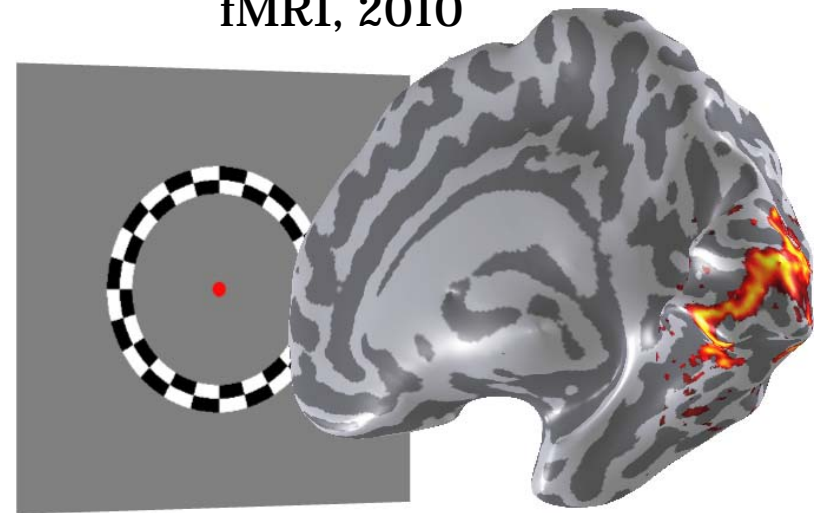
—
cm

Human visual cortex

PET, 1990

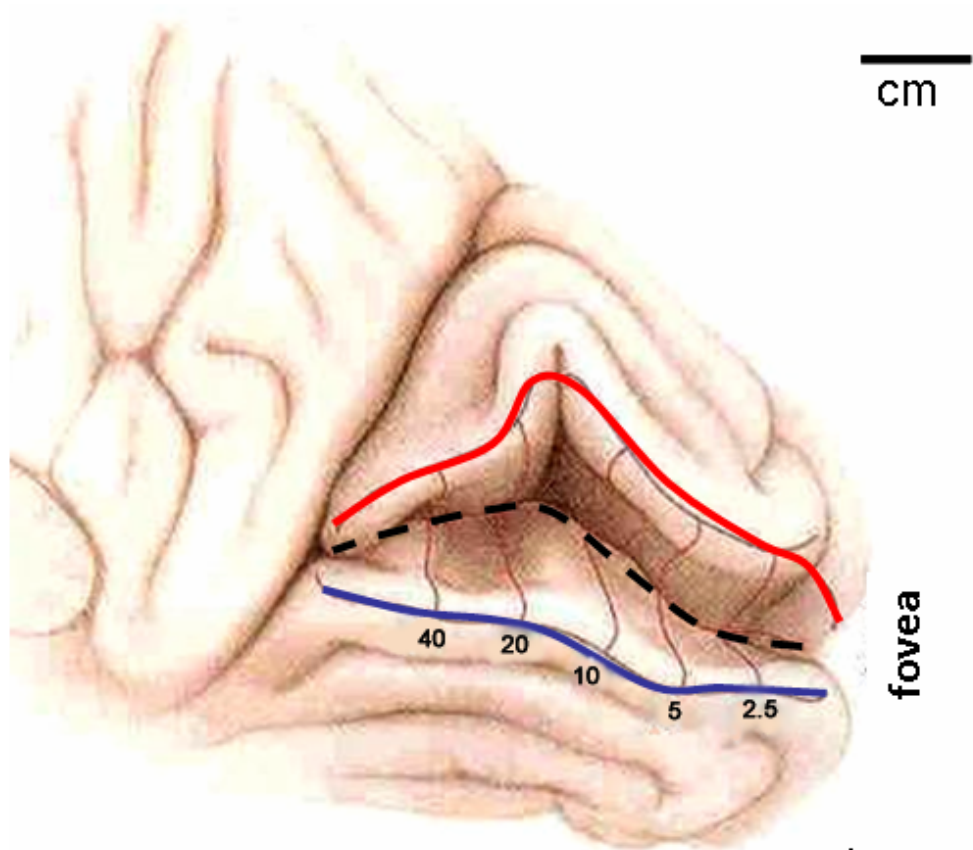


fMRI, 2010

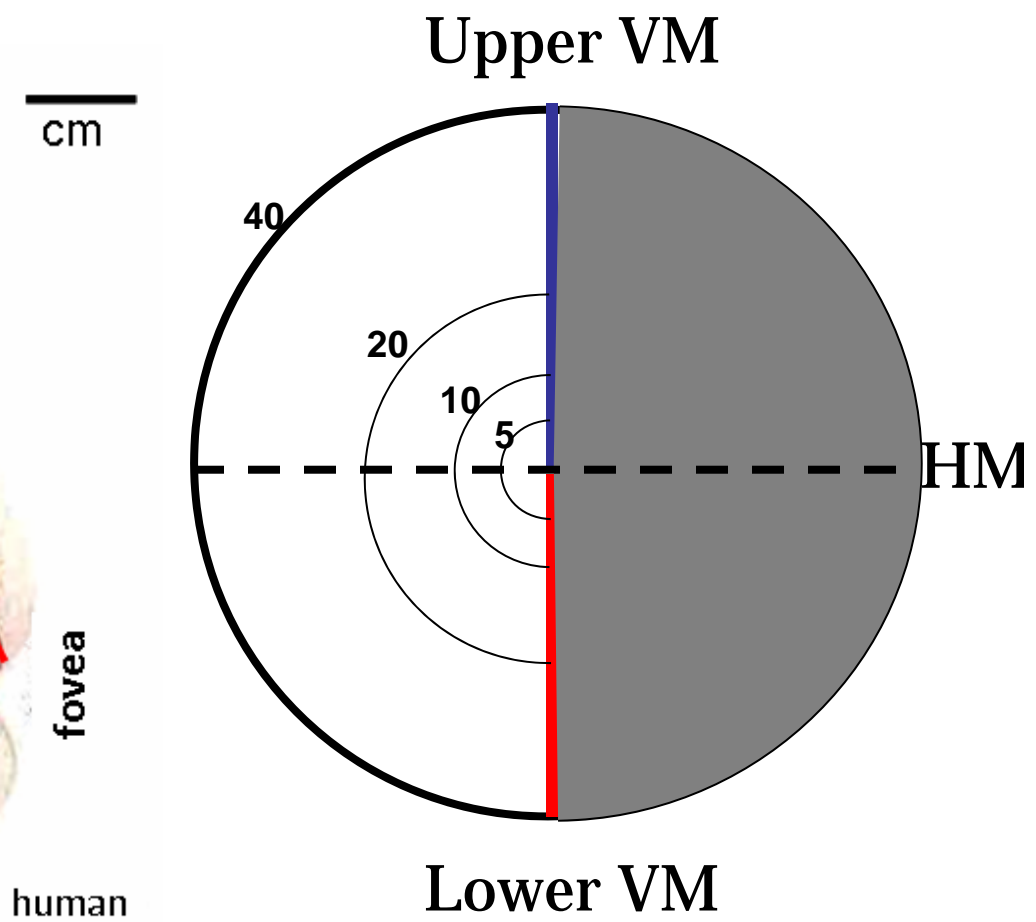


Voxel volume

Primary visual cortex (V1) contains a visual field map



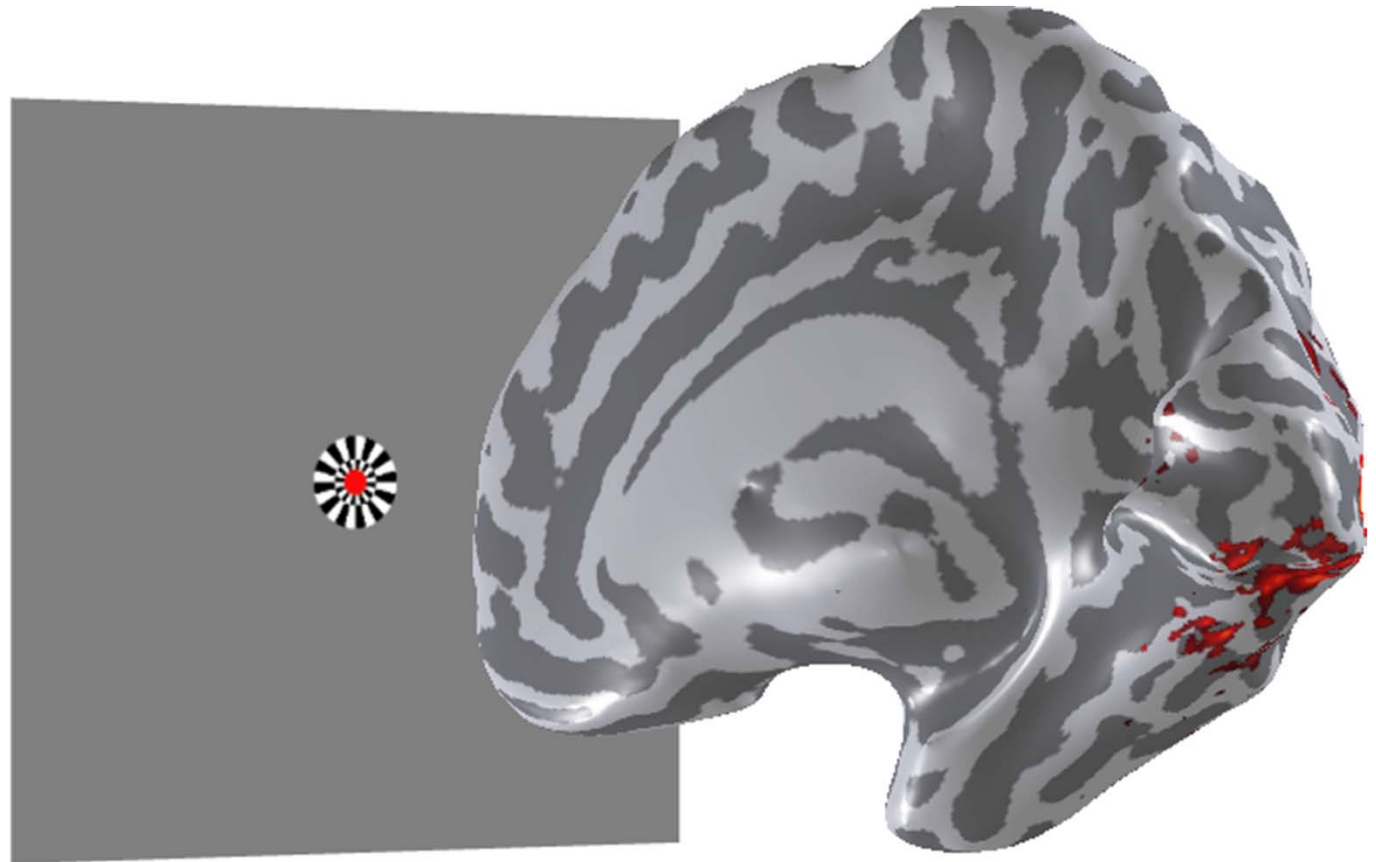
Horton and Hoyt (1991)



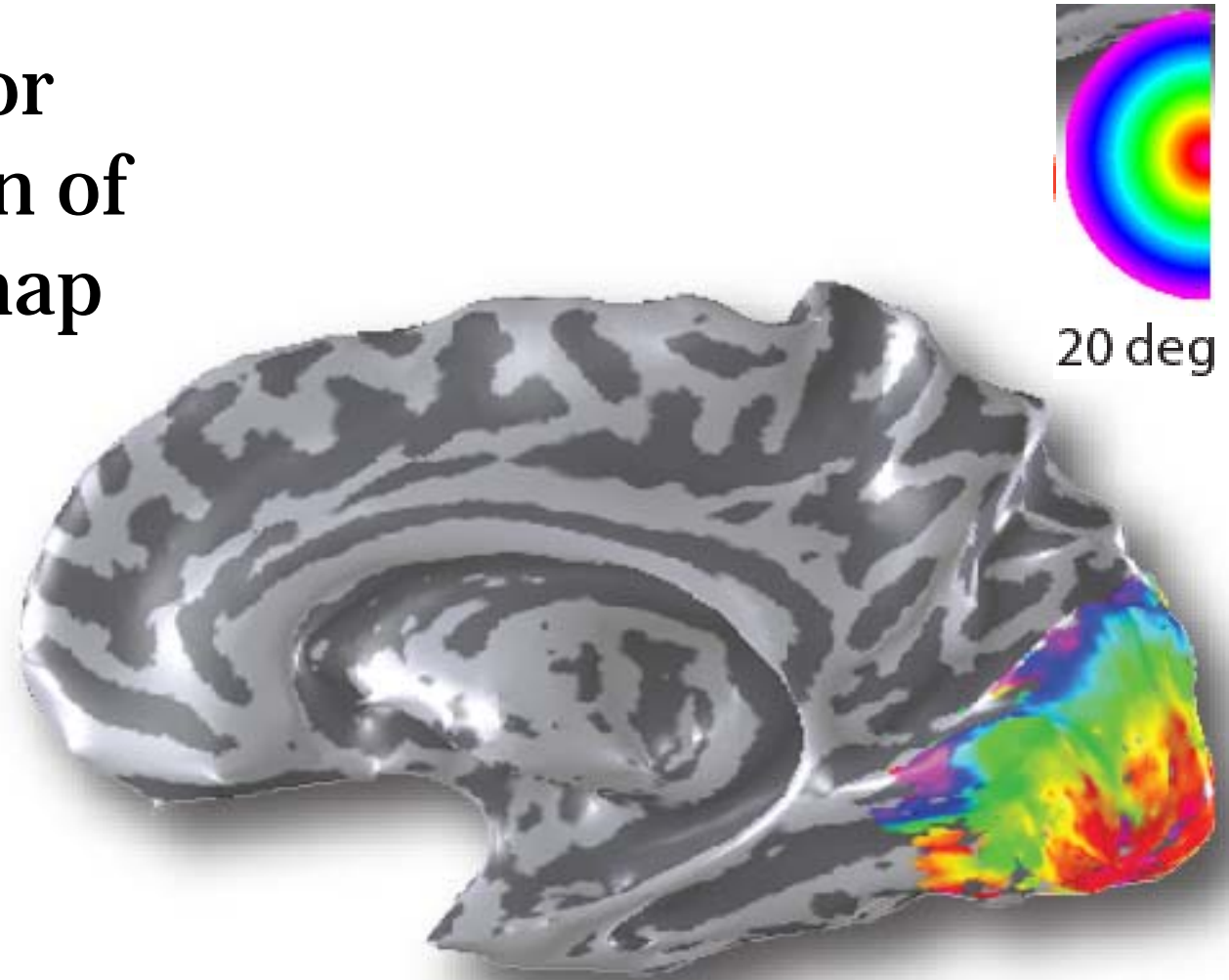
human

Human eccentricity mapping

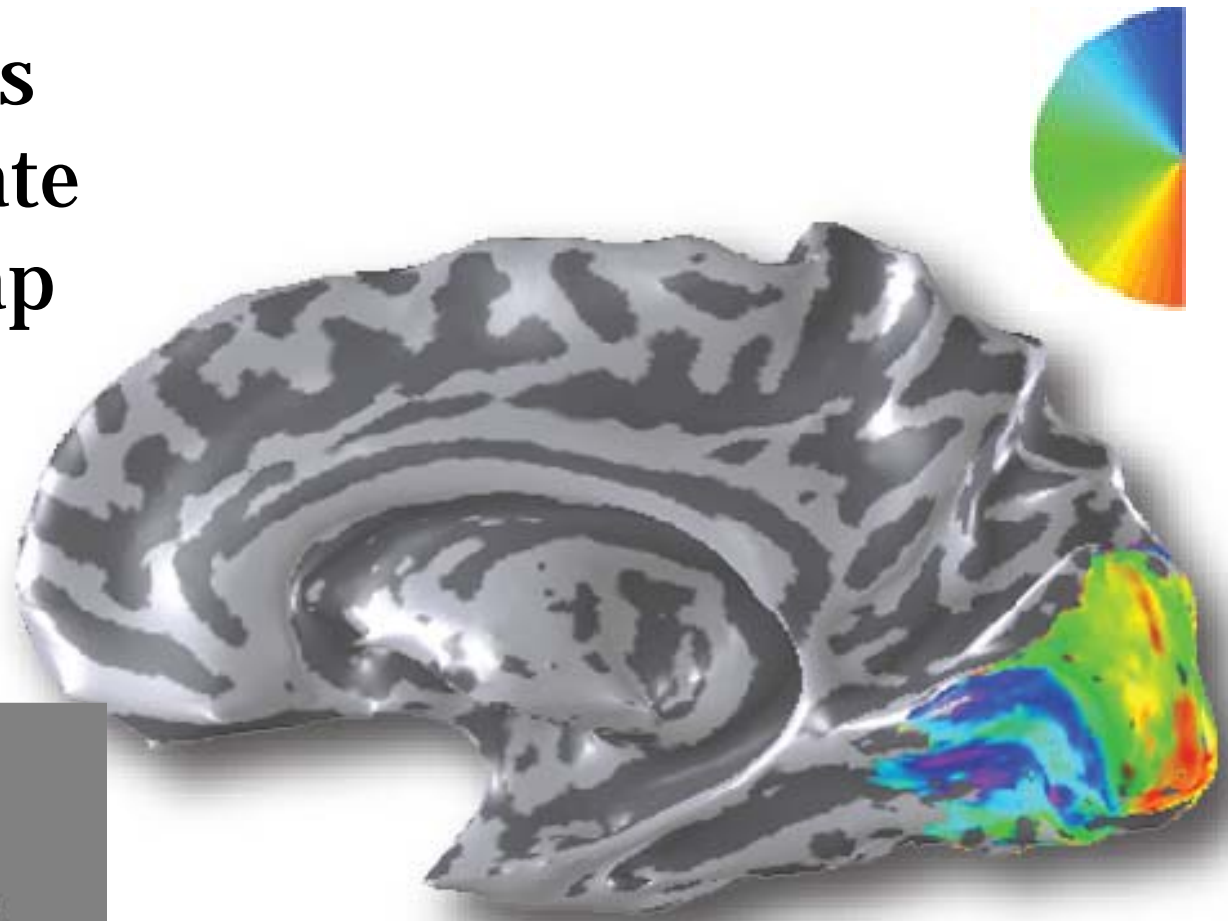
(Engel et al., 1994,1997; Sereno; DeYoe; Others)



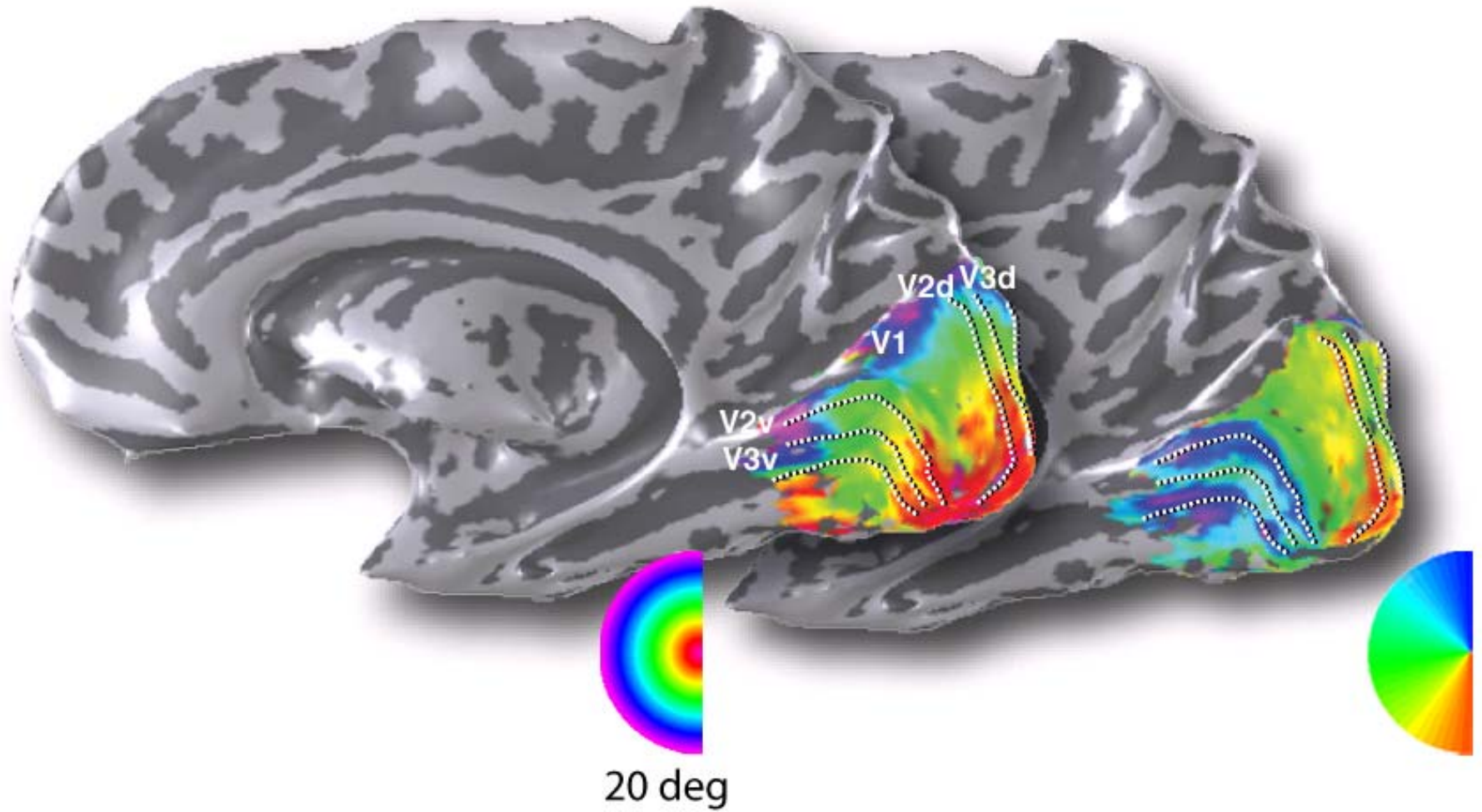
Pseudo-color
representation of
visual field map



Angular
measurements
sharply delineate
visual field map
boundaries

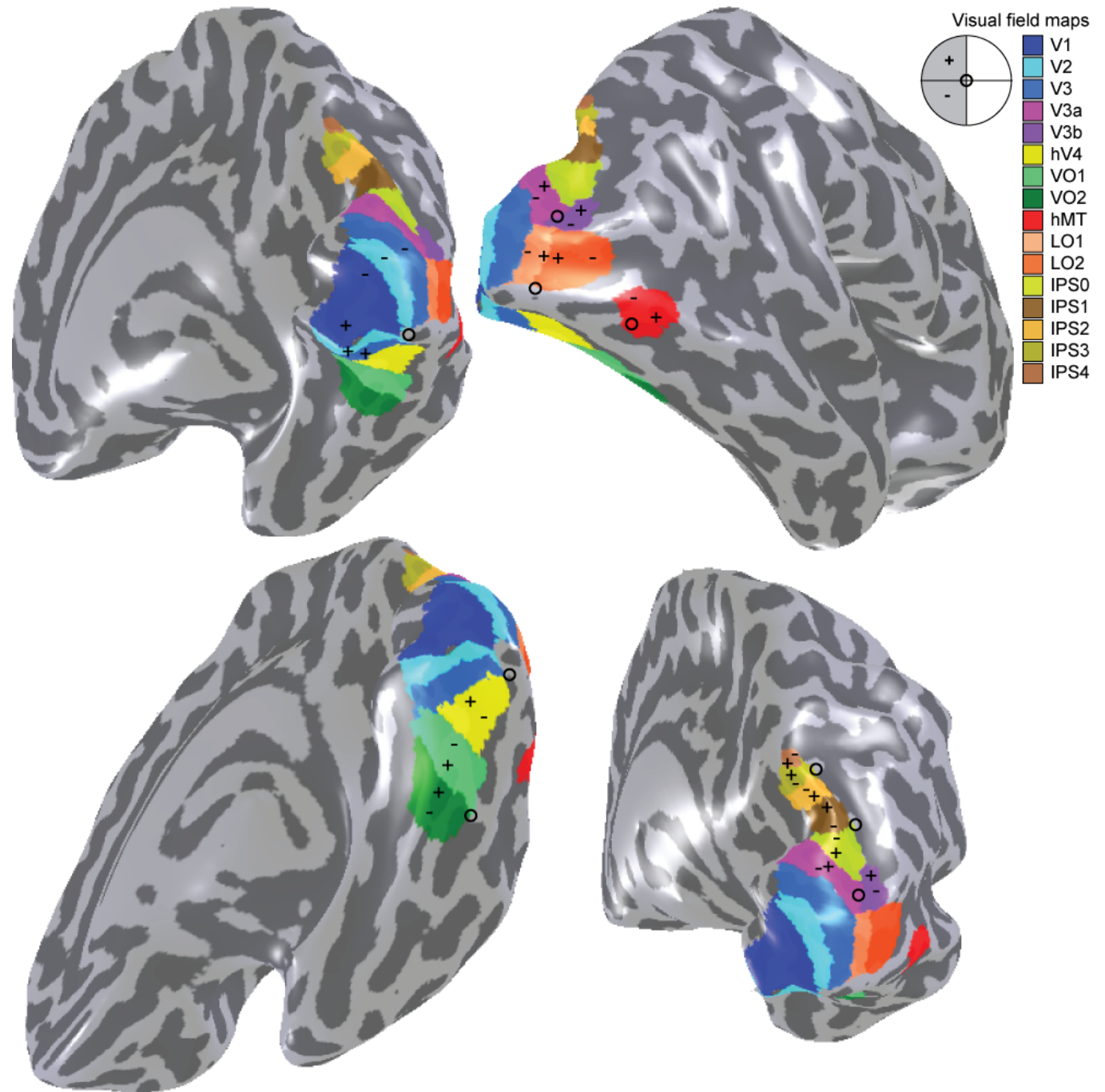


Combining eccentricity and angle data yields maps



More than sixteen visual field maps

Wandell,
Dumoulin,
Brewer (2007)
Neuron

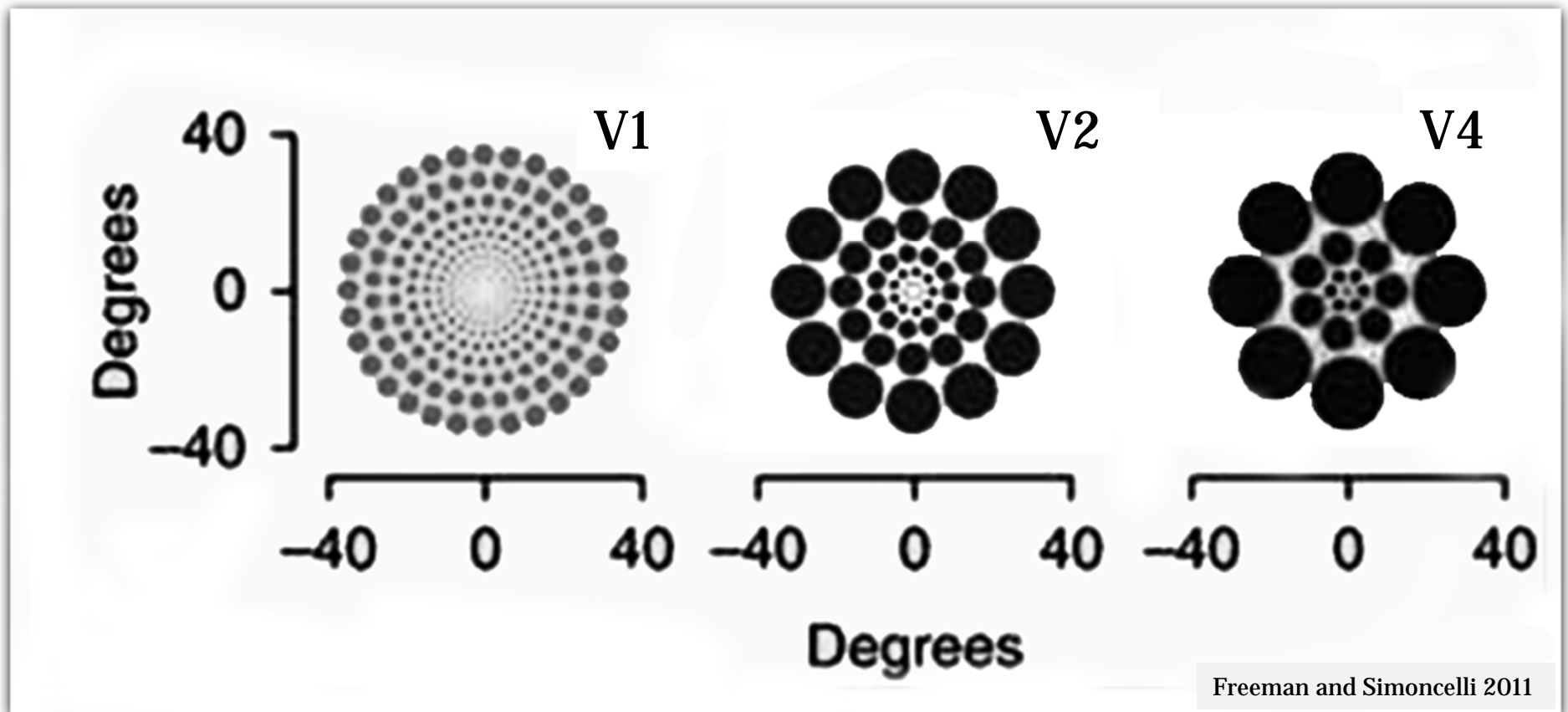


New developments in fMRI signal processing:

Modeling neurons that cause the fMRI response

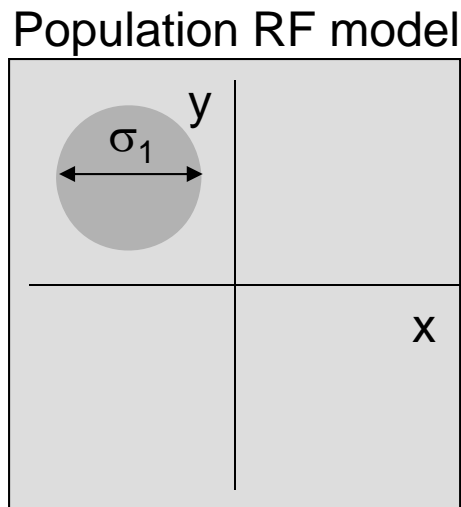
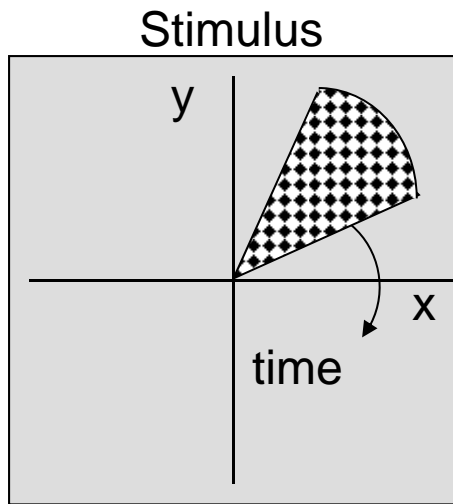
RF size increases across maps and eccentricity

'Responses can be obtained in a given optic nerve fiber only upon illumination of a certain restricted region of the retina, termed the receptive field of the fiber (Hartline, 1936)'.



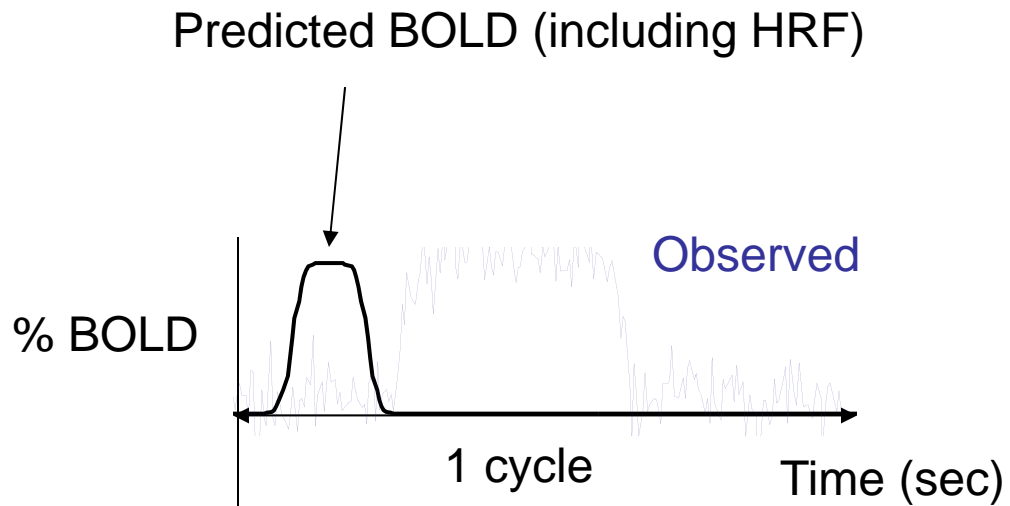
Population RF estimation

(Dumoulin and Wandell, 2008)

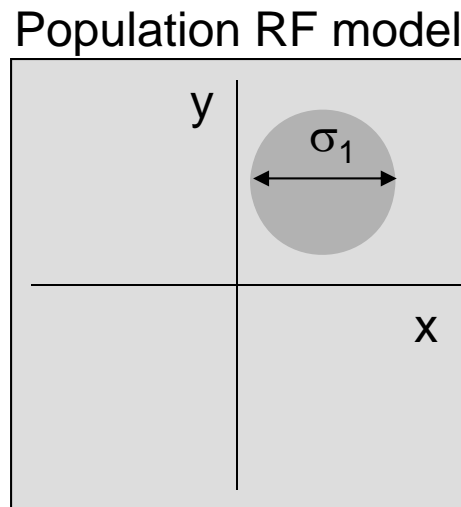
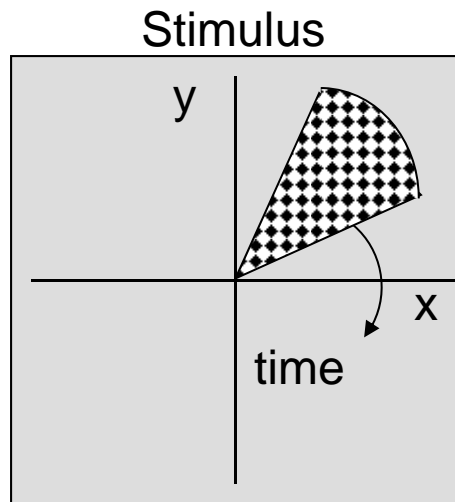


Parameters

(x_1, y_1, σ_1)



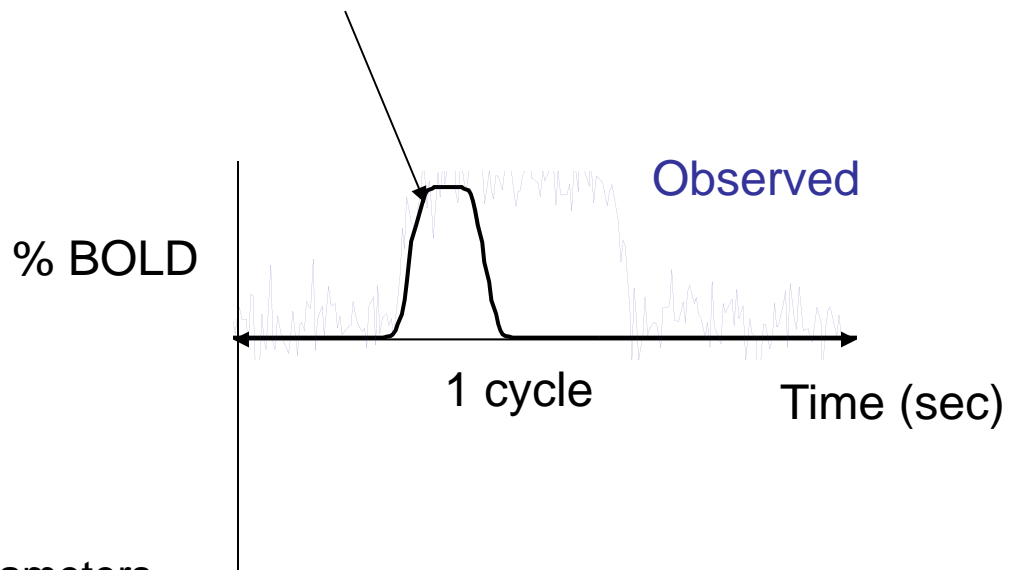
Population RF estimation



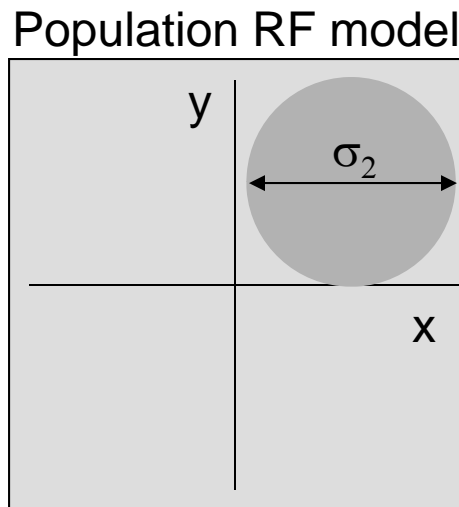
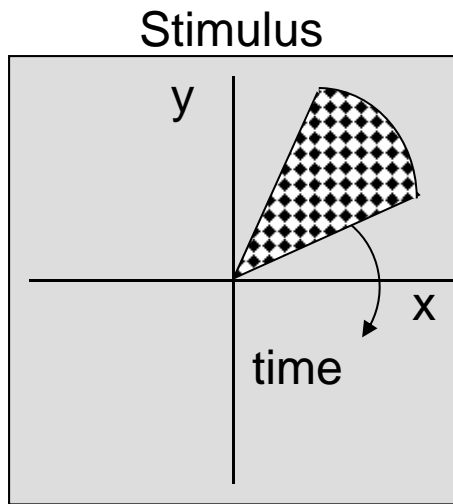
Parameters

(x_2, y_2, σ_1)

Predicted BOLD (including HRF)

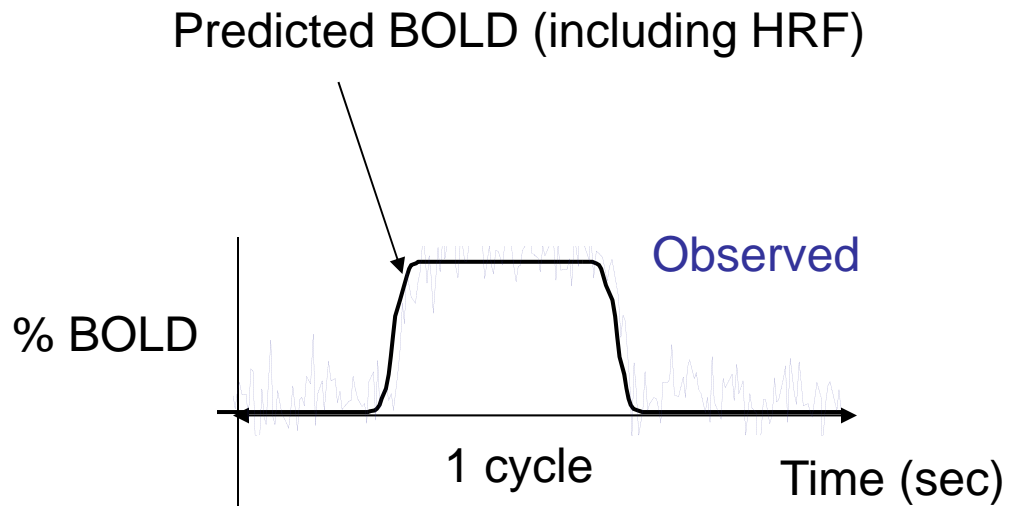


Population RF estimation

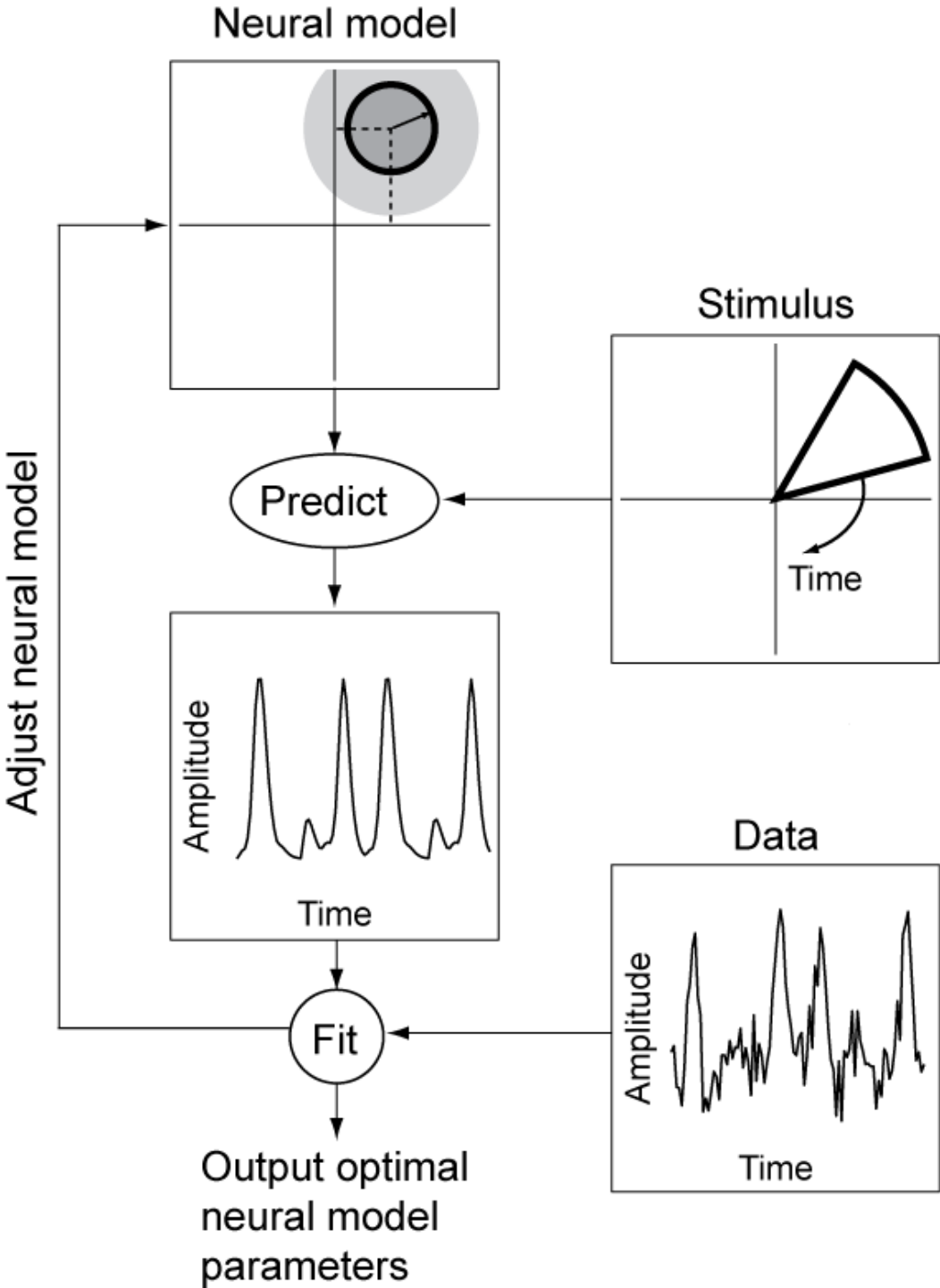


Parameters

(x_2, y_2, σ_2)

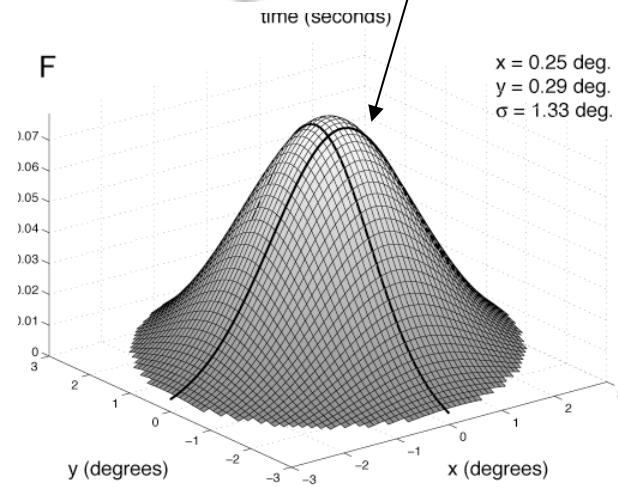
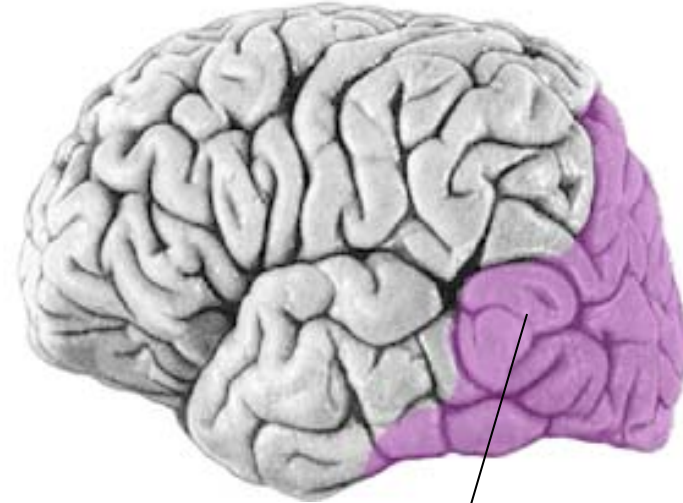
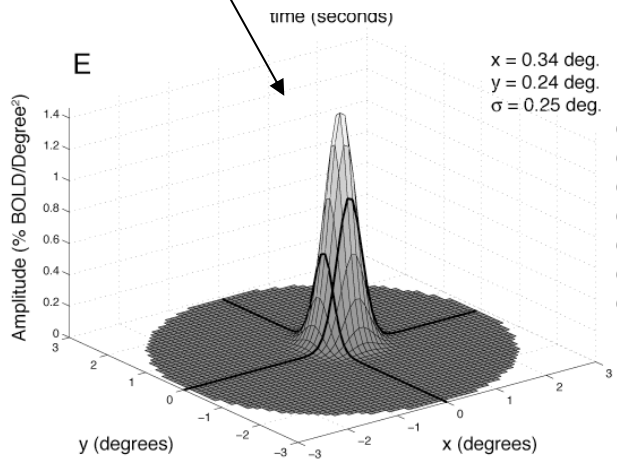
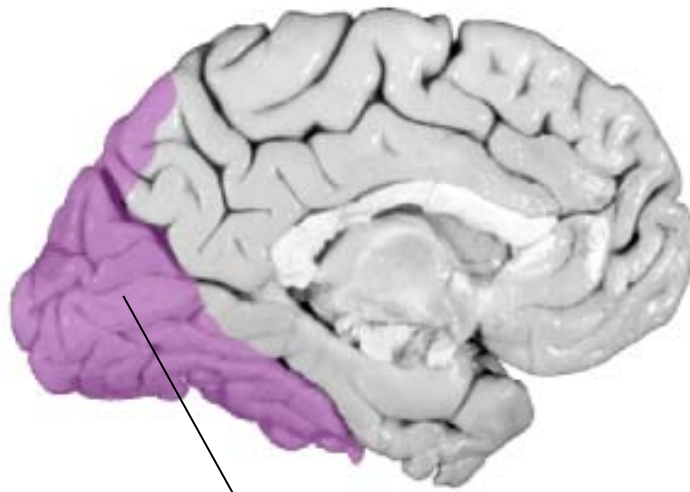


(Dumoulin and Wandell, 2008)

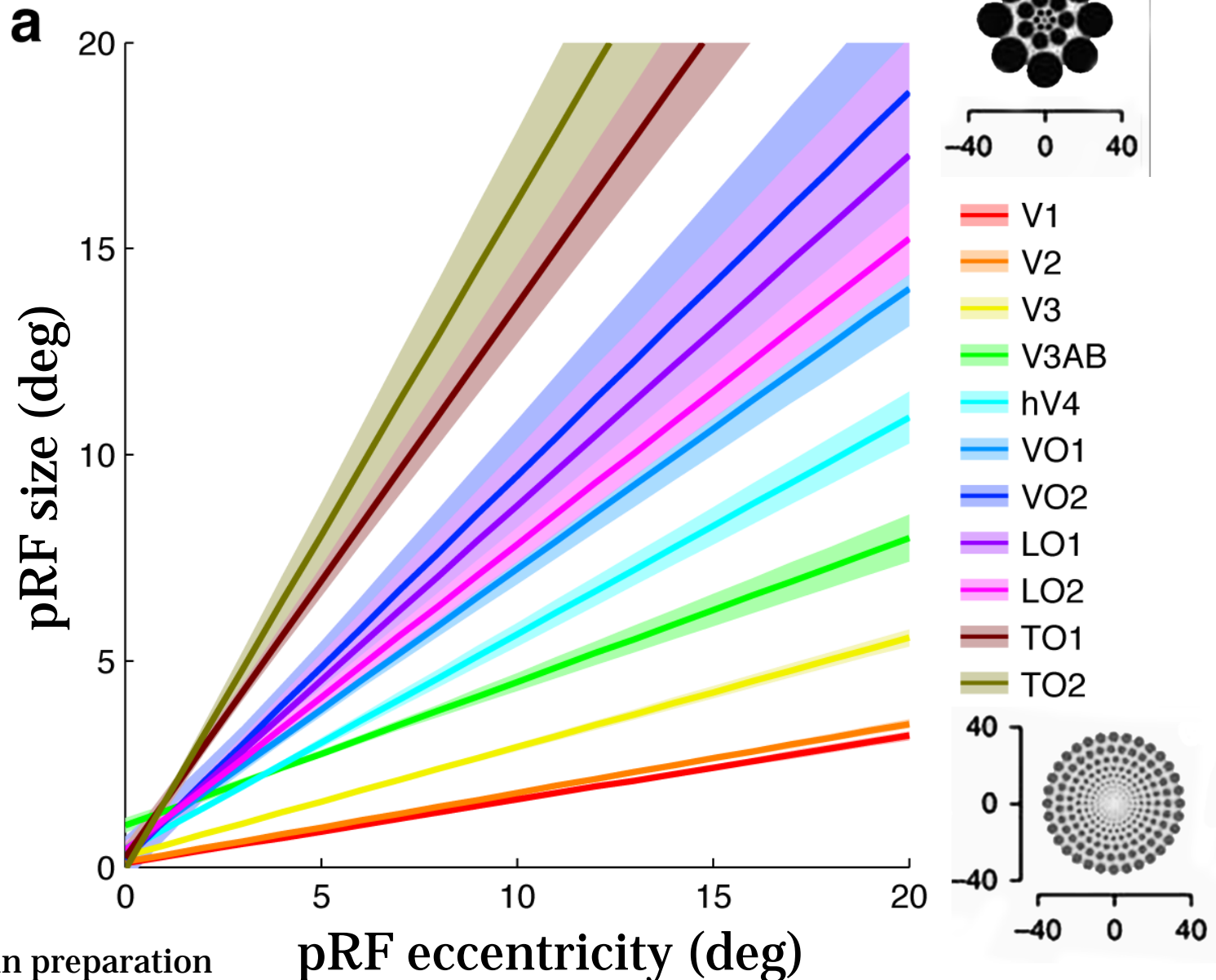


(Dumoulin and Wandell, 2008)

Population receptive field vary significantly across human visual cortex

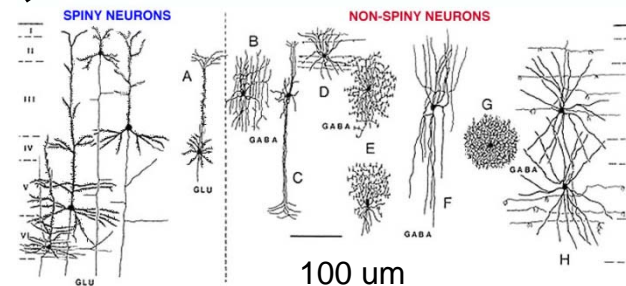
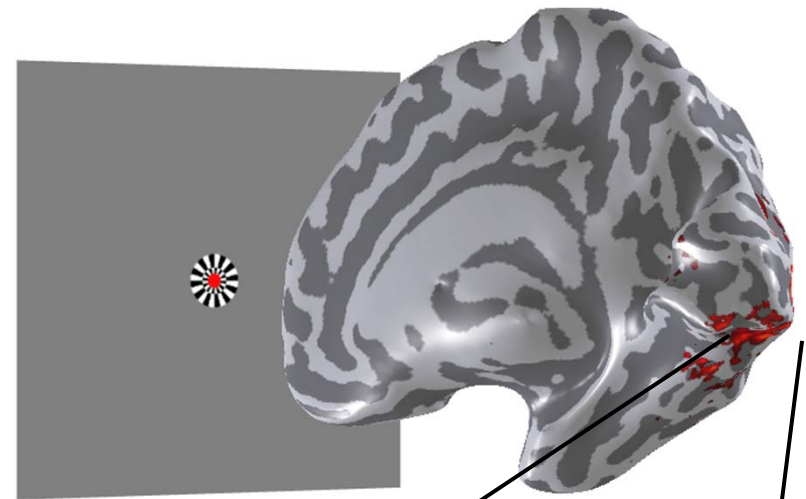


Population RF increases with eccentricity in each map



What's next

We are building computational models connecting the BOLD time series to different types of single units. We are adding experimental methods **and** computational modeling



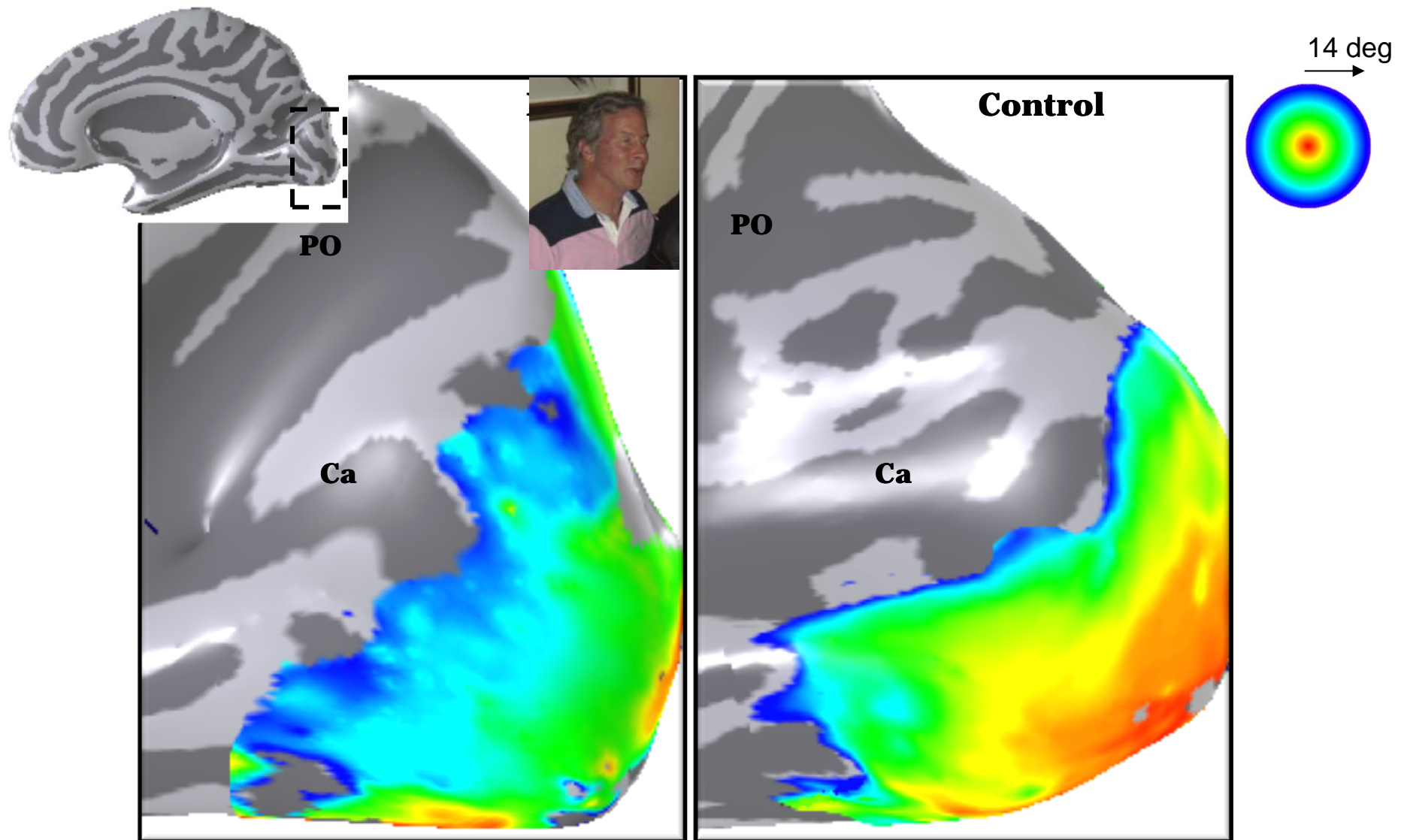
One motivation for why we would like to know:
Curing blindness

Stem cells, curing blindness



IMAGES COPYRIGHT MICHAEL MAY

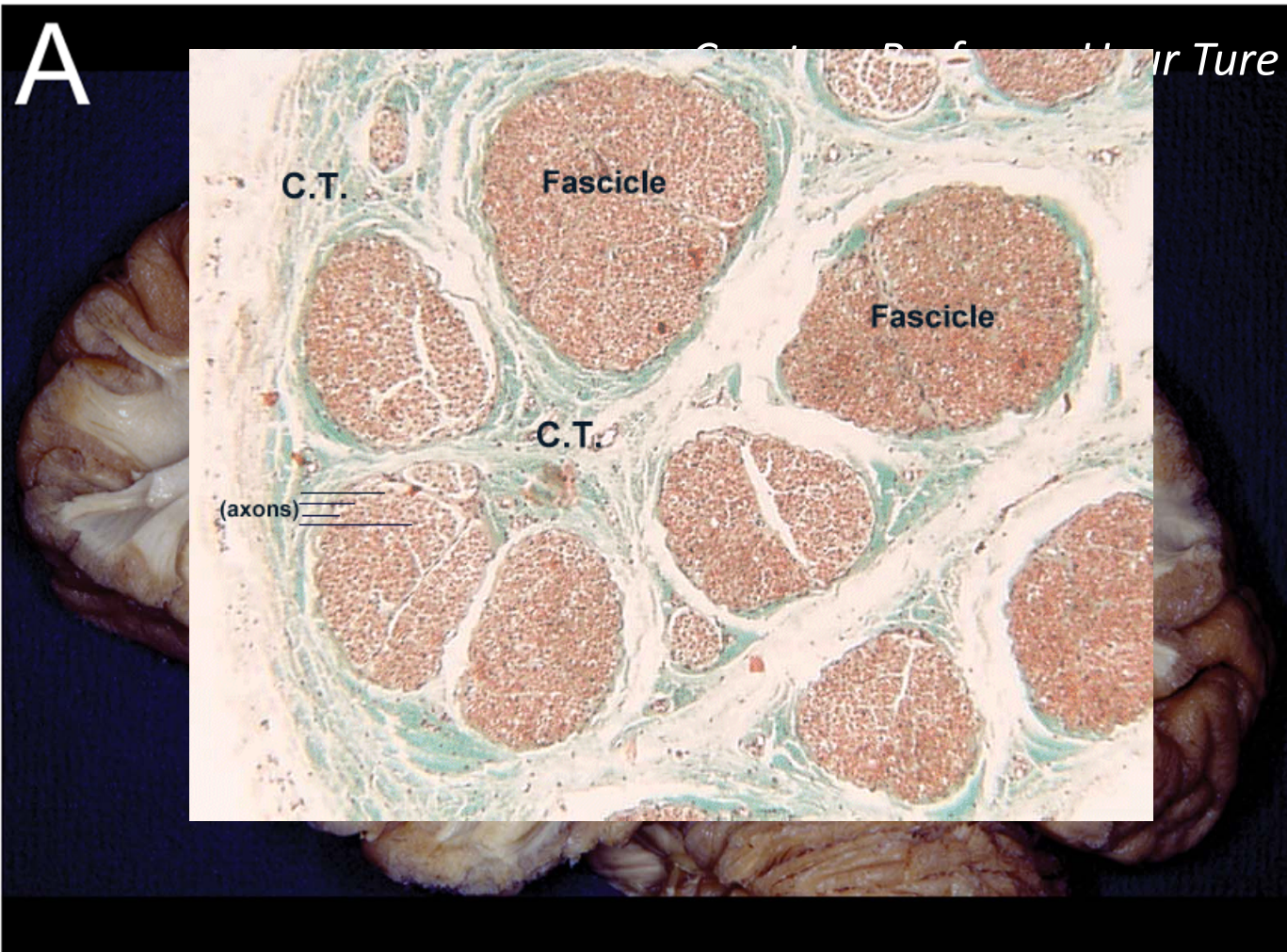
Why can't Mike see? Missing signals to visual cortex



Human white matter

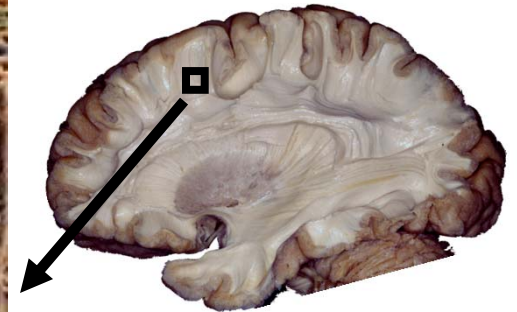
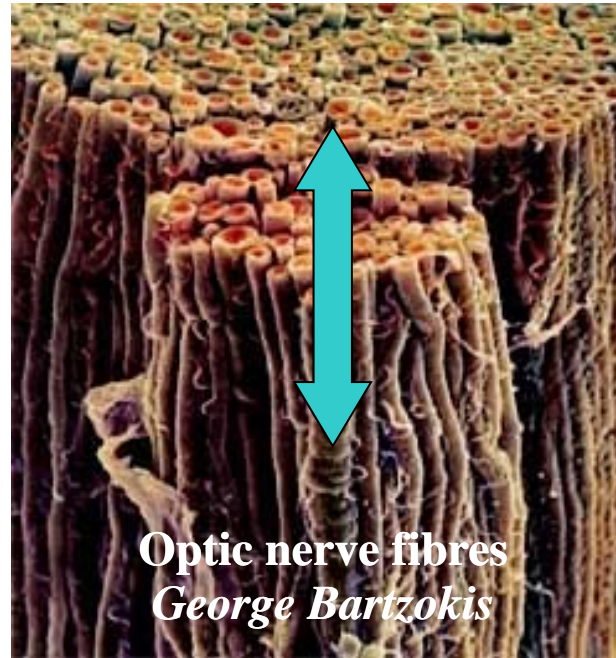
Measuring the major connections
using diffusion imaging

Human fiber tracts



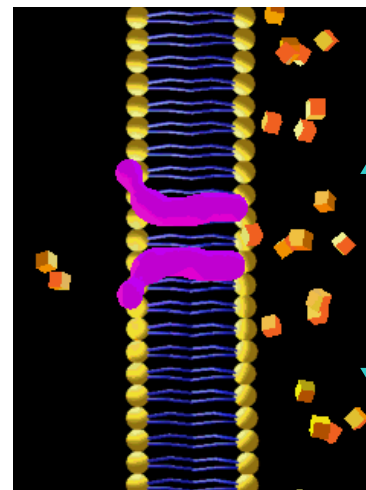
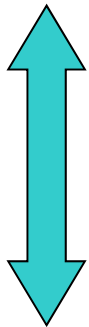
Diffusion probes brain microscopic structure

*Along the axon, within the cytoskeleton, water diffuses easily and the **Apparent Diffusion Coefficient (ADC)** is large*



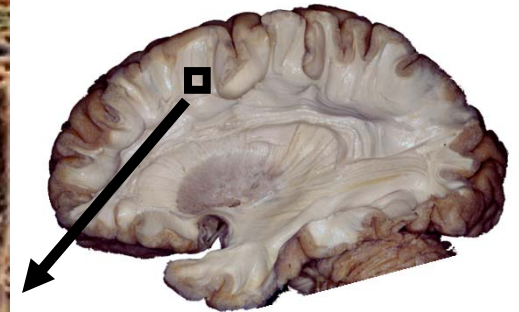
5 μm

Longitudinal Diffusivity ($\mu\text{m}^2/\text{ms}$)



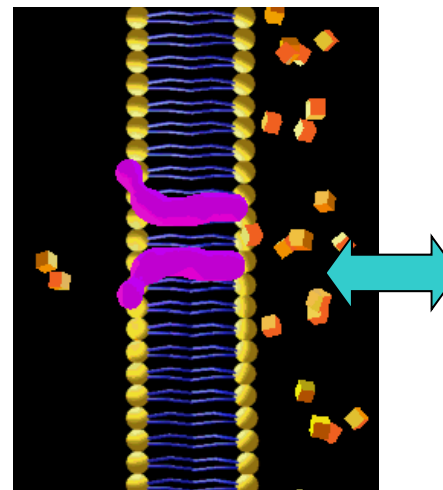
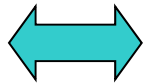
Diffusion probes brain microscopic structure

Bi-lipid cell membranes limit diffusion. Hence, perpendicular to axons the ADC is small



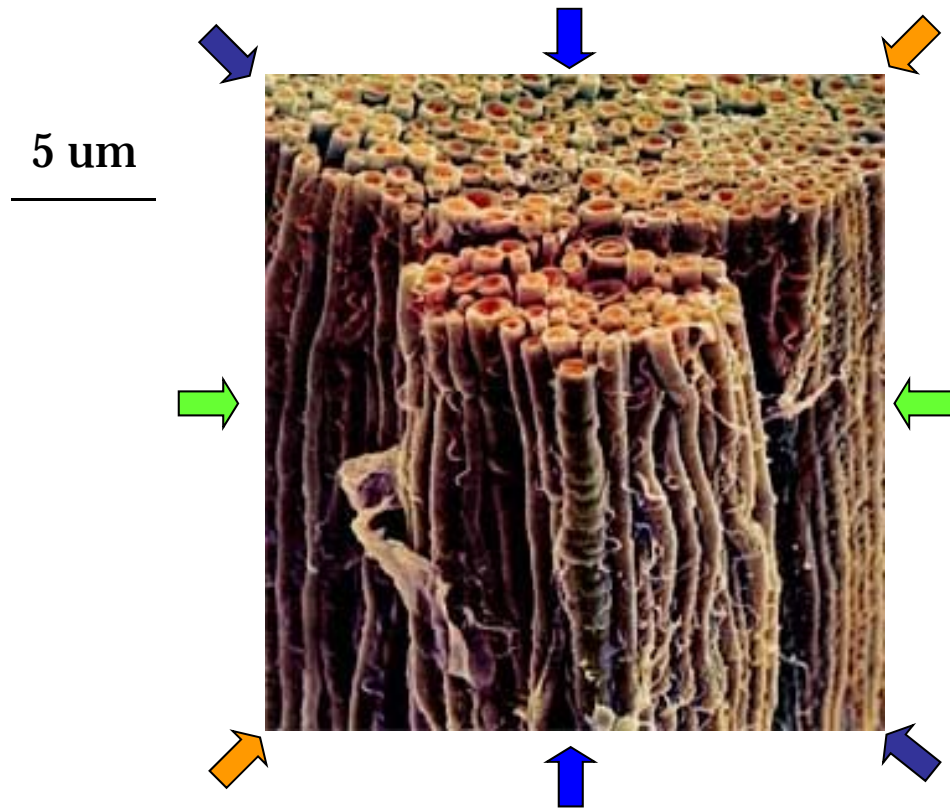
5 μm

Radial Diffusivity ($\mu\text{m}^2/\text{ms}$)



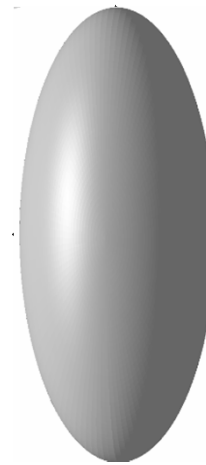
Diffusion Tensor Imaging (DTI)

A summary of the ADC at low b-values



$$1 = v' Q^{-1} v,$$

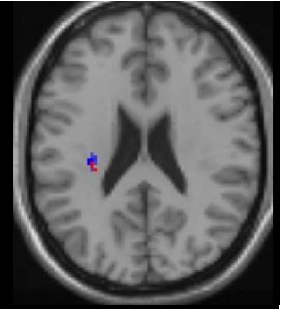
v is a 3d-vector



The **mean** distance a typical water molecule will diffuse in a unit of time

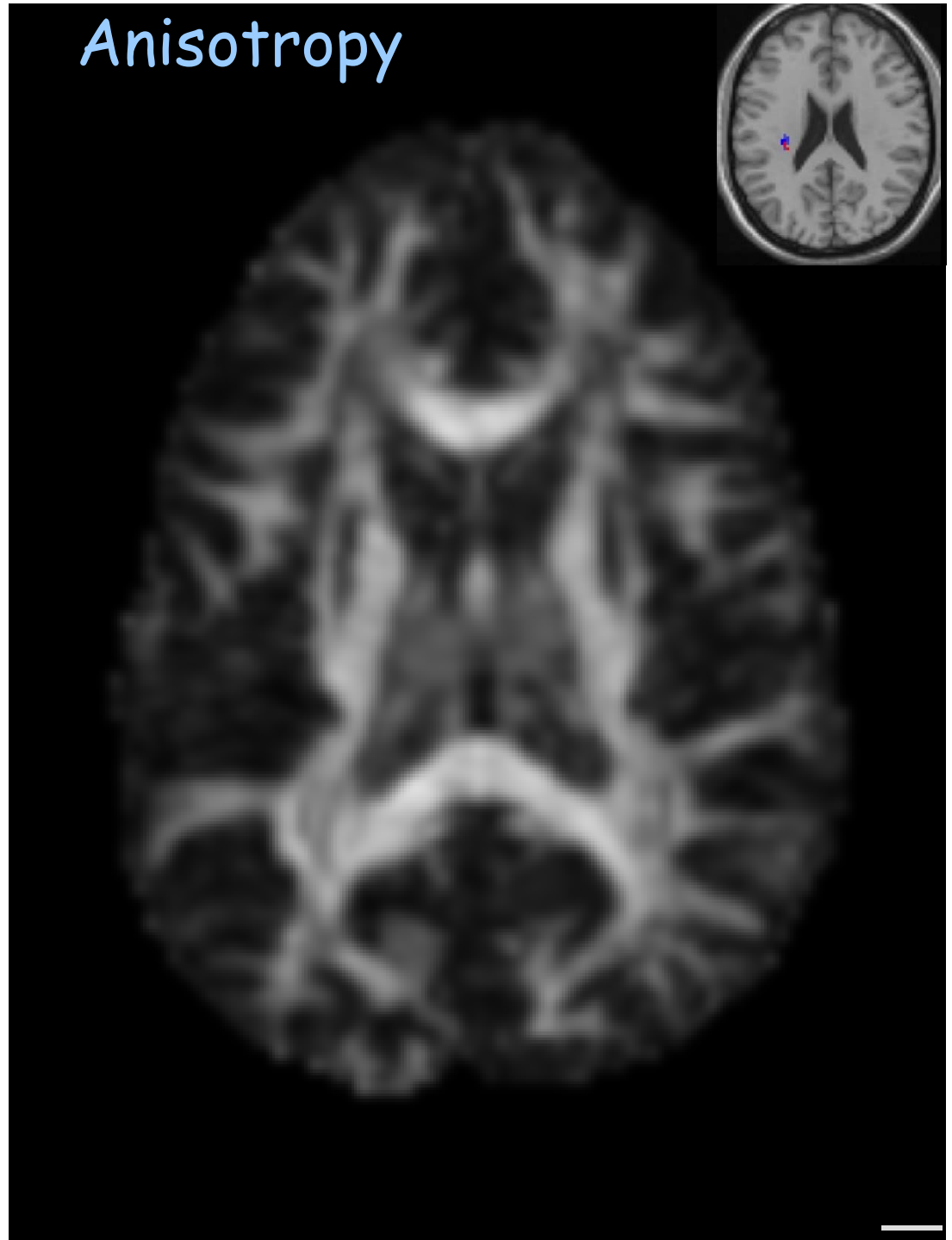
$$A = u' Q u$$

Anisotropy



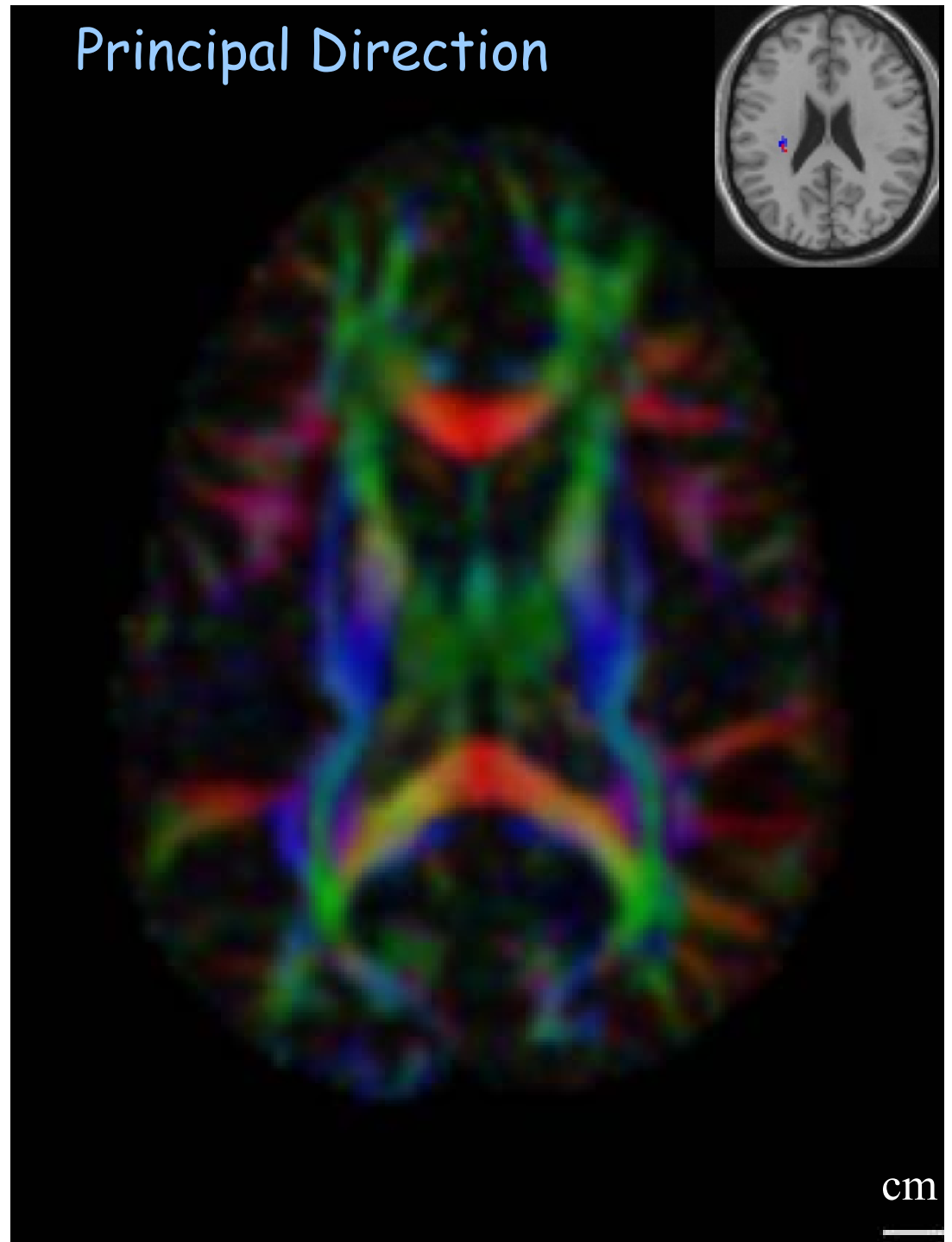
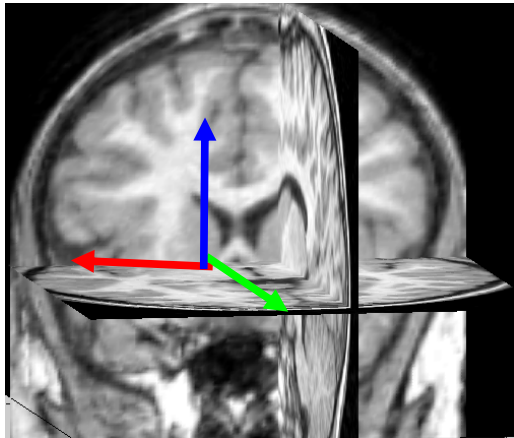
DTI summary measures
of white matter
microstructure

Fractional anisotropy



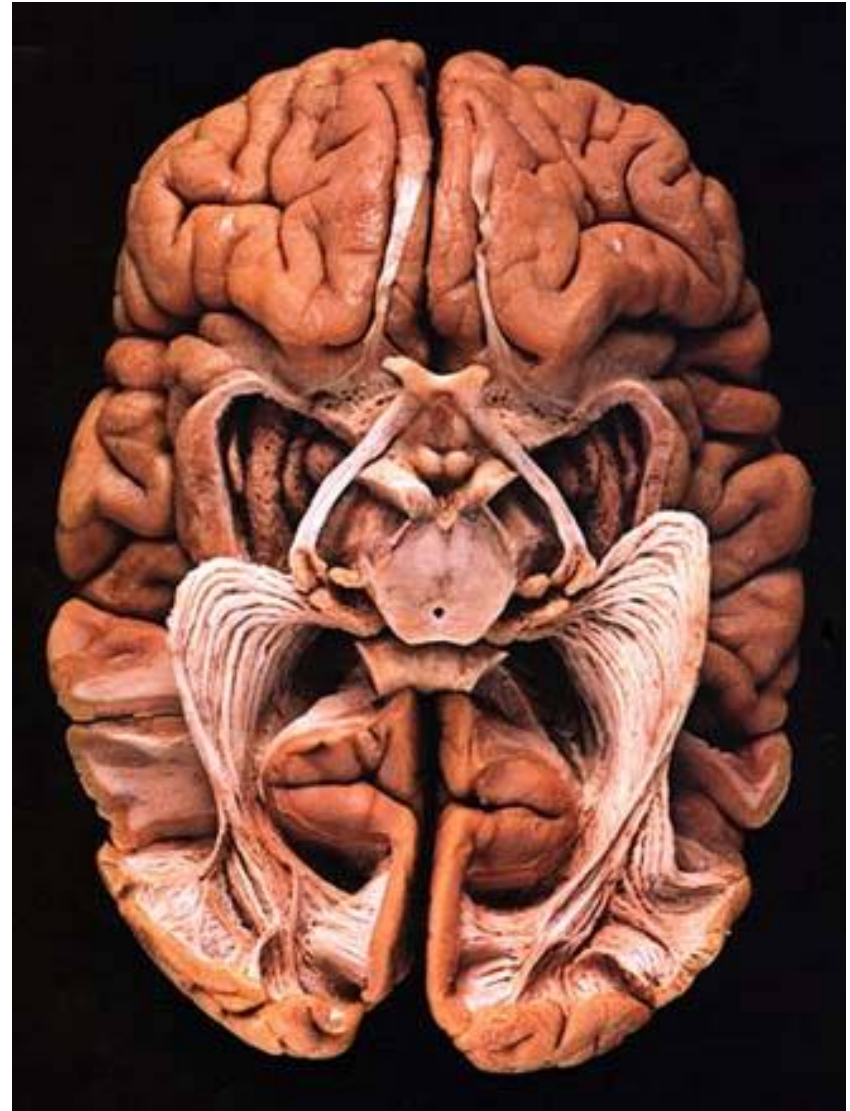
DTI summary measures of white matter microstructure

Principal diffusion direction



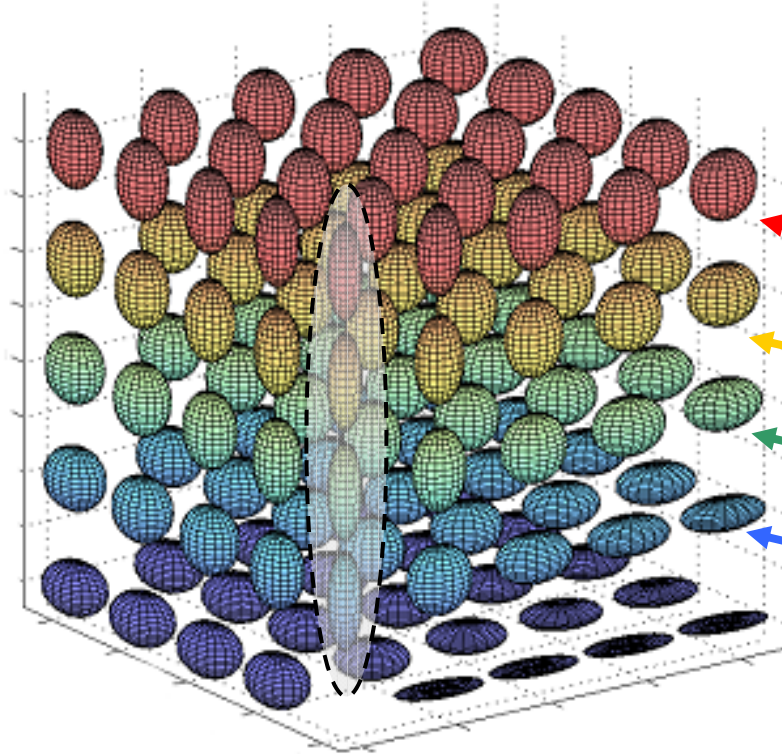
Tractography

- Assembling the local (voxel) measurements to estimate white matter tracts



Tractography: Integrates the local diffusion data to an estimate of long-range tracts

DTI data are surfaces



Conventional MR volumes are real-valued

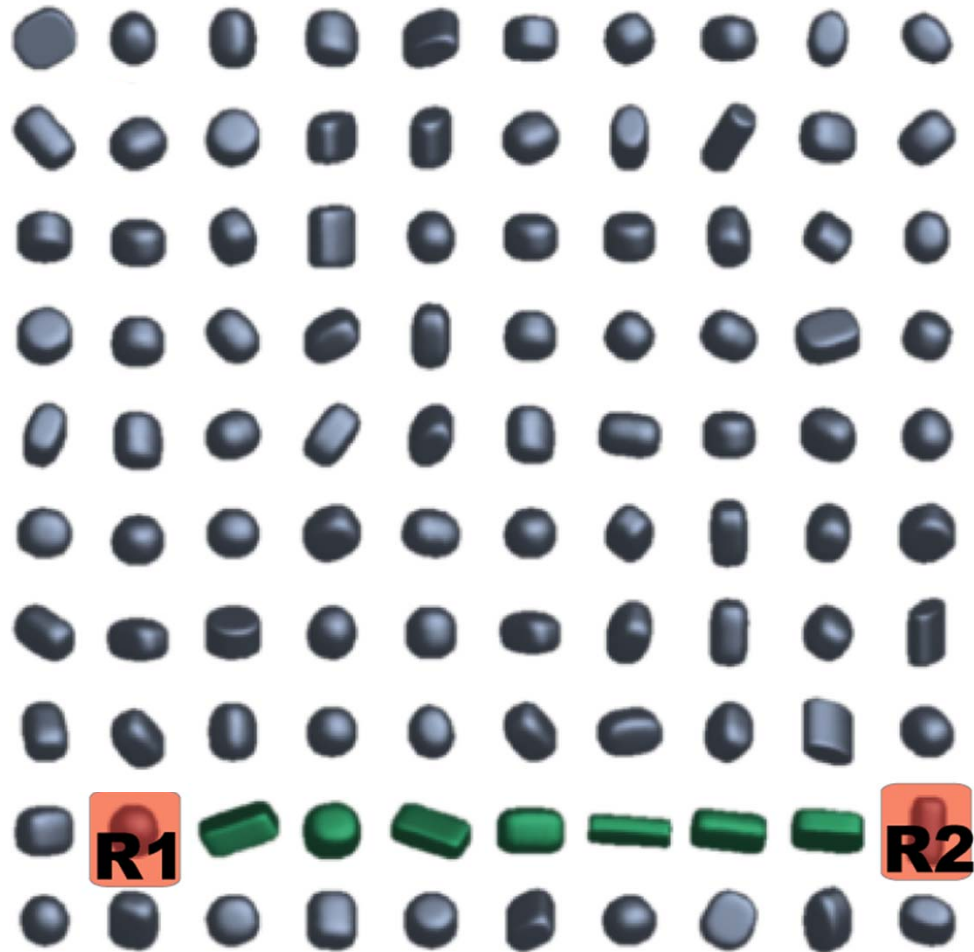


Tractography desiderata

Separate scoring and inference

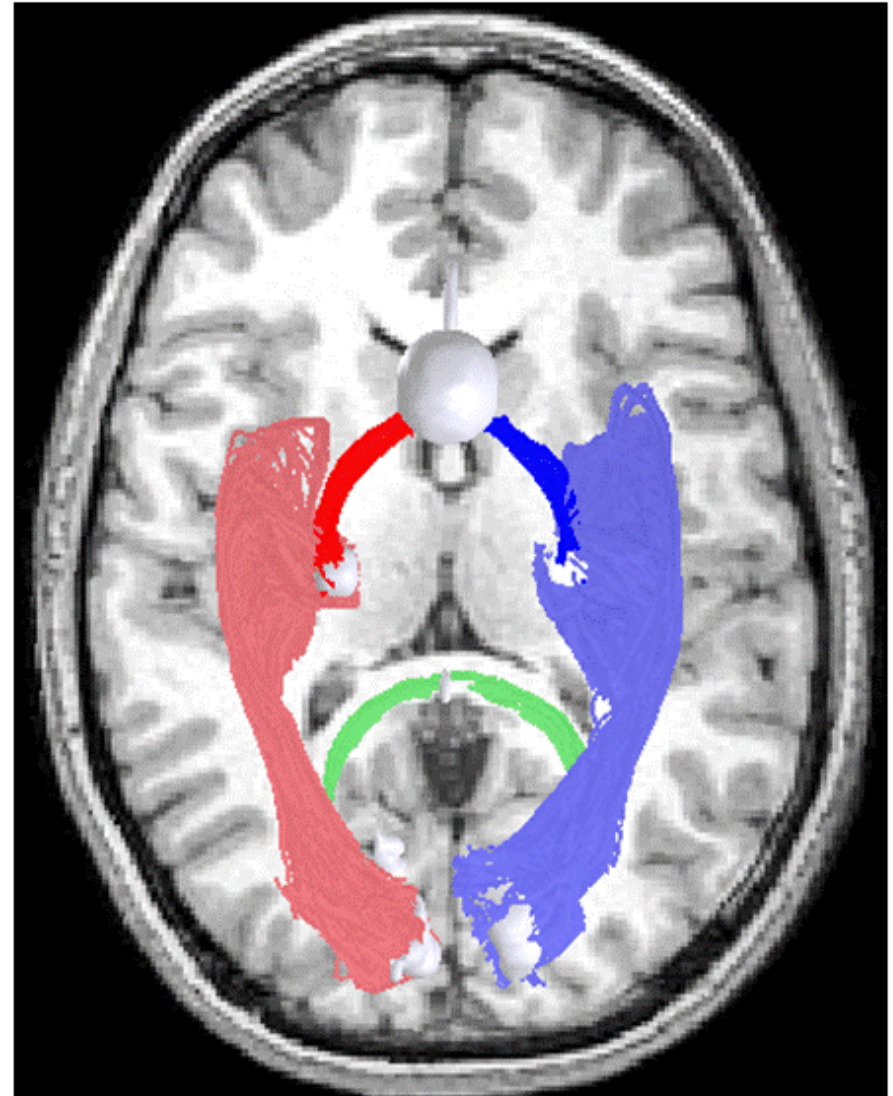
(Sherbondy et al., 2008)

- Symmetry
- Independence



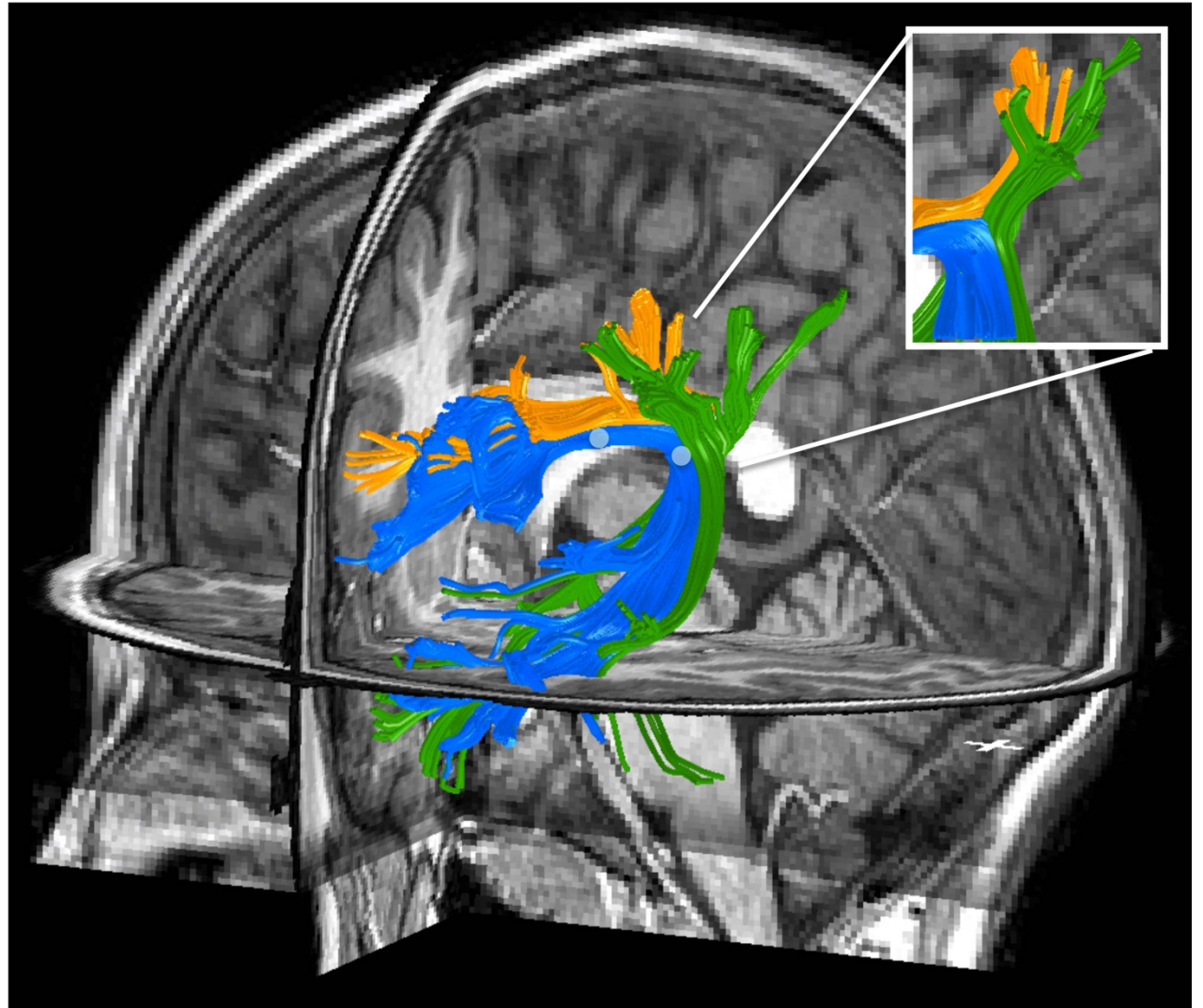
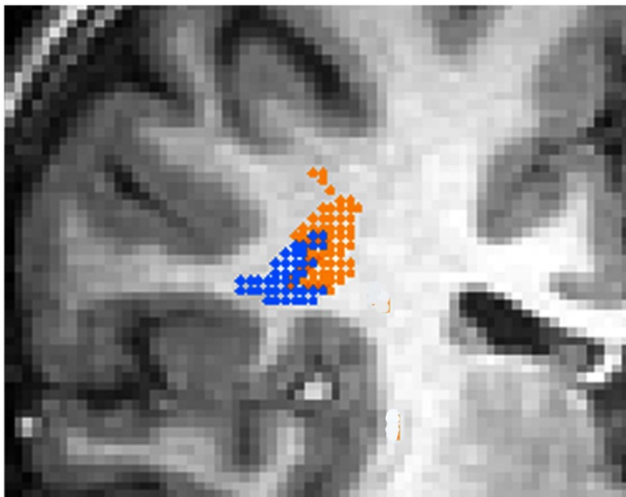
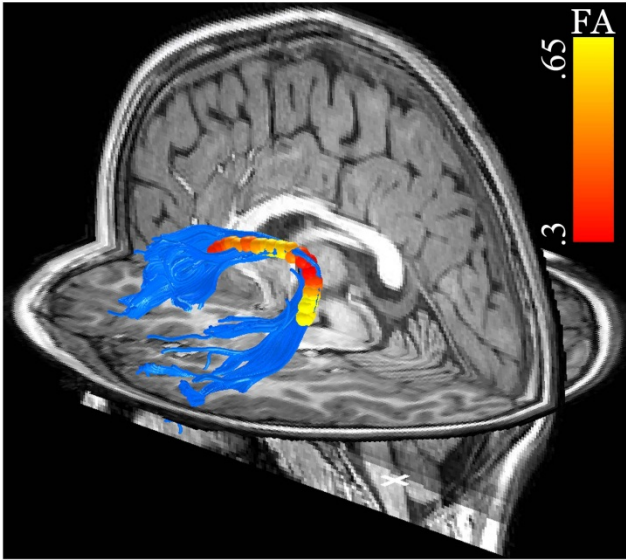
Major visual white matter tracts

(Sherbondy et al., 2008; N. Levin. et al.. Neuron. 2010)

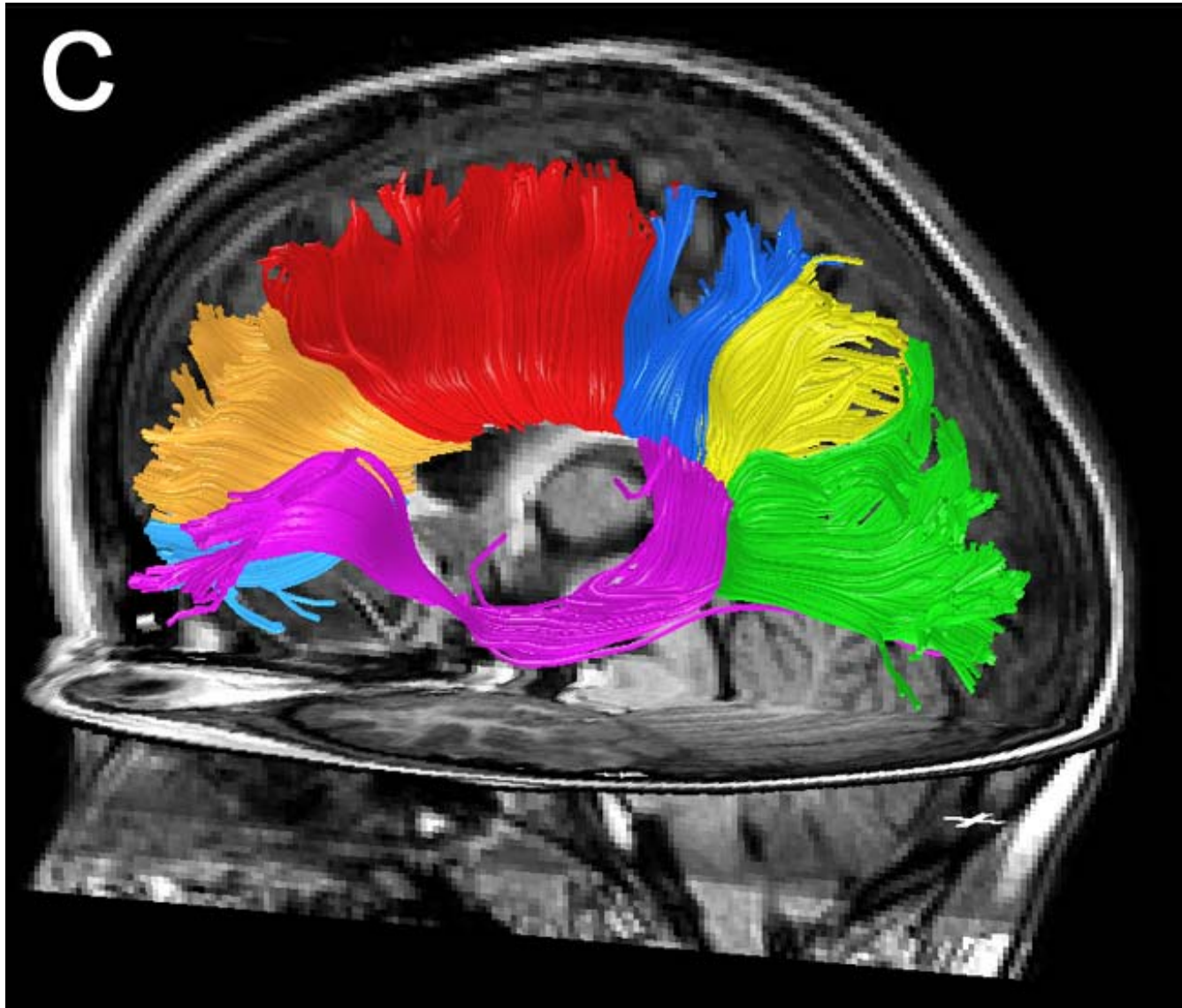


Reading related tracts

(Yeatman et al., 2011)

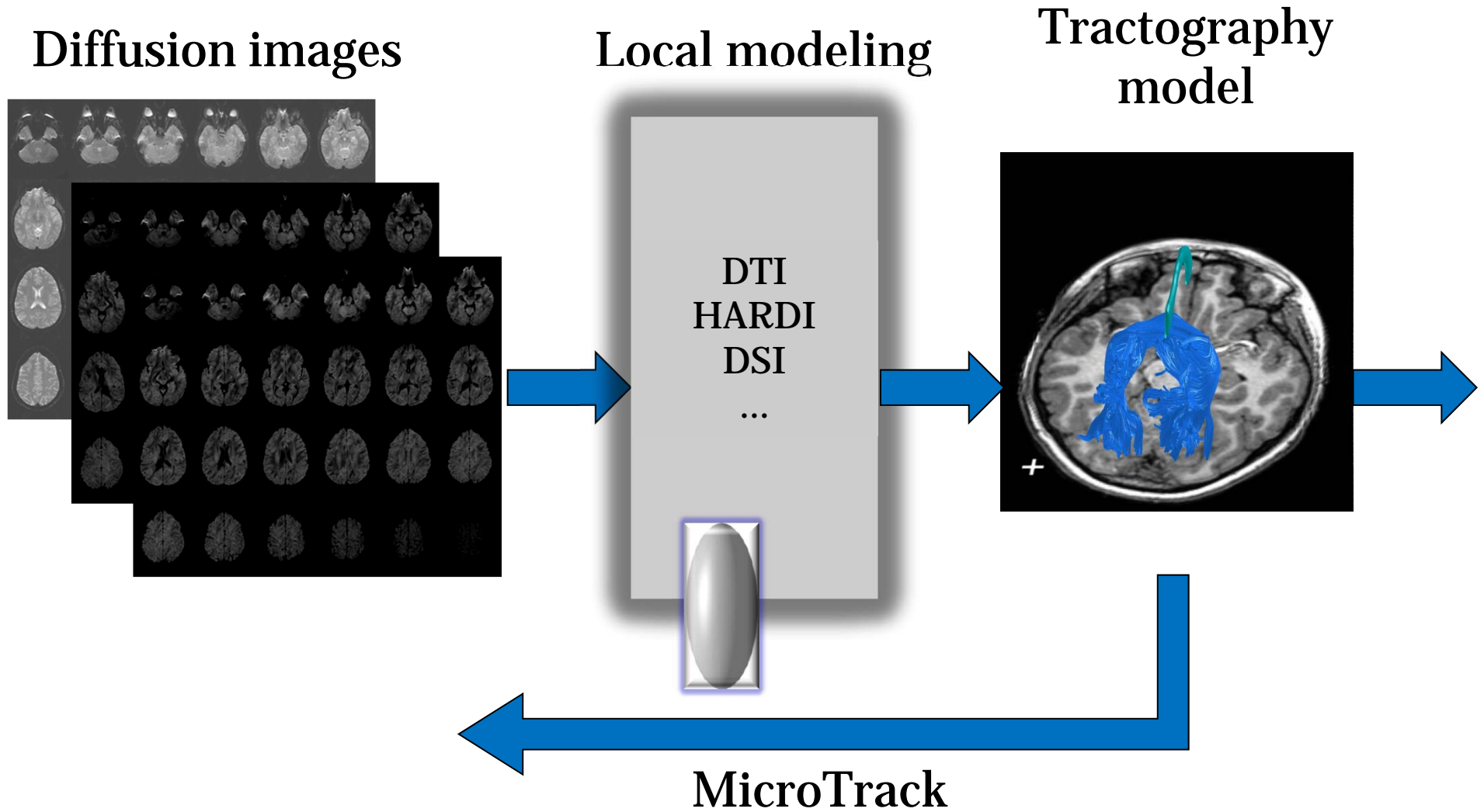


Inter-hemispheric tracts



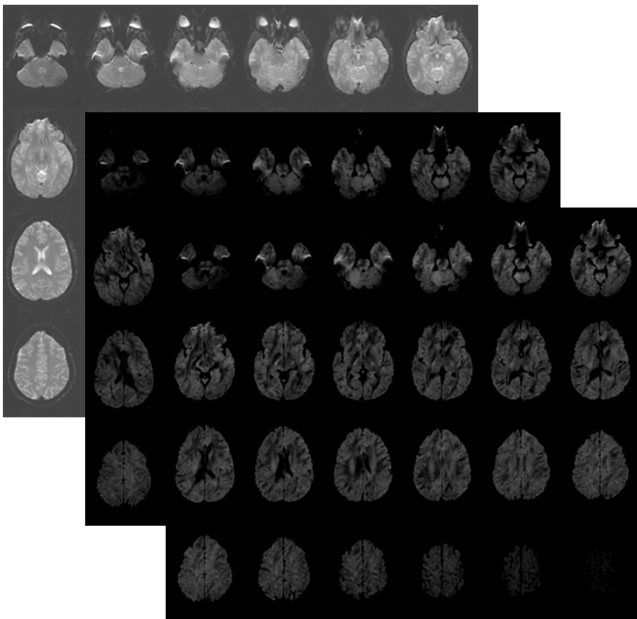
What's next: Evaluate the tracts

MicroTrack: Closing the loop



MicroTrack: Hypothesis testing

Diffusion images

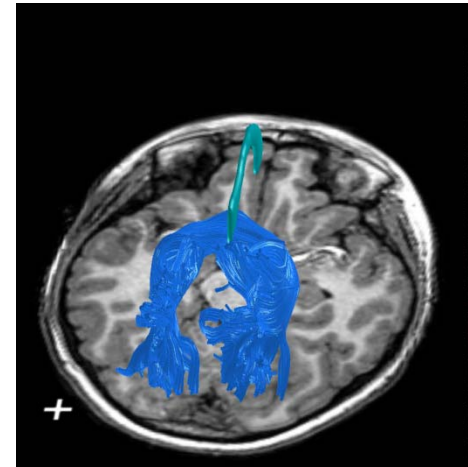


- Volume regularization
- Diffusion predictions

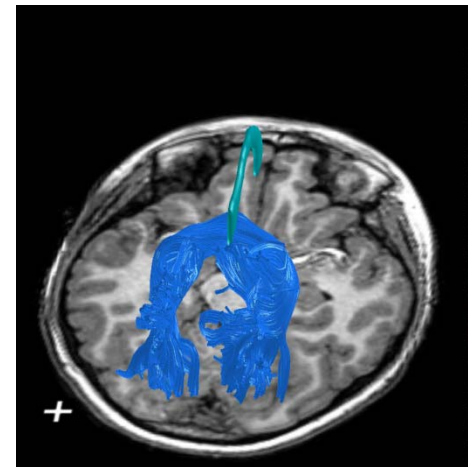


MicroTrack

Fascicles A



Fascicles B

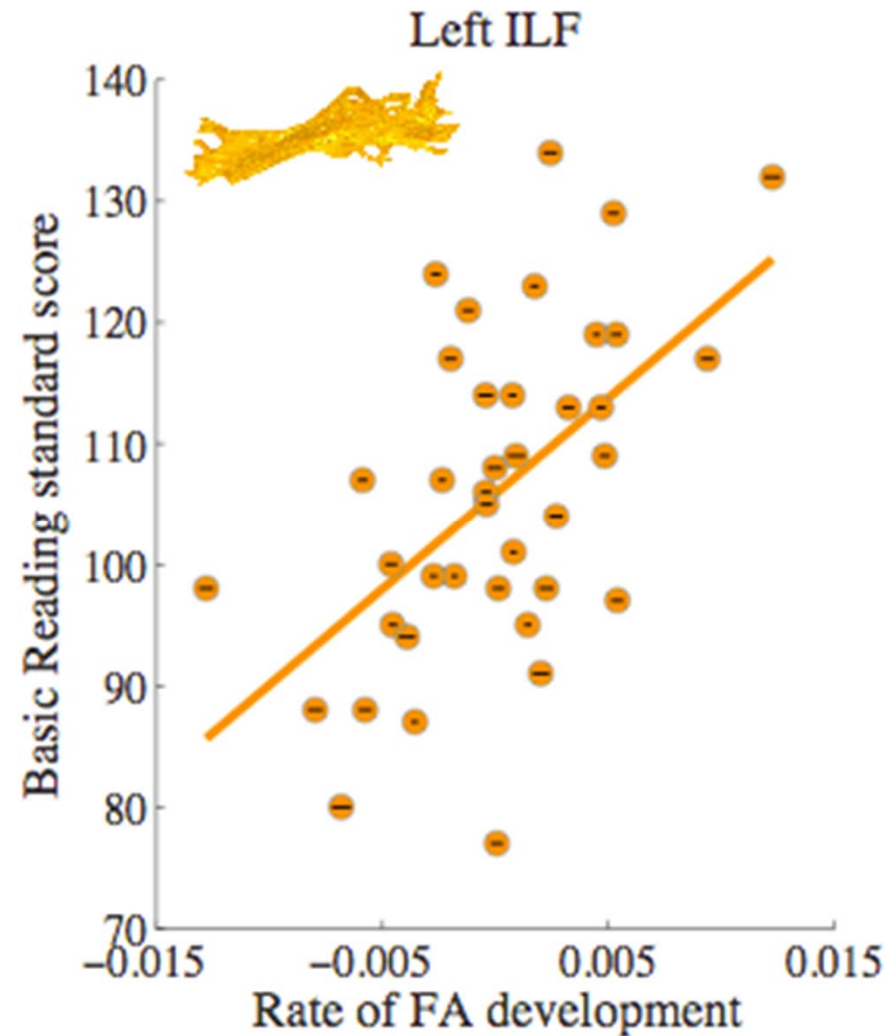


Applications of tractography
Reading development

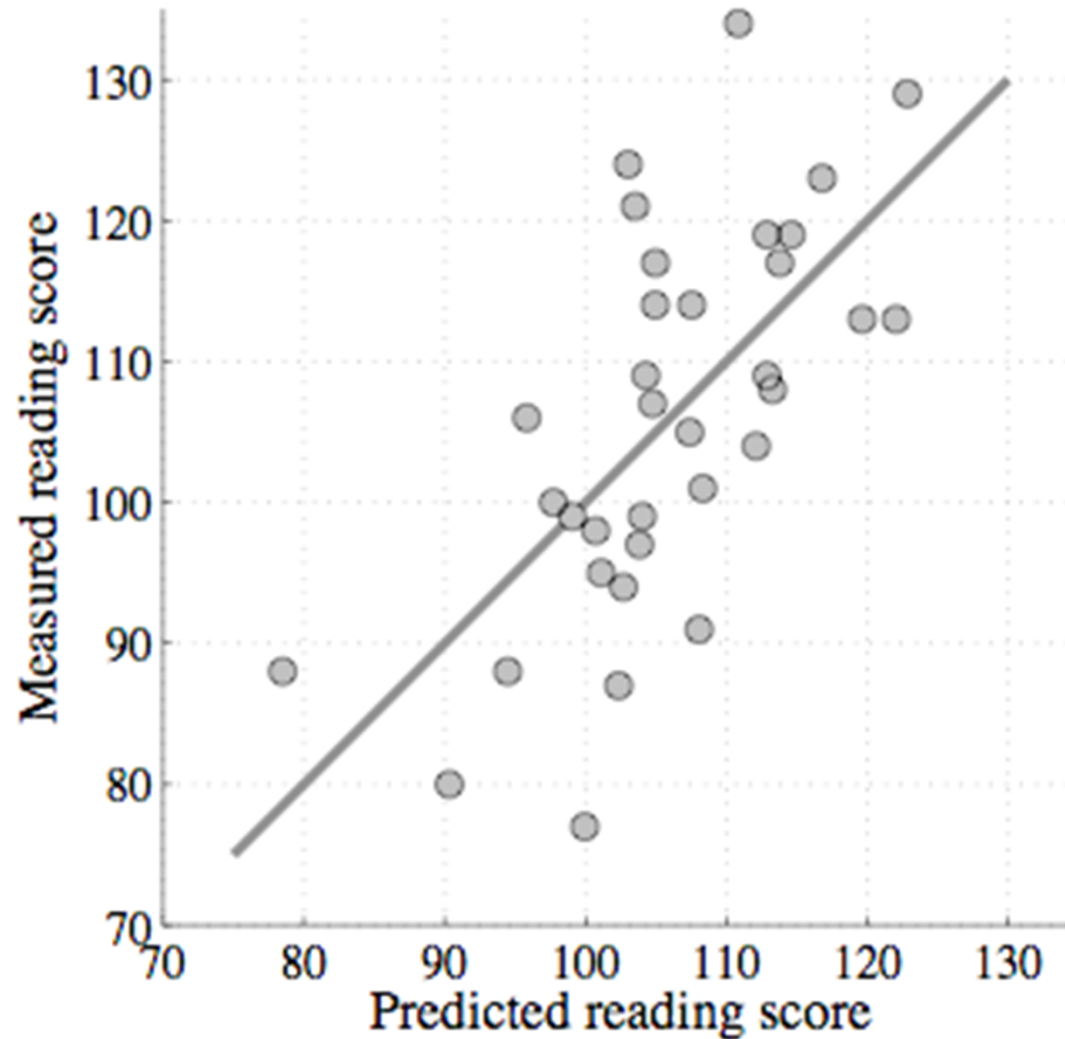
Strong associations between white matter tract FA and reading

(Yeatman et al., 2011)

This is one of several examples



Predicting reading scores from white matter maturity

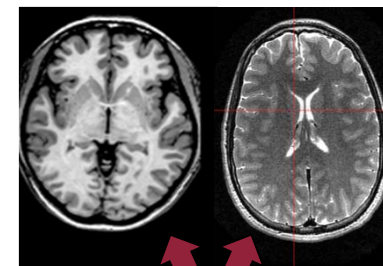
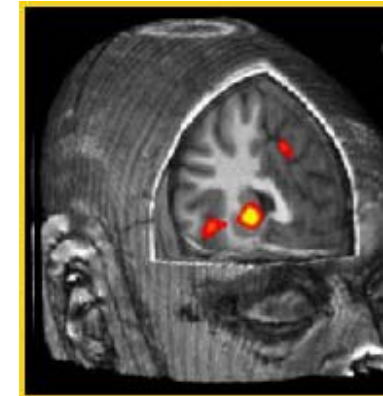
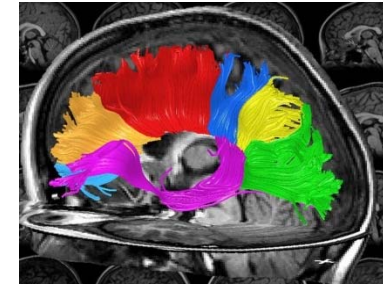




Mission

Discoveries about the brain have implications for fields ranging from Business, Law, Psychology, and Education.

The Stanford Center for Cognitive and Neurobiological Imaging (CNI) supports scientific investigations into the human brain that make rigorous connections between neuroscience and society.





Neuro-law applications

- Predict neurological disease – Alzheimer, schizophrenia
- Brain-reading (e.g., lie detection)
- Sentencing (juvenile cases)
- End-of-life (e.g., vegetative state)
- Brain interventions for offenders (addiction, sex-offenders)
- Neuroenhancement – witnesses and memory pills for examinations



Education and Neuroscience

brain Connection™

No Child Left Behind: Learn how this works scientifically.

BC Home Education Connection Library Brain Teasers Market Place

Thu, 06/24/2010

BrainConnection.com is a Web resource from [Positive Psychology Science](#).

Subscribe to the monthly "Brain Fitness News," the latest news about the brain.

EDUCATION CONNECTION

LIBRARY

Choose Topic

- Bilingual Education
- Child Development
- Disorders
- Early Reading

TALK

- Blog
- Columnists
- Interviews
- Your Voices
- Conference Presenters

EXPLORE

- Brain Basics
- Image Gallery
- Brain Facts

EDUCATION CONNECTION
Applying Brain Science to Teaching and Learning

Issues in Education

Reference Article **A Fresh Look at Brain-Based Education**

It has been more than 20 years since it was first suggested that there could be connections between brain function and educational practice. In the face of all the evidence that has now accumulated to support this notion, Mr. Jensen advocates that educators take full advantage of the relevant knowledge from a variety of scientific disciplines. [Find out more...](#)

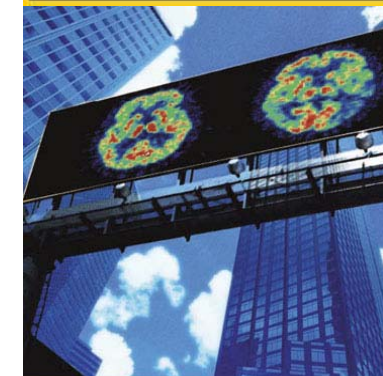
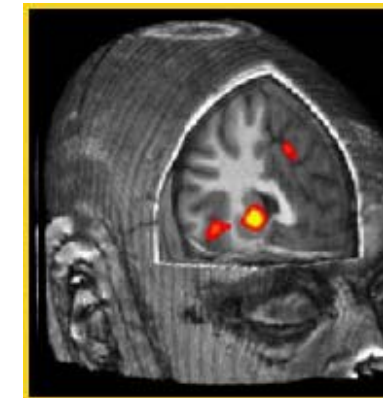
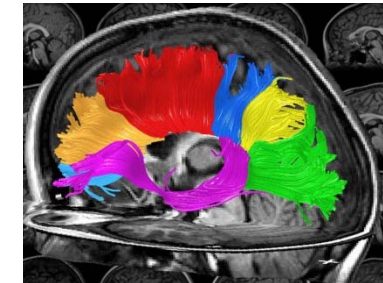
See more [Education Topics...](#)

The Learning Brain

Can Music Education Really Enhance Brain Functioning and Academic Learning?

Should the studies exploring the relation between music and the brain determine the school curriculum? Read both sides of the argument. [Find out more...](#)

See more articles on [The Learning Brain...](#)





Business decision-making (Marketing)

MICHIGAN
ROSS SCHOOL OF BUSINESS

leading in thought
and action

Summer Workshop on Decision Neuroscience

Home
Conference Schedule
Sponsors
Participants
Presenters
Travel & Accommodations
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Home
How Neuroscience Can Inform Behavioral Decision Making Research: Overview, Methods and Applications

****PLEASE NOTE:** While we appreciate your interest, applications are no longer being accepted for this workshop!
We're including the information below for the benefit of our current roster of registered participants.

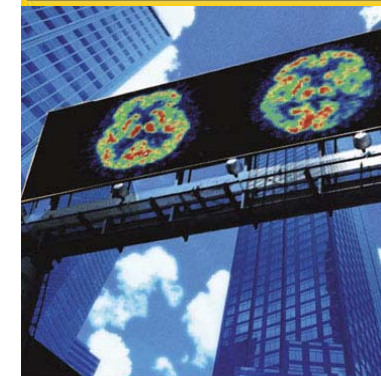
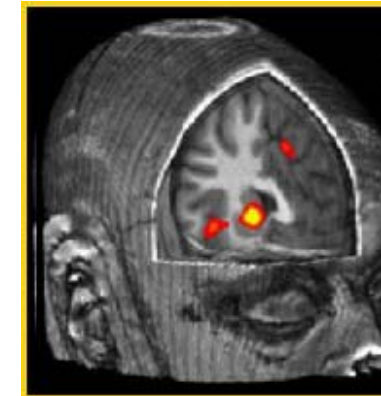
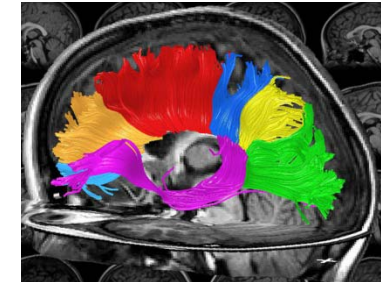
Workshop Participants:
Refer to this site's Conference Schedule tab for recommended readings you can start on now.

Jointly hosted by INSEAD and the Ross School of Business, University of Michigan

Where: Ross School of Business
When: August 21-23, 2009
Organizers: [James Bettman](#), Duke University
[Joseph Kable](#), University of Pennsylvania
[Hilke Plassmann](#), INSEAD
[Carolyn Yoon](#), University of Michigan

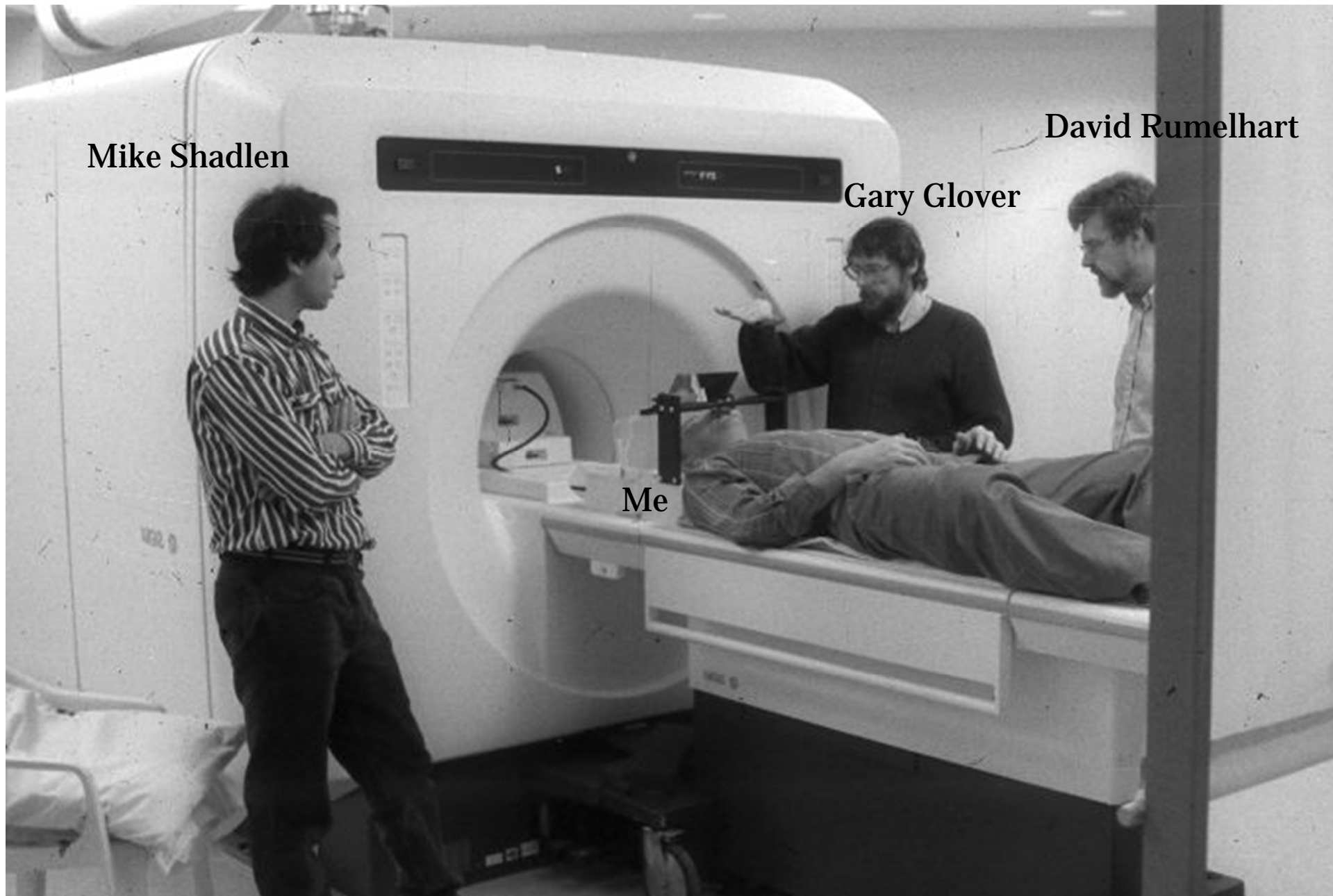
Goals:
The workshop aims to bring together researchers and graduate students from neuroscience, behavioral decision making and marketing to provide:

- methodological training for students



Acknowledgements

1991



Mike Shadlen

David Rumelhart

Gary Glover

Me



Alex Wade

Alyssa Brewer

Yoichiro Masuda

Kaoru Amano

Jon Winawer

Joyce Farrell

Hiroshi Horiguchi



Tony Sherbondy





**Robert
Dougherty**

**Serge
Dumoulin**

**Andreas
Rauschecker**

**Michal
Ben-Shachar**

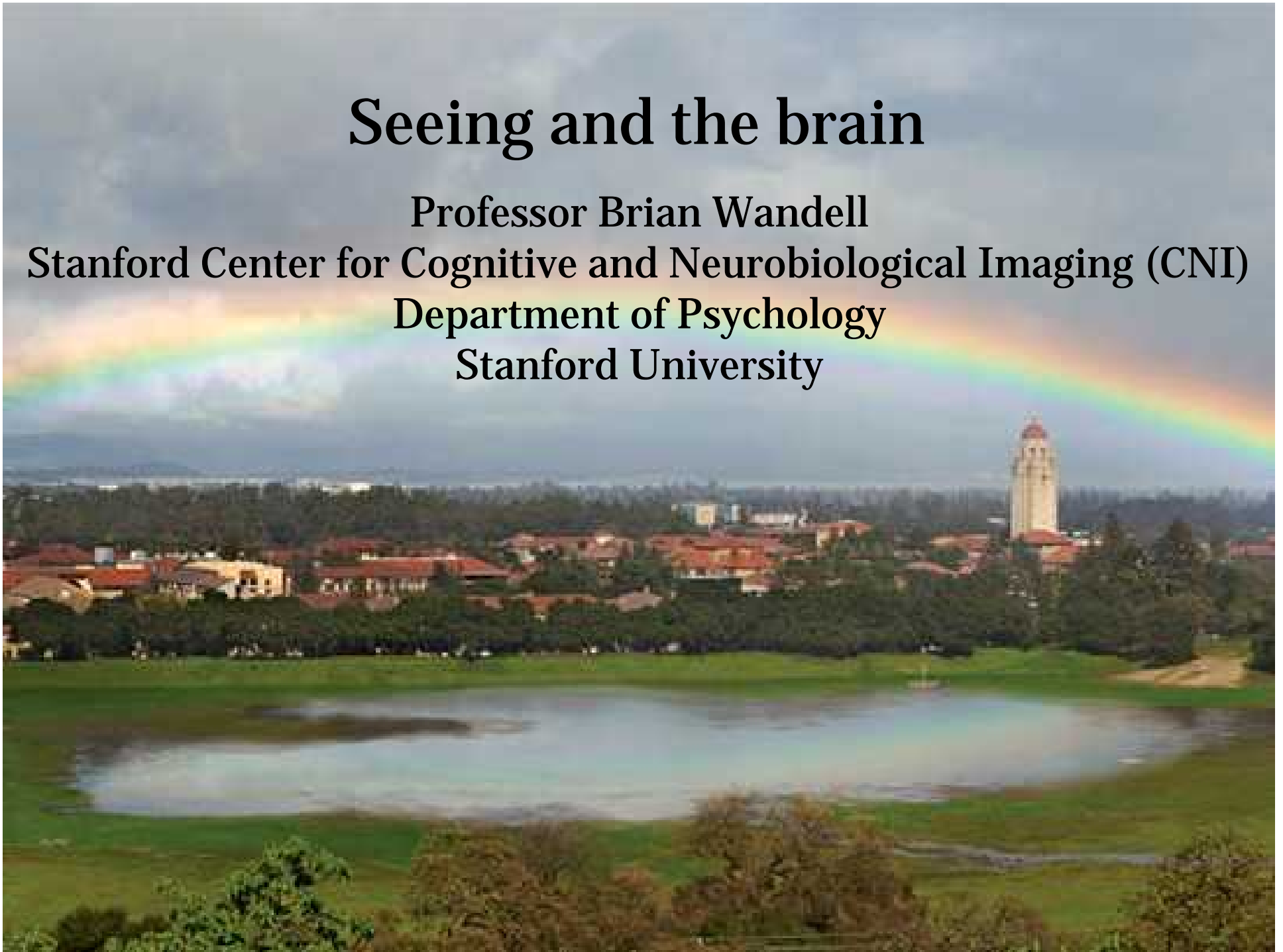
Seeing and the brain

Professor Brian Wandell

Stanford Center for Cognitive and Neurobiological Imaging (CNI)

Department of Psychology

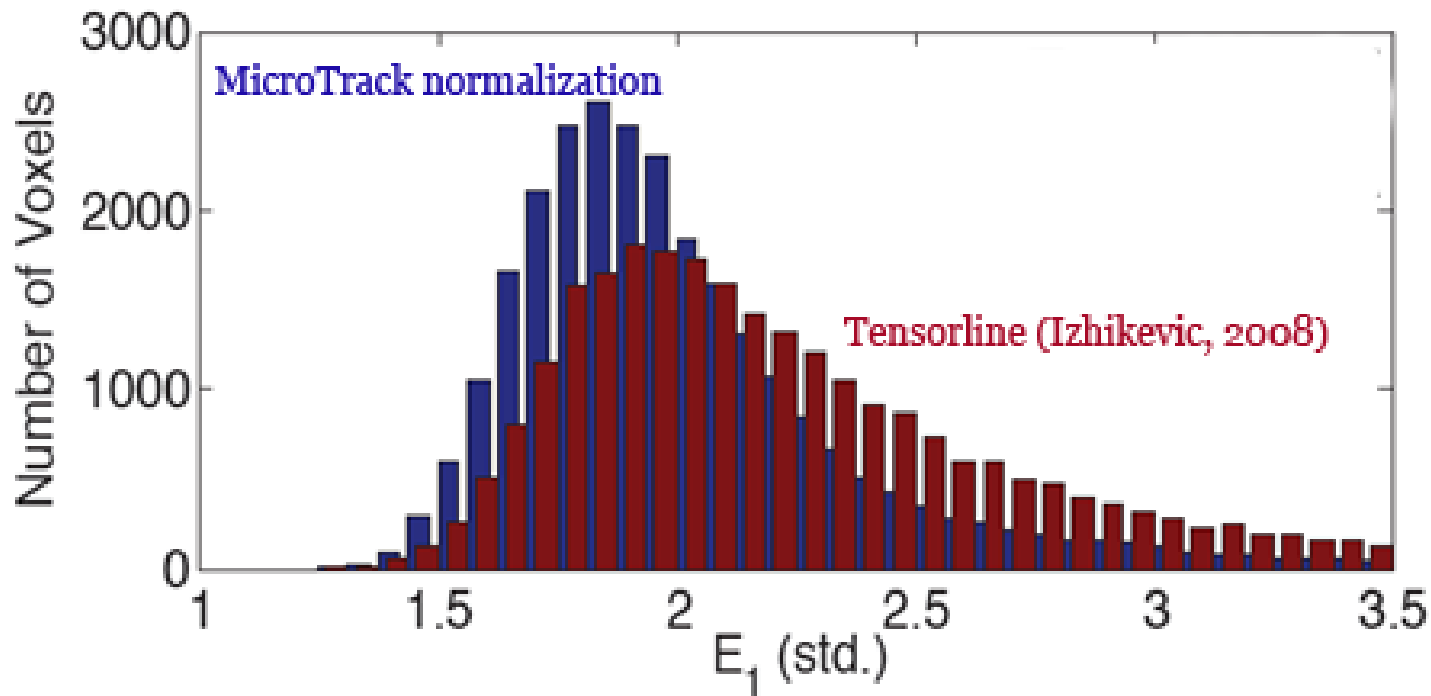
Stanford University



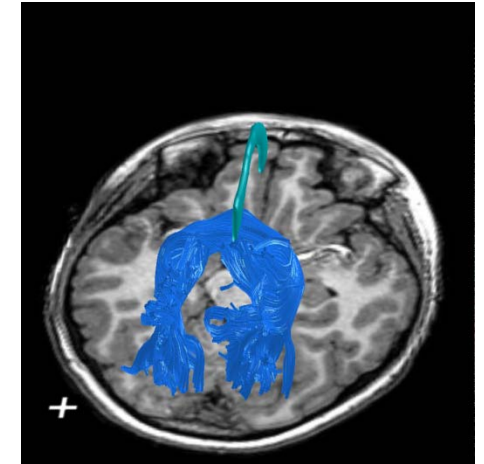
End

MicroTrack: Error measures

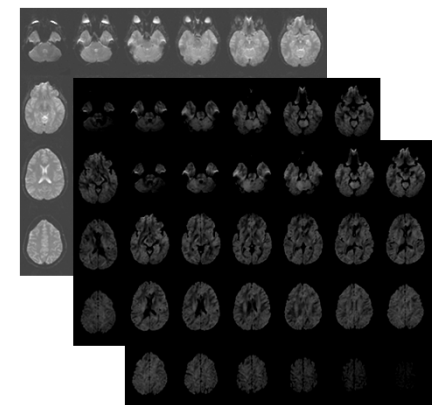
Diffusion prediction error



Tractography
model

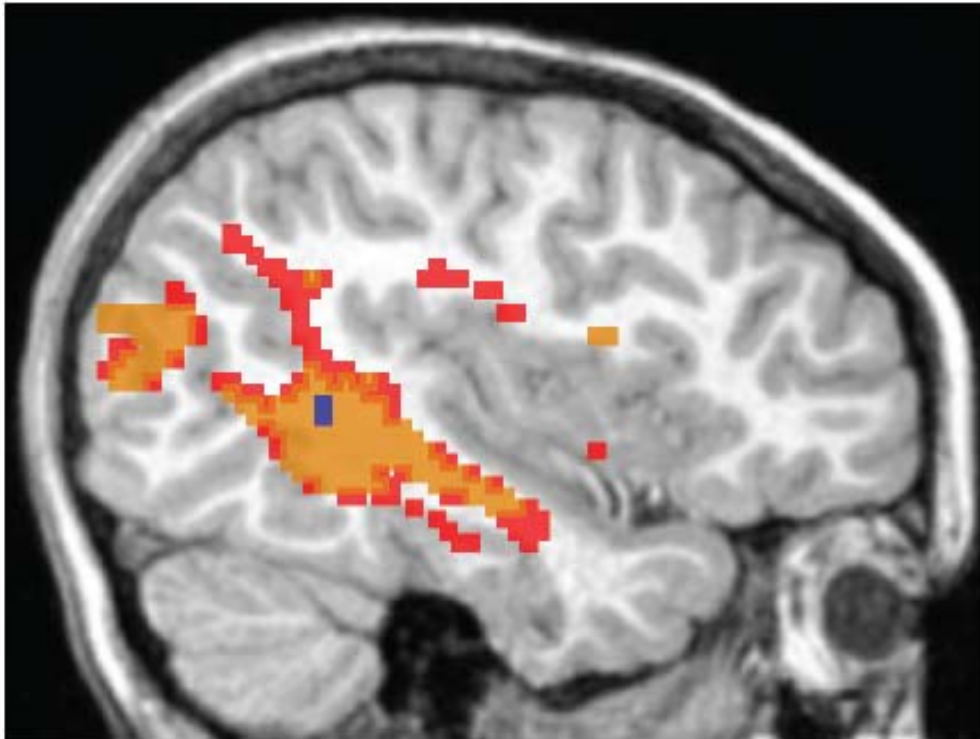


Target data



MicroTrack: Error measures

Volume



Tensorline

After
normalization

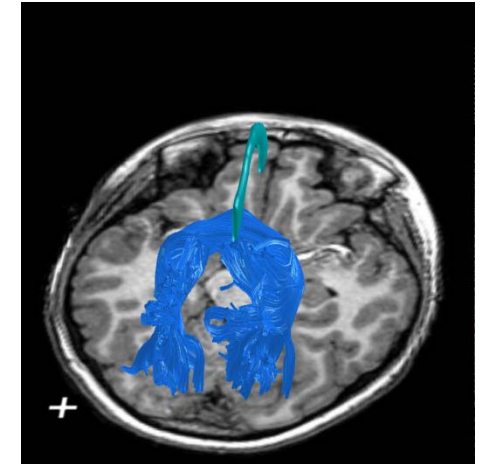
Overfill

2x

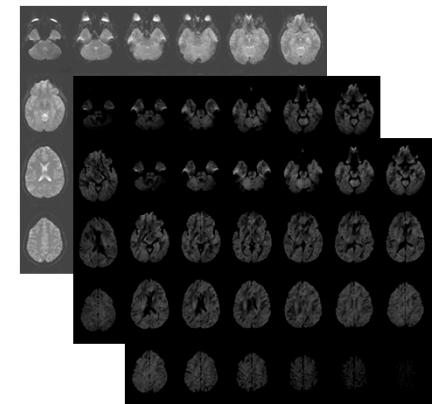
3x

2x

Tractography model



Target data



Tractography and diffusion papers

<http://vistalab.stanford.edu/~brian/refs.html>

- **Contrack and Microtrack**

Sherbondy, ConTrack, JOV (2008)

Sherbondy, Optic radiation, JOV (2009)

Sherbondy et al. MICCAI (2009, 2010)

- **Statistical analysis of tensors**

Schwartzmann et al. , Tensor statistics, (2006, 2009)

Masuda et al. (Cerebral Cortex, IOVS) (2008, 2010)

- **Diffusion, tractography, reading**

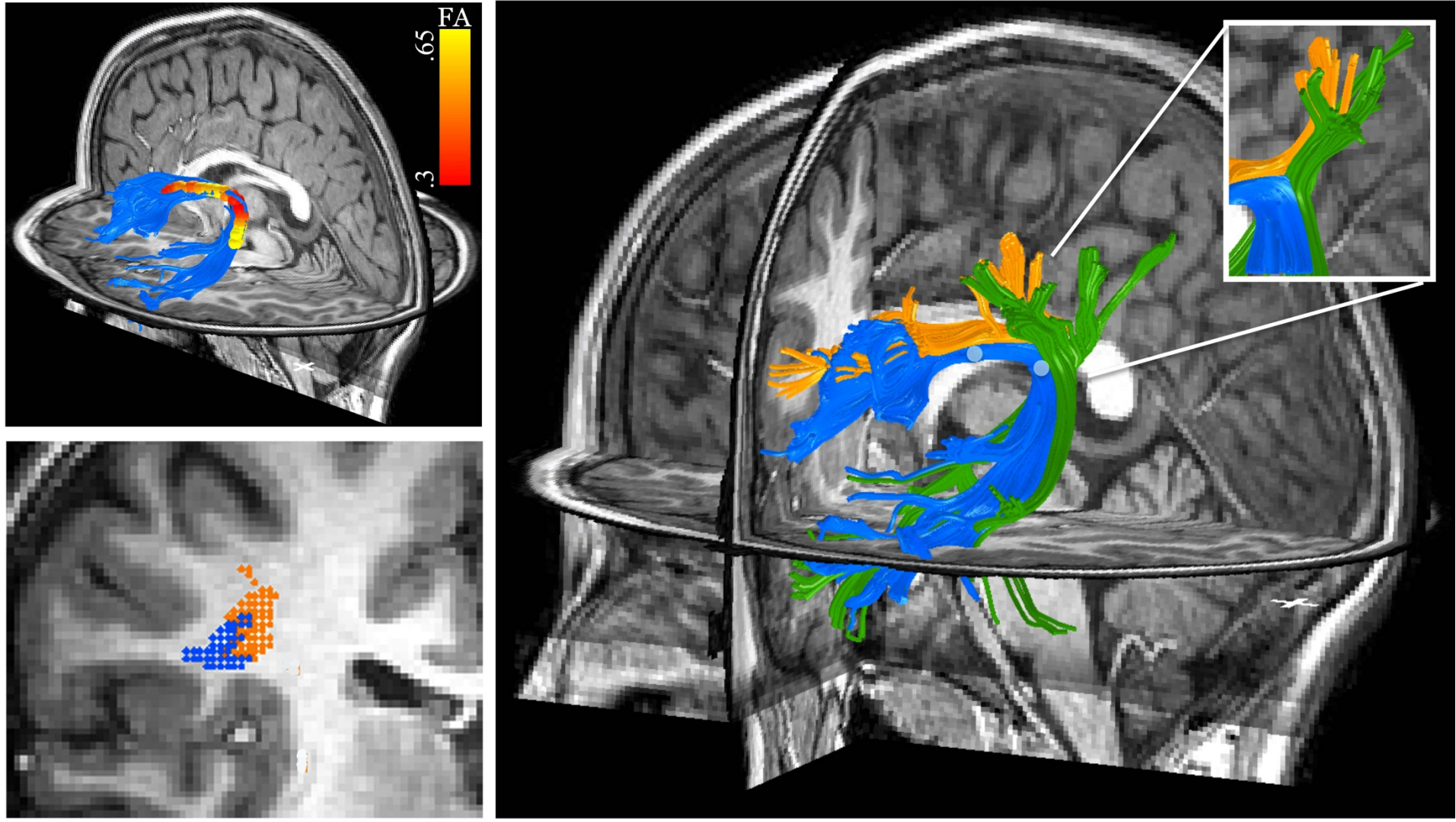
Dougherty et al. (2005, 2007)

Tsang et al., Arithmetic processing, PNAS (2010)

Ben-Shachar, BOLD, VWFA, MT+ and reading (2007, 2008, 2009)

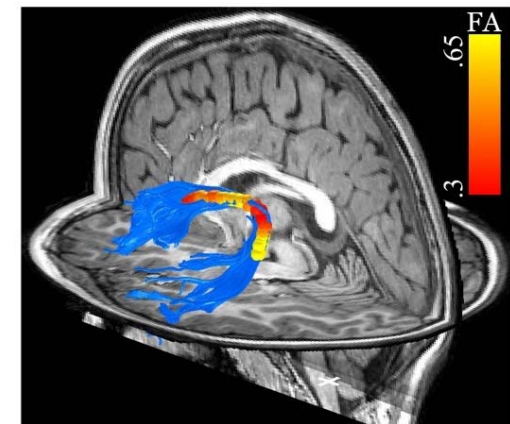
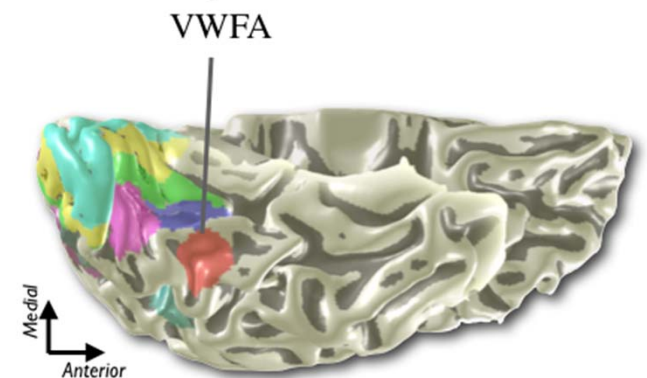
Deutsch et al. Diffusion and reading (2005)

Additional diffusion behavior correlations continue to arise



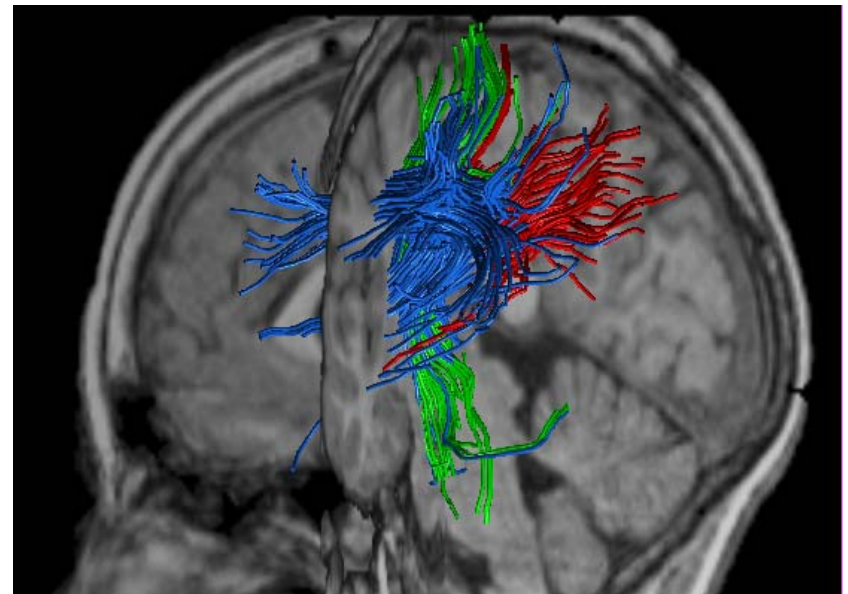
Summary

- Reading requires quickly and accurately identifying forms (seeing words)
- The cortex learns to do this using the VWFA, a region located amidst a set of visual field maps
- The VWFA signals must be communicated to parts of cortex used in language and phonology
- White matter development (arcuate, ILF) is part of reading development



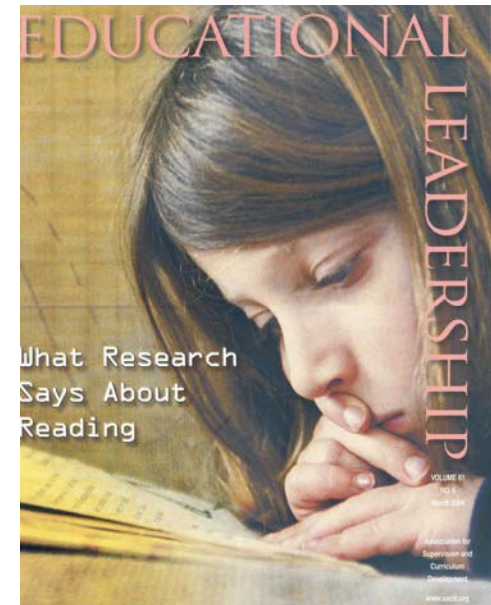
Specific Reading Pathways

- Brain definitions and background
- Magnocellular hypothesis (MT)
- Temporo-parietal junction, dyslexia
- OTS
- Diffusion Tensor Imaging



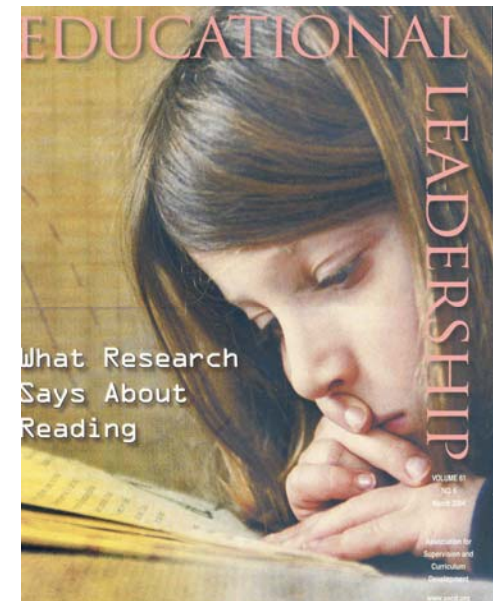
Neuroscience for Society

- Pain, Blindness, Deafness
(Medicine)
- Learning and reading disabilities
(Education)
- Depression, memory loss
(Psychiatry, Neurology)
- Intentionality
(Law, Business)



Neuroscience for Society

- What happens to cortical neurons that stop receiving their input?
 - Understanding which neurons change, which stay the same, when and why, is important for making decisions about inserting these visual prosthetics.
-
- Specialized brain are trained for seeing words and reading
 - Can neuroimaging identify early markers to understand when children are ready to learn to read, and how to intervene and help children with reading disabilities?



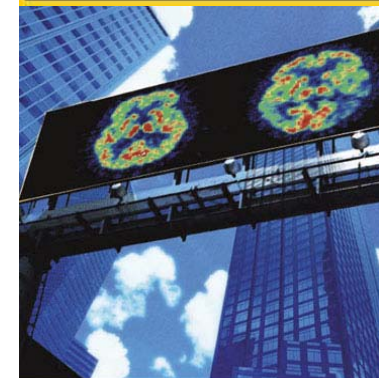
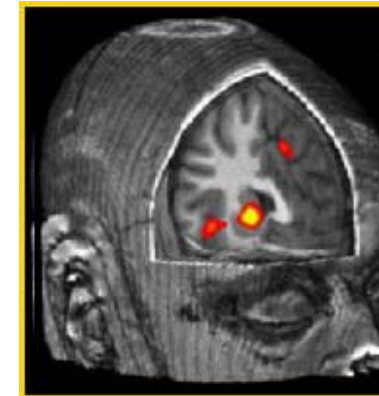
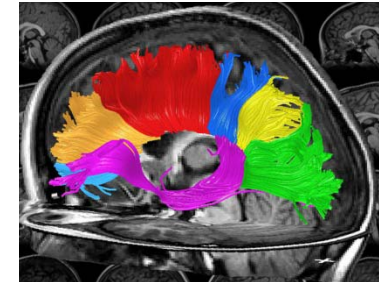


Understanding brain computations is transforming the human sciences

- **Education** - Reading
- **Law** - Lie-detection, memory
- **Business** - Decision-making
- **Mental health** - Depression

Integrating technology

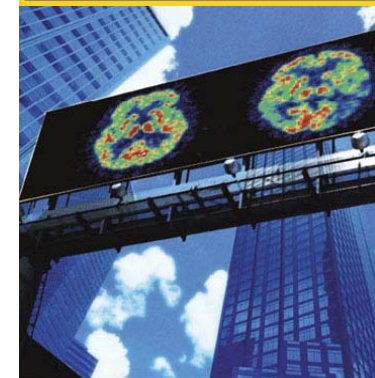
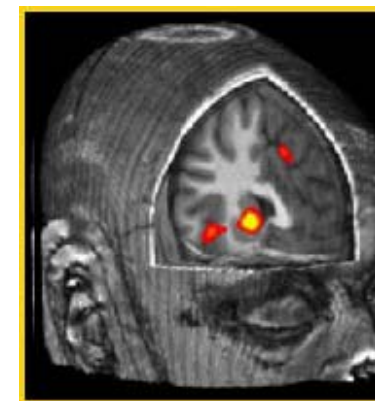
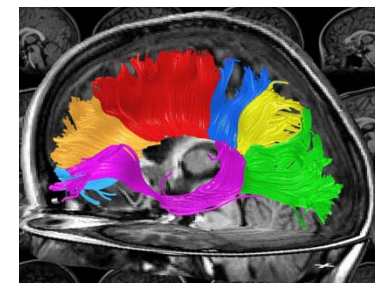
- **Engineering** - MR Methods, Databases, Statistics
- **Teaching** - Educated member of society and the brain



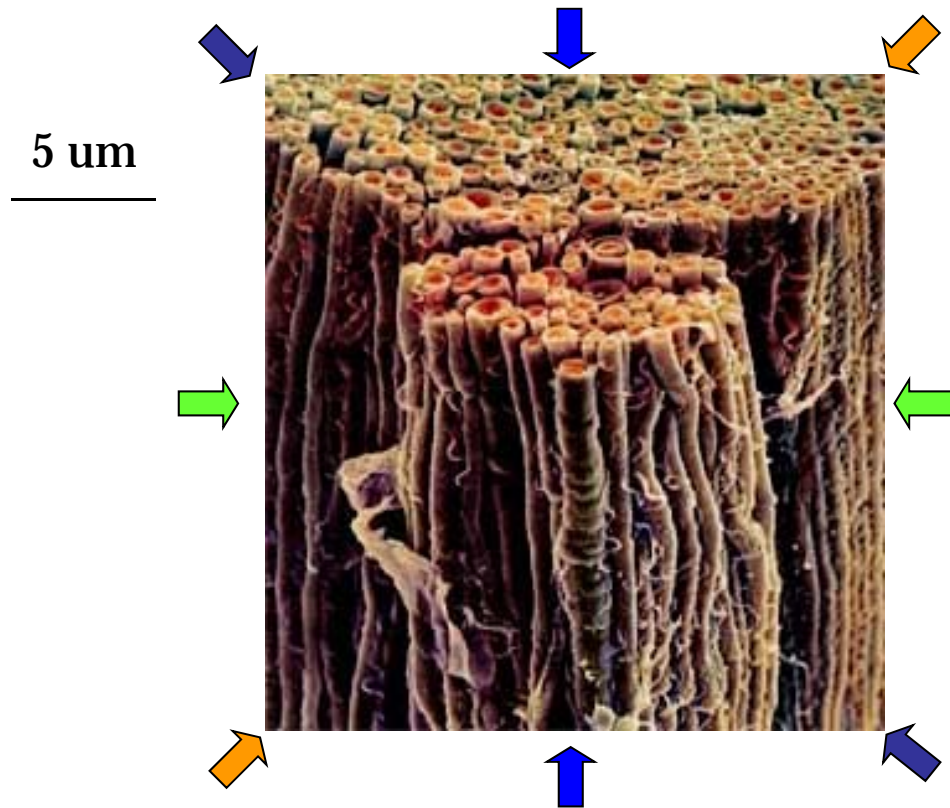


Scientific and Engineering MR model

- **Differs from medicine**
- **Methods**
 - Software, software, software
(10% at scanner, 90% in analysis)
 - Quantitative MR
 - Database focus on sharing, computing, not privacy
 - Visualization
- **Integration across modalities**
 - Coordination with animal models
 - Linking across length- and time-scales



Diffusion distance



$$1 = v'Q^{-1}v,$$

v is a 3d-vector



The **mean** distance that a typical water molecule will diffuse in a unit of time



Lie-Detection



Home	Product	Customers	Investors	Test Centers	Publications	About Us
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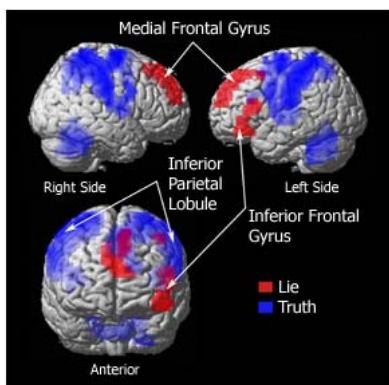
New Truth Verification Technology

No Lie MRI, Inc. provides unbiased methods for the detection of deception and other information stored in the brain.

The technology used by No Lie MRI represents the first and only direct measure of truth verification and lie detection in human history!

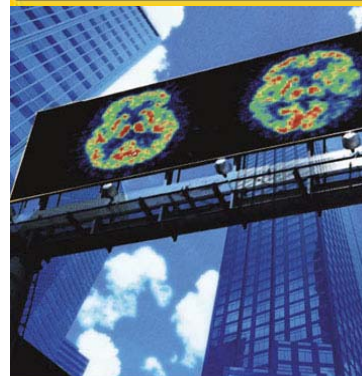
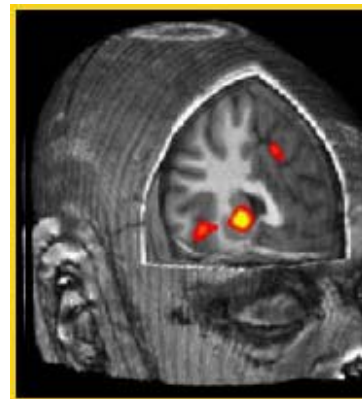
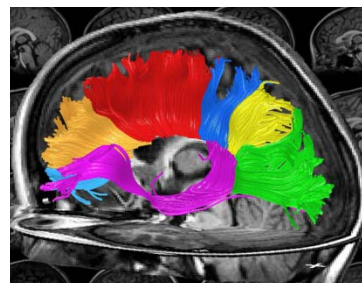
No Lie MRI uses techniques that:

- Bypass conscious cognitive processing
- Measure the activity of the central nervous system (brain and spinal cord) rather than the peripheral nervous system (as polygraph testing does).



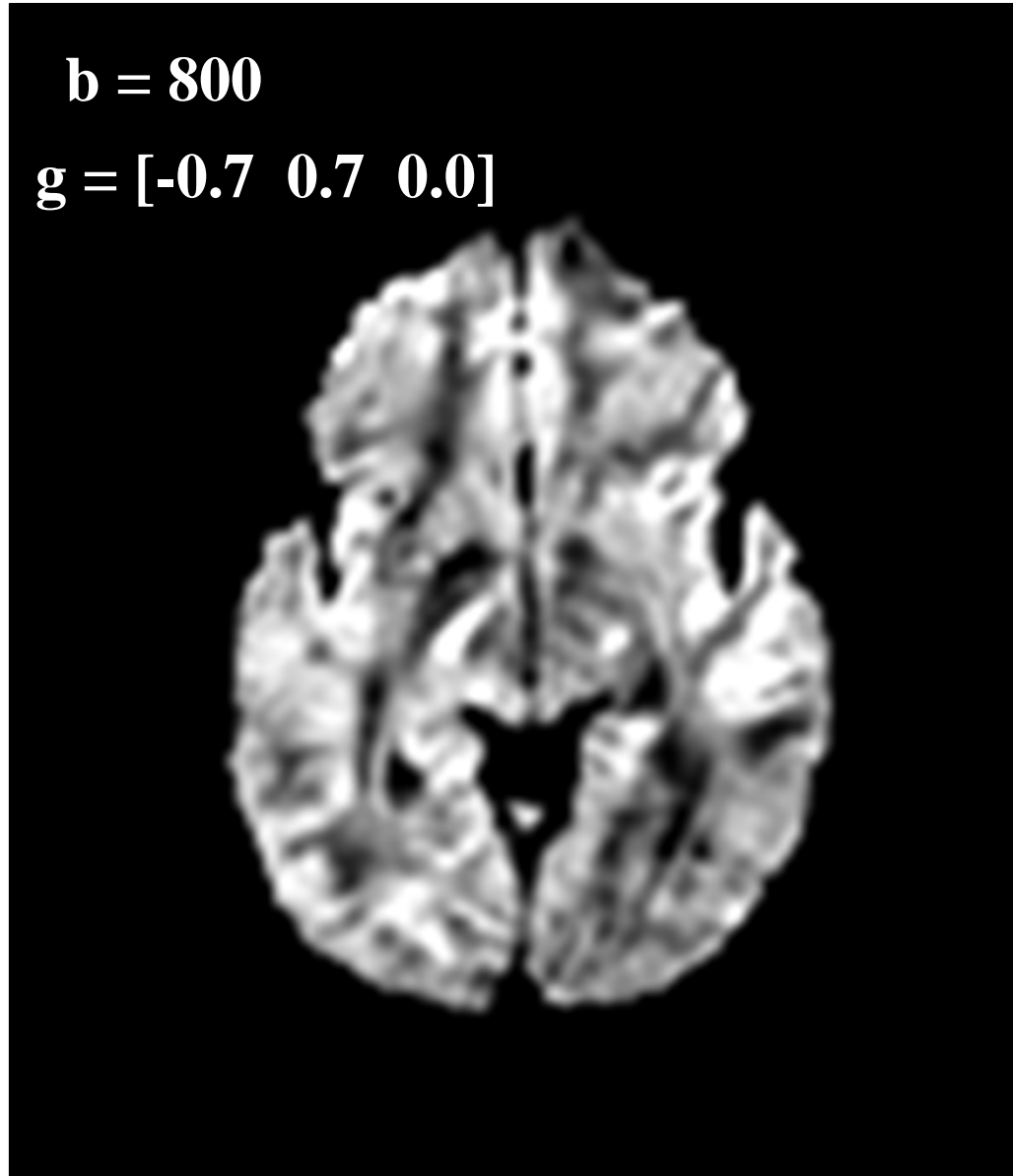
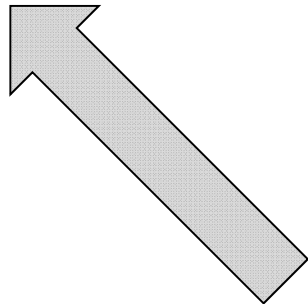
To help identify the information of most interest to you, please let us know who you are.

Individual Customers	Lawyers / Law Firms
Corporate Customers	Government Customers
Prospective Test Centers	Prospective Investors



Raw Diffusion MR Images

Dark means large
ADC (a great deal
of signal
attenuation)



Raw Diffusion MR Images

Dark means large
ADC (a great deal
of signal
attenuation)

