Outline

• Introduction to the Brain
  – Anatomic Structure
  – Blood Vessels
  – Functional Organization

• Preliminaries
  – Mathematical Preliminaries, Matlab Primer, Matrix Primer
  – Image File Formats
  – Overview of Software Packages
  – Introduction to two Matlab Software Packages

A Neuroanatomy primer.
Gross surface anatomy of the human brain.

References:
A myriad of web sites – surf to your heart’s content!
http://www.neuropat.dote.hu/anastru/anastru.htm
http://www.neuropat.dote.hu/atlas.html
http://www.med.harvard.edu/AANLIB/home.html
http://www.neuroguide.com/neuroimg_1.html#human_neuroanatomy

Defining the lobes
- central (rolandic) sulcus
- sylvian (lateral) sulcus
- frontal lobe
- temporal lobe
- occipital lobe
- parietal lobe

14 Major Sulci
- Main sulci are formed early in development
- Fissures are really deep sulci

Typically continuous sulci
- Interhemispheric fissure
- Sylvian fissure
- Parieto-occipital fissure
- Collateral sulcus
- Central sulcus
- Calcarine Sulcus

Typically discontinuous sulci
- Superior frontal sulcus
- Inferior frontal sulcus
- Postcentral sulcus
- Intraparietal sulcus
- Superior temporal sulcus
- Inferior temporal sulcus
- Cingulate sulcus
- Precentral sulcus

Other minor sulci are much less reliable

Source: Ono, 1990

Interhemispheric Fissure
- Hugely deep (down to corpus callosum)
- Divides brain into 2 hemispheres

Sylvian Fissure (or lateral sulcus)
- Deep, mostly horizontal
- Insula (purple) is buried within it
- Separates temporal lobe from parietal and frontal lobes
Parieto-occipital Fissure and Calcarine Sulcus

- Parieto-occipital fissure (red)
  - Very deep
  - Often Y-shaped from sagittal view, X-shaped in horizontal and coronal views
- Calcarine sulcus (blue)
  - Contains V1

Calcarine sulcus (blue)
- Visual areas on medial side above calcarine (lower visual field)

Collateral Sulcus
- Divides lingual (yellow) and parahippocampal (green) gyrus from fusiform gyrus (pink)

Cingulate Sulcus
- Divides cingulate gyrus (turquoise) from presuncous (purple) and paracentral lobule (gold)

Central, Postcentral and Precentral Sulci

Central Sulcus (red)
- Usually freestanding (no intersections)
- Just anterior to ascending cingulate

Postcentral Sulcus (red)
- Often in two parts (superior and inferior)
- Often intersects with intraparietal sulcus
- Marks posterior end of postcentral gyrus (somatosensory strip, purple)

Precentral Sulcus (red)
- Usually in two parts (superior and inferior)
- Often intersects with intraparietal sulcus
- Marks anterior end of precentral gyrus (motor strip, yellow)

Intraparietal Sulcus
- Anterior end usually intersects with inferior postcentral (some texts call inferior postcentral the ascending intraparietal sulcus)
- Posterior end usually forms a T-junction with the transverse occipital sulcus (just posterior to the parieto-occipital fissure)
- IPS divides the superior parietal lobule from the inferior parietal lobule (angular gyrus, gold, and supramarginal gyrus, lime)

Slice Views
- Inverted omega = hand area of motor cortex
Superior and Inferior Temporal Sulci
- Superior Temporal Sulcus (red)
  - divides superior temporal gyrus (peach) from middle temporal gyrus (lime)
- Inferior Temporal Sulcus (blue)
  - not usually very continuous
  - divides middle temporal gyrus from inferior temporal gyrus (lavender)

Superior and Inferior Frontal Sulci
- Superior Frontal Sulcus (red)
  - divides superior frontal gyrus (mocha) from middle frontal gyrus (pink)
- Inferior Frontal Sulcus (blue)
  - divides middle frontal gyrus from inferior frontal gyrus (gold)
  - orbital gyrus (green) and frontal pole (gray) also shown
  - Frontal Eye fields lie at this junction
  - Superior frontal gyrus continues on medial side
  - Frontal pole (gray) and orbital gyrus (green) also shown

Medial Frontal
- Superior frontal gyrus continues on medial side
- Frontal pole (gray) and orbital gyrus (green) also shown

Anatomical Localization
Sulci and Gyri
- gray matter (dendrites & synapses)
- white matter (axons)

Variability of Sulci
- Source: Szikla et al., 1977 in Tamraz & Comair, 2000
**Sulcal Formation**

Although sulci vary considerably from person to person (even in identical twins), there is considerable regularity in where the folds occur. Why?

David Van Essen proposes that as the brain develops, areas that are richly interconnected will be pulled together to form a gyrus (and those that are weakly interconnected form sulci).

- **Development of Sulci**

Sulci appear at predictable points in fetal development with the most prominent sulci (e.g., Sylvian fissure) appearing first.
Arterial Blood Supply

- Internal carotids supply hemispheres:
  - Middle, anterior cerebral arteries, ophthalmic artery
- Vertebrals supply hemispheres, brainstem, spinal cord, cerebellum via numerous vessels.

Circle of Willis

- Internal carotid and vertebrals anastomose in the Circle of Willis

Anterior / Posterior Cerebals

- Middle Cerebral
Blood supply – lateral surface
- Middle cerebral artery – red
- Posterior cerebral artery – blue
- Anterior cerebral artery – green
- Veins - black

Blood supply – medial surface
- Anterior cerebral artery – green
- Posterior cerebral artery – blue
- Veins - black

Blood supply – inferior surface
- Anterior cerebral artery – green
- Posterior cerebral artery – blue
- Veins - black

Aneurysms
- Angiogram - Aneurysm of ICA
- Blood vessels dissected - ACA aneurysm
- Aneurysm displaces hemisphere

Cerebral Vessel Infarcts
- Infarct of MCA
- Watershed infarct - fragile area at boundary of 2 vessels

Large draining veins.
- Cerebral veins drain into venous sinuses and into internal jugular
- Superficial veins lie on surface of cortex and drain into superior sagittal sinus
- Deep veins drain internal structures and empty into the straight sinus
- Large draining veins can lead to artefacts in fMRI

See Nolte, J. The Human Brain
**Brodmann’s Areas**

Brodmann (1905): Based on cytoarchitectonics; study of differences in cortical layers between areas. Most common delineation of cortical areas. More recent schemes subdivide Brodmann’s areas into many smaller regions. Monkey and human Brodmann’s areas not necessarily homologous.

**Variability of Functional Areas**

Watson et al., 1995 - Functional areas (e.g., MT) vary between subjects in their Talairach locations. The location relative to sulci is more consistent.

**Visual Pathways**

Visual Pathways

**Ocular Dominance Columns**

Ocular Dominance Columns

**Somatosensory Pathway**

Somatosensory Pathway
Language

  - Beautiful pictures
  - Clear anatomy
  - Slices of real brain

- Damasio, 1995, _Human Brain Anatomy in Computerized Images_
  - Good for showing sulci across wide range of slice planes
  - Really crappy reconstructions

- Ono, 1990, _Atlas of the Cerebral Sulci_
  - Great for showing intersubject variability
  - Gives probabilities of configurations and stats on sulci

- Tamraz & Comair, 2000, _Atlas of Regional Anatomy of the Brain Using MRI with Functional Correlations_
  - Good overview

Learning More Anatomy

Outline

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  - Anatomical Structure
  - Blood Vessels
  - Functional Organization

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  - Password for book chapters
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Language

- Damage to superior temporal area
- Recipient of Wernicke’s areas; unable to understand or to express spoken language

Motor cortex

Wernicke’s area

Broca’s area

Caveats:

- Inter-subject variability in anatomy (e.g., sulcal variation)
- Variability in structure-function relationships

Dealing with different heads: spatial normalization

Normalize via affine transformation and non-linear deformation
Inner Product & Norm

\[ (\mathbf{x}, \mathbf{y}) = \sum_{k} x_k y_k^* = \mathbf{x}^T \mathbf{y} \quad \text{and} \quad ||\mathbf{x}||^2 = (\mathbf{x}, \mathbf{x}) \]

Correlation

\[ r = \frac{\mathbf{x} \cdot \mathbf{y}}{||\mathbf{x}|| \cdot ||\mathbf{y}||} \]

where \( \mathbf{A} = \mathbf{B} - \mathbf{B} \) and \( \mathbf{A} = \Sigma_{j \neq i} a_j / N \), and where \( [A] = a_j \) the standard deviation of \( a \) (see Equation (1.3)). The quantity \((X, Y)\) is the covariance between \( \mathbf{X} \) and \( \mathbf{Y} \) for i and j. The cross-correlation and convolution of two vectors in \( \mathbb{C}^N \) may be

\[ (\mathbf{x} \circ \mathbf{y})_k = \sum_{j=1}^{n} x_j e^{2\pi i j k/N} \quad \text{and} \quad (\mathbf{x} \ast \mathbf{y})_k = \sum_{j=1}^{n} x_j e^{2\pi i j k/N} \]

Fourier Transform & Inverse Fourier Transform

\[ \mathcal{F}(g \ast f) = (\mathcal{F}g)(\mathcal{F}f) \quad \text{and} \quad \mathcal{F}(g \circ f) = (\mathcal{F}g)(\mathcal{F}f) \]

Convolutions

\[ \mathbf{y} = \sum_{j \neq k} \mathbf{x}_j \mathbf{y}^*_j \]

Image File Formats

- **DICOM**
- **Analyze**
- **NifTI**

DICOM

The Digital Imaging and Communications in Medicine (DICOM) standard was created by the National Electrical Manufacturers Association (NEMA) to aid the distribution and viewing of medical images.

Analyze

- Analyze format
  - .img, .hdr, binary data: 3D or 4D
  - .hdr Small binary header
    - Image dimension
    - Voxel size
    - Origin in voxels
    - First element 1, not 0
  - .mat Optional, SPM2 extension (deprecated in SPM5!)
    - Decribes transformation from voxel to world space
    - If exists, .hdr voxel size & origin are ignored
    - Origin can be represented as mm location
    - e.g. between voxels

NifTI

- .nii + .hdr
  - Like Analyze, but different .hdr definition different
    - .nii Small file
      - Header and Image file concatenated
      - SPM can read .nii files, but doesn't write them
    - World space transformation coded in NIFTI header
      - No more .img, .mat files!
Software Packages

- **AFNI** (http://afni.nimh.nih.gov/afni): A set of programs for processing, analyzing, and displaying functional imaging data. It runs on Unix-based systems and is currently freely available.

- **FSL** (http://www.fmrib.ox.ac.uk/fsl/): FSL is a comprehensive library of image analysis and statistical tools for FMRI, MRI and DTI brain imaging data. FSL is written mainly by members of the Analysis Group, FMRIB, Oxford, UK.

- **FreeSurfer** (http://surfer.nmr.mgh.harvard.edu/): A program for reconstruction of the brain's cortical surface and overlay of functional data onto the reconstructed surface. The program is developed by Martin Sereno.

- **SPM** (http://www.fil.ion.ucl.ac.uk/spm/): A powerful set of MATLAB functions for preprocessing, analysis and display of FMRI and PET data. It is currently freely available.

- **IMSim** (http://learnfmri.ucsd.edu/index.php?option=com_content&task=view&id=16&Itemid=38): A MATLAB tool to simulate MRI Imaging - developed inhouse at the UCSD fMRI center.

- **VoxBo** (http://www.voxbo.org/): A package that contains both analysis tools and project management features for tracking the status of analyses. It runs on Unix-based systems and is currently freely available.

**Two Complementary Software Packages**

- **SPM** Implements General Linear Model (Model-Based, Univariate)

- **GIFT** Implements Independent Component Analysis (Data-Driven, Multivariate)

Intro to Statistical Parametric Mapping

Statistical Parametric Mapping (SPM)
- Started in 1991 in response to PET studies
- Regions of Interest (ROIs);
- Tons of data to a few regions;
- Poor use of data; localization; reproducibility
- Made publicly available in 1994 (SPMclassic)
- SPM94 - PET
- SPM95 – PET/IMRI
- SPM96 – Major revision
- SPM97 – Event-related IMRI
- SPM99 – Major revision
- SPM2 – Major revision
- SPM5 – Latest release

Advantages
- Free
- Relatively easy to use (help list)
- Platform independent (matlab)
- Can be (relatively) easily modified
- 10 different people involved in coding
- 100s of users
- Modules are subjected to peer review
- Customizable – edit/tool boxes/etc.

fMRI Data analysis

Inference with
Gaussian field theory

Design matrix

Template

Parameter estimates

Spatial modes and effective connectivity

Adjusted regional data

General linear model

Smoothing

Realignment

MRI time-series

Kernell

Reference with
gaussian field theory

p < 0.05