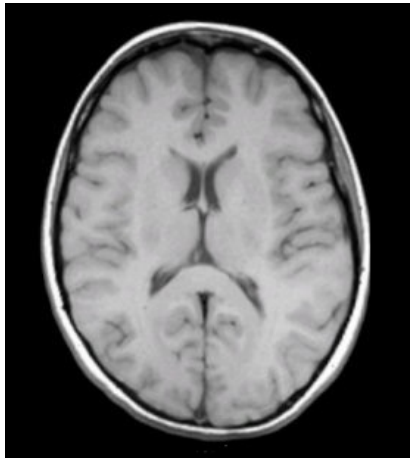
Medical/Bio Research Topics Ⅰ : Week 02 (10.03.2023)

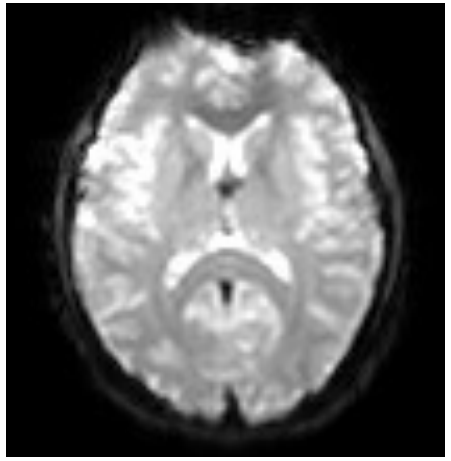
General introduction of brain imaging
(뇌영상 소개)

Brain Imaging

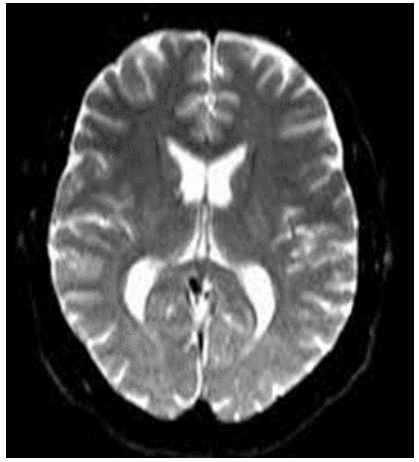
CT



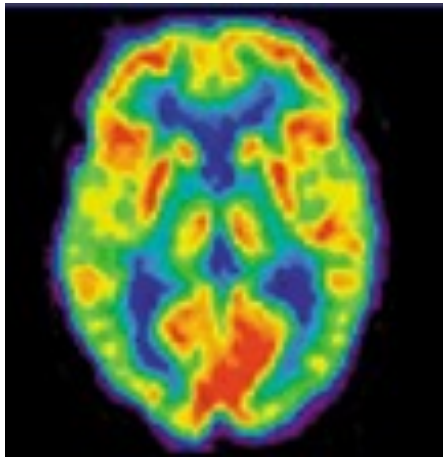
Structural MRI



Functional MRI



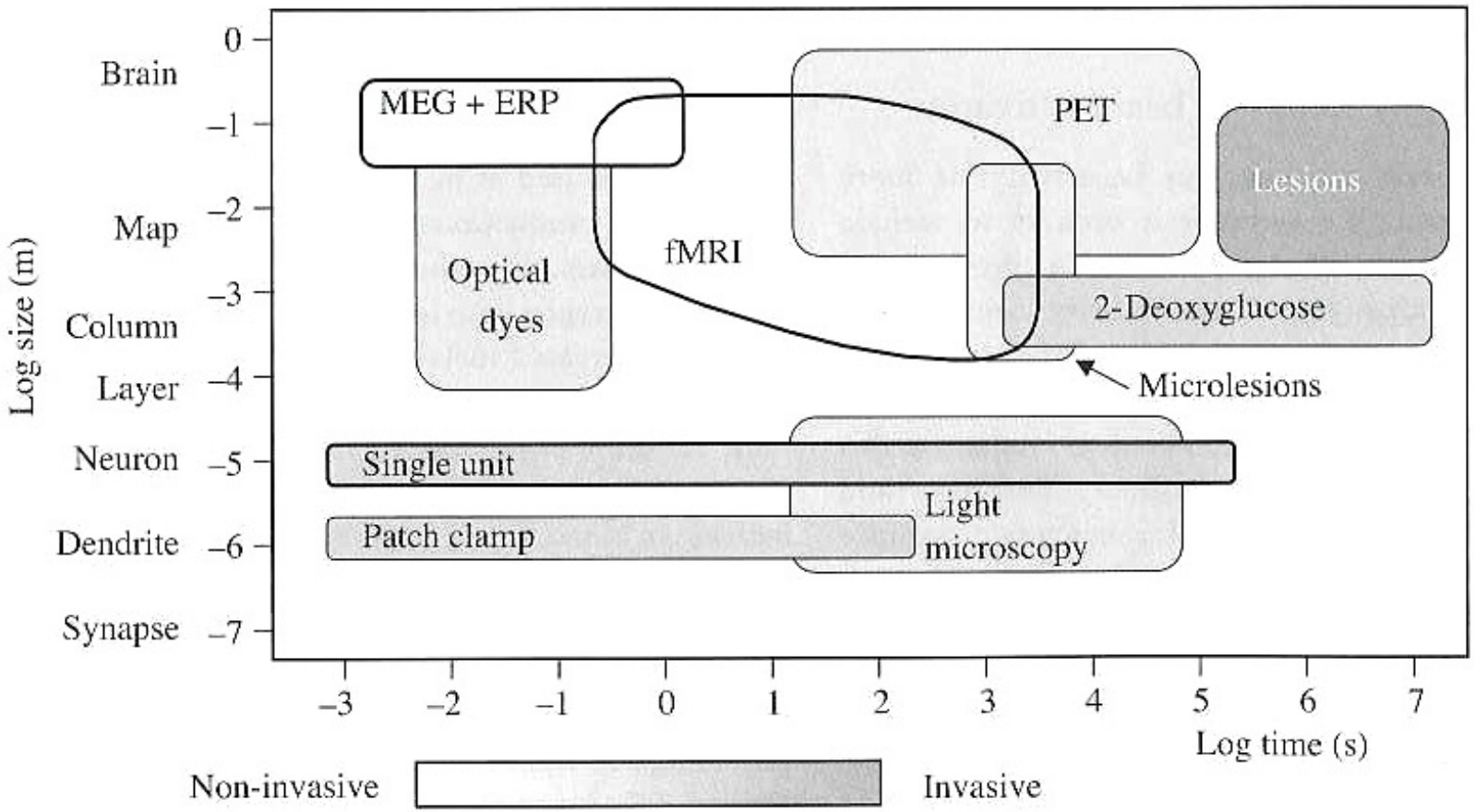
Diffusion-weighted MRI



PET

CT, Computed Tomography (컴퓨터단층촬영)
MRI, Magnetic Resonance Imaging (자기공명영상)
PET, Positron Emission Tomography (양전자방출단층촬영)

- Various techniques for imaging the structure or function of the brain
  - Computed Tomography (CT)
  - Magnetic Resonance Imaging (MRI)
    - Structural MRI (sMRI)
    - Functional MRI (fMRI)
    - Diffusion-weighted MRI (dMRI)
  - Positron Emission Tomography (PET)

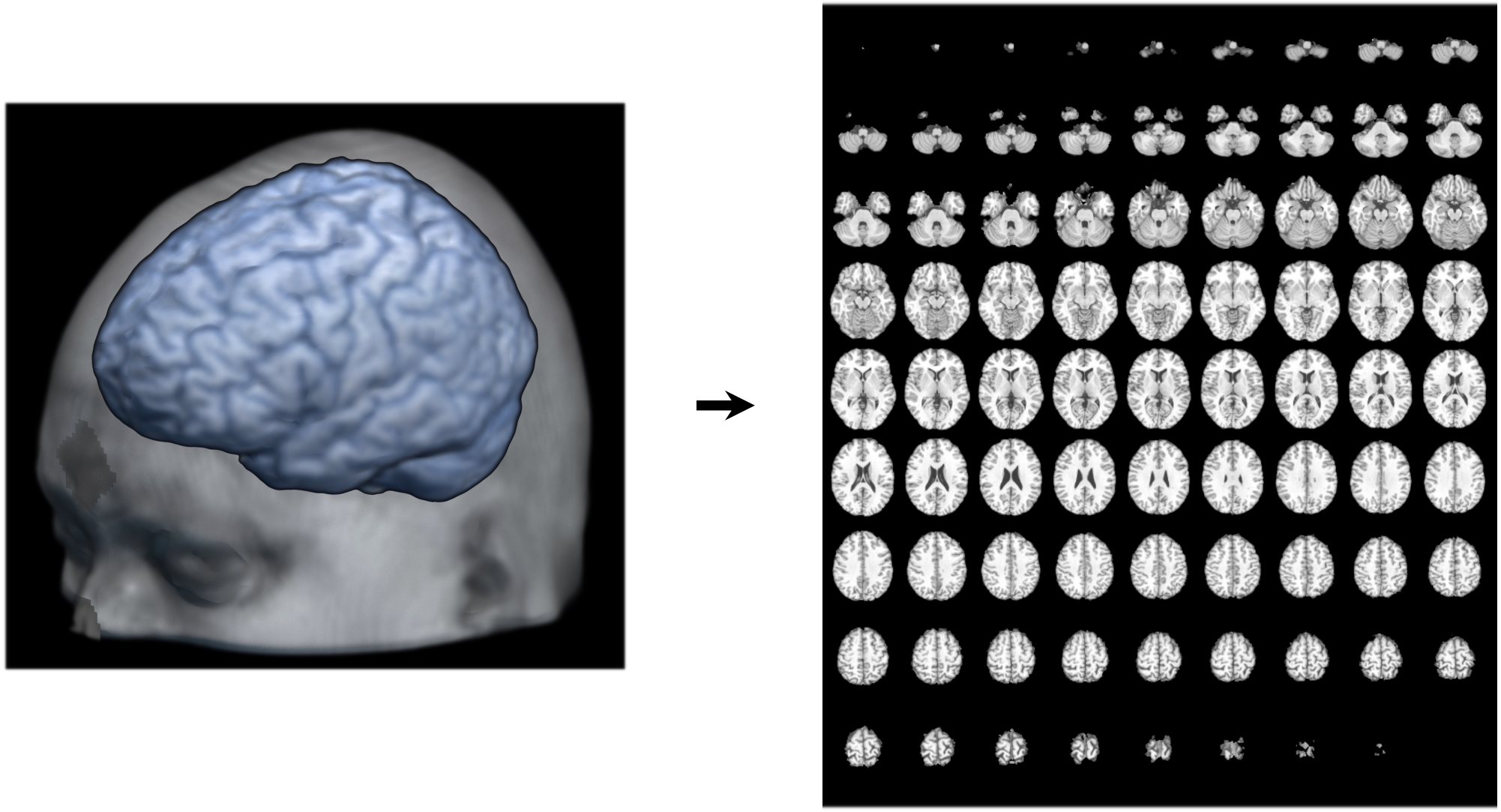


[Churchland and Sejnowski, 1988]

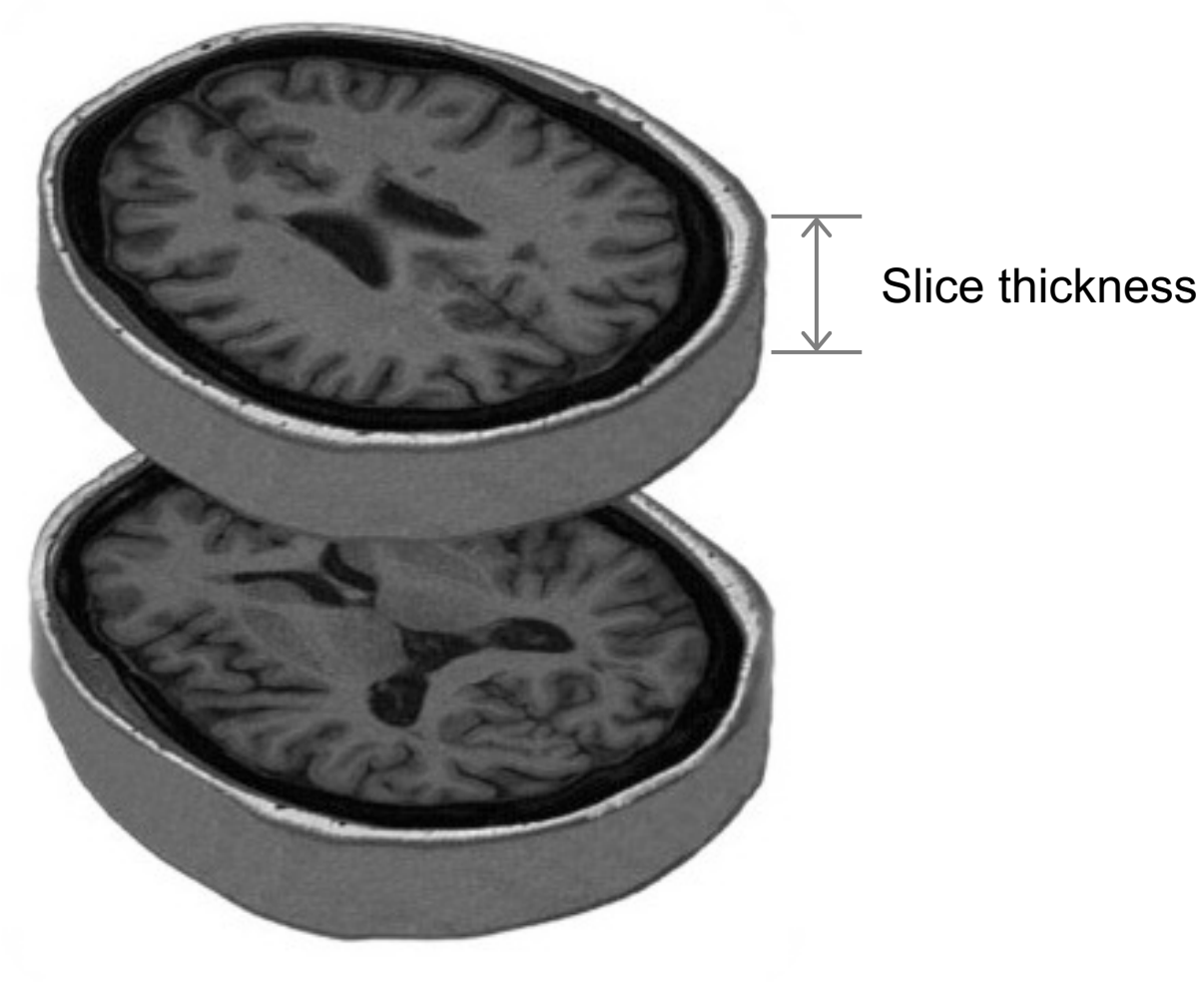
Neuroscience methods

Brain Imaging Data

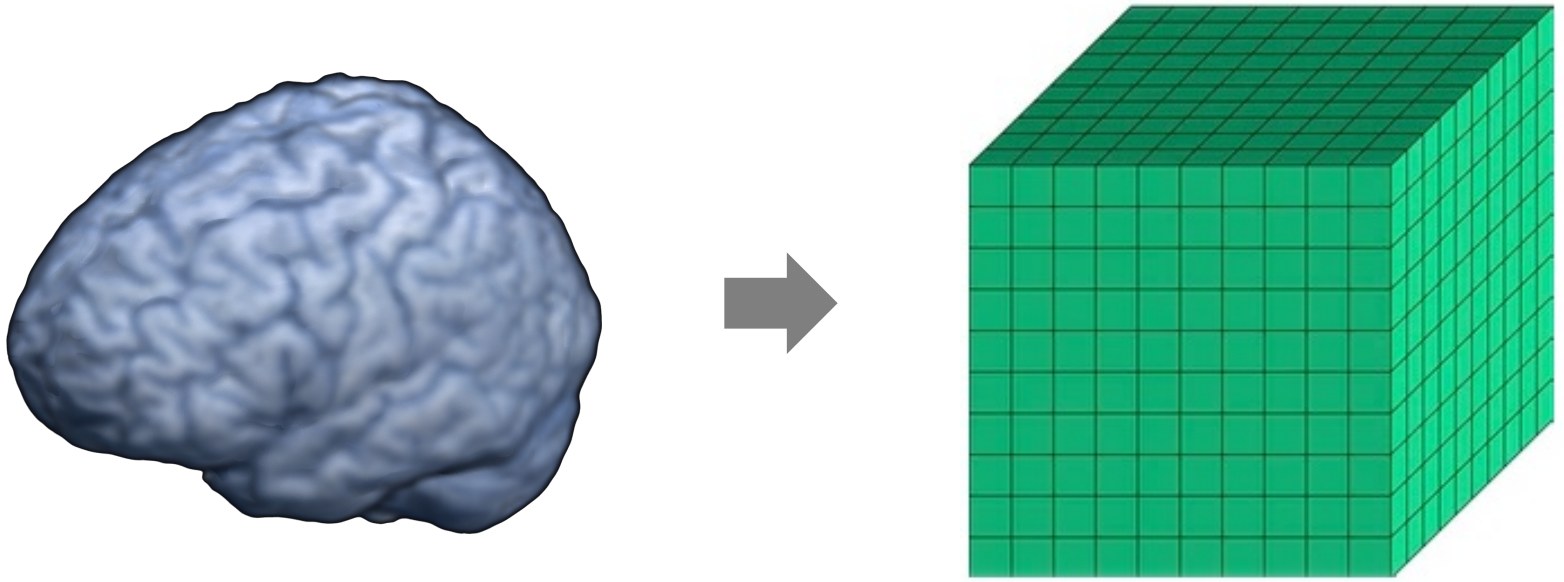
- Volumetric description of the brain as a 3D array [Larobina and Murino, 2014]
  - Representation of the structure or function of the brain in the form of an array of voxels
  - Discrete representation resulting from a sampling/reconstruction process that maps numerical values to positions of the space



Brain volume as a series of slices in a stack



Slice with thickness



Brain volumetric data as a 3D array

Image File Format

- Provides a standardized way to store the information describing an image in a computer file [Larobina and Murino, 2014]
  - How image data are organized inside an image file
  - How image data should be interpreted by a software for the correct loading and visualization

- Basic concepts common to all image file formats
  - Voxel depth: number of bits used to encode the information of each voxel
    - Integer, real number, or complex number in different bits
  - Photometric interpretation: how image data should be interpreted for the correct image display as a monochrome or color image
    - Samples per voxel: number of channels
    - MRI data has a gray scale photometric interpretation

- Metadata: information that describe an image
  - Typically stored at the beginning of the file as a header
  - Contains at least image matrix dimensions, spatial resolution, voxel depth, and photometric interpretation
  - Enables a software to recognize and correctly open an image in a supported file format
  - Tool to annotate and exploit image-related information for clinical and research purposes
- Image data: section where numerical values of voxels are stored
  - Usually stored as integers or floating-point numbers using the minimum number of bytes required to represent values according to a designated data type

- Image file size = header size + image data size
  - Metadata and image data may be contained in a single file or in separate files
- Major file formats currently used in brain imaging
  - Intended to standardize images generated by diagnostic modalities
    - Digital Imaging and Communications in Medicine (DICOM)
  - Aimed to facilitate and strengthen post-processing analysis
    - Analyze
    - Neuroimaging Informatics Technology Initiative (NIfTI)

Format	Header	Extension	Data types
Analyze	Fixed-length: 348 byte binary format	.img and .hdr	Unsigned integer (8-bit), signed integer (16-, 32-bit), float (32-, 64-bit), complex (64-bit)
Nifti	Fixed-length: 352 byte binary format[a] (348 byte in the case of data stored as .img and .hdr)	.nii	Signed and unsigned integer (from 8- to 64-bit), float (from 32- to 128-bit), complex (from 64- to 256-bit)
Minc	Extensible binary format	.mnc	Signed and unsigned integer (from 8- to 32-bit), float (32-, 64-bit), complex (32-, 64-bit)
Dicom	Variable length binary format	.dcm	Signed and unsigned integer, (8-, 16-bit; 32-bit only allowed for radiotherapy dose), float not supported

[Larobina and Murino, 2014]

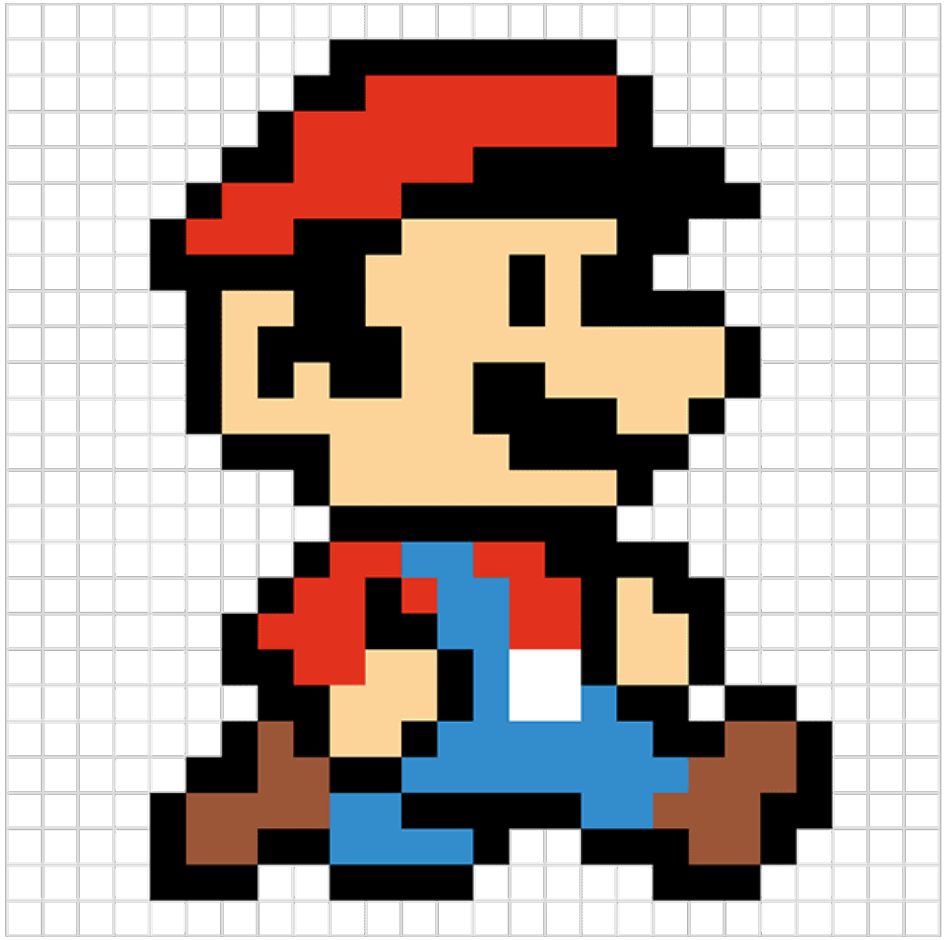
Characteristics of image file formats

- DICOM
  - Not only a file format but also a network communication protocol
  - Established by the American College of Radiology and the National Electric Manufacturers Association
  - Introduced to imaging departments at the end of 1990s
  - Today, the backbone of every medical imaging department
  - Contains the most complete description of the entire procedure used to generate an image, such as acquisition protocol, scanning parameters, and patient information, in the header
  - Can only store voxel values as integers

- NIfTI
  - Created at the beginning of 2000s by a committee based at the National Institutes of Health
  - Thought as a revised Analyze format
    - Can store new information like image orientation with the intent to avoid the left–right ambiguity
  - Typically saved as a single .nii file in which the header and image data are merged
    - The header has a size of 352 bytes in the case of a single .nii
  - Adopted as the default format by the most widespread public domain software packages

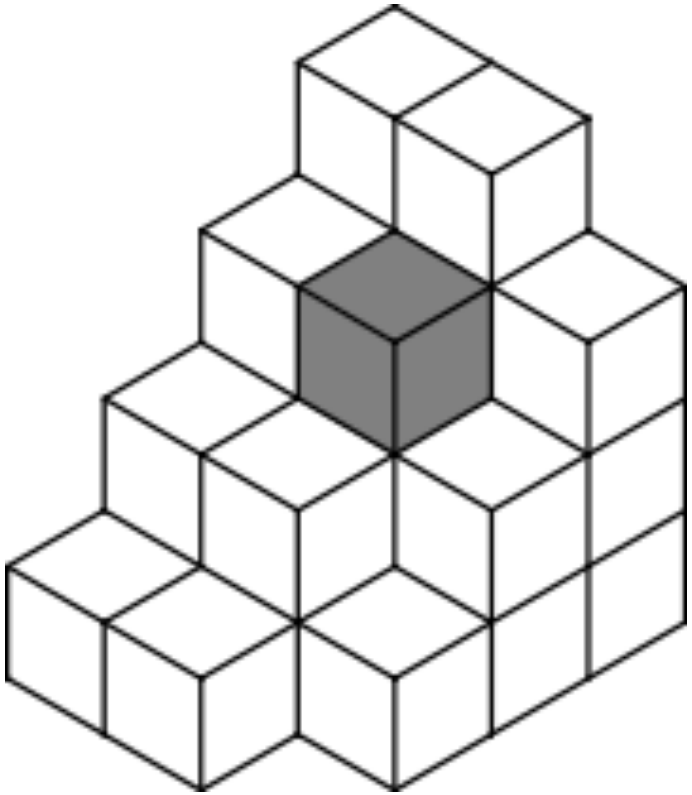
Voxel

- Volume element or volumetric pixel
  - Analogous to a pixel in 2D space



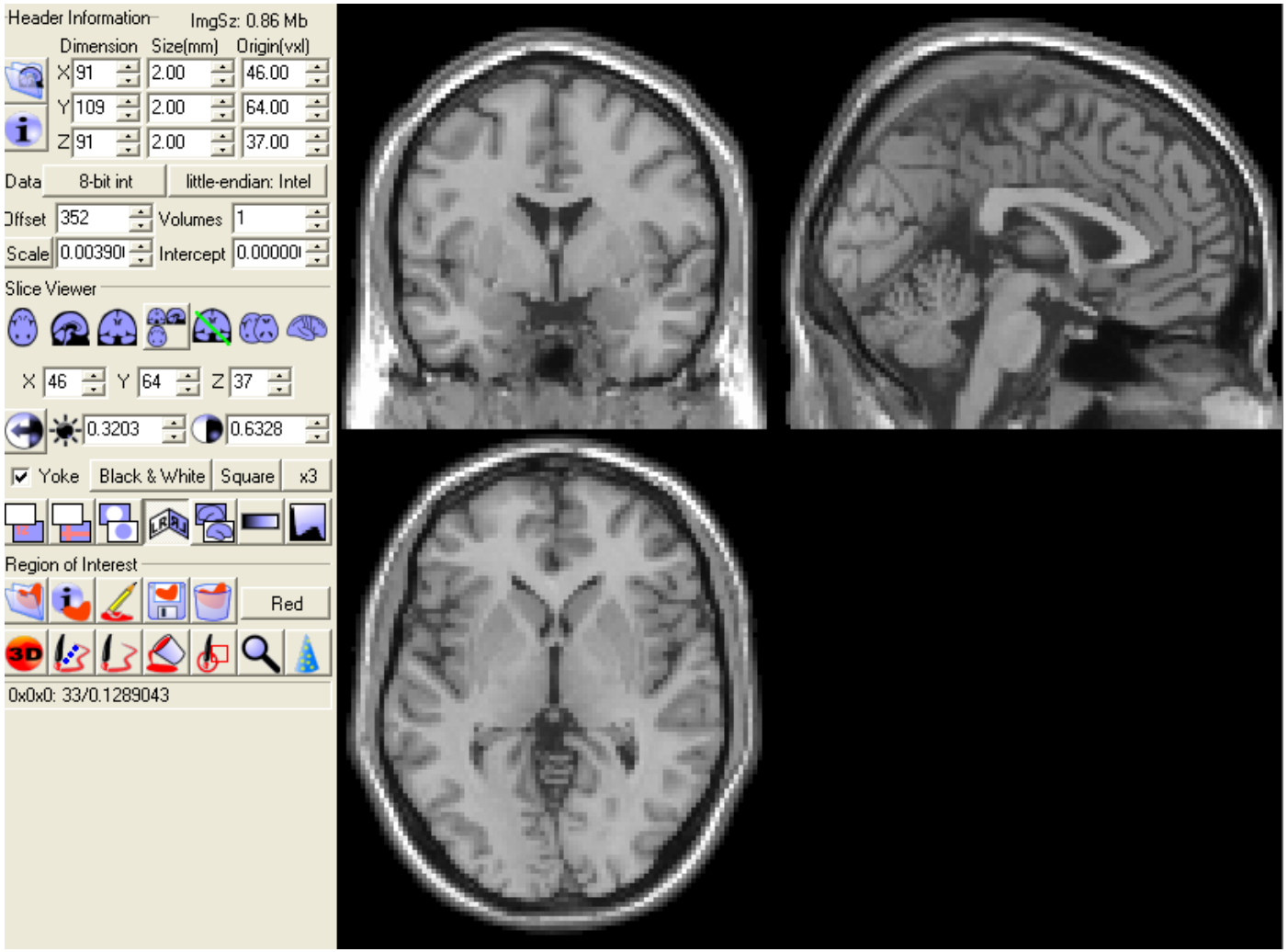
[https://easydrawingguides.com/how-to-draw-mario-pixel-art/]

2D raster image composed of pixels or picture elements



[https://en.wikipedia.org/wiki/Voxel]

Voxels representing regularly sampled spaces

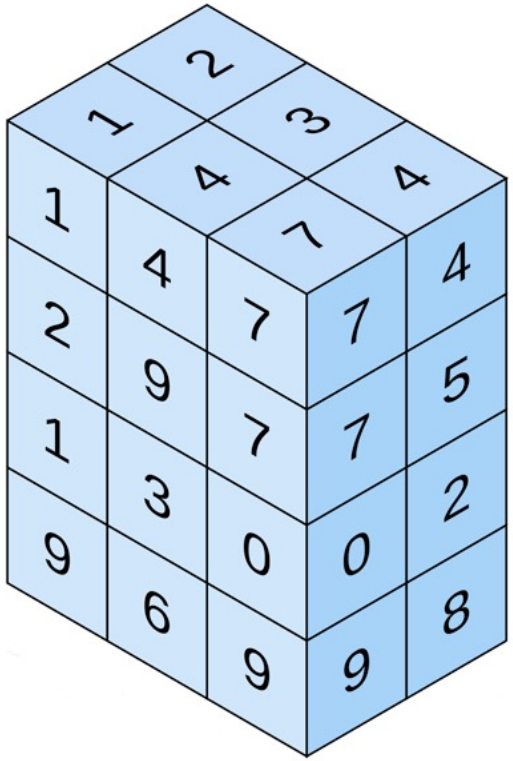


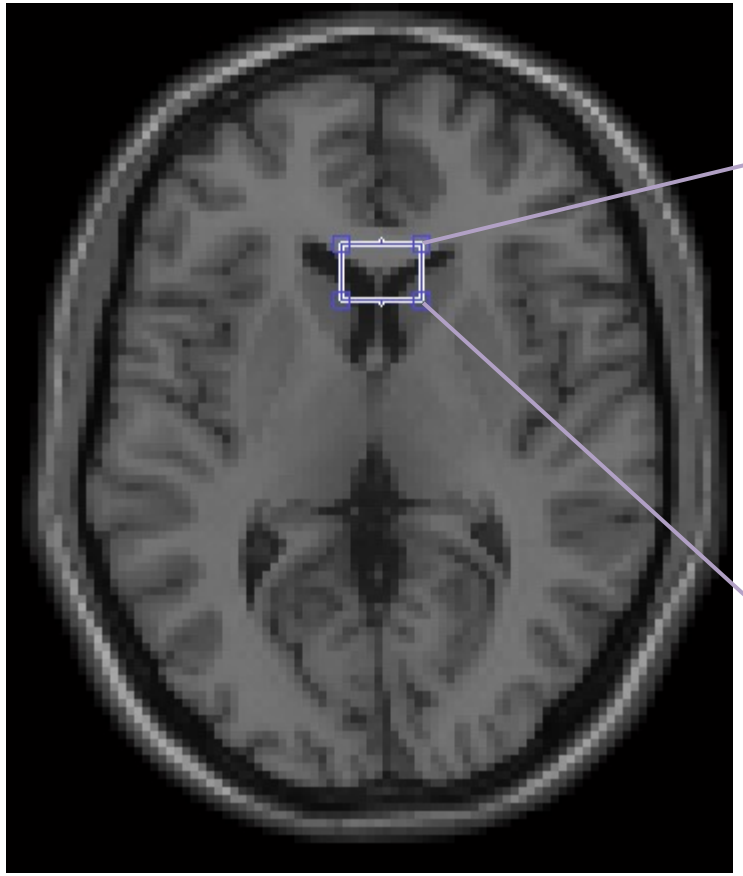
Dimensions: 91 × 109 × 91
Voxel depth: 8-bit integer
Voxel size: 2 mm × 2 mm × 2 mm
Origin: [46, 64, 37]

File size:
Header = 352 B
Image data = 91 × 109 × 91 × 8 bits
Total = 352 B + 902,629 B
= 902,981 B
= 0.86 MB

MRI image composed of voxels

- Represents a value on a regular grid in 3D space
  - Sub-volume box with a constant value inside

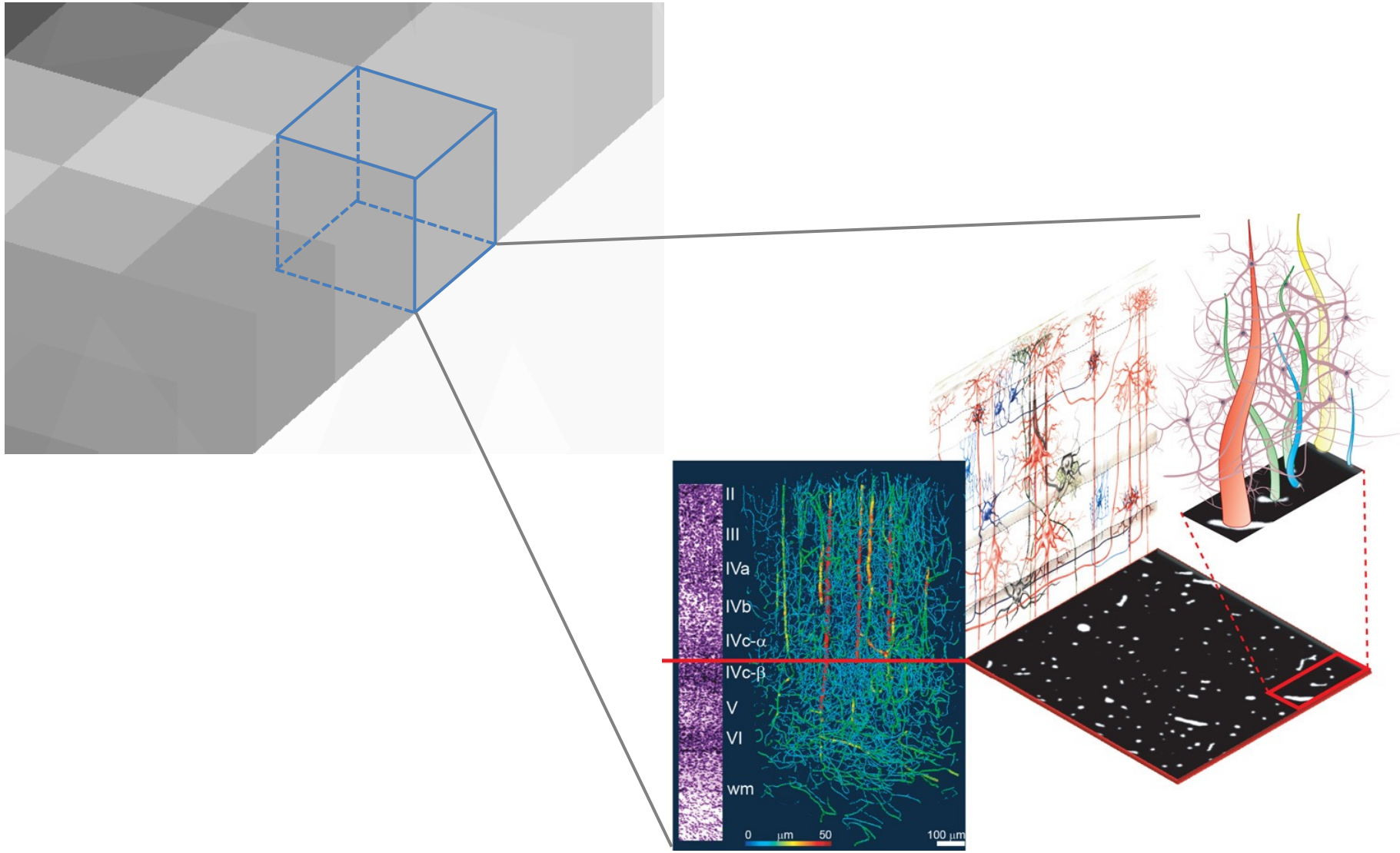




0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
0.41	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.44
0.16	0.28	0.40	0.45	0.45	0.43	0.43	0.41	0.29	0.15
0.12	0.12	0.17	0.33	0.29	0.37	0.24	0.13	0.12	0.13
0.12	0.11	0.12	0.15	0.31	0.18	0.11	0.11	0.17	0.31
0.18	0.12	0.11	0.11	0.27	0.11	0.11	0.14	0.31	0.33
0.32	0.12	0.11	0.11	0.22	0.11	0.11	0.24	0.32	0.33

Voxels representing values

- Typical fMRI voxel [Logothetis, 2008]
  - In-plane resolution: 2×2 mm^2 to 4×4 mm^2
  - Slice thickness: 3 mm to 7 mm
  - Occupied by:
    - Vessels for less than 3% of the volume
    - Neural elements for the rest
  - Contains:
    - 5.5 million neurons
    - 2.2 - 5.5 $\times$ 10^{10} synapses
    - 22 km of dendrites
    - 220 km of axons



[Logothetis, 2008]

Neural and vascular contents within a voxel

MRI Coordinate System

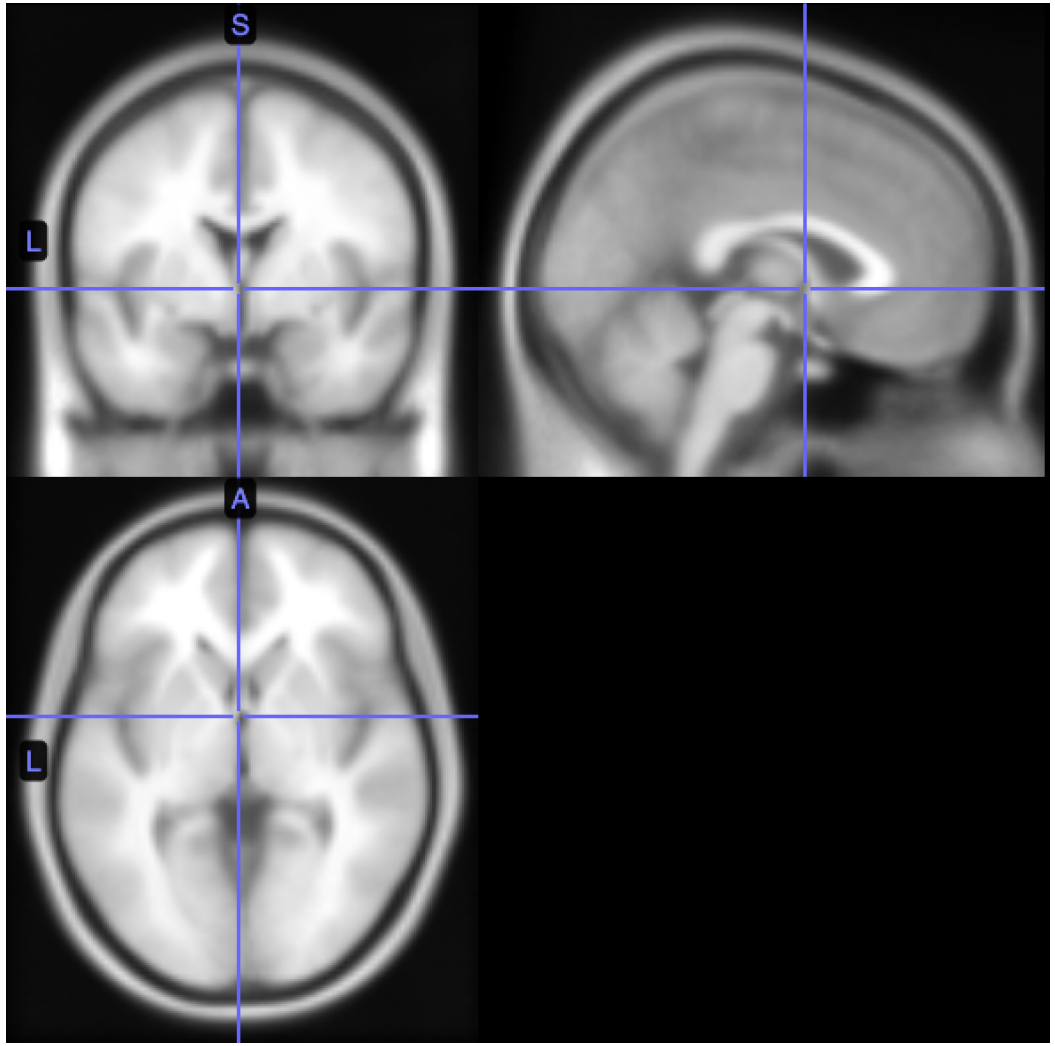
- Reference frame in a 3D space that assigns *x*, *y*, and *z* coordinates to anatomical regions [https://www.fieldtriptoolbox.org/faq/coordsys/]
  - What is the definition of the origin, *i.e.* [0, 0, 0]?
  - In which directions are the *X*-, *Y*- and *Z*-axis pointing?
  - In what units are coordinates expressed?
  - Is the geometry scaled to some template or atlas, or does it still match the individual's brain size?

system	units	orientation	origin	scaling	notes
ACPC	mm	RAS	anterior commissure	native, i.e., not normalized to a template	
Allen Institute	mm	RAS	Bregma point		
Analyze	mm	LAS		native	
BTi/4D	m	ALS	between the ears	native	
CTF MRI	mm	ALS	between the ears	native	voxel order can be arbitrary
CTF gradiometer	cm	ALS	between the ears	native	
CapTrak	mm	RAS	approximately between the ears		
Chieti ITAB	mm	RAS	between the ears	native	
DICOM	mm	LPS	centre of MRI gradient coil	native, see here	
EEGLAB	mm	ALS	between the ears	native	
FreeSurfer	mm	RAS	center of isotropic 1 mm 256x256x256 volume		
MNI	mm	RAS	anterior commissure	scaled to match averaged template	
NIfTI	mm	RAS		see here, search for "Orientation information".	
Neuromag/Elekta /Megin	m	RAS	between the ears	native	
Paxinos-Franklin	mm	RSP	Bregma point		
Scanner RAS (`scanras`)	mm	RAS	scanner origin	native	
Talairach-Tournoux	mm	RAS	anterior commissure	scaled to match atlas	
Yokogawa		ALS	center of device		

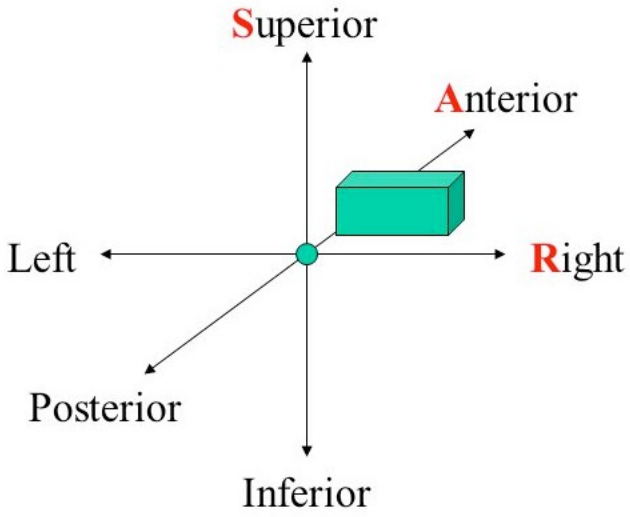
[https://www.fieldtriptoolbox.org/faq/coordsys/]

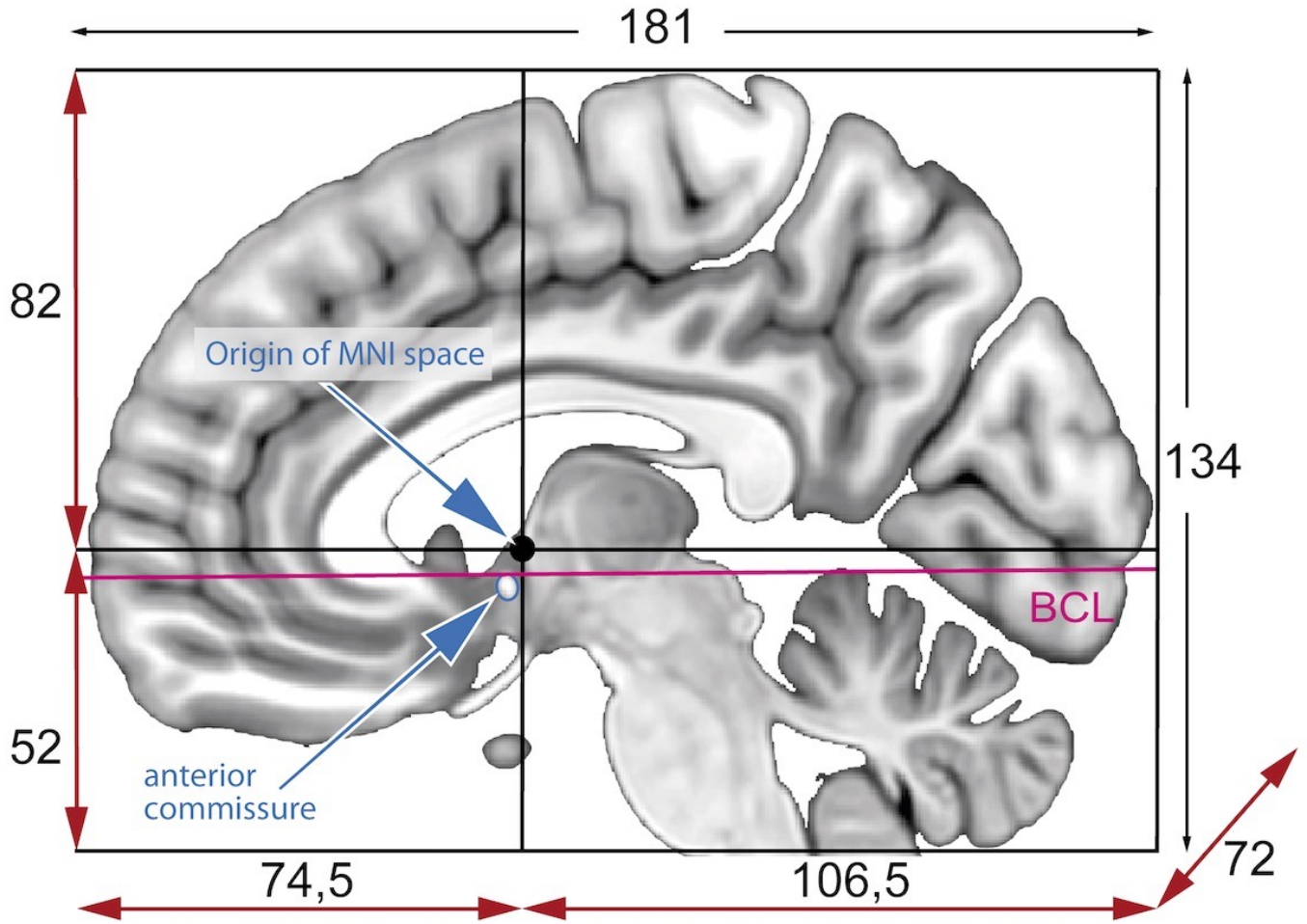
Different MRI coordinate systems

- Montreal Neurological Institute (MNI) coordinate system
  [https://www.fieldtriptoolbox.org/faq/coordsys/]
  - The origin is the anterior commissure
  - The *X*-axis points from left to right
  - The *Y*-axis points from posterior to anterior
  - The *Z*-axis points from inferior to superior
  - Used if the geometry is spatially warped to the MNI152 template brain (average of 152 T1-weighted MRI scans from young adults)



MNI152 template brain

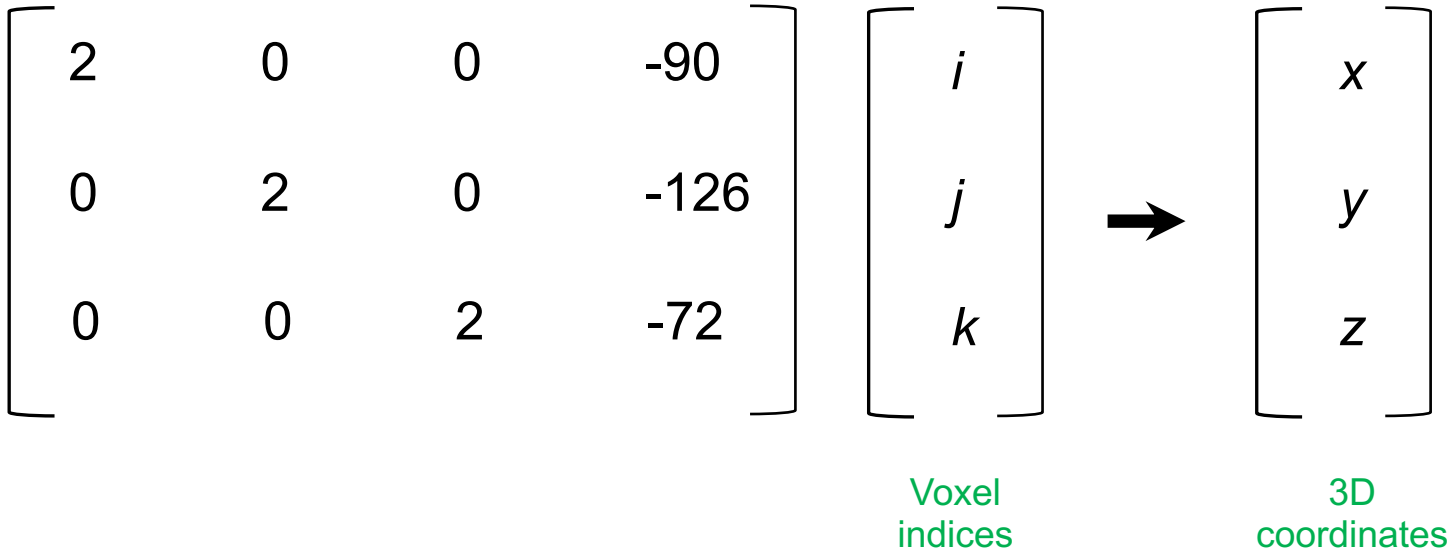




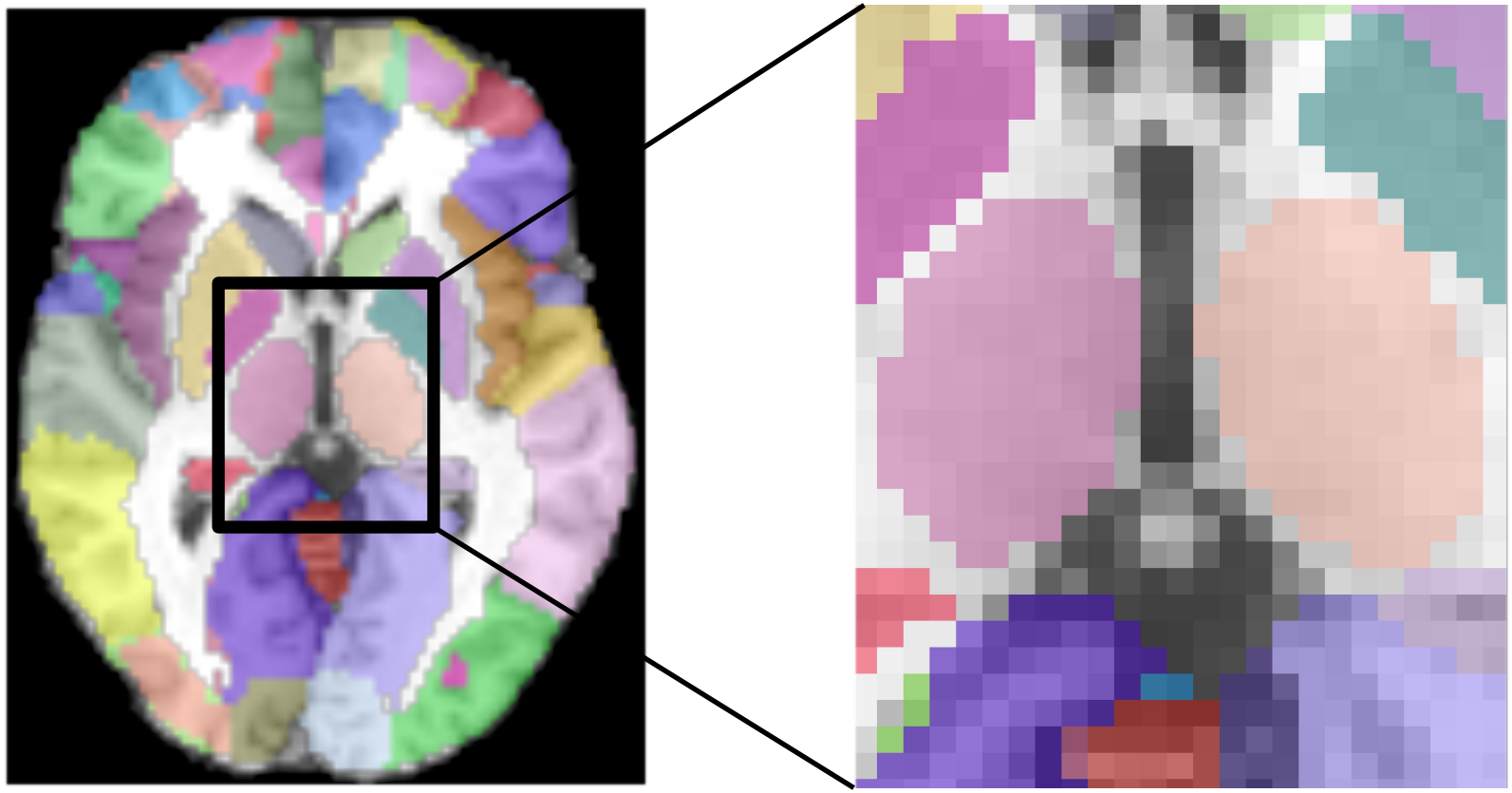
[https://carpentries-incubator.github.io/SDC-BIDS-sMRI/03-Image_Spatial_Normalization/index.html]

MNI coordinate system

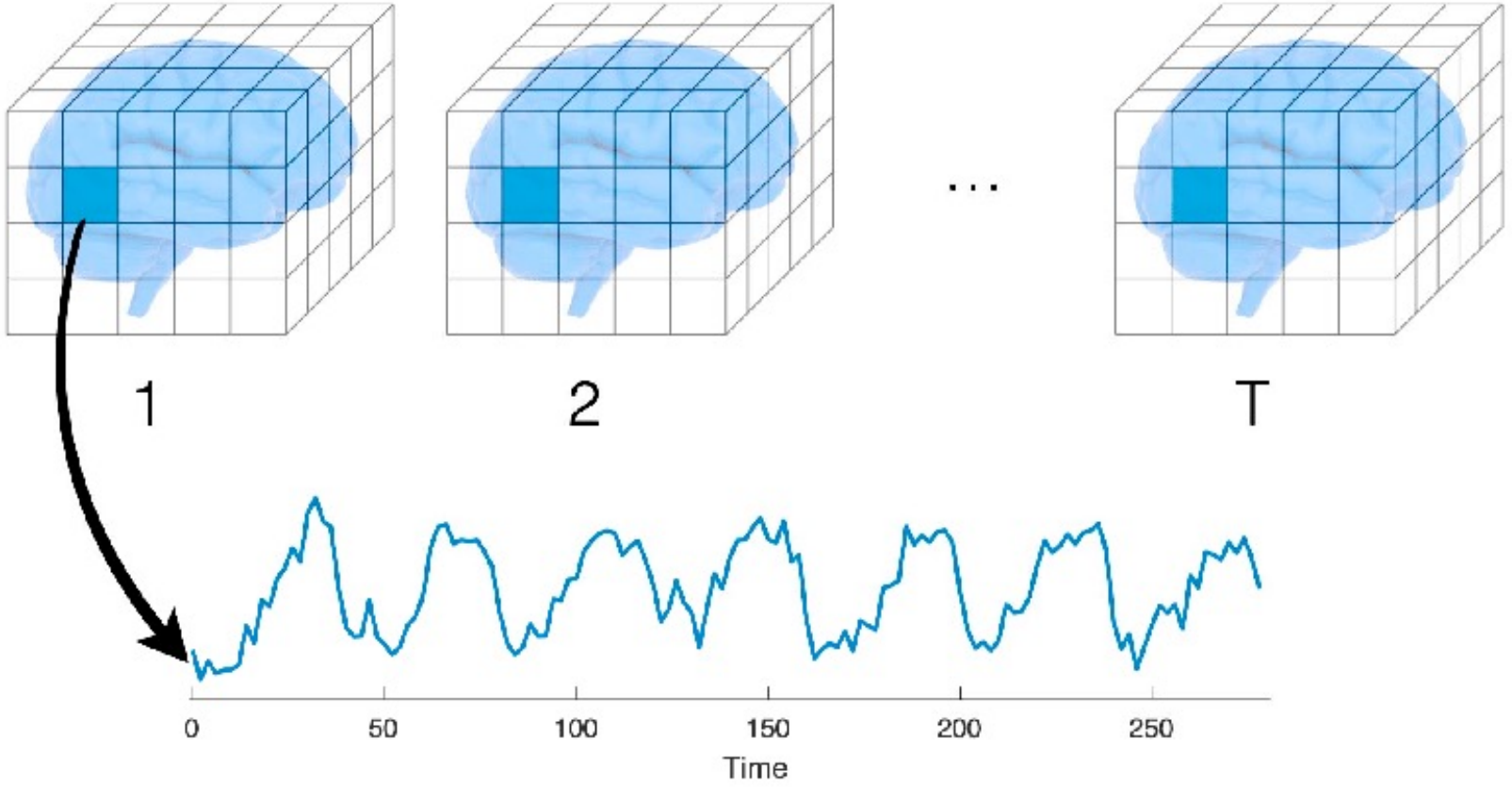
- Transformation matrix
  - Links array indices to 3D coordinates



- Usability of 3D coordinates
  - Identifying voxels corresponding to a specific brain region in terms of their 3D locations

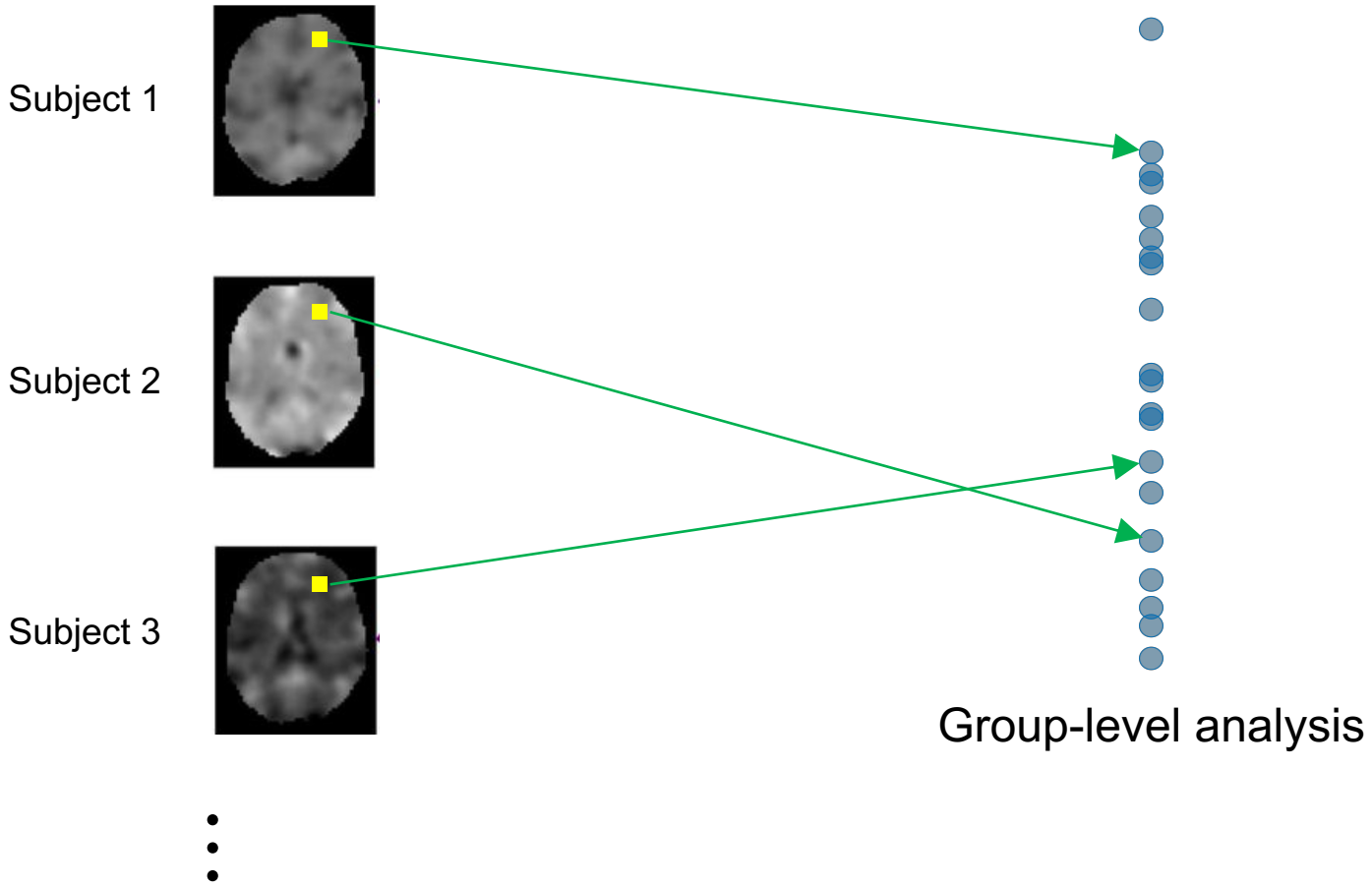


– Extracting a voxel timeseries from the same 3D location of a single subject's brain volumes across multiple time points



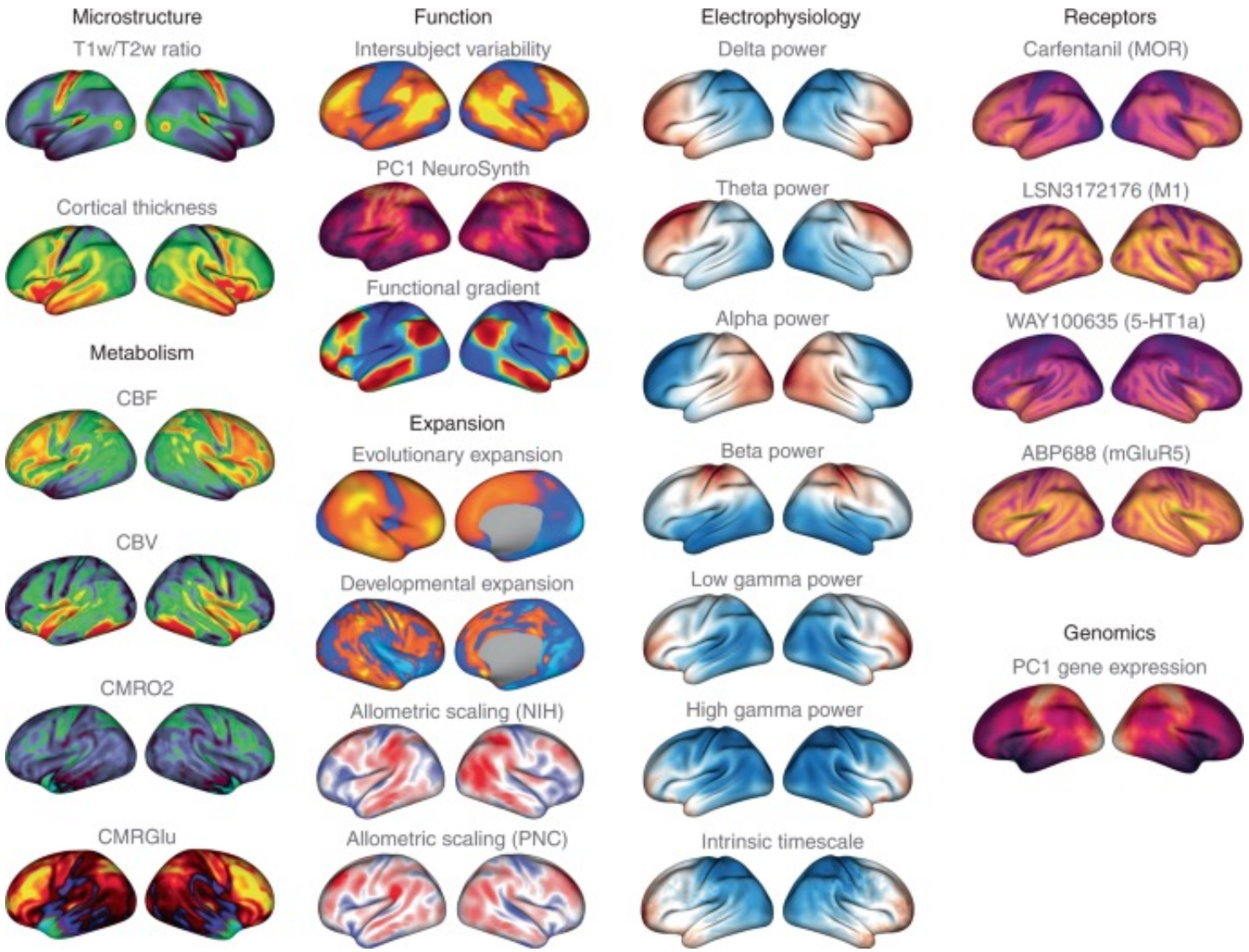
[Sidén, 2020]

– Collecting voxel values from the same 3D location of individual subjects' brain volumes for group-level analysis



Brain Mapping

- Mapping of quantities or properties onto spatial representations of the brain [https://en.wikipedia.org/wiki/Brain_mapping]
  - All brain imaging is considered part of brain mapping
  - Conceived as a higher form of brain imaging
  - What the numerical value of a voxel expresses depends on imaging modality, acquisition protocol, reconstruction, and additional data processing or analysis



[Markello et al., 2022]

Collection of brain maps obtained from the published literature over the past decade