Introduction to Brain Science and fMRI
(1)The human brain structure and functions
Tokyo Tech OCW version

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About this lecture

This lecture provides an introduction to the basic theory and practice of brain science based on the technology of magnetic resonance imaging (MRI). Students learn the human brain structure and functions, especially related to language, memory, perception, motion and emotion, and computational programming technologies pertaining to the applied informatics. Some methods of fMRI analysis will be discussed such as general linear model (statistical hypothesis testing), multi-voxel pattern analysis (machine learning) and resting-state functional connectivity (application of graph theory).We will conduct a tour of the fMRI facility of the school of bio-science and bio-technology on the campus of O-okayama.

Today's topics

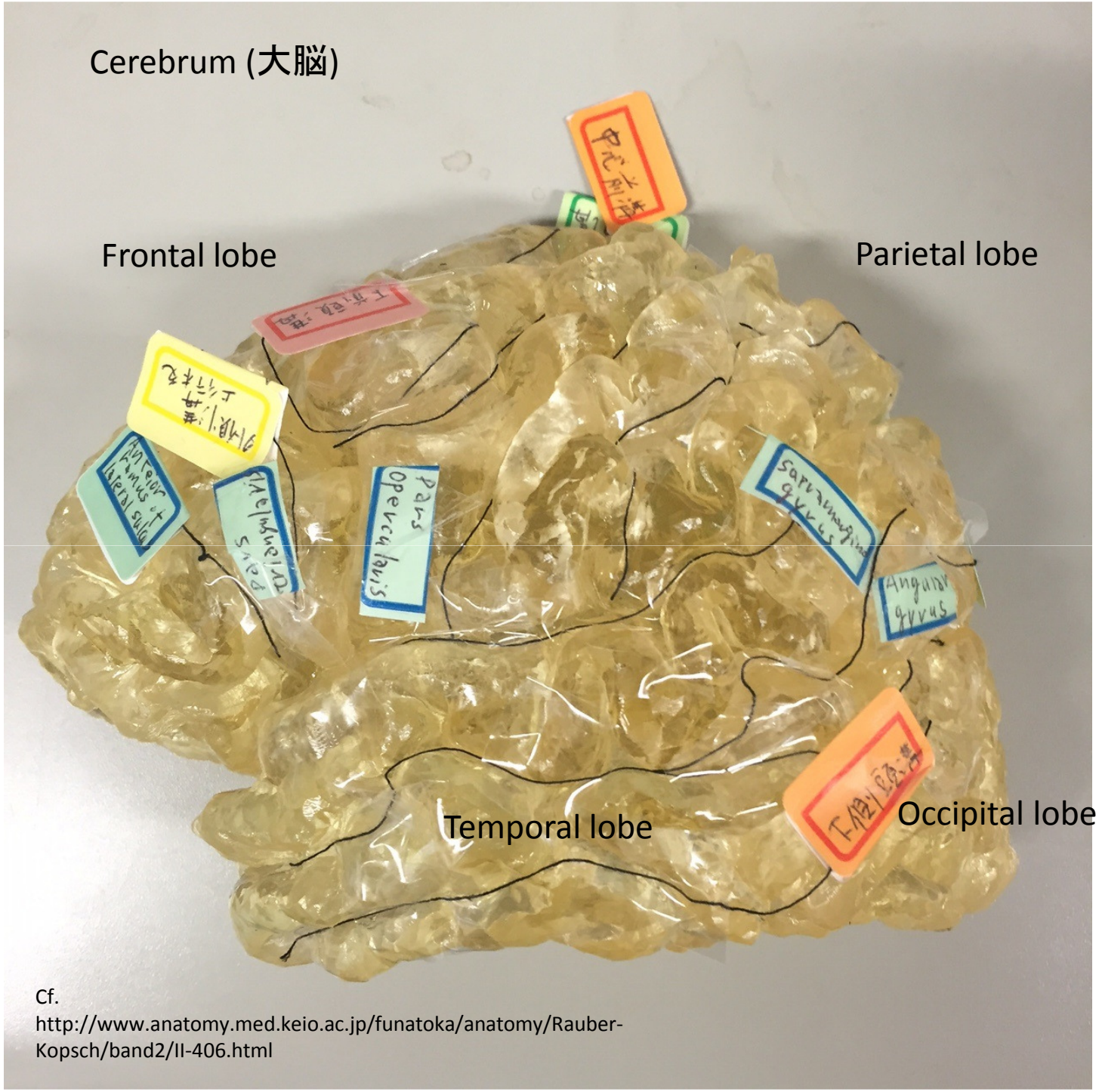
- The human brain structure and functions
- Students will be able to learn the outline of the functional anatomy.
- Functional anatomy is a system of knowledge about the (somatotopic) relationship between the abilities of the humans and the brain regions engaged in these abilities.
- Brain mapping, neuroanatomy or structural/functional MRI (magnetic resonance imaging) are the keywords of this lecture.

This is my brain (left hemisphere; lateral view).

The object was produced from an MRI scan (T1 image) and using the 3D Printer at Tokyo Tech.

Each black string represents an important “sulcus” (a furrow or fissure.)

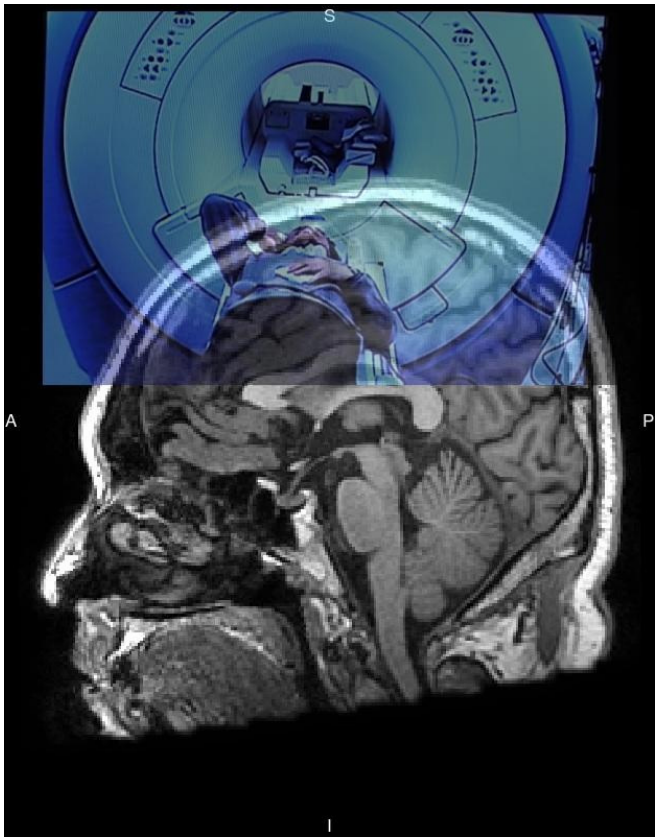
Between sulci, there is a “gyrus” (convoluted ridge).



Cf.
http://www.anatomy.med.keio.ac.jp/funatoka/anatomy/Rauber-Kopsch/band2/II-406.html

MRI facility at Tokyo Tech (Ookayama campus)

Anatomical (Structural) scan



Software
SPM
Freesurfer
CAD

Brain

- Prosencephalon (forebrain)(前脳)
  - telencephalon(終脳:大脳半球のこと)
    - cerebral cortex(大脳皮質)
    - white matter(白質)
    - basal ganglia(基底核)
      - striatum(線条体)
        - dorsal striatum(背側線条体)
          - caudate(尾状核)
          - putamen(被核)
        - ventral striatum(腹側線条体)
          - nucleus accumbens(側坐核)
          - olfactory tubercle(嗅結節)
      - pallidum(淡蒼球)
      - subthalamic nucleus(視床下核)
      - substantia nigra(黒質)
  - diencephalon(間脳)
    - mid-diencephalic territory
      - prethalamus(視床腹部)
      - zona limitans intrathalamica(ZLI)
      - thalamus(視床)
    - hypothalamus(視床下部)
    - epithalamus(視床上部)
    - pineal gland(松果体)
    - metathalamus(視床後部)
- Mesencephalon(midbrain)(中脳)
  - tectum(被蓋)
    - inferior colliculi(下丘)
    - superior colliculi(上丘)
  - cerebral peduncle(大脳脚)
    - midbrain tegmentum(中脳被蓋)
    - crus cerebri(大脳脚)
    - substantia nigra(黒質)
- Rhombencephalon(hindbrain)(後脳)
  - metencephalon(medulla oblongata)(後脳;延髄)
  - myelencephalon(髄脳; 延髄)
    - pons(橋)
    - cerebellum(小脳)
- Spinal cord(脊髄)

Reference:
http://www.wikicell.org/index.php/Telencephalon

Figure will be here.

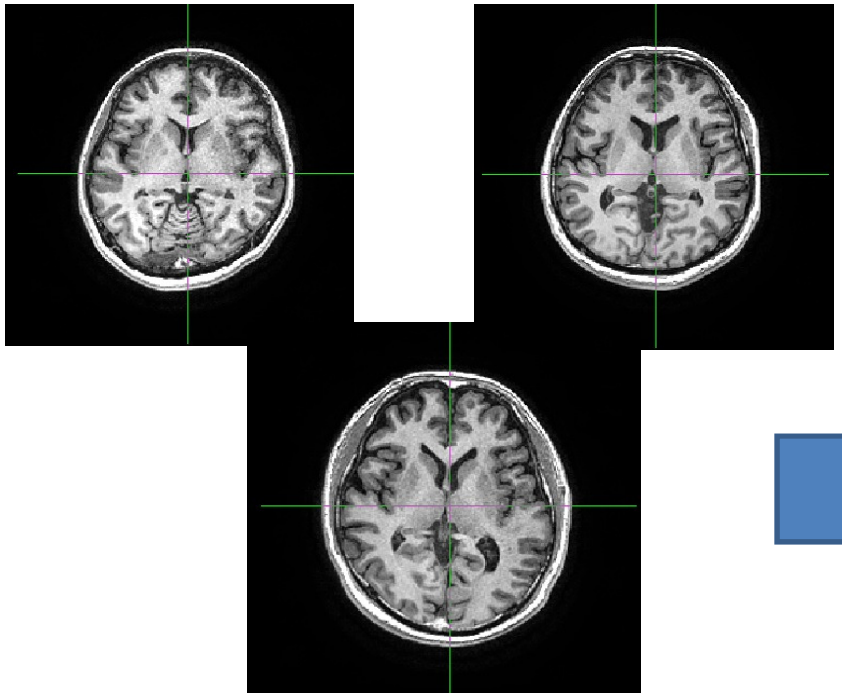
https://en.wikipedia.org/wiki/Hindbrain#/media/File:EmbryonicBrain.svg

Figure will be here.

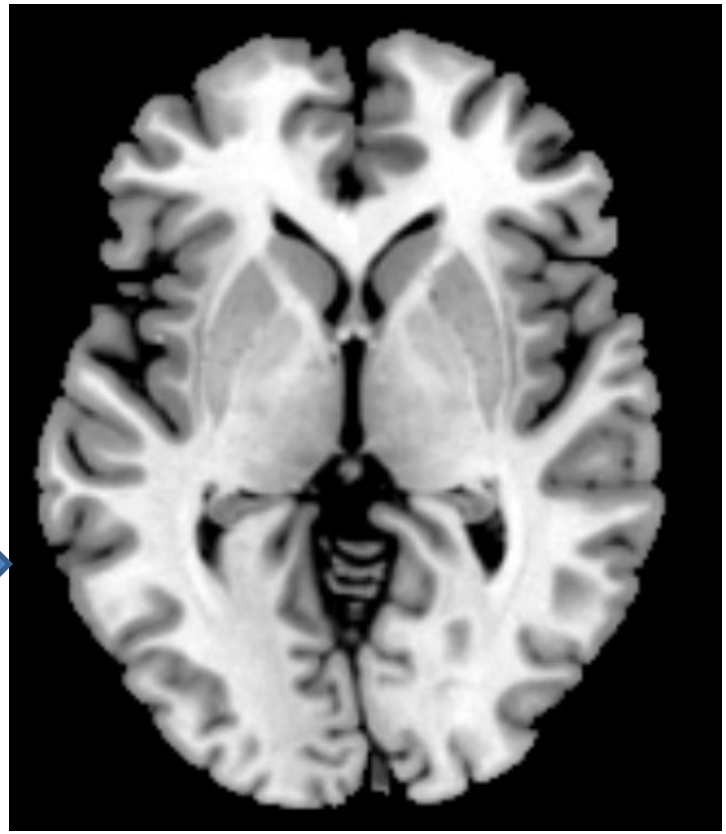
From Eric R. Kandel et at., Principles of Neural Science, p10. Figure1-3

Individual brain and Standard brain

An individual brain
Idiosyncratic
Individual Variability
<-3D rendering from
an anatomical scan



Standard brain
served as a statistically balanced
(averaged) template
-MNI (Montreal Neurological Institute)
Space
-Talairach Space



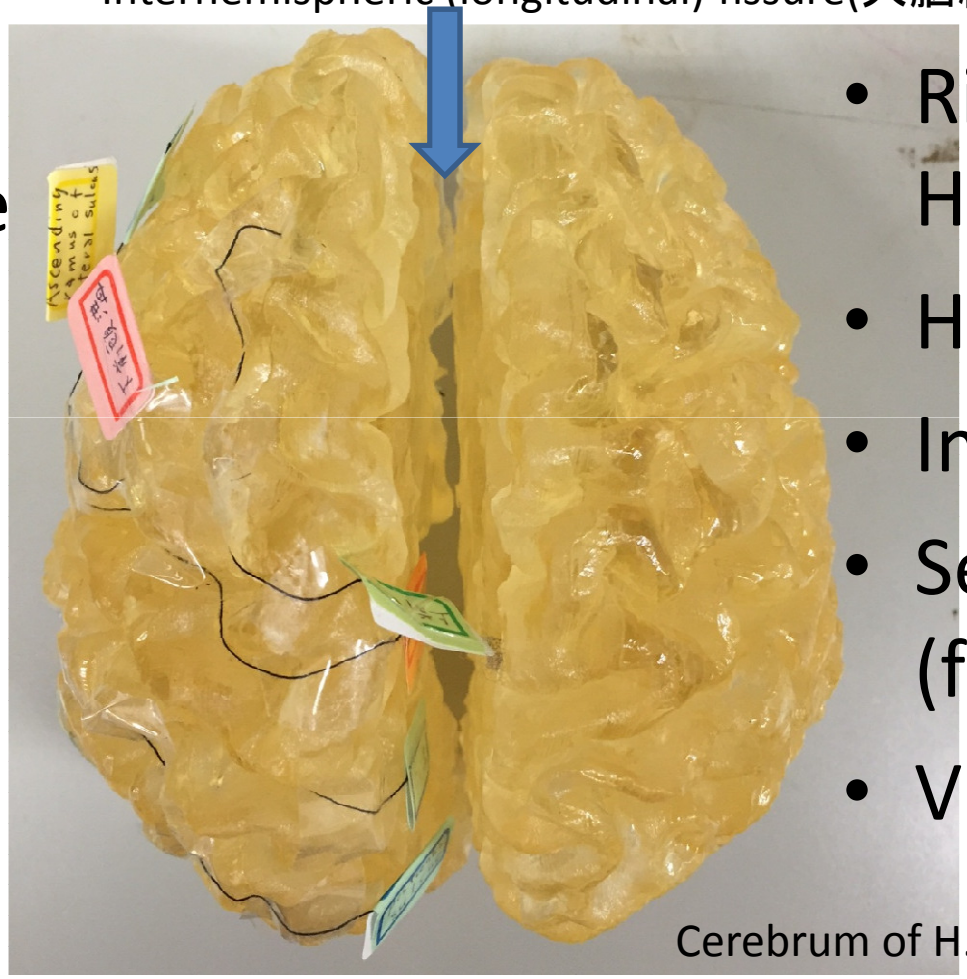
Each hemisphere is concerned with sensory/motor processes on the contralateral (opposite) side of the body.

Hemispheric lateralization (specialization)

Telencephalon(終脳)

Interhemispheric (longitudinal) fissure(大脳縦裂)

- Left Hemisphere
- Analytic
- Logic
- Rational
- Fine motor control



Cerebrum of H. Akama

- Right Hemisphere
- Holistic
- Intuition
- Sense (feeling)
- Vision

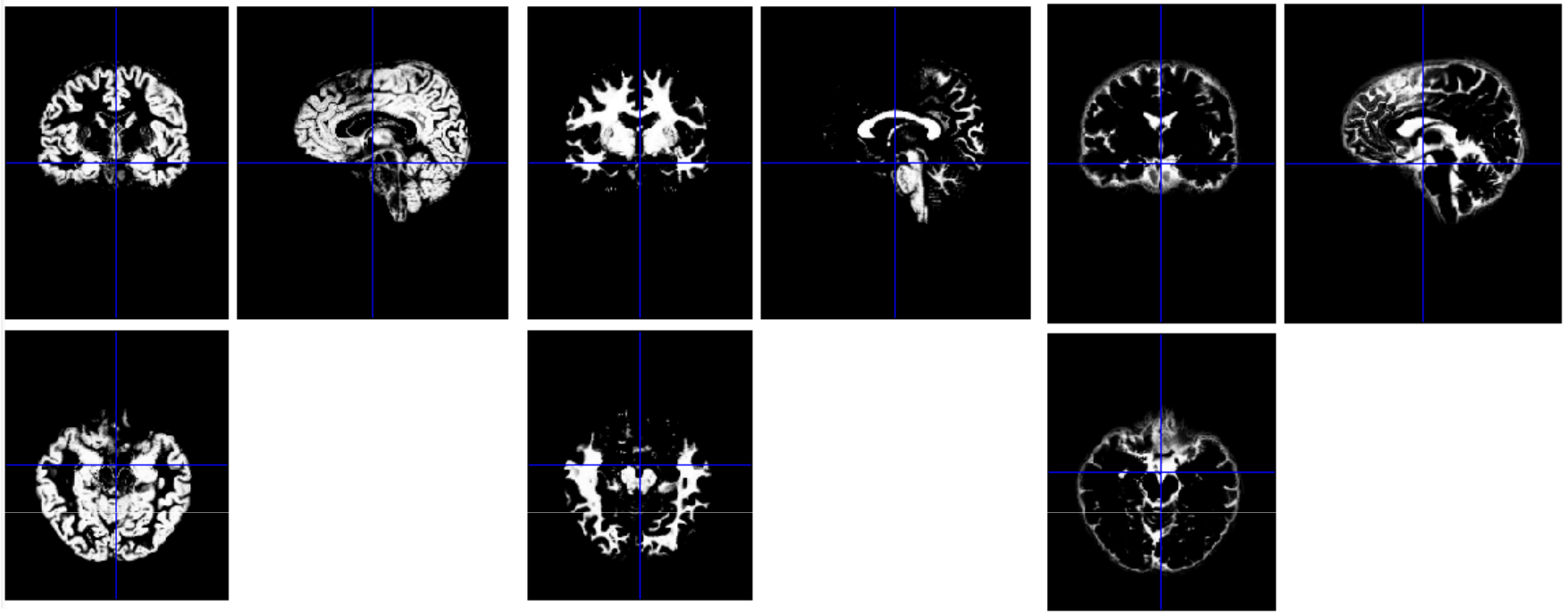
From Eric R. Kandel et at., Principles of Neural Science, etc.etc.

Cerebral Cortex

- The thin outer layer of the Left and right cerebral hemispheres
- Neural tissue called grey matter divided by the medial longitudinal fissure
- Layer divided into 4 major lobes
- Frontal（前頭葉）; anterior to the central sulcus; motion control, reward (dopamine-sensitive neurons), emotion, etc.
- Parietal（頭頂葉）; posterior to the central sulcus (behind frontal) and anterior to the parietal-occipital sulcus; sensory input, sensory information,
- Occipital（後頭葉）; most backward, smallest: visual processing
- Temporal（側頭葉）; beneath the lateral fissure; memories, language comprehension, auditory and visual input, etc.

From Eric R. Kandel et at., Principles of Neural Science

Segmentation



Grey Matter(灰白質)

Contains neural
cell bodies

White Matter(白質)

Contains myelinated
axon tracts

Cerebrospinal fluid(脳脊髄液)

colorless bodily fluid
(the brain "floats" in it.)

Segmentation can be done by
1.difference in brightness
2.tissue probability map

From SPM8, Wellcome Trust Center, UK

Brain Atlas

外側:lateral

内側:medial

中心溝

帯状回

帯状溝

頭頂葉

前頭葉

脳梁

頭頂後頭溝

後頭葉

fissure of Sylvius

外側溝

Figure will be here.

Figure will be here.

鳥距溝

側頭葉

延髄

小脳

橋

脊髄

From Eric R. Kandel et at., Principles of Neural Science

尾状核

帯状回

脳室

淡蒼球

被殻

弁蓋

外側溝

島皮質

尾側

Brain Atlas

吻側

扁桃体

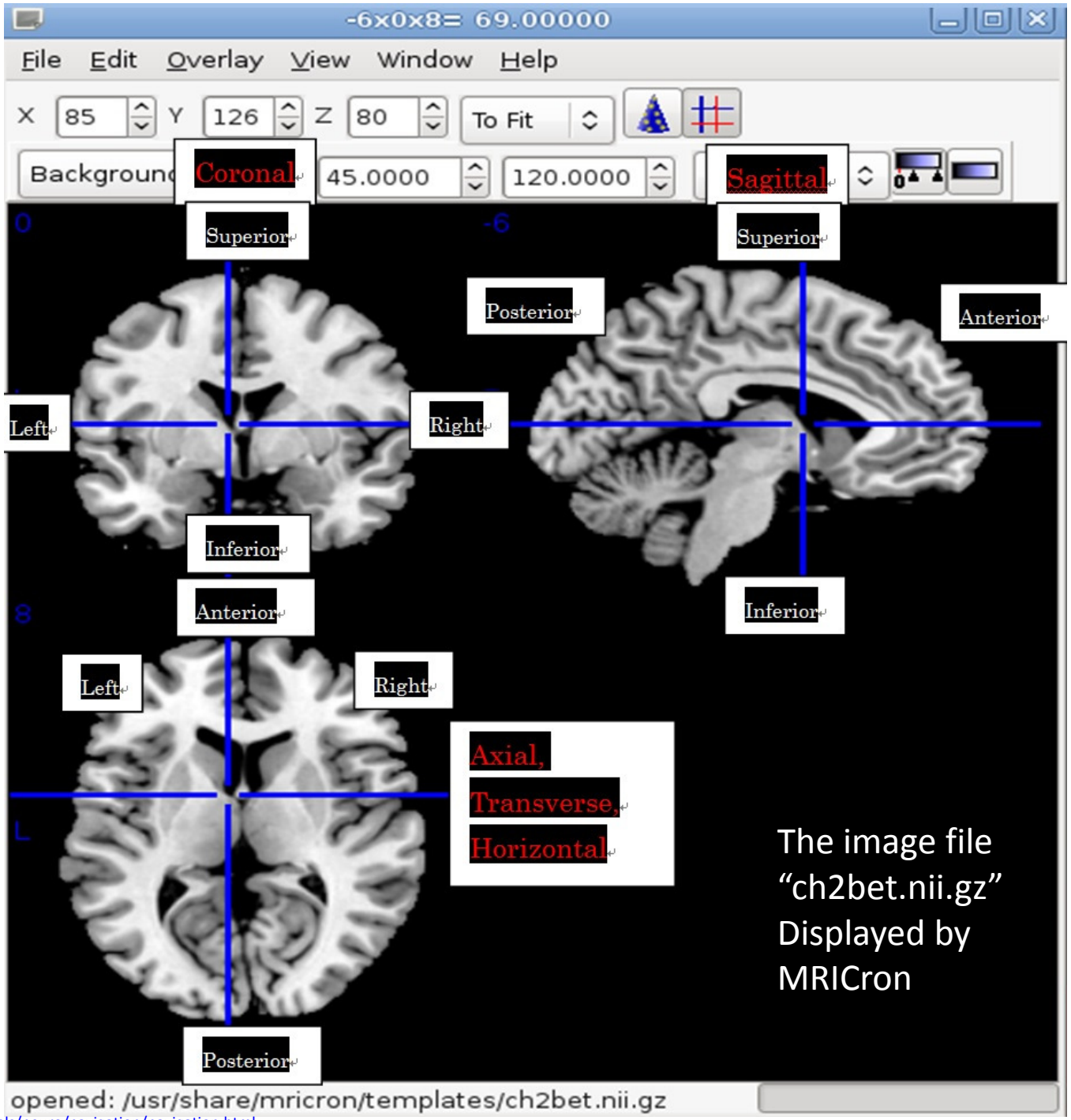
Figure will be here.

From Eric R. Kandel et at., Principles of Neural Science

Three planes (perpendicular to each other)

Coronal(xz): a longitudinal plane which splits the brain into belly and back sections.
Sagittal(yz): a vertical plane which passes from anterior to posterior splitting the brain into the left and right hemispheres
Axial(transverse) (xy):a horizontal plane which splits the brain into superior and inferior parts
For sections and orientation of the brain, check

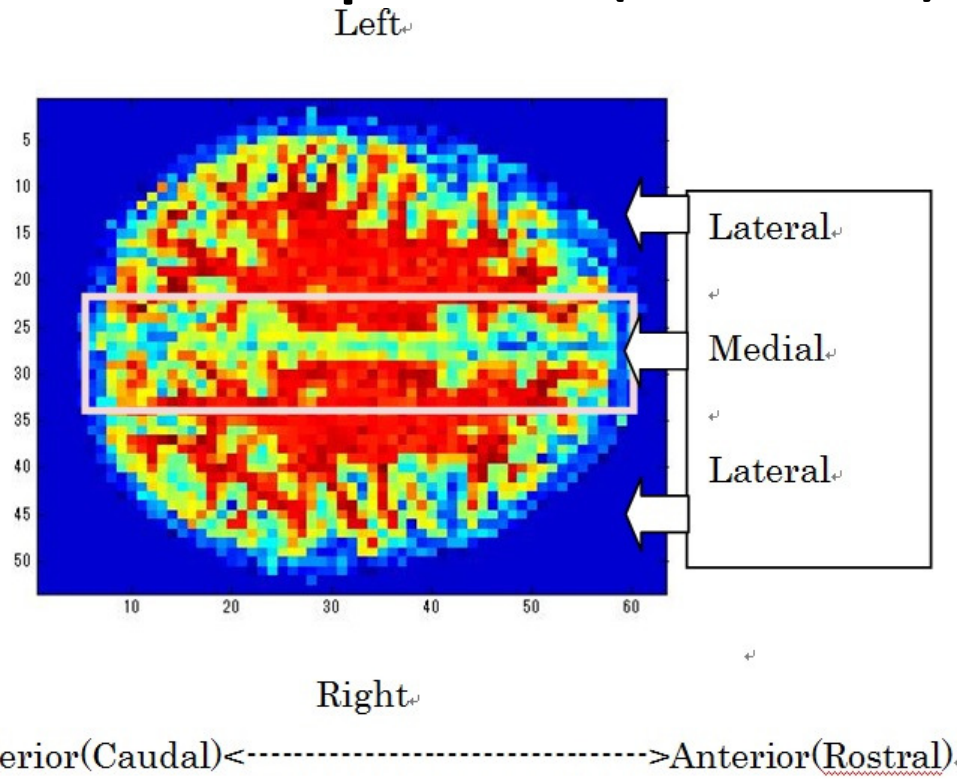
http://www.columbia.edu/cu/psychology/courses/1010/mangels/neuro/navigation/navigation.html



The image file "ch2bet.nii.gz" Displayed by MRICron

Axial, transverse, horizontal plane (横断面)

Important terms for the anatomy
Lateral (外側): farther away from the midline
Medial(内側): closer to the midline
Rostral(吻側): toward the oral or nasal region, toward the tip of the frontal lobe. (Wikipedia)
Caudal(尾側): near the posterior end of the body, toward the "tail“ (the spinal cord, and body) (Wikipedia).



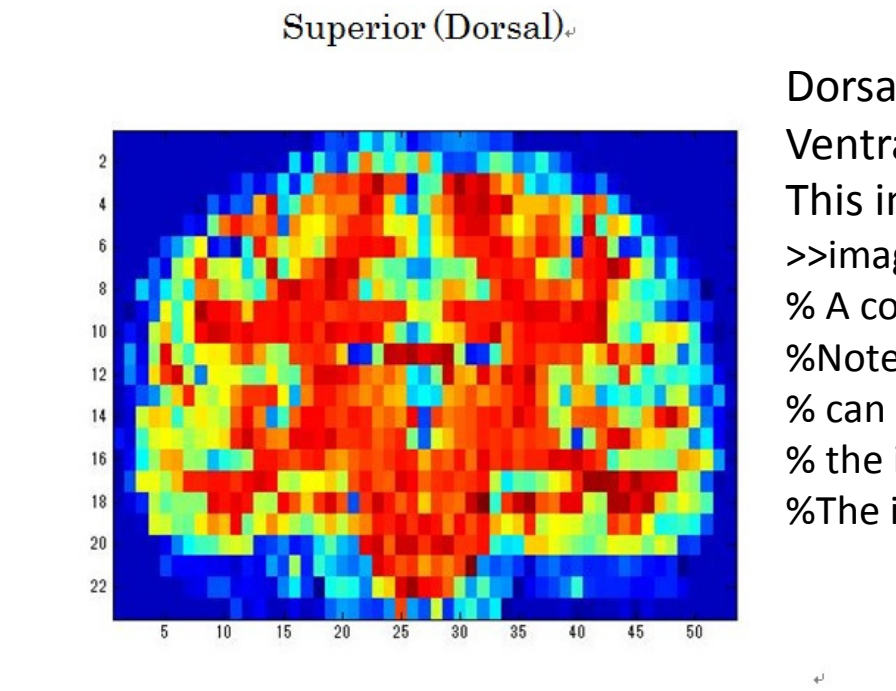
The brain image can be represented by a 3D array with the difference in color, brightness, etc.

The following operations can be done with the educational computer system of GSIC.

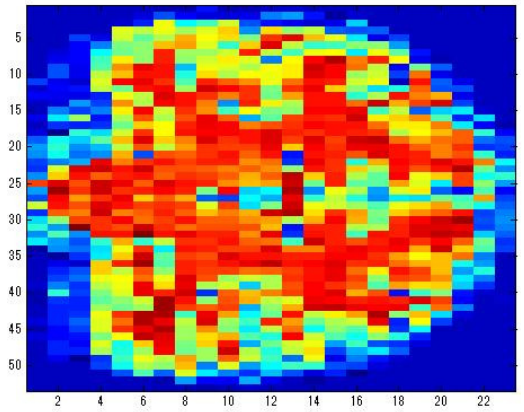
This slice can be visualized by using MATLAB and the file distributed in this class ('brainimg.mat').

```
>> load('brainimg.mat');
%A data in the variable of which the name is 'brainimg' is now loaded in the work space.
>> imagesc(brainimg(:,:,15))
%One axial (transverse, horizontal) slice
```

Coronal plane (冠状面)

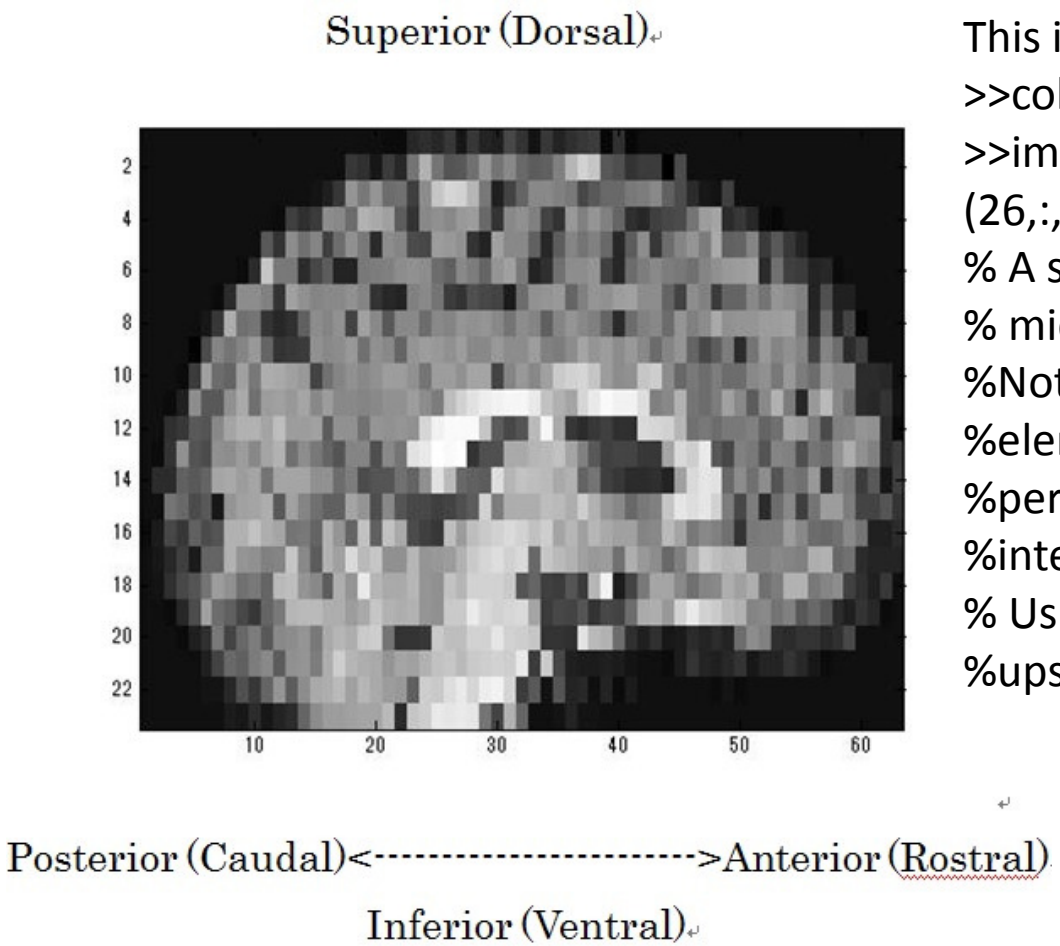


Dorsal (背側): back
Ventral(腹側): belly, lower side
This image can be shown by running
>>imagesc(flipud(transpose(permute(brainimg(:,30,:), [1 3 2]))))
% A coronal slice (=x-z plane).
%Note that the slice number 30 (in the middle, as a 'y' value)
% can be specified by a permutation order of [1 3 2] and that
% the integer 2 for 'y' value is at the end of this list.
%The image is toppled over sideways.



Can you explain this one?

Sagittal Plane(矢状面)



This image can be shown by running
>>colormap(gray)
>>imagesc(flipud(transpose(permute(brainimg (26,:,:), [2 3 1]))))
% A sagittal slice (=a y-z plane) near the
% midline (we have 53 sagittal slices in total).
%Note that the slice number 26 (as the first
%element, an 'x' value) can be specified by a
%permutation order of [2 3 1] and that the
%integer 1 for 'x' value is at the end of this list.
% Using the flipud function, the image is not
%upside down.

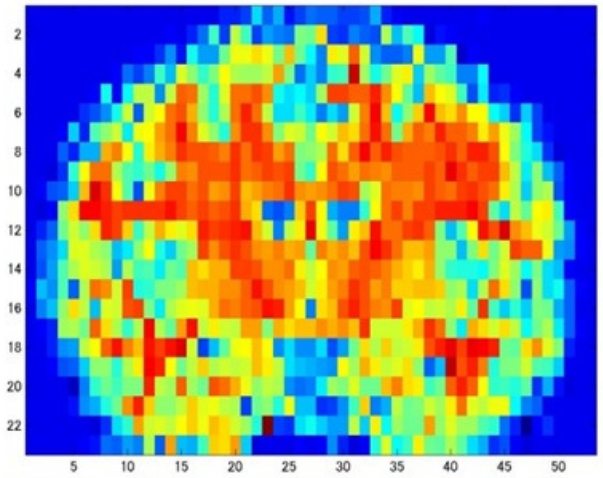
Left or Right?

- There are two kinds of ways to define Left and Right:
- Neurological Left-Right versus Radiological Left-Right.
- Neurological: Left and Right for a subject, so thought from behind him/her.
- Radiological: Left and Right for an observer looking toward the face of a subject.

Figure will be here.

Left or Right?

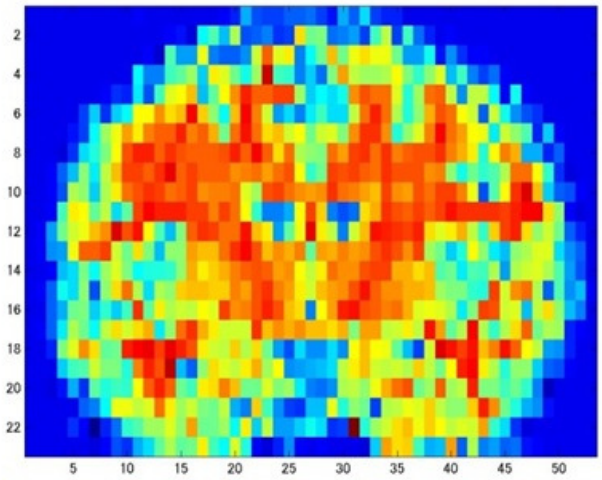
Superior



Inferior

Left<----------->Right

Superior

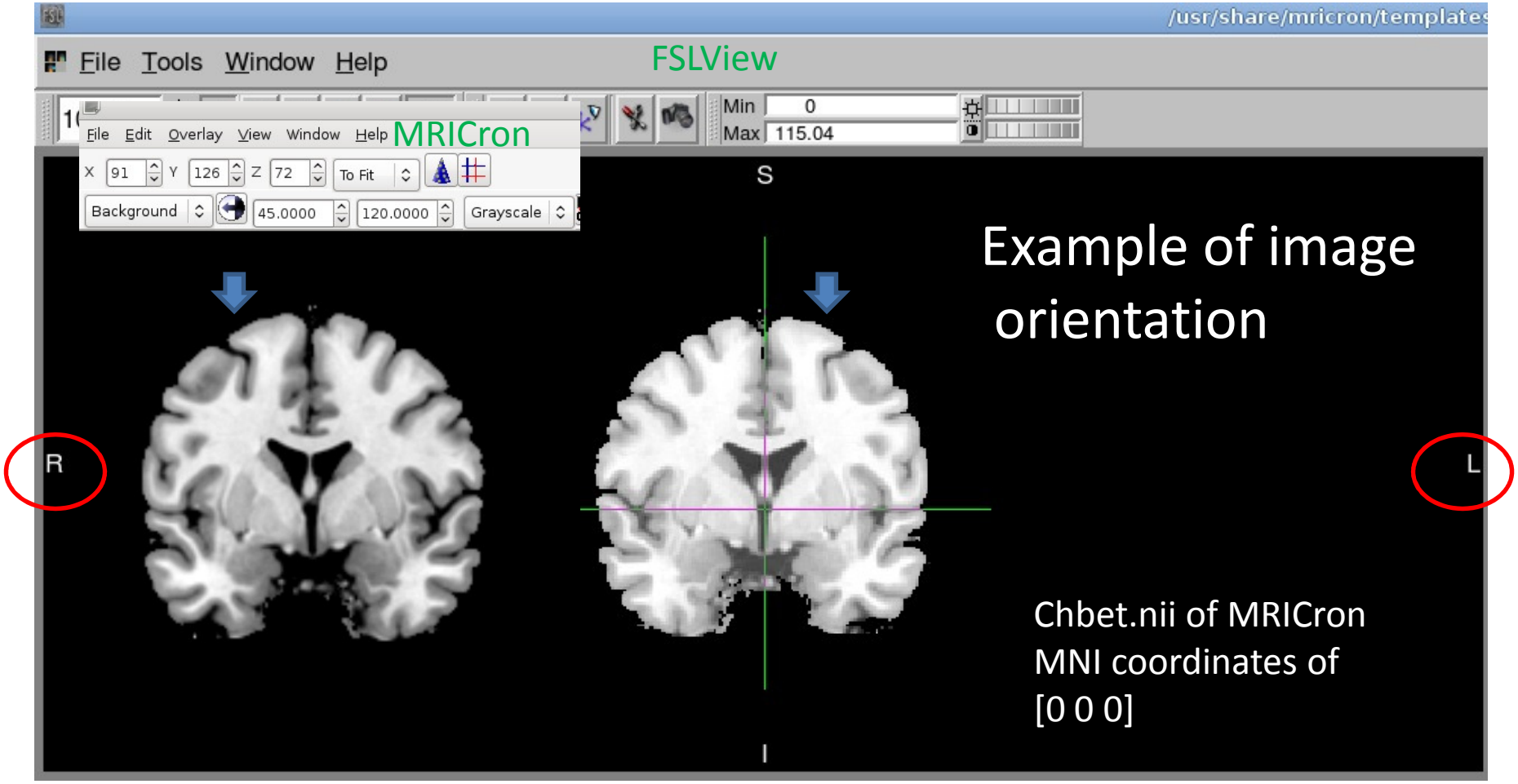


Inferior

Right<----------->Left

%A coronal slice and its flipped coronal slice. Left-Right versus Right-Left.

>>coronal_img=imagesc(flipud(transpose(permute(brainimg(:,35,:), [1 3 2]))));
>>flipped_coronal_img=imagesc(fliplr(flipud(transpose(permute(brainimg(:,35,:), [1 3 2])))));
% You can make a **mirror-reversed** image using the function of fliplr().
>>saveas(coronal_img,'coronal_img.jpg','jpg')
>>saveas(flipped_coronal_img,'flipped_coronal_img.jpg','jpg')



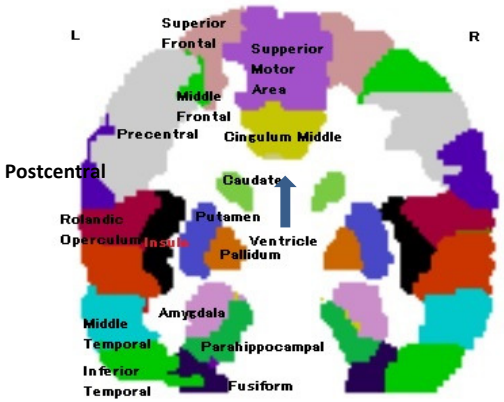
Some applications use the system of radiological left-right, while the others the neurological.
Compare the two images of the identical slice of an identical brain template image.

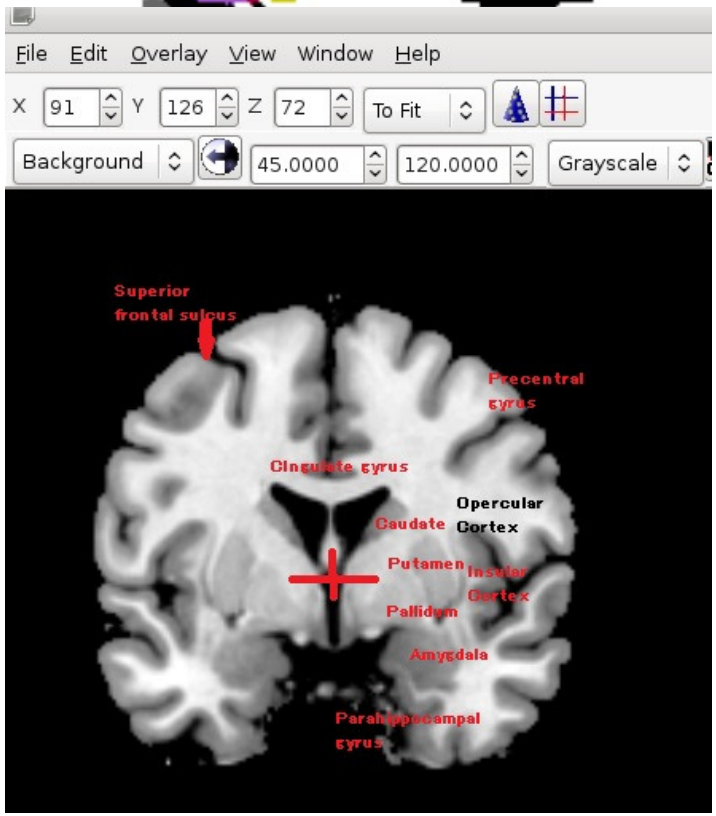
Left: MRIcron (Radiological)

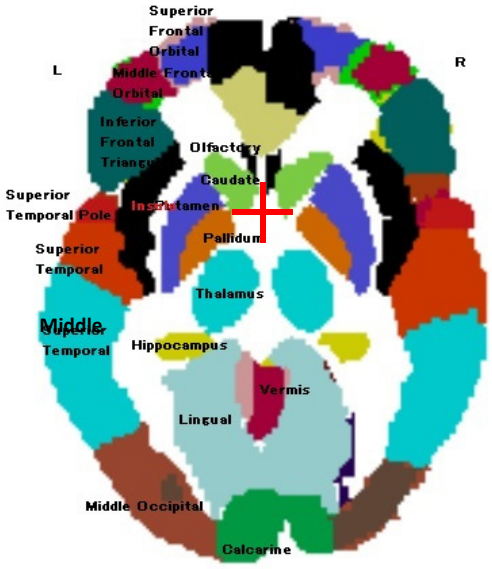
Right: FSLview (Neurological)->You must pay attention to

Radiological vs neurological conventions adopted by your software

Structure in the middle of the hemispheres



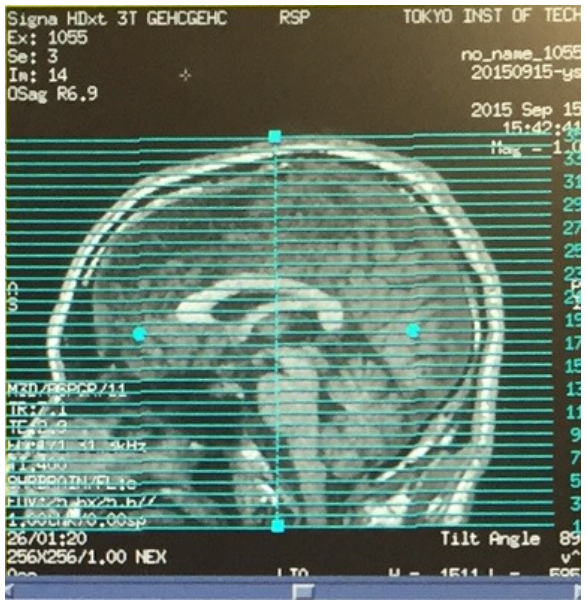




- Anatomical Labeling
- There are various ways of identifying the brain regions.
- This example is based on AAL (Automated Anatomical Labeling) by N. Tzourio-Mazoyer et al., 2002
- Using MRICron (MNI position: 0 0 0)

Anatomical labeling(1)

- Anatomical labeling is probabilistically determined.
- For example the anatomical labels of
- the coordinated [0,0,0] in the MNI brain (standard brains from the Montreal Neurological Institute)
  - Very close to the Anterior Commissure (AC; 前交連; a bundle of nerve fibers (white matter), connecting the two cerebral hemispheres across the midline--Wikipedia)
- Are, according to the atlas information from FSView
  - Harvard-Oxford Subcortical Structural Atlas
    - 13% Left Cerebral White Matter, 8% Right Cerebral White Matter, 3% Left Thalamus, 2% Right Thalamus, 1% Left Lateral Ventrical
  - Juelich Histological Atlas
    - 57% WM Fornix (脳弓)
  - MNI Structural Atlas
    - 1% Thalamus
  - Oxford Thalamic Connectivity Probability Atlas
    - No label found!
  - Talairach Daemon Labels
    - Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*



Slices almost parallel to AC-PC

T1 image scanned at Tokyo Tech

PC: Posterior Commissure;後交連;posterior band of white fibers

Anatomical Labeling(2)

- Brodmann's areas
  - https://en.wikipedia.org/wiki/Brodmann_area
- Brodmann in 1909 divided the cerebral cortex into 47 regions based on the cytoarchitectonic (細胞構築上の) differences.
  - Layers above and below layer IV (there are six main layers characterizing the neurons of the cerebral cortex)(6層構造のうち第4)
  - Cell size
  - Packing characteristic

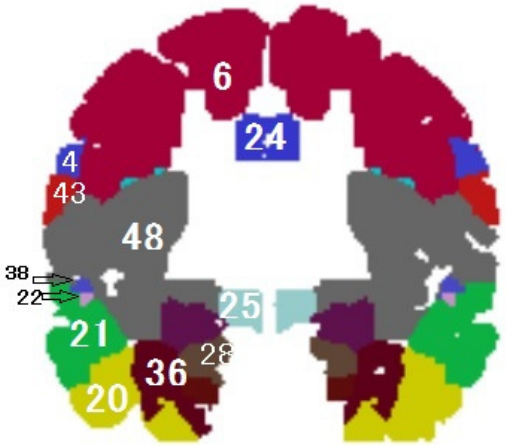
Figure will be here.

Layers of the cerebral cortex

https://en.wikipedia.org/wiki/Cerebral_cortex#/media/File:Gray754.png

Cf. E. Kandel et al., p.347

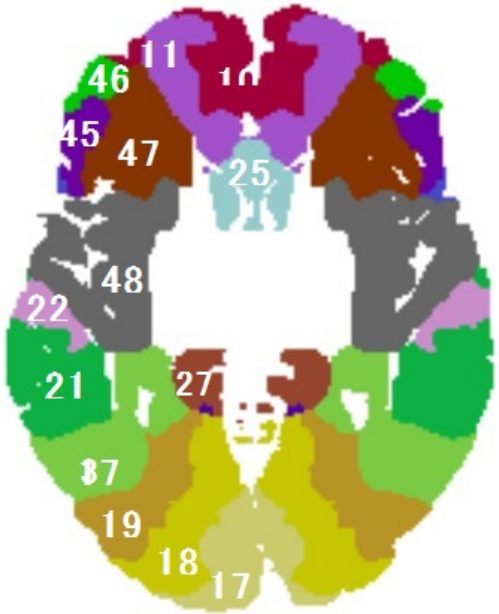
Some regions of interest (ROI) around AC



The image file brodmann.nii.gz displayed by MRICron

From Wikipedia

https://en.wikipedia.org/wiki/Brodmann_area



Area 4 – Primary Motor Cortex
Area 6 – Premotor cortex and Supplementary Motor Cortex (Secondary Motor Cortex)(Supplementary motor area)
Area 10 – Anterior prefrontal cortex (most rostral part of superior and middle frontal gyri)
Area 11 – Orbitofrontal area (orbital and rectus gyri, plus part of the rostral part of the superior frontal gyrus)
Area 17 – Primary visual cortex (V1)
Area 18 – Secondary visual cortex (V2)
Area 19 – Associative visual cortex (V3,V4,V5)
Area 21 – Middle temporal gyrus
Area 22 – Superior temporal gyrus, of which the caudal part is usually considered to contain the Wernicke's area
Area 24 – Ventral anterior cingulate cortex
Area 25 – Subgenual area (part of the Ventromedial prefrontal cortex)
Area 27 – Piriform cortex
Area 28 – Ventral entorhinal cortex
Area 36 – Ectorhinal area, now part of the perirhinal cortex (in the rhinal sulcus)
Area 37 – Fusiform gyrus
Area 38 – Temporopolar area (most rostral part of the superior and middle temporal gyri)
Area 43 – Primary gustatory cortex
(Area 44 – Pars opercularis, part of the inferior frontal gyrus and part of Broca's area)
Area 45 – Pars triangularis, part of the inferior frontal gyrus and part of Broca's area
Area 46 – Dorsolateral prefrontal cortex
Area 47 – Pars orbitalis, part of the inferior frontal gyrus
Area 48 – Retrosubicular area (a small part of the medial surface of the temporal lobe)

Some regions of interest (ROI) around AC

emphasizing here Basal ganglia (基底核) and Limbic system (辺縁系)

- Basal Ganglia(基底核)
  - nuclei strongly interconnected with the cerebral cortex(大脳皮質), thalamus(視床), and brainstem(脳幹) etc;
  - involved in control of voluntary motor movements, procedural learning, routine behaviors, eye movements, cognition and emotion (Wikipedia).
  - Striatum(線条体)
    - A subcortical part of the forebrain and a critical component of the reward system
      - Dorsal striatum (背側線条体)
        - Caudate nucleus (尾状核)
          - responsible largely for voluntary movement, learning, memory, sleep, and social behavior. (Wikipedia).
        - Putamen (被核)
          - regulates movements and influence various types of learning (Wikipedia).

ROI (region of interest) for the bilingual brain!

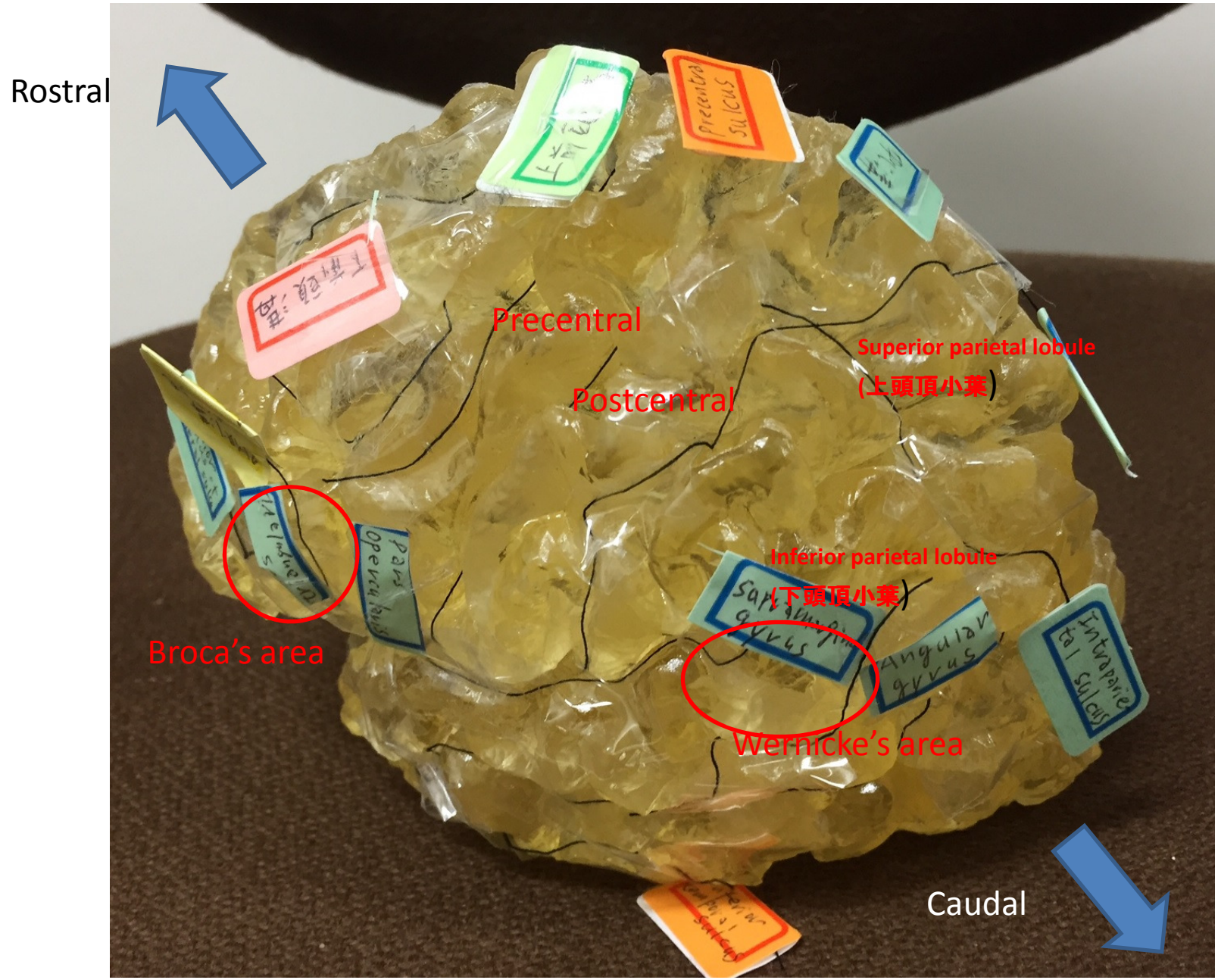
  - Globus pallidus (Pallidum)(淡蒼球)
    - Major component of Basal Ganglia
    - involved in the regulation of voluntary movement

From Eric R. Kandel et at., Principles of Neural Science Figure of the coronal slice close to [0 0 0] of the MNI

Limbic system (辺縁系)

- A complex set of brain structures located on both sides of the thalamus, right under the cerebrum.
- the olfactory bulbs(嗅球), hippocampus(海馬), amygdala(扁桃体), mammillary body(乳頭体), cingulate gyrus (帯状回), parahippocampal gyrus(海馬傍回), etc.
- associated with emotional and motivational processes.
- Cingulate cortex(帯状皮質)
  - Anterior cingulate cortex (ACC); frontal part ; rational cognitive functions, such as reward anticipation, decision-making, empathy, impulse control, and emotion (Wikipedia).
  - Posterior cingulate cortex (PCC): backmost part, sorrounded by the retrosplenial cortex (脳梁膨大後部皮質)and the precuneus(楔前部); important node of Default Mode Network (DMN)
- Amygdala(扁桃体): Pain area

Language Areas



Language Areas

- Broca's area(ブロカ野)
- Area for speech production
  - Broca's Aphasia(ブロカ失語) (expressive)
  - In 1861 Paul Broca described a patient, Lebrogne, who could not speak although he could understand language (motor deficits of the tongue).
- Left precentral (左中心前回) dominant.
- Brodmann's cytoarchitectonic map (areas 44 and 45)
- Pars triangularis (三角部, BA45) and pars opercularis(弁蓋部, BA44) of the inferior frontal gyrus (下頭頂回).
- Recent finding; considerably involved in language comprehension (not only in motor control for utterance).
- Cf. E. Kandel et al., p.11 and Wikipedia

- Wernicke's area(ウェルニッケ野)
- Area for language comprehension
  - Wernicke's Aphasia (ウェルニッケ失語) (receptive)
  - Wernicke's patient could form words but could not understand language.
  - The lesion found in the posterior part of the cortex where the temporal lobe meets the parietal and occipital lobes.
- Brodmann's cytoarchitectonic map (BA 22)
- Part of the superior temporal gyrus (上側頭回)(near the lateral sulcus and above the superior temporal sulcus), which is close to the inferior parietal lobule (下頭頂小葉)(region beneath the intraparietal sulcus(頭頂間溝))
- Connected to Broca's area by by a bundle of axons arcuate fasciculus(弓状束), which is a part of superior longitudinal fasciculus (上縦束)

Some regions of interest for language

- Pars opercularis (弁蓋部) (BA 44)
  - Region of Inferior frontal gyrus (下前頭回)
  - located between the lower part of Precentral sulcus (中心前溝) and the ascending ramus of lateral sulcus (aca sylvian fissure) (外側溝上行枝)
  - an operculum (Latin, meaning "little lid (蓋)") to cover the insula (島)
  - responsible for the motor (executive) control of the vocal organ (due to the closeness to the motor area)
- Pars triangularis (三角部)(BA45)
  - Region of Inferior frontal gyrus (下前頭回)
  - Circumscribed by Inferior frontal sulcus (下前頭溝), Anterior ramus of lateral sulcus (外側溝前水平枝) and the ascending ramus of lateral sulcus (aca sylvian fissure) (外側溝上行枝)
  - Thought as responsible for various factors of language process

Cf. E. Kandel et al. and Wikipedia

Major regions of interest for language

- Supramarginal gyrus(縁上回)(BA40)
  - Part of the inferior parietal lobule (下頭頂小葉) with the Angular gyrus; Subregion of the parietal lobe, circumscribing (beneath the intraparietal sulcus) the ascending ramus of the lateral sulcus (外側溝の上行枝)
  - engaged in language perception and processing as a part of Wernicke's area.
  - somatosensory association cortex (体性感覚連合皮質) involved in the interpretation of space through the tactile sense.
  - also involved in identifying postures and gestures of other people->locus for communication: empathy and sympathy toward the others->**mirror system**
- Angular gyrus(角回)(BA39)
  - Part of the inferior parietal lobule (下頭頂小葉) with the supramaginal gyrus; subregion in the parietal lobe, that lies near the superior edge of the temporal lobe, and immediately posterior to the supramarginal gyrus
  - related to language (especially metaphor understanding), number processing and spatial cognition, memory retrieval, attention, and **theory of mind** (心の理論; the ability to understand the mental state of the others)

Cf. E. Kandel et al. and Wikipedia

Major regions of interest for language

Homunculus

http://willcov.com/bio-consciousness/diagrams/Homunculus%20(Topographic)%20Diagram.htm

- Primary motor cortex and its motor strip have been discussed with the metaphor of **Homunculus**
  - Somatotopic representation of the different body parts in an arrangement called a motor homunculus (Latin: little person)(from Wikipedia)
- So Broca's area for speech production is close to the mouth area of the Homunculus

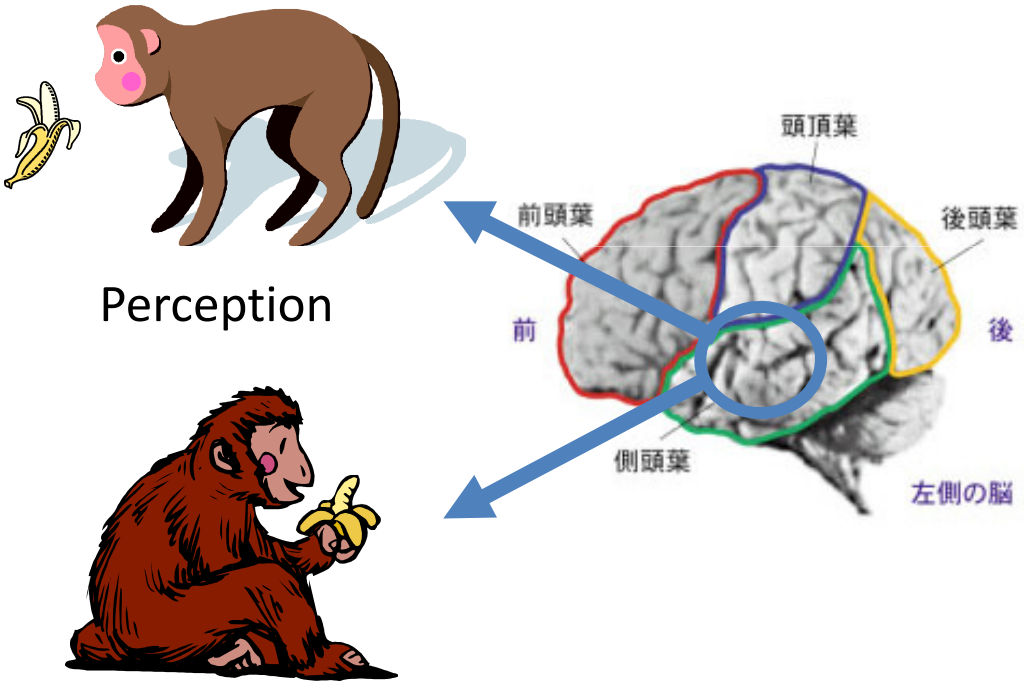
Figure will be here.

- Distributed representation or classic hodological (network) view of language processing in the brain (Kandel et al., p.11-12)
  - Wernicke's area processes auditory input coming from the primary auditory cortex (一次聴覚皮質).
  - Angular gyrus (角回)combines auditory input and visual input from the visual cortex.
  - Broca's area controls intelligible speech production based on the information communicated by the arcuate fasciculus(弓状束).

From Eric R. Kandel et at., Principles of Neural Science, p11. Figure1-4

Digression: Mirror System

Neurons for processing the motor action language ?



The neurons of the area F5 of macaque monkeys, motor systems for the goal-directed hand and mouth movement are also used in action perception.

Gallese , V., Fadiga, L., Fogassi, L., & Rizzolatti, G.. 1996. Action recognition in the premotor cortex. Brain 119: 593-609.

Digression: Mirror System

- A neuroanatomical theory about the special neurons proposed by Giacomo Rizzolatti, Vittorio Gallese and the others at the University of Parma, Italy.
- A group of neurons responsible for both the observation and the execution of identical muscular efforts
- Similarity between the area F5 of macaque monkeys and the Broca's area of the humans in spite of the difference in effector（even though the former is related to the hands, the latter to the mouth.）
- The meaning shared by the language is rooted in the perception and the observation of physical activities →Simulation Semantics
- The thought (the imagery) of objects (equivalent simulation) are sufficient for evoking the activation of the relevant motor system necessary for the real scenes of life.

Brain Mapping in line with the mirror system?

- When observing a human effort to ***grasp*** something : Activation of the superior temporal sulcus (上側頭溝) and the posterior part of the inferior frontal gyrus（下前頭回-ブロカの領域）?
- Superior temporal sulcus上側頭溝 : Area in which there are some neurons responsive to the actions executed by the various parts of a body→Similor to F5 ?
- Inferior frontal gyrus下前頭回→Speech area (Broca's Area) similor to F5?
- Can the oral pronunciation and the manual gesture be defined by embryologically identical origins?

To be continued.