25 research labs (10 new hires)
Theory center (6 PIs)
Campus hub for 200 neuroscience labs
Building to be occupied fall 2019
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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
Installing the MRI scanner at the CNI (2008)
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**

- Scanner uptime estimated at 99%
- 6,000 subjects
- 100 T of MRI data just at this one center
Main points

• The human brain – its size and some of its properties
• How we see
• Mis-wiring at birth: Amazing recovery
• Damage a few years later: Not much recovery
• Putting the parts together: Reading circuitry
Cortical computational elements

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!

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

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
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 human brain

1: 15: 3000 (volume ratios)

• Brains differ
• Check which system was measured
Human functional and anatomical MRI

- Basic facts about the human brain and how we see
• Even simple judgments – such as lightness - depend on substantial interpretation of the image data carried out by brain circuits

• The vision science has been influential in developing principles for other neuroscience fields and artificial intelligence

• Vision science fundamentals are important for the entire imaging industry

(Anderson and Winawer, Nature, 2005)
1992

- MRI acquisition methods have become more complex
- MRI computations (reconstruction, data analysis) have become more complex
- Networking and computer technology have advanced
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 a lot of the back part of the brain
- The maps appear to be specialized for important stimuli – motion, depth, faces, navigation
- We have learned how to find the positions to within a couple of millimeters just from the anatomy
Mis-wiring at birth

The case of a missing optic chiasm
(Hoffman et al., 2012)
The axonal pathways from the eye to brain

- The optic nerve from each eye meets in the optic chiasm
- Half the fibers cross to the other side of the brain
- In the typical brain to the right of fixation drives activity left hemisphere activity; and conversely
The optic chiasm

• The chiasm is visible in a standard anatomical image
We can measure the axonal pathways using another MRI modality, diffusion MRI (dMRI) coupled with computational algorithms (tractography).
A subject without a chiasm (Achiasmic)

- Eye movement (nystagmus)
- Discovered during routine testing for nystagmus
- Resolved after a few weeks
Achiasmic axonal pathways from the eye to brain

- For this subject, the optic nerves do not cross!

- The right eye sends signals only to the right brain, and the left eye only to the left brain
FMRI confirms that in this person’s brain the right and left visual fields are overlaid in cortex.
FMRI confirms that in this person’s brain the right and left visual fields are overlaid in cortex.
1. A genetic defect that disrupts crossing at the chiasm signaling causes a developmental reorganization in visual cortex.

2. Despite the profoundly disrupted maps, the rest of the brain figures out what to do.
First point

In some cases, when a child is born with a very unexpected pattern of brain connections, during development the brain can compensate and the system can still function.

There are probably millions of people in the world functioning with these types of natural brain experiments.
Brain plasticity and stability
Michael May

- Chemical explosion (3 yrs old)
- One eye lost; other cornea (and limbic stem cells) destroyed
- Blind (no contrast or form) from age 3 through 46

Images courtesy of Michael May, Sendero Group
Recovered sight?
(images courtesy Michael May)

Limbic stem cells and corneal replacement
• Similar to controls at low spatial frequency
• Substantially worse above 0.25 cpd
• Constant for the 7 years following surgery
MM has an unusual cortical map
Specializations of brain function

Damage to small regions of gray matter can produce very specific cognitive problems, such as face-blindness, loss of color vision, loss of motion perception, or loss of reading ability.

Wandell et al. 2007, New Encyclopedia of Neurosciences
Motion selective cortex

- Responds powerfully
- Is organized as a map
- Has the same size as in controls
Object and face-related responses
In some critical systems repairing damage after development requires that neuroscientists learn more about restoring plasticity.

Restoring plasticity in the adult is a research goal; it is a dangerous and uncertain path.
Brain connections: Diagnosing the reading circuitry

The what matter connections for reading
White matter fascicles are generated by step-wise sampling of local diffusion information.
The goal: Diagnosis

Identifying the locations and responses in a poor reader that differ significantly from measurements in good readers.
Diffusion (FA) changes differ between good and poor readers

- 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 both the Arcuate and the ILF
Diffusion (FA) changes differ between good and poor readers

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Correlations between tract diffusion change and seeing words

(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.

- The predictions are not yet useful; they are statistically reliable.

Measured reading score vs. Measured FA development rate.
The future: Modeling the biological networks that carry visual signals for reading

Car analogy

General visual inputs

VOT
Specialized processing for faces, words, other things
The future: Modeling the biological networks that carry visual signals for reading

Car analogy

General visual inputs
Most newspaper reports about clinical diagnoses describe a single factor – a place in the brain, a type of cell, or a type of molecule.

I am urging students and colleagues to think about how the parts of the system work together, not about a single critical object.
• The human brain has unique properties
• We have learned much about the visual parts of the brain
• Mis-wiring at birth: Amazing recovery
• Damage a few years later: Not much recovery
• Future: studying reading the circuitry
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