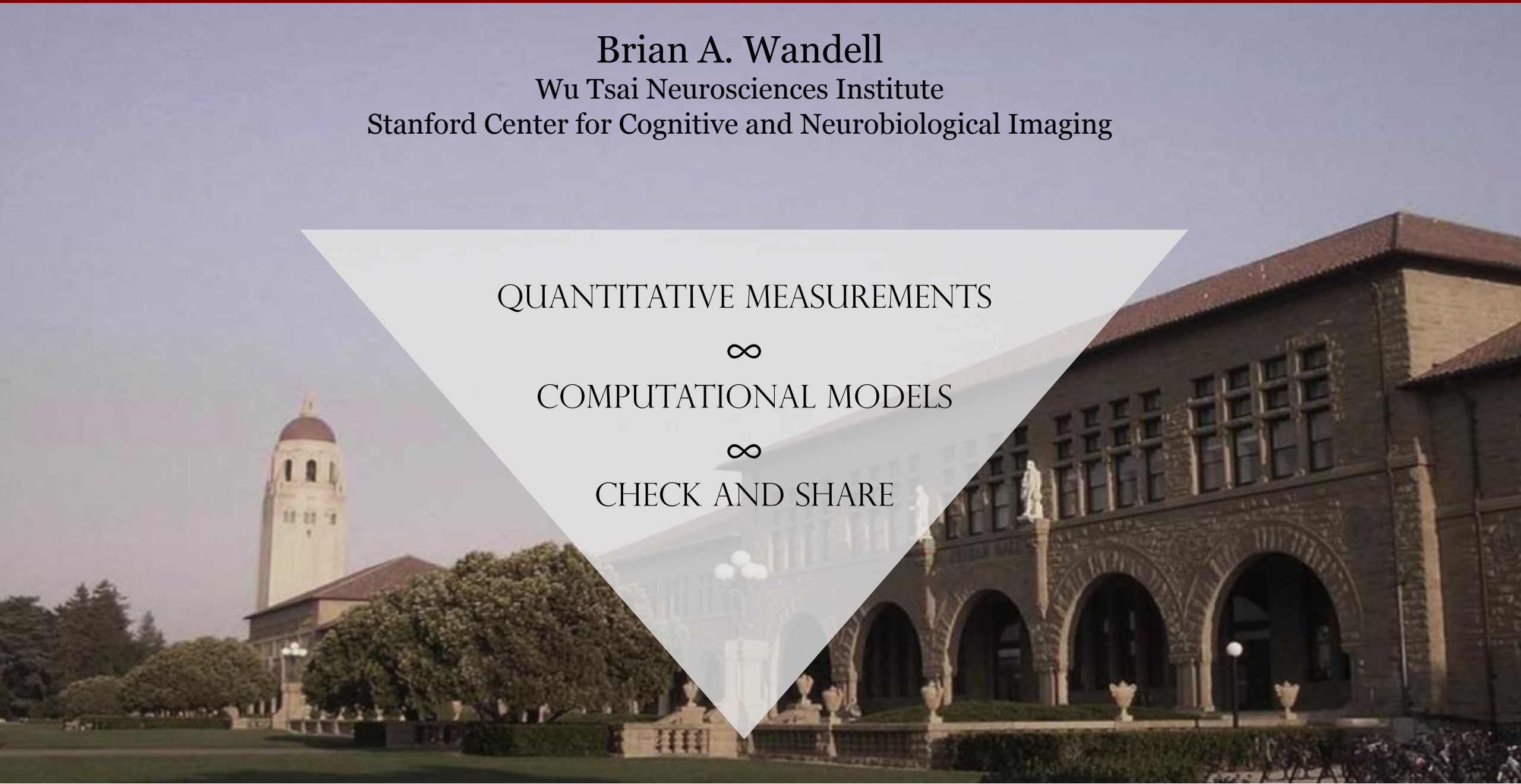
Neural circuitry for vision and reading

Brian A. Wandell
Wu Tsai Neurosciences Institute
Stanford Center for Cognitive and Neurobiological Imaging



Wu Tsai Neurosciences Institute building (March 19, 2019)

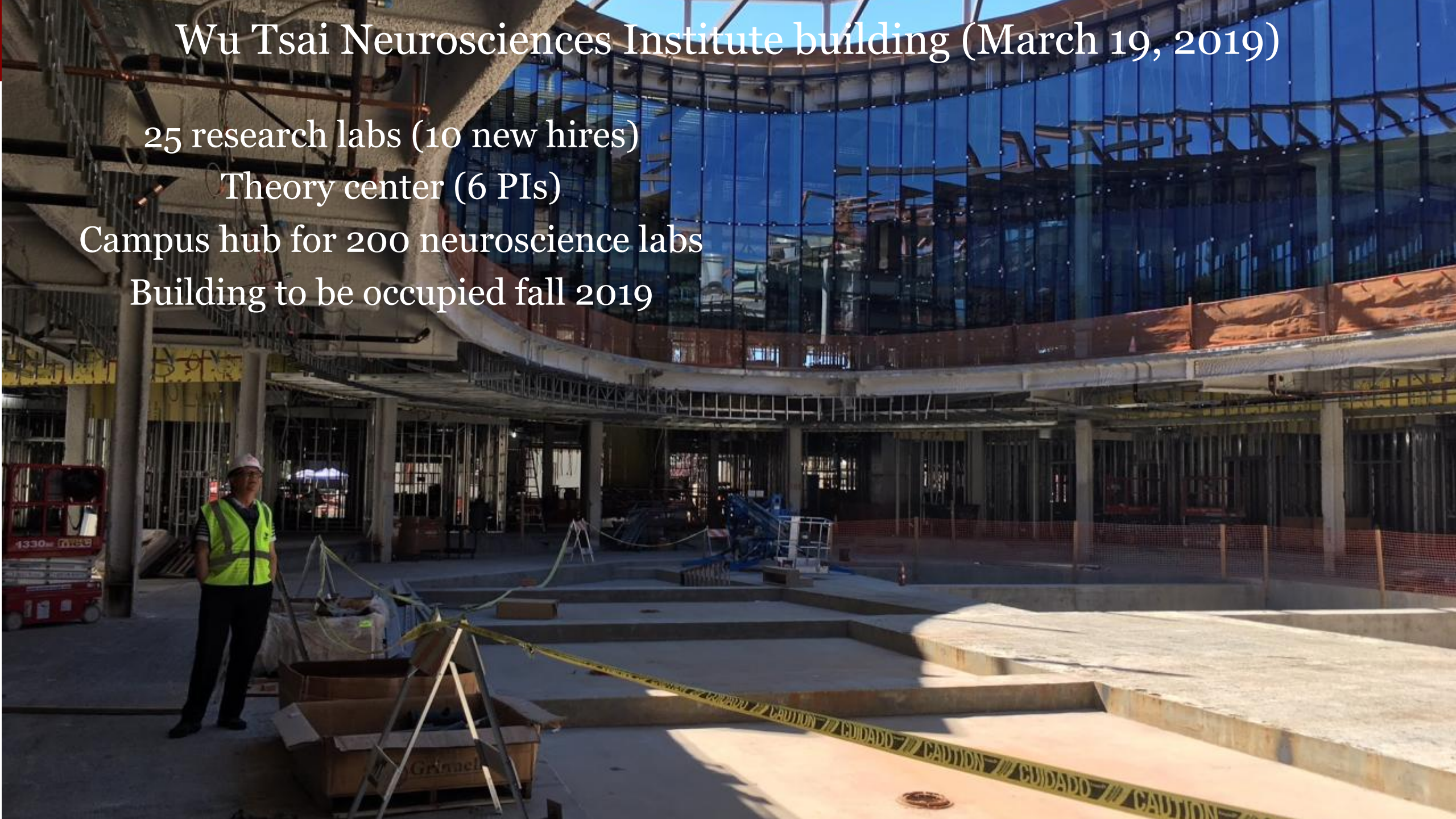
25 research labs (10 new hires)

Theory center (6 PIs)

Campus hub for 200 neuroscience labs

Building to be occupied fall 2019

Wu Tsai Neurosciences Institute building (March 19, 2019)



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WU TSAI NEUROSCIENCES INSTITUTE - 2014-2019

Neuro-Discovery

Our scientists develop cutting-edge techniques to make fundamental discoveries in brain science — discoveries that could unlock new medical treatments, transform education, inform public policy

Neuro-Engineering

Our engineers are developing ways to manipulate neural circuits with electricity, light, ultrasound and magnetic fields. They are inventing algorithms and theories to guide understanding

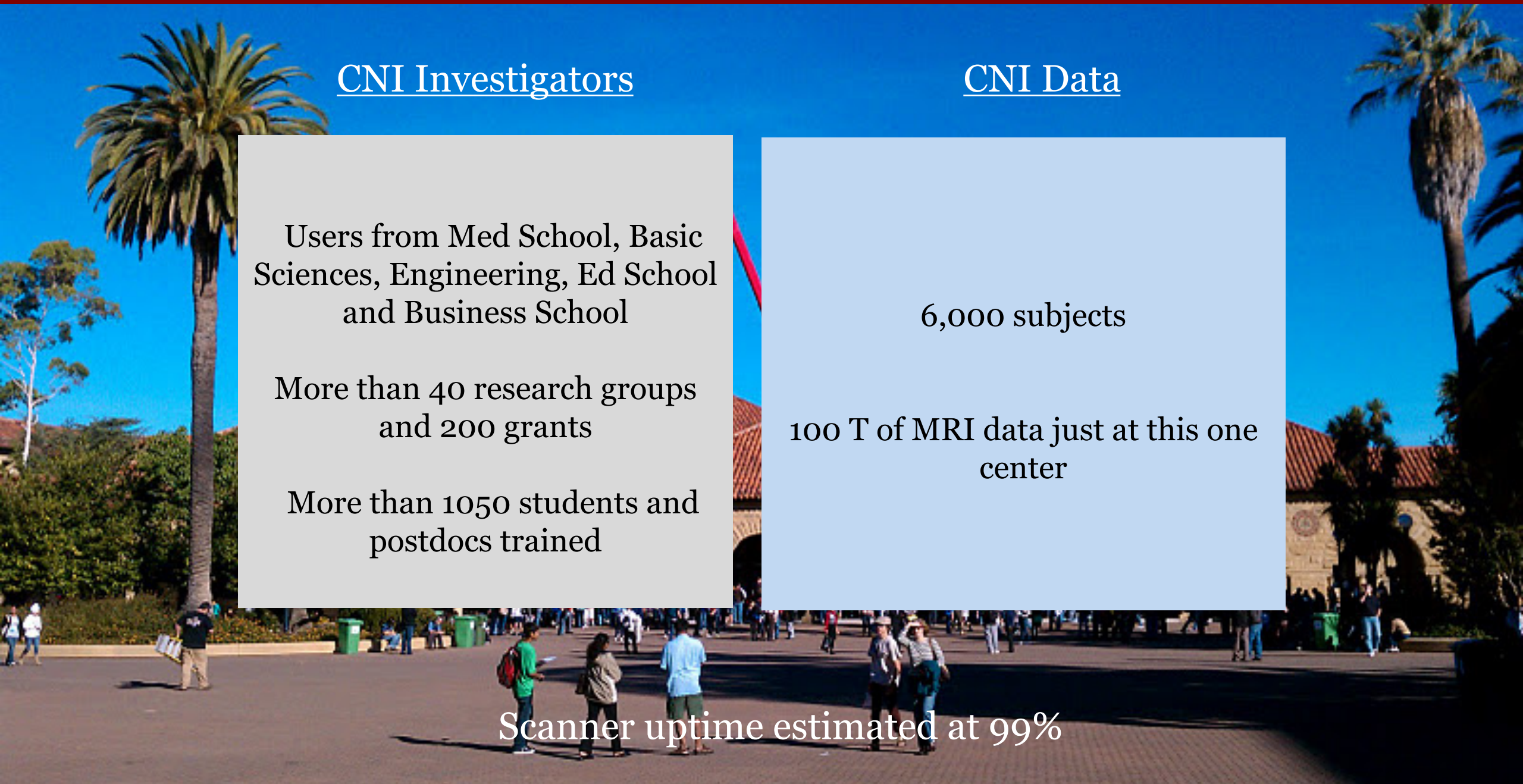
Neuro-Health

Our clinicians collaborate with scientists and engineers to pioneer novel treatments for psychiatric and neurological disease, easing the devastating consequences of diseases such as stroke, epilepsy, and depression.

Stanford's Center for Cognitive and Neurobiological Imaging (CNI)

- Support neuroscience discovery for enhancing society
- Develop and disseminate imaging methods
- Create a structured, safe, and innovative teaching environment for human neuroscience research

CNI: The most heavily used MRI research scanner on Stanford campus



CNI Investigators

Users from Med School, Basic Sciences, Engineering, Ed School and Business School

More than 40 research groups and 200 grants

More than 1050 students and postdocs trained

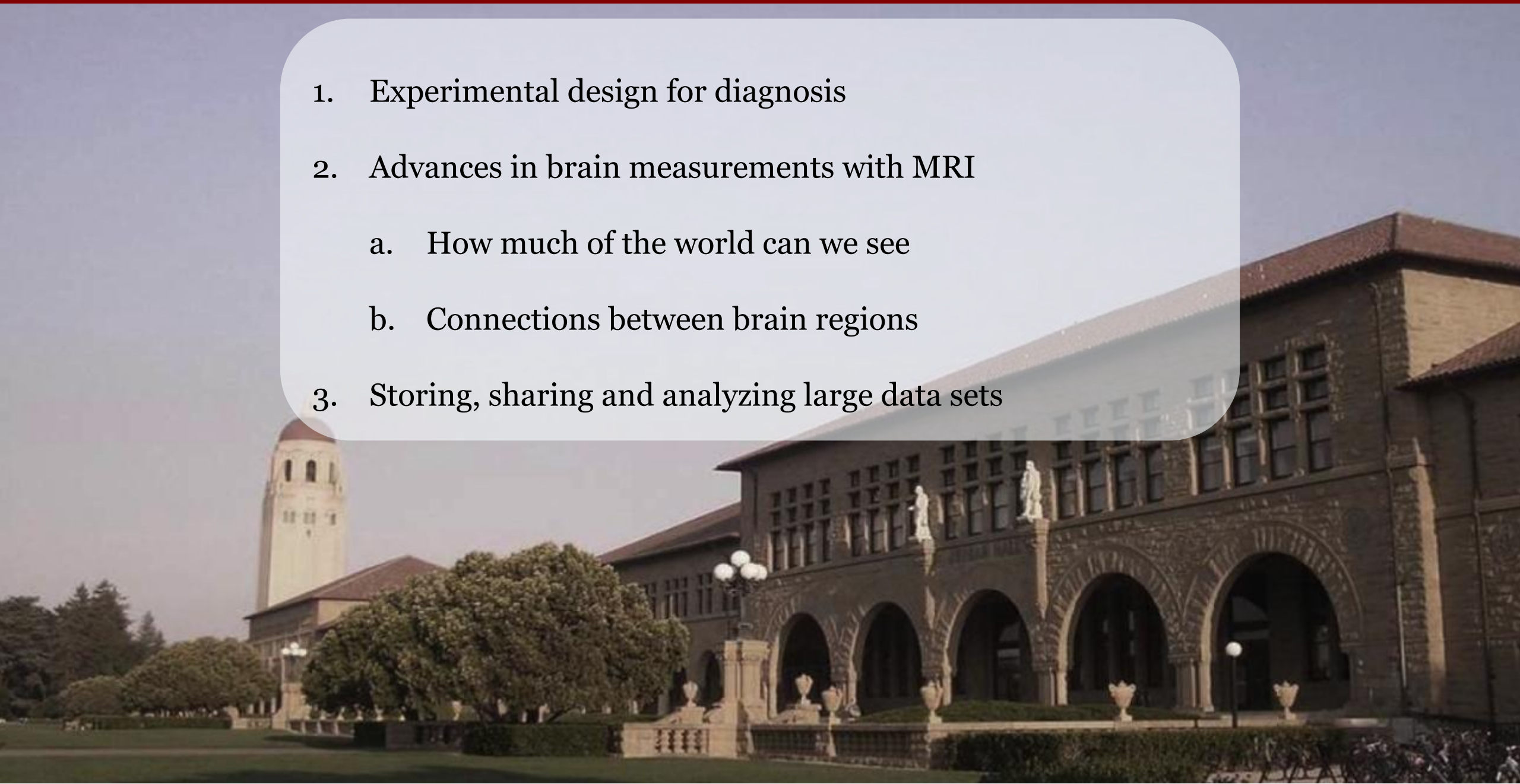
CNI Data

6,000 subjects

100 T of MRI data just at this one center

Scanner uptime estimated at 99%

Talk plan: Neural circuitry for vision and reading

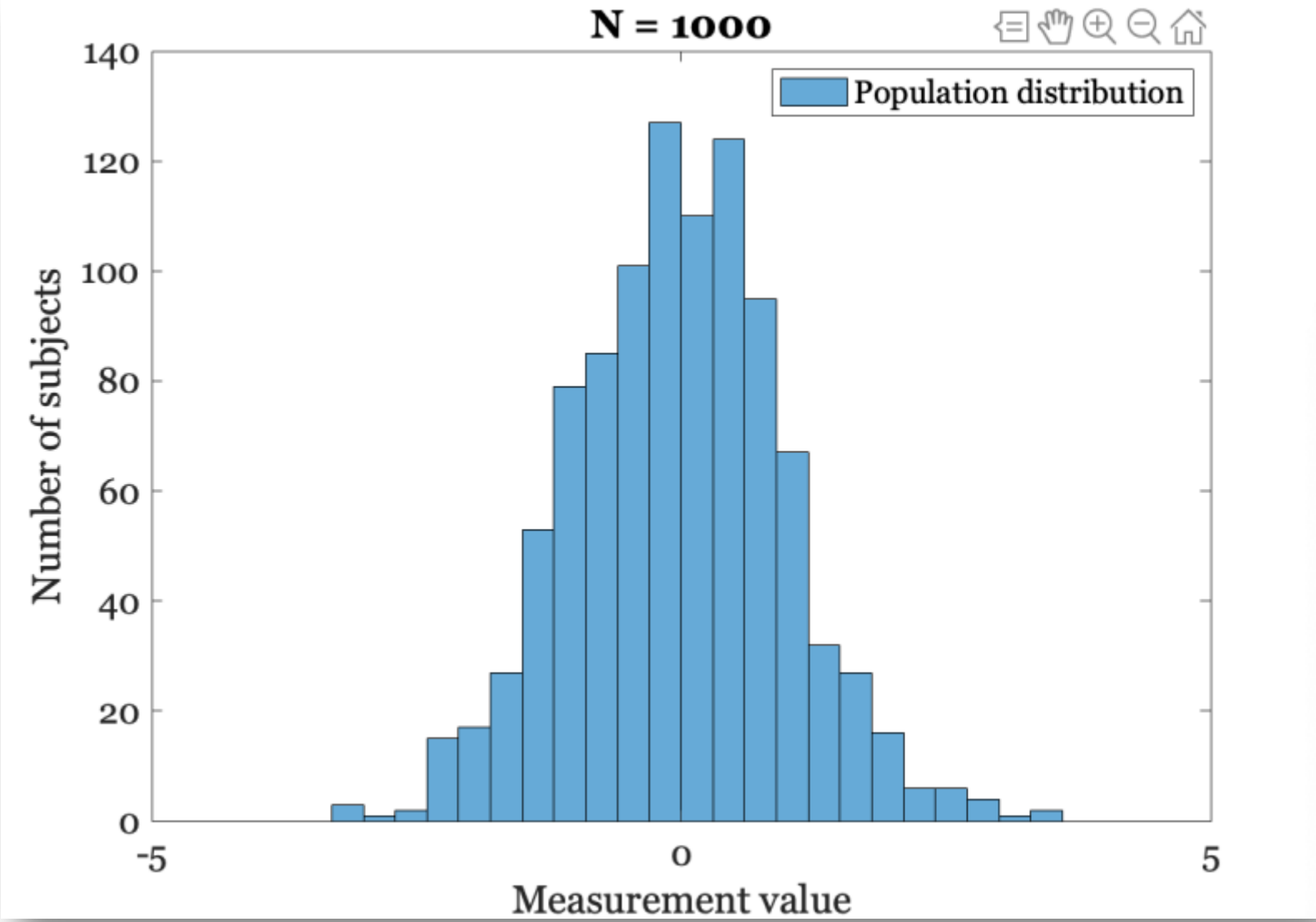


1. Experimental design for diagnosis
2. Advances in brain measurements with MRI
    a. How much of the world can we see
    b. Connections between brain regions
3. Storing, sharing and analyzing large data sets

1. Experimental design for diagnosis

- **Goal**: Determine as early as possible the best way to help a particular child to become a successful reader

- The distribution (blue) at the right shows a population distribution of a potentially helpful diagnostic measurement

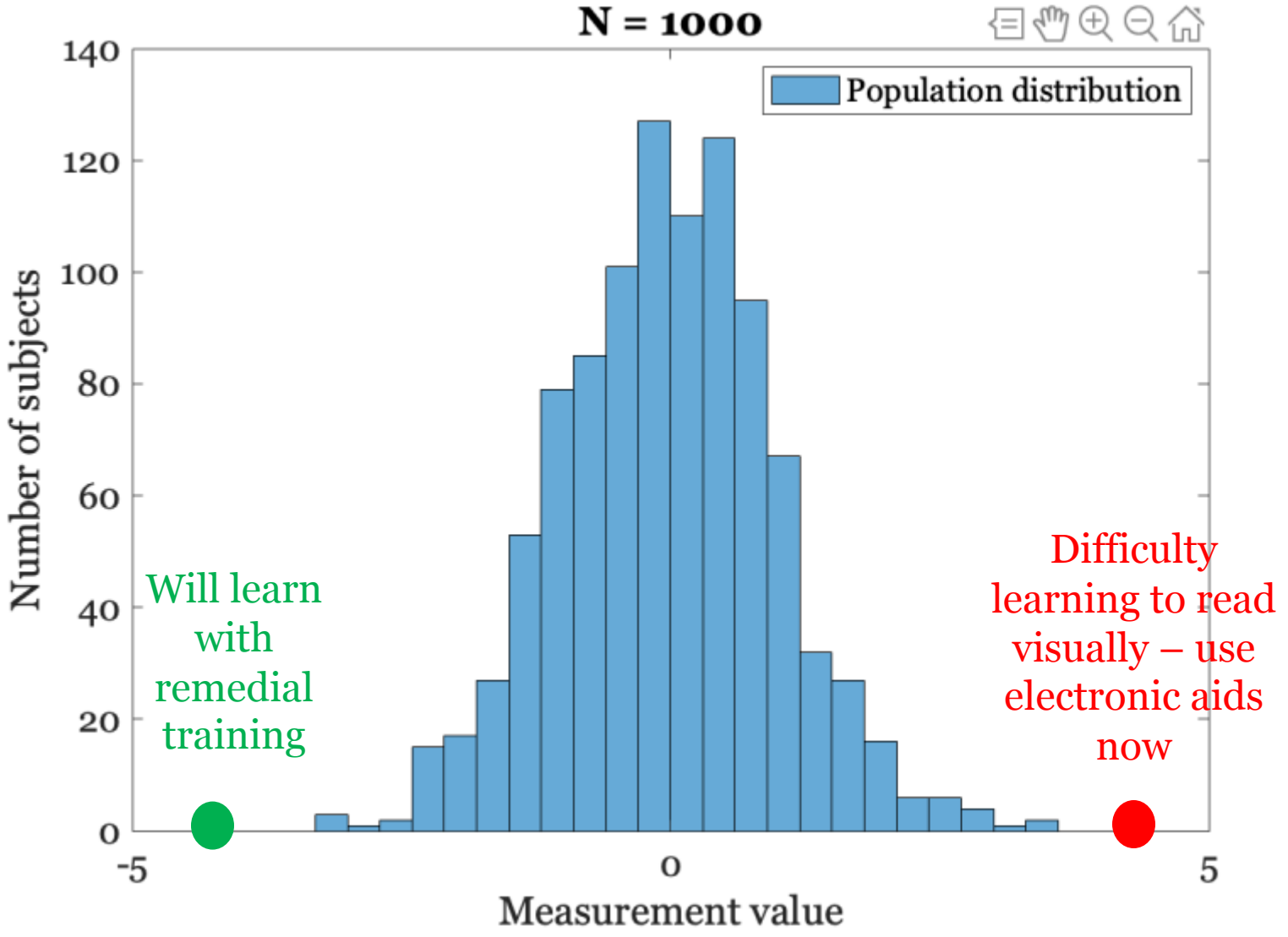


1. Experimental design for diagnosis

- **Goal**: Determine as early as possible the best way to help a particular child to become a successful reader

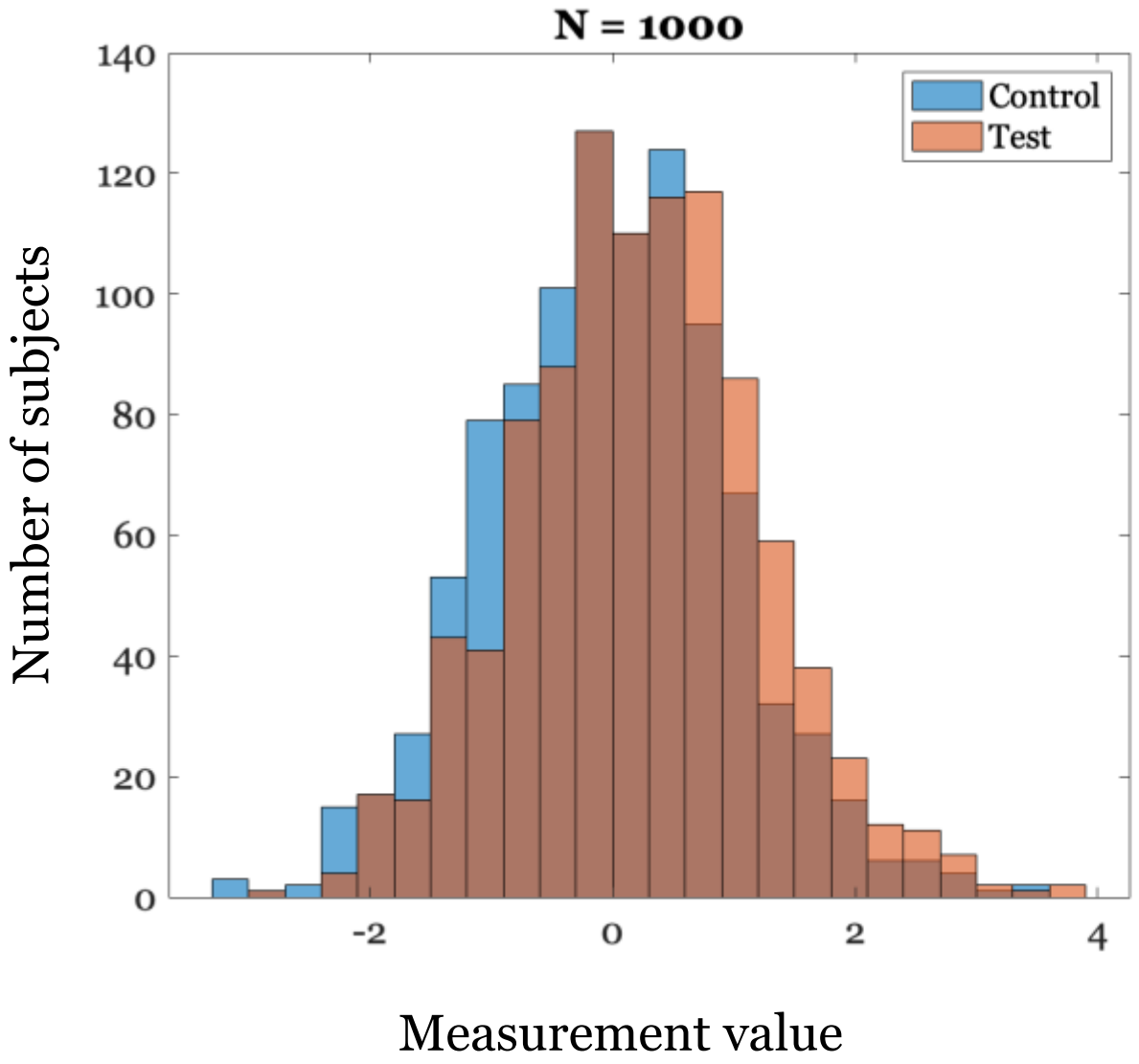
- The distribution (blue) at the right shows a population distribution of a potentially helpful diagnostic measurement

- The filled circles are measurements from two children; we would like to use the measurement to decide how to support the child



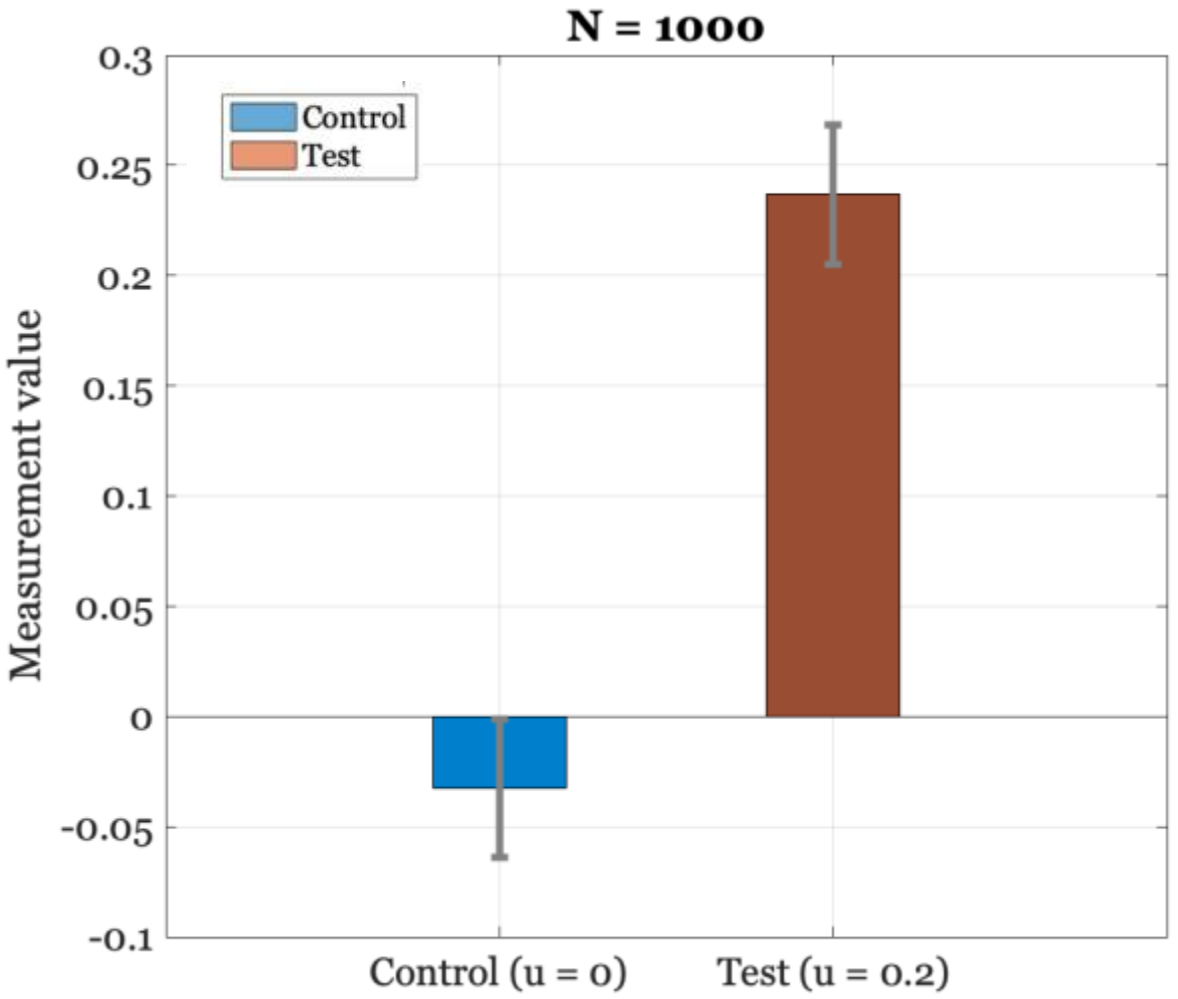
1. Experimental design for diagnosis - the problem with group comparisons

- This example shows a typical group comparison one might see reported in the literature
- We would never use this measure to diagnose a child – it does not distinguish the groups well



1. Experimental design for diagnosis - the problem with group comparisons

- These are the same data as the histograms, but plotted as a group comparison
- We often see publications that show the mean and the SEM, as in this bar chart
- The author might conclude that we have a potential biomarker, although when N is large that will not be true

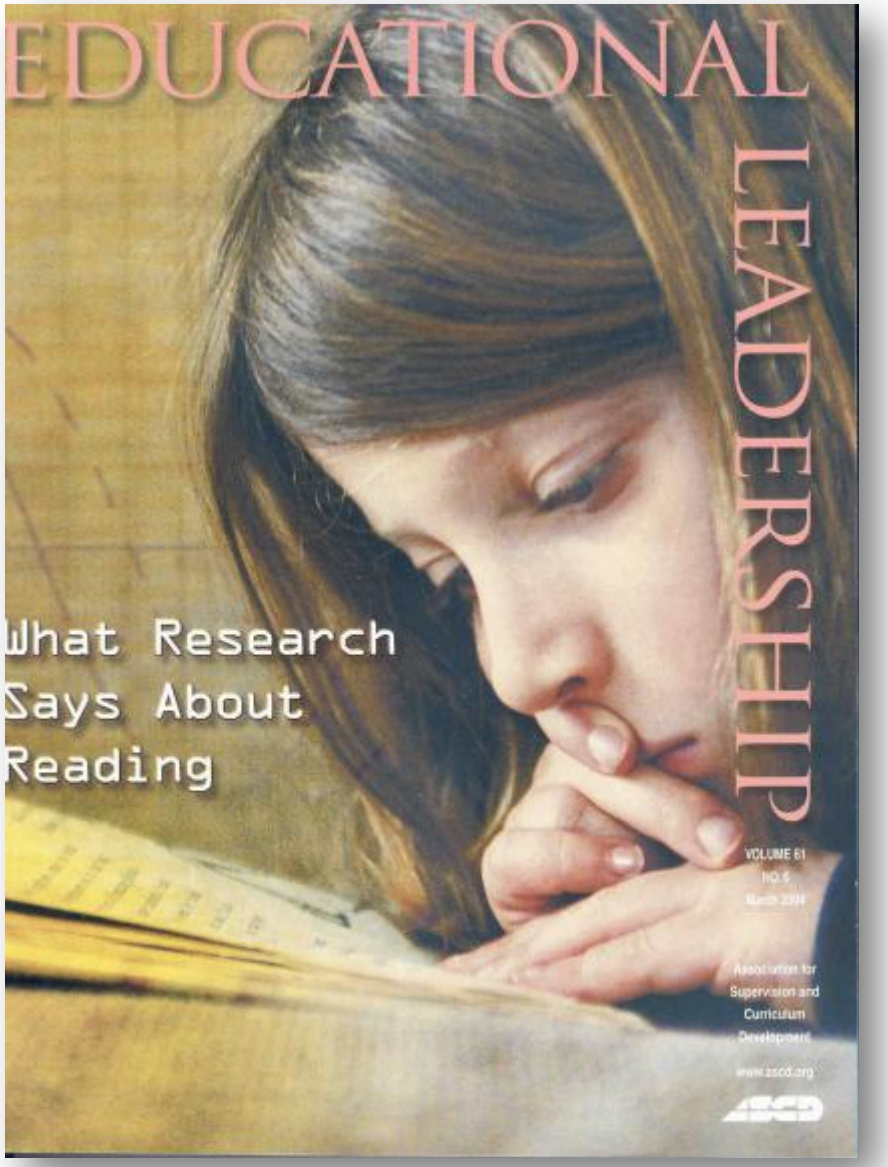


1. Experimental design for diagnosis – summary

Use experimental designs for single subjects and choose experiments and analyses that can diagnose individuals, not groups

2. Advances in cortical mapping – why use neural measurements

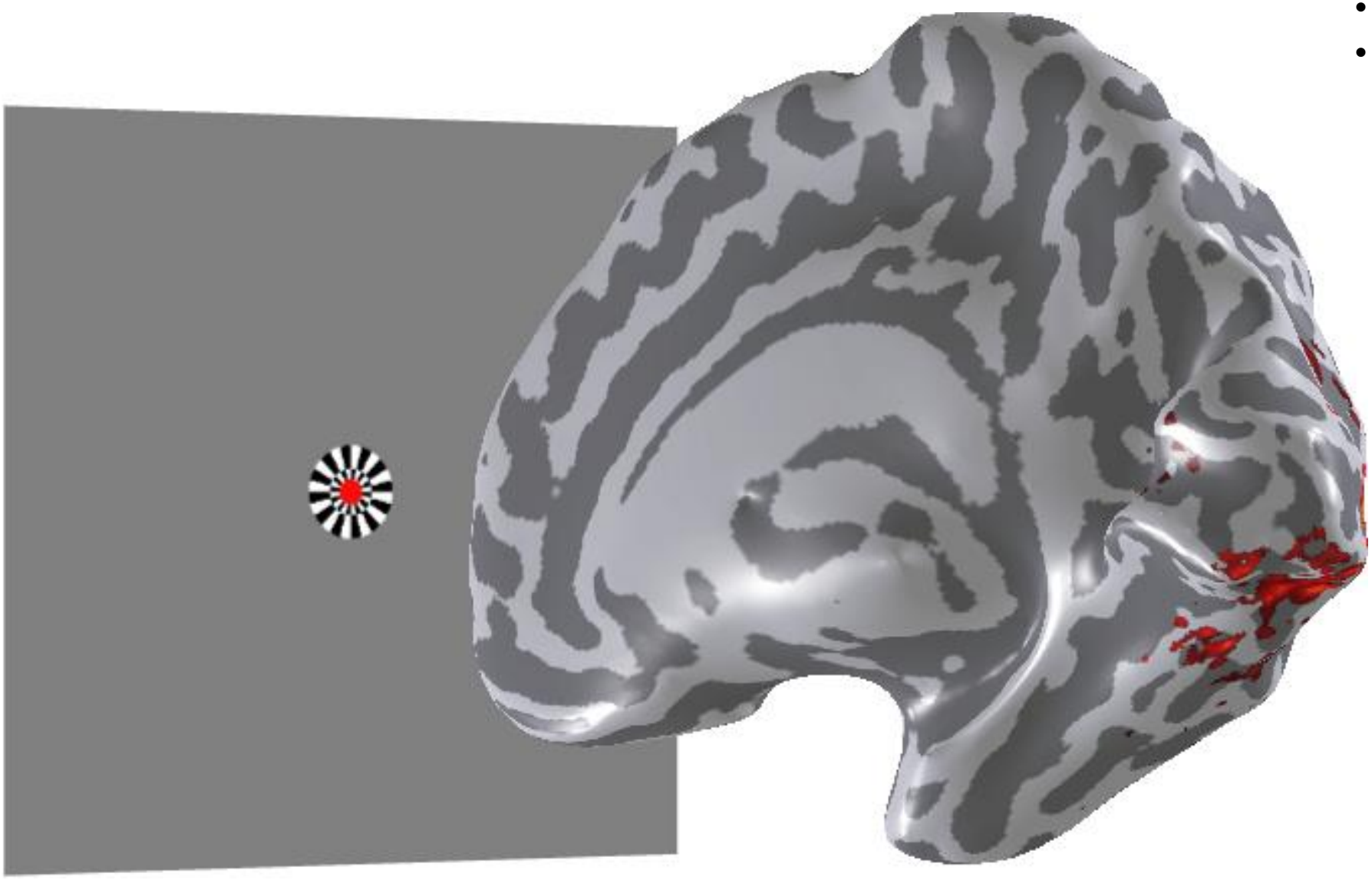
- It may be possible to find satisfactory methods using only behavioral measures
- The interest in brain imaging arises because of concerns about the reliability of behavior
- The possibility that neural measures will help with diagnoses is a hope for now



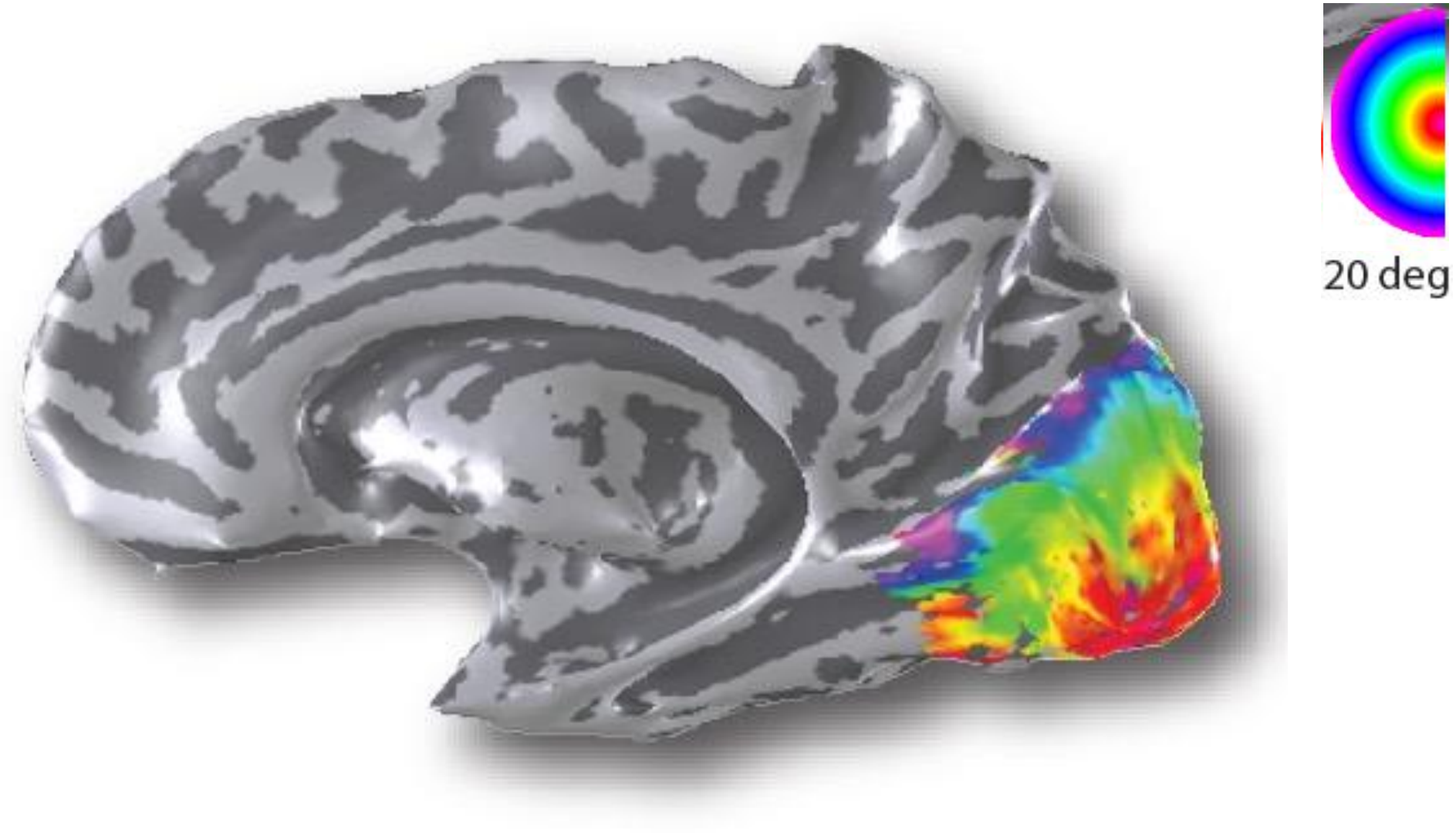
2. Advances in cortical mapping: eccentricity map

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

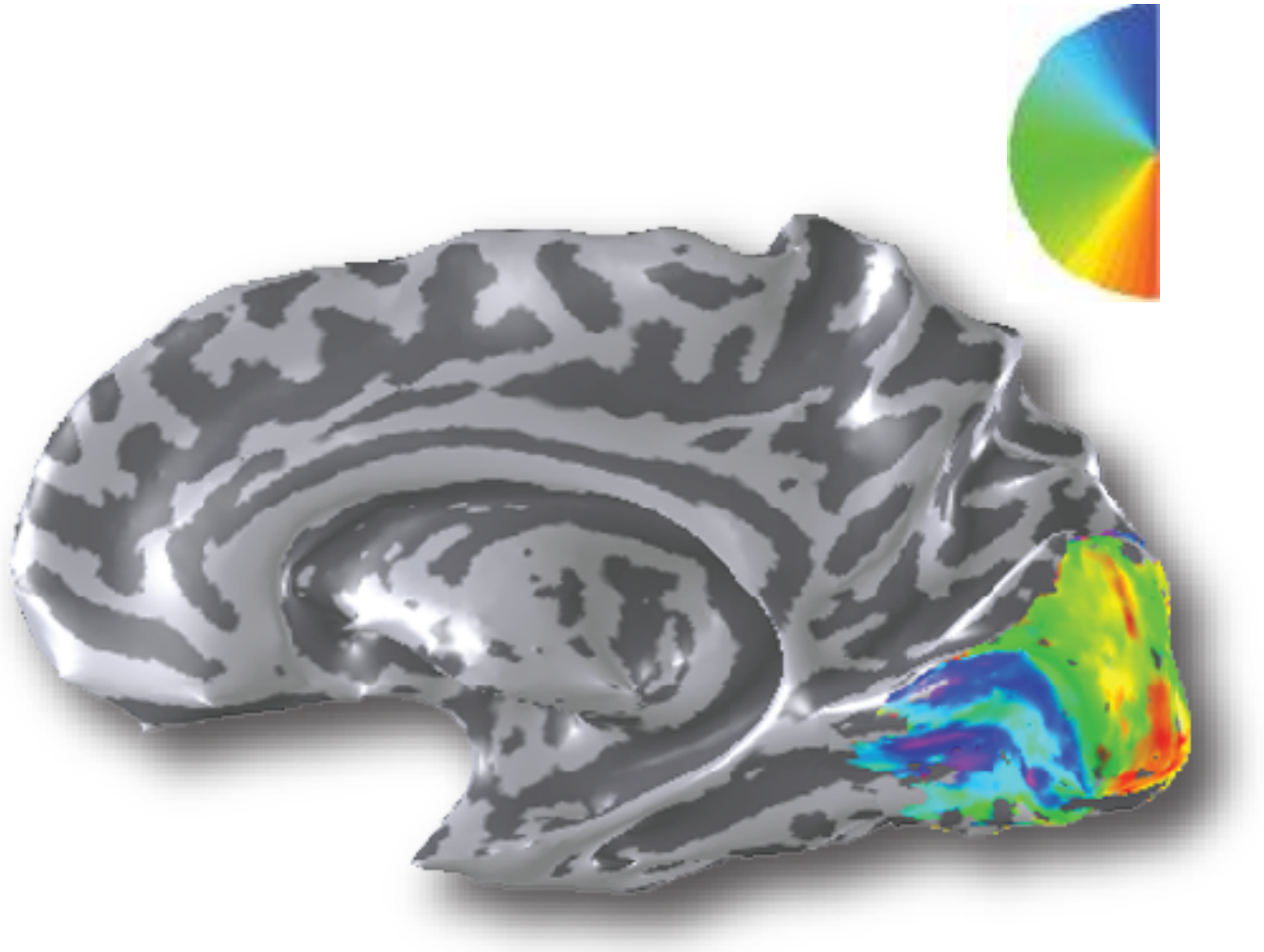
- Inflated brain
- Gray/white are sulci/gyri



2. Advances in cortical mapping: eccentricity map



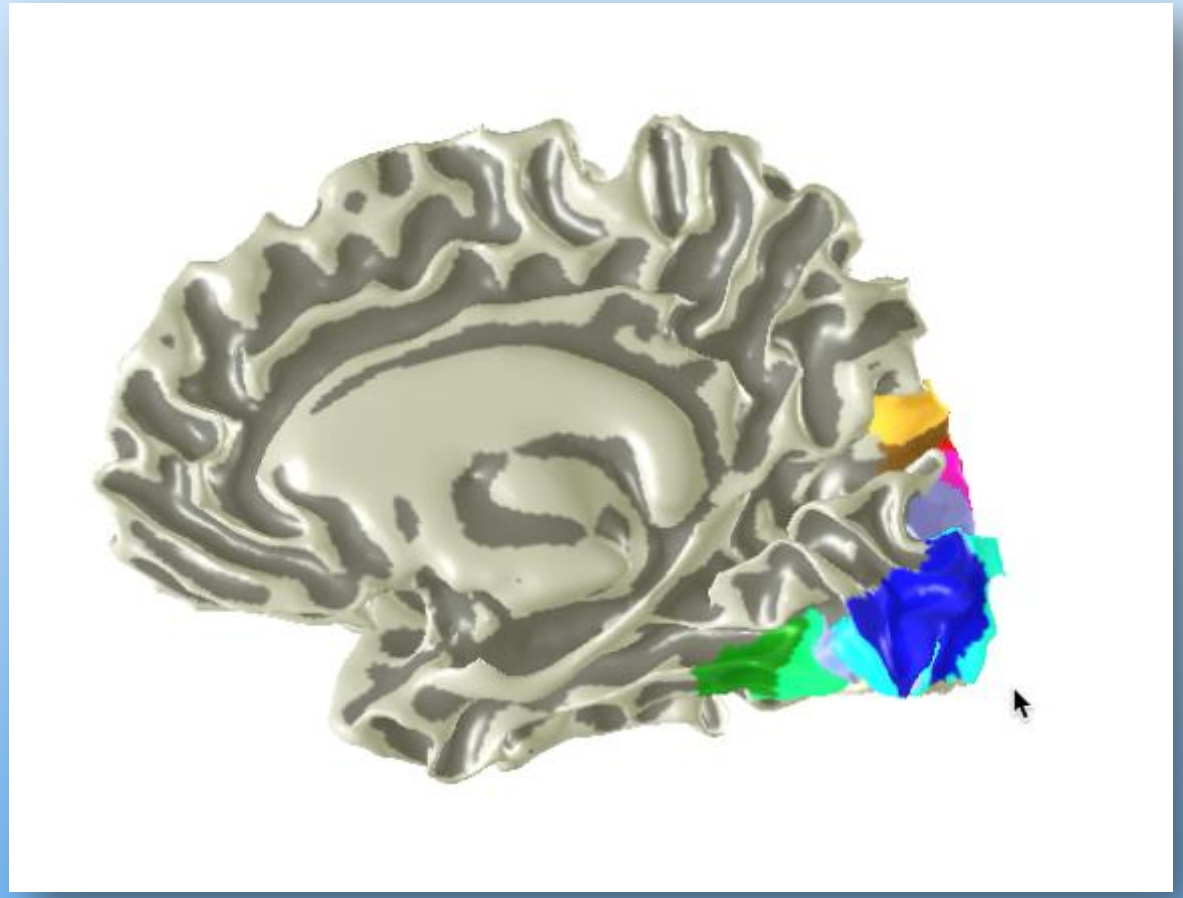
2. Advances in cortical mapping: angular map



Summary point: Visual field maps

Winawer

Brewer



366 Neuron 56, October 25, 2007

Neuron
Review

Visual Field Maps in Human Cortex

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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.

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Review

Imaging retinotopic maps in the human brain

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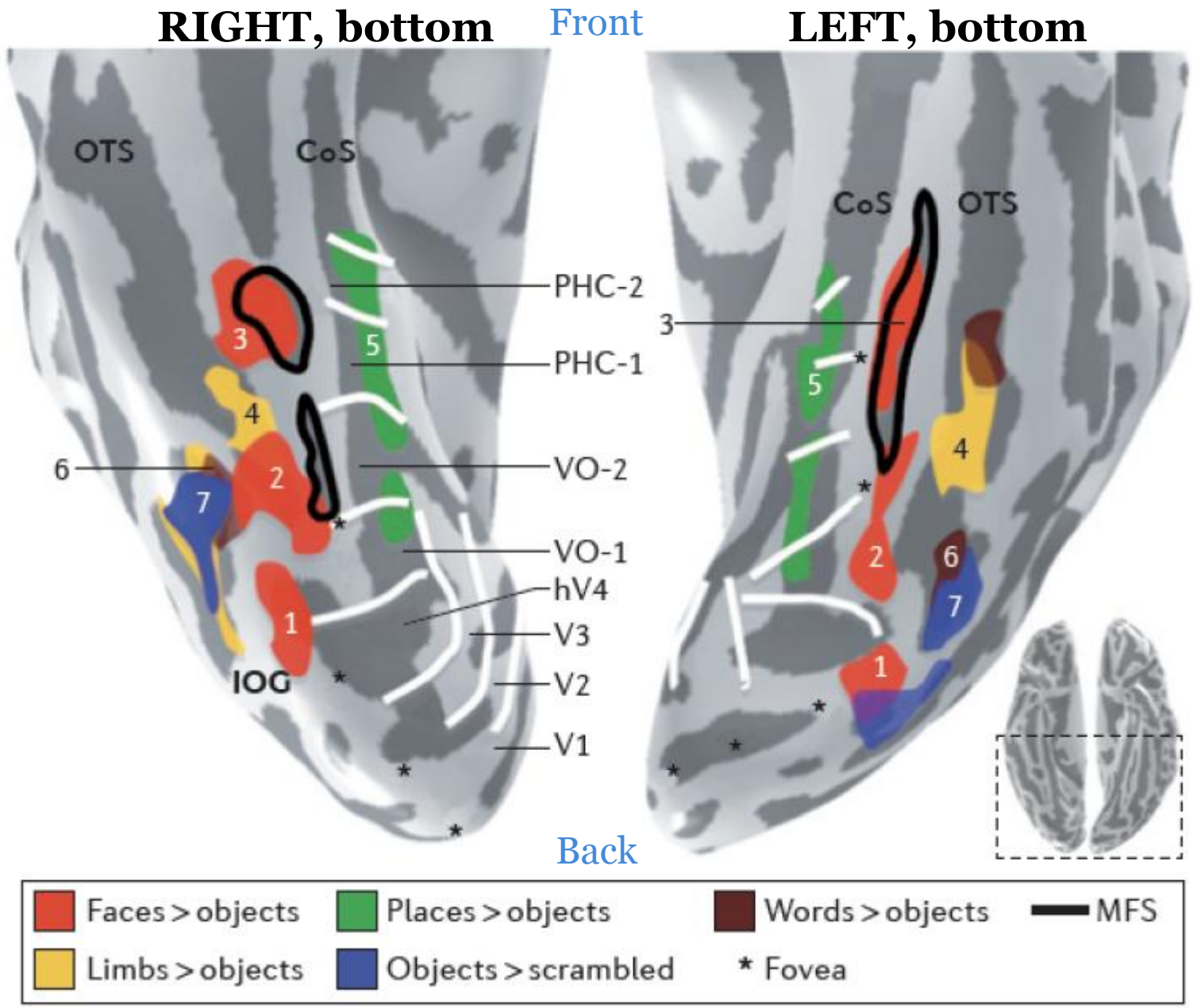
ABSTRACT

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 (MRI), 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-

2. Advances in cortical mapping: functional specializations

- Ventral occipito-temporal cortex (VOTC), near the visual field maps, contains several specialized processing regions
- Each region responds better to some class of stimuli than others (functional specialization)
- The visual word form area (VWFA) is one of these specializations



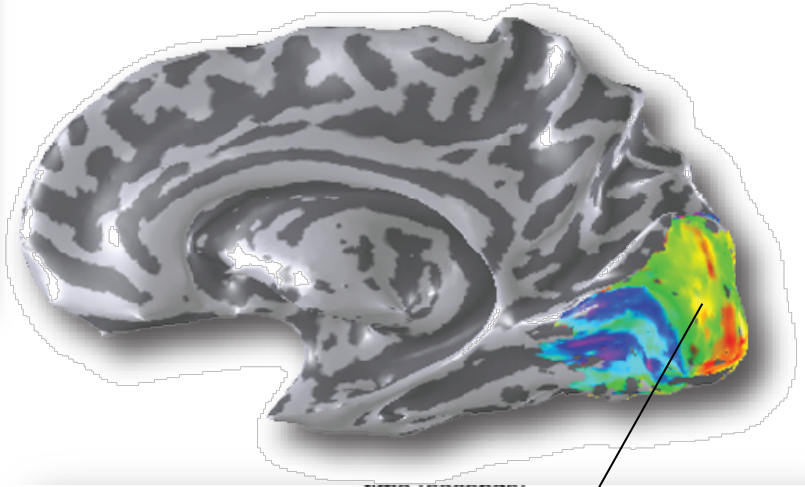
Grill-Spector and Weiner
Nature Reviews Neuroscience, 2014

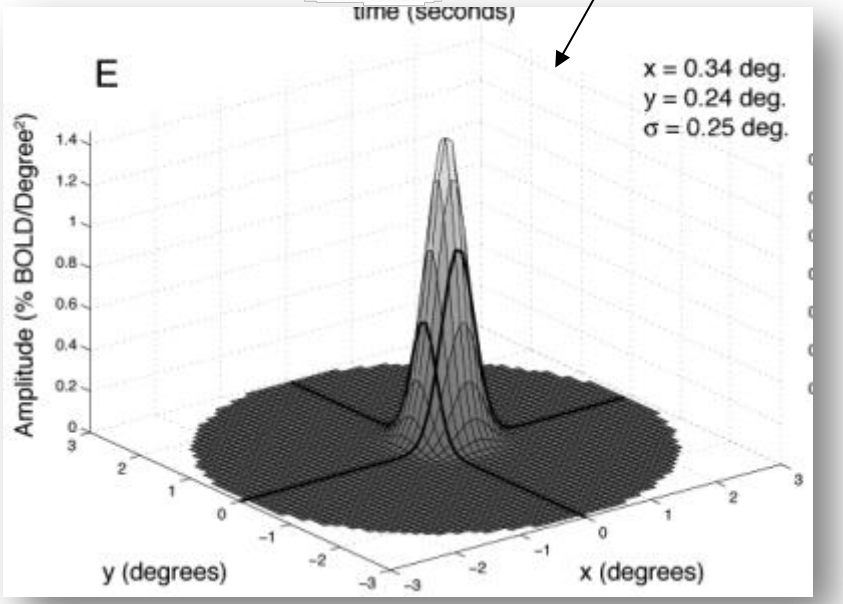
2a. Advances in cortical mapping - the field of view

Dumoulin

- A single voxel within, say V1, responds to a small part of the visual field and thus has a small **field of view**

Amano et al. 2009



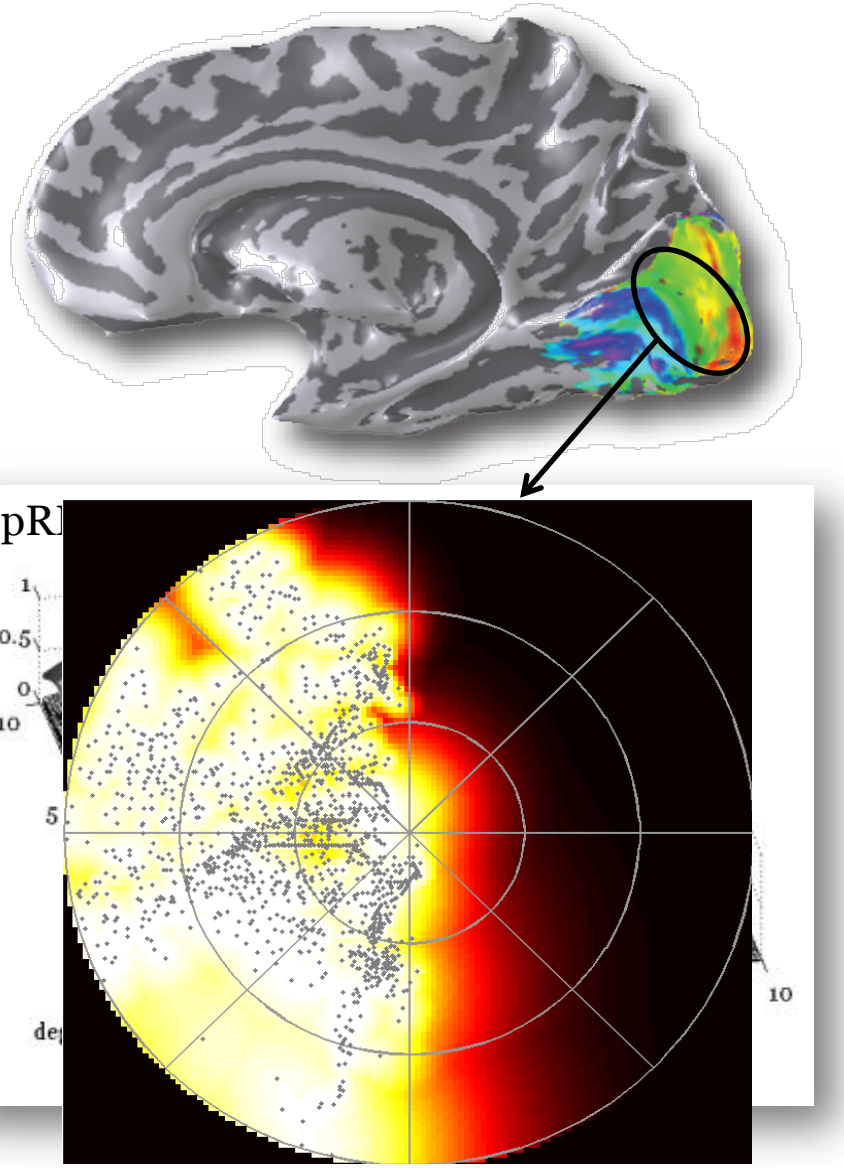


2. Advances in cortical mapping – the field of view of V1

Amano et al. 2009

- A single voxel within, say V1, responds to a small part of the visual field and thus has a small **field of view**

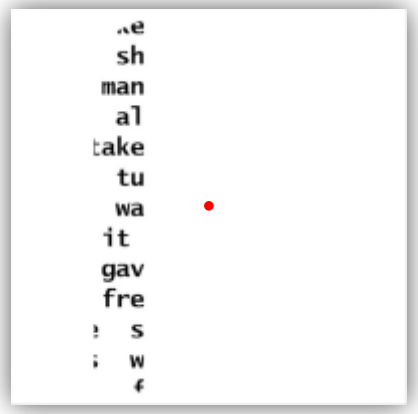
- Combining the pRFs from the voxels in a region, say all of V1, describes the region's field of view



Field of view in reading circuitry of a single subject

- Using these methods, we have learned that the portion of cortex engaged in reading only sees a small part of the visual field – it has **a small field of view**

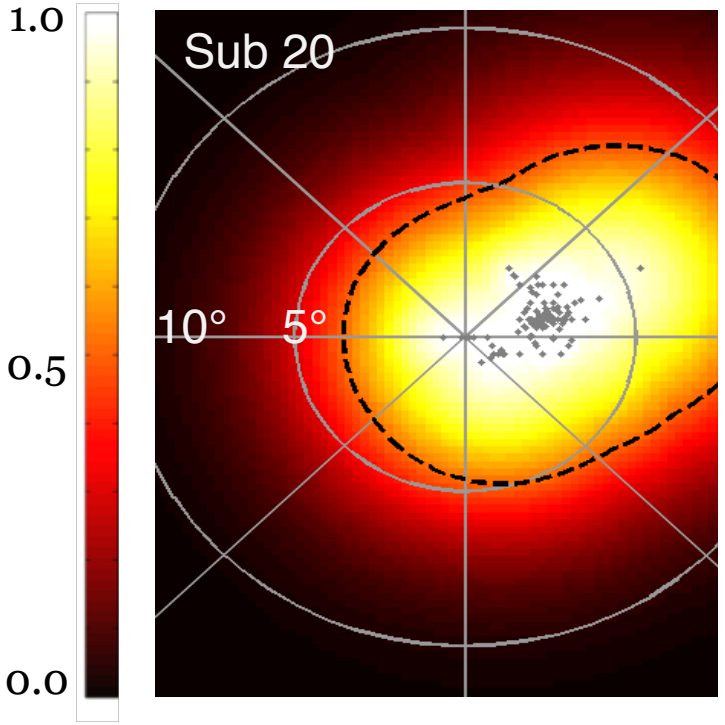
- We can measure these in individual participants



Bottom, left

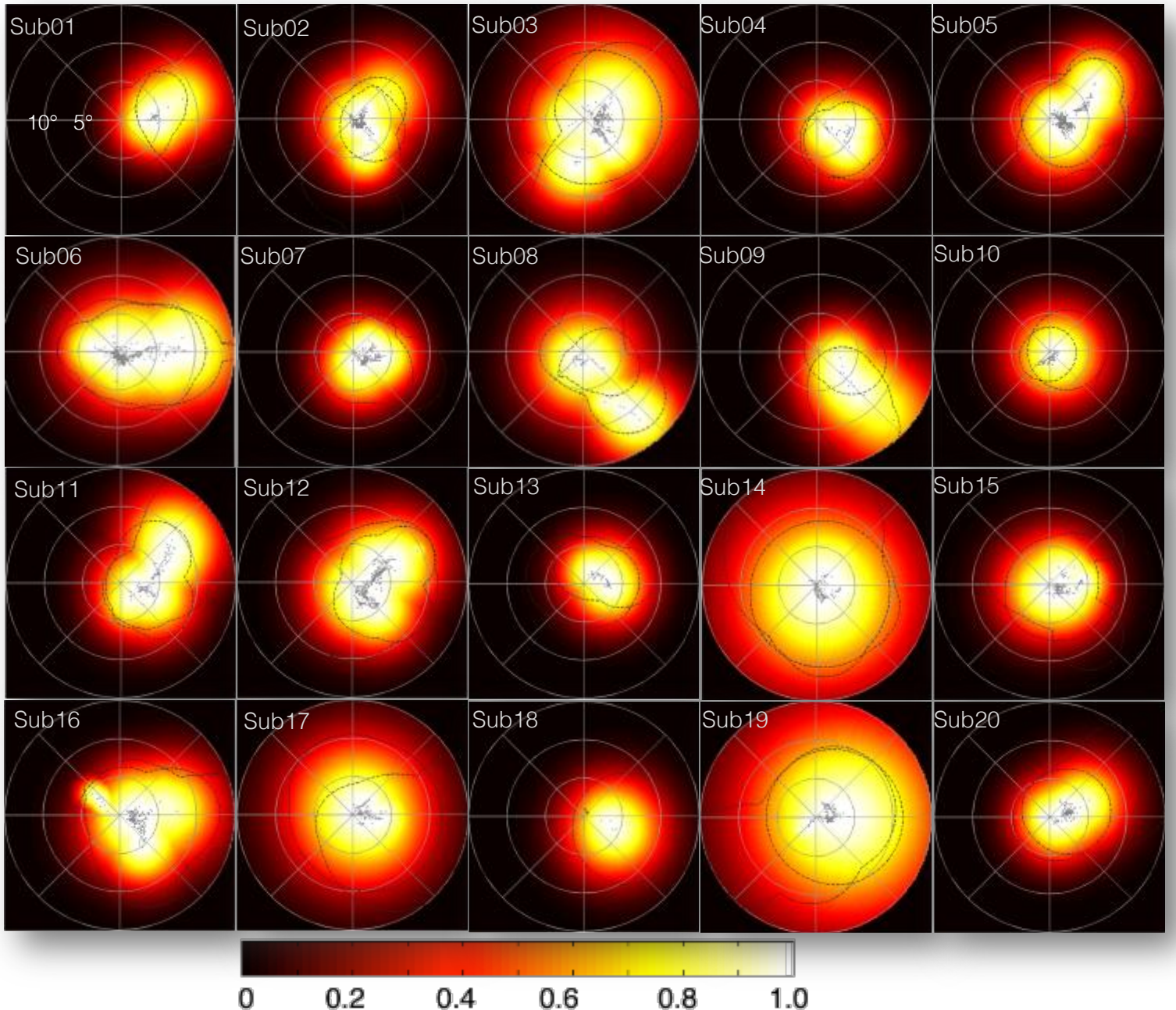
Measure the VWFA region

Sub 20



2a. Advances in cortical mapping –VWFA field of view in different subjects

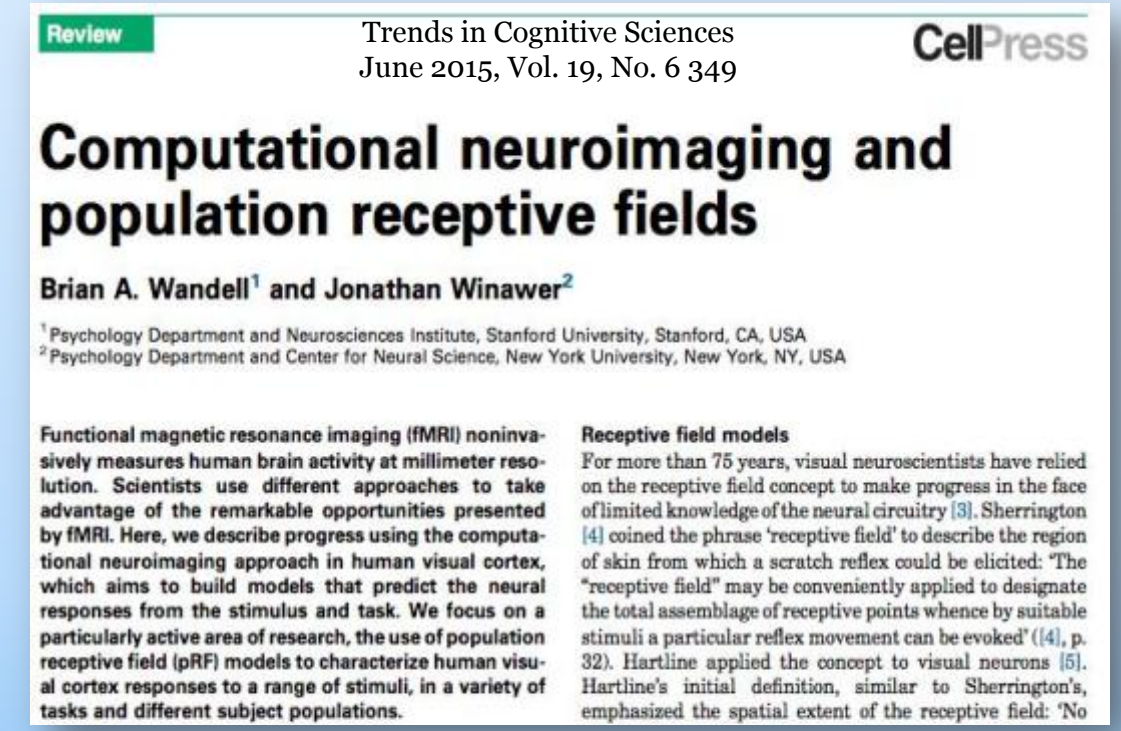
- There are significant differences between participants
- We will correlate these differences with measures of word recognition and eye movement patterns



Left hemisphere only

2. Advances in cortical mapping – summary

The visual circuitry for seeing words can be identified and certain properties, such as the field of view, can be reliably estimated in single subjects. These measurements are quantitative and might help diagnose part of the reading circuitry.



Review

Trends in Cognitive Sciences
June 2015, Vol. 19, No. 6 349

CellPress

Computational neuroimaging and population receptive fields

Brian A. Wandell[1] and Jonathan Winawer[2]

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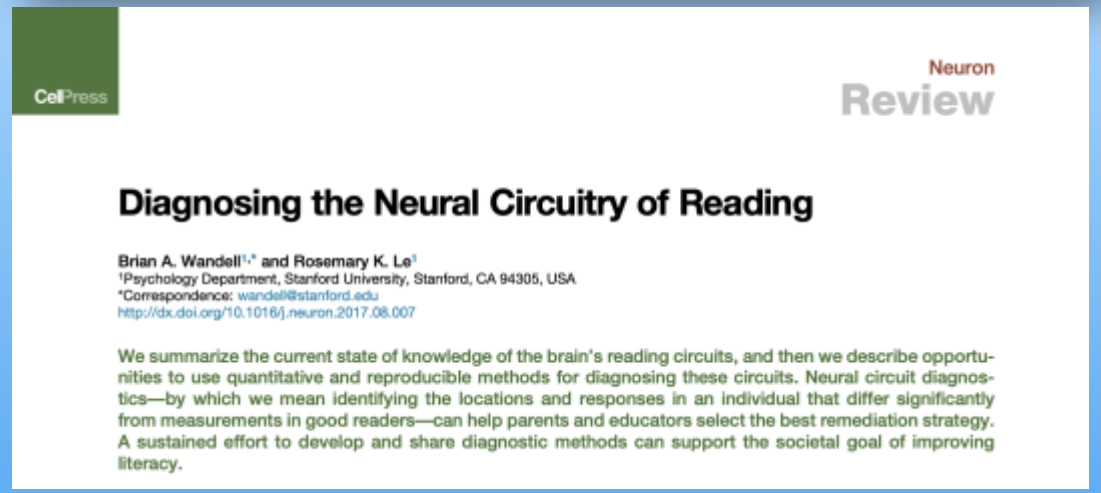
Functional magnetic resonance imaging (fMRI) noninvasively measures human brain activity at millimeter resolution. Scientists use different approaches to take advantage of the remarkable opportunities presented by fMRI. Here, we describe progress using the computational neuroimaging approach in human visual cortex, which aims to build models that predict the neural responses from the stimulus and task. We focus on a particularly active area of research, the use of population receptive field (pRF) models to characterize human visual cortex responses to a range of stimuli, in a variety of tasks and different subject populations.

Receptive field models

For more than 75 years, visual neuroscientists have relied on the receptive field concept to make progress in the face of limited knowledge of the neural circuitry [3]. Sherrington [4] coined the phrase 'receptive field' to describe the region of skin from which a scratch reflex could be elicited: 'The "receptive field" may be conveniently applied to designate the total assemblage of receptive points whence by suitable stimuli a particular reflex movement can be evoked' ([4], p. 32). Hartline applied the concept to visual neurons [5]. Hartline's initial definition, similar to Sherrington's, emphasized the spatial extent of the receptive field: 'No



CellPress

Neuron
Review

Diagnosing the Neural Circuitry of Reading

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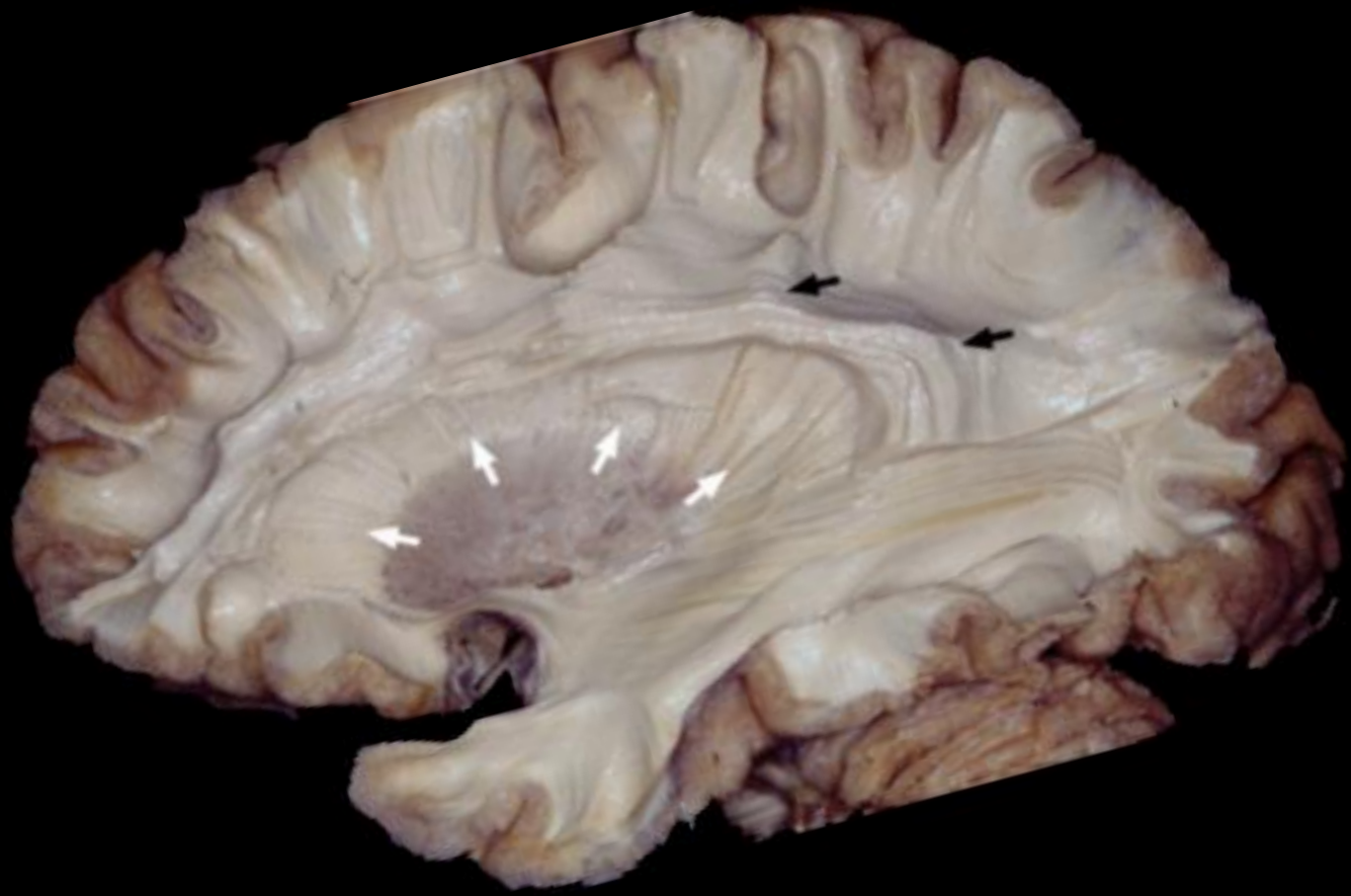
*Correspondence: wandell@stanford.edu
http://dx.doi.org/10.1016/j.neuron.2017.08.007

We summarize the current state of knowledge of the brain's reading circuits, and then we describe opportunities to use quantitative and reproducible methods for diagnosing these circuits. Neural circuit diagnostics—by which we mean identifying the locations and responses in an individual that differ significantly from measurements in good readers—can help parents and educators select the best remediation strategy. A sustained effort to develop and share diagnostic methods can support the societal goal of improving literacy.

2b. Connections between brain regions

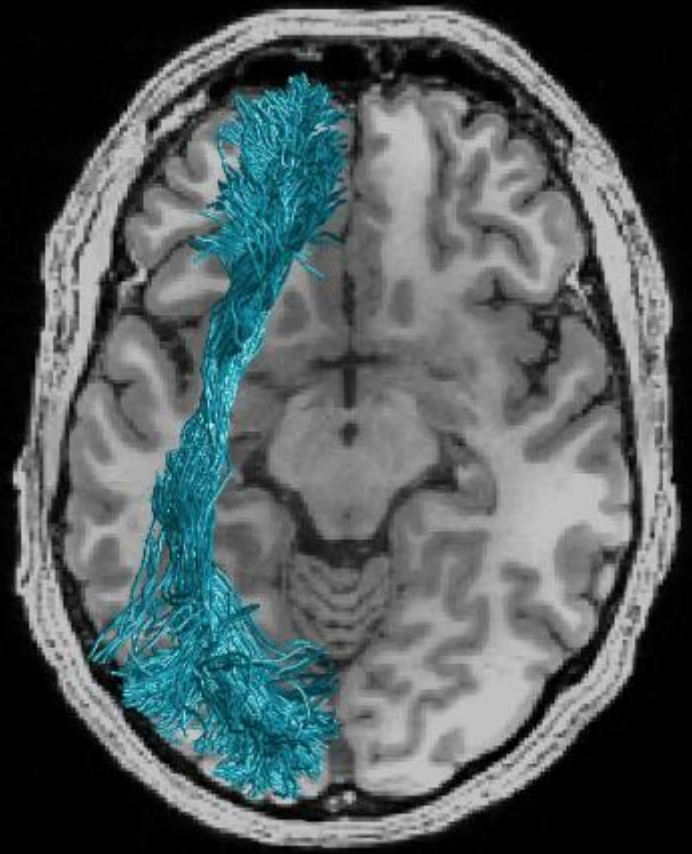
- There are many long-range connections
- These connections are not passive – they change their properties in response to use
- A system with active wires



Courtesy Professor Ugur Ture

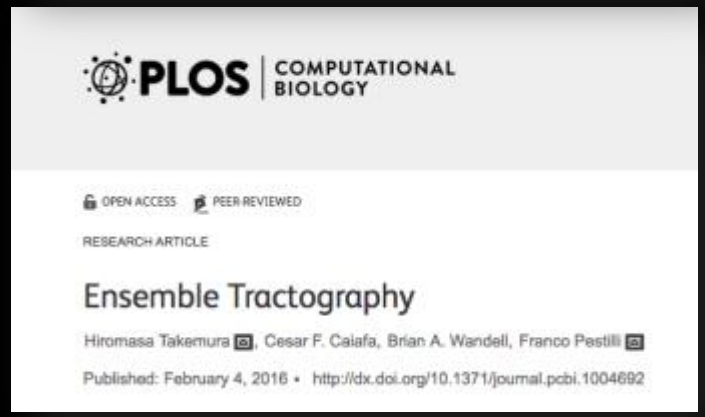
2b. Connections between brain regions - tracts

Left IFOF

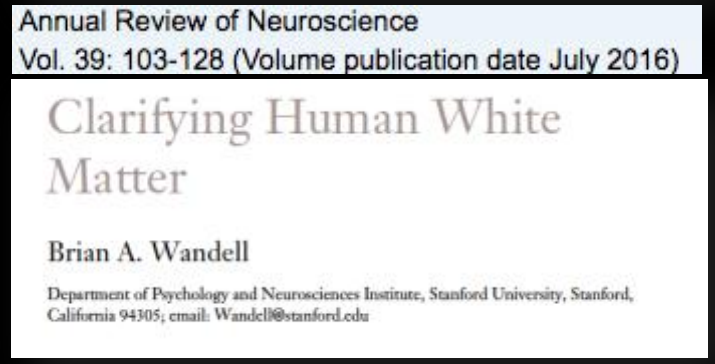


150 Directions, 2 mm^3, B=2000 projected on a 1 mm^3 T1 anatomical image

Introduction to LiFE

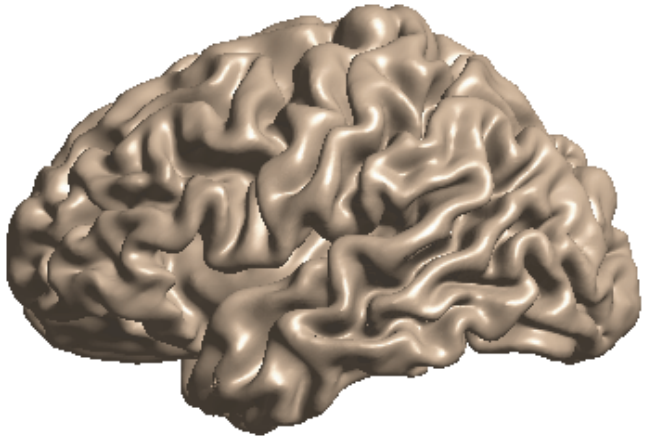


Extension to ensemble method



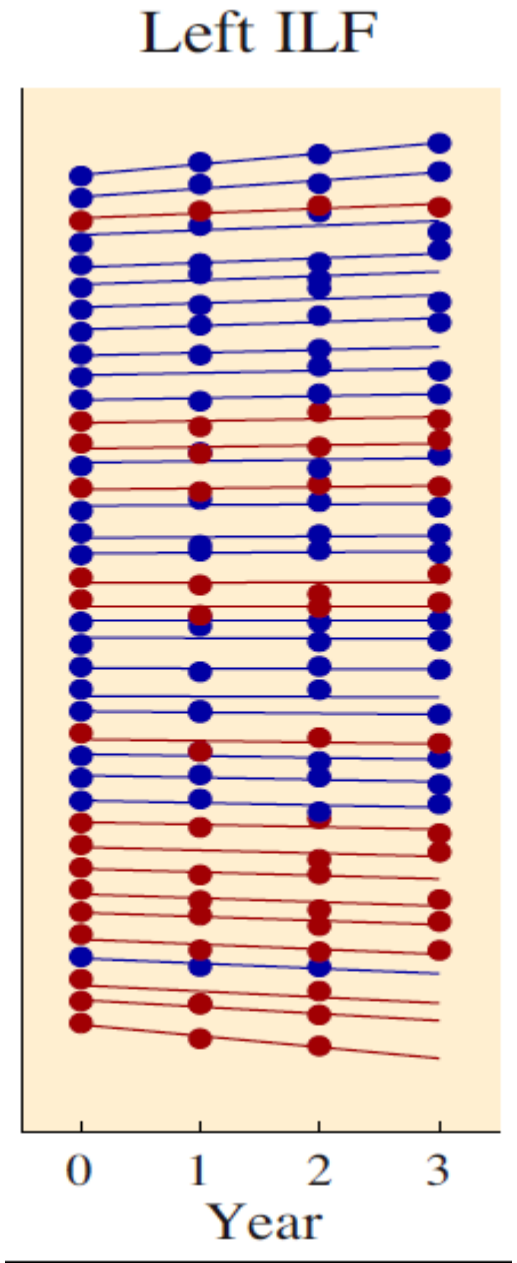
Review of diffusion imaging

2b. Connections between regions – good and poor readers develop differently



- Measured brain and behavior at 4 time points **(data management!)**
- The first measurements predict reading over the next few years
- The rate and direction of FA development differs between good and poor readers in the Arcuate and the ILF

- Fractional anisotropy (FA)
- Displaced vertically for each participant
- Ordered by slope
- Colored by reading score



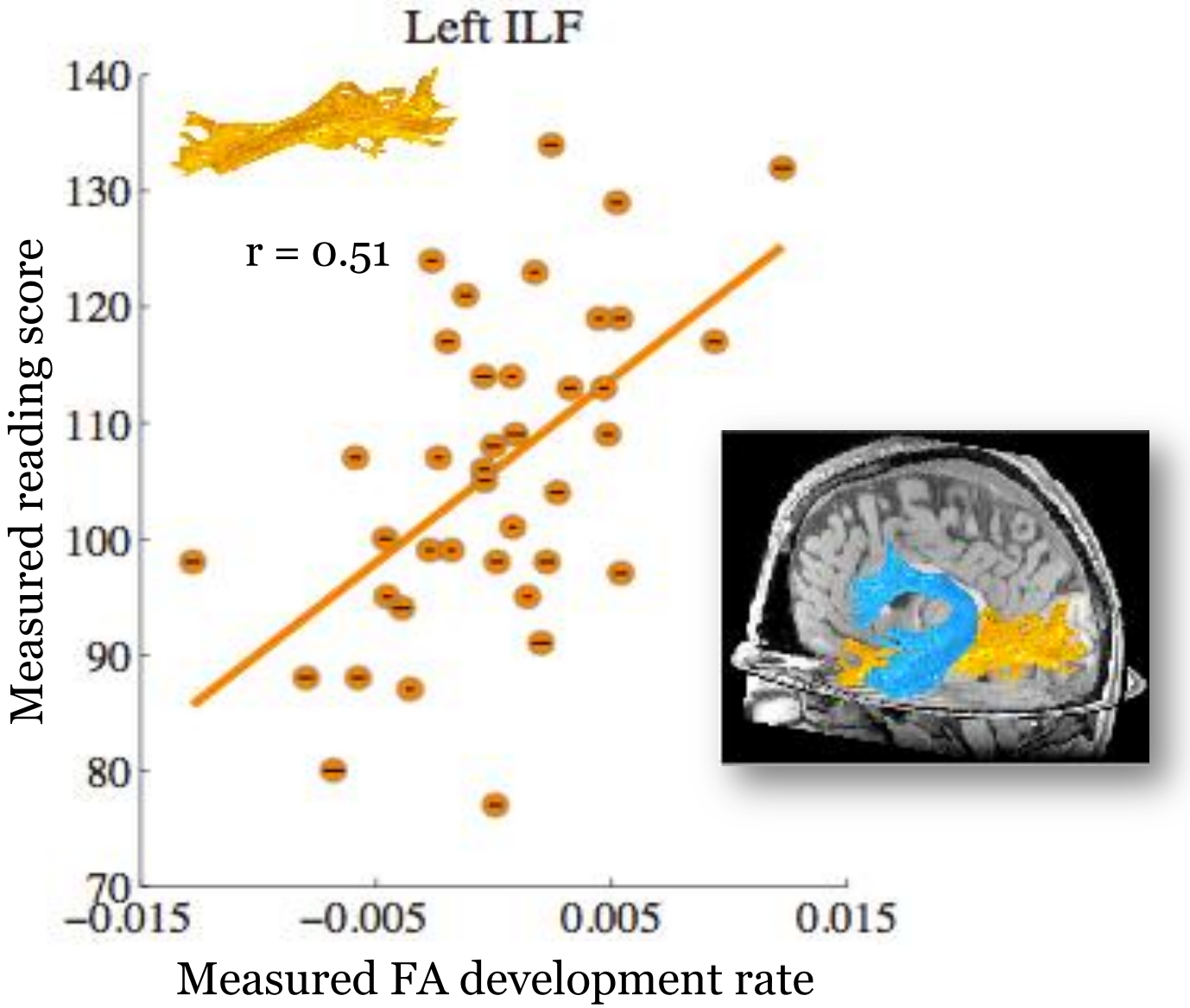
Blue: Good readers
Red: Poor readers

2b. Connections between regions – good and poor readers develop differently

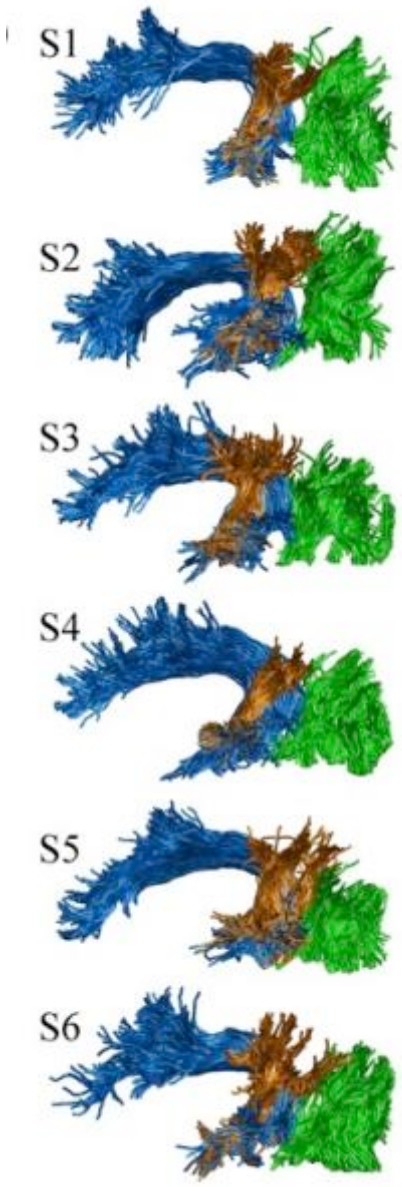
(Yeatman et al., 2012, *PNAS*)

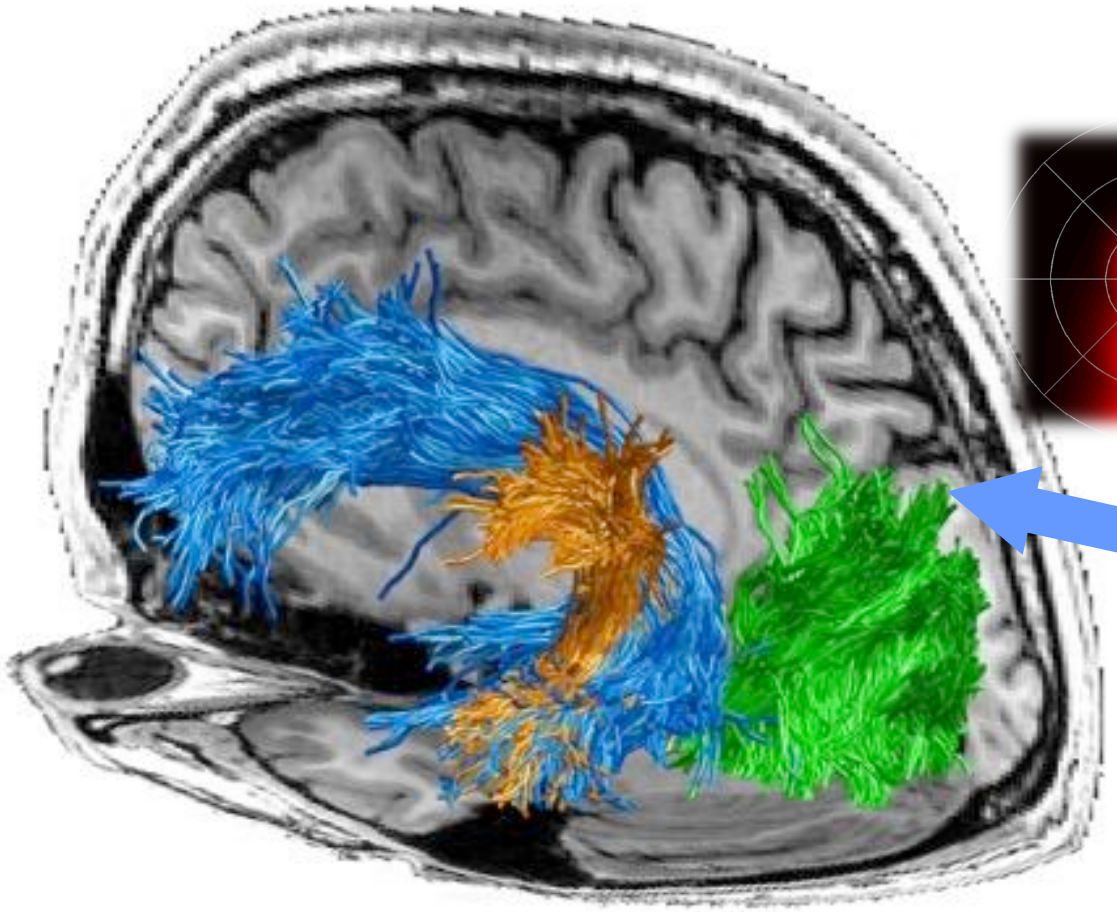
- Development measured by dMRI in the ILF and Arcuate, but not others tracts, correlates with the ability to rapidly see words

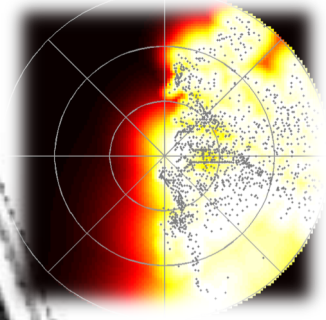
- This is one reason we think that the wires are active, changing in response to learning and memory



2b. Connections between regions – people differ



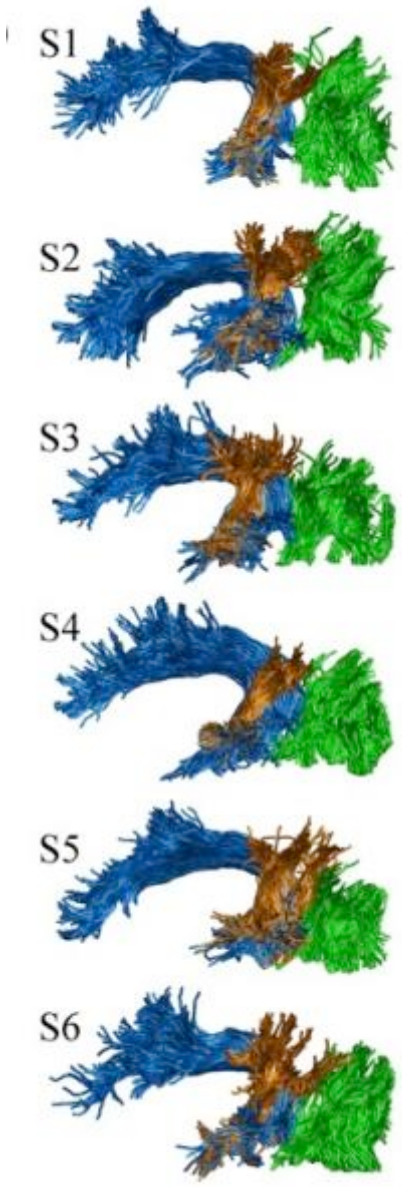


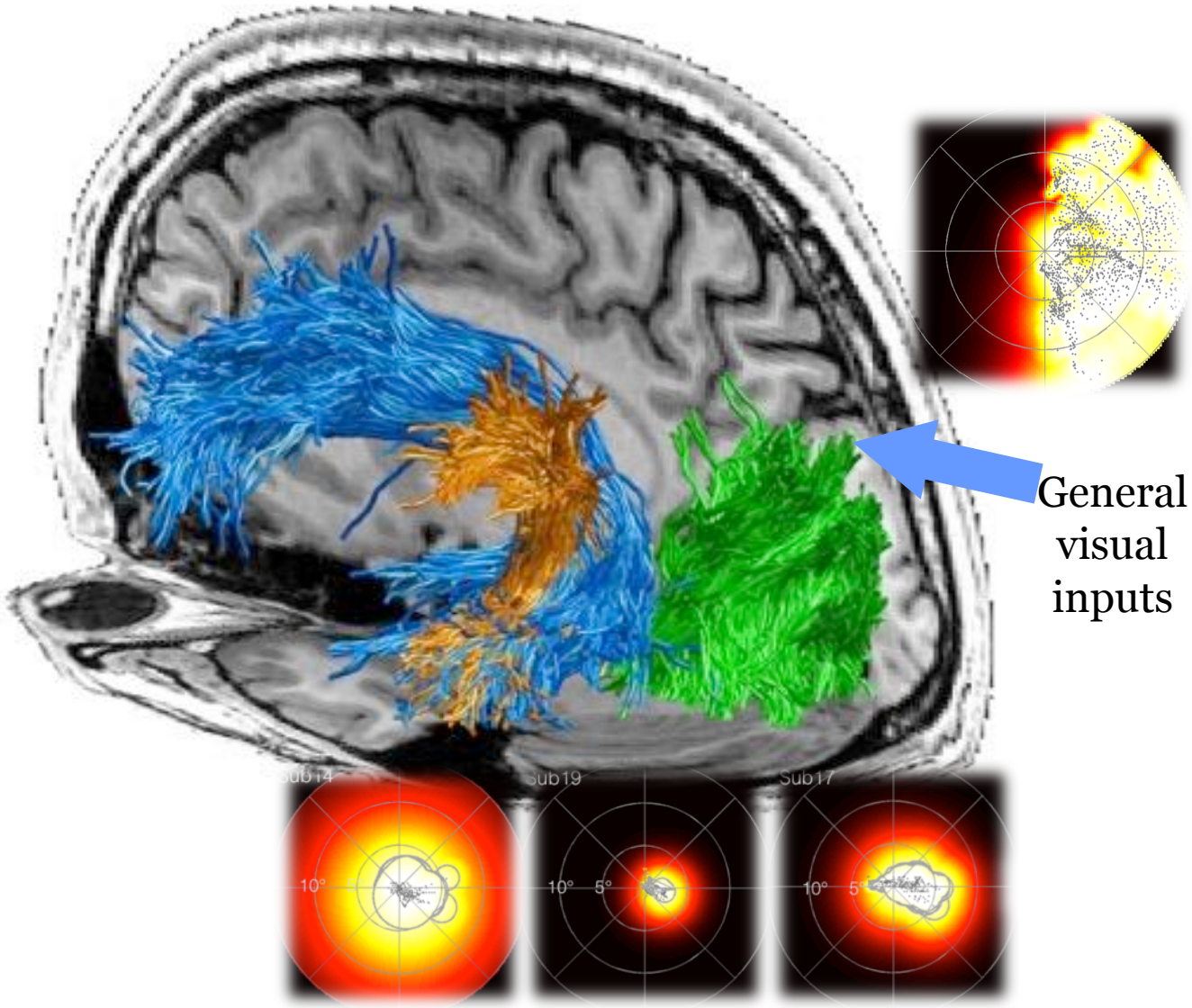


General visual inputs

VOT
Specialized processing for faces, words, other things

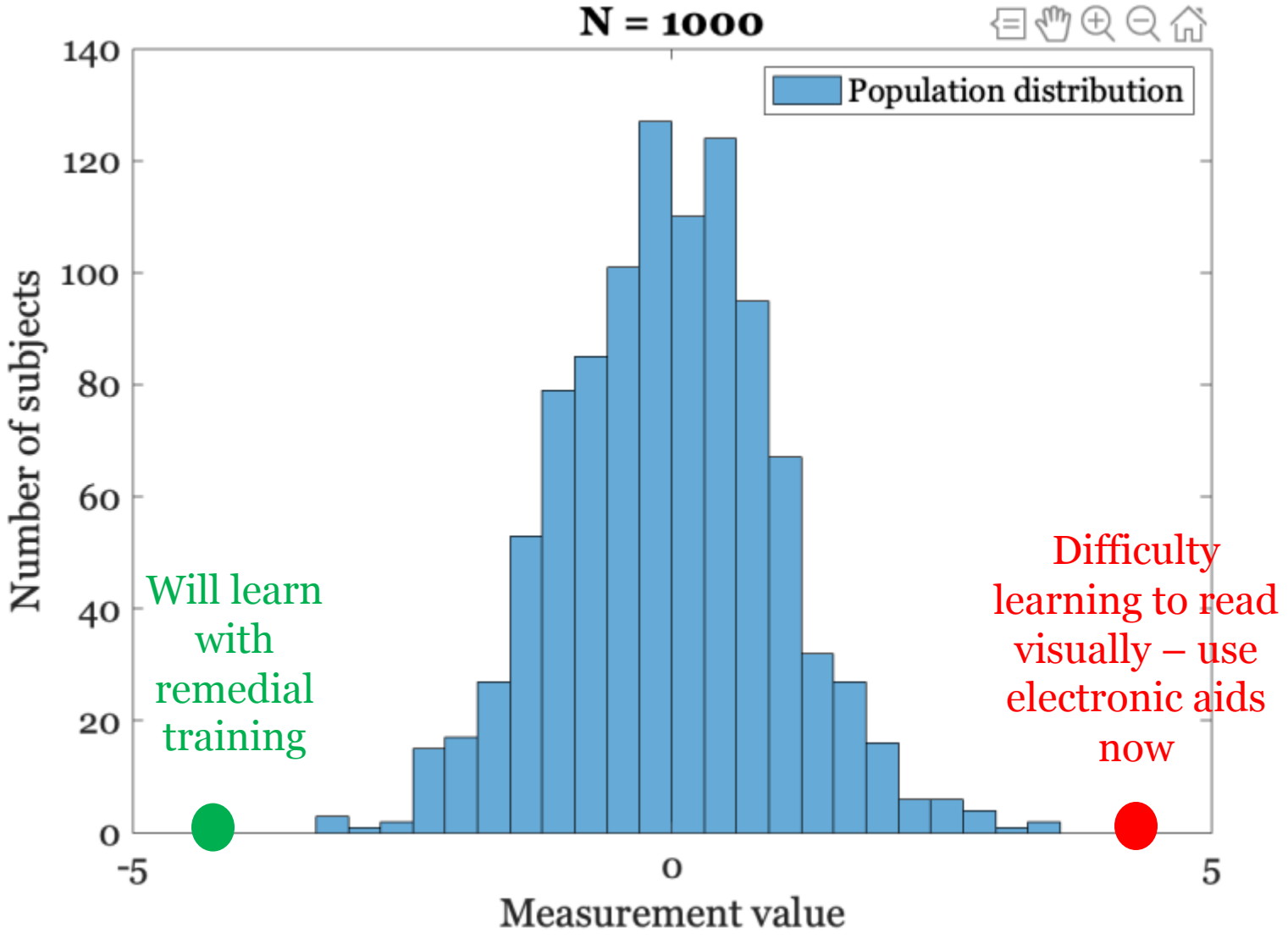
2b. Connections between regions – can this difference be a factor in poor reading?





Circle back to the beginning distribution

- **Goal:** We want a measure with its population distribution that we can use to assess a child
- For the neuroimaging measures, FOV size or tract FA, we must collect, store and be able to analyze large datasets
- This requires sharing data and using a database that can be used for computing and comparing



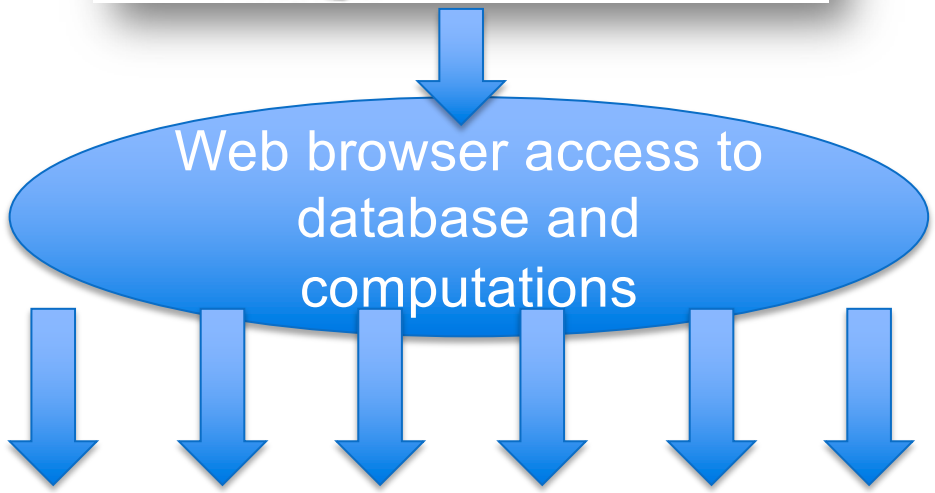
4. Data and computational management: both are important for diagnosis

- Most MRI Centers provide one of these data retrieval options from the MRI scanner
    - Copy data to CD, DVDs, USB hard drive
    - Copy to a server and remote login
- Data and metadata are transferred to a system controlled by a student or post-doc
- **Limitations** – reuse and sharing become burdensome; metadata and pre-processing information are frequently lost

Data transferred to laboratories from the scanner

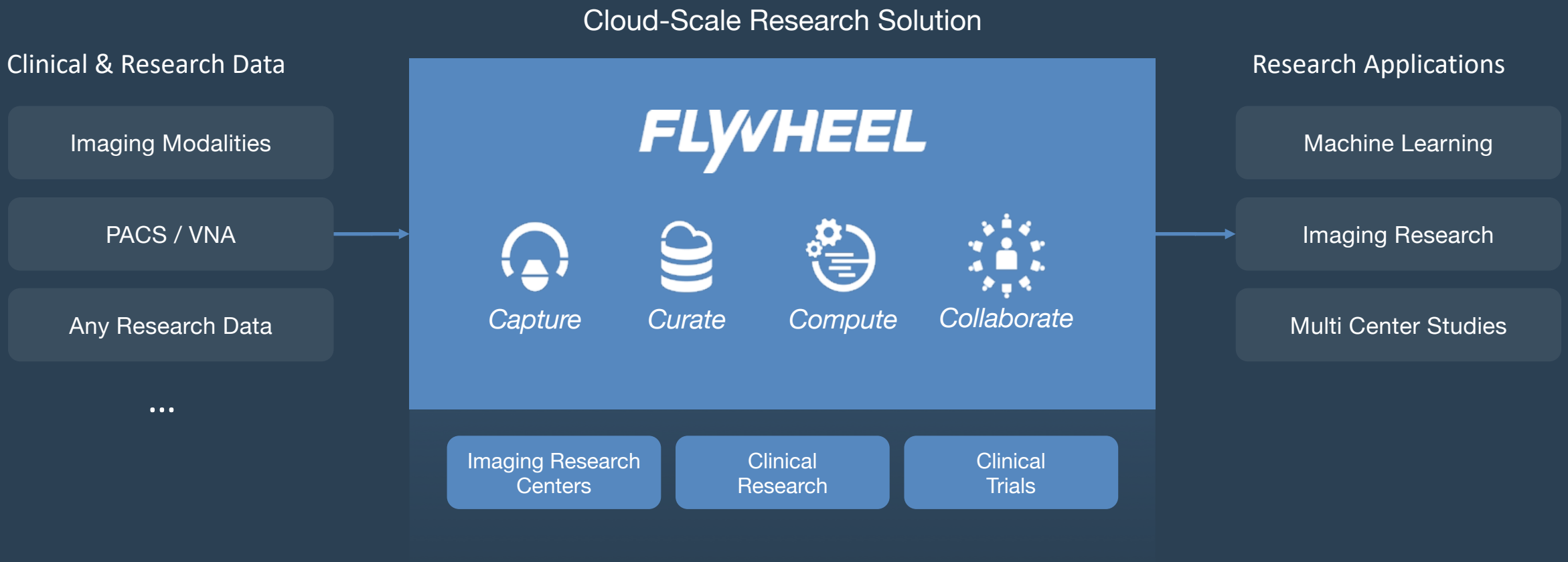
4. Data and computational management: both are important for diagnosis

- Archiving MRI Center data eliminates the need for users to gather the data again for publication
- The data should be available through a platform-independent web browser to simplify access
- Basic tools, such as search, visualization, and pre-processing can be available through the browser
- The data are ready for sharing and reuse; metadata can be stored; pre-processing methods shared can be shared



Data transferred to laboratories from the data system

Modern Informatics Platform for Biomedical Research and Collaboration



I am a co-founder of the company FLYWHEEL

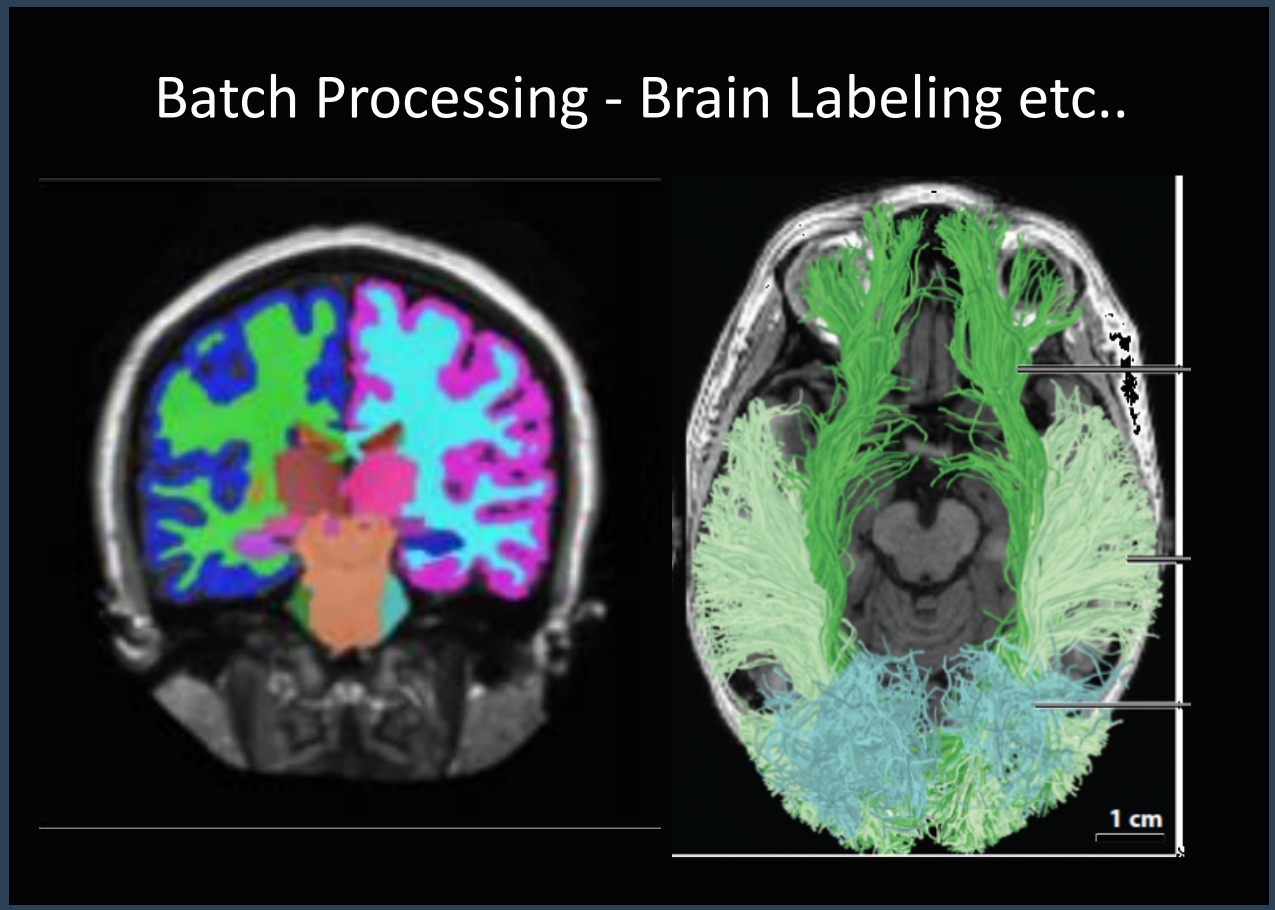
4. Data and computational management – computation

Video

- The algorithms you used and their parameters are stored in the Provenance tab
- Here is a FreeSurfer run

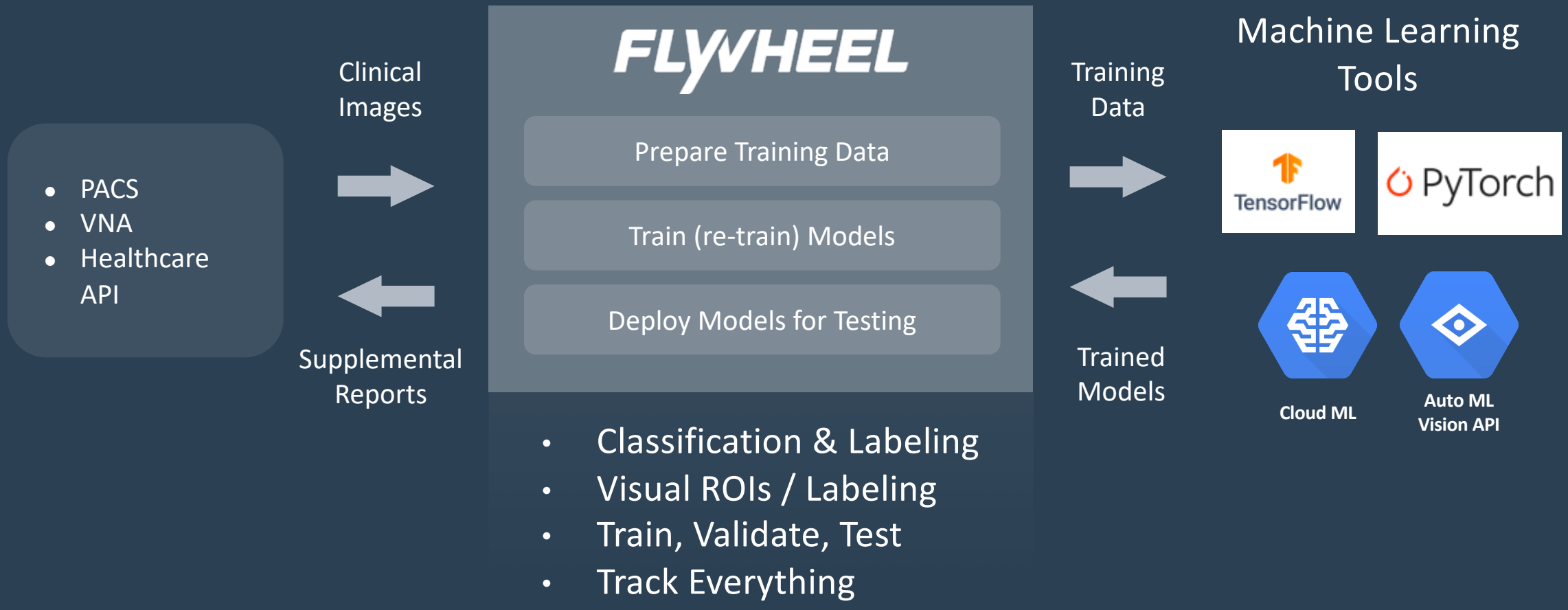
Search

- Index all metadata
- Visual search
  - In project
  - Across projects
- Act on results
  - Save to collections
  - Download
  - Batch process (Gears)
  - Create ML Training Set



FLYWHEEL

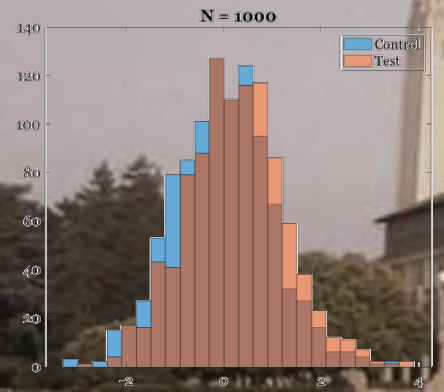
Machine Learning Workflow

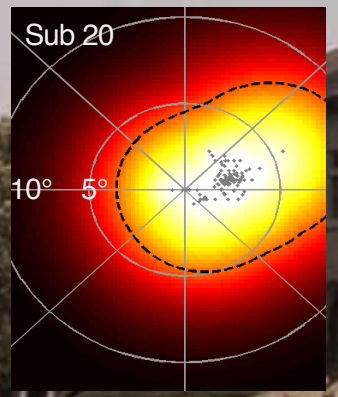


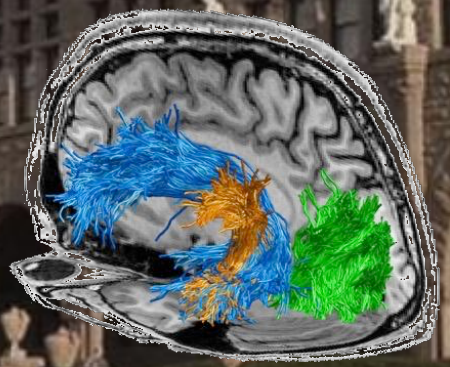
FLYWHEEL

Talk review: Neural circuitry for vision and reading

1. Experimental design for diagnosis
2. Advances in brain measurements with MRI
    a. How much of the world can we see
    b. Connections between brain regions
3. Storing, sharing and analyzing large data sets







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