Seeing and the brain

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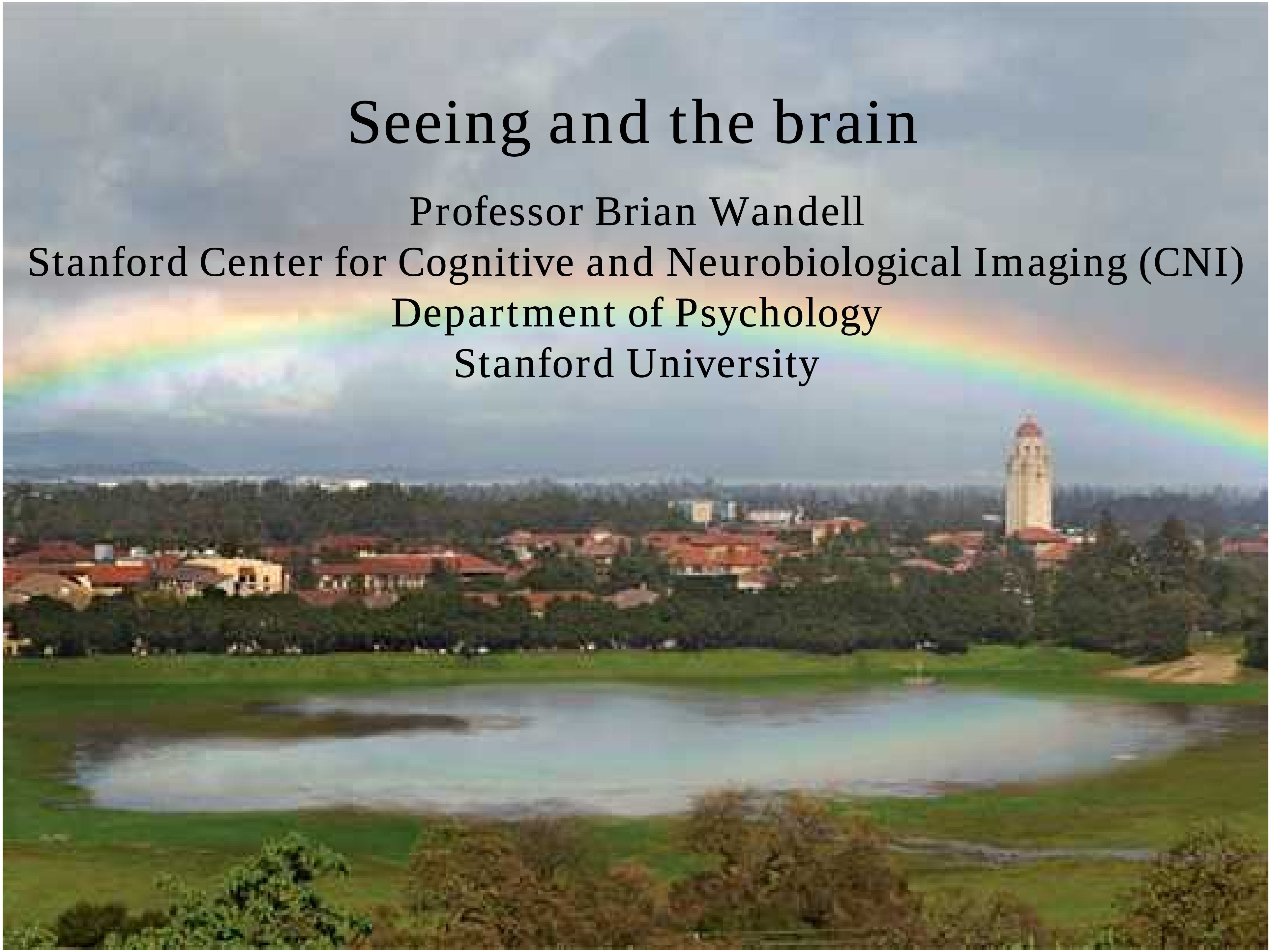
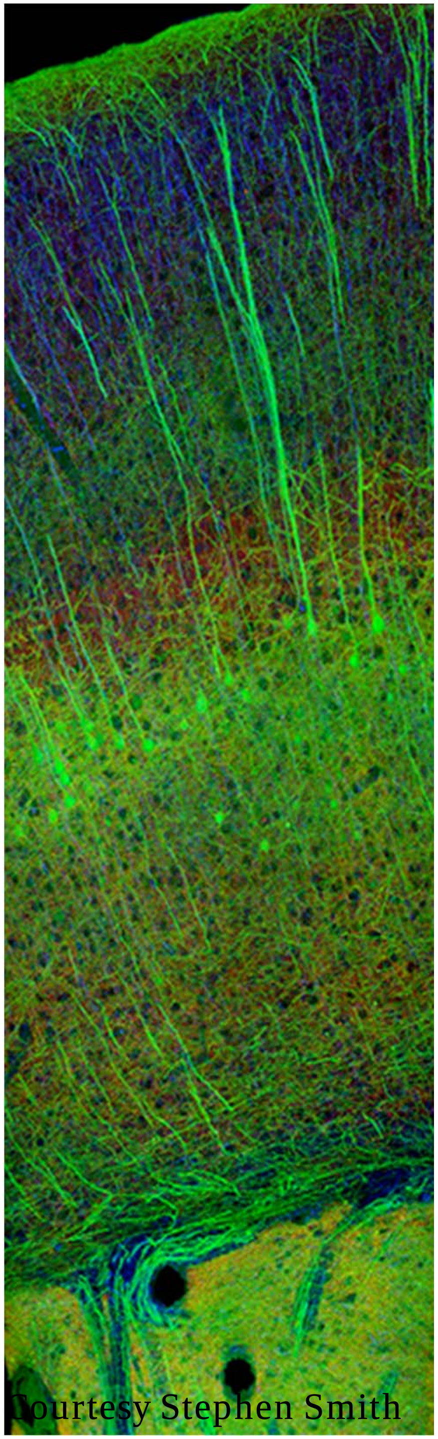
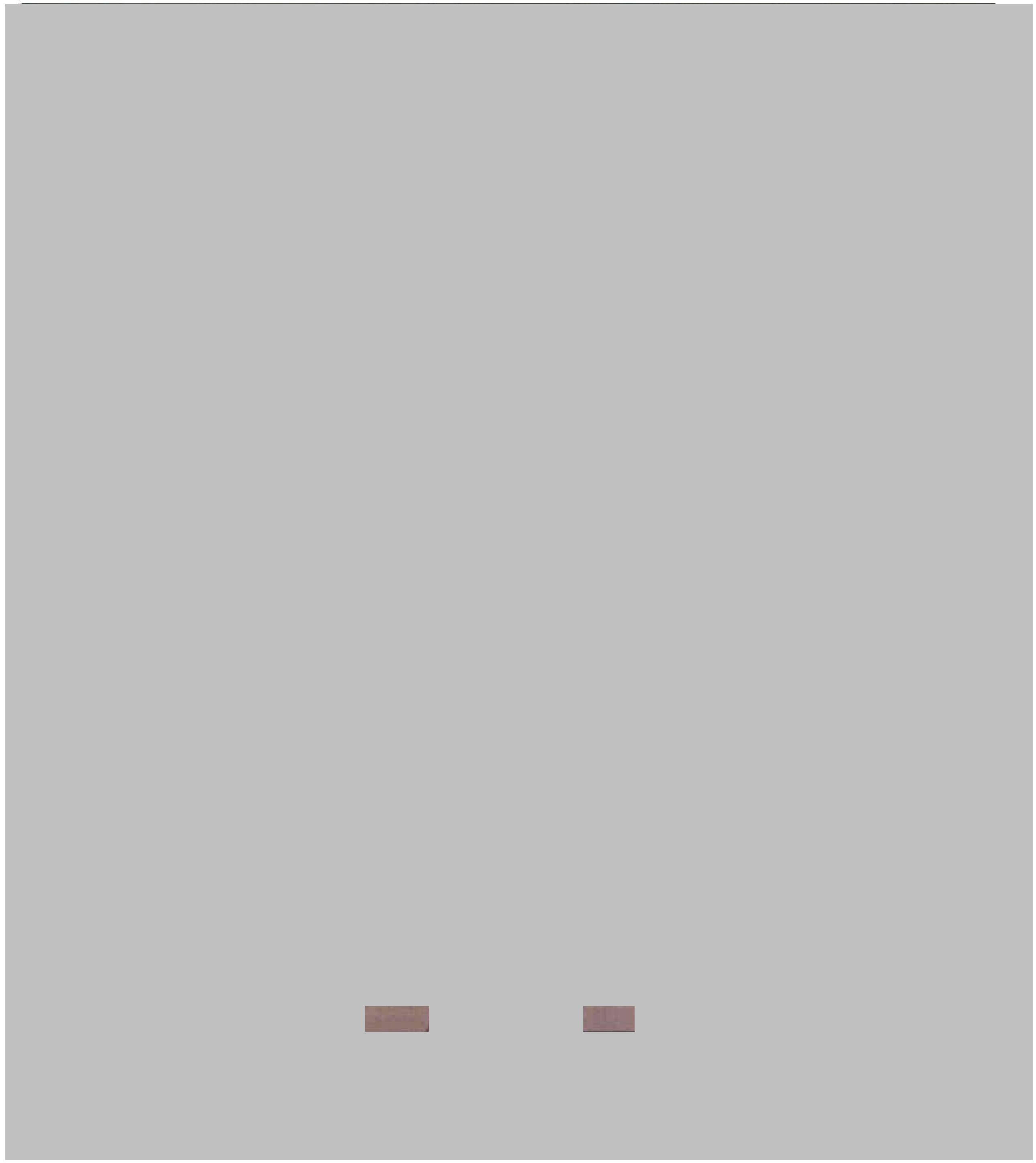


Preview

- 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)

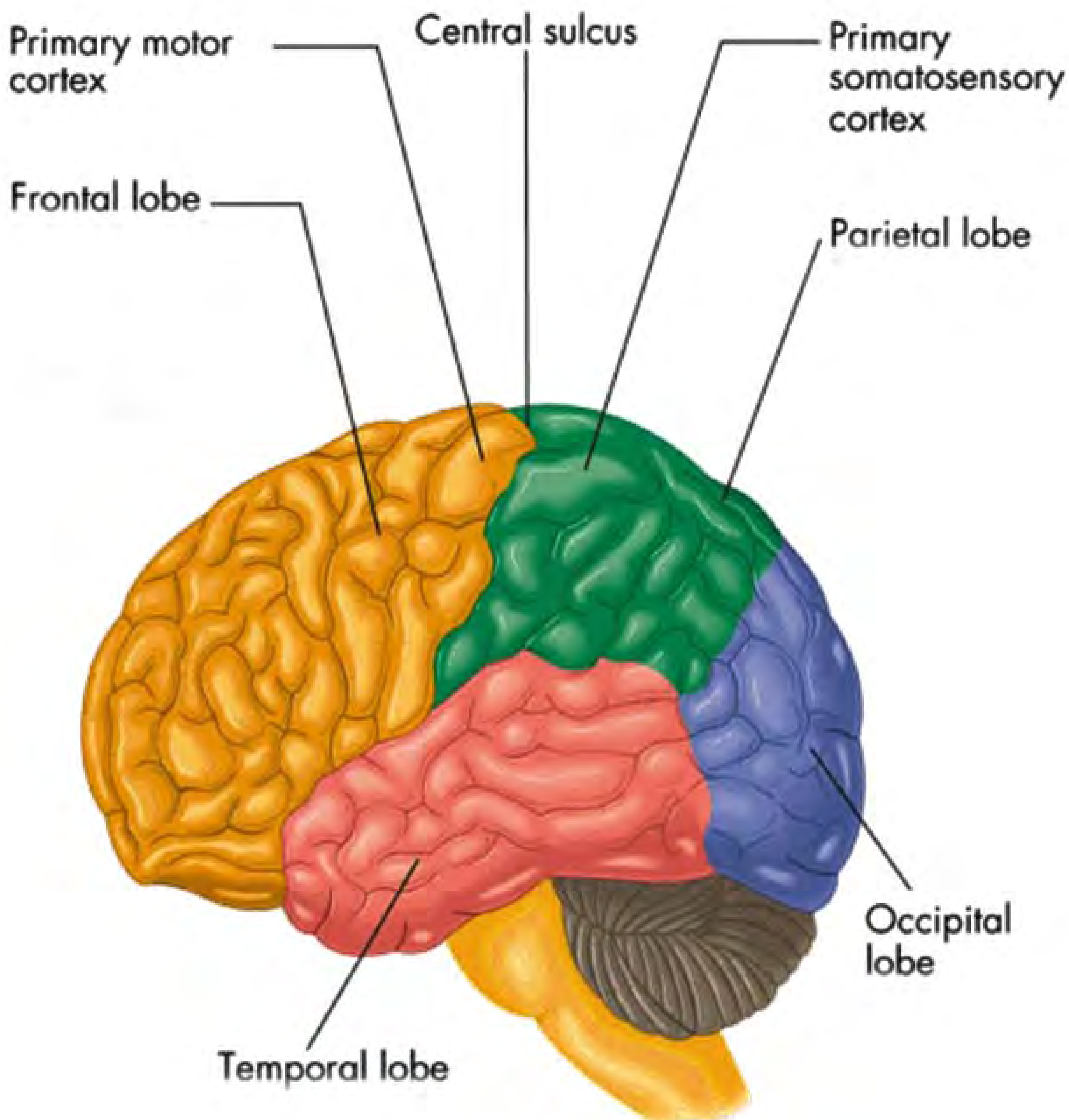


Lobes and functions

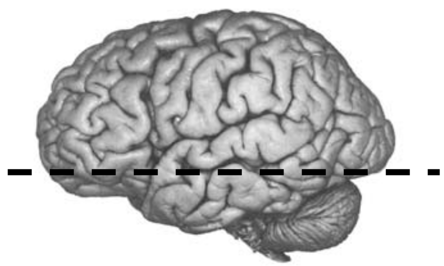
Vision – Occipital and temporal

Reading – Temporal, parietal, Frontal

Hearing – Temporal

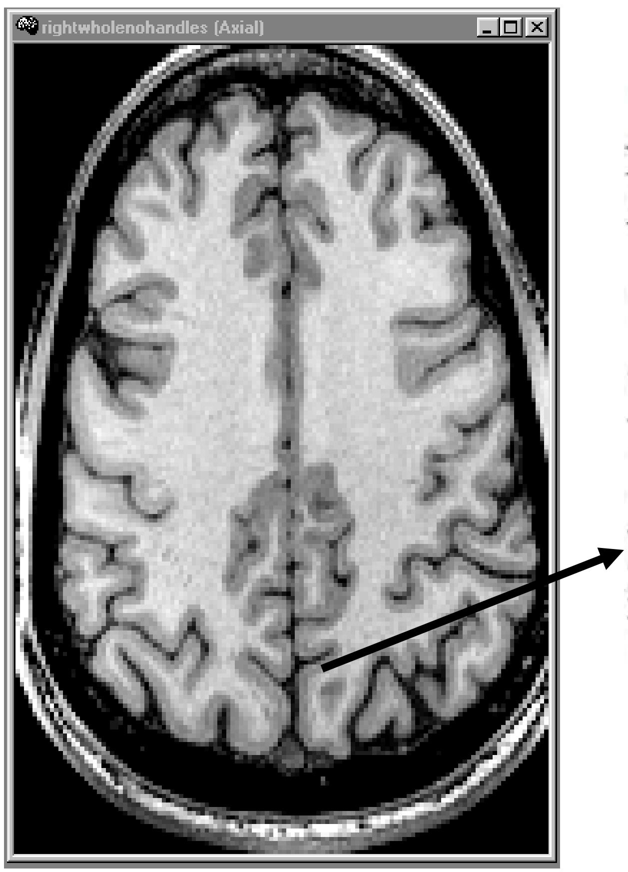


Many types of neurons

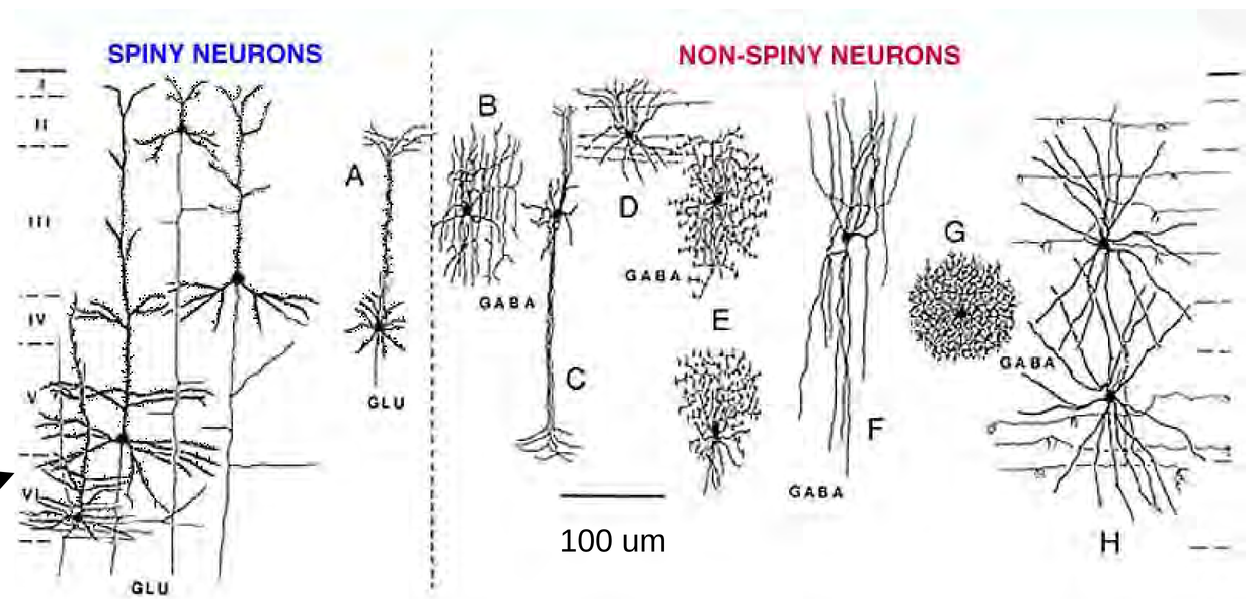


Primary visual cortex

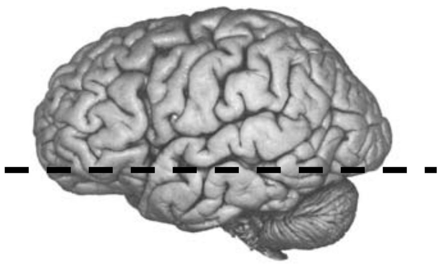
- Spiny pyramidal – excitatory
- Spiny stellate – excitatory
- Smooth or sparsely spiny - inhibitory

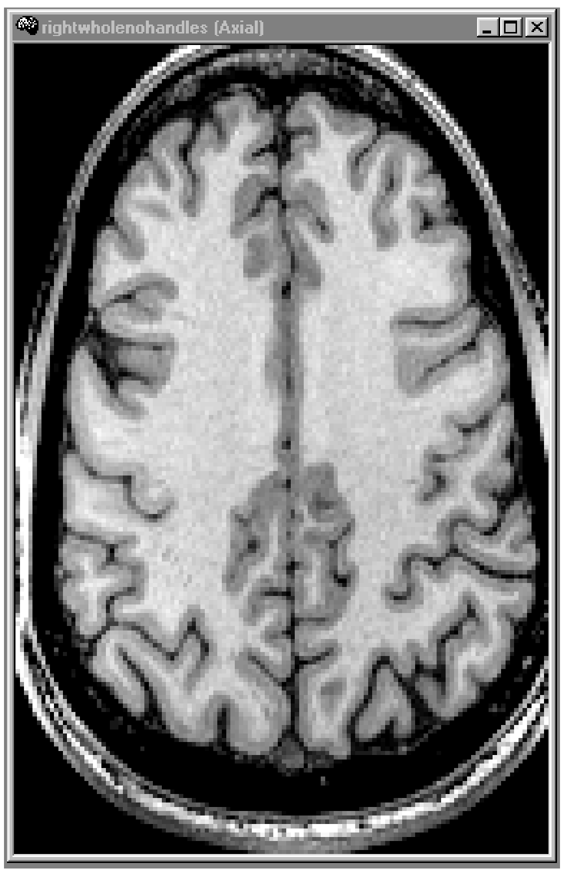


Structures



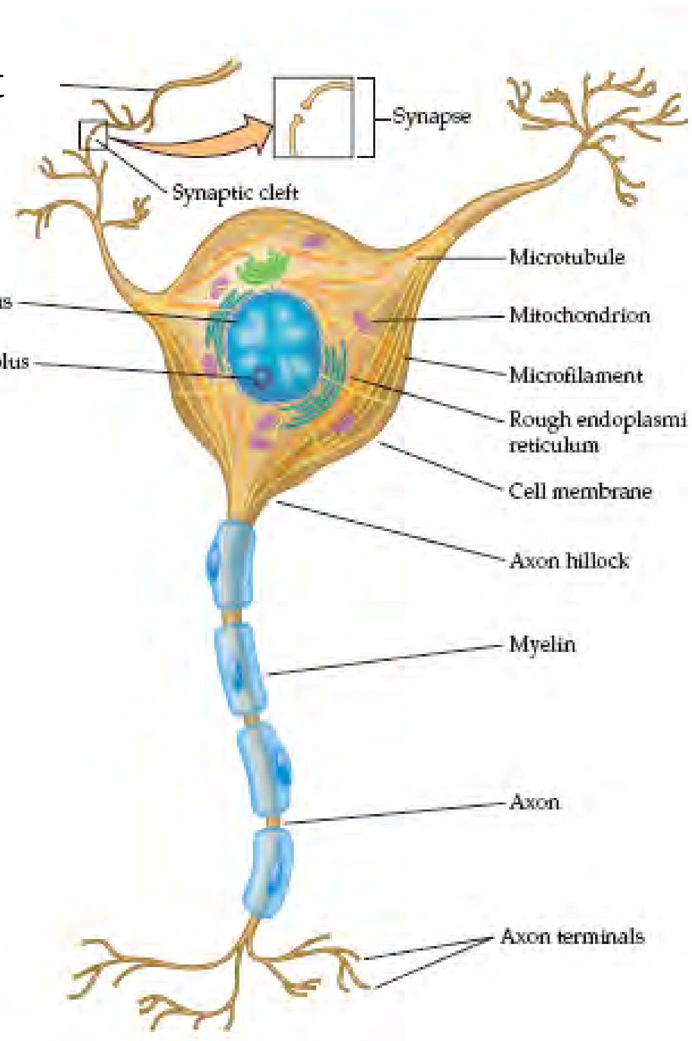
Neuron: The parts





Structures

Axon input



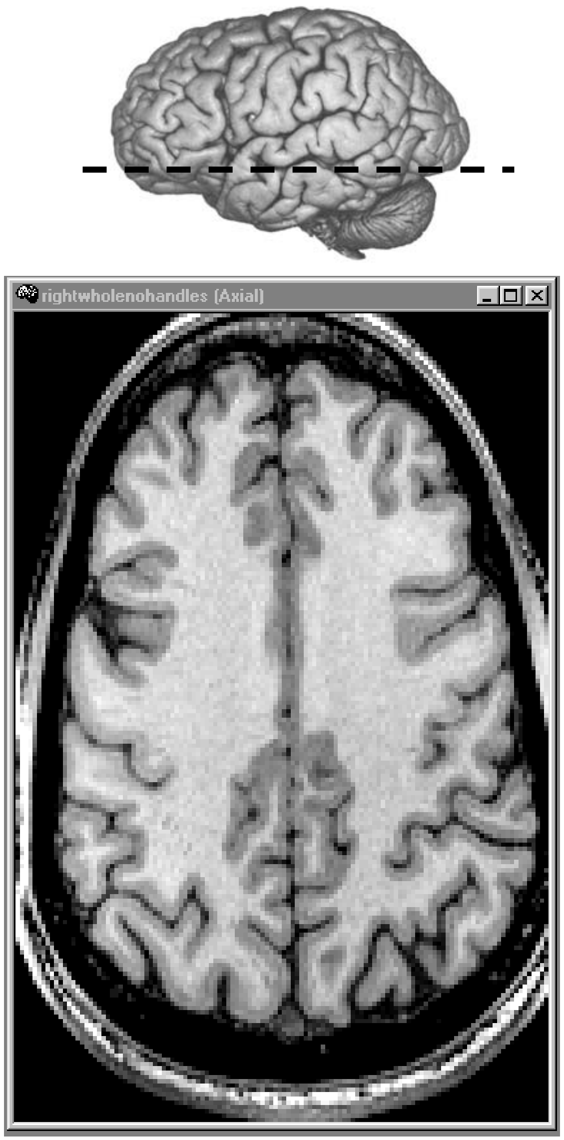
Dendrites

Soma

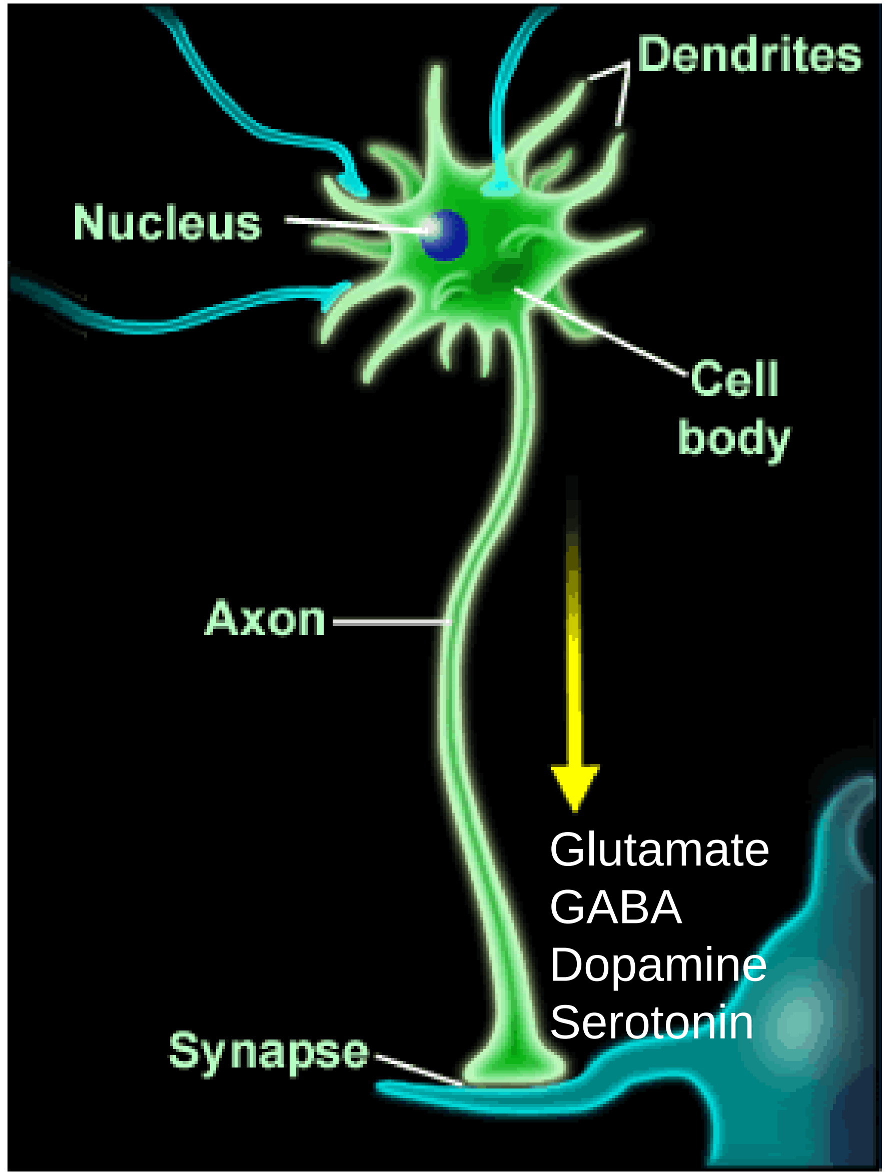
Axons

Axon terminals

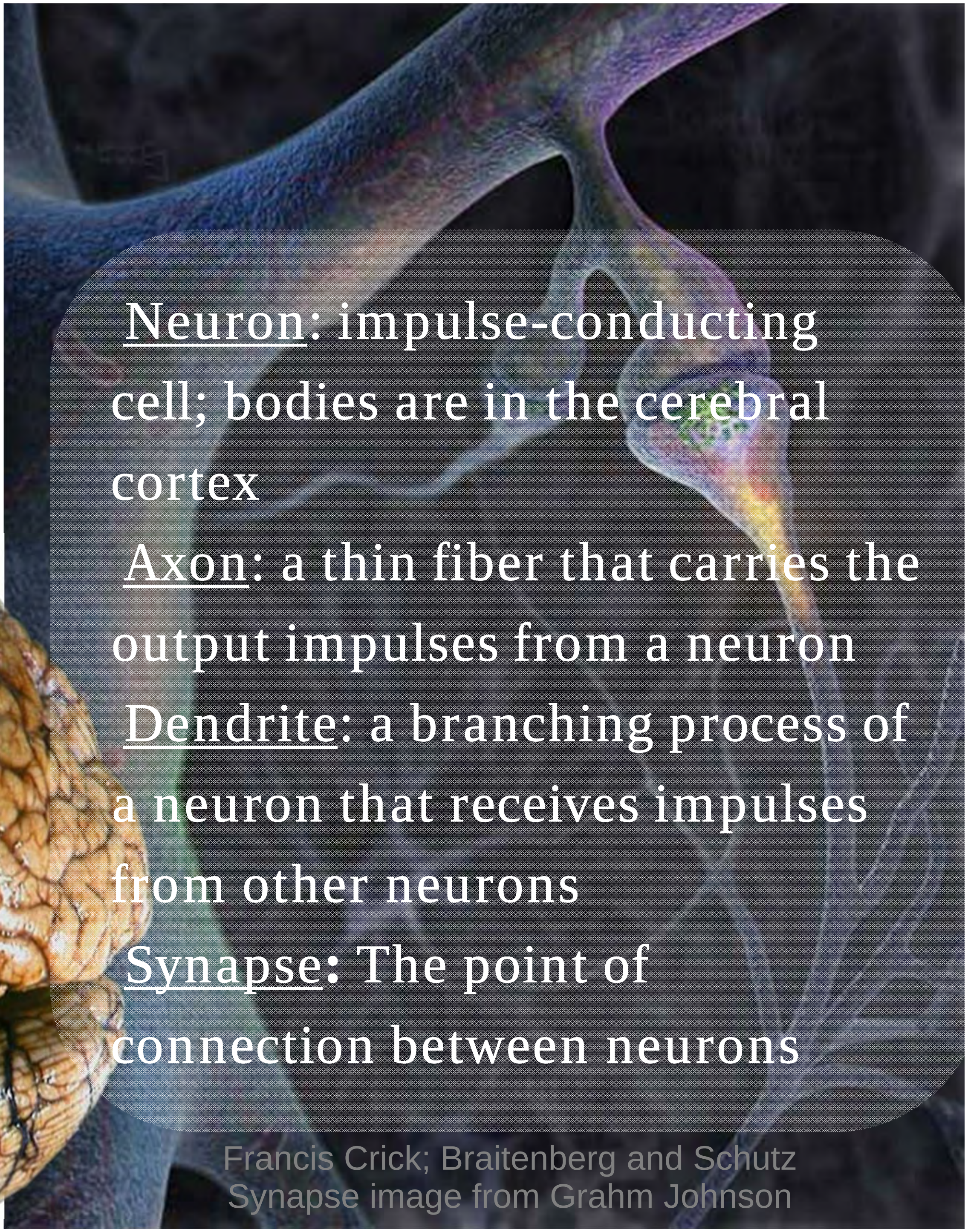
Axons and transmitters



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

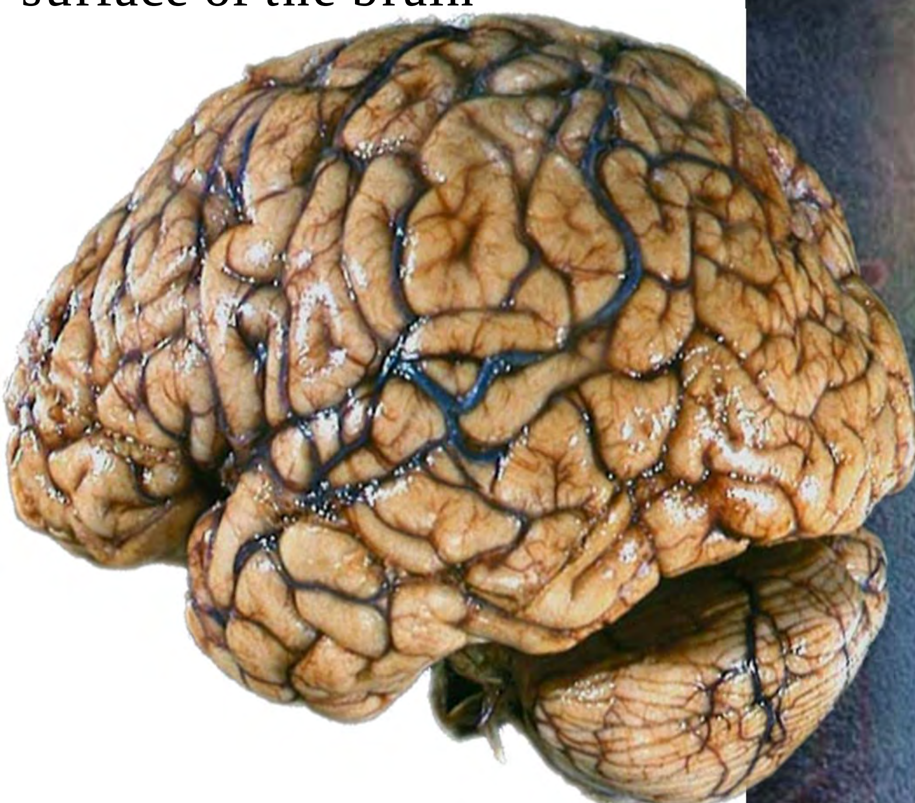
Axon: a thin fiber that carries the output impulses from a neuron

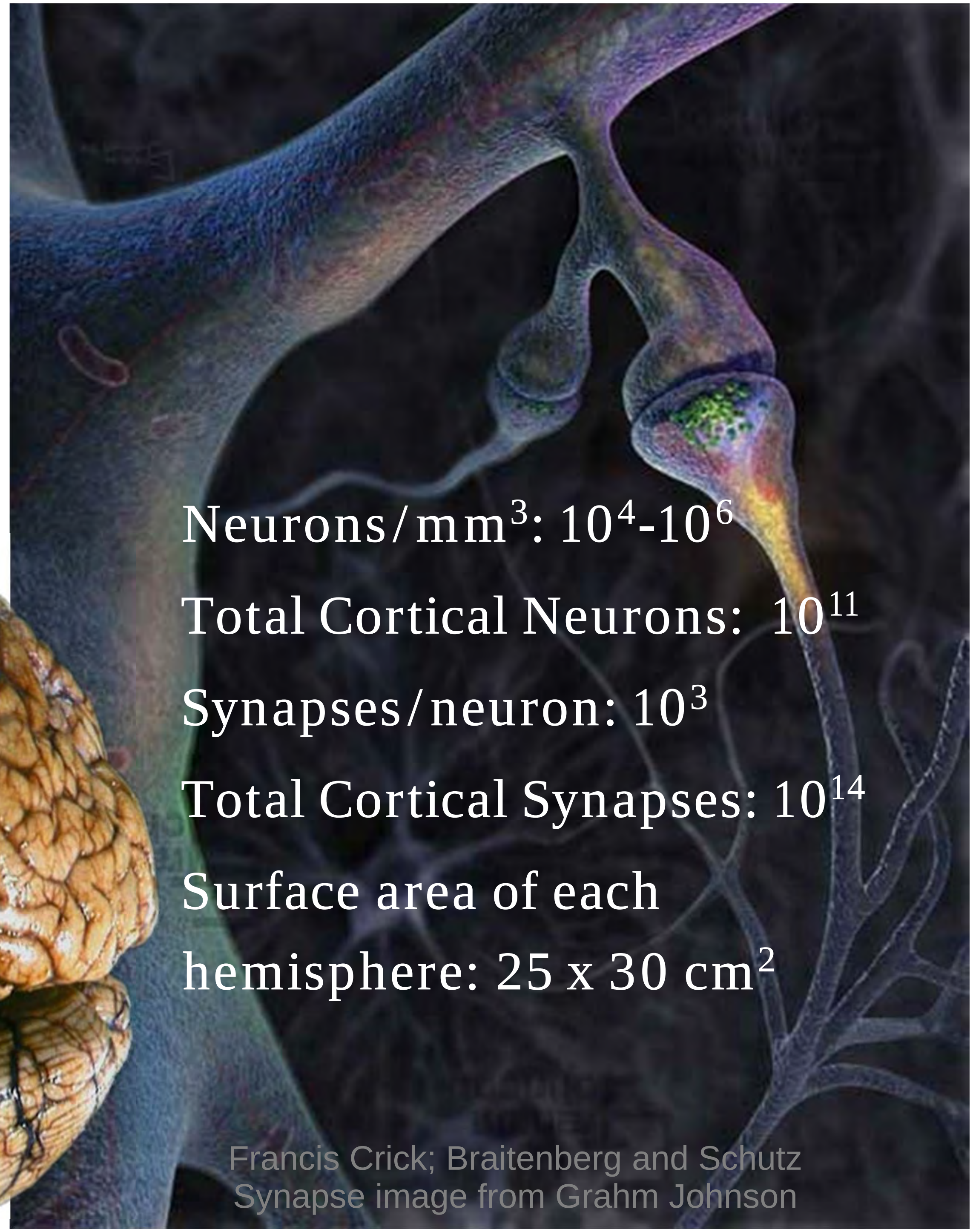
Dendrite: a branching process of a neuron that receives impulses from other neurons

Synapse: The point of connection between neurons

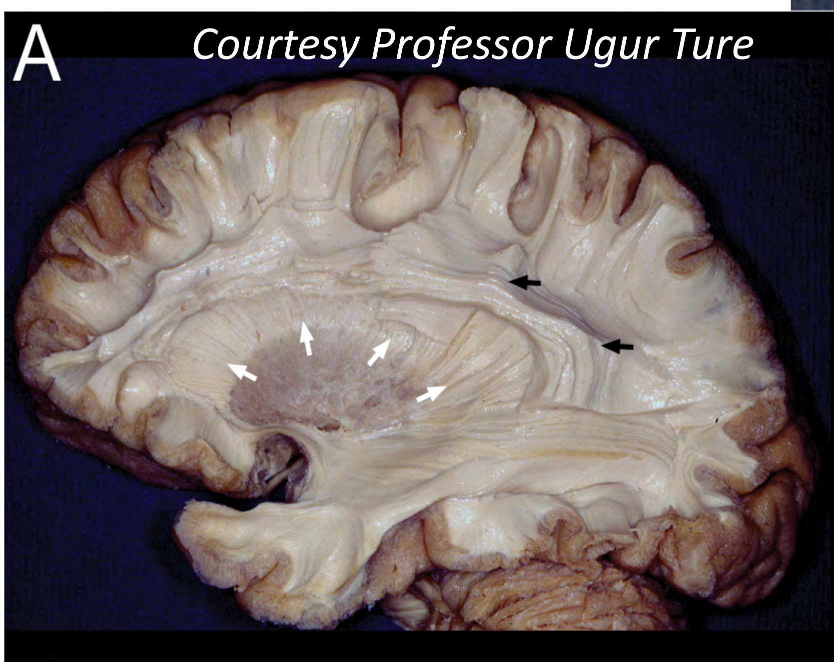
Francis Crick; Braitenberg and Schutz
Synapse image from Grahm Johnson

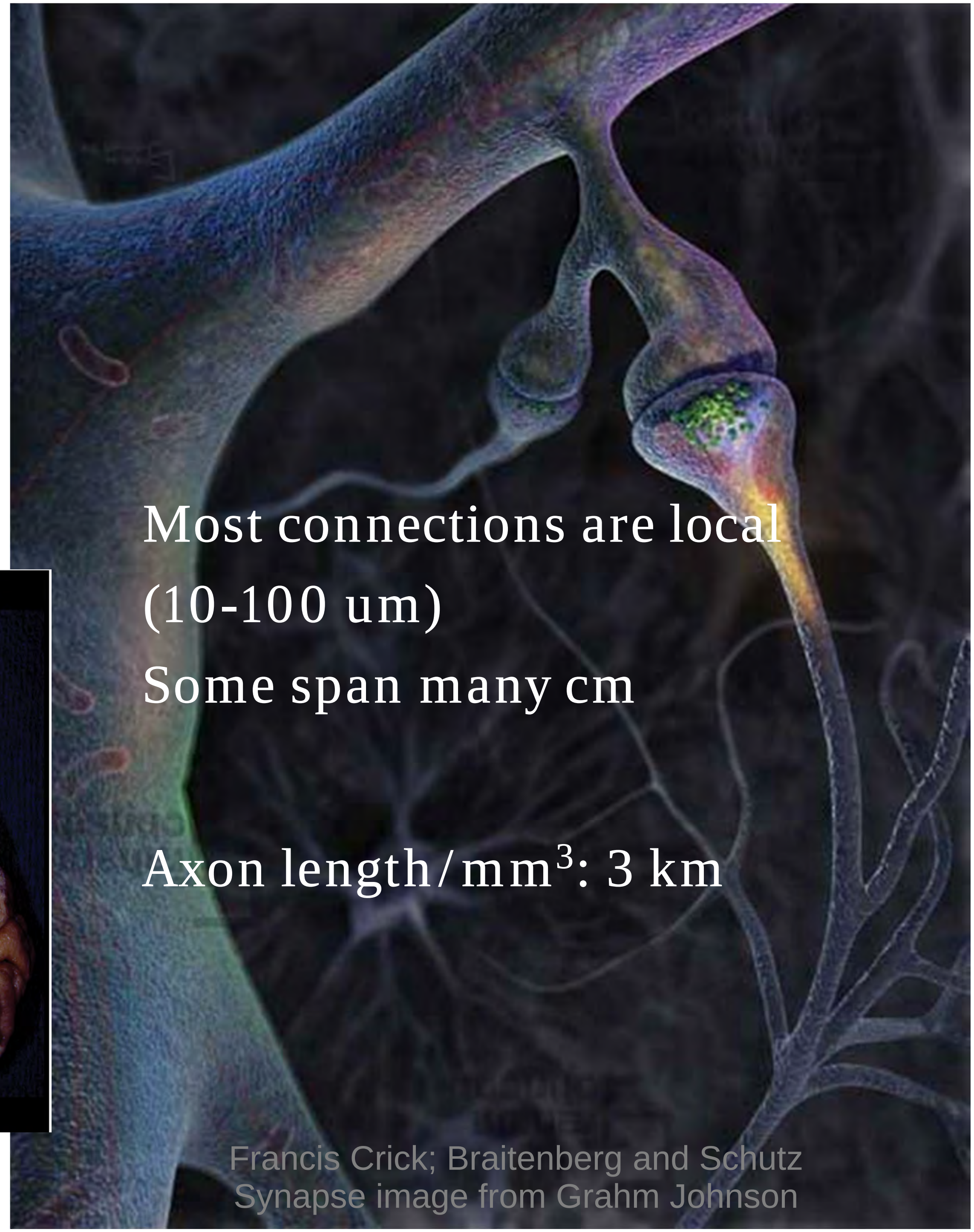
Brain computations takes place in the gray matter (also called cerebral cortex), a thin (2-4 mm) sheet of neural tissue that cover the surface of the brain





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





Most connections are local (10-100 um)

Some span many cm

Axon length/mm^3: 3 km

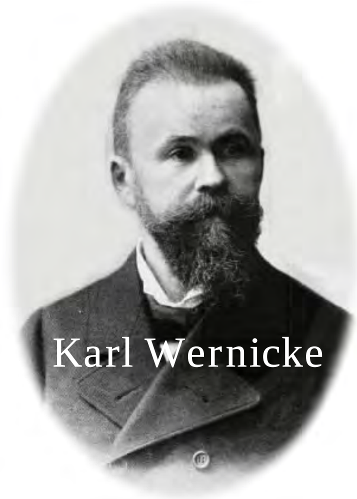
Francis Crick; Braitenberg and Schutz
Synapse image from Grahm Johnson

Neurology

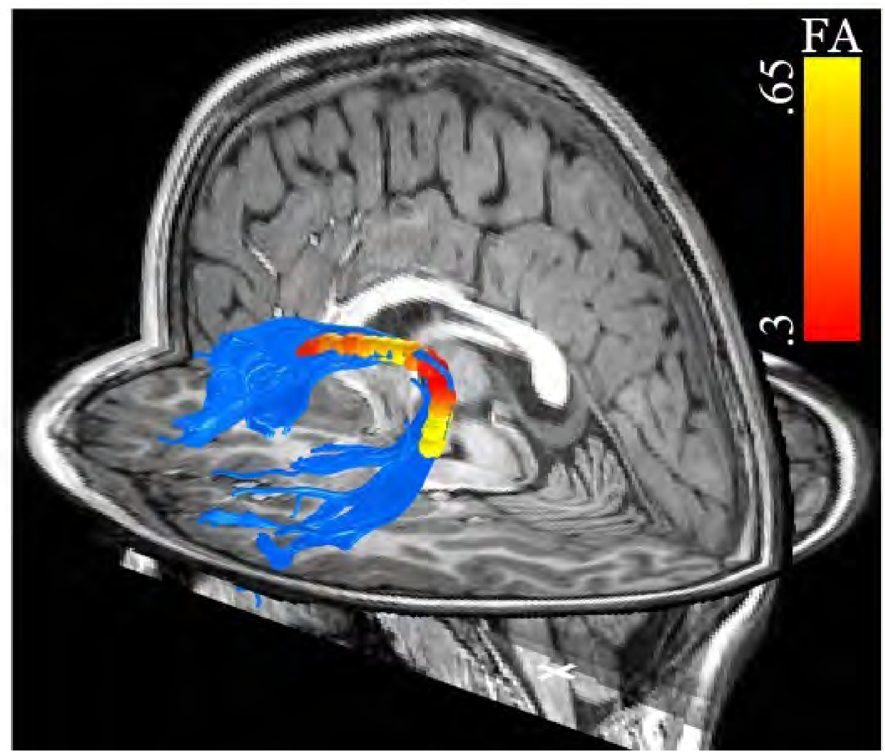
Theory of function at coarse scale

Neurology

Wernicke, Dejerine,
Geschwind, others

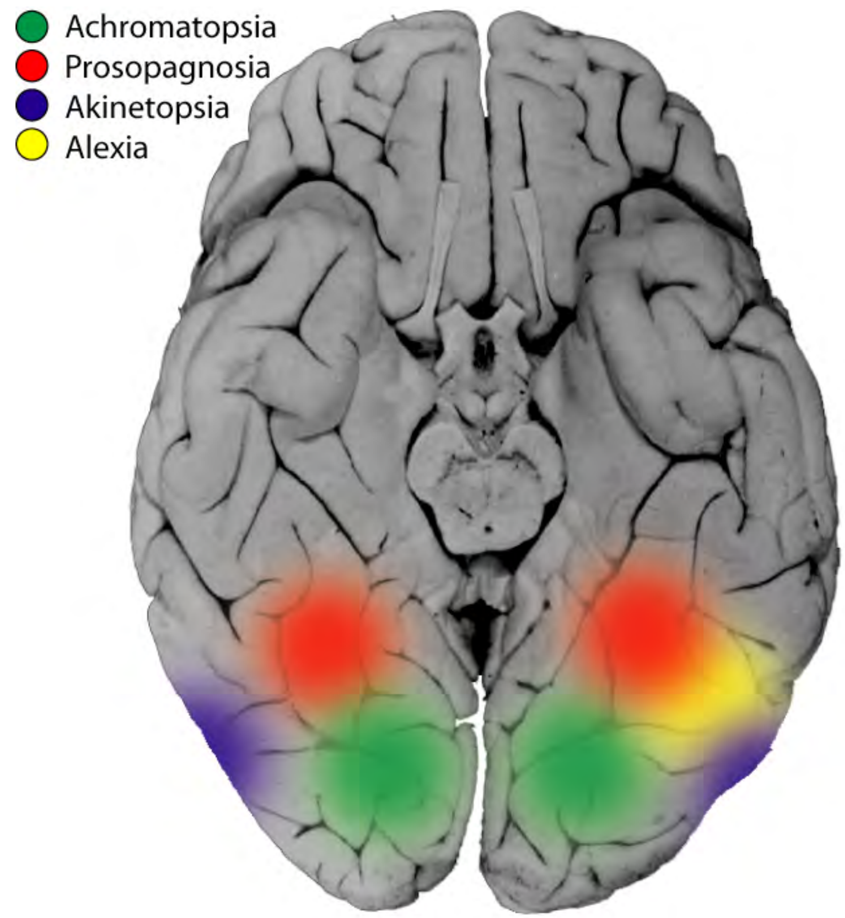


- Connectionist - cognitive functions explained by **white matter** connections between sensory and motor regions



Neurology

Kinsbourne, Warrington,
Shallice, others



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

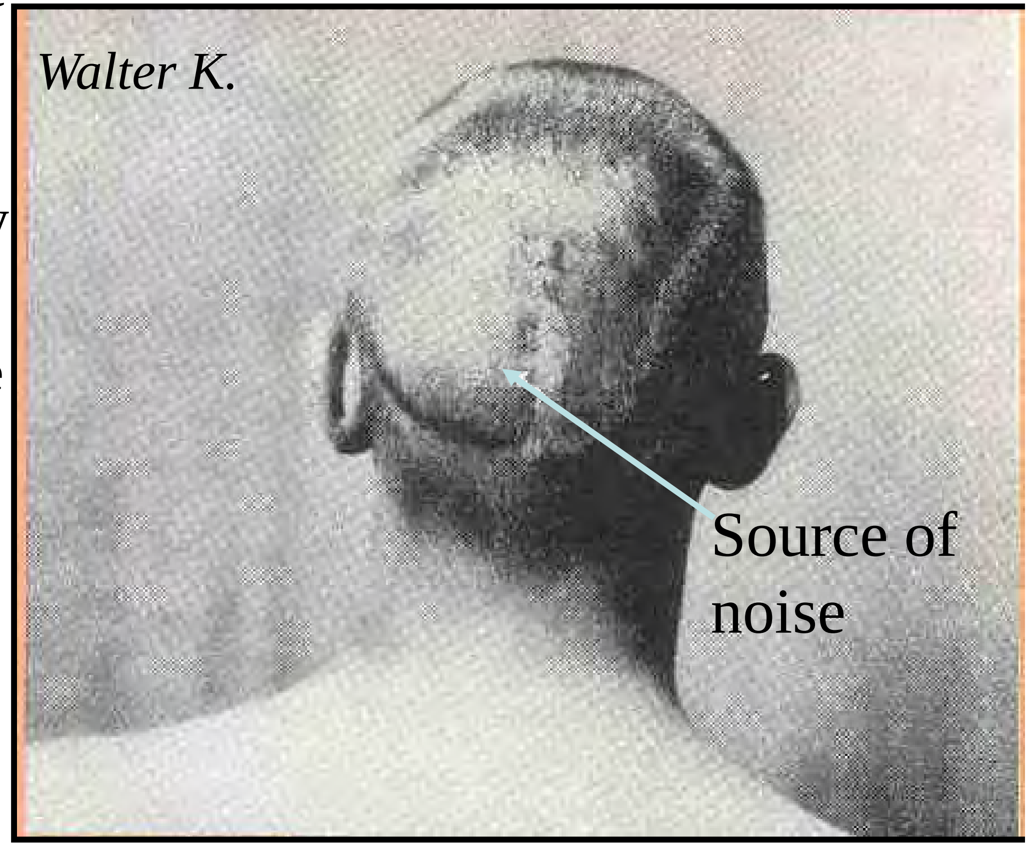
The rise of functional Magnetic Resonance Imaging (fMRI)

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

Neural and vascular activity are coupled

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.

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



Neural and vascular activity are coupled

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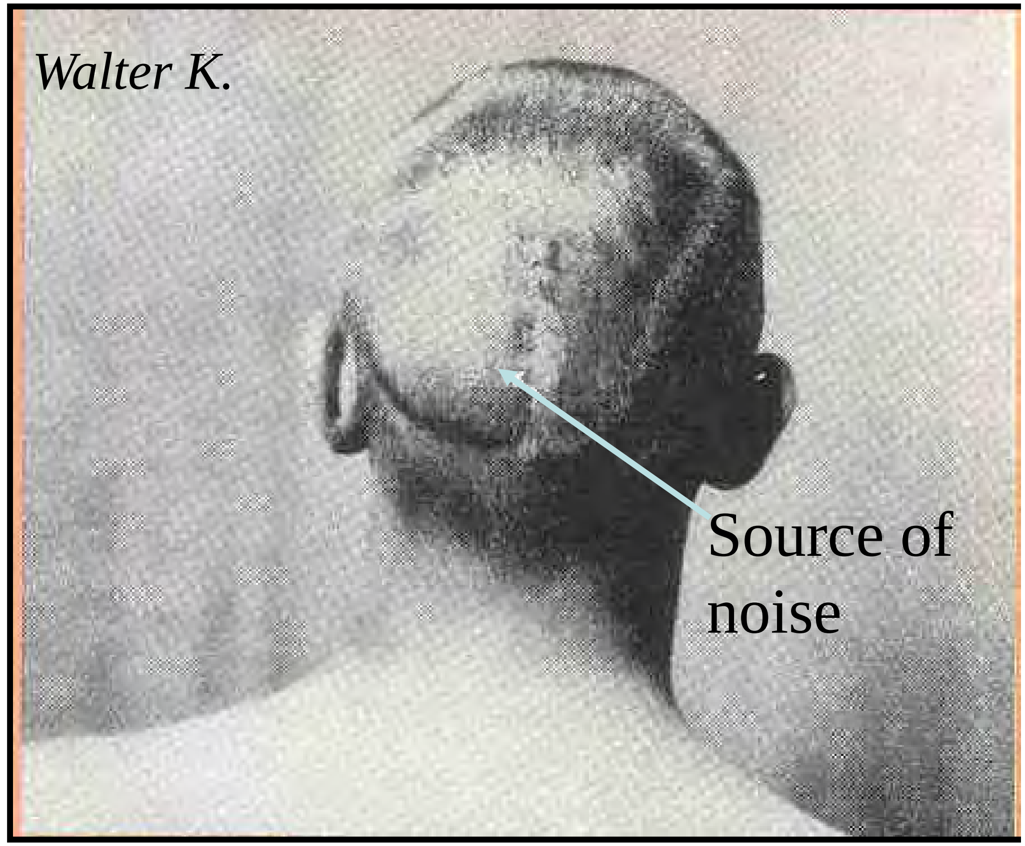
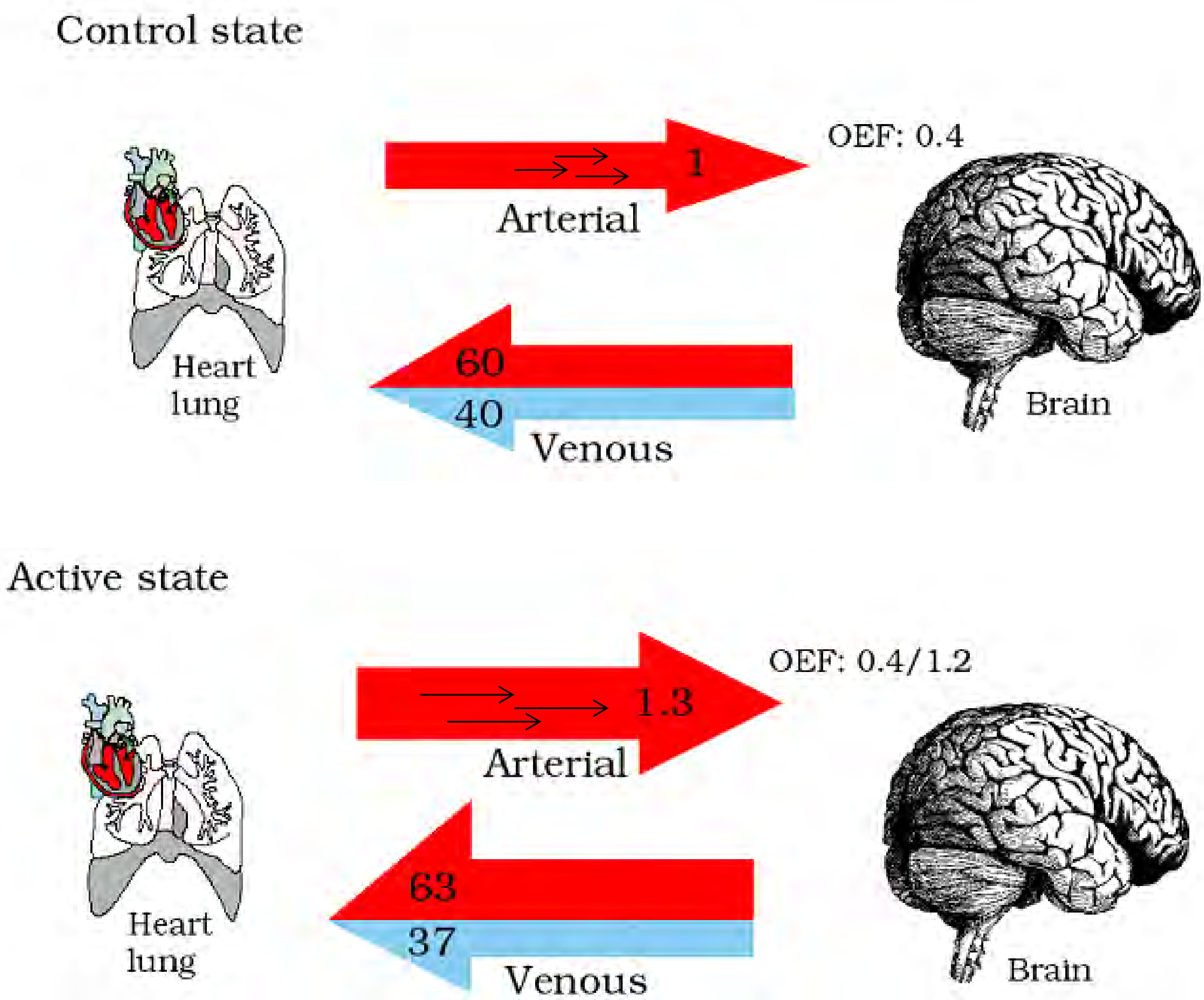


- Subject noted that 'the noise in the back of his head increased in intensity when he was using his eyes.'

- No increase for hearing, touch or smell

- Increased more when he tried harder

Blood oxygenation increase is localized



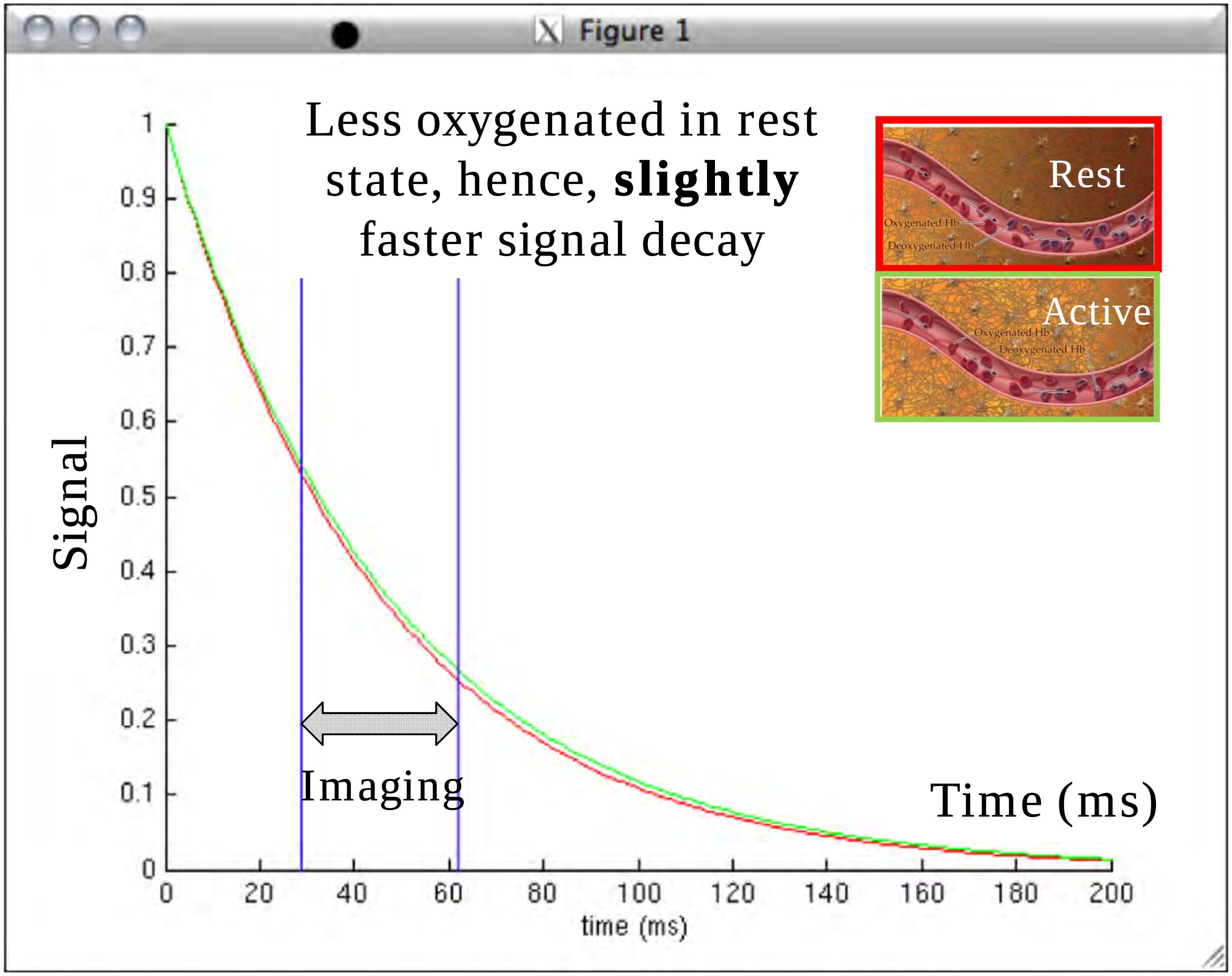
Sokolow
Raichle
Fox

MRI scanners measure the blood oxygen level

FUNCTIONAL MAGNETIC RESONANCE IMAGING, Figure 1.2

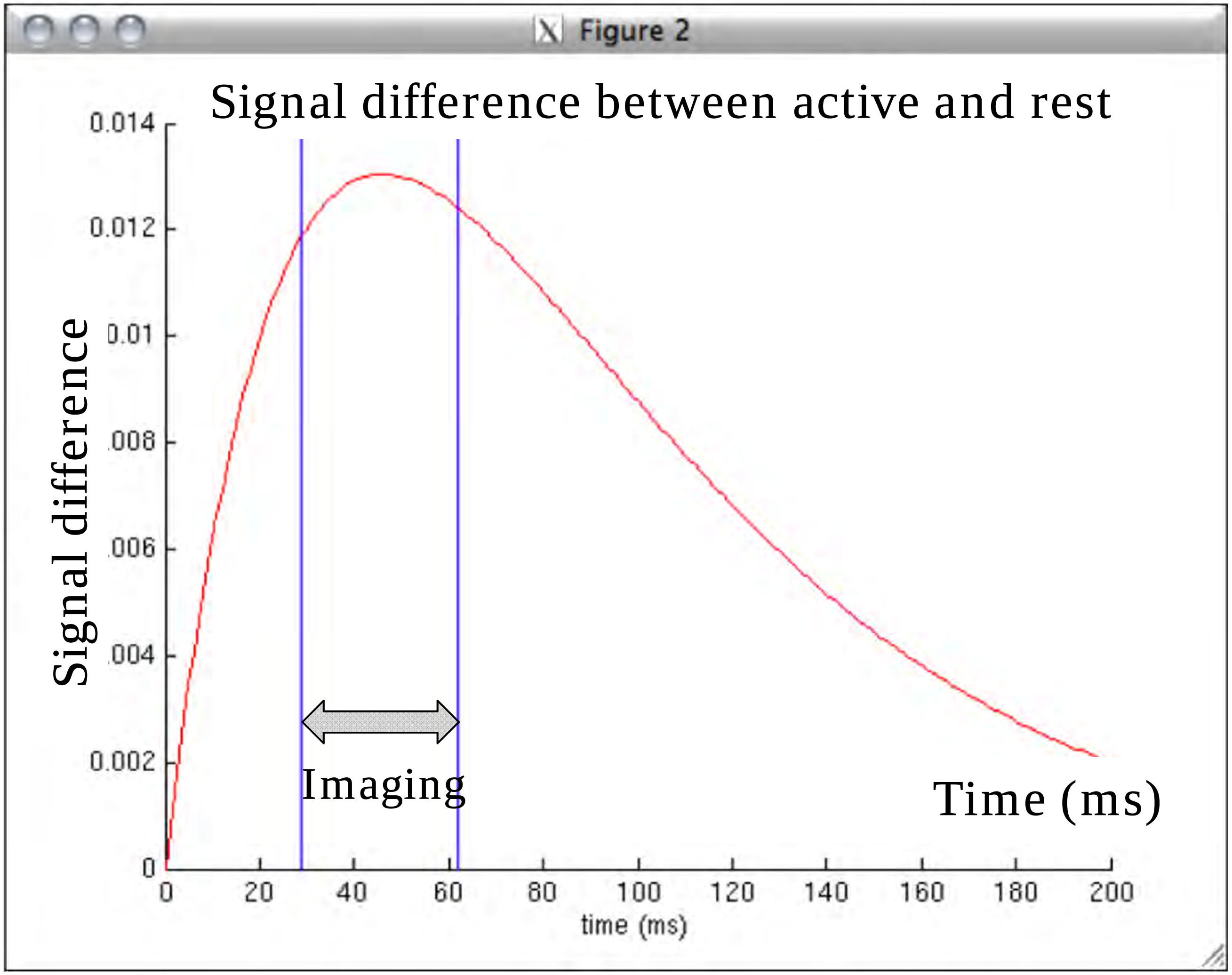
How will BOLD imaging work?

fMRI signal decay for rest and active



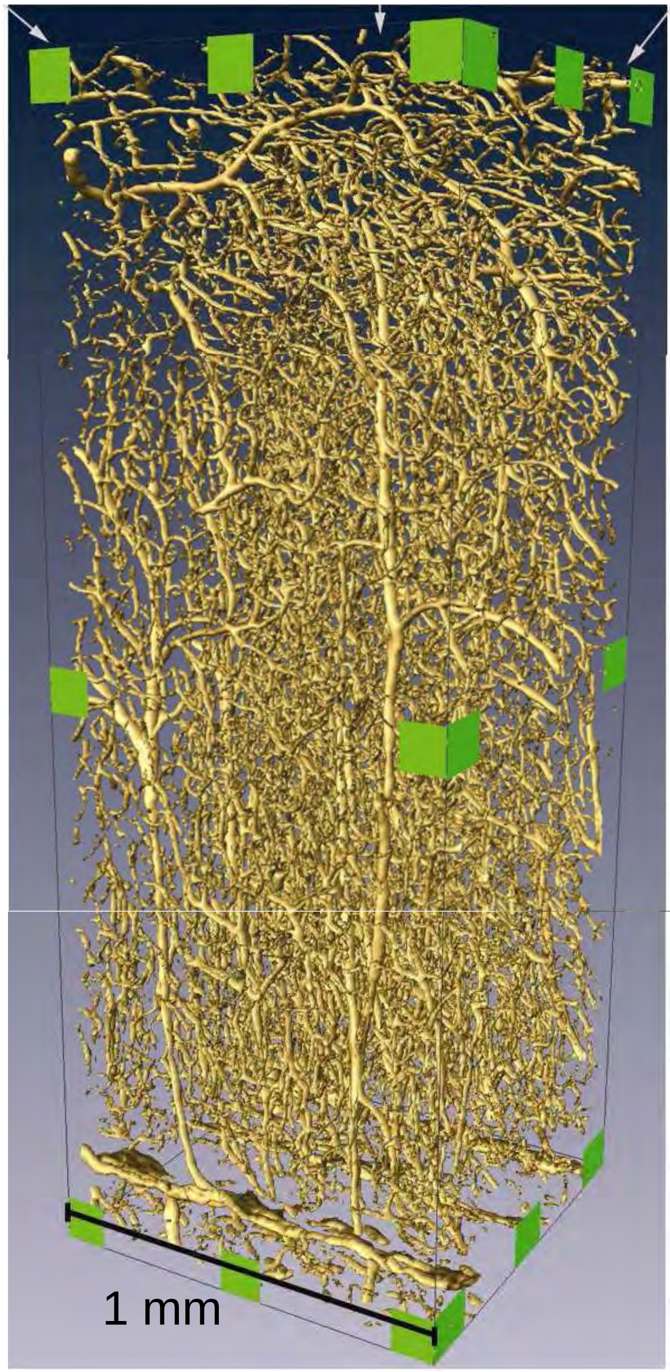
How will BOLD imaging work?

fMRI signal decay **difference** (active – rest)



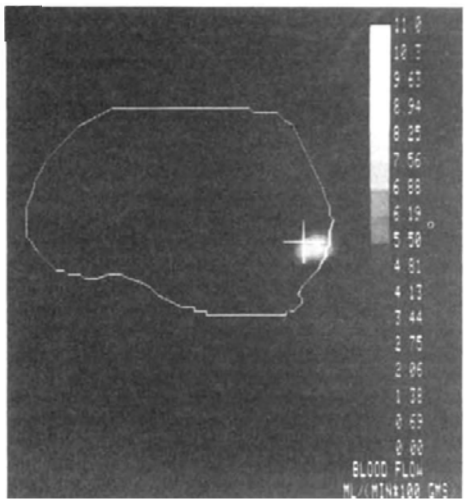
The cortical vasculature is dense

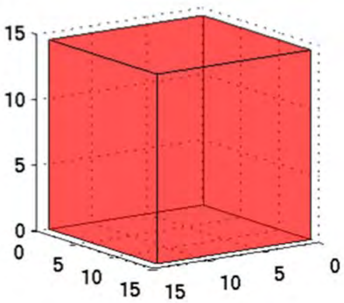
(Lauwersa et al., Neuroimage, 2007)



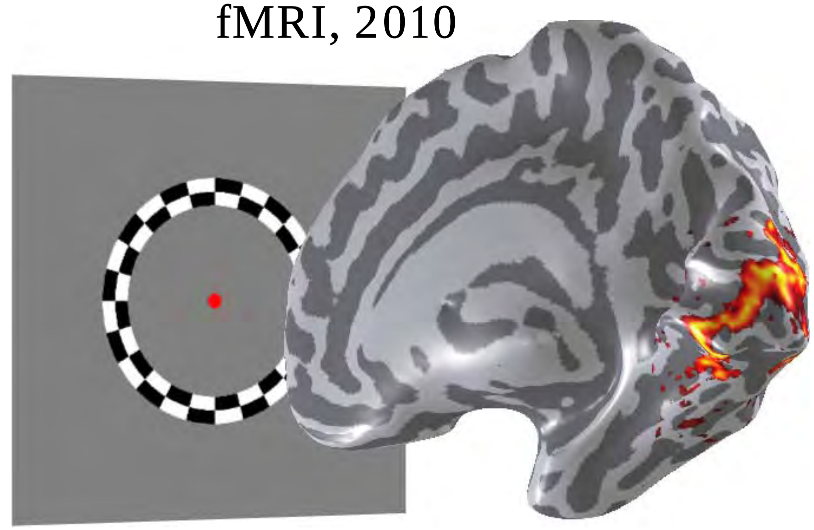
Human visual cortex

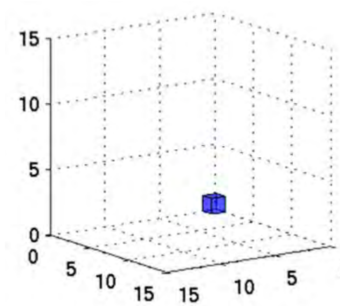
PET, 1990





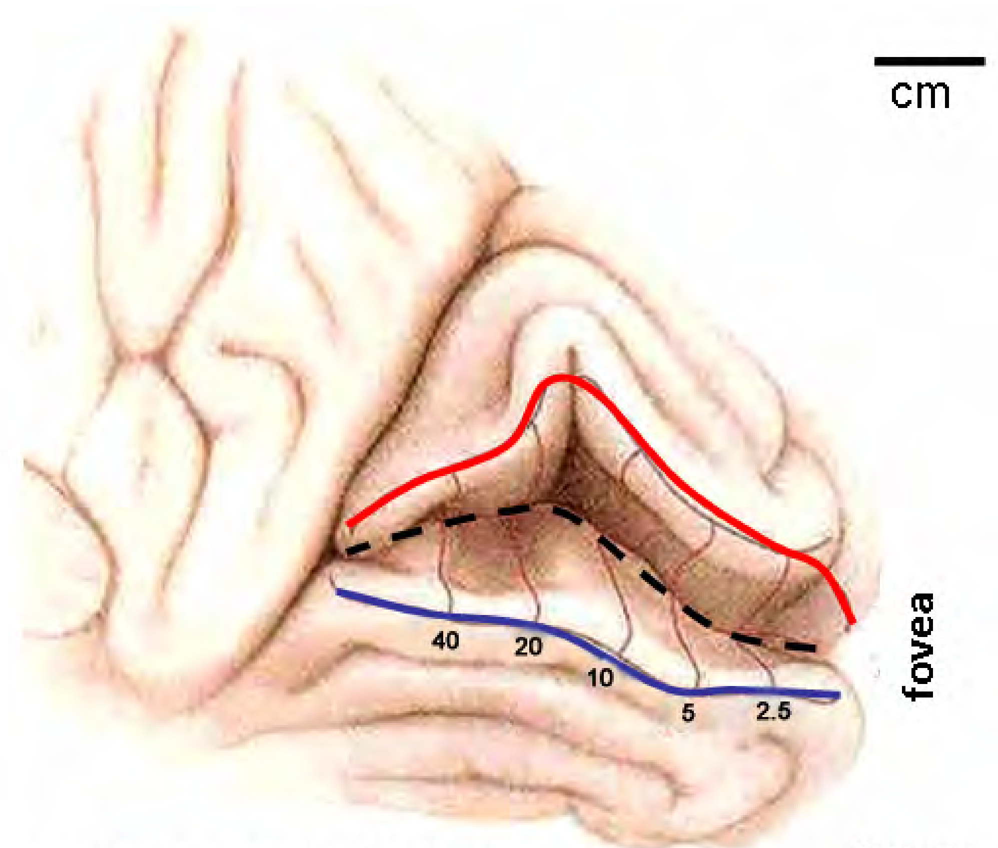
fMRI, 2010



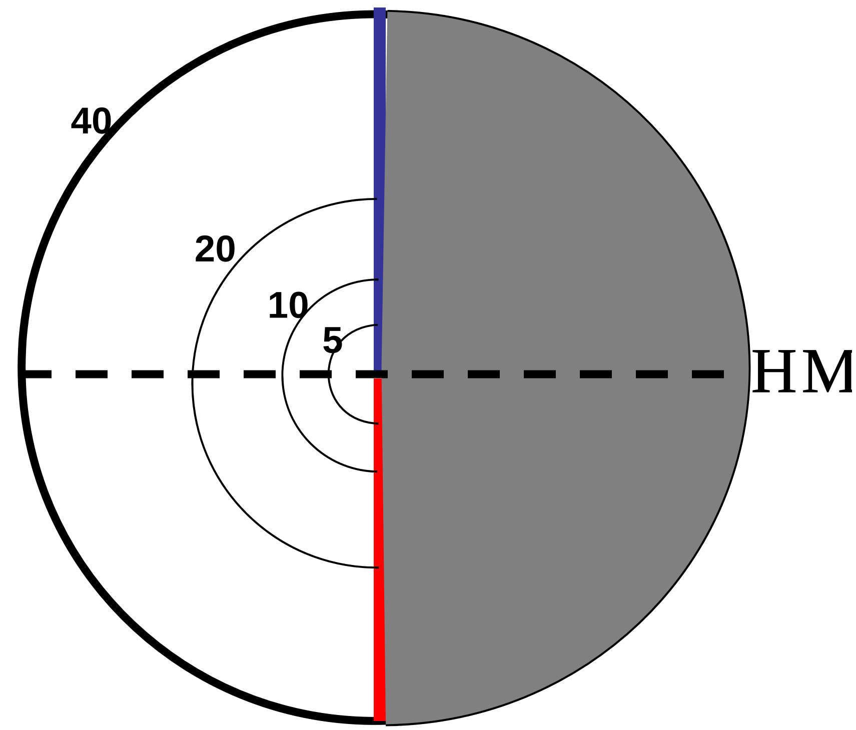


Voxel volume

Primary visual cortex (V1) contains a visual field map

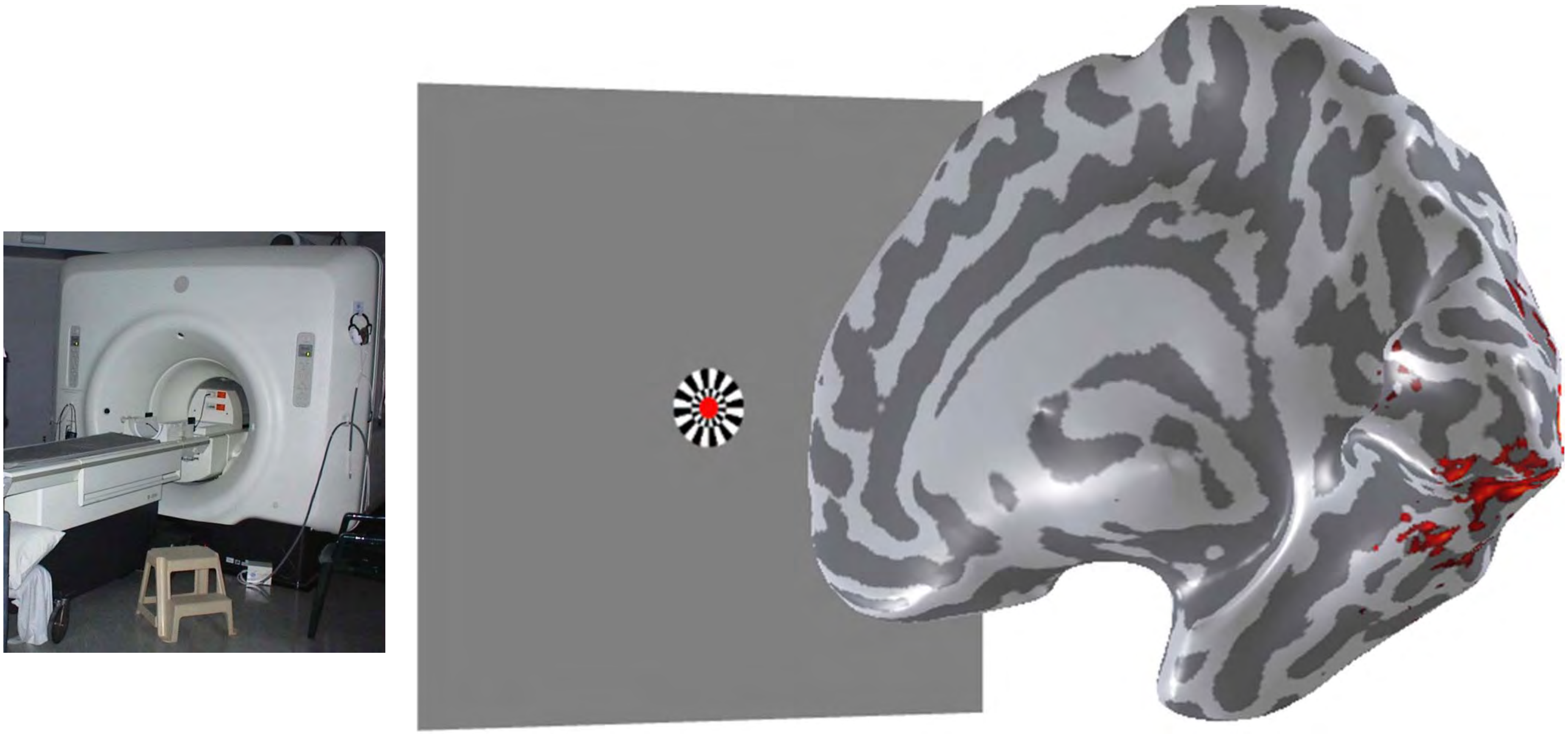


Horton and Hoyt (1991)

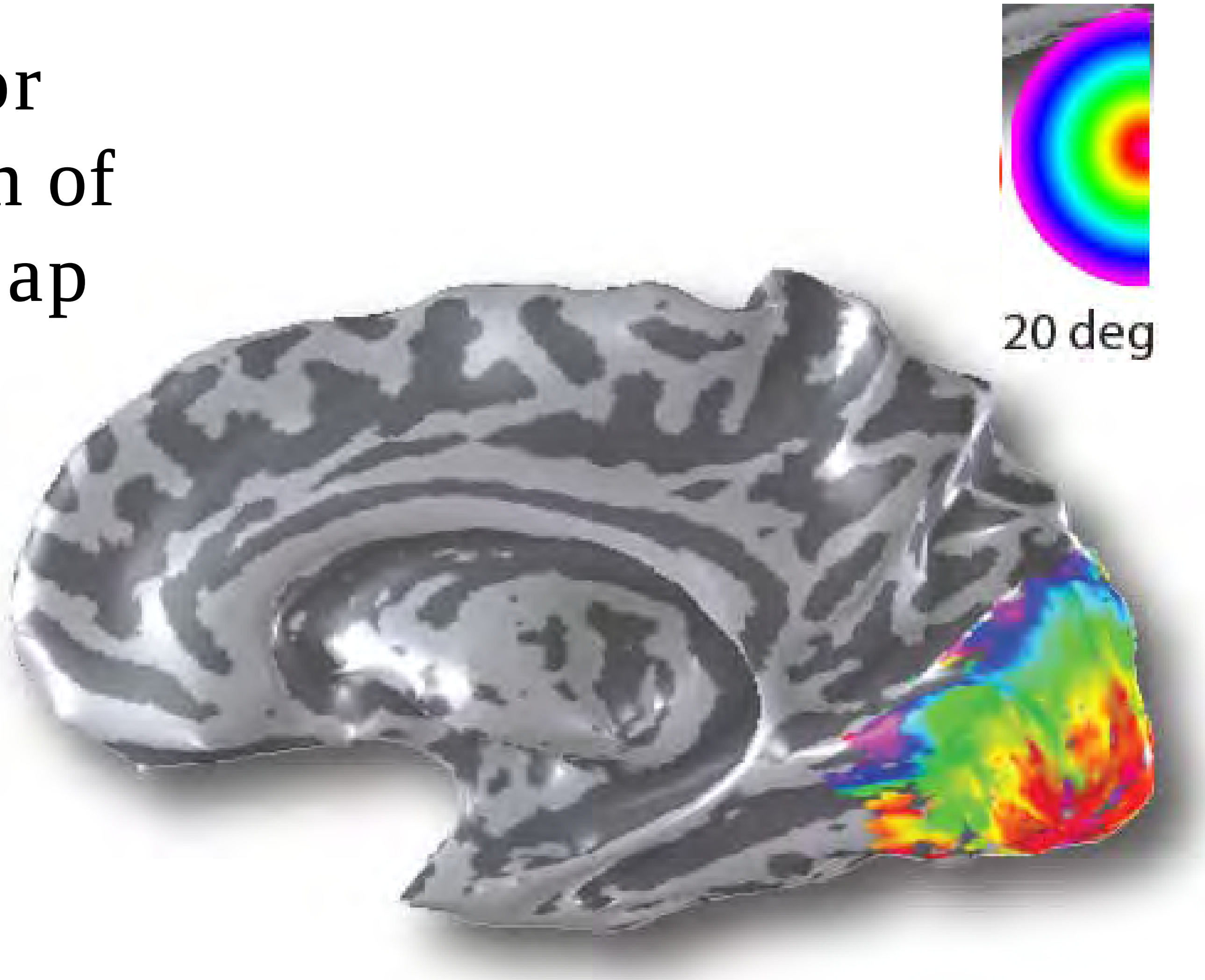


Human eccentricity mapping

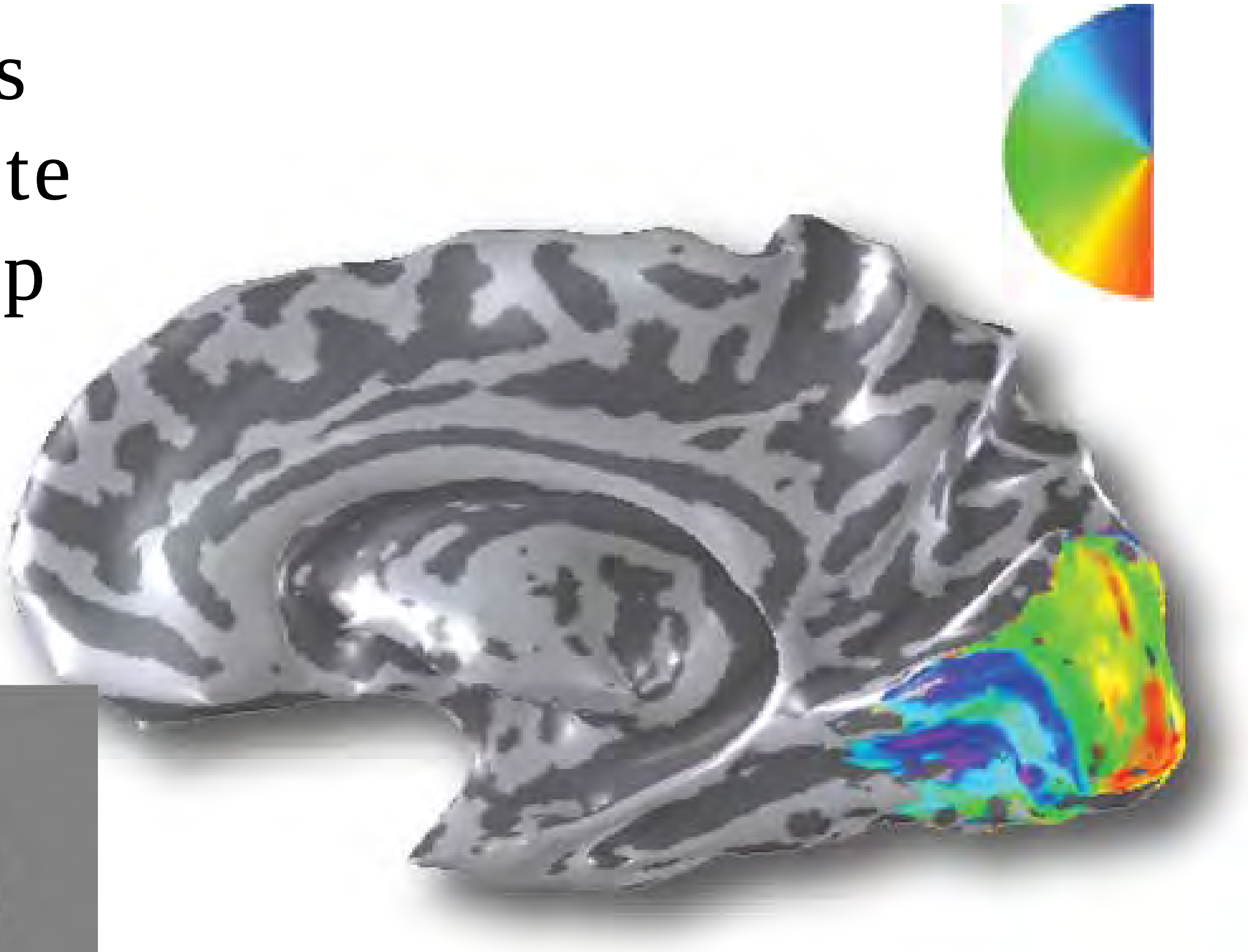
(Engel et al., 1994,1997; Sereno; DeYoe; Others)

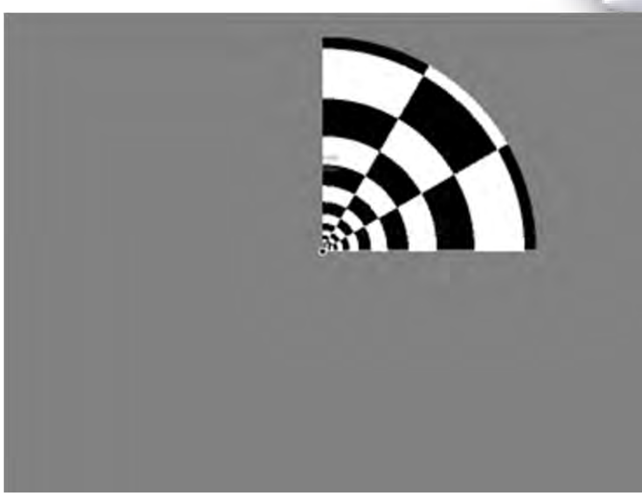


Pseudo-color representation of visual field map

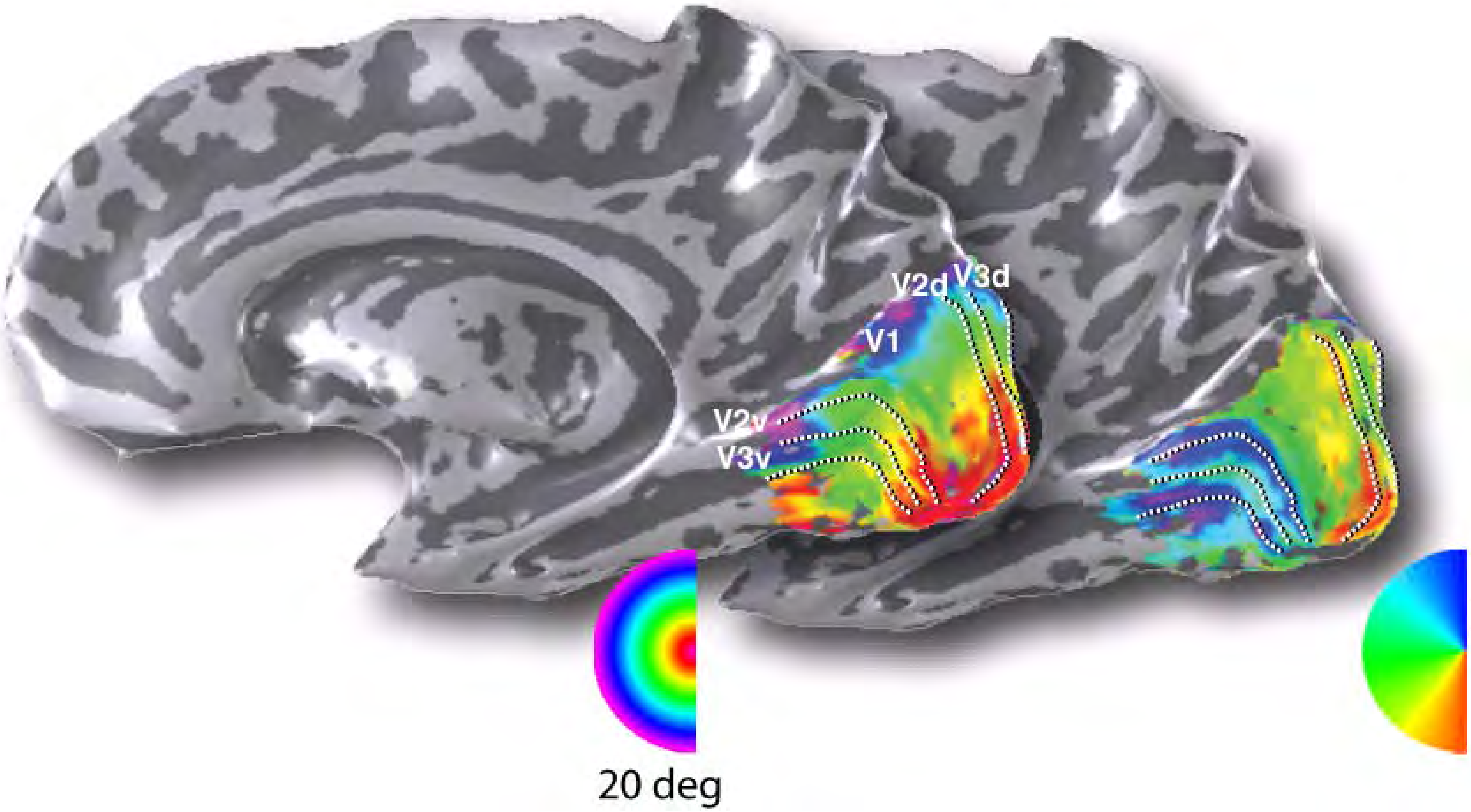


Angular measurements sharply delineate visual field map boundaries



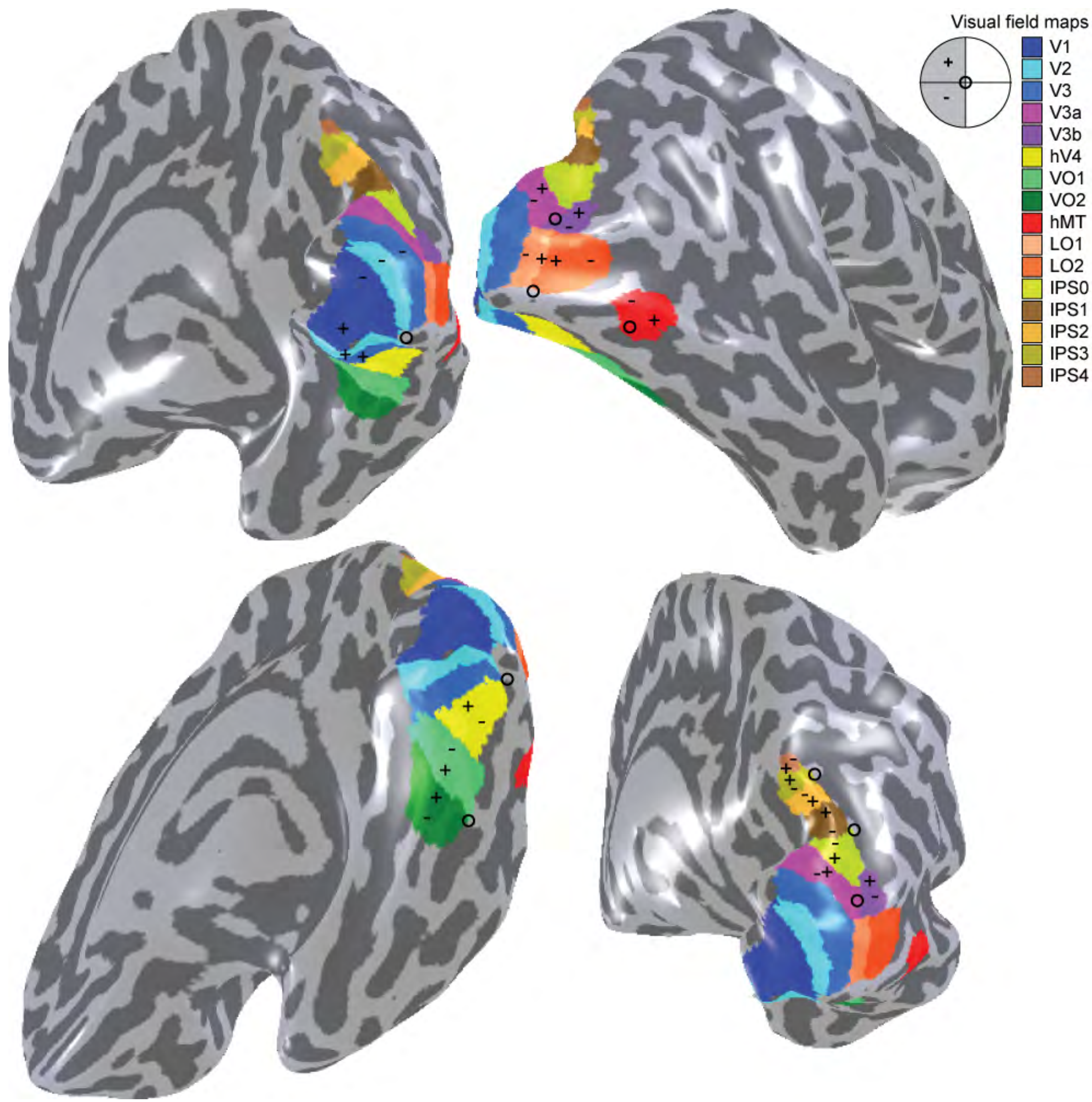


Combining eccentricity and angle data yields maps



More than sixteen visual field maps

Wandell, Dumoulin, Brewer (2007) Neuron

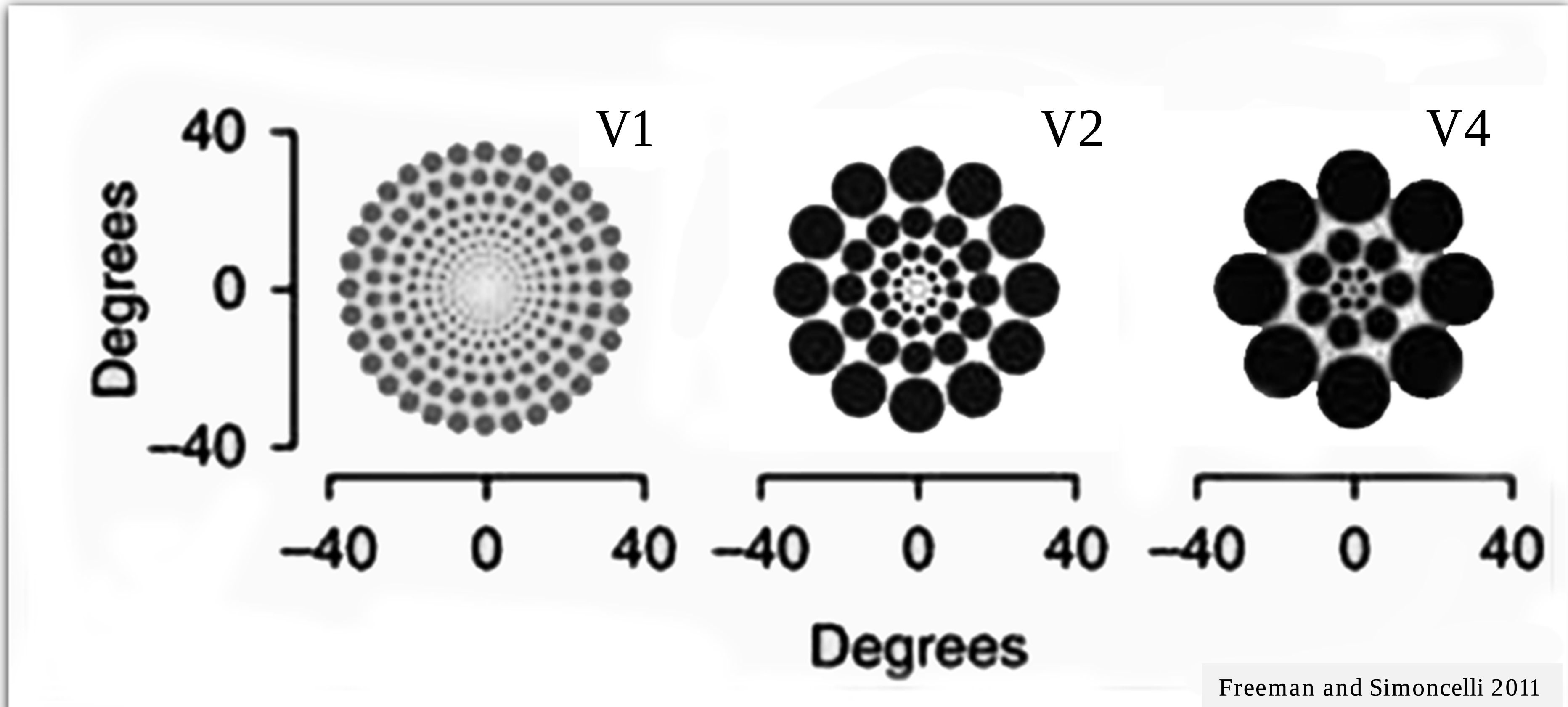


New developments in fMRI signal processing:

Modeling neurons that cause the fMRI response

RF size increases across maps and eccentricity

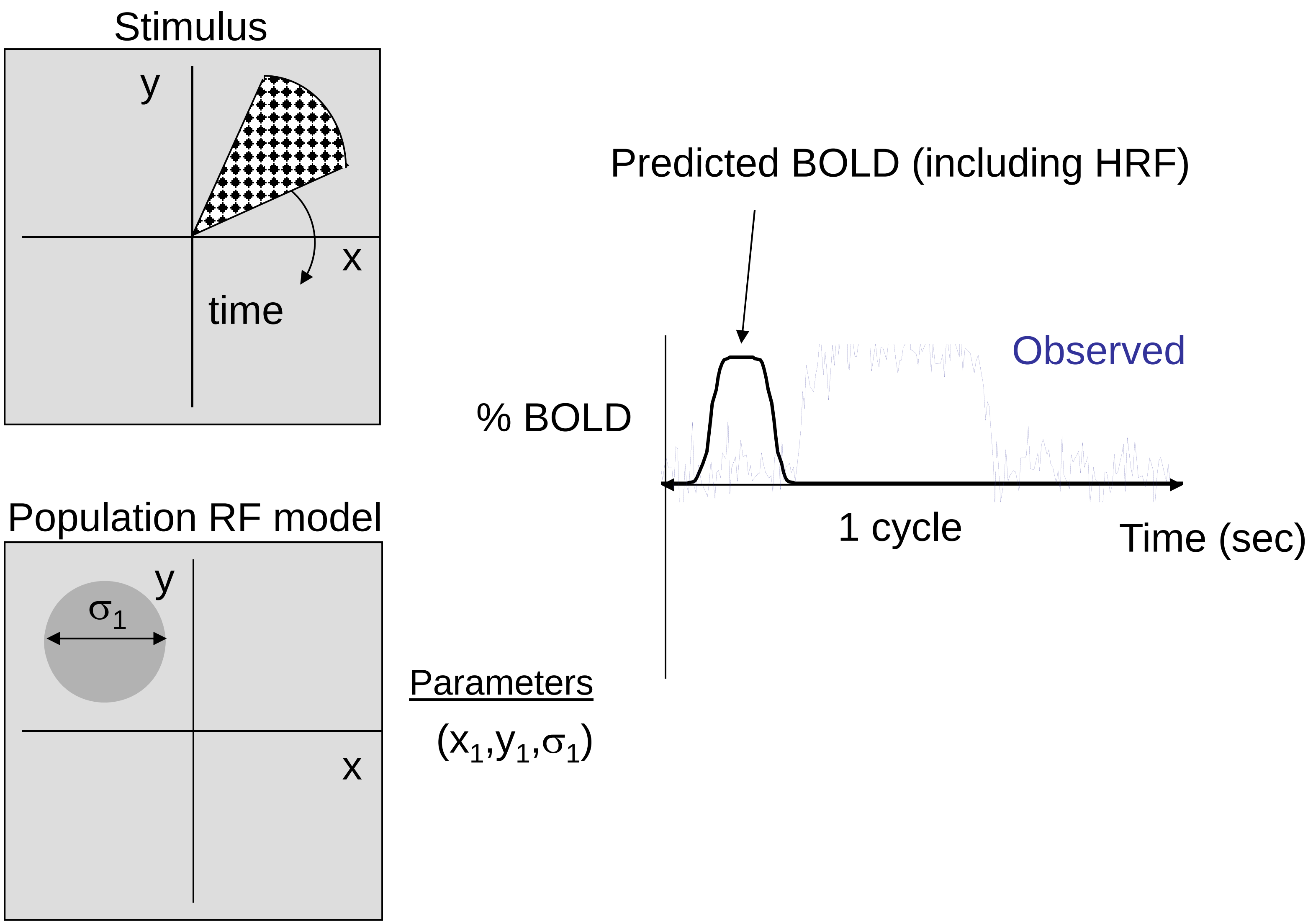
'*Responses can be obtained in a given optic nerve fiber only upon illumination of a certain restricted region of the retina, termed the receptive field of the fiber (Hartline, 1936)*'.



Freeman and Simoncelli 2011

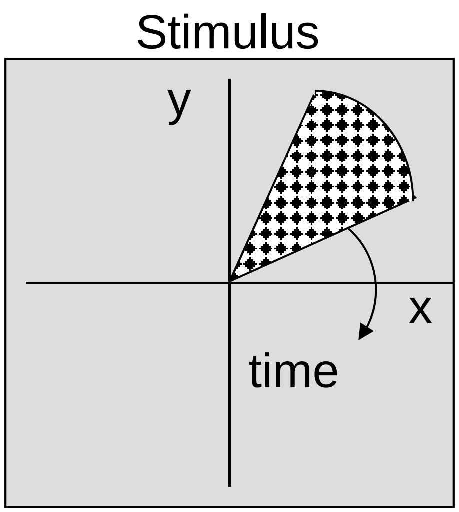
Population RF estimation

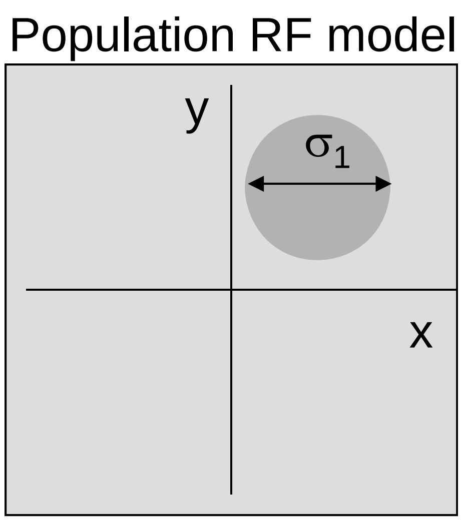
(Dumoulin and Wandell, 2008)



(Dumoulin and Wandell, 2008)

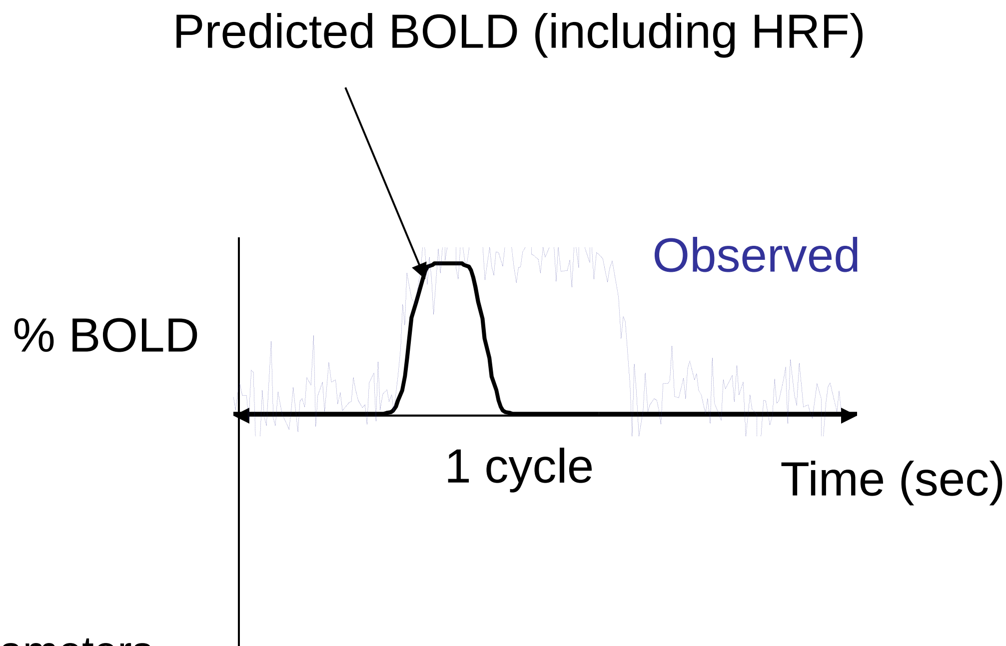
Population RF estimation





Parameters

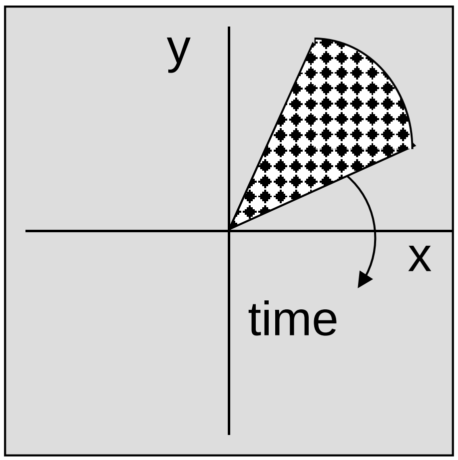
(x_2, y_2, σ_1)



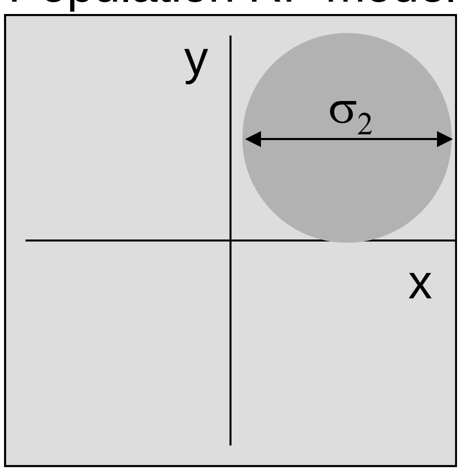
(Dumoulin and Wandell, 2008)

Population RF estimation

Stimulus

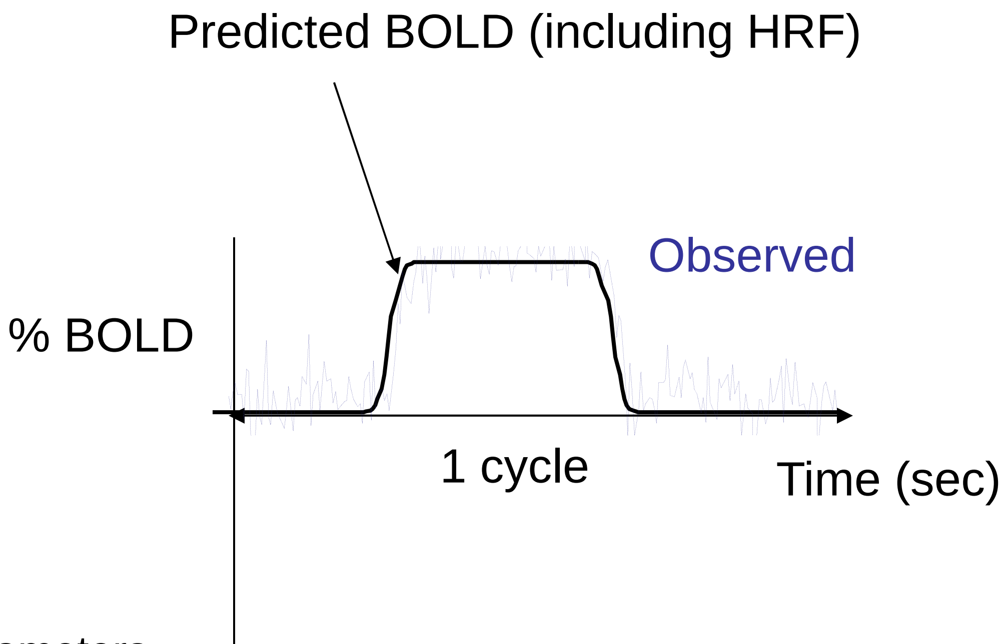


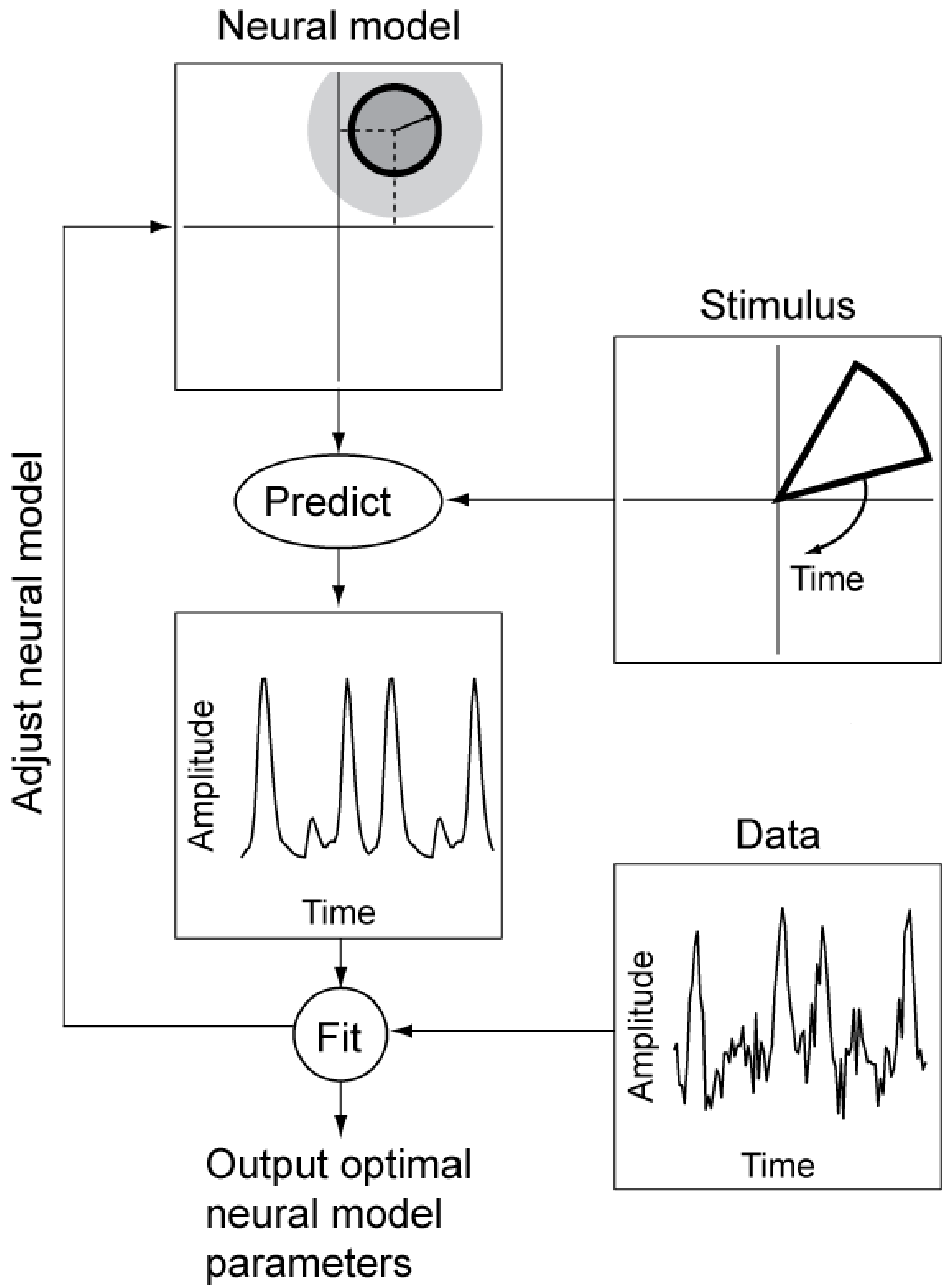
Population RF model



Parameters

(x_2, y_2, σ_2)

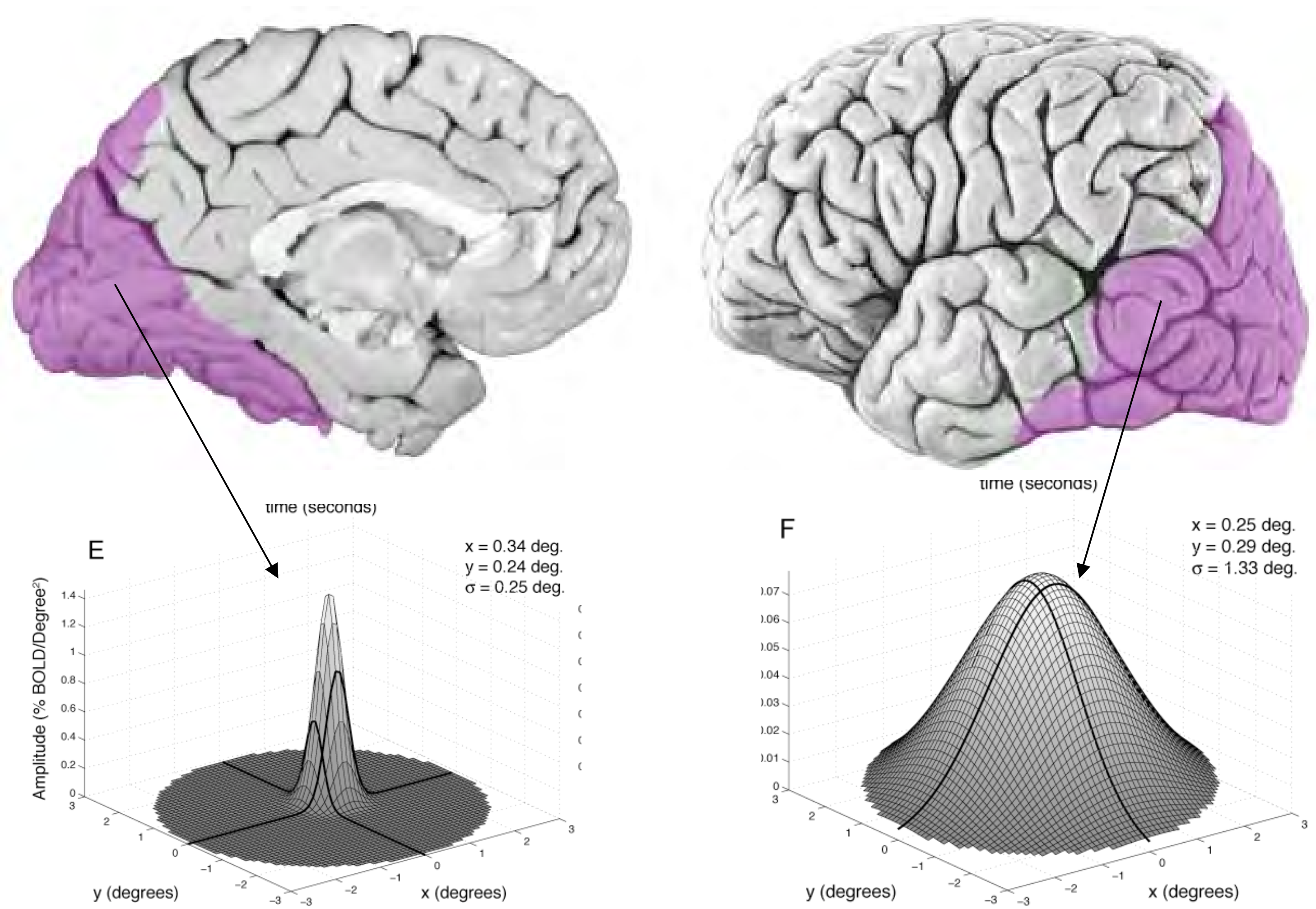




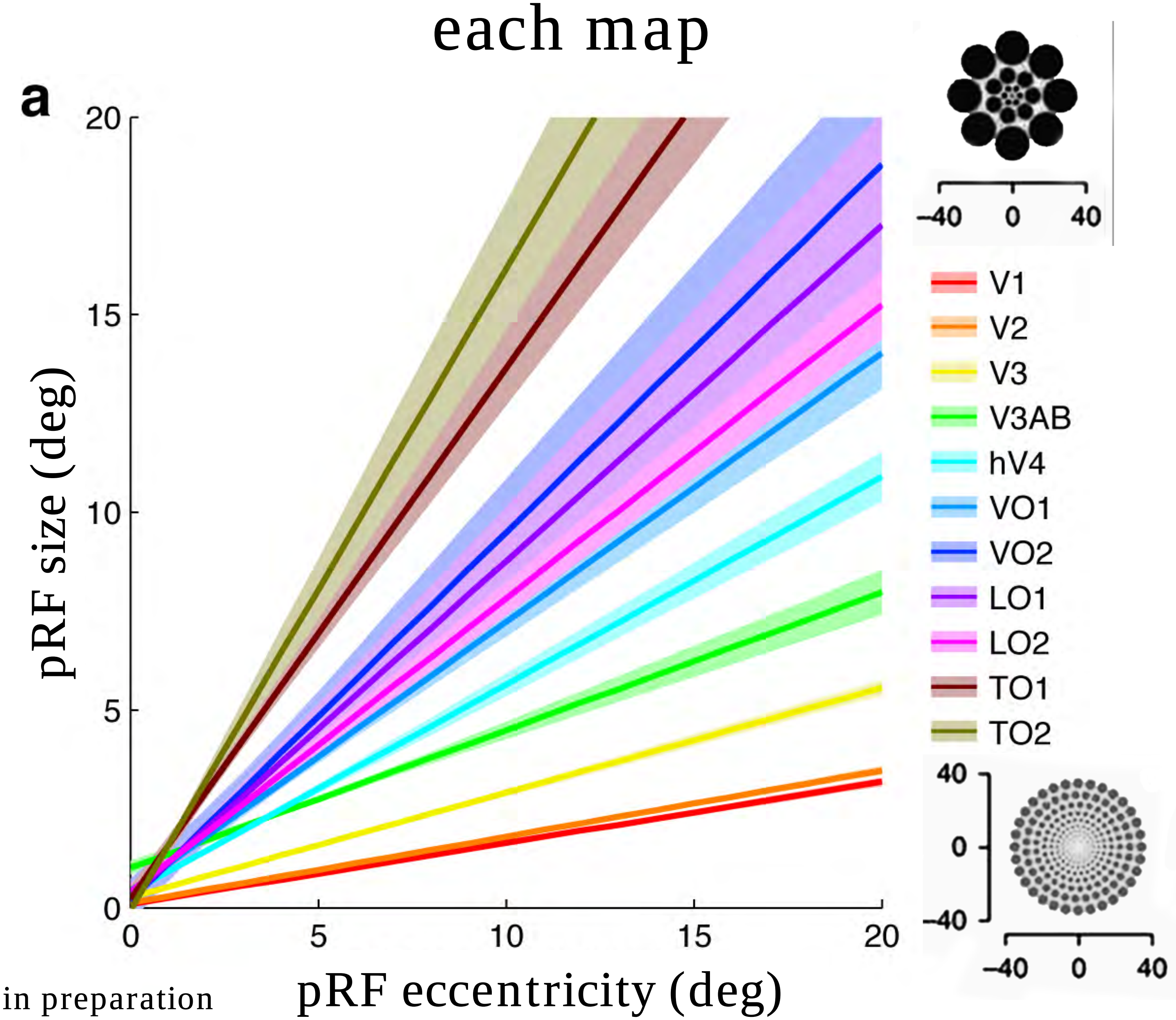
(Dumoulin and Wandell, 2008)

(Dumoulin and Wandell, 2008)

Population receptive field vary significantly across human visual cortex



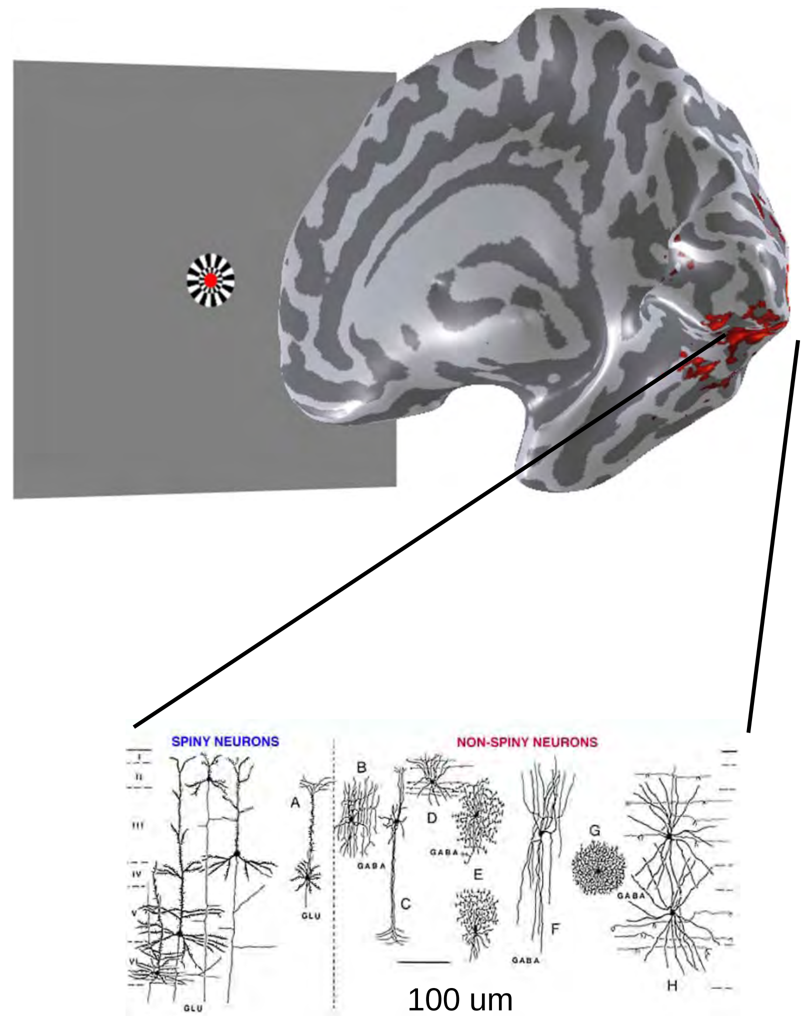
Population RF increases with eccentricity in each map



Kay et al., in preparation

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:

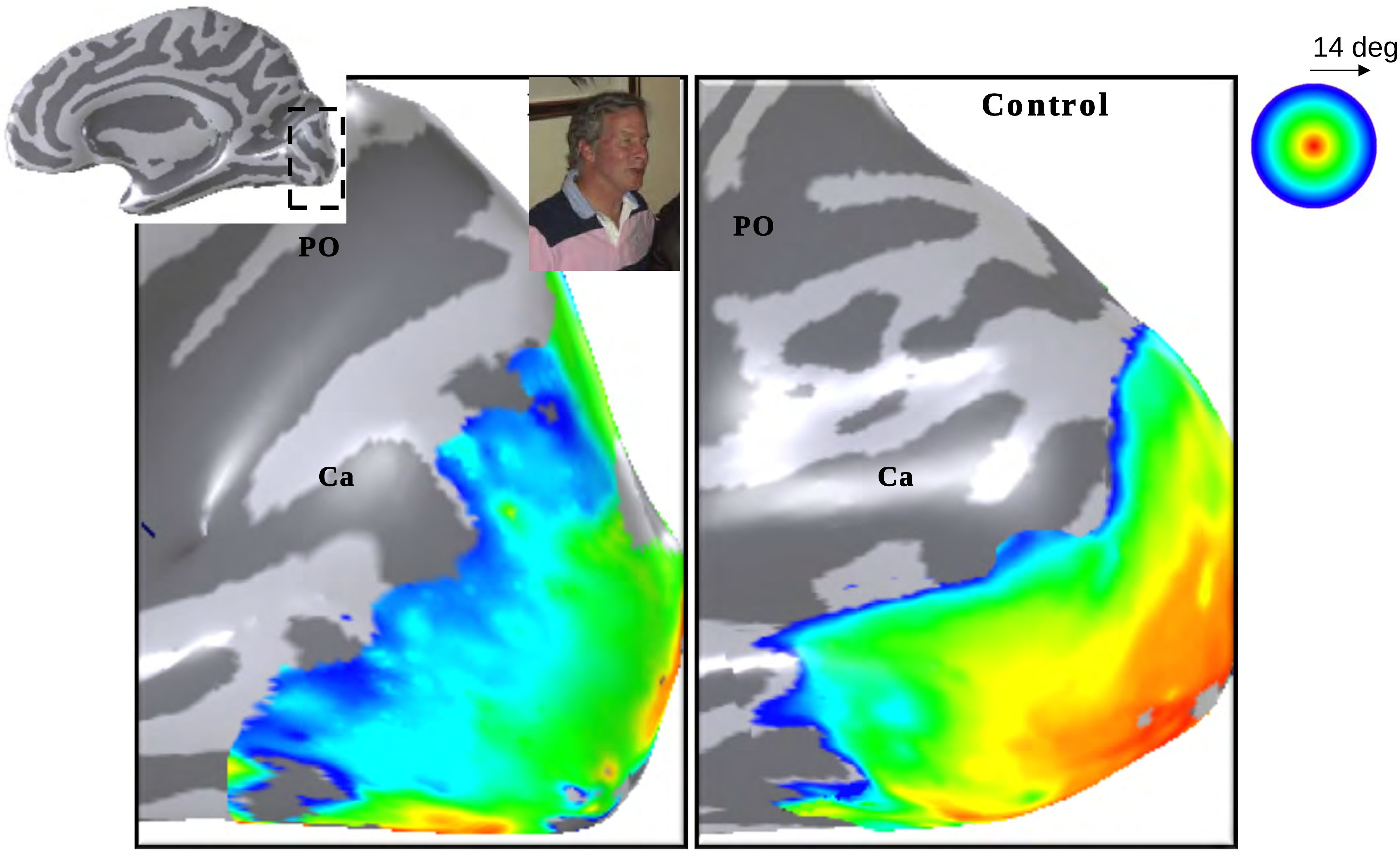
Curing blindness

Levin et al., 2010, Neuron

Stem cells, curing blindness

Levin et al., 2010, Neuron

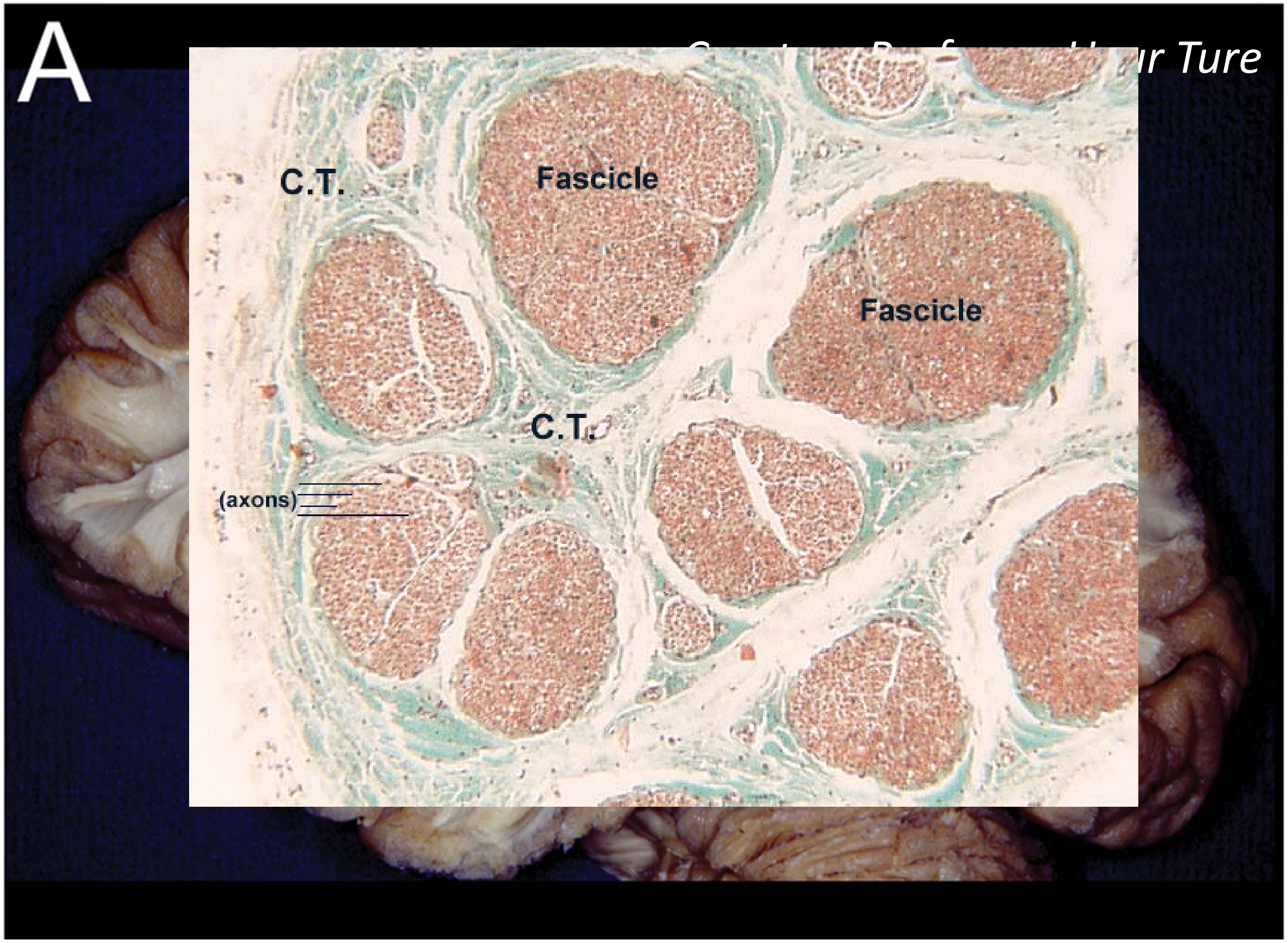
Why can't Mike see?
Missing signals to visual cortex



Human white matter

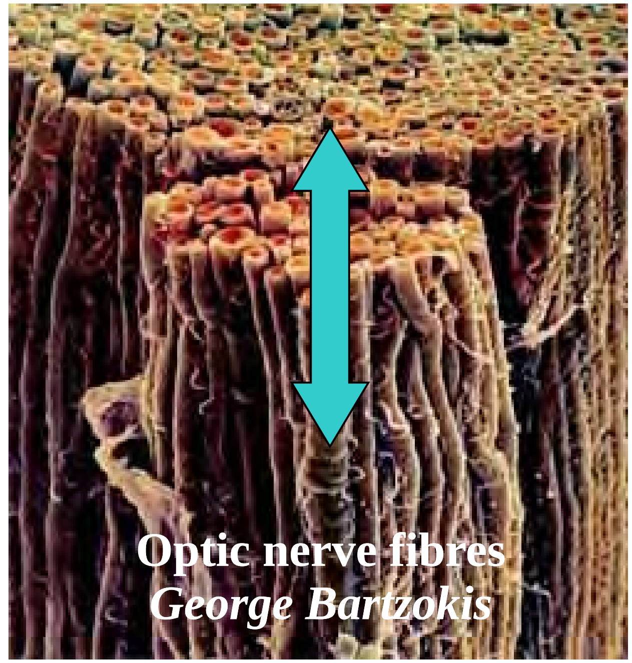
Measuring the major connections using diffusion imaging

Human fiber tracts



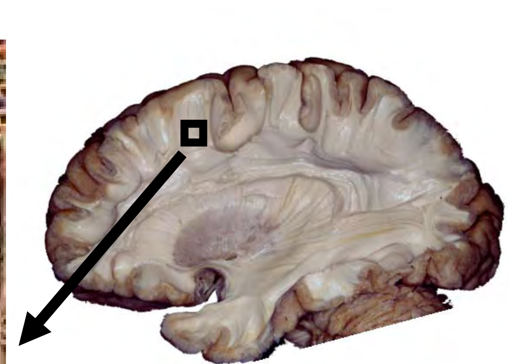
Diffusion probes brain microscopic structure

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

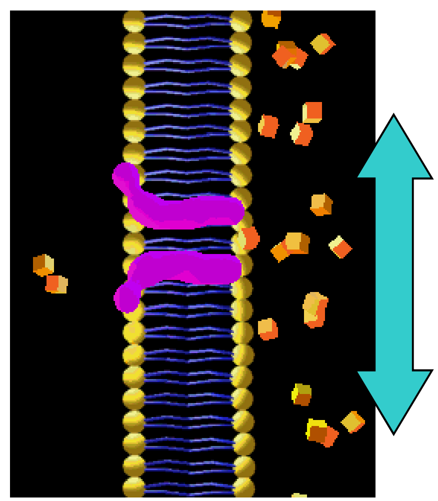


Optic nerve fibres
George Bartzokis

5 um

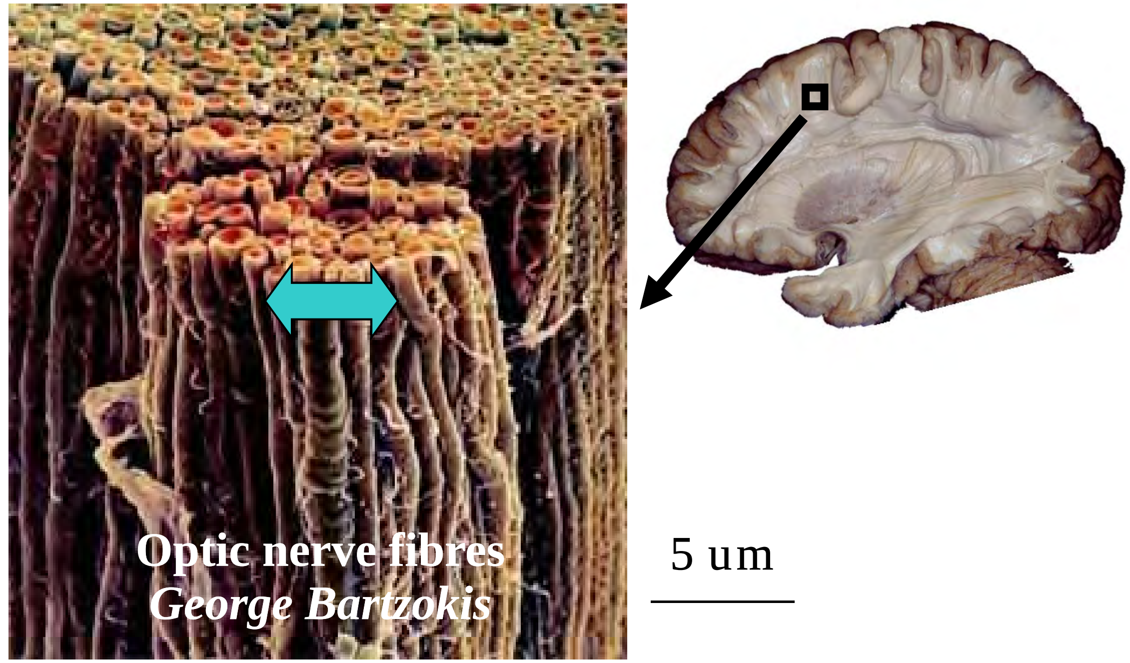


Longitudinal Diffusivity ($\mu m^2/ms$)

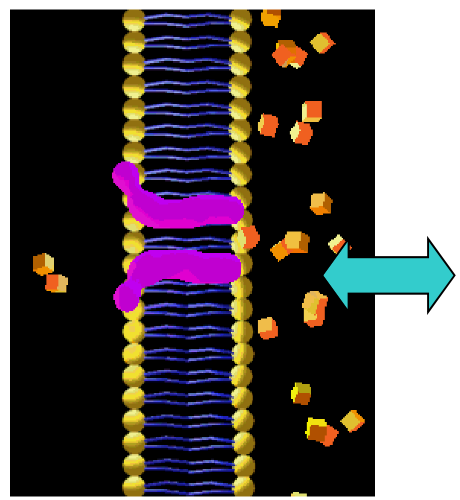


Diffusion probes brain microscopic structure

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

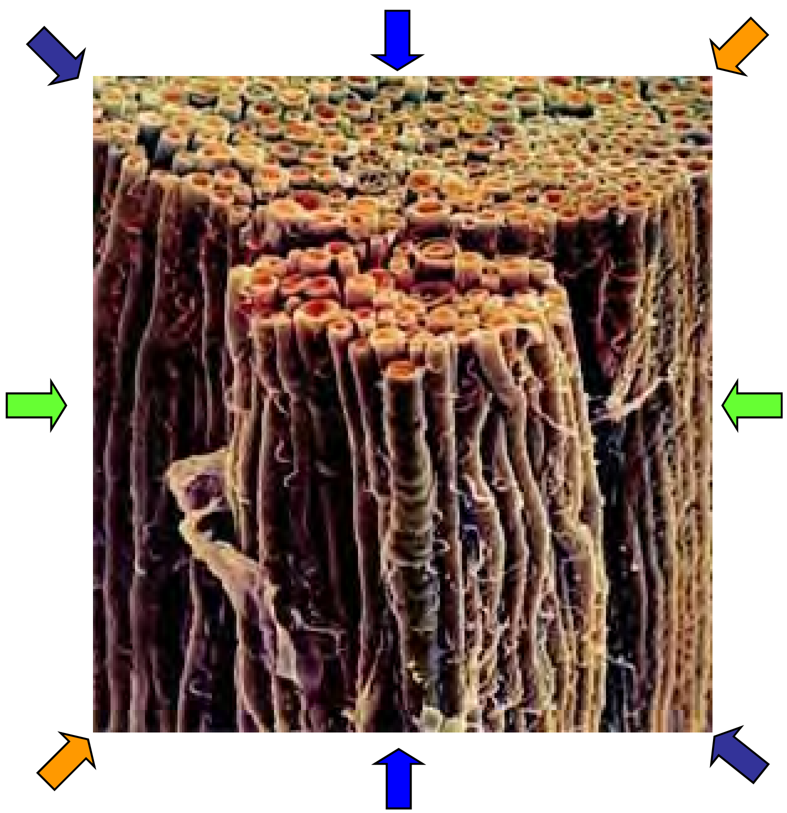


Radial Diffusivity (μm^2/ms)



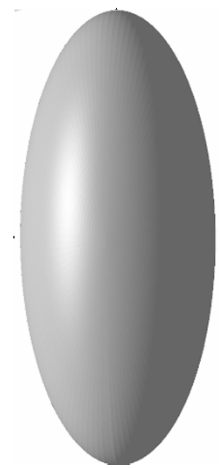
Diffusion Tensor Imaging (DTI)
A summary of the ADC at low b-values

5 um



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

v is a 3d-vector

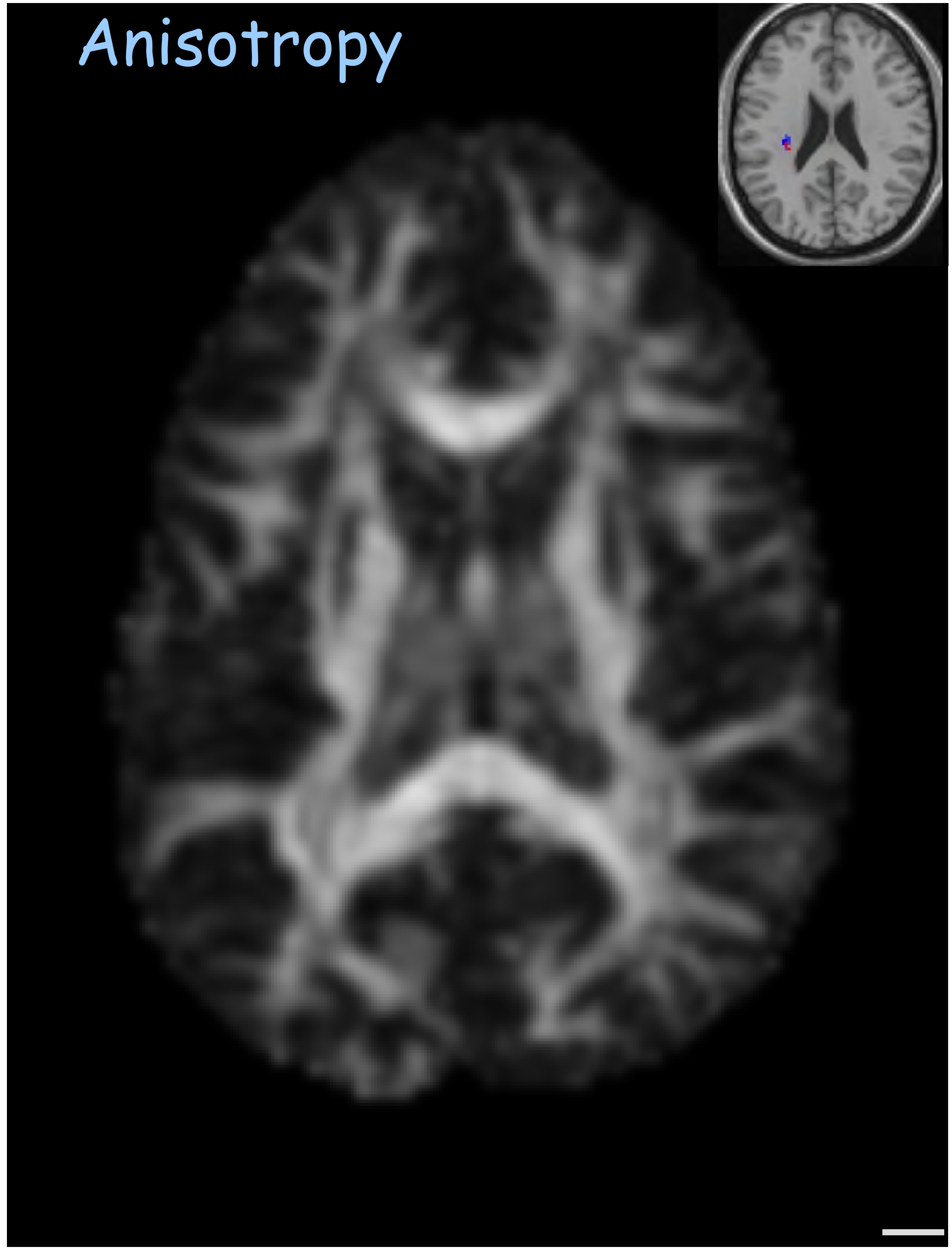


The **mean** distance a typical water molecule will diffuse in a unit of time

$$A = u' Q u$$

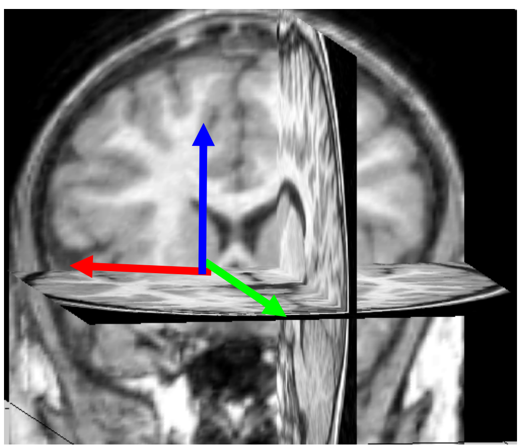
DTI summary measures of white matter microstructure

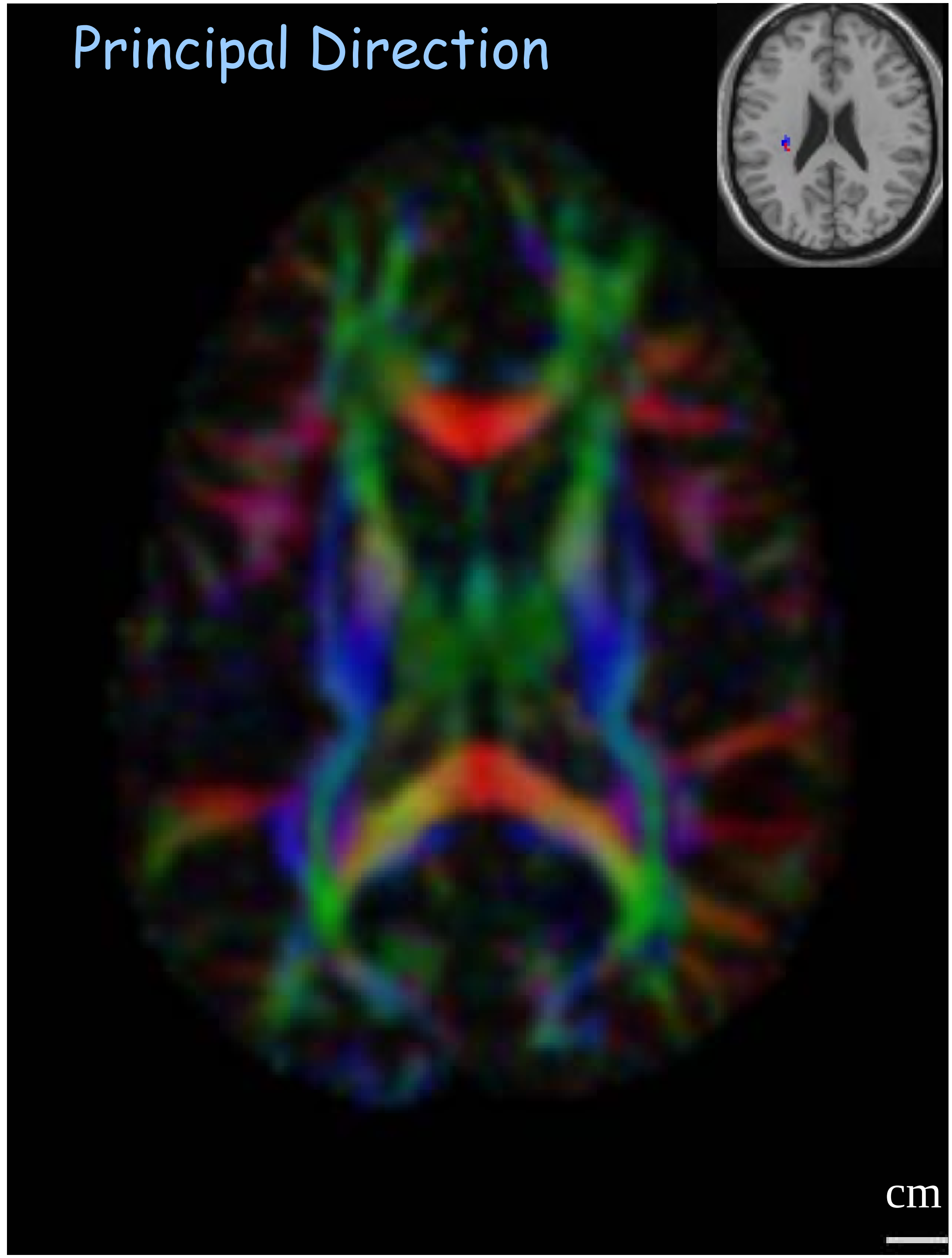
Fractional anisotropy



DTI summary measures of white matter microstructure

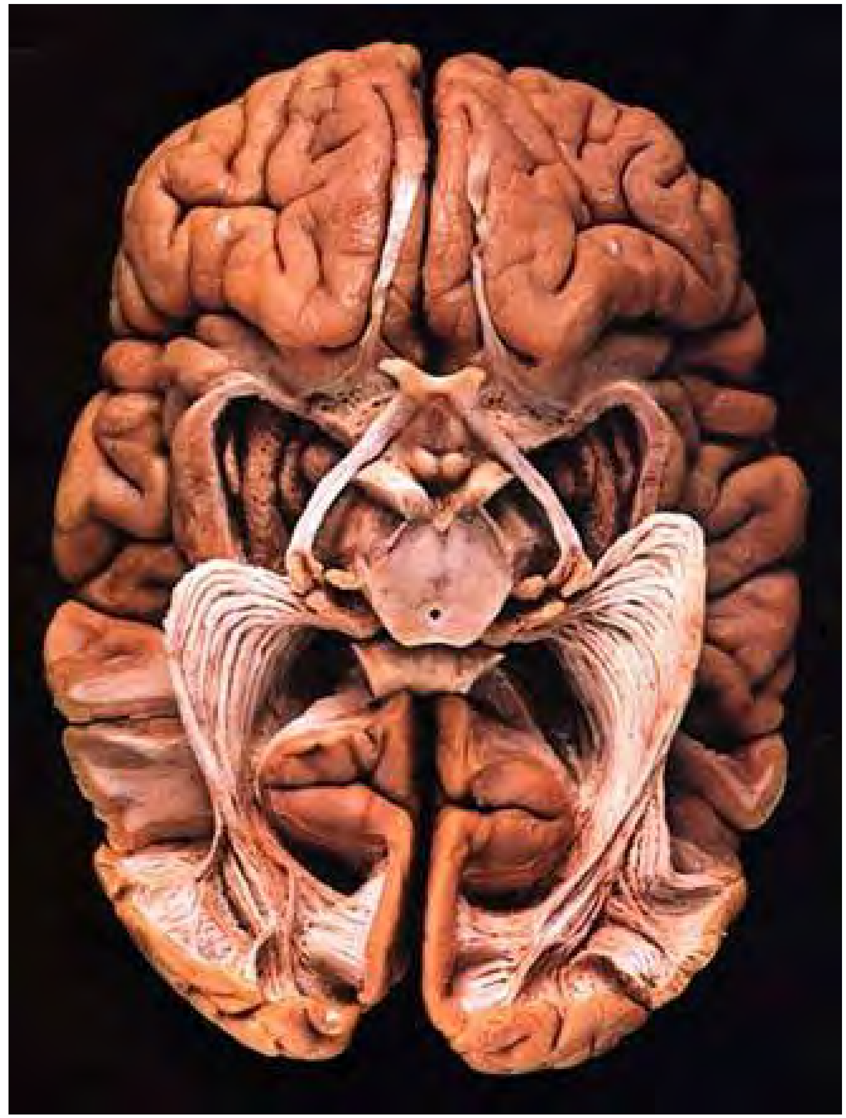
Principal diffusion direction





Tractography

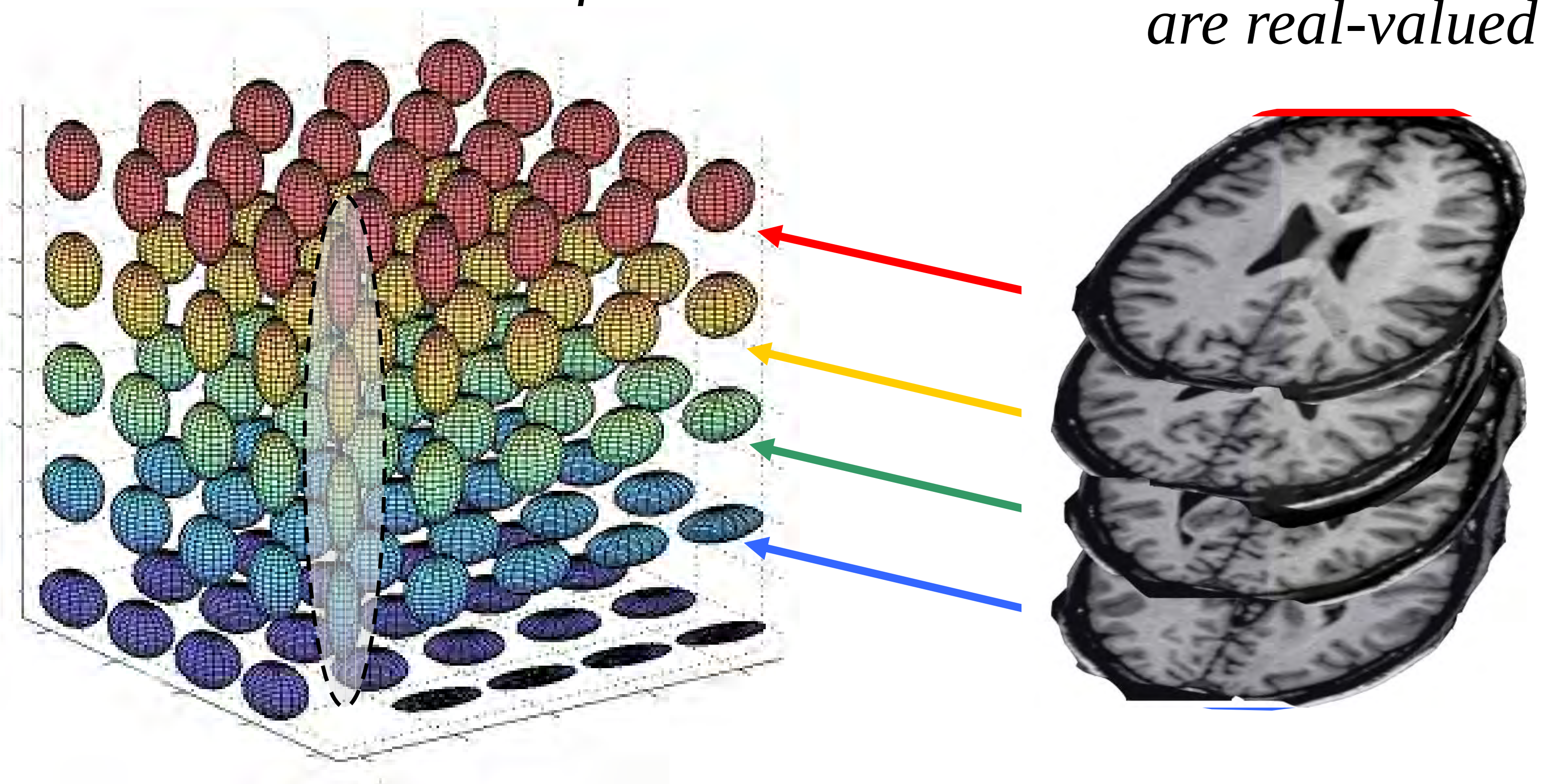
- Assembling the local (voxel) measurements to estimate white matter tracts



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

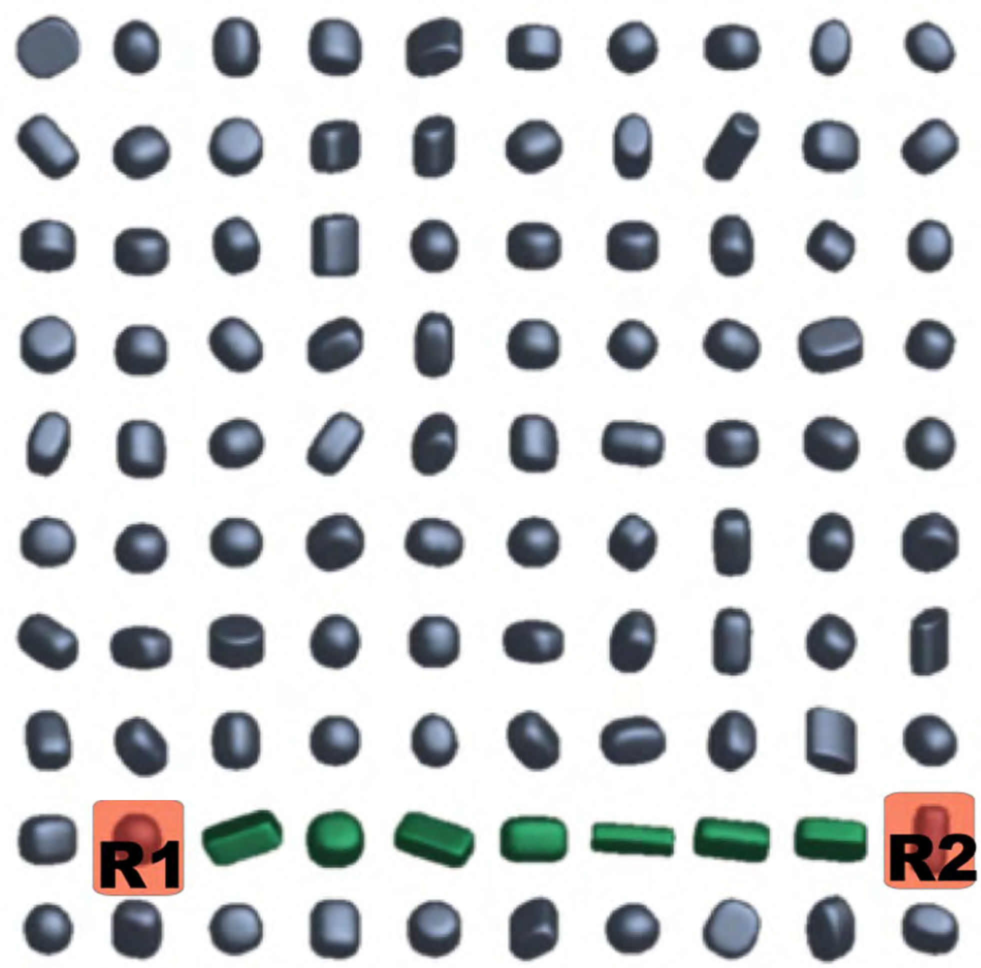
DTI data are surfaces

Conventional MR volumes are real-valued



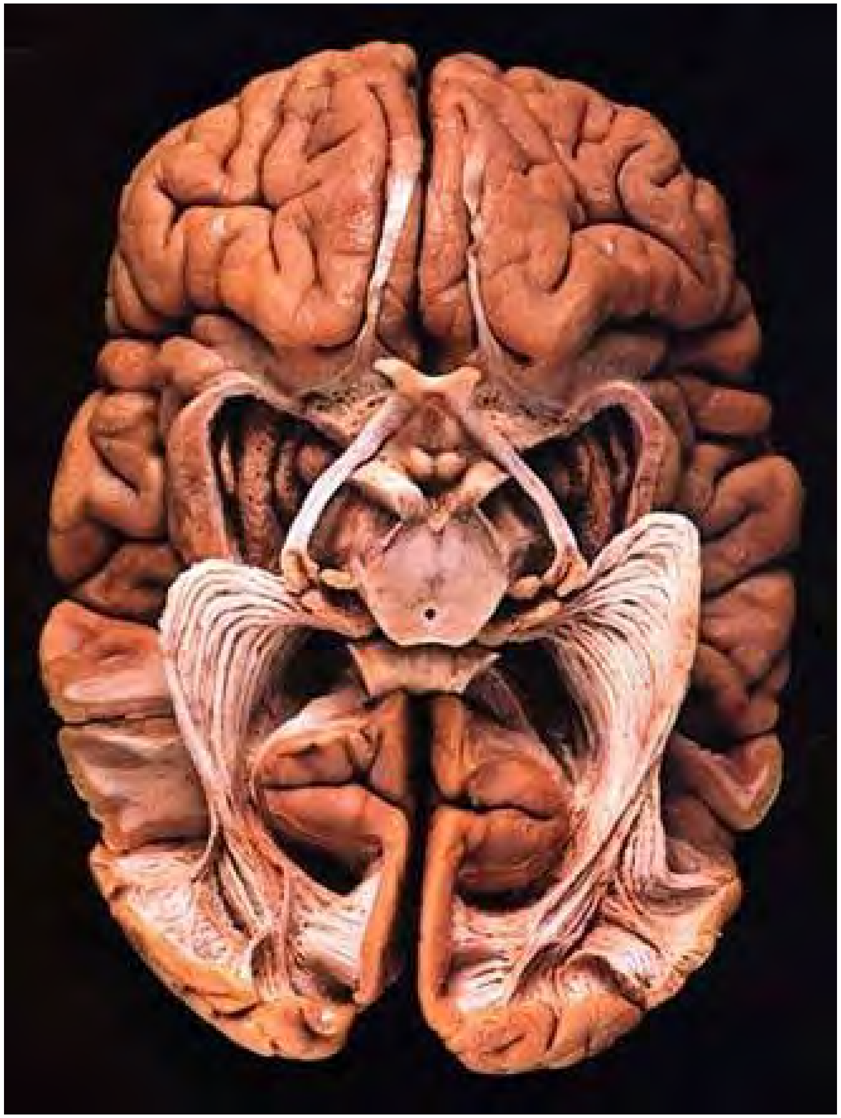
Tractography desiderata
Separate scoring and inference
(Sherbondy et al., 2008)

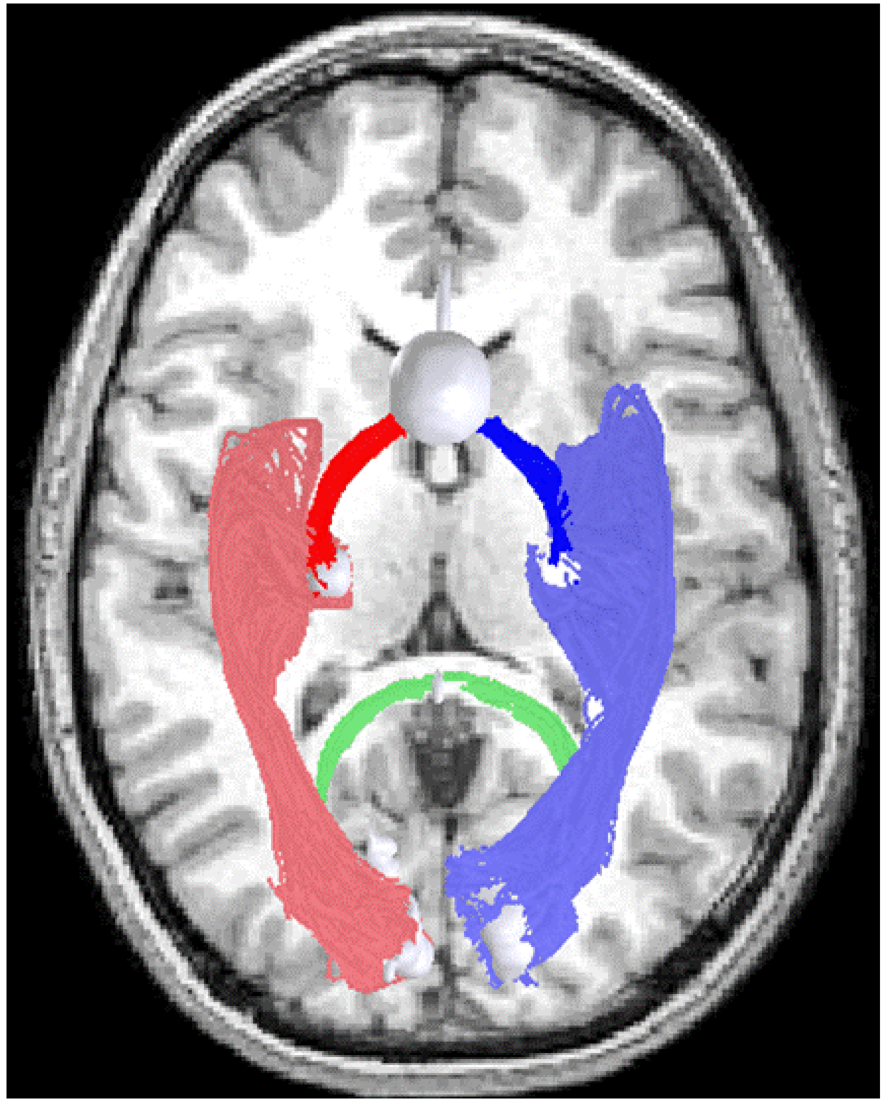
- Symmetry
- Independence



Major visual white matter tracts

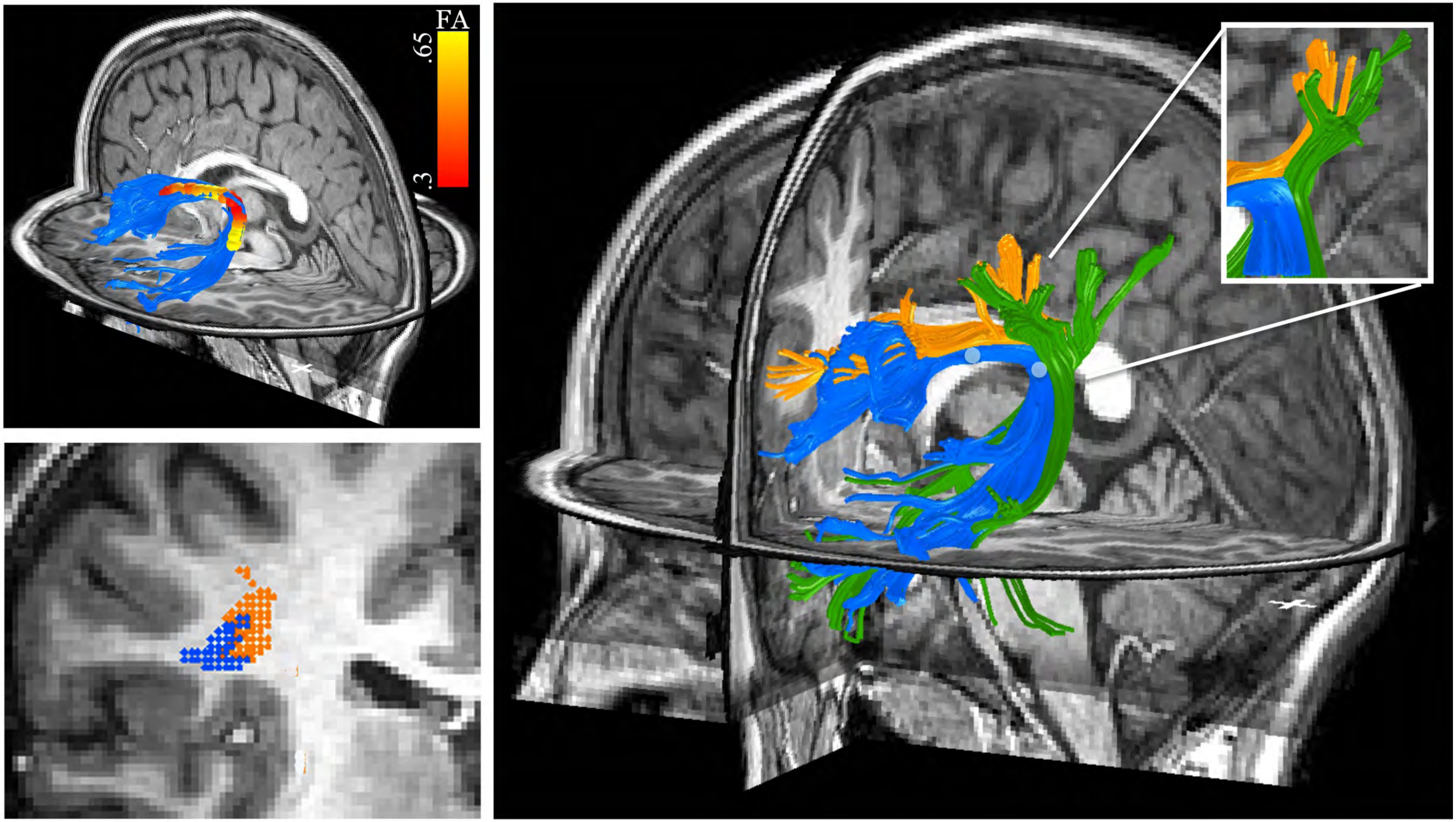
(Sherbondy et al., 2008; N. Levin. et al.. Neuron. 2010)



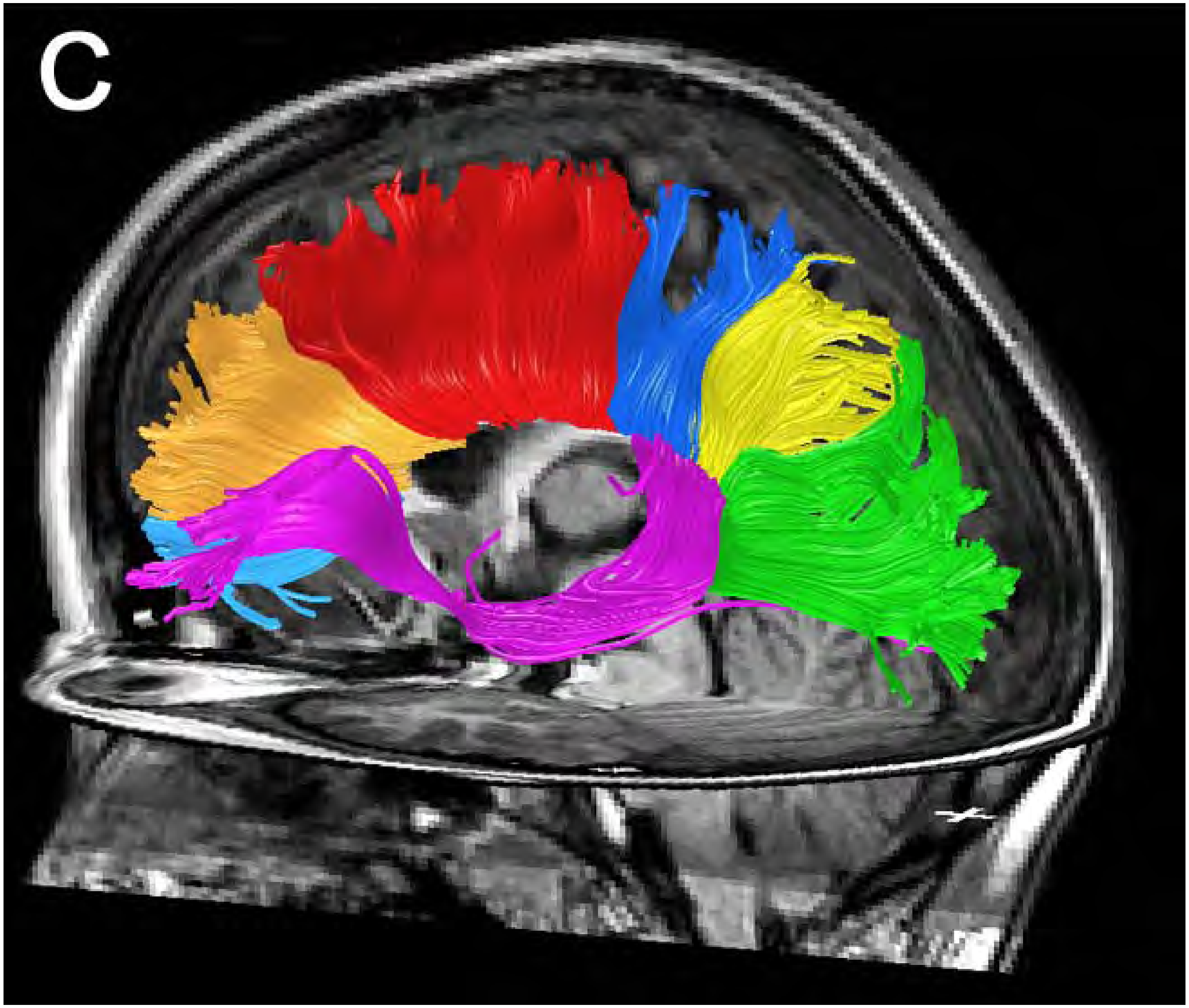


Reading related tracts

(Yeatman et al., 2011)

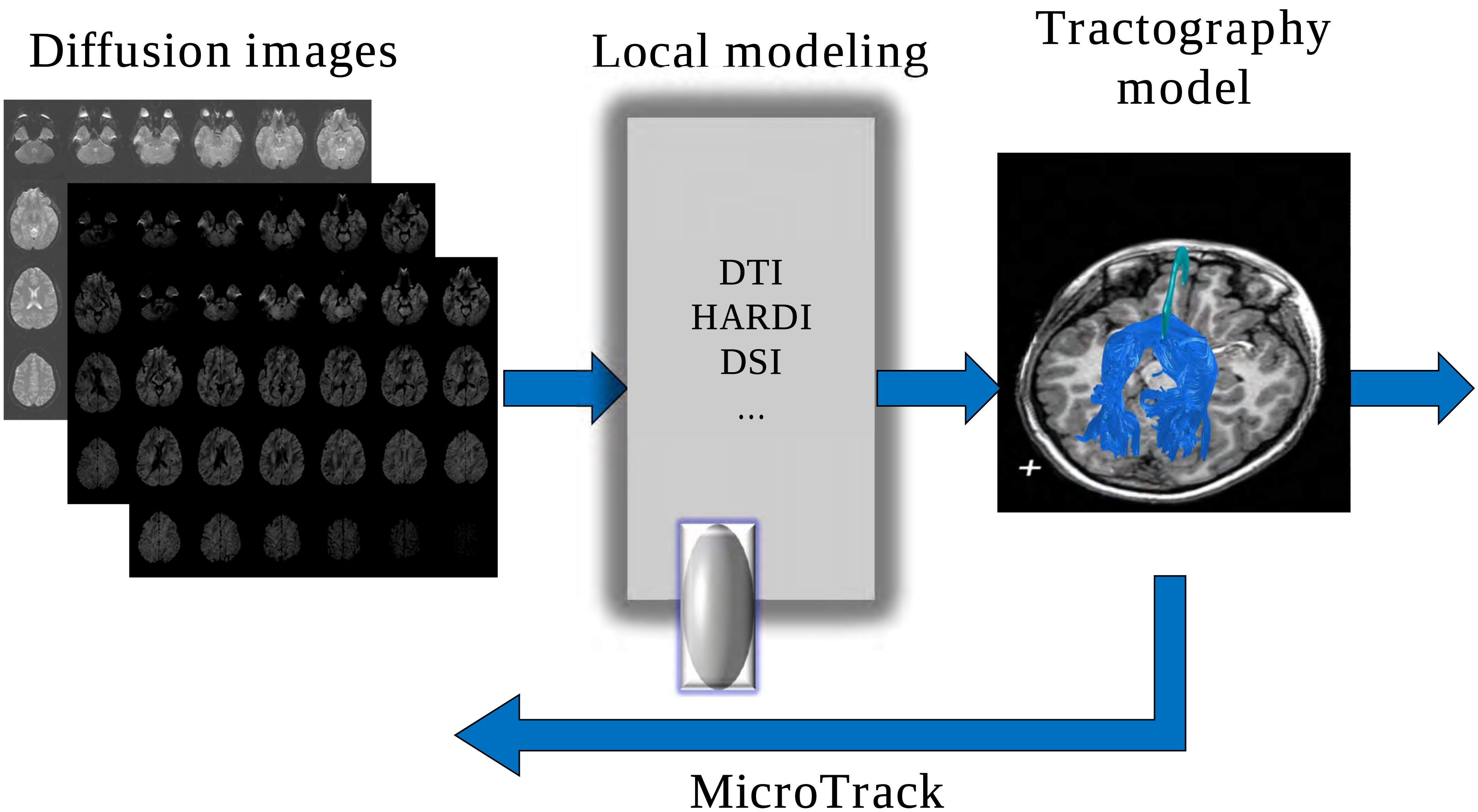


Inter-hemispheric tracts



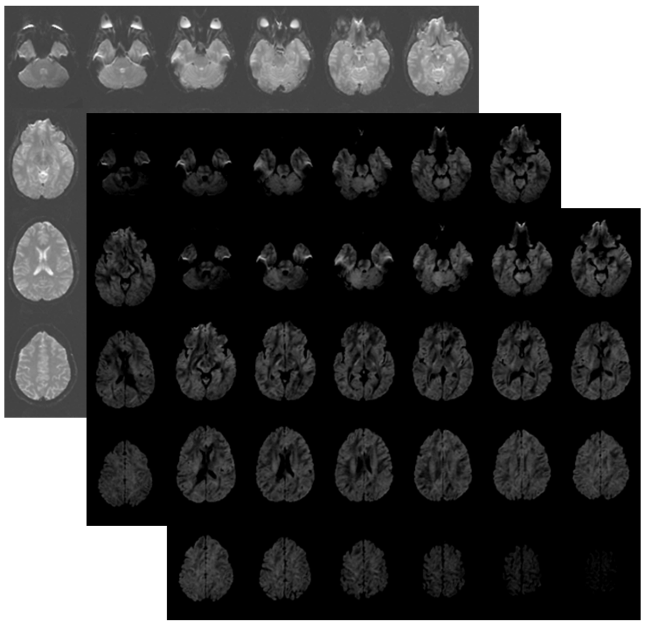
What’s next: Evaluate the tracts

MicroTrack: Closing the loop



MicroTrack: Hypothesis testing

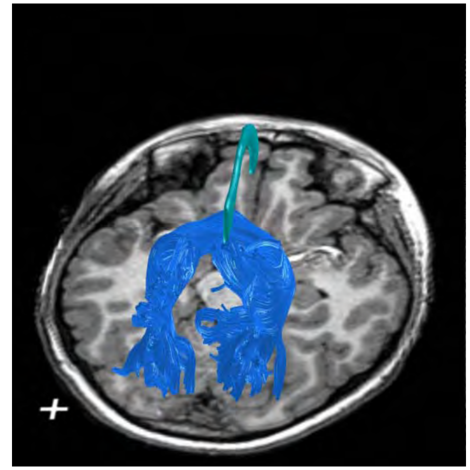
Diffusion images



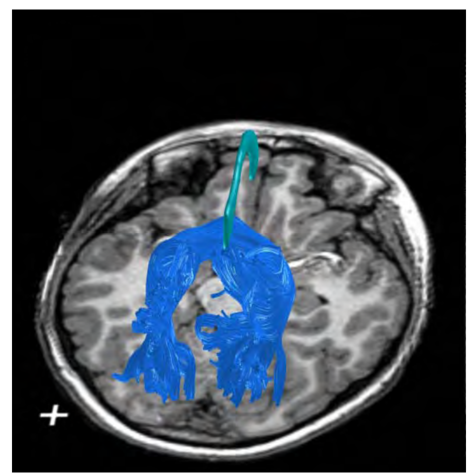
- Volume regularization
- Diffusion predictions

MicroTrack

Fascicles A



Fascicles B

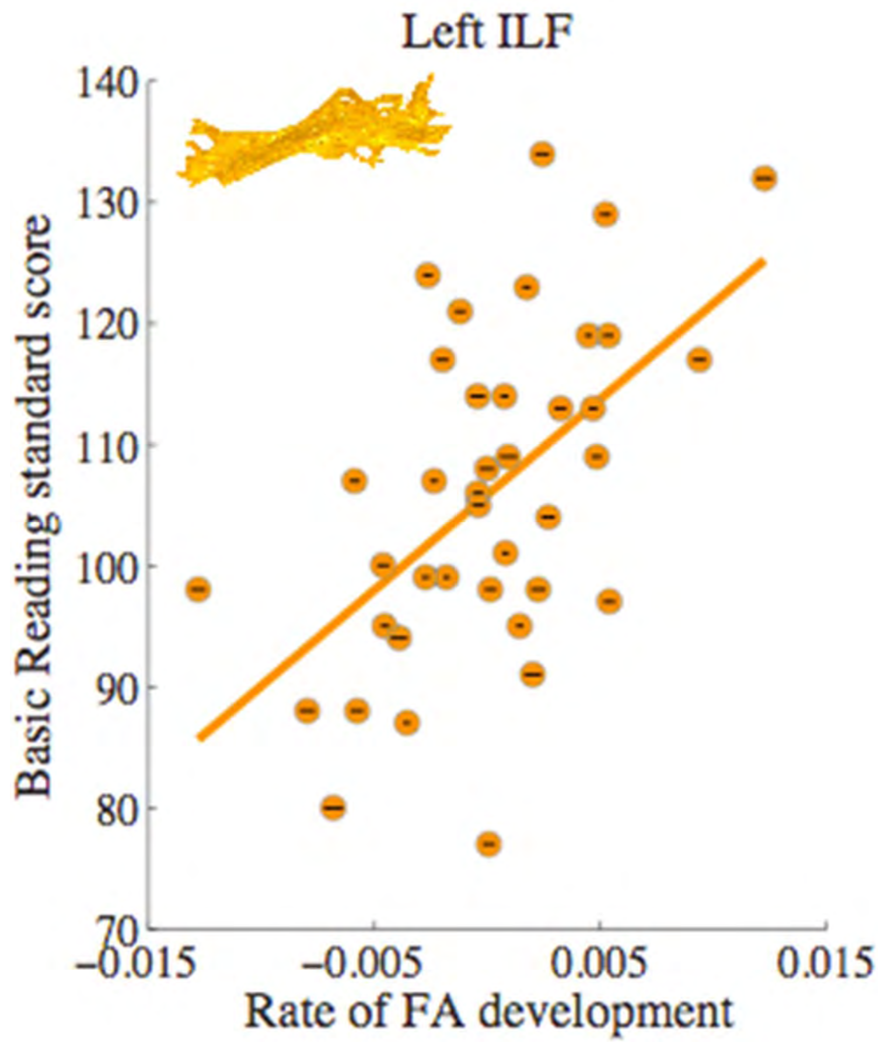


Applications of tractography

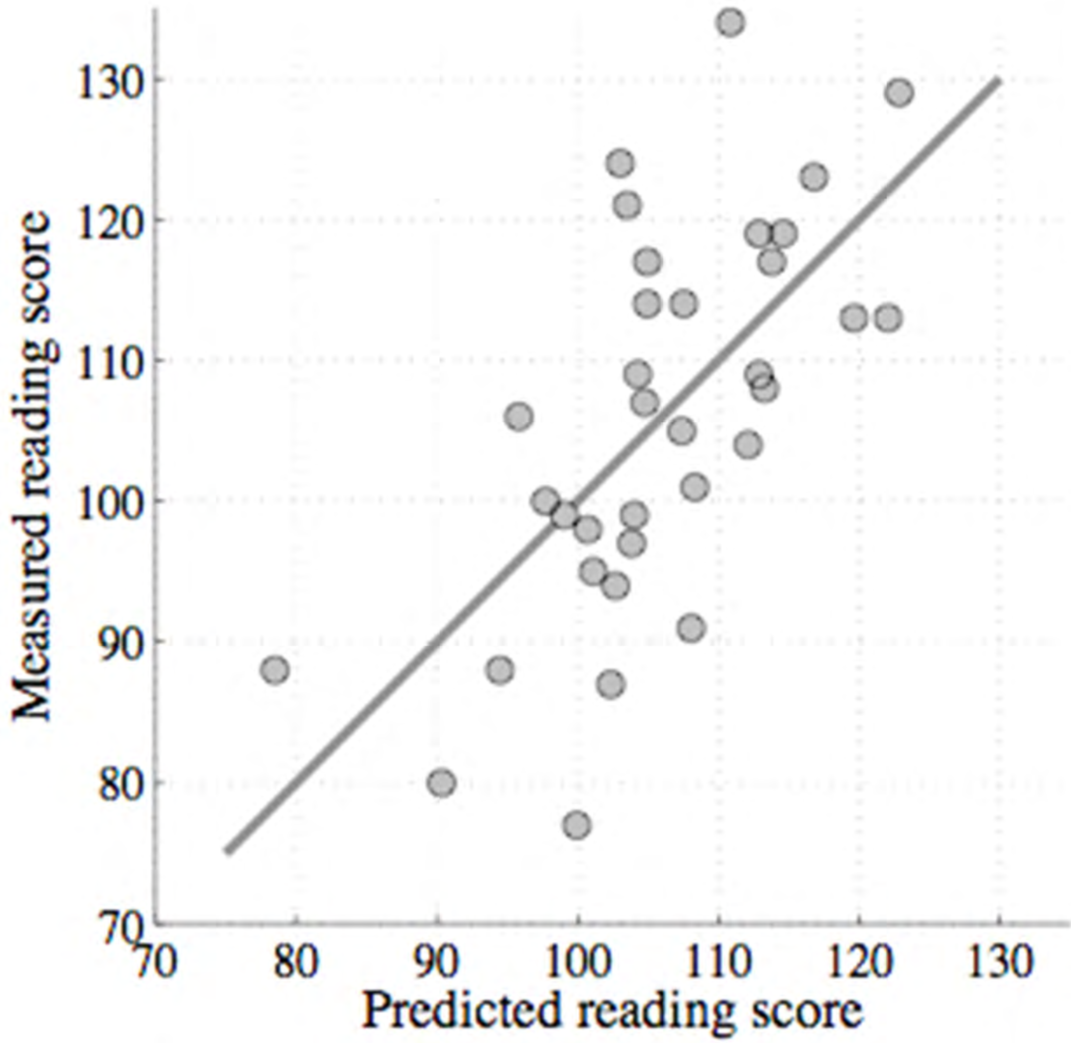
Reading development

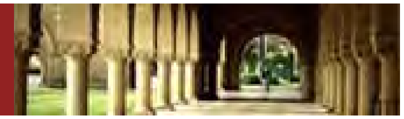
Strong associations between white matter tract FA and reading
(Yeatman et al., 2011)

This is one of several examples



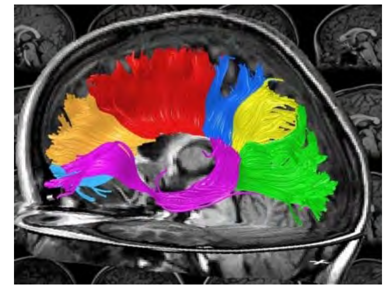
Predicting reading scores from white matter maturity

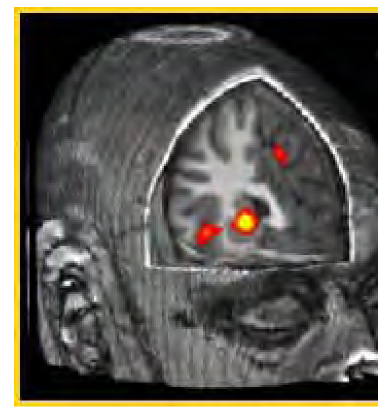




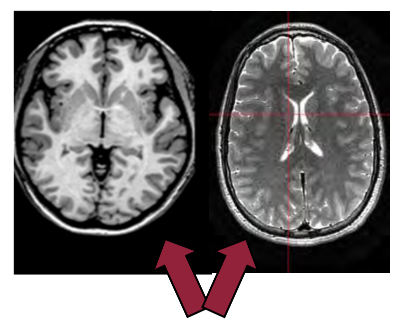
Mission

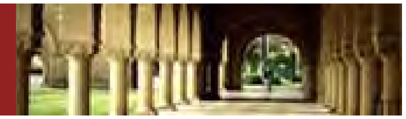
Discoveries about the brain have implications for fields ranging from Business, Law, Psychology, and Education.





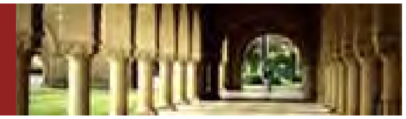
The Stanford Center for Cognitive and Neurobiological Imaging (CNI) supports scientific investigations into the human brain that make rigorous connections between neuroscience and society.



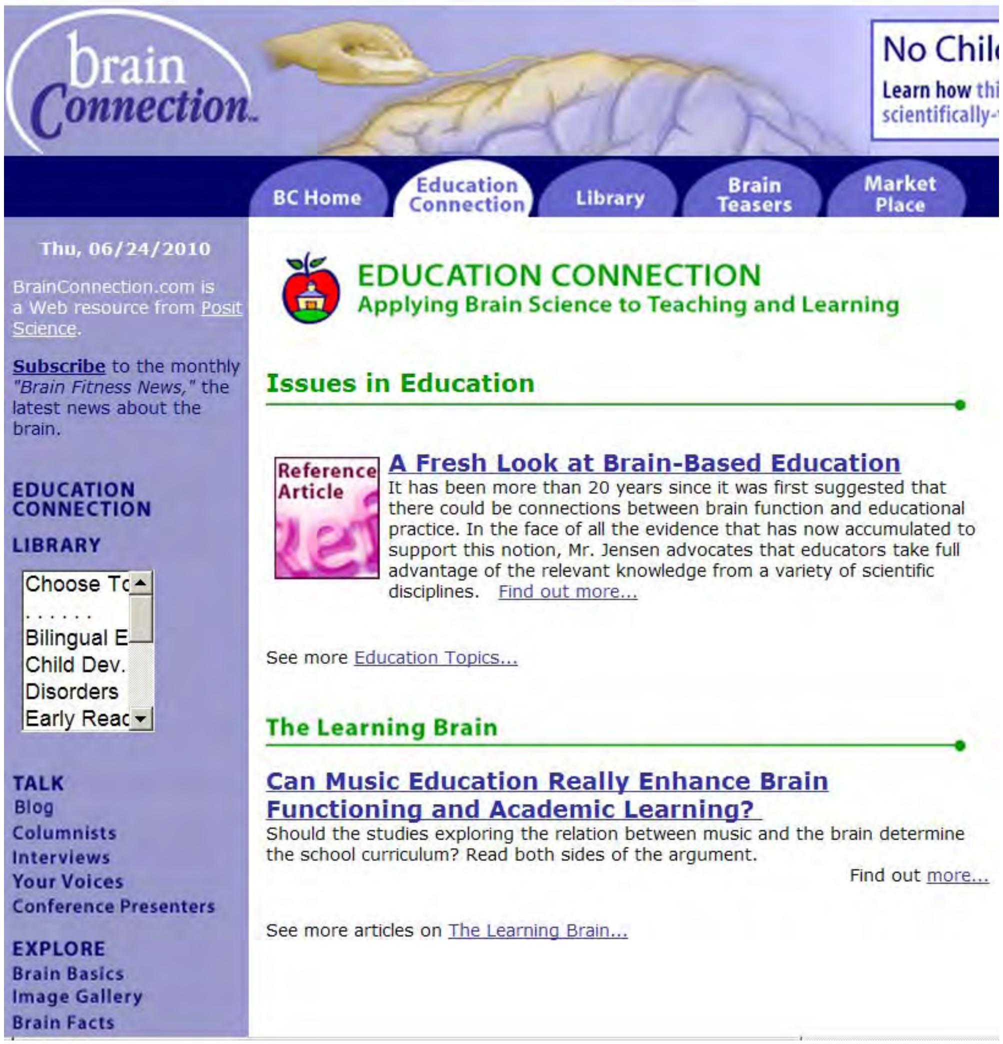


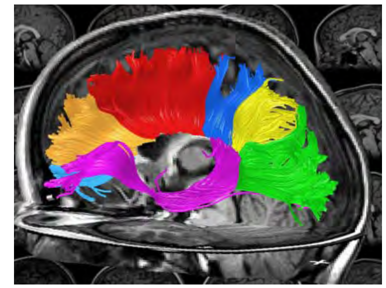
Neuro-law applications

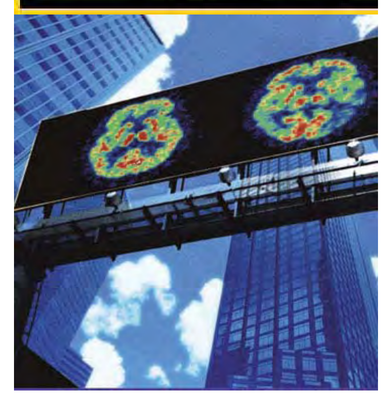
- Predict neurological disease – Alzheimer, schizophrenia
- Brain-reading (e.g., lie detection)
- Sentencing (juvenile cases)
- End-of-life (e.g., vegetative state)
- Brain interventions for offenders (addiction, sex-offenders)
- Neuroenhancement – witnesses and memory pills for examinations

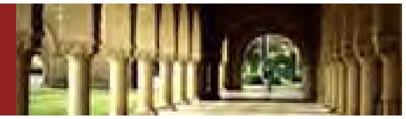


Education and Neuroscience

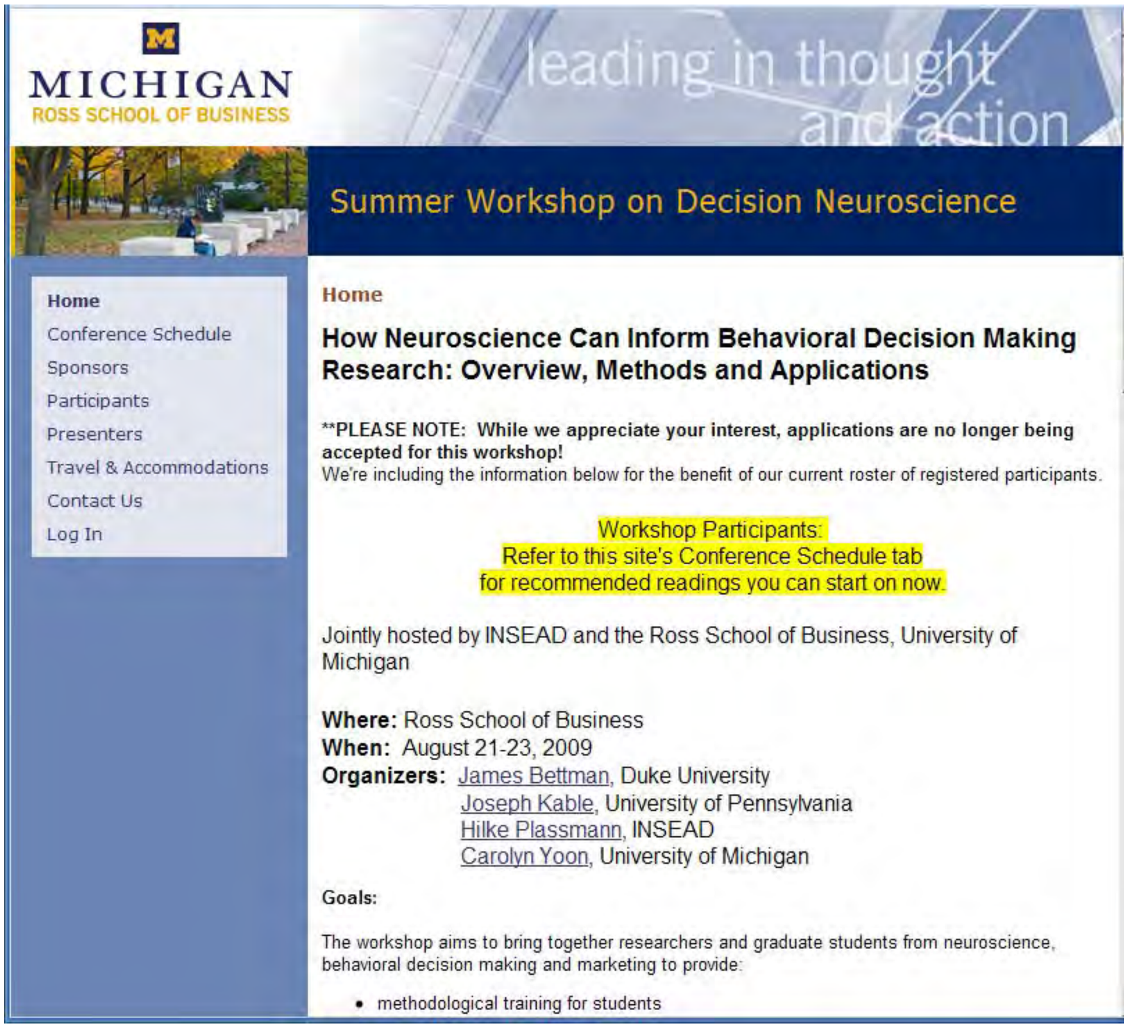








Business decision-making (Marketing)



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Summer Workshop on Decision Neuroscience

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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.

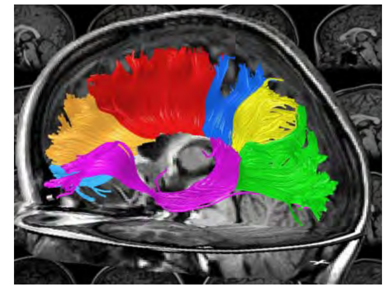
Jointly hosted by INSEAD and the Ross School of Business, University of Michigan

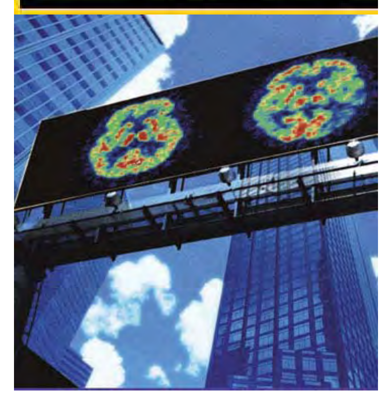
Where: Ross School of Business
When: August 21-23, 2009
Organizers: James Bettman, Duke University
Joseph Kable, University of Pennsylvania
Hilke Plassmann, INSEAD
Carolyn Yoon, University of Michigan

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

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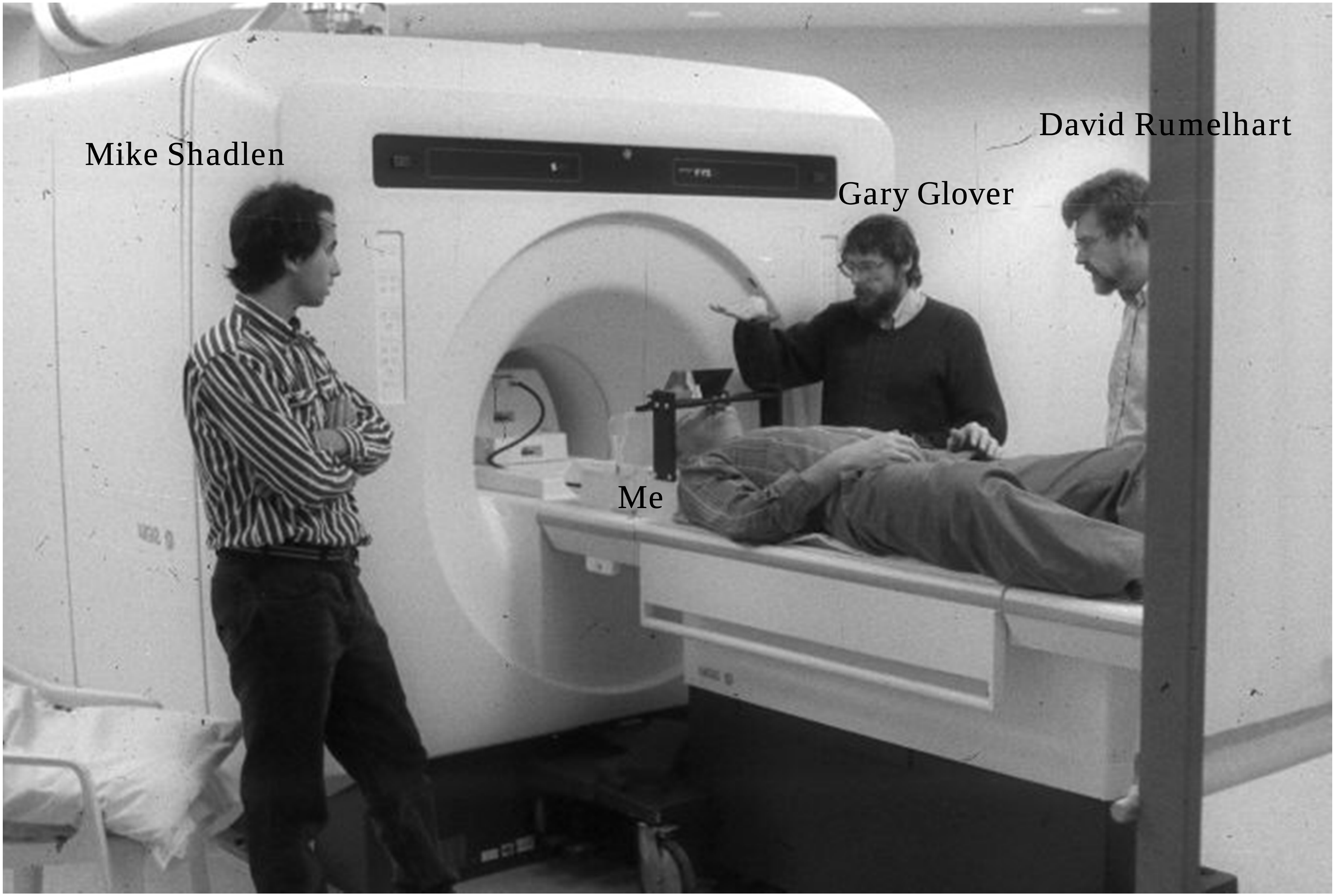



Alyssa Brewer
Alex Wade

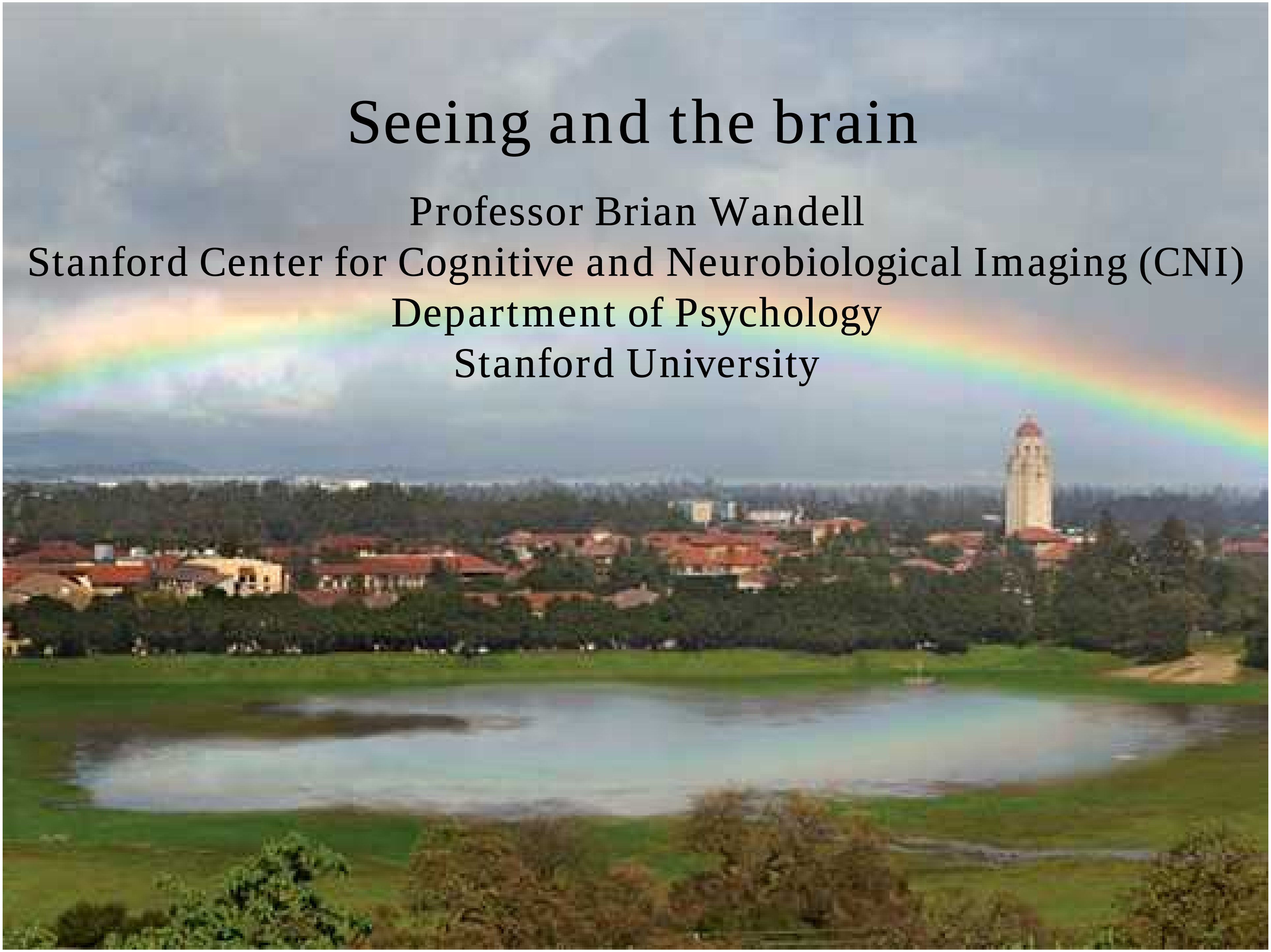
Hiroshi Horiguchi

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



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