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

Courtesy Stephen Smith
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
Neuron: The parts

- **Axon input**
- **Dendrites**
- **Soma**
- **Axons**
- **Axon terminals**

- **Structures**
  - Nucleus
  - Nucleolus
  - Microtubule
  - Mitochondrion
  - Microfilament
  - Rough endoplasmic reticulum
  - Cell membrane
  - Axon hillock
  - Myelin
  - Axon
  - Axon terminals
Axons and transmitters

Structures

- Nucleus
- Cell body
- Axon
- Synapse

Transmitters:
- Glutamate
- GABA
- Dopamine
- Serotonin
Brain computations take 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 Graham Johnson
Brain computations take 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.

**Neurons/mm³**: $10^4$-$10^6$

**Total Cortical Neurons**: $10^{11}$

**Synapses/neuron**: $10^3$

**Total Cortical Synapses**: $10^{14}$

**Surface area of each hemisphere**: $25 \times 30 \text{ cm}^2$

Francis Crick; Braitenberg and Schutz
Synapse image from Graham Johnson
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/mm³: 3 km
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

- 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

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

Control state

Arterial

OEF: 0.4

Venous

Active state

Arterial

OEF: 0.4/1.2

Venous

Sokolow Raichle Fox
MRI scanners measure the blood oxygen level
How will BOLD imaging work?

fMRI signal decay for rest and active

Less oxygenated in rest state, hence, **slightly** faster signal decay
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

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)’.
Population RF estimation
(Dumoulin and Wandell, 2008)

Predicted BOLD (including HRF)

% BOLD

Observed

1 cycle
Time (sec)

Parameters
$(x_1, y_1, \sigma_1)$
Population RF estimation

(Dumoulin and Wandell, 2008)
Population RF estimation

Stimulus

Population RF model

Predicted BOLD (including HRF)

Parameters

(Dumoulin and Wandell, 2008)
Population receptive field vary significantly across human visual cortex

(Dumoulin and Wandell, 2008)
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
Stem cells, curing blindness

Levin et al., 2010, Neuron

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

Levin et al., 2010, Neuron
Human white matter

Measuring the major connections using diffusion imaging
Human fiber tracts

A

C.T.

Fascicle

(axons)
Diffusion probes brain microscopic structure

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

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 ($\mu m^2/ms$)
Diffusion Tensor Imaging (DTI)
A summary of the ADC at low b-values

\( A = u'Qu \)

1 = \( v'Q^{-1}v \),

\( v \) is a 3d-vector

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

5 um
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

Diffusion images → Local modeling → Tractography model

Local modeling: DTI, HARDI, DSI, ...

MicroTrack
MicroTrack: Hypothesis testing

- Volume regularization
- Diffusion predictions

Diffusion images

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
Issues in Education

A Fresh Look at Brain-Based Education
It has been more than 20 years since it was first suggested that there could be connections between brain function and educational practice. In the face of all the evidence that has now accumulated to support this notion, Mr. Jensen advocates that educators take full advantage of the relevant knowledge from a variety of scientific disciplines. Find out more...

See more Education Topics...

The Learning Brain

Can Music Education Really Enhance Brain Functioning and Academic Learning?
Should the studies exploring the relation between music and the brain determine the school curriculum? Read both sides of the argument. Find out more...

See more articles on The Learning Brain...
Business decision-making (Marketing)

Summer Workshop on Decision Neuroscience

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.

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
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Tony Sherbondy
Seeing and the brain

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End
MicroTrack: Error measures

Diffusion prediction error

MicroTrack normalization

Tensorline (Izhikevic, 2008)

Tractography model

Target data
MicroTrack: Error measures

Volume

Tensorline

Overfill
- Yellow: 2x
- Red: 3x
- Blue: 2x

After normalization

Tractography model

Target data
Tractography and diffusion papers
http://vistalab.stanford.edu/~brian.refs.html

• Contrack and Microtrack
  Sherbondy, ConTrack, JOV (2008)
  Sherbondy, Optic radiation, JOV (2009)

• Statistical analysis of tensors
  Masuda et al. (Cerebral Cortex, IOVS) (2008, 2010)

• Diffusion, tractography, reading
  Dougherty et al. (2005, 2007)
  Tsang et al., Arithmetic processing, PNAS (2010)
  Deutsch et al. Diffusion and reading (2005)
Additional diffusion behavior correlations continue to arise
Summary

- Reading requires quickly and accurately identifying forms (seeing words)
- The cortex learns to do this using the VWFA, a region located amidst a set of visual field maps
- The VWFA signals must be communicated to parts of cortex used in language and phonology
- White matter development (arcuate, ILF) is part of reading development
Specific Reading Pathways

- Brain definitions and background
- Magnocellular hypothesis (MT)
- Temporo-parietal junction, dyslexia
- OTS
- Diffusion Tensor Imaging

LR, 11yrs old
Neuroscience for Society

- Pain, Blindness, Deafness  
  (Medicine)
- Learning and reading disabilities  
  (Education)
- Depression, memory loss  
  (Psychiatry, Neurology)
- Intentionality  
  (Law, Business)

Applications
Neuroscience for Society

• What happens to cortical neurons that stop receiving their input?
• Understanding which neurons change, which stay the same, when and why, is important for making decisions about inserting these visual prosthetics.

• Specialized brain are trained for seeing words and reading
• Can neuroimaging identify early markers to understand when children are ready to learn to read, and how to intervene and help children with reading disabilities?
Understanding brain computations is transforming the human sciences

- **Education** - Reading
- **Law** - Lie-detection, memory
- **Business** - Decision-making
- **Mental health** - Depression

Integrating technology

- **Engineering** - MR Methods, Databases, Statistics
- **Teaching** - Educated member of society and the brain
Scientific and Engineering MR model

- **Differs from medicine**
- **Methods**
  - Software, software, software
    (10% at scanner, 90% in analysis)
  - Quantitative MR
  - Database focus on sharing, computing, not privacy
  - Visualization
- **Integration across modalities**
  - Coordination with animal models
  - Linking across length- and time-scales
Diffusion distance

The mean distance that a typical water molecule will diffuse in a unit of time is a 3d-vector $v$, with $1 = v'Q^{-1}v$, where $v$ is a 3d-vector.

The mean distance that a typical water molecule will diffuse in a unit of time
Lie-Detection

No Lie MRI, Inc. provides unbiased methods for the detection of deception and other information stored in the brain.

The technology used by No Lie MRI represents the first and only direct measure of truth verification and lie detection in human history!

No Lie MRI uses techniques that:
- **Bypass conscious cognitive processing**
- Measure the activity of the central nervous system (brain and spinal cord) rather than the peripheral nervous system (as polygraph testing does).

Medial Frontal Gyrus

To help identify the information of most interest to you, please let us know who you are.

- **Individual Customers**
- **Lawyers / Law Firms**
- **Corporate Customers**
- **Government Customers**
- **Prospective Test Centers**
- **Prospective Investors**
Raw Diffusion MR Images

Dark means large ADC (a great deal of signal attenuation)

\[ b = 800 \]
\[ g = [-0.7 \ 0.7 \ 0.0] \]
Raw Diffusion MR Images

Dark means large ADC (a great deal of signal attenuation)

\[ b = 800 \]
\[ g = [-0.7, -0.7, 0.0] \]