MRI: Maps and models in the human visual brain

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QUANTITATIVE MEASUREMENTS

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COMPUTATIONAL MODELS

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CHECK AND SHARE
• Human brain
• Visual cortex: maps and models
• Reading circuitry
• Cloud-scale collaborative science
Even simple judgments – such as lightness - depend on substantial interpretation of the image data carried out by brain circuits.

Cognitive neuroscience is the study of how the brain performs these interpretations.

(Anderson and Winawer, Nature, 2005)
Brain computations depend on a variety of cells; one important cell type, 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
Tractography modeling

Tracts with at least one endpoint in the visual parts of the brain

Introduction to LiFE

Extension to ensemble method

Review of diffusion imaging
Tractography modeling

Introduction to LiFE

Extension to ensemble method

Review of diffusion imaging

Left IFOF

Evaluation and statistical inference for human connectomes
Franco Pestilli, Jason D Yeatman, Ariel Rokem, Kendrick K Kay & Brian A Wandell

Ensemble Tractography
Himansu Takemura, Cesar F. Caiafa, Brian A. Wandell, Franco Pestilli
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Clarifying Human White Matter
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150 Directions, 2 mm³, B=2000 projected on a 1 mm³ T1 anatomical image
The human brain

1: 15: 3000 (volume ratios)

- Brains differ
- Check which system was measured
The brain is studied at an enormous range of spatial scales

- There is no reliable theory or model that relates measurements at different scales.
- This doesn’t stop scientists from speculating or speaking hopefully about relationships.
Organization of visual cortex

• Visual field maps
Remarkable progress from PET to advanced MRI in 25 years

(Wandell and Winawer, 2011)
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
- Maps tile the occipital lobe
- Extend into IPS and VOT
- Response properties differ
- Identification from gross anatomy
Modeling visual cortex responses

• Population receptive fields
‘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
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).
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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
Attention

Stability and Plasticity

Prosopagnosia

Development and aging

Autism

Alzheimer’s disease
Diagnosing the reading circuitry
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

Learning to See Words
Locating reading circuits and maps

VWFA - essential for reading, but not unique to reading
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.
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.
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Field of view of the VOT reading circuitry

- 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.

Left hemisphere only.
Computational reproducibility is not an afterthought—it is something that must be designed into a project from the beginning. **One does need to develop a whole set of programming and research disciplines** with the end result in mind and stick with them.
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
Each subject with the disease has some variation and we would like to know, and track each one over time.
I founded a commercial venture, Flywheel.io, to implement the vision

See How Flywheel Empowers Neuroimaging Research

A Stanford University VistaLab Success Story

DOWNLOAD IT HERE
Research Data Management Solution

Capture | Curate | Compute | Collaborate

- Core Facilities
- Labs
- Clinical Research
- Clinical Trials

- Multi-Modality Imaging
- Any Research Data
- Metadata

- Machine Learning
- Imaging Research
- Multi Center Studies

Regulatory Compliance
Cloud or On Premises Deployment
Stanford CNI

Overview
15,000 scan sessions
7,500 subjects
40 research groups

Data acquisitions
75,000 fMRI
25,000 Anatomical (T1)
7500 Diffusion
640 Spectroscopy
Quantitative MRI: new opportunities in mental health care

- New applications for MRI
  - Psychiatric disorders
  - Reading and learning disorders
  - The effect of drug therapies on neurodegenerative diseases ...

- Quantitative and labeled data
  - Machine learning applications
  - Comparisons across instruments, people and over time

Data acquisition sites around the world

Stanford, NYU, Spain, Israel, Japan
Cloud-scale collaborative science

- Quantitative MRI for generalization across instruments, time, and people
- Data management from multiple universities and research hospitals
- Computational support, including machine-learning, for science and precision health
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