

Thanks for the lunch

Brian A. Wandell

Stanford Neurosciences Institute

Stanford Center for Cognitive and Neurobiological Imaging

Stanford Center for Image Systems Engineering

Presenting the work of many people from my lab at Stanford

QUANTITATIVE MEASUREMENTS

∞

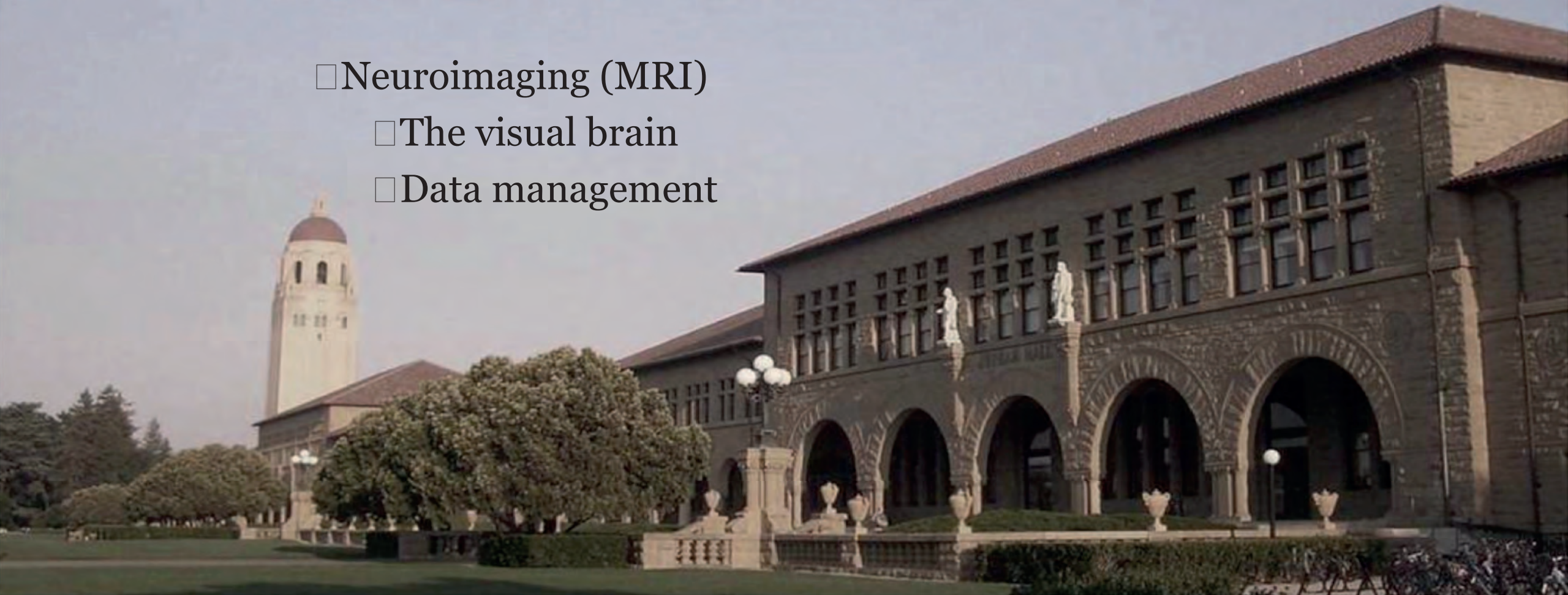
COMPUTATIONAL MODELS

∞

CHECK AND SHARE

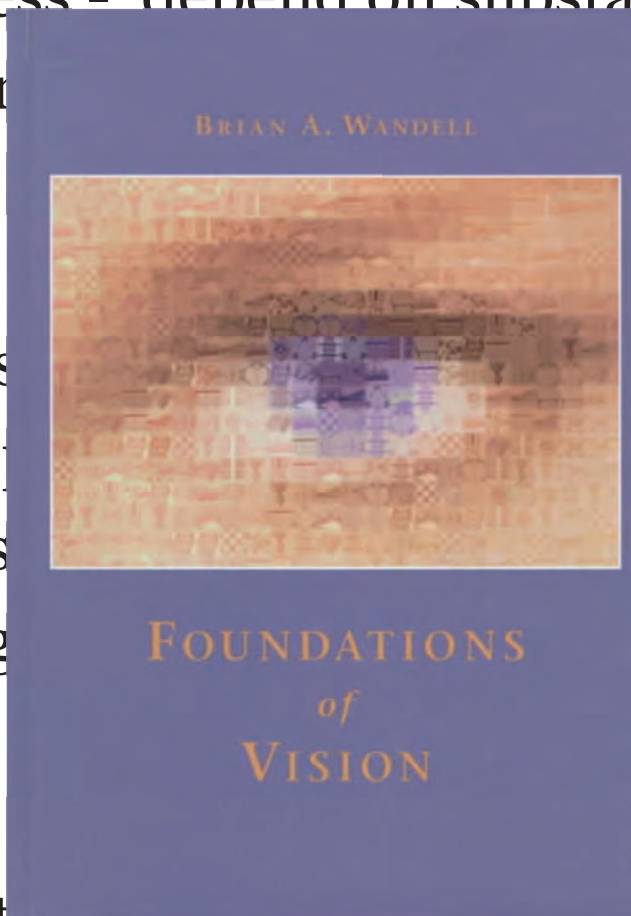
Outline

- Vision science and Image systems engineering
 - Image systems engineering for cameras
 - Simulating the front end of human vision
- Neuroimaging (MRI)
 - The visual brain
 - Data management



Vision and computation

- Even simple judgments – such as lightness - depend on substantial interpretive data carried out by
- The vis... influential in
develo... er
neuros... cial
intellig...
- Vision... are
important for the entire imaging industry



(Anderson and Winawer,
Nature, 2005)

A few words about ISEP and SCIEN

Image Systems Engineering at Stanford
Goodman and Wandell (1996) International
Conference on Image Processing (ICIP).

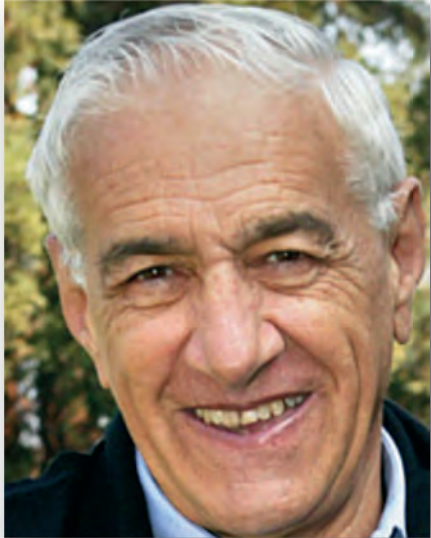


Image Systems Engineering at Stanford

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McCullough 150, Stanford University
Stanford, CA 94305 USA

Abstract

A new Image Systems Engineering Program (ISEP) has recently been launched at Stanford University. The program includes more than a dozen faculty participants drawn from four departments. The planned stages of growth of the Program are described, with emphasis on the anticipated respective roles of the university and industry.

end-to-end design of an image system also requires an unusual interdisciplinarity, and thus a special program is needed to serve as a vehicle to integrate the training and research from faculty in different disciplines. Finally, there exists a large and still-growing collection of companies whose products are mainly concerned with the creation, manipulation, and delivery of images. This industry is international in character, but a substantial computer-related segment resides in Silicon Valley, physically near

Key recruitments

Bernd Girod's
Faculty director (2000)



Joyce Farrell
Executive director (2002)

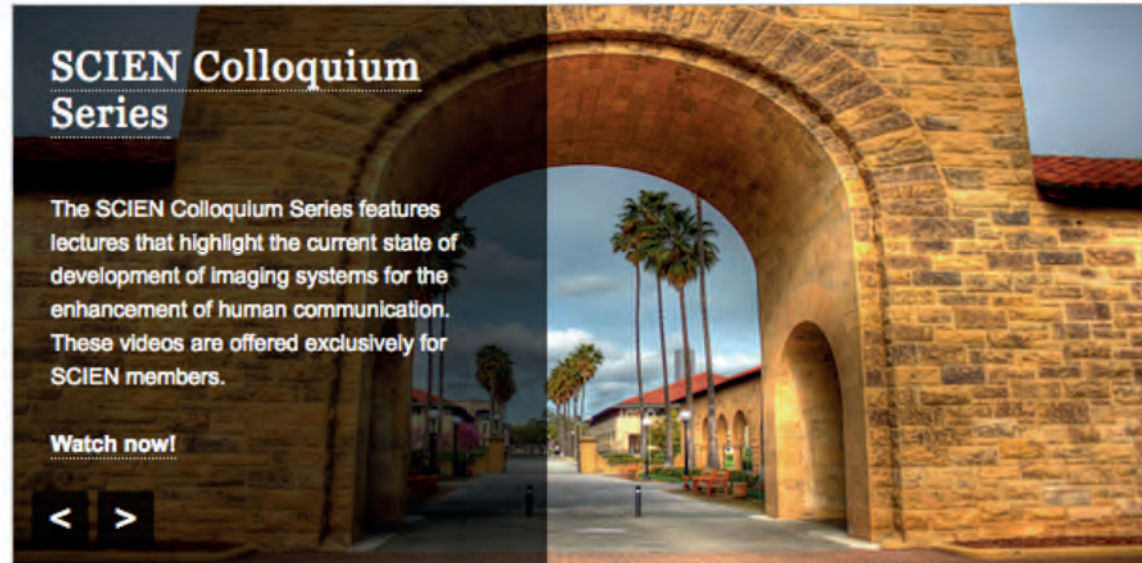


Image Systems Engineering at Stanford
Goodman and Wandell (1996) International
Conference on Image Processing (ICIP).

- There is no stronger indication of commitment to a subject by a research university than one or more new faculty appointments in that area. We anticipate at least one faculty appointment in the next year or two, with the specific area being chosen based on our internal perceptions of need and the advice received from our industrial advisors.

SCIEN

SCIEN Member Login

A banner for the SCIEN Colloquium Series. The background is a photograph of a stone archway leading to a courtyard with palm trees. The text is overlaid on the left side of the image.

SCIEN Colloquium Series

The SCIEN Colloquium Series features lectures that highlight the current state of development of imaging systems for the enhancement of human communication. These videos are offered exclusively for SCIEN members.

Watch now!

< >

The Stanford Center for Image Systems Engineering (SCIEN) is a partnership between the Stanford School of Engineering and technology companies developing imaging systems for the enhancement of human communication. The mission of SCIEN is to support multidisciplinary training, research and collaboration on technologies leading to novel imaging systems that include the capture, processing, transmission and rendering of visual information.

- Weekly seminar series of academics and new technology companies
- More than 200 talks are recorded and available to everyone at Stanford
- A resource for teaching (e.g., Psych 221)



Programmable digital camera project

Stanford Report

April 26, 2001

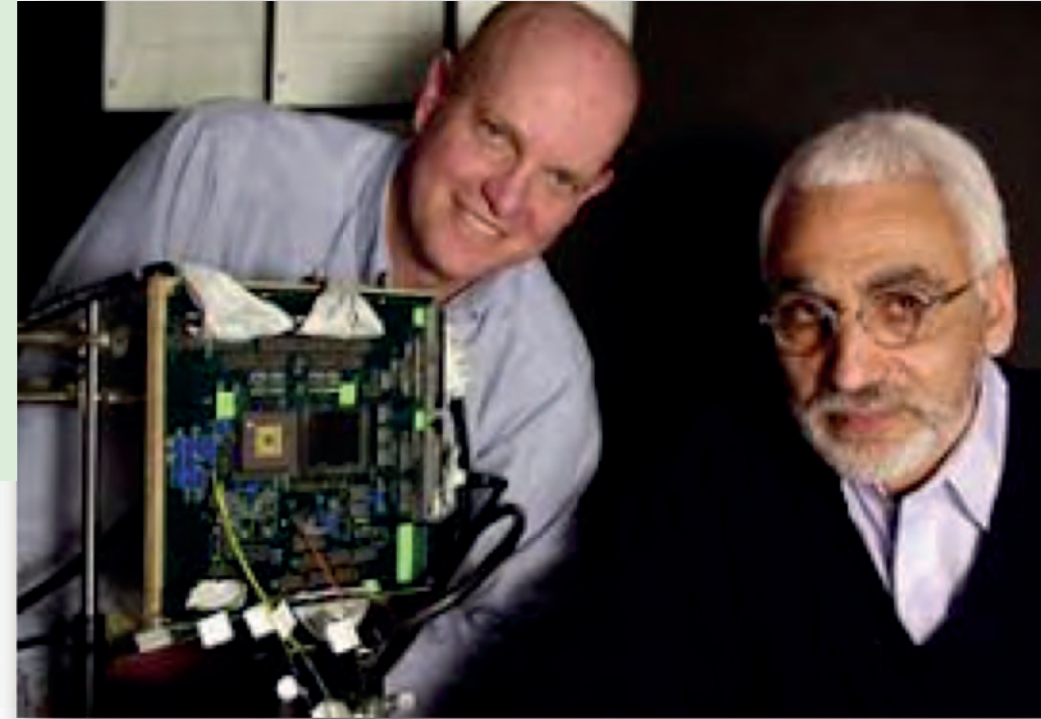
Speedy camera-on-a-chip both captures and processes images
BY DAWN LEVY

Faster than a speeding bullet. Able to leap photographic obstacles with a single computer chip. It's a camera. It's a chip. It's a camera-on-a-chip.

Thanks to the efforts of electrical engineering Professor Abbas El Gamal, psychology and electrical engineering Professor Brian Wandell and their students, it's getting harder to take a bad picture.

Many EE students worked on this project and its continuation in my lab; even more in Abbas' lab

- Trisha Lian – 4th year
- Henryk Blasinski - Apple
- Haomiao Jiang - Google
- Andy Lin - Apple
- Steven Lansel - Facebook
- Peter Catrysse - Stanford
- Feng Xiao - Fengyun Vision
- Jeff DiCarlo – Intuitive Surgical

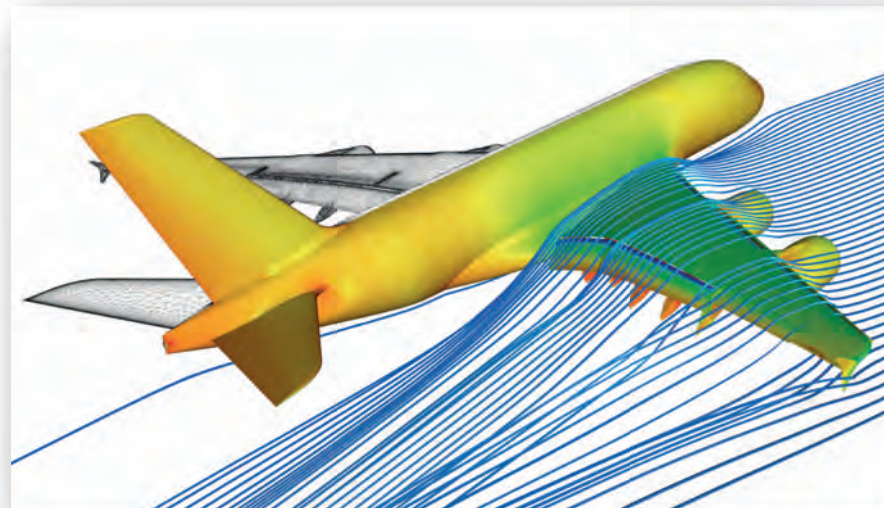


The main idea now: Image systems simulation

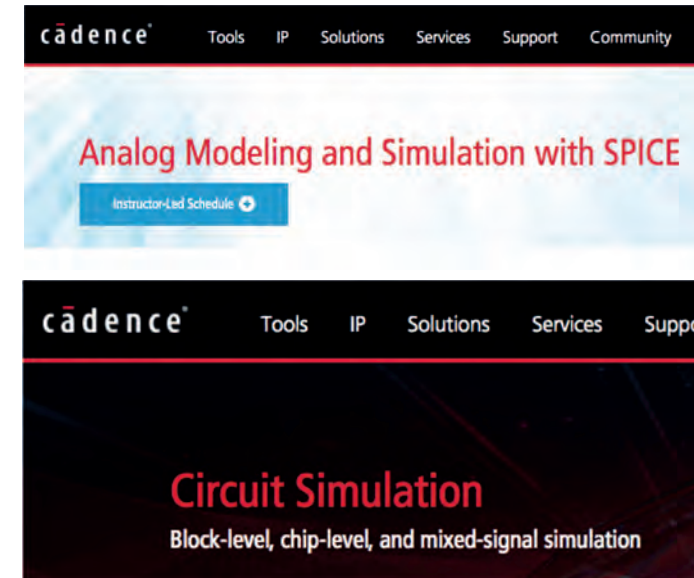
System simulation is important in many mature industries



ECU (Electronic Control Unit) Simulation for Automobiles



Numerical flow simulation on an Airbus A380

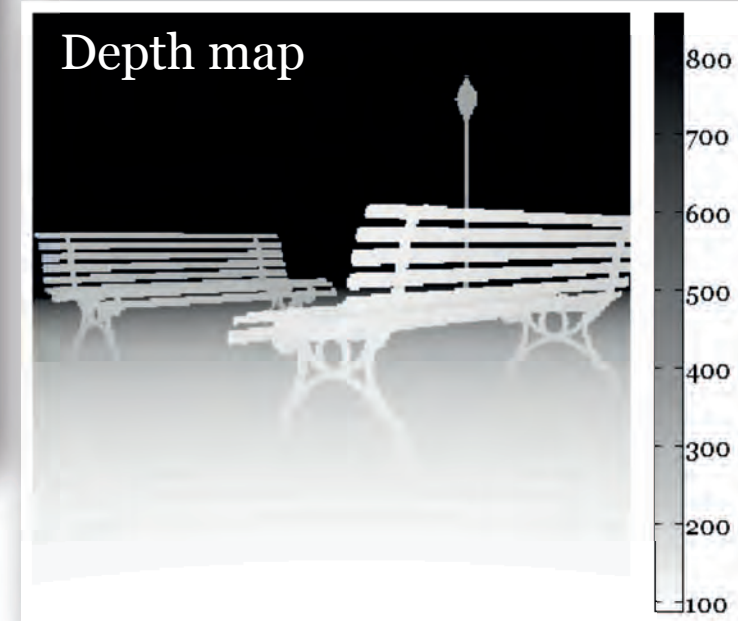
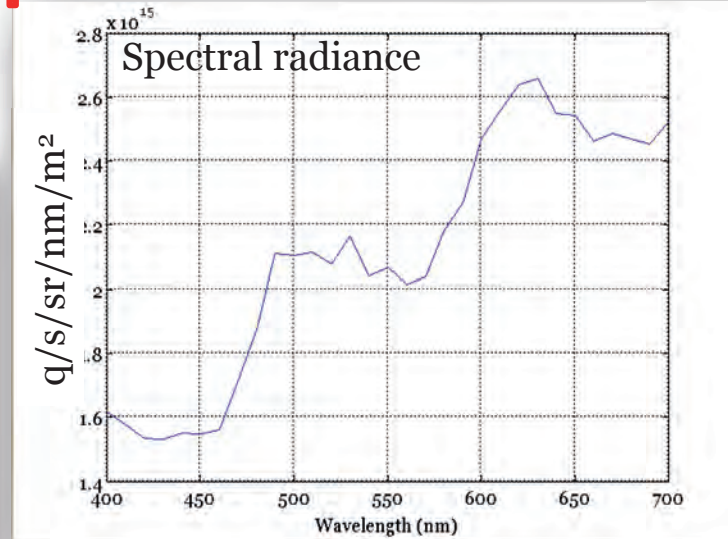


Integrated circuitry

Essential technologies for image systems simulation

Quantitative computer graphics

- Scene spectral radiance data are critical; depth information is important for many natural images
- Acquiring such data for natural images has been a limitation; some valuable cases are extremely difficult to obtain (e.g. high dynamic range, under water, inside the body, automotive)



Quantitative computer graphics

Tools for modeling shapes, lights, material geometry

- Progress in computer graphics enables us to create synthetic and yet highly realistic input data.
- We want simulations with meaningful units; quantitative computer graphics
- Ask me about the challenges later, if you are interested

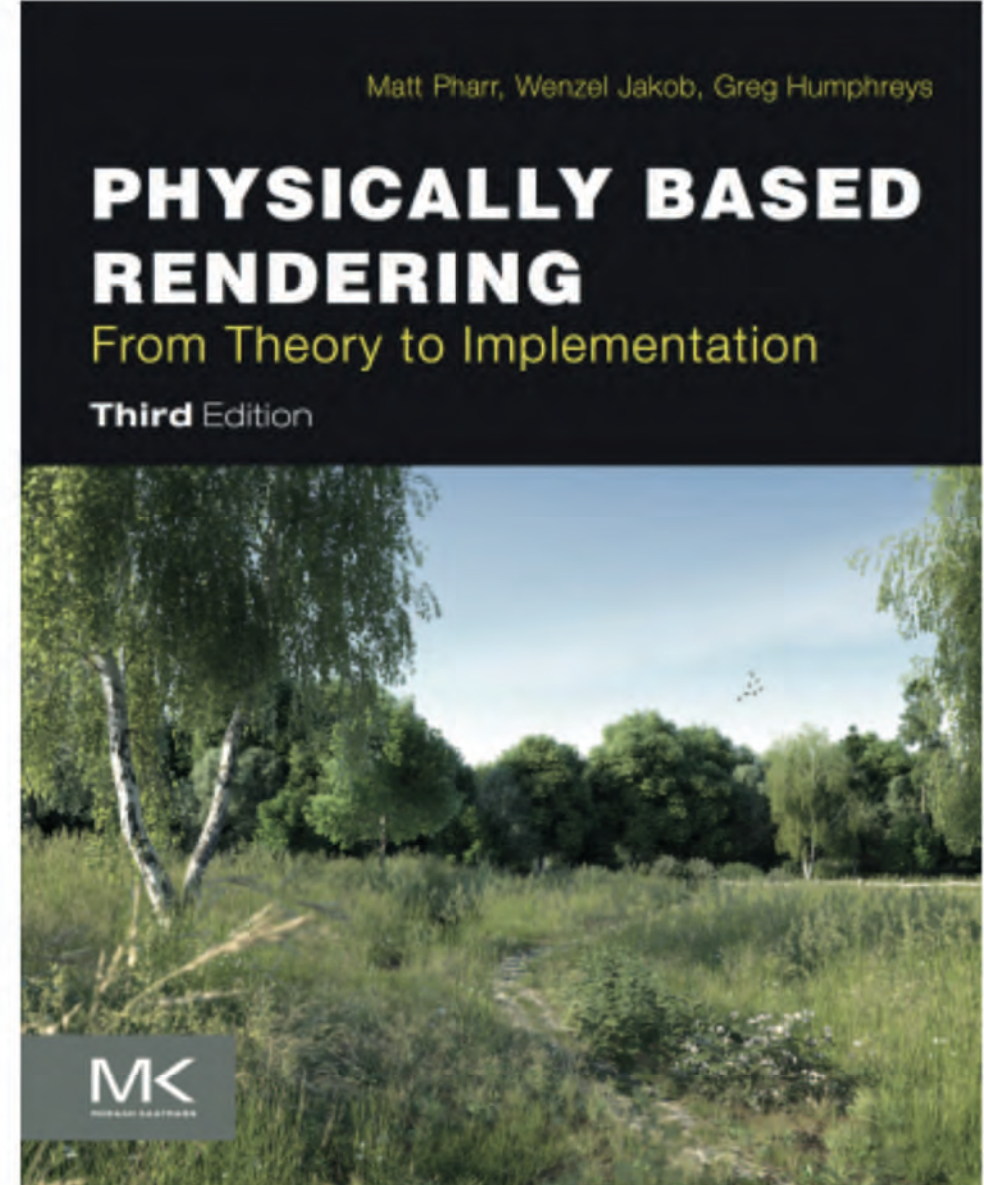
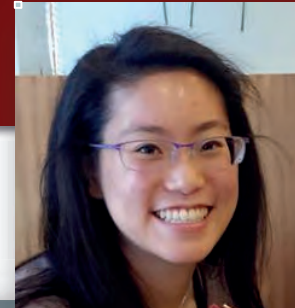


Image Systems Simulation for 360° Camera Rigs

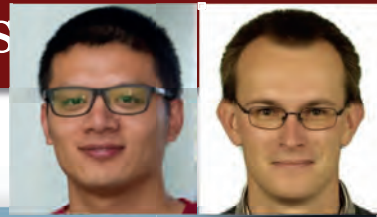


Trisha Lian

- Tools to help design camera rigs for 360 deg acquisition (camera positions, sensors, optics)
- Work with Jayant Thatte and Bernd Girod, thinking through these issues



Designing camera systems for autonomous vehicle applications



Zhenyi
Liu



Henryk
Blasinski

Realistic city model

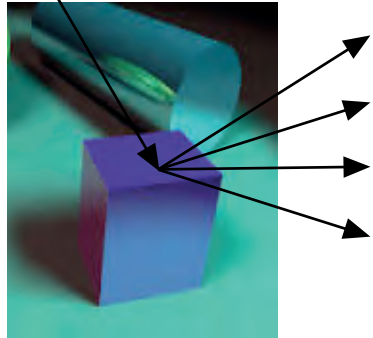
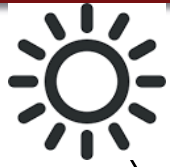
- Multispectral
- High Dynamic Range (HDR)
- Physically accurate (dimensions, surface properties, radiance, irradiance)

Realistic camera and lens models

- Open-source software (ISETCAM, ISET3D)
- TensorFlow and Google curated networks (zoo)



Image systems simulation for biology (ISETBIO)



Scene spectral radiance



Physiological optics

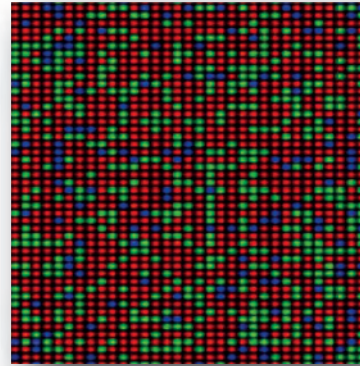
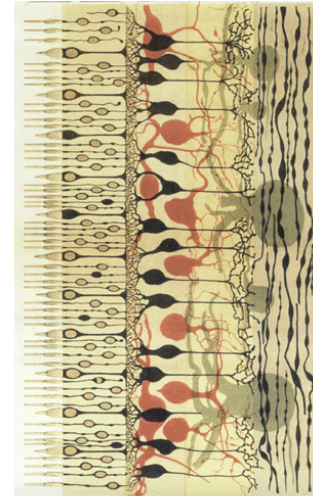


Photo transduction



Retinal processing



Inference



Brian Wandell



David Brainard



James Golden



????? ???? ?



Nicolas Cottaris



Fred Rieke



E.J. Chichilnisky



Xiaomao Ding



Jon Winawer



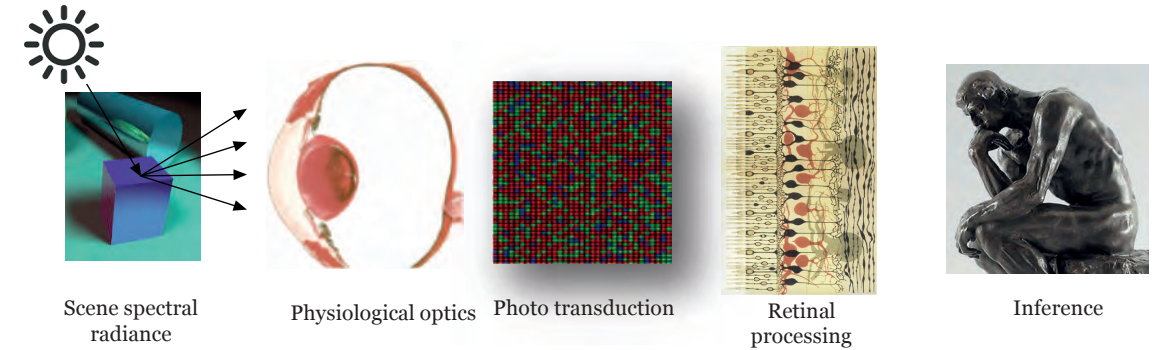
????? ???? ?



Haomiao Jiang

Image systems simulation for biology

- ISETBIO is a set of computational tools to calculate and model how light from a scene is encoded and processed in the visual circuitry
- The goal is to clarify the impact of the different elements of the eye and neural processing in the retina and brain on visual perception
- The tool is designed to support both basic and applied vision research

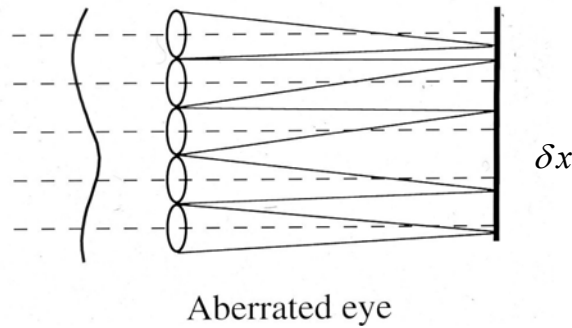
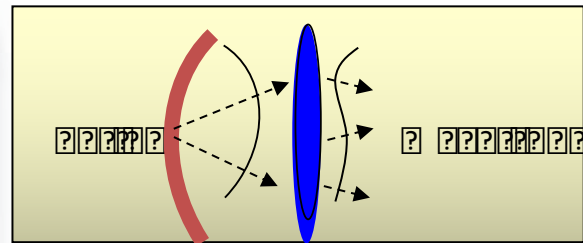
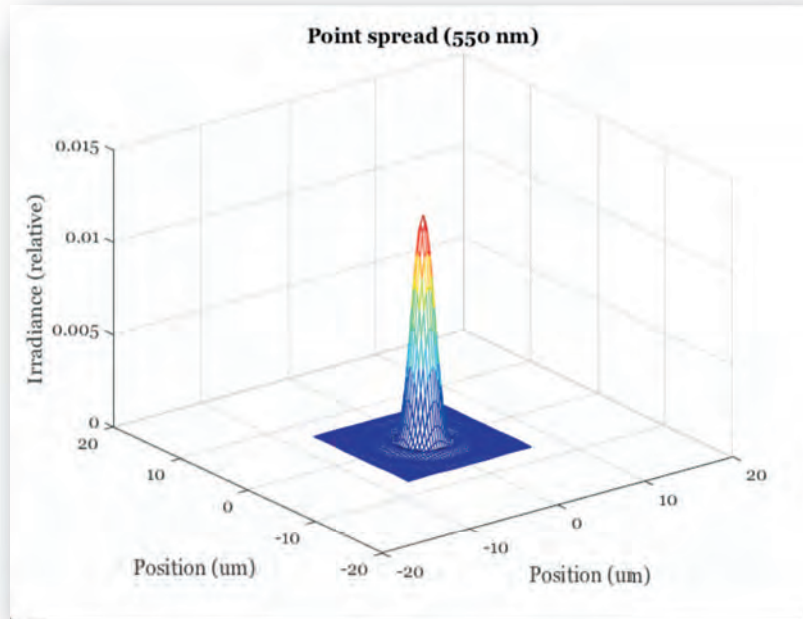


4

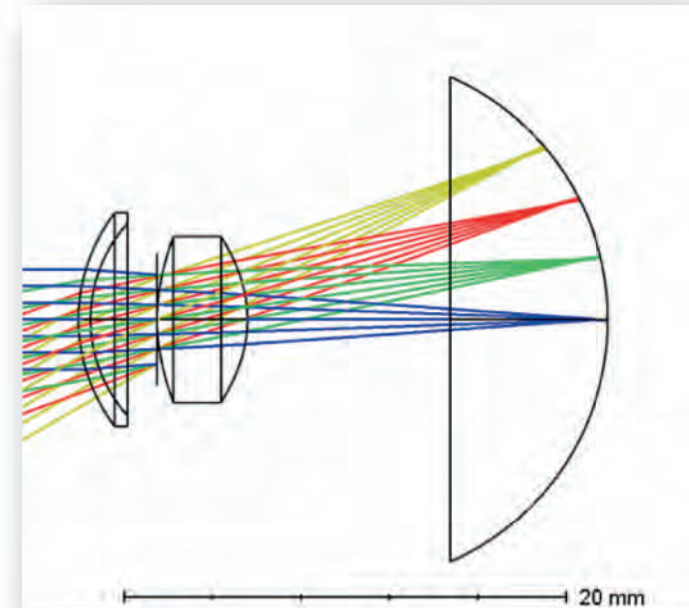
Spectral radiance, refraction, optics, Snell's law, diffraction, Airy disk, photons, energy, Planck's constant, chromatic aberration, retinal irradiance, pupil aperture, eye movements (tremor, drift, saccade), plenoptic function, wavefront aberrations, macular pigment, lens pigment, photopigments, rod and cone absorptions, color-matching functions, transduction, photocurrent, receptive fields, convolution, normalization, linear-nonlinear models, linear classifier theory, ideal observer theory ...



Shift-invariant models from diffraction to
AO wavefront measures
(Zernike polynomial)



Ray trace 3D models of the
scene accounting for
diffraction and the human
optics



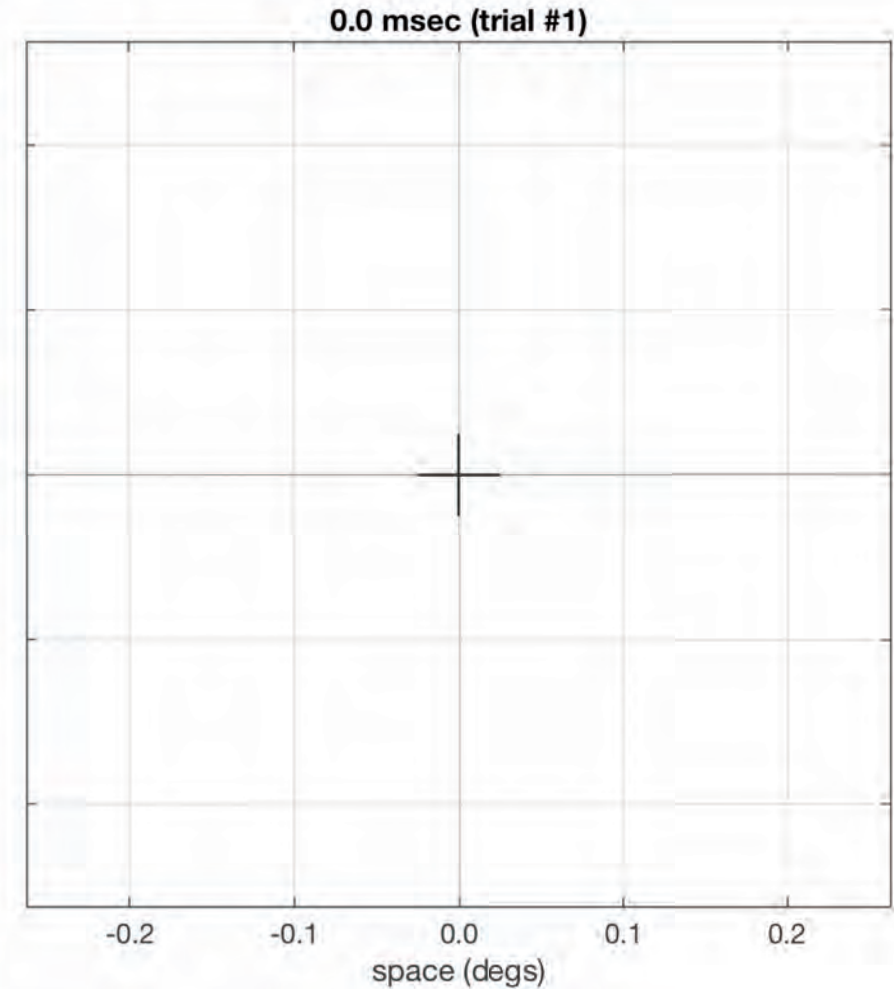
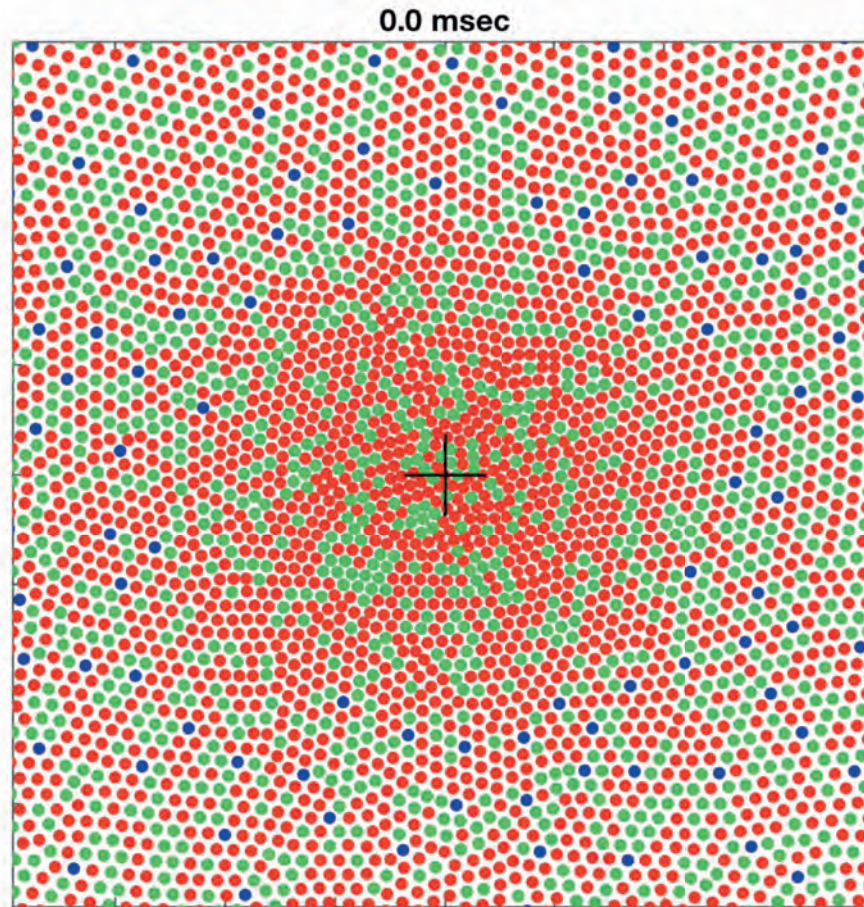
Longitudinal and transverse chromatic aberration

- Chromatic aberration (and diffraction)
- Inert pigments of the eye (lens and macula) are incorporated



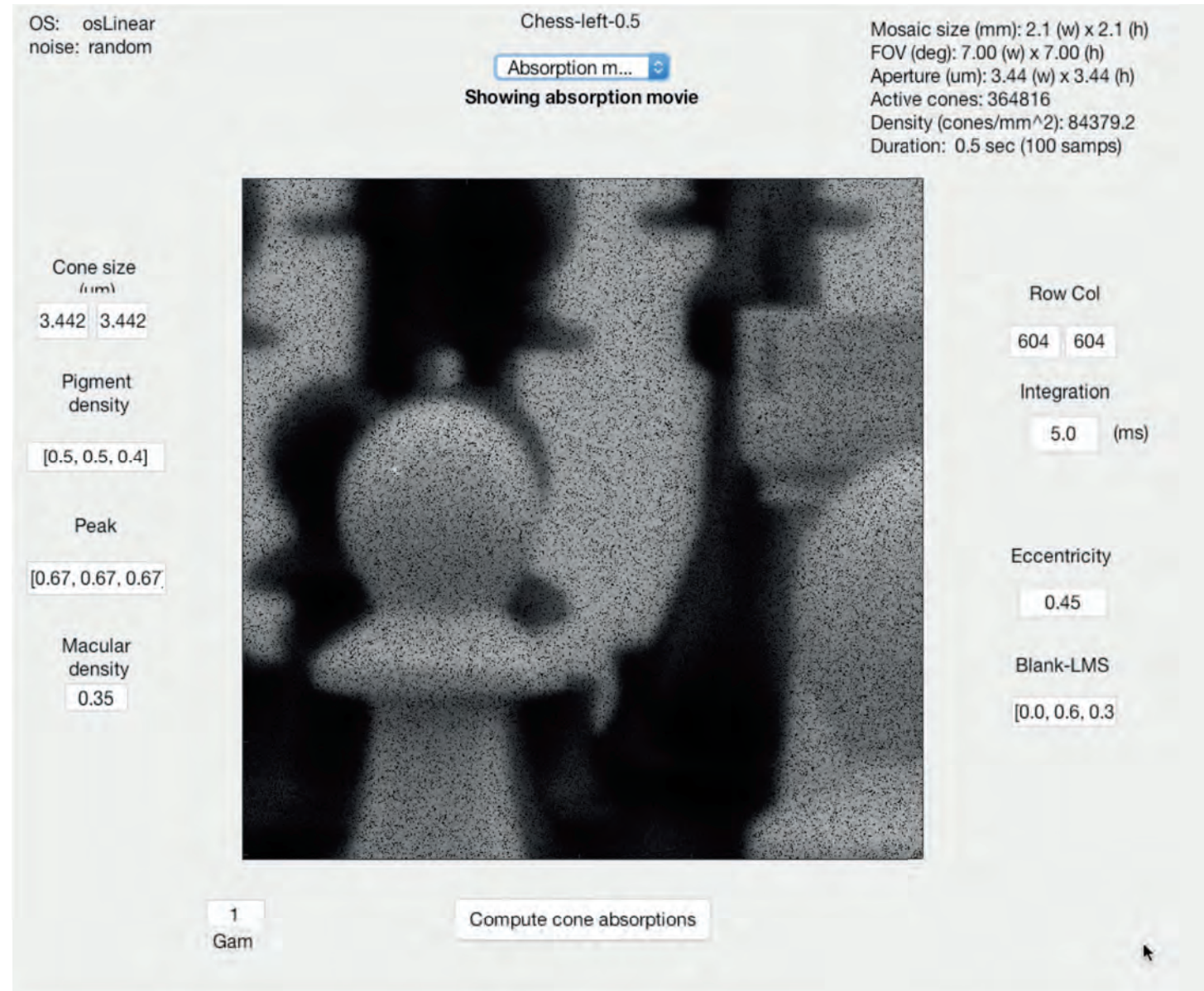
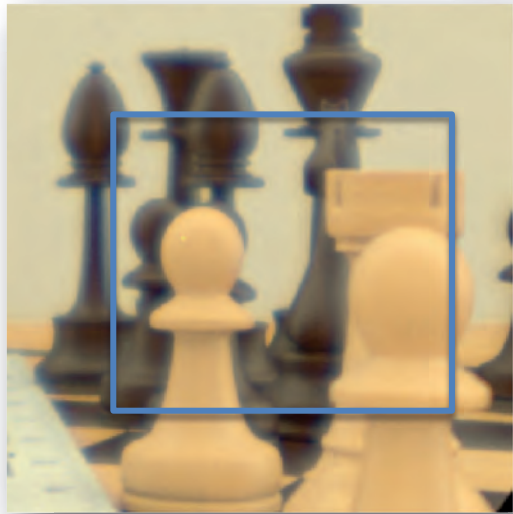
Eye movement modeling (Nicolas Cottaris)

- Uniform and space-varying cone density representations
- Cone spacing and cone aperture size vary with distance from the fovea
- Inhomogeneous cone sampling densities



Cone mosaic absorptions and eye movements

- Eye movements (tremor, drift, saccade)
- Photo and inert pigment properties (e.g., density)
- Cone aperture variations with eccentricity



0.5 deg ecc

Github code and wiki – continuous integration

This repository

isetbio / isetbio

Code Issues 54 Pull requests 0 Projects 0 Wiki Pulse Graphs Settings

Tools for modeling image systems engineering in the human visual system front end

1,702 commits 3 branches 2 releases 8 contributors MIT

Author	Commit Message	Time
benjamin-heasley	ieValidateFullAllAssert -> ieValidateFullAll('asAssertion', true)	Latest commit 256fa43 8 hours ago
	configuration Fixed syntax error in isetbioLocalHookTemplate	a month ago
	documentation/resources Initial import of clean version of 0.1 dev branch, now the master bra...	2 years ago
	external Added StructUtils from BrainardLabToolbox	19 days ago
	isettools Took computeDensityMap out of visualizeGrid	a day ago
	scripts Working still on tutorials.	2 months ago
	tutorials Put t_eyeMovement in the right place	3 days ago
	utility Pulled out as much as I could easily find that depends on sensor, pix...	2 months ago
	validation ieValidateFullAllAssert -> ieValidateFullAll('asAssertion', true)	8 hours ago
	.gitignore Updated for DS_STORE and local	2 months ago
	LICENSE Initial import of clean version of 0.1 dev branch, now the master bra...	2 years ago
	README.md Adding build status icon	8 days ago
	isetbioRootPath.m Initial import of clean version of 0.1 dev branch, now the master bra...	2 years ago

build **passing**

The Image System Engineering Toolbox for Biology ISETBIO is a Matlab toolbox designed for calculating the properties of the front end of the visual system. This includes a description of the scene, the optics and retinal image, the capture of light by the photopigment, the photocurrent responses in the receptors, bipolar responses, and retinal ganglion cell responses.

This repository includes a [WIKI](#) that describes the software as well as many examples of how to perform computations to calculate the visual encoding of light in the eye. The [WIKI](#) also describes tools to view and and

isetbio / isetbio

Code Issues 54 Pull requests 0 Projects 0 Wiki Pulse Graphs Settings

Cone mosaic

Brian Wandell edited this page 26 days ago · 51 revisions

The cone mosaic object converts the optical image irradiance into the cone absorptions and photocurrent. For details, please refer to

```
doc coneMosaic
```

The main top-level coneMosaic object commands are

```
cmosaic = coneMosaic; - Create cone mosaic. Many parameters can be set.
cmosaic.compute(oi); - Compute the absorptions from the optical image, oi
cmosaic.computeCurrent; - Compute the photocurrent using the attached outerSegment model
```

The coneMosaic class has an interactive window. This window differs from sceneWindow and oiWindow because like all of the newer ISETBIO concepts, the coneMosaic is a class. Also, there is a growing number of plotting methods.

```
cmosaic.window; - An interactive window to view the mosaic, absorptions and current
cmosaic.plot(); - Plotting methods
```

File Edit Plot Cones Help

OS: oslinux
noise: off

cone mosaic
Cone mosaic

Mosaic size: 0.2 (w) x 0.1 (h)
FCM size: 0.08 (w) x 0.49 (h)
Aperture size: 2.00 (w) x 2.00 (h)
Active cones: 6356
Density (cones/mm²): 250000
Duration: 0.05 sec (1 sampling)

Cone size: 100
3 3

Pigment density

Blue Col: 73 88
Integration: 0.0

Pages

- Home
- Installation
- Getting Started
- Data types
 - Scenes
 - Retinal image
 - Cone mosaic
 - Bipolar cells
 - Retinal ganglion cells
- Compute overview
 - Retina model comparisons
- Tutorial scripts
- Numerical utility functions
- ISETBIO Data
- ISETBIO Videos
- Validation
- For Developers

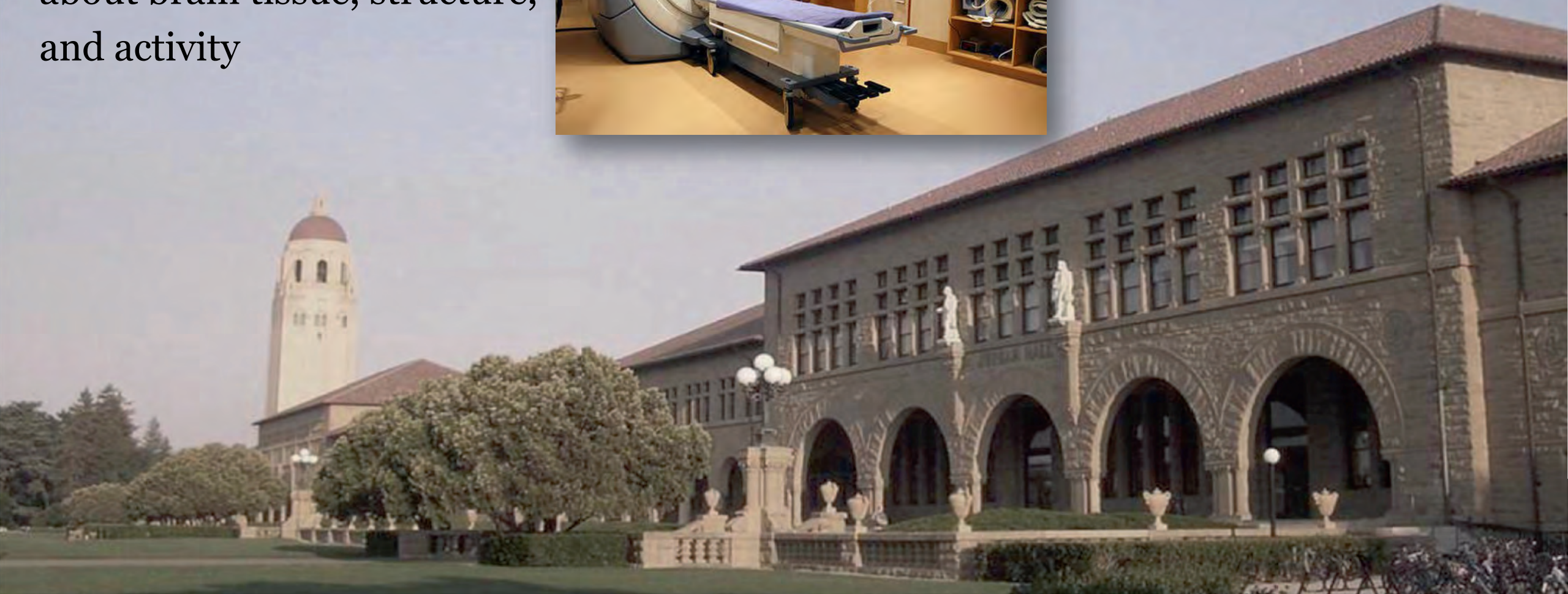
Clone this wiki locally

<https://github.com/isetbio/>

Clone in Desktop

MRI instrumentation

MRI instrumentation can be used in many ways to learn about brain tissue, structure, and activity



Cortical computational elements

Brain computations depend on a variety of cells; an important class of these cells, the neurons, have their cell bodies located in the cerebral cortex (gray matter).

The cortex is a sheet (2-4 mm thick) of tissue that covers the surface of the brain; other subcortical regions and types of cells matter too!

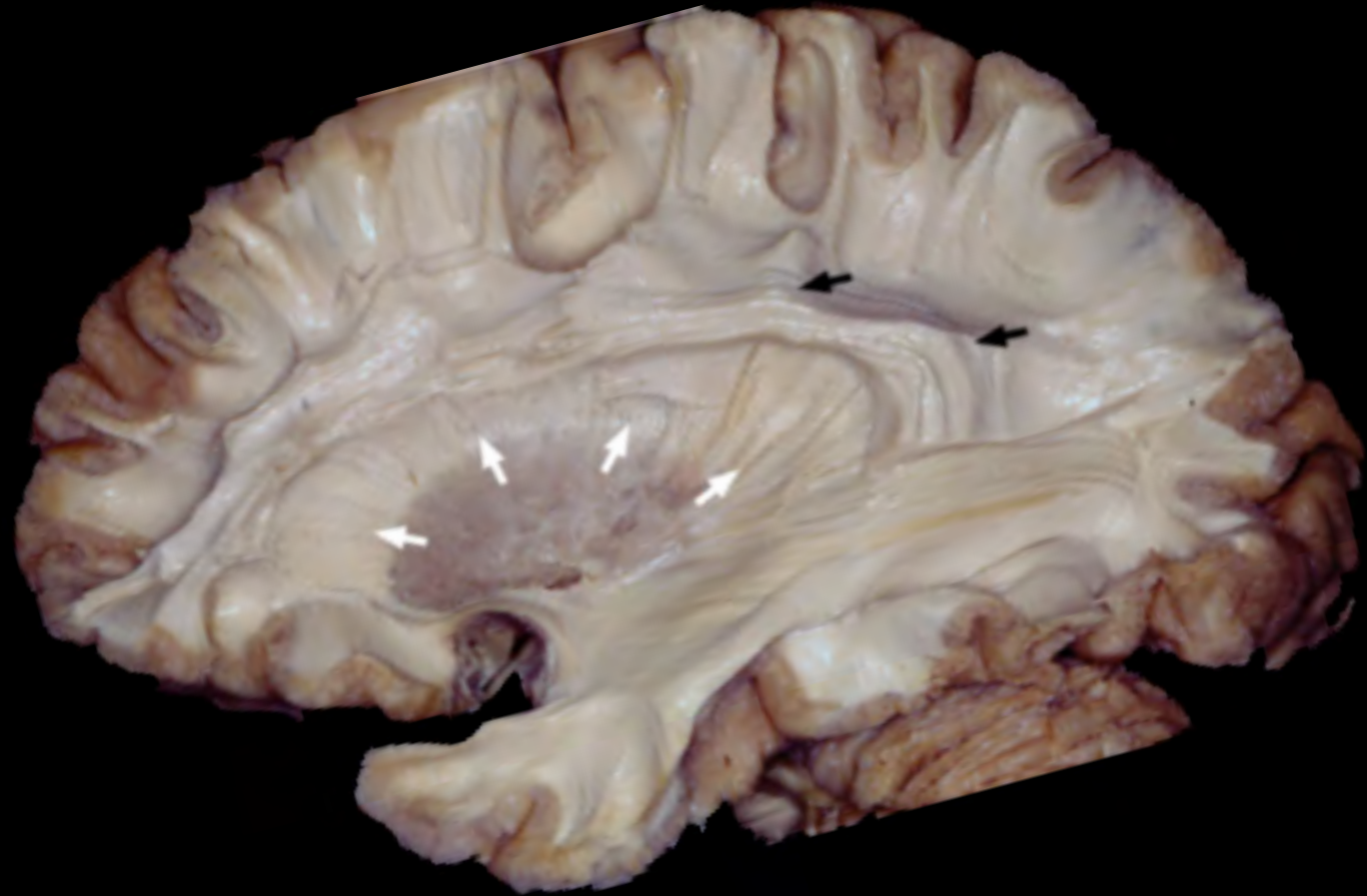
Neuron: impulse-conducting cell; bodies are in the cerebral cortex
Axon: a thin fiber that carries the output impulses from a neuron
Dendrite: a branching process of a neuron that receives impulses from other neurons
Synapse: The point of connection between neurons



- Neurons/mm³: 10^4 - 10^6
- Cortical Neurons: 10^{11}
- Synapses/neuron: 10^3
- Cortical Synapses: 10^{14}
- Surface area of each hemisphere: 20 x 30 cm²

Long-range communication architecture (tracts)

- There are many long-range connections
- These connections are not passive – they change their properties in response to use
- A system with active wires



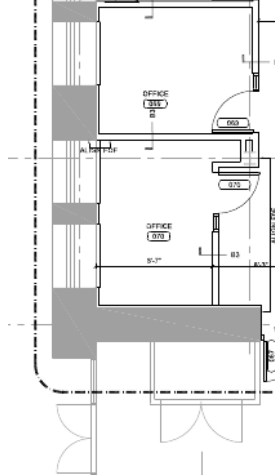
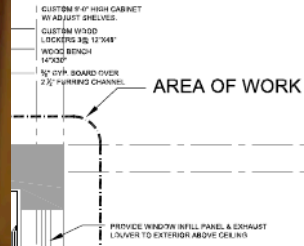
Courtesy Professor Ugur Ture

The early fMRI experiments

Gary Glover from Radiology
Dave Rumelhart
Mike Shadlen
Me



Many more meetings...



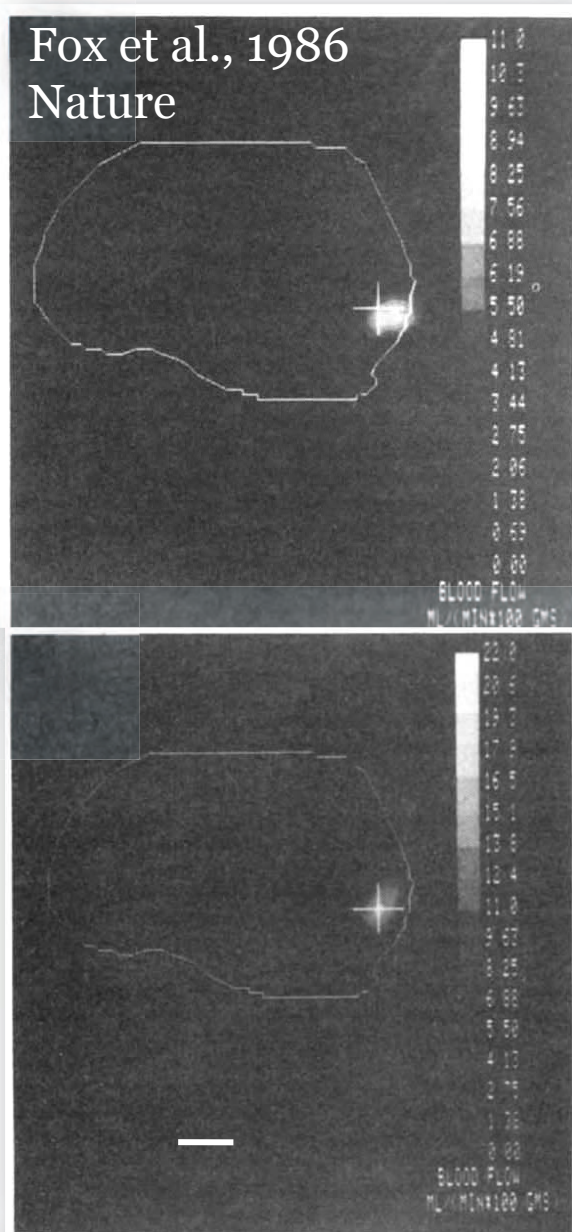
Human functional and anatomical MRI

- Human visual cortex – some things we know that we didn't know when I started



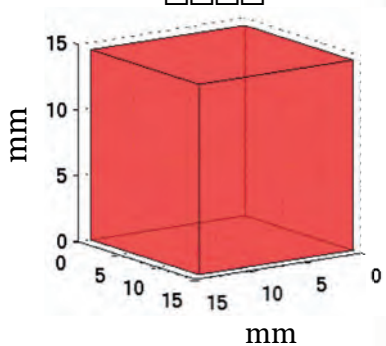
Remarkable progress from PET to advanced MRI in 25 years

(Wandell and Winawer, 2011)



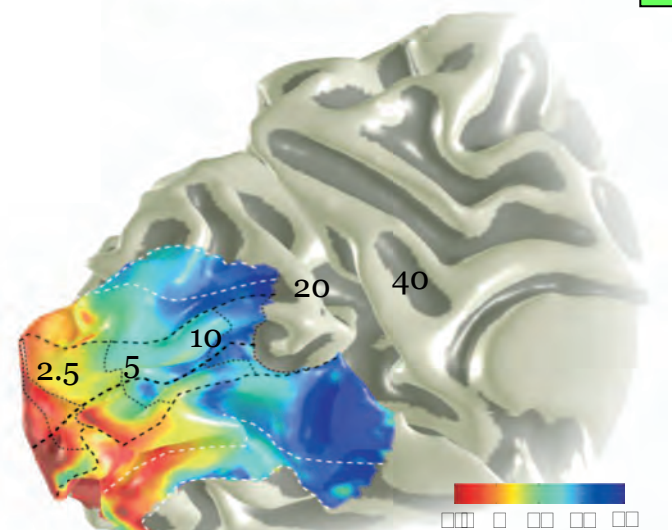
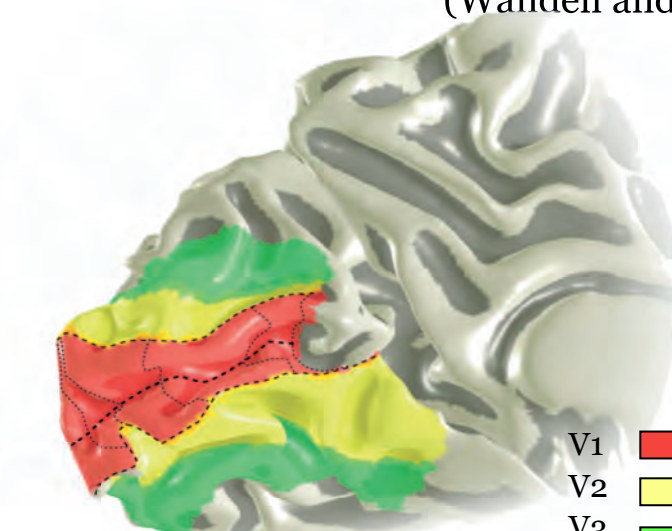
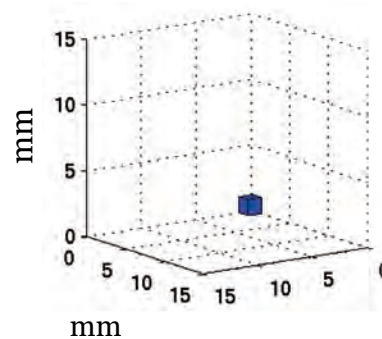
Voxel size

????



Voxel size

????

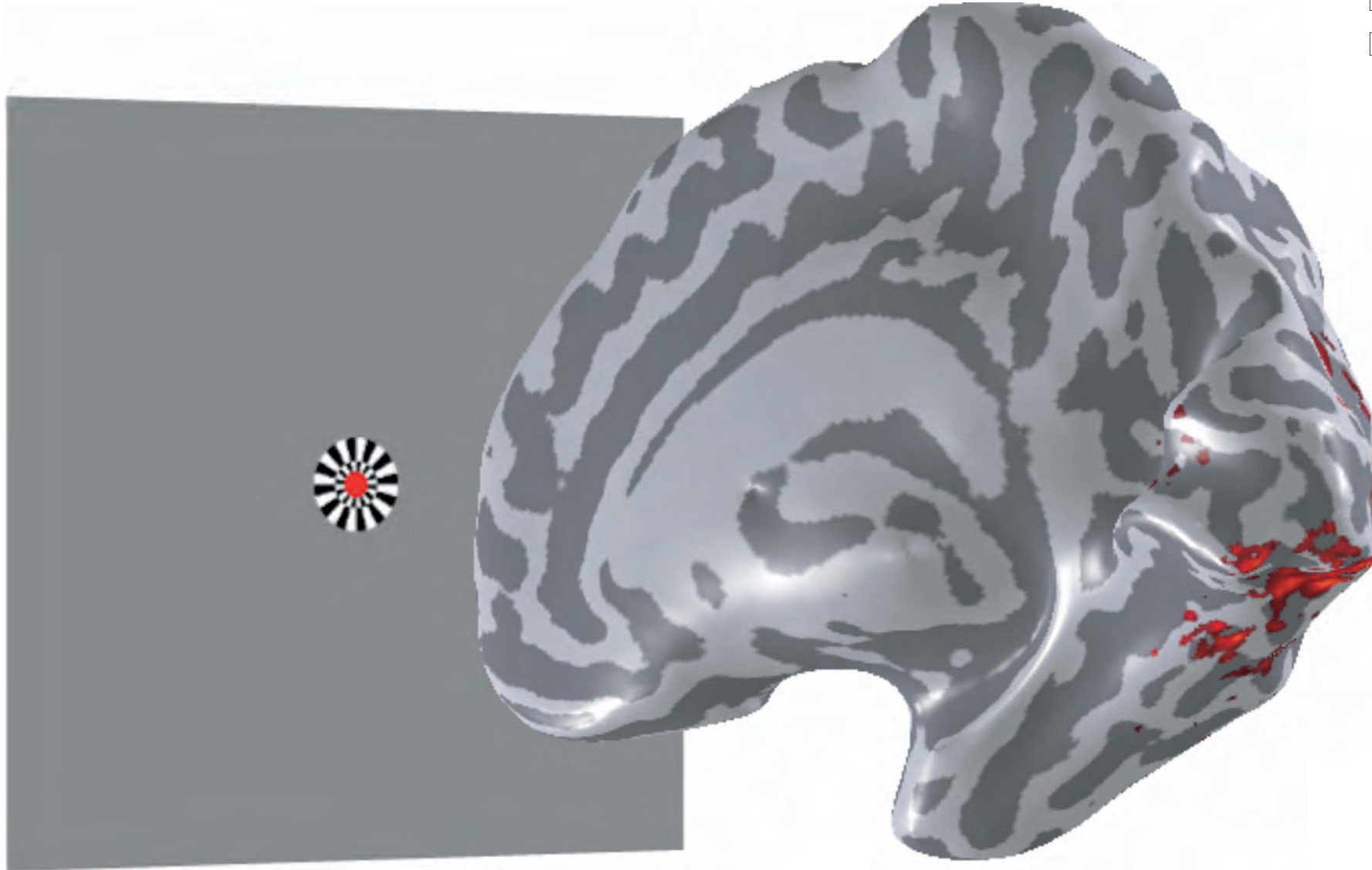


1 cm

Eccentricity
(deg)

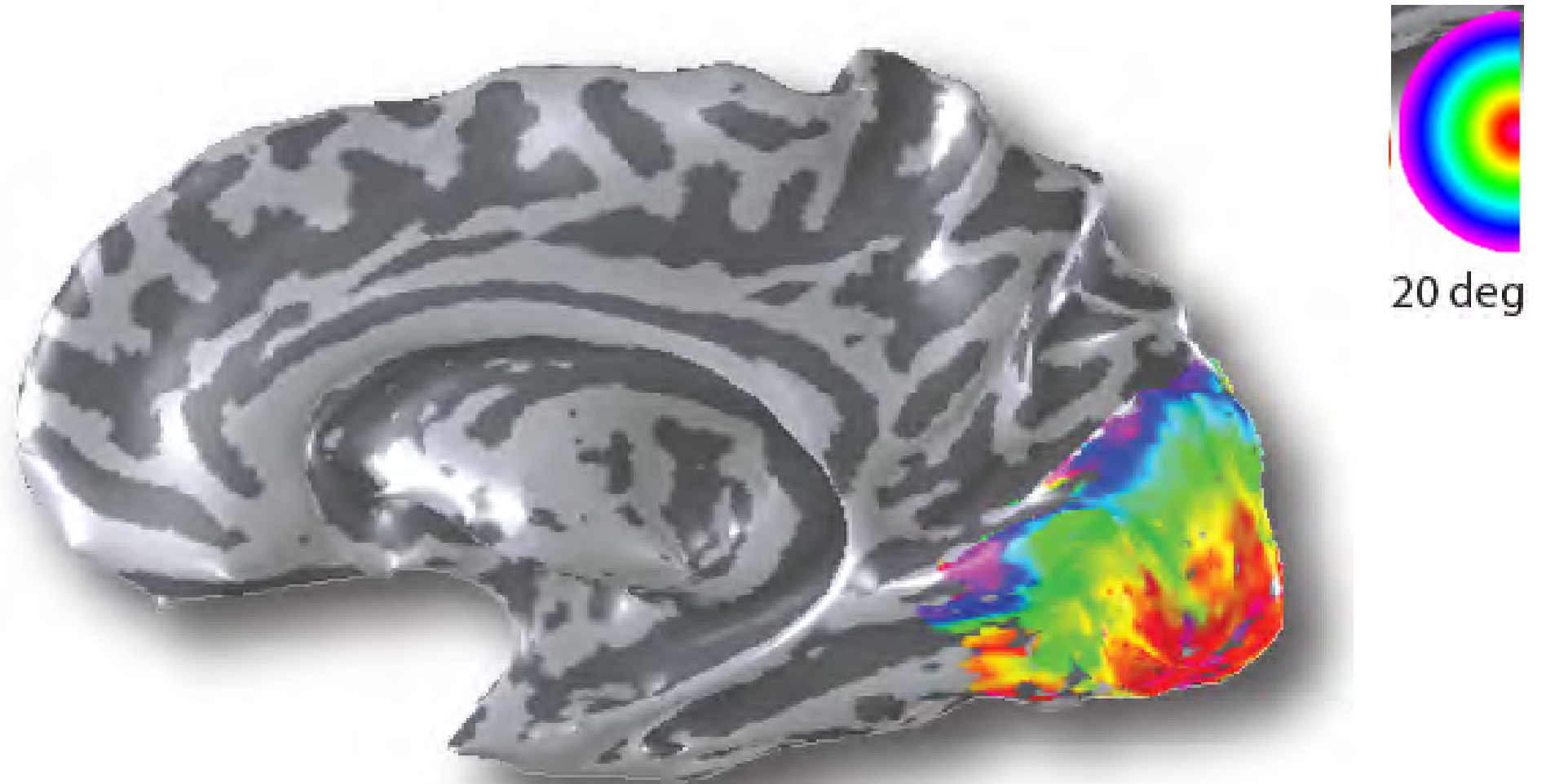
Human eccentricity mapping with fMRI

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

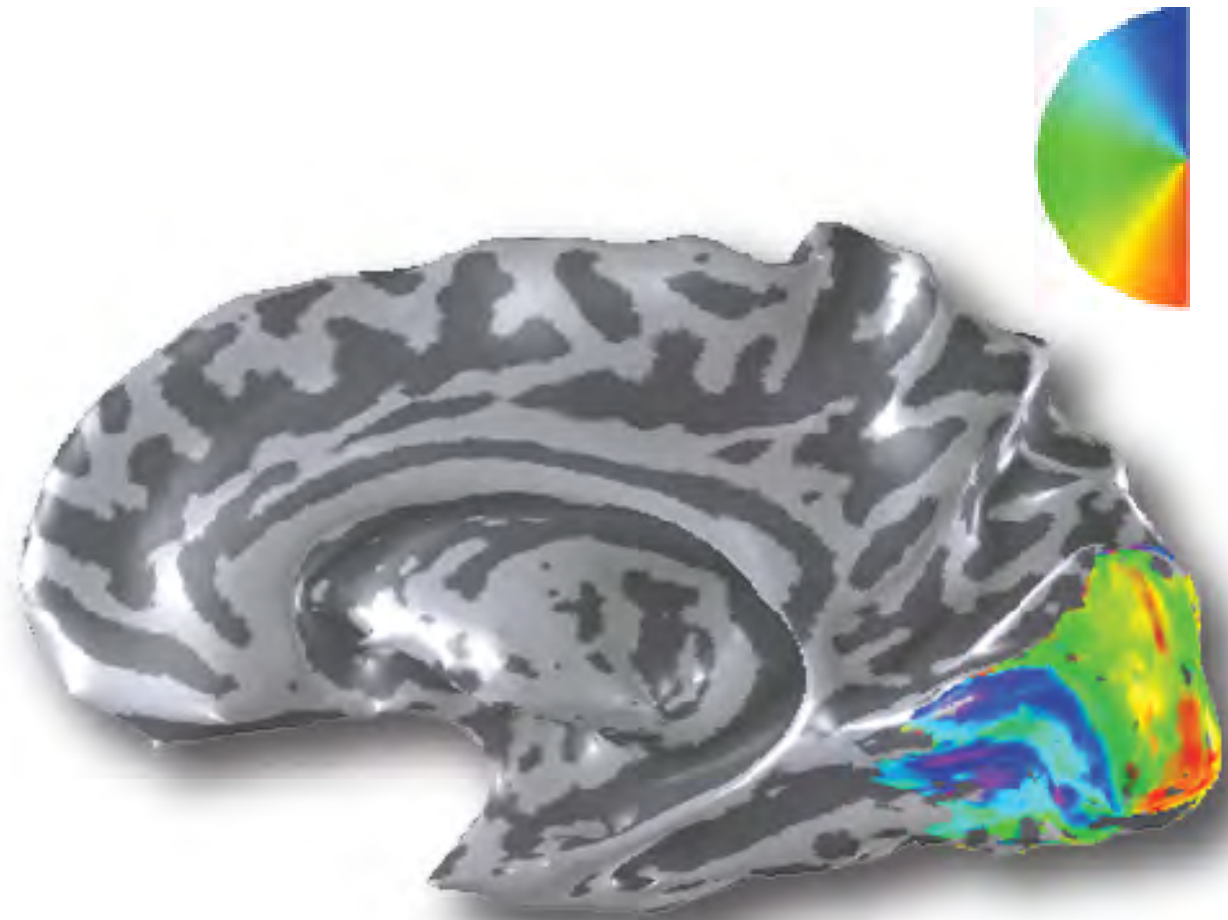


- Inflated brain
- Gray/white are sulci/gyri

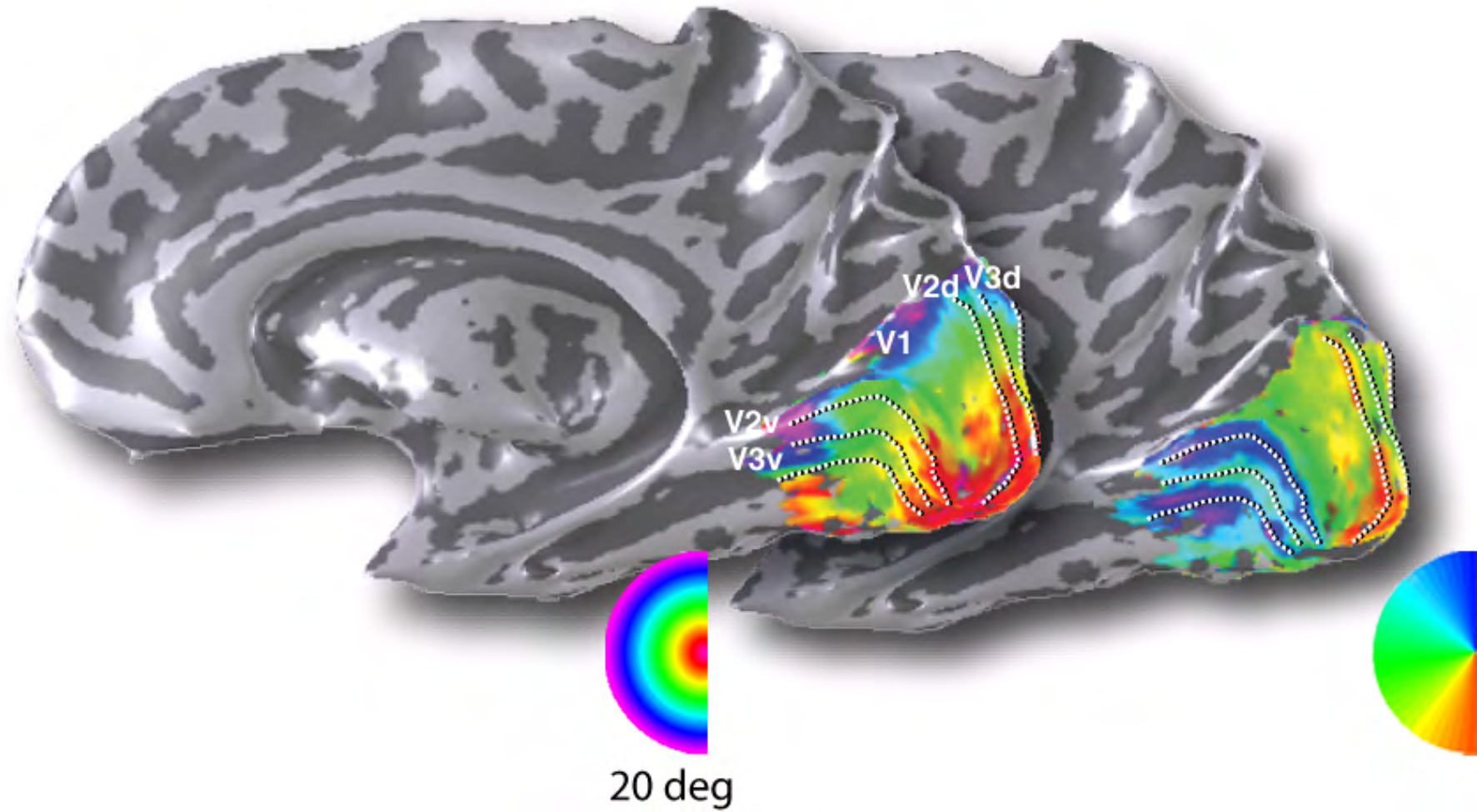
Pseudo-color representation of visual field map



Angular measurements delineate visual field map boundaries

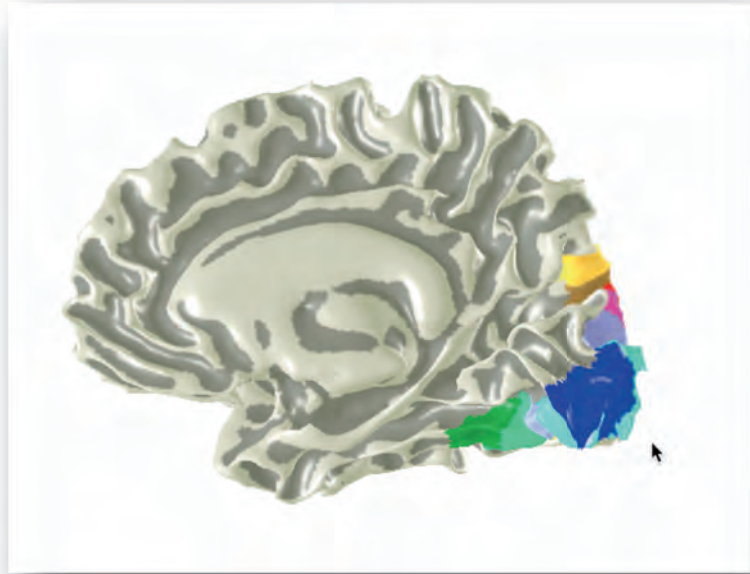


Combining eccentricity and angle data yields maps





Visual field map reviews



- Maps tile the occipital lobe
- Extend into IPS and VOT
- Response properties differ
- Identification from gross anatomy

Cell PRESS 366 Neuron 56, October 25, 2007 Neuron Review

Visual Field Maps in Human Cortex

Brian A. Wandell,^{1,*} Serge O. Dumoulin,¹ and Alyssa A. Brewer²

¹Psychology Department, Stanford University, Stanford, CA 94305-2130, USA
²Department of Cognitive Sciences, University of California, Irvine, Irvine, CA 92697, USA
 *Correspondence: wandell@stanford.edu
 DOI 10.1016/j.neuron.2007.10.012

Much of the visual cortex is organized into visual field maps: nearby neurons have receptive fields at nearby locations in the image. Mammalian species generally have multiple visual field maps with each species having similar, but not identical, maps. The introduction of functional magnetic resonance imaging made it possible to identify visual field maps in human cortex, including several near (1) medial occipital (V1, V2, V3), (2) lateral occipital (LO-1, LO-2, hMT+), (3) ventral occipital (hV4, VO-1, VO-2), (4) dorsal occipital (V3A, V3B), and (5) posterior parietal cortex (IPS-0 to IPS-4). Evidence is accumulating for additional maps, including some in the frontal lobe. Cortical maps are arranged into clusters in which several maps have parallel eccentricity representations, while the angular representations within a cluster alternate in visual field sign. Visual field maps have been linked to functional and perceptual properties of the visual system at various spatial scales, ranging from the level of individual maps to map clusters to dorsal-ventral streams. We survey recent measurements of human visual field maps, describe hypotheses about the function and relationships between maps, and consider methods to improve map measurements and characterize the response properties of neurons comprising these maps.

Vision Research 51 (2011) 718-737

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Review

Imaging retinotopic maps in the human brain

Brian A. Wandell ^{*}, Jonathan Winawer

Psychology Department, Stanford University, Stanford, CA 94305, United States

<p>ARTICLE INFO</p> <p><small>Article history:</small> Received 5 April 2010 Received in revised form 2 August 2010 Available online 6 August 2010</p>	<p>ABSTRACT</p> <p>A quarter-century ago visual neuroscientists had little information about the number and organization of retinotopic maps in human visual cortex. The advent of functional magnetic resonance imaging (fMRI), a non-invasive, spatially-resolved technique for measuring brain activity, provided a wealth of data about human retinotopic maps. Just as there are differences amongst non-human primate maps, the human maps have their own unique properties. Many human maps can be measured reliably in individual sub-</p>
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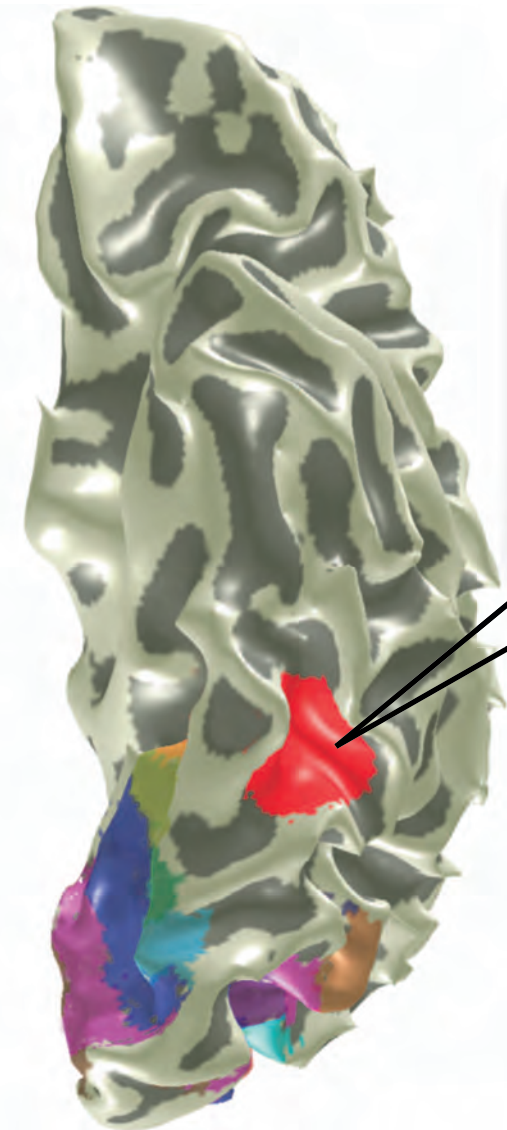
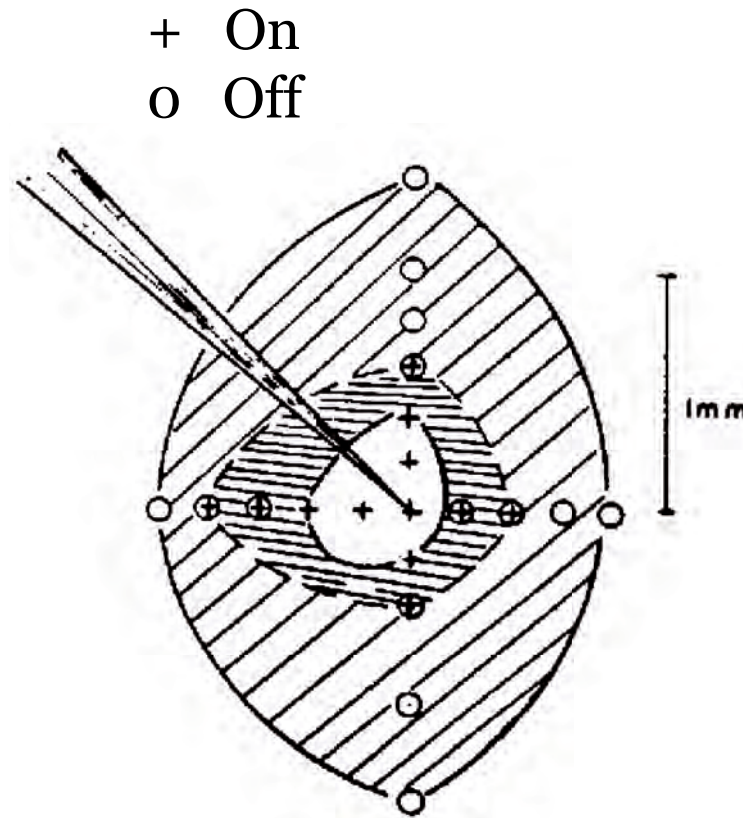
Quantitative modeling: the population receptive field (pRF)

‘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)’.

Sherrington, 1910

Kuffler, 1953

- Functional description
- Stimulus-referred

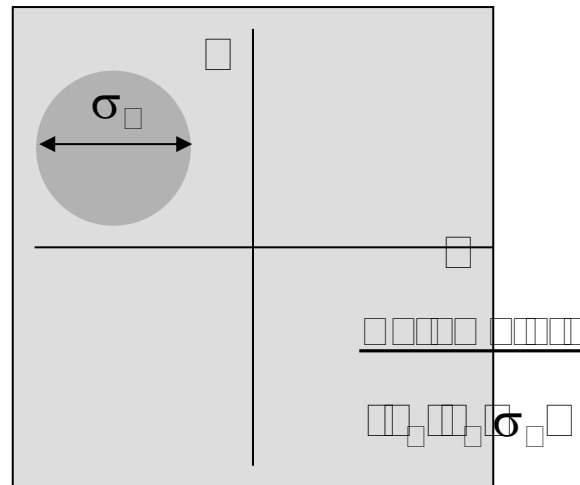
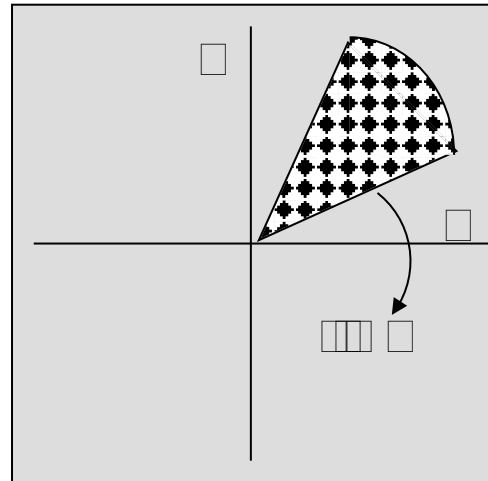


FUNCTIONAL MAGNETIC RESONANCE IMAGING, Figure 1.3 © 2004 Elsevier

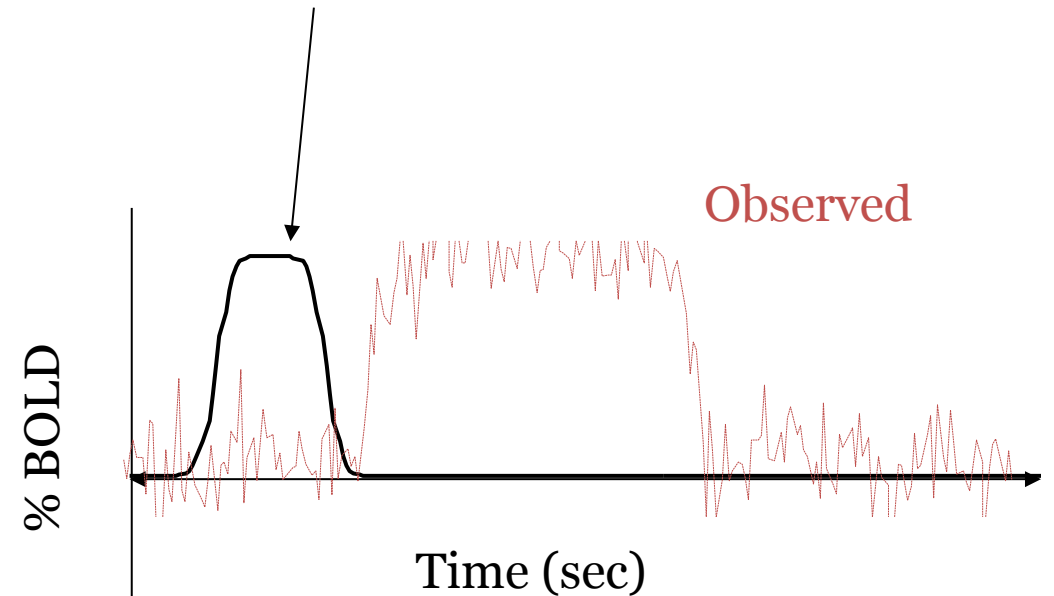
Population receptive field idea

- For each voxel, find a spatial receptive field that explains the fMRI measurement.
- The spatial RF model is the object of interest.
- Minimally, the model is linear in contrast and has an (x,y) location in the visual field and a spread
- More complex models are also being studied (e.g., CSS)

Stimulus



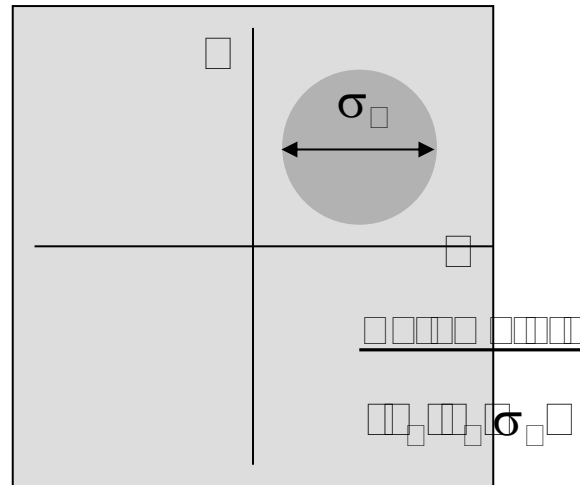
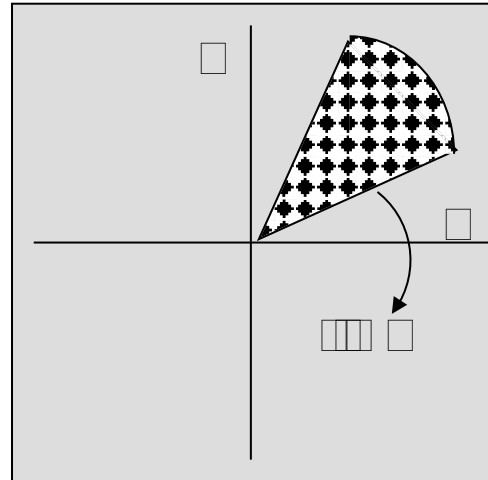
Predicted BOLD (including HRF)



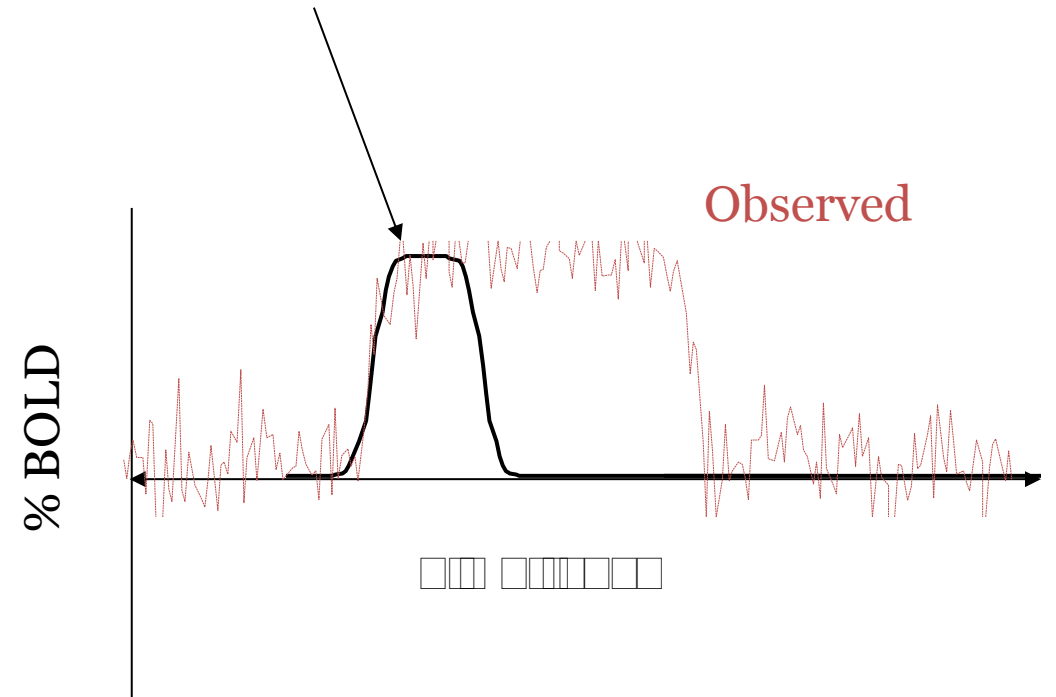
Population receptive field idea

- For each voxel, find a spatial receptive field that explains the fMRI measurement.
- The spatial RF model is the object of interest.
- Minimally, the model is linear in contrast and has an (x,y) location in the visual field and a spread
- More complex models are also being studied (e.g., CSS)

Stimulus



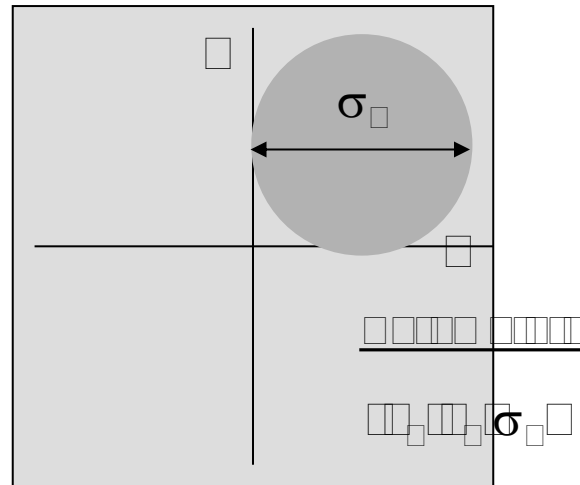
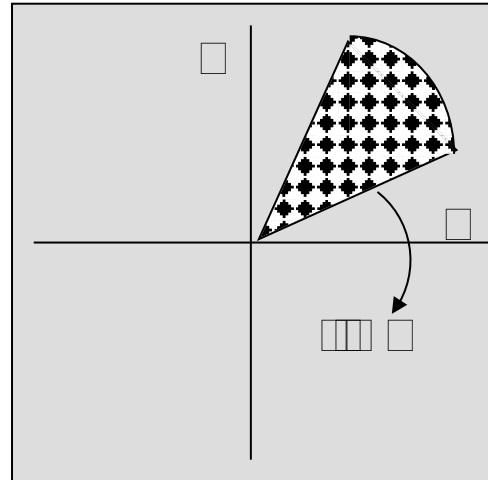
Predicted BOLD (including HRF)



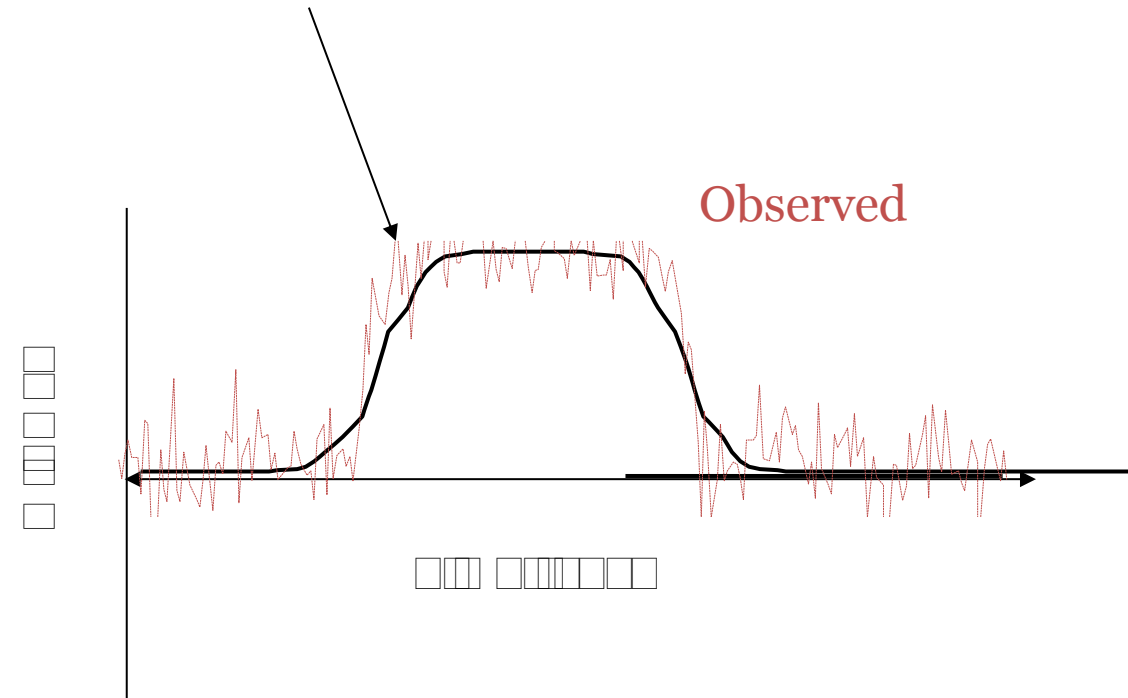
Population receptive field idea



Stimulus



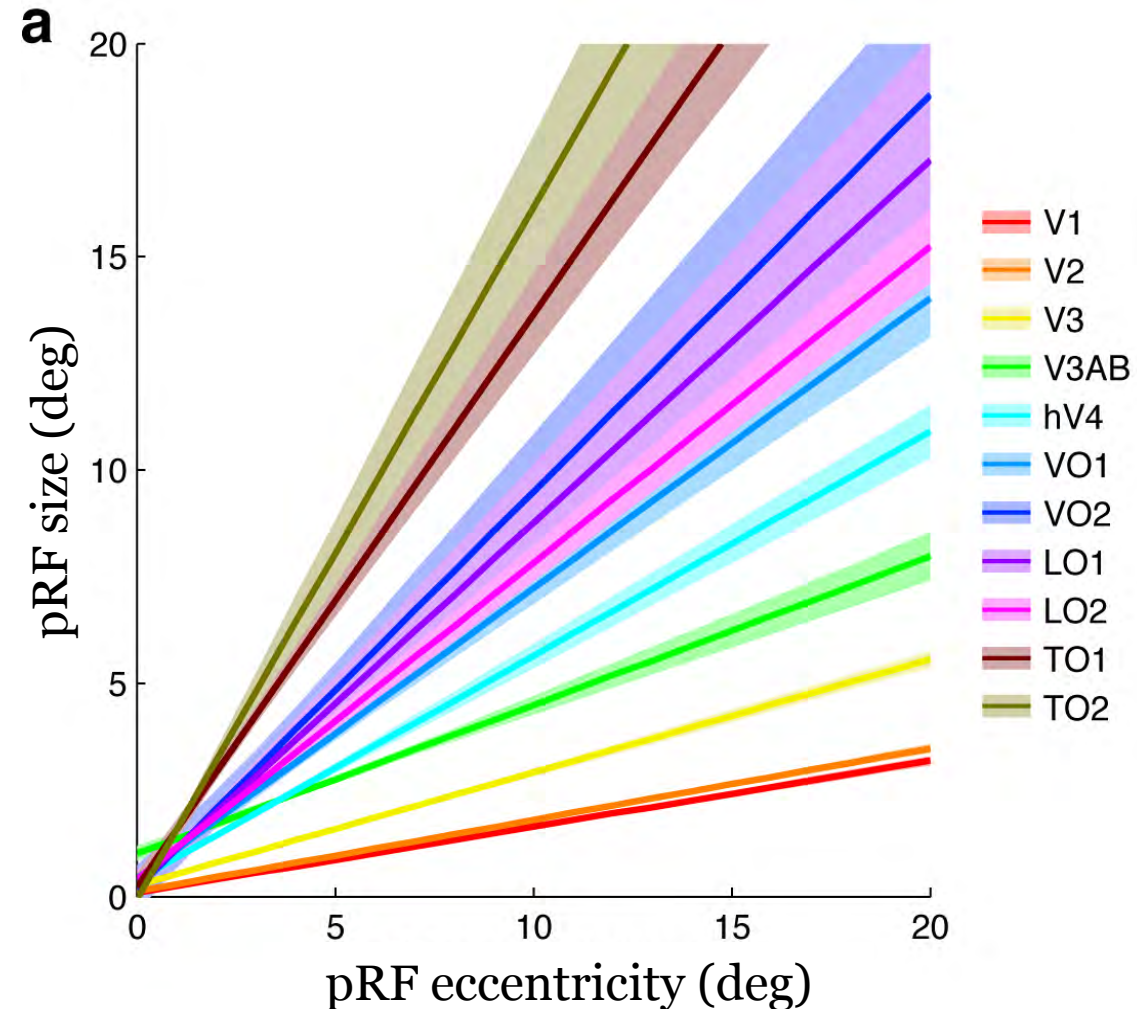
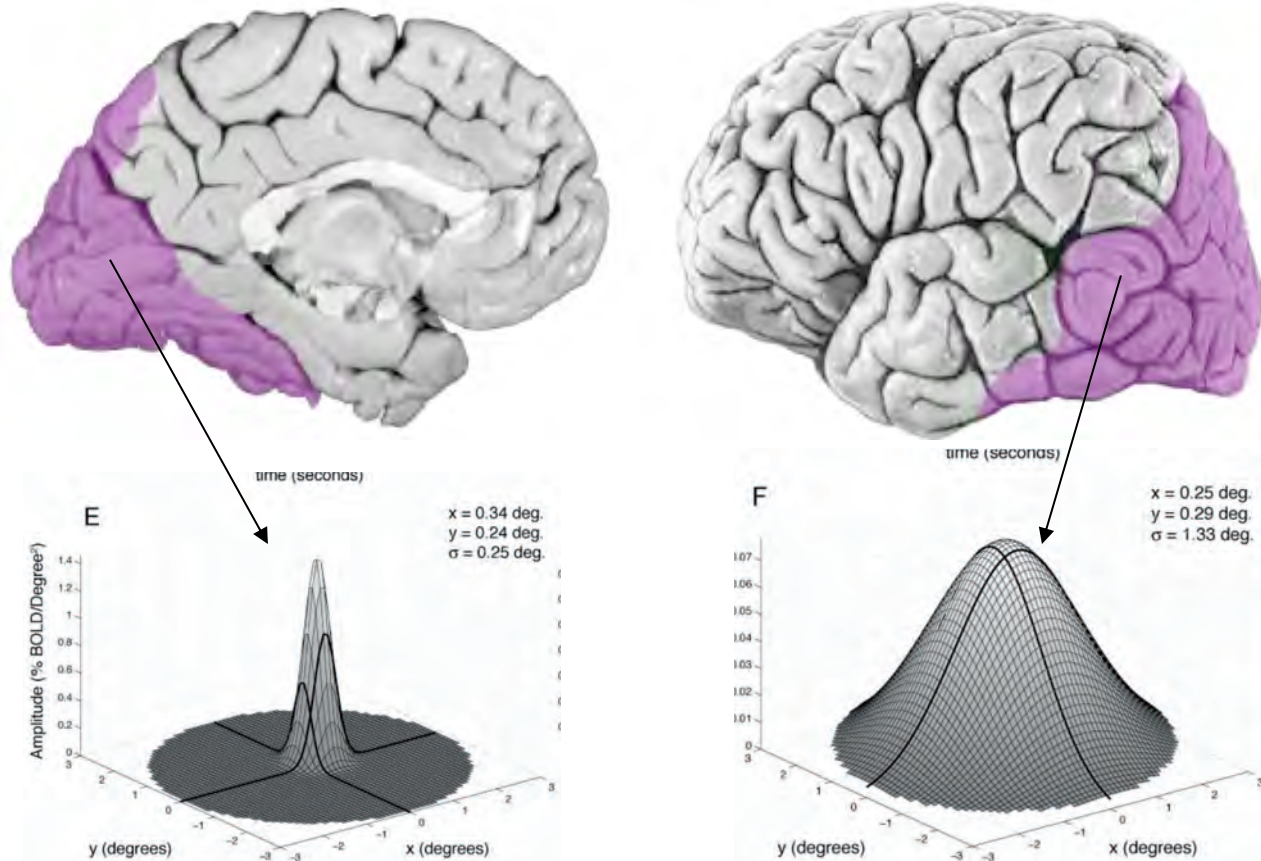
Predicted BOLD (including HRF)



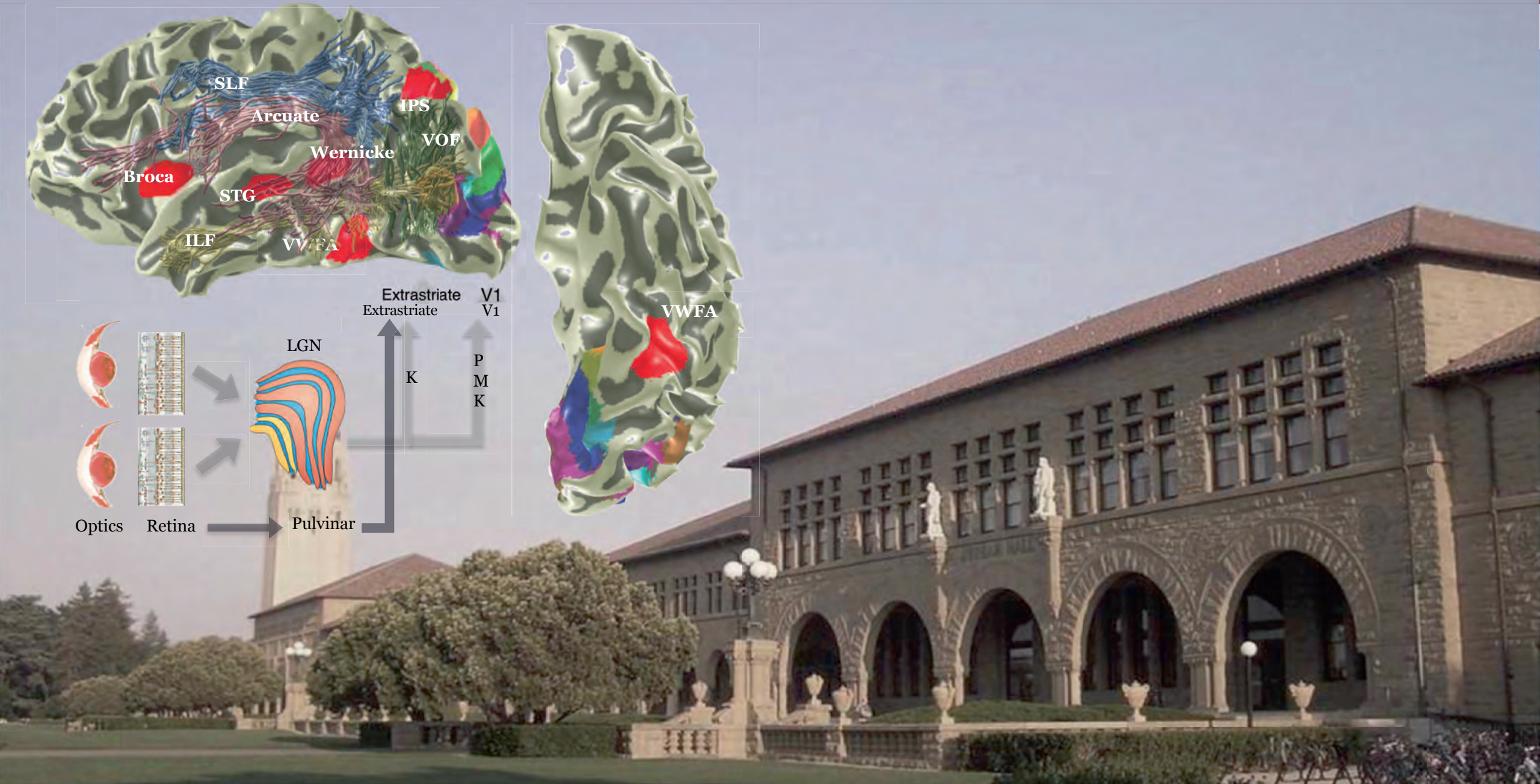
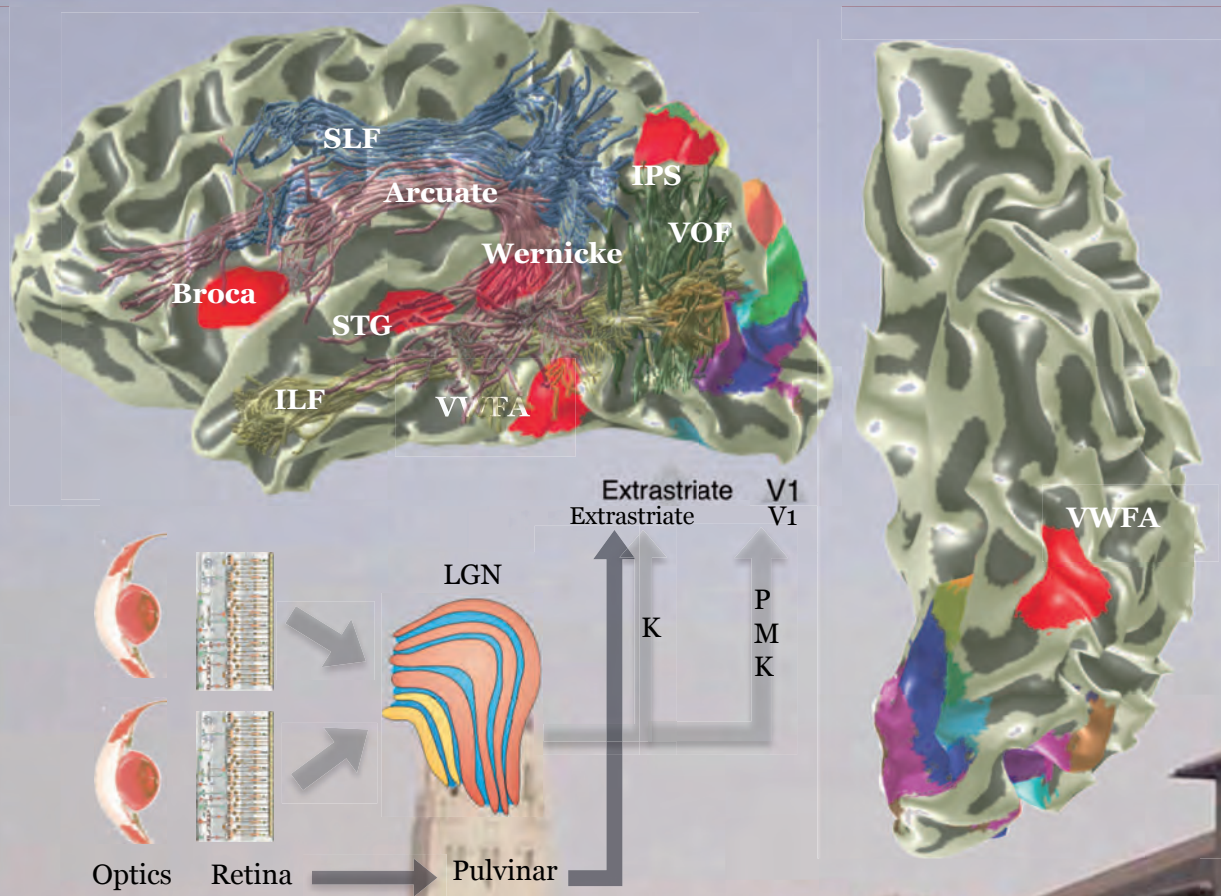
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PRF size varies substantially and regularly across visual cortex

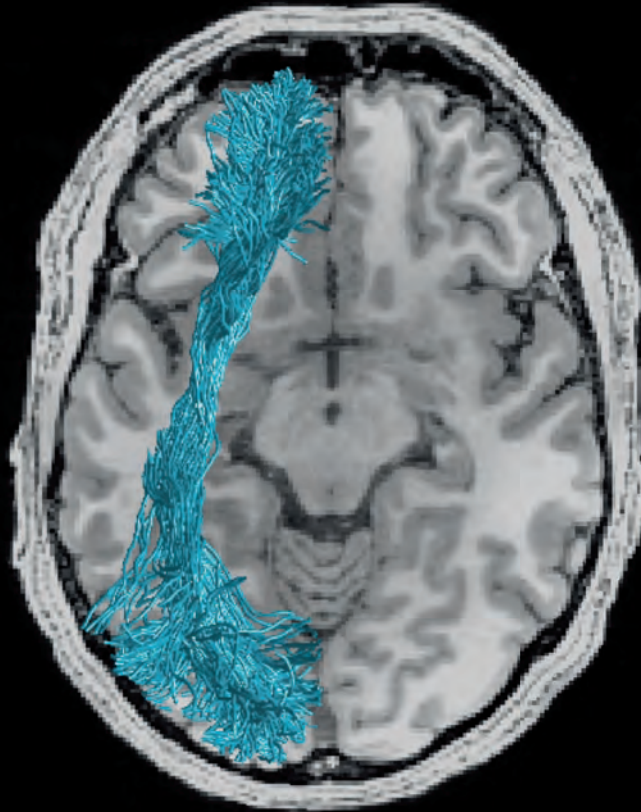
- At common eccentricities, different maps have different pRF sizes
- PRF size increases with eccentricity for all maps
- Bands are bootstrap estimates of the standard error



Diagnosing the reading circuitry



White matter fascicles are generated
by step-wise sampling of local diffusion information



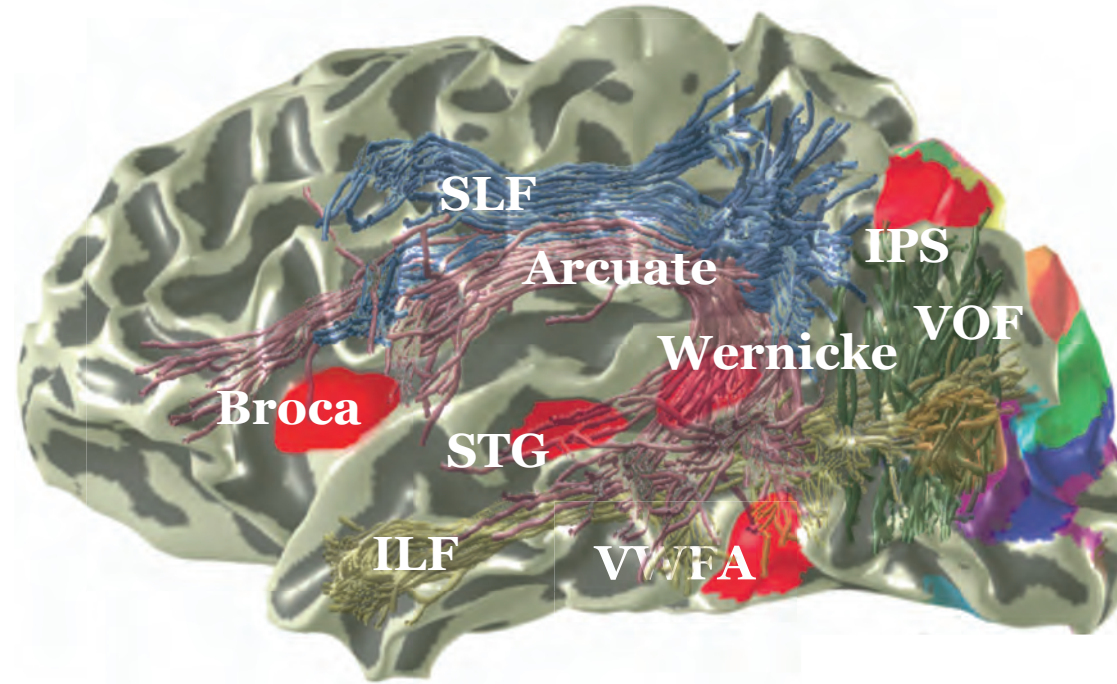
Left
IFOF

150 Directions, 2 mm³, B=2000 projected on a 1 mm³ T1 anatomical image

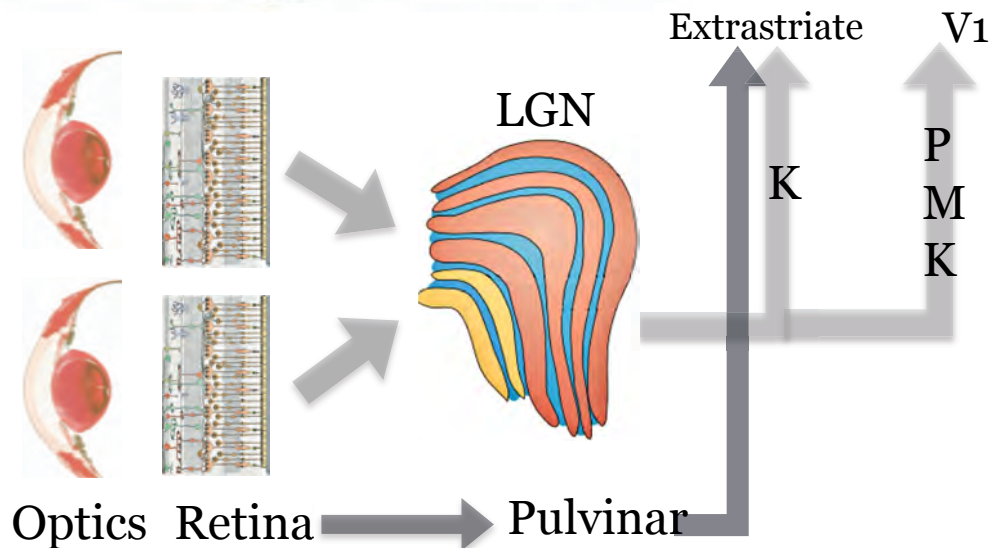
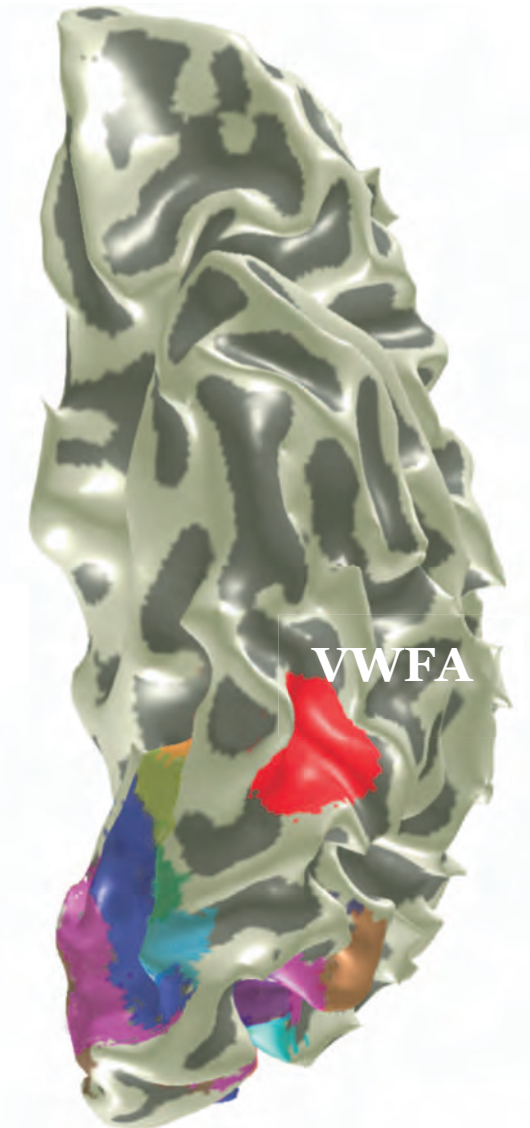
Major components of the reading pathway

The goal: Diagnosis

Identifying the locations and responses in a poor reader that differ significantly from measurements in good readers

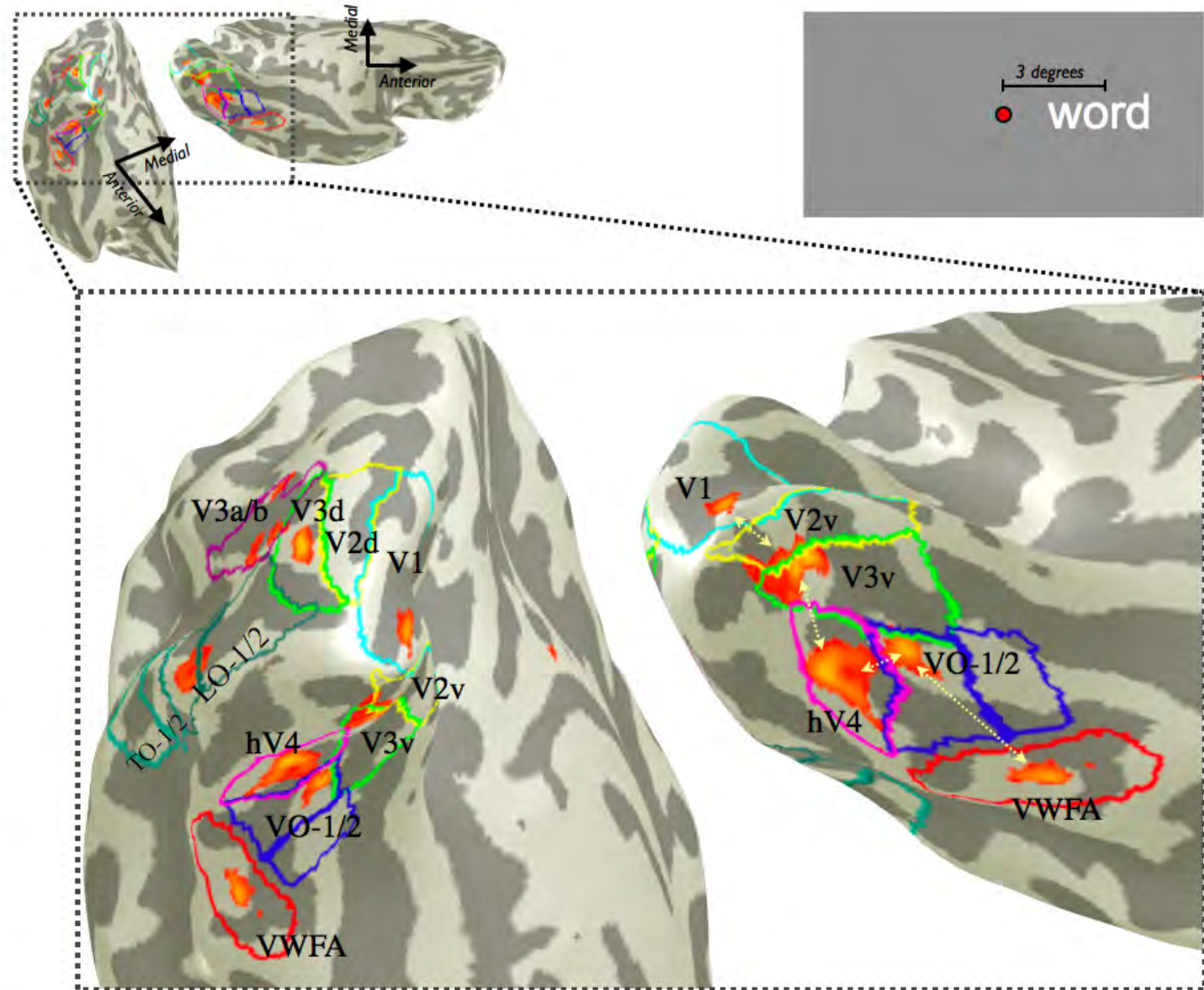


Wandell and Le (2017)



Learning to See Words
B.A. Wandell, A. Rauschecker and J. Yeatman (2012).
Annual Review of Psychology Vol. 63, pp.31-53.

Measuring the activity while reading (fMRI)



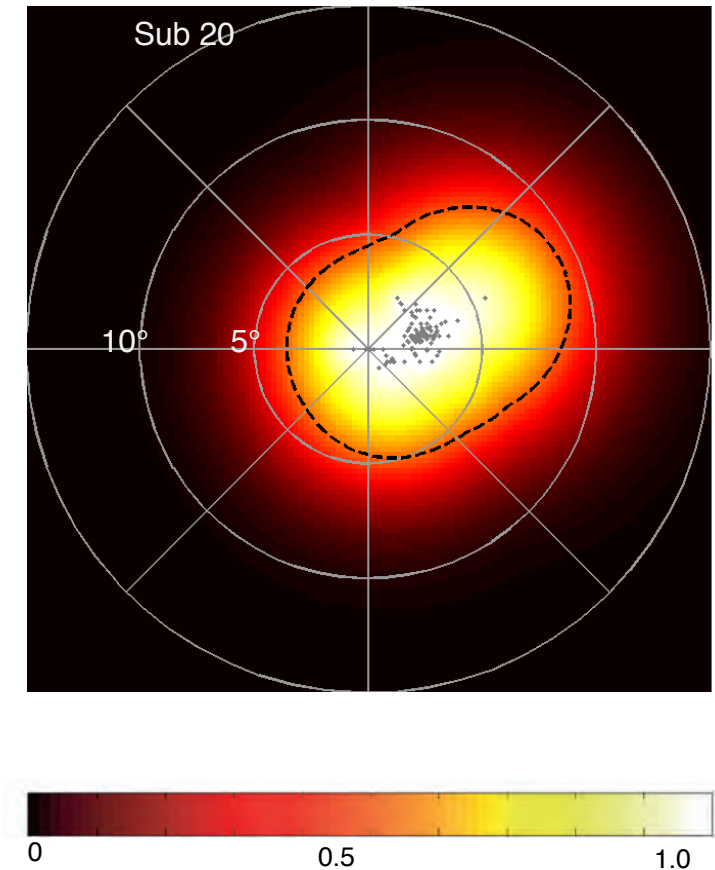
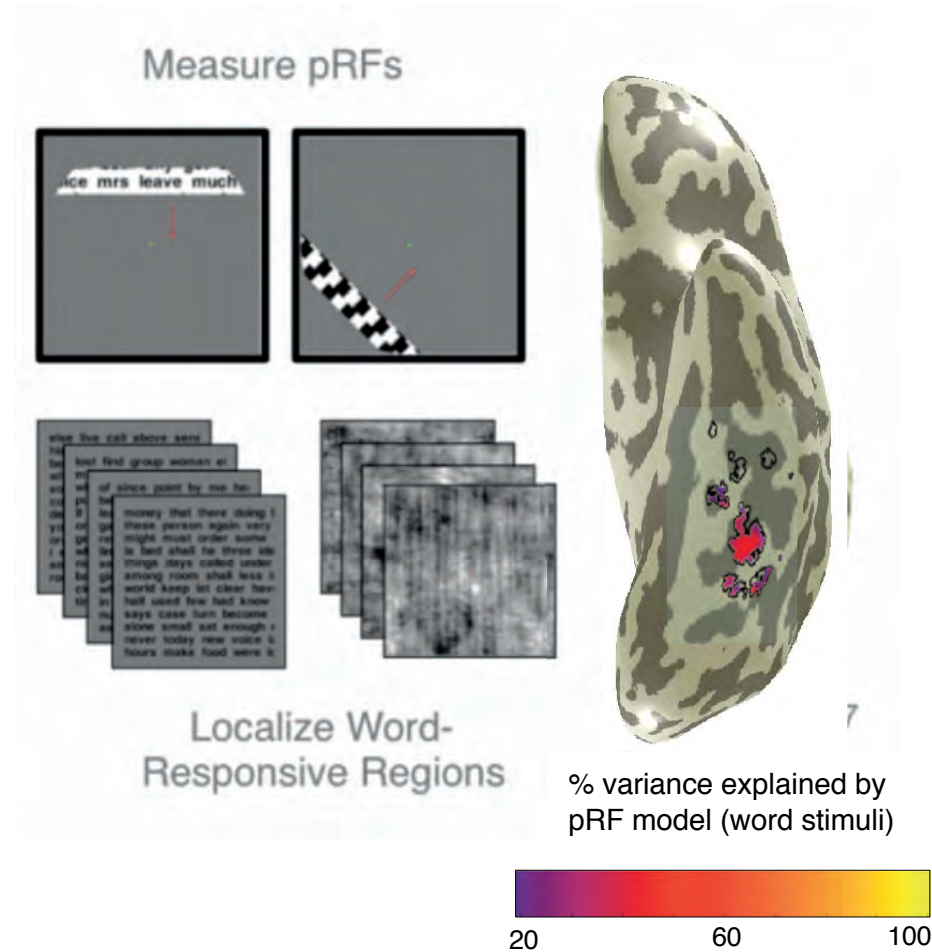
We can see the locations of the cortical activations during reading

Through the maps and on to the VWFA

Field of view in reading circuitry of a single subject

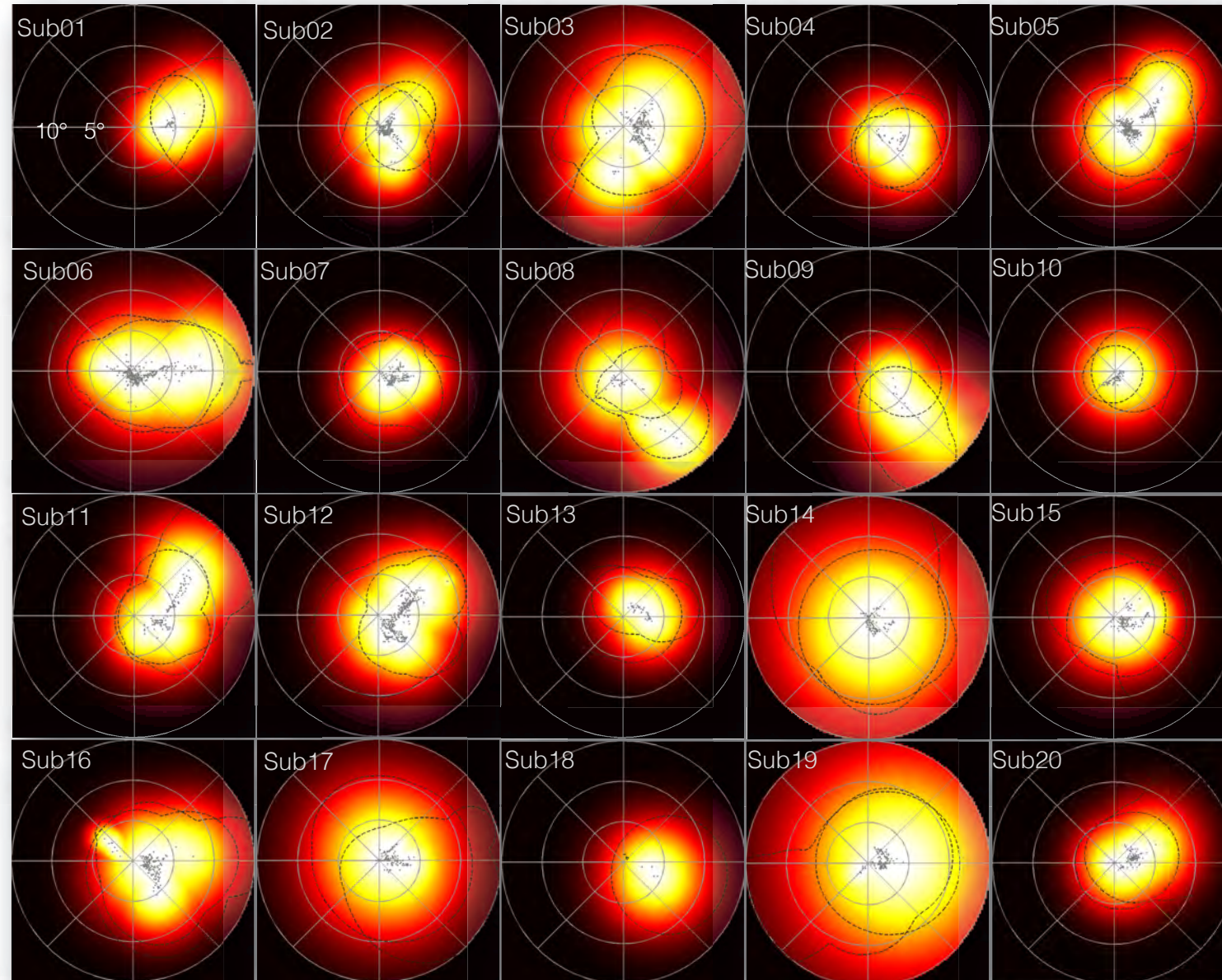
Using pRF methods, we have learned that the portion of cortex engaged in reading only sees a small part of the visual field

This may be why it is very hard to read in the peripheral field



Field of view of the VOT reading reading circuitry

Left hemisphere only



- There are significant differences between participants
- We are correlating these differences with measures of word recognition
- With colleagues we are studying how the FOV in Israeli readers

- Reproducible research
- Analyzing one person at a time

Stanford | Project on Scientific Transparency

ABOUT NIMS INTERACTIVE COMPUTING THE POST TEAM CONTACT

SCITRAN

Scientific data management

NIMS is a scientific data management system, specifically designed for neuroimaging data.
Click to learn more about NIMS!

POST NIMS



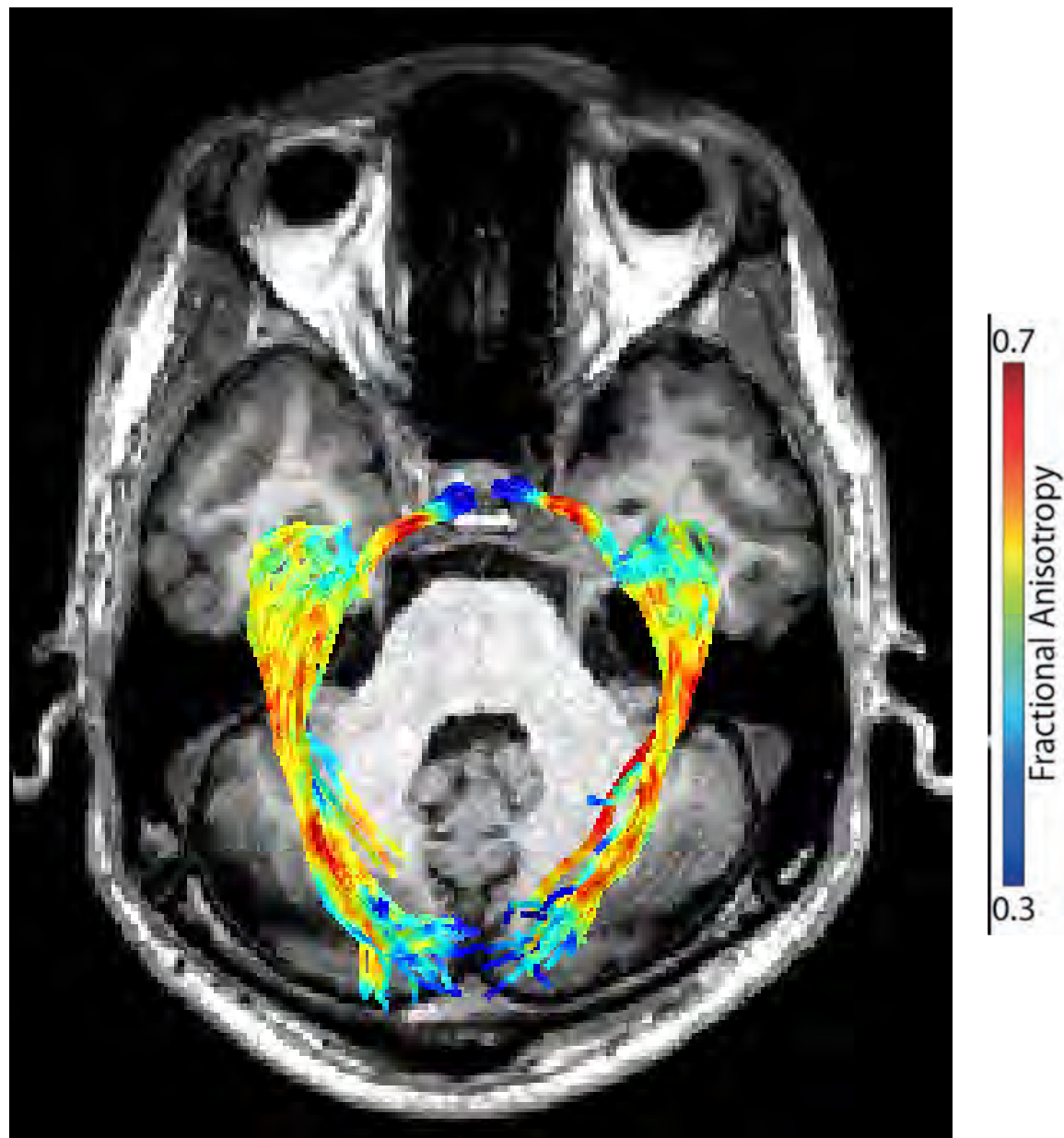
A motivating example

- A subject or patient with a retinal eye disease comes to the lab
- We want to know the consequences of retinal degeneration on cortical structures

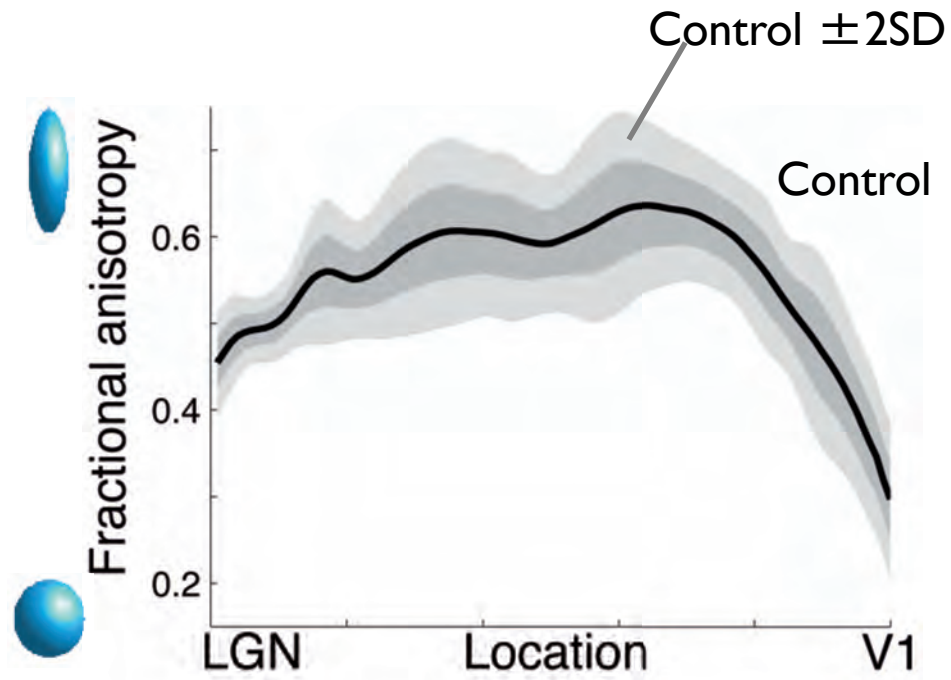


A motivating example

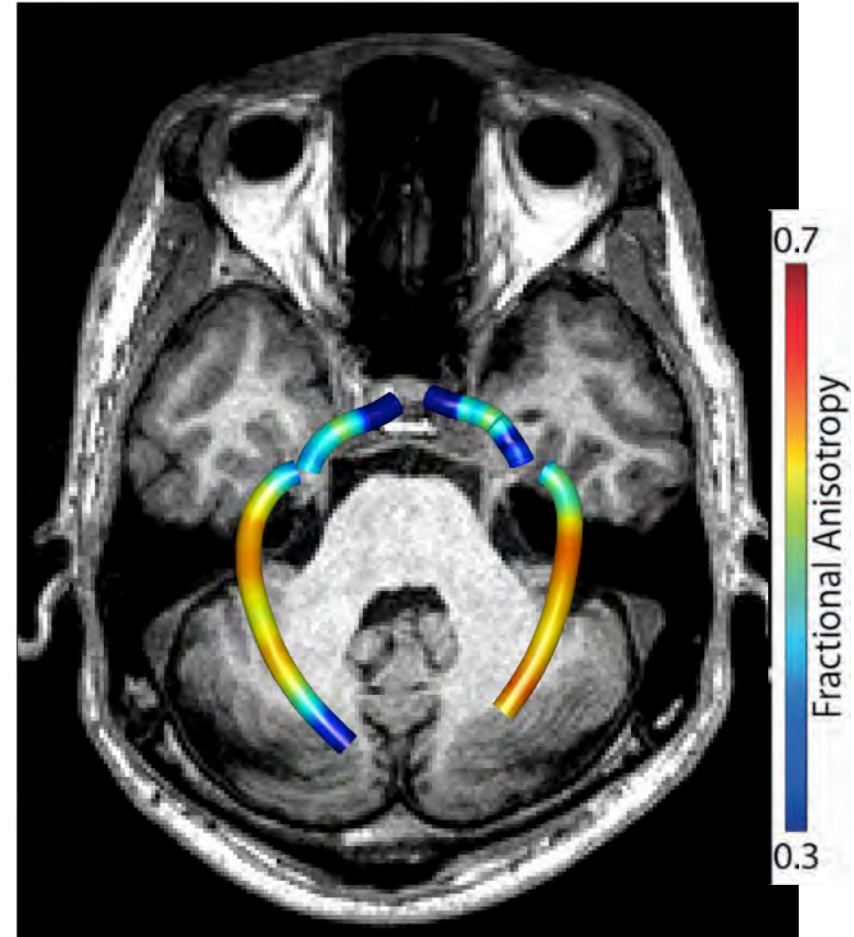
- Measure the subject's visual white matter and secure the data!
- Use validated computational tools for quality assurance
- Use open-source software for tract identification, tissue estimation and comparison with other populations



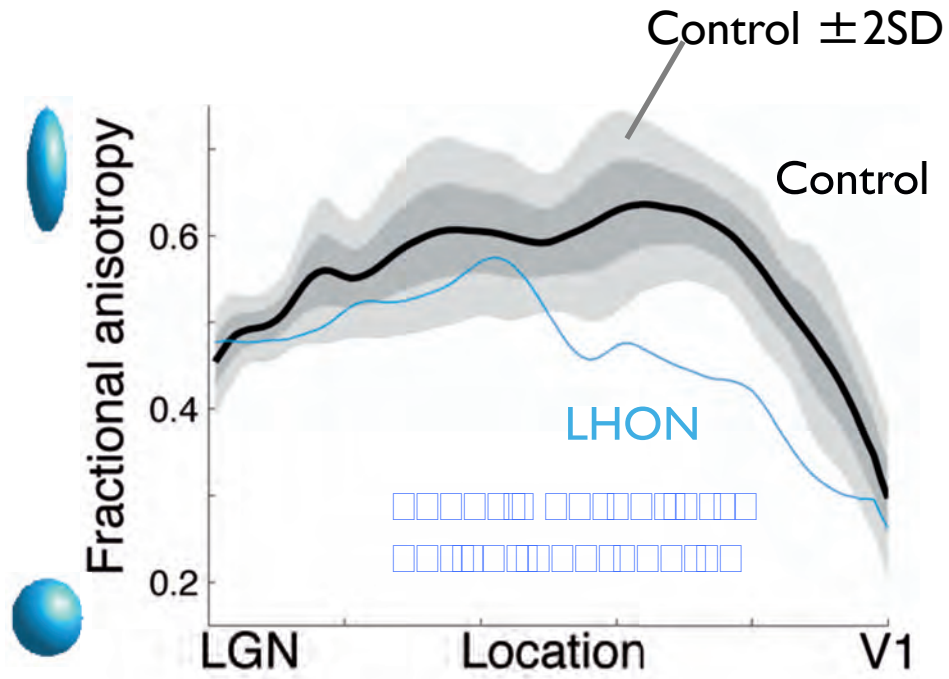
Use databases to find control data



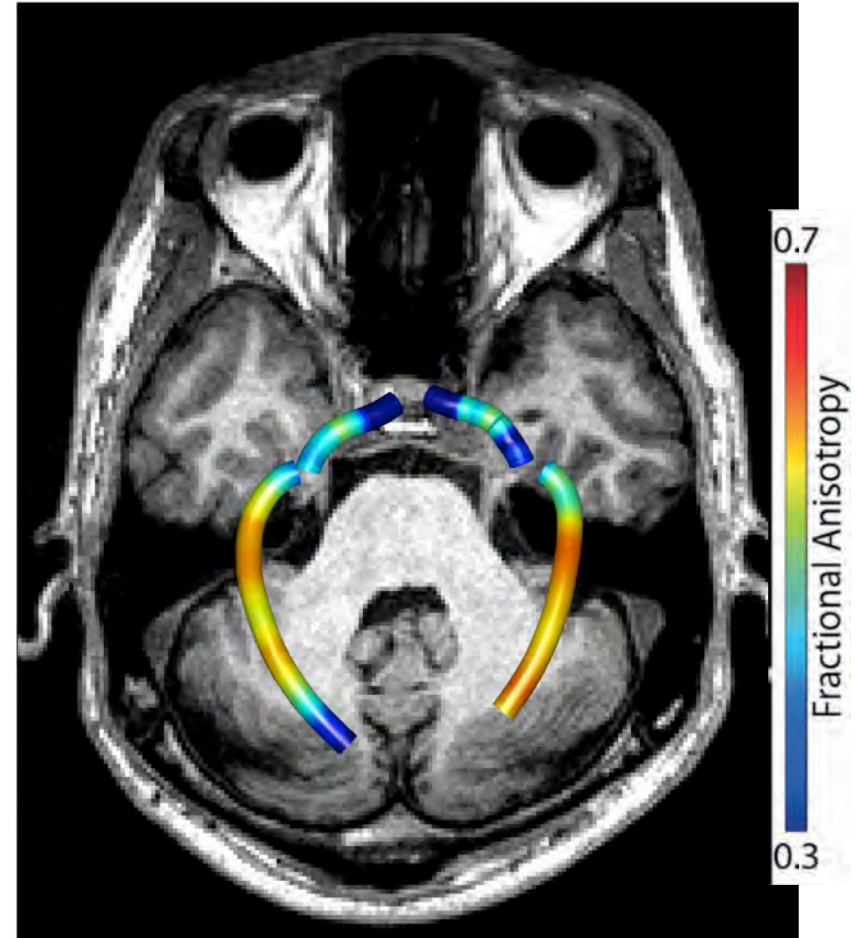
The expectation based on data
acquired and stored



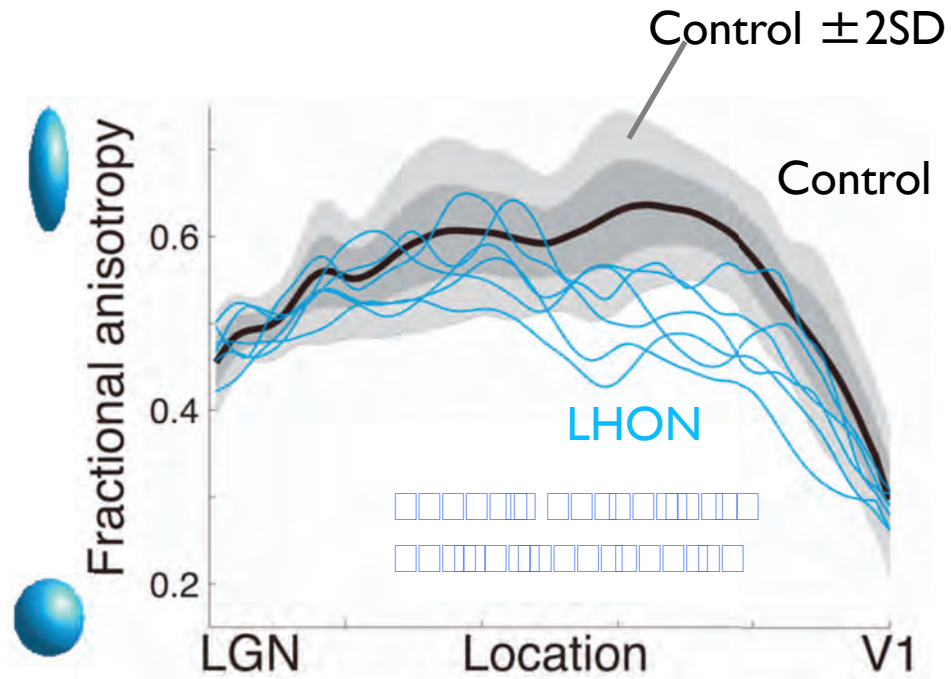
Compare your subject with the distribution and think



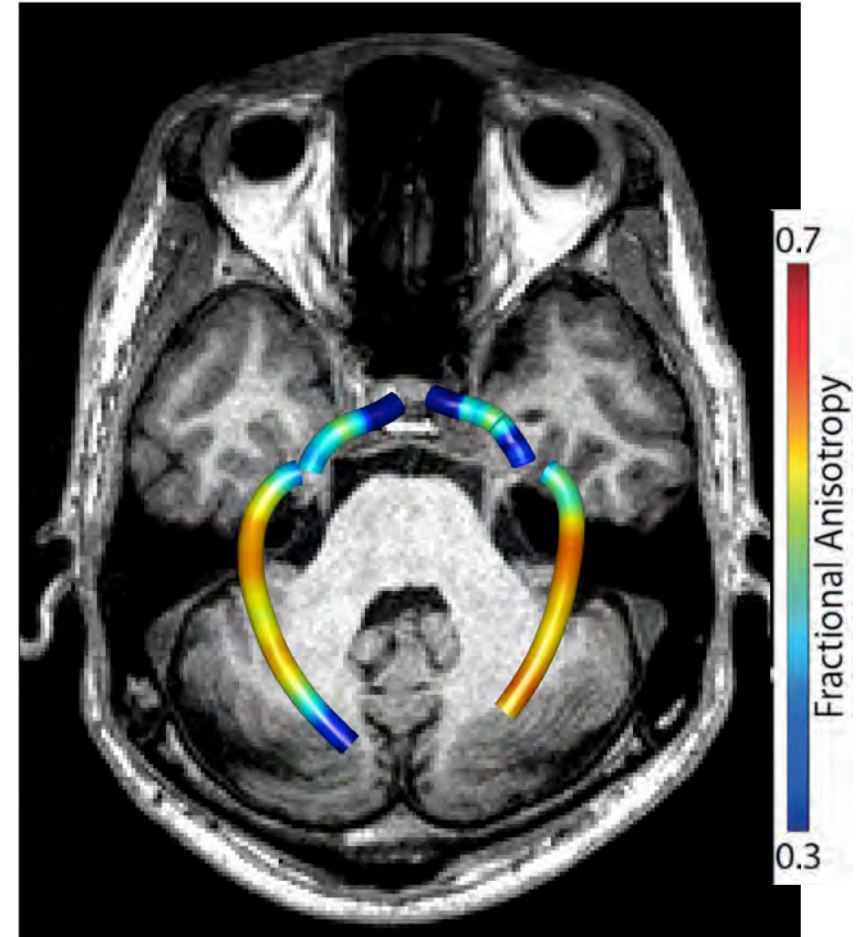
This subject compared to the expectation



Data science and statistics issues



Each subject with the disease has some variation and we would like to know, and track each one over time



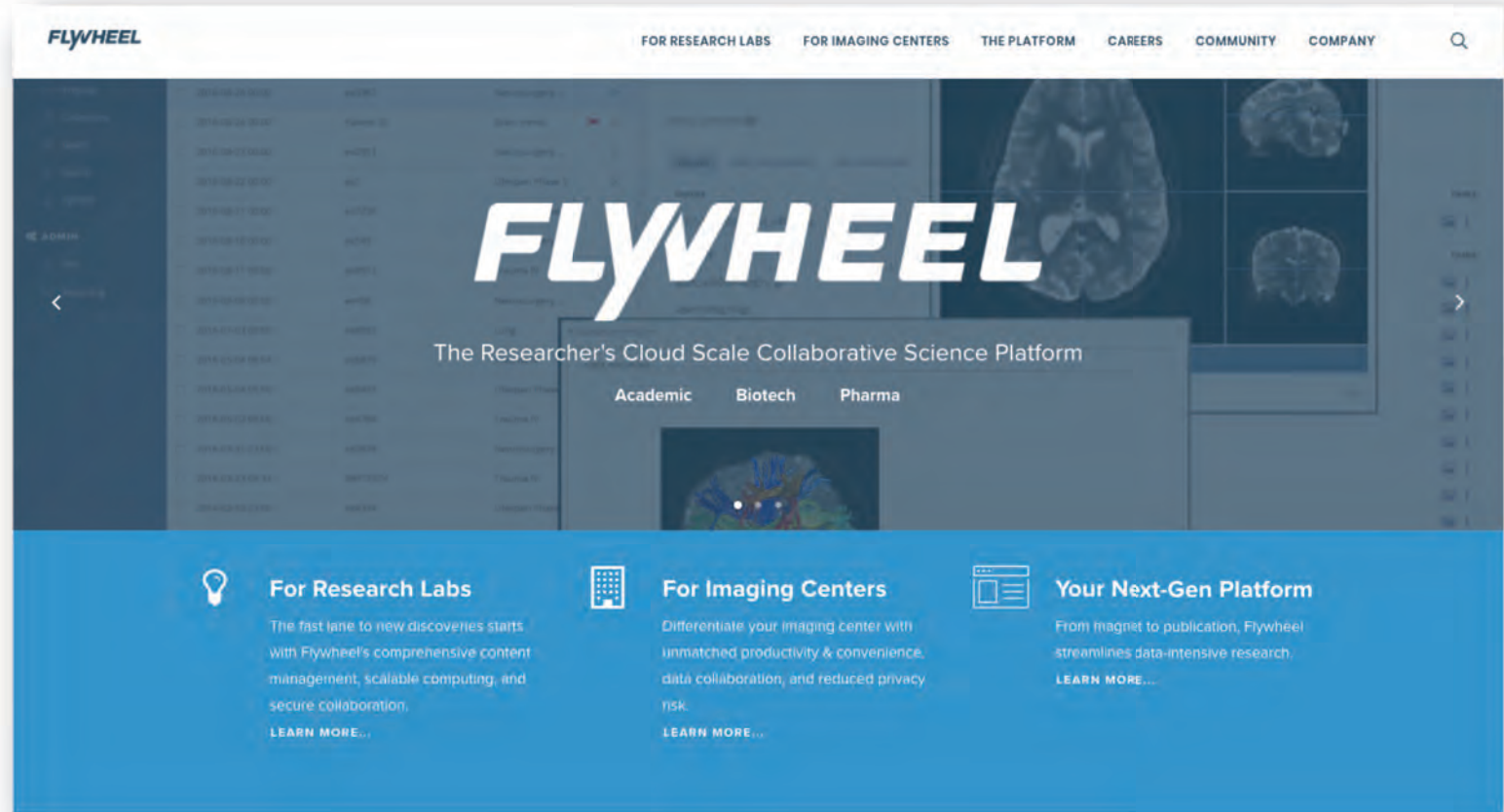
Data status at the CNI (03/11/2018)

People

900 scientists
7000 research subjects
70 research groups

MRI data

16,000 scan sessions
150,000 acquisitions
67,000 fMRI
13,488 T1 anatomical
6700 diffusion
600 spectroscopy



- Full stack web interface
- Google Cloud Platform or on-prem
- SDK for searching, downloading, classifying and processing data
- Docker and Kubernetes for cloud-scale computing
- Object storage (next quarter)
- User rights management, MongoDB, Rest API

