



MRC Cognition
and Brain
Sciences Unit



UNIVERSITY OF
CAMBRIDGE

fMRI analysis

Dace Apšvalka
[Datza]



<http://www.dcdace.net>

Winter, 2023

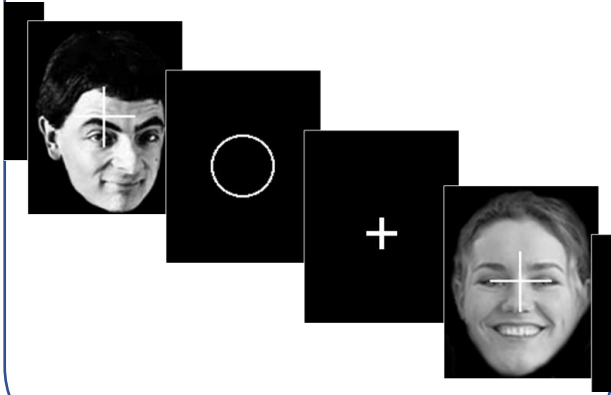
Materials



https://github.com/dcdace/fMRI_training

Famous vs Unfamiliar
faces are processed
differently in the brain

Design an experiment



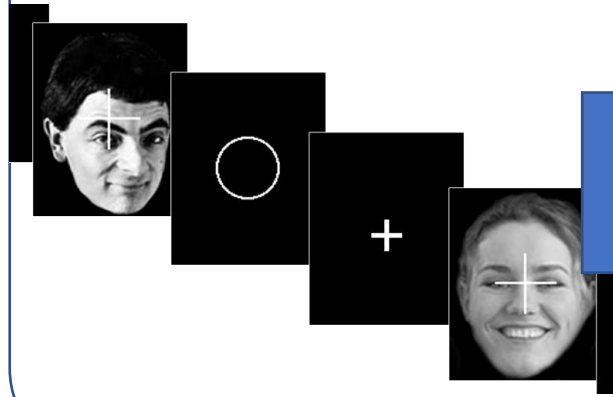
Collect the MRI data



What do we
do now?

Famous vs Unfamiliar
faces are processed
differently in the brain

Design an experiment



Data

Stimuli
Timing

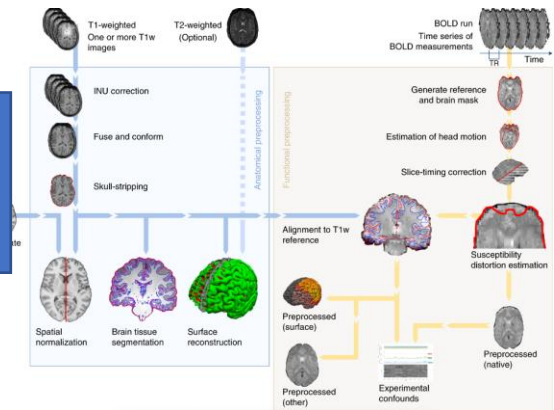
Collect the MRI data



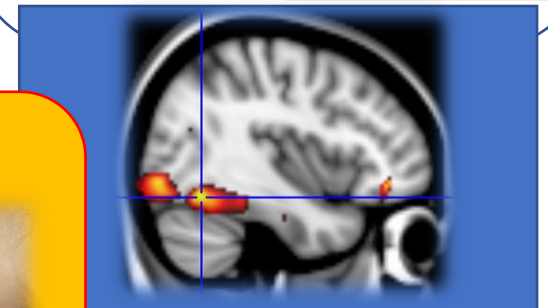
Data

Anatomical image
Functional images
Event details

Pre-process & Analyse



The final push



Environment



Data
Organise & Manage

Pre-process

Analyse

Report

SCIENTIFIC DATA

OPEN

SUBJECT CATEGORIES

- » Electroencephalography
-EEG
- » Brain imaging
- » Functional magnetic
resonance imaging
- » Cognitive neuroscience

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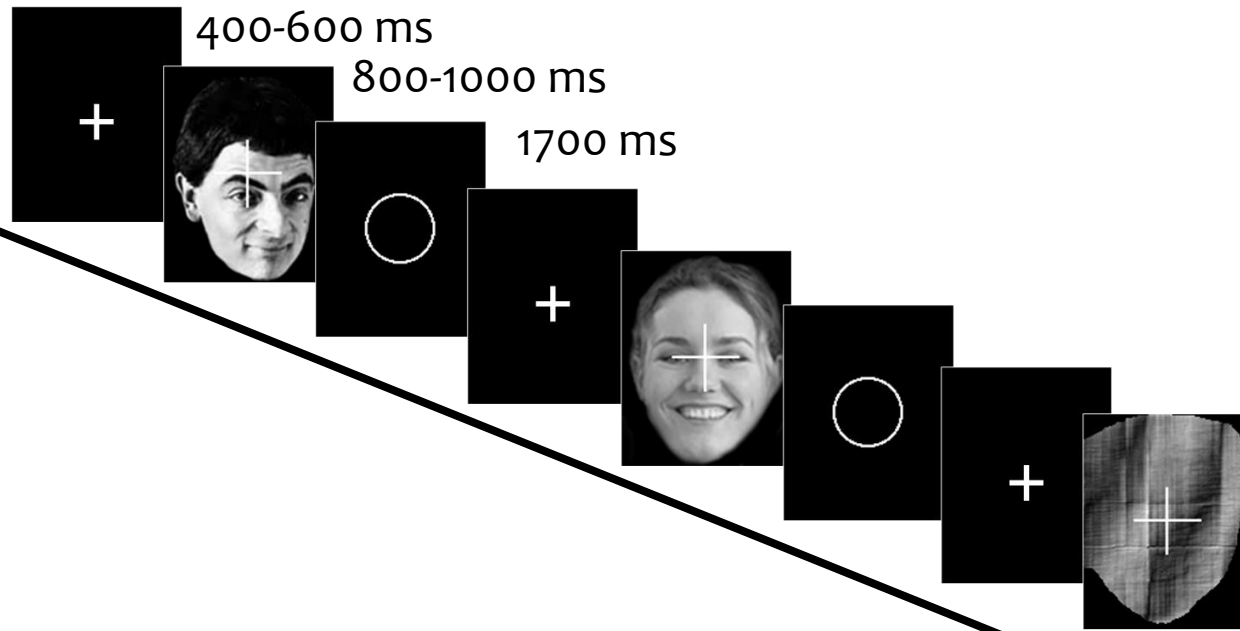
A multi-subject, multi-modal human neuroimaging dataset

Daniel G. Wakeman^{1,2} & Richard N. Henson²

We describe data acquired with multiple functional and structural neuroimaging modalities on the same nineteen healthy volunteers. The functional data include Electroencephalography (EEG), Magnetoencephalography (MEG) and functional Magnetic Resonance Imaging (fMRI) data, recorded while the volunteers performed multiple runs of hundreds of trials of a simple perceptual task on pictures of familiar, unfamiliar and scrambled faces during two visits to the laboratory. The structural data include T1-weighted MPRAGE, Multi-Echo FLASH and Diffusion-weighted MR sequences. Though only from a small sample of volunteers, these data can be used to develop methods for integrating multiple modalities from multiple runs on multiple participants, with the aim of increasing the spatial and temporal resolution above that of any one modality alone. They can also be used to integrate measures of functional and structural connectivity, and as a benchmark dataset to compare results across the many neuroimaging analysis packages. The data are freely available from <https://openfmri.org/>.

- Been used in many methods projects and publications, as well as tutorials (e.g. “multimodal” dataset in SPM12 manual)
- Here we will analyse it from the very root – the raw DICOM images

Experiment: Face Recognition



N = 16 subjects

Stimuli: 3 types of greyscale face images:

~150 x Famous

~150 x Unfamiliar

~150 x Scrambled

Task: Judge face symmetry

7 min long runs
9 runs
20s Rest after ever 50s

Environment

Data

Organise & Manage

Pre-process

Analyse

Report

Environment

PROGRAMMING LANGUAGES



BASH
&
Shell Scripts

A low-level programming language providing a command line user interface for Unix-like operating systems (e.g., Linux, macOS).

Used to automate repetitive tasks and manage system processes and resources.



A high-level, general-purpose programming language.
License-free – good for reproducible & open code.



A high-level programming language designed for engineers and scientists.

Requires a license. Provides loads of useful resources for Neuroimaging analysis.

Environment

PROGRAMMING LANGUAGES



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Environment

PROGRAMMING LANGUAGES



BASH
&
Shell Scripts



PACKAGE MANAGER



Conda is an open-source, cross-platform, language-agnostic package manager and environment management system.

With conda, you can use environments that have different versions of Python and packages installed in them.

You can, for example, create your fMRI analysis environment that includes packages needed for your analysis work.

Environment

PROGRAMMING LANGUAGES



BASH
&
Shell Scripts



PACKAGE MANAGER



CODE EDITOR

Code editors simplify and speed up typing of source code. They also support running and debugging the code.

The best editors are cross-language, cross-platform and support version control.

Environment

PROGRAMMING LANGUAGES

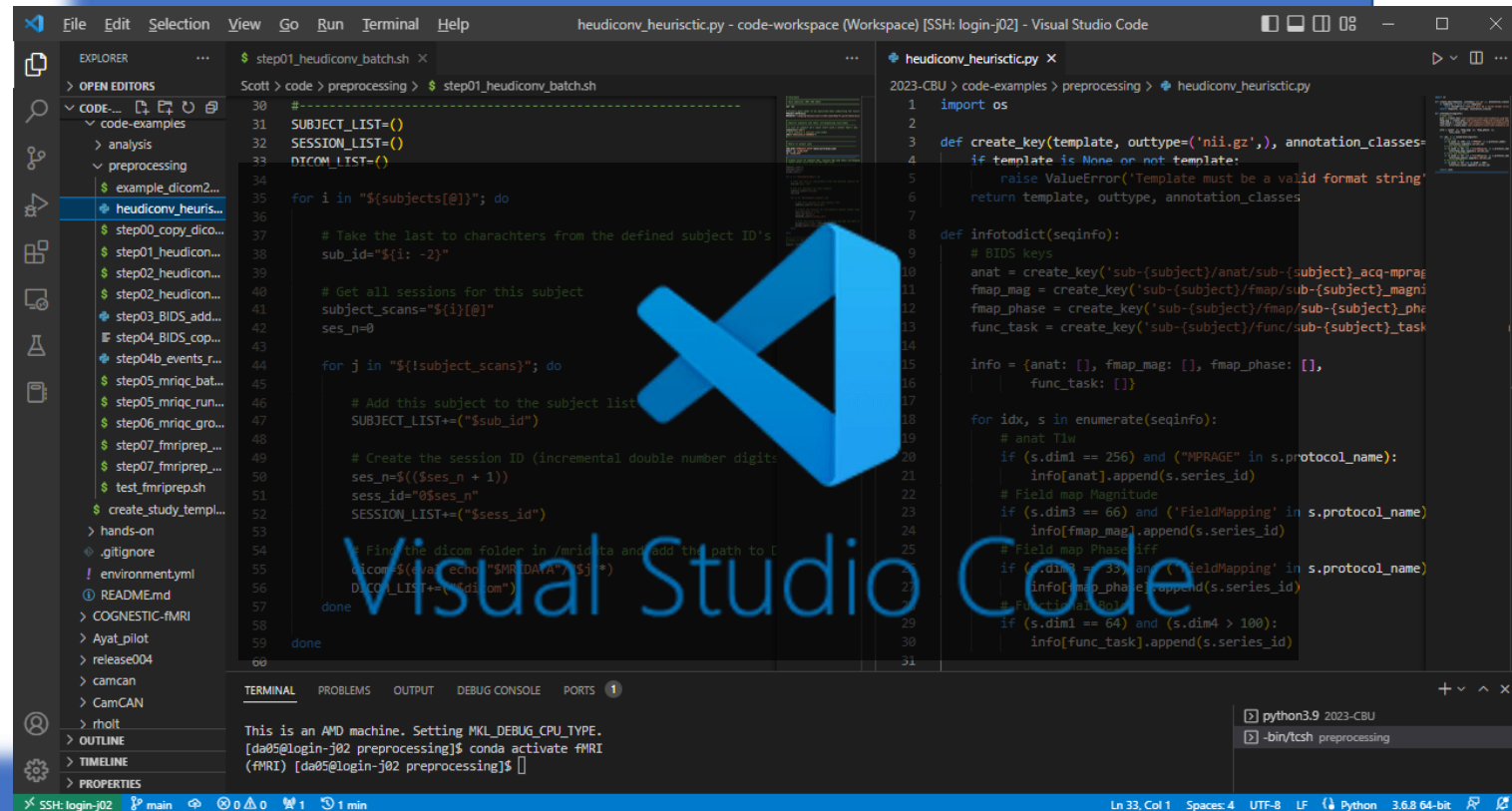
PACKAGE MANAGER

CONDA

CODE EDITOR



BASH
&
Shell Scripts



Environment

PROGRAMMING LANGUAGES



BASH
&
Shell Scripts



PACKAGE MANAGER



CODE EDITOR



Visual Studio Code

VERSION CONTROL



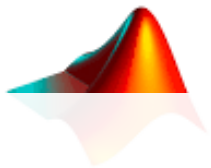
The practice of tracking and managing changes to software code - your analysis code. It allows to revert selected files back to a previous state, revert the entire project back to a previous state, compare changes over time, do collaborative coding etc.

Environment

PROGRAMMING LANGUAGES



BASH
&
Shell Scripts



MATLAB®

PACKAGE MANAGER



CODE EDITOR



Visual Studio Code

VERSION CONTROL



ANALYSIS NOTEBOOK



[01_Analysis_Environment.ipynb](#) notebook

✓ Environment

Data
Organise & Manage

Pre-process

Analyse

Report

Environment

Data

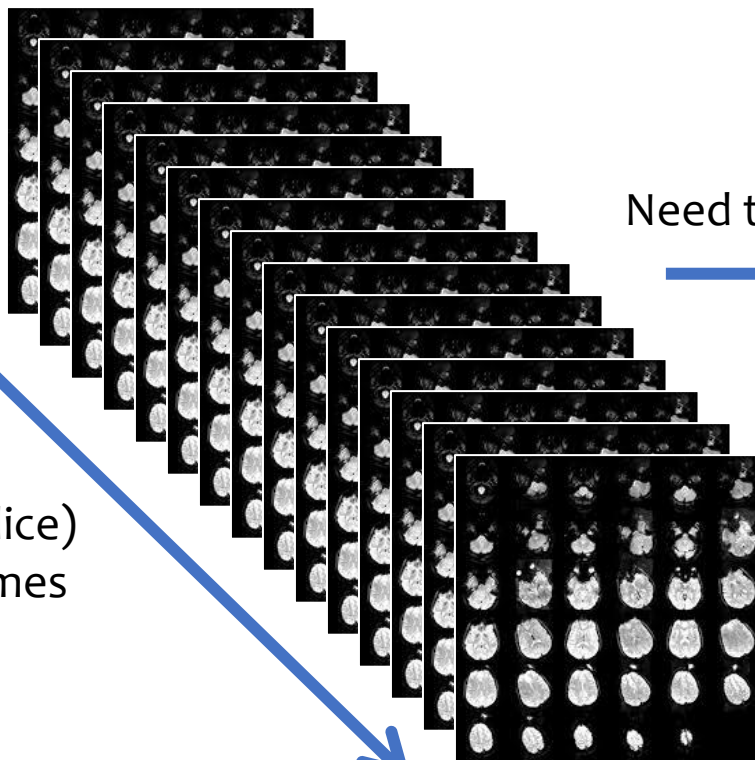
Organise & Manage

fMRI file formats

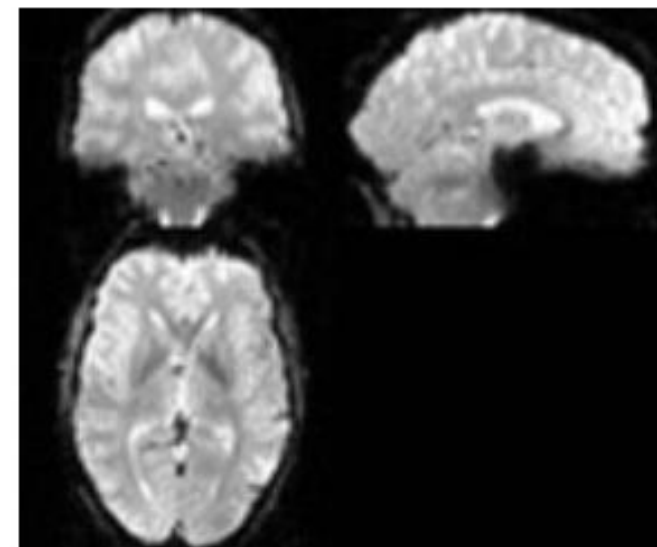
Collect the data



DICOM format



Need to convert to NIfTI



functional scan

A brain volume (slice-by-slice)
scanned every 2s > 100 times

Anatomical (T1w) scans

20090826_164150	
Series_001_CBU_Localiser	
Series_002_CBU_MPRAGE	
Series_003_CBU_DWEPI_BOLD210	
Series_004_CBU_DWEPI_BOLD210	
Series_005_CBU_DWEPI_BOLD210	
Series_006_CBU_DWEPI_BOLD210	
Series_007_CBU_DWEPI_BOLD210	
Series_008_CBU_DWEPI_BOLD210	
Series_009_CBU_DWEPI_BOLD210	
Series_010_CBU_DWEPI_BOLD210	
Series_011_CBU_DWEPI_BOLD210	
Series_012_CBU_FieldMapping	
Series_013_CBU_FieldMapping	

Name
DCM File (192)
1.3.12.2.1107.5.2.32.35119.2009082616480248824672575.dcm
1.3.12.2.1107.5.2.32.35119.2009082616480263974172579.dcm
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1.3.12.2.1107.5.2.32.35119.2009082616480283389772589.dcm
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1.3.12.2.1107.5.2.32.35119.2009082616480314408372615.dcm
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1.3.12.2.1107.5.2.32.35119.2009082616480334100772625.dcm

Functional (T2*/BOLD) scans

20090826_164150	
Series_001_CBU_Localiser	
Series_002_CBU_MPRAGE	
Series_003_CBU_DWEPI_BOLD210	
Series_004_CBU_DWEPI_BOLD210	
Series_005_CBU_DWEPI_BOLD210	
Series_006_CBU_DWEPI_BOLD210	
Series_007_CBU_DWEPI_BOLD210	
Series_008_CBU_DWEPI_BOLD210	
Series_009_CBU_DWEPI_BOLD210	
Series_010_CBU_DWEPI_BOLD210	
Series_011_CBU_DWEPI_BOLD210	
Series_012_CBU_FieldMapping	
Series_013_CBU_FieldMapping	

Name
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1.3.12.2.1107.5.2.32.35119.200908261650211329574782.dcm

- **DICOM** - Digital Imaging and Communications in Medicine (.dcm)
 - Raw data standard for storing and communicating **medical images**
 - Contains a **header** (meta data) and the actual **image** itself
 - Images are stored in **2D layers**
 - A separate file for each slice or volume

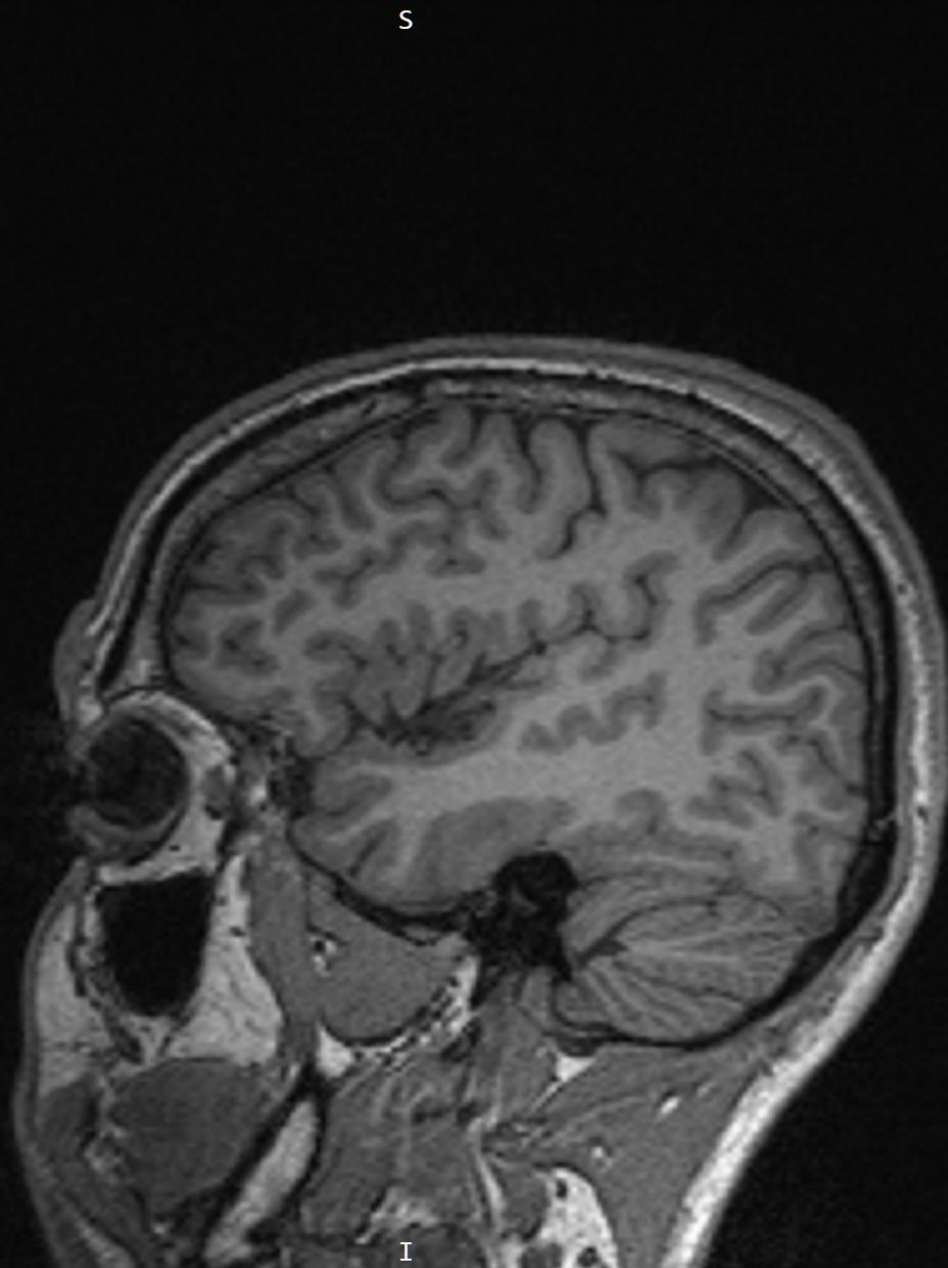
DICOM: Anatomical

[illegible]

CBU090938
MR09029
4-September-1983 M
CBU Neuroimaging
CBU_MPRAGE
V
V

A

```
ST: 1 SL: -46.243837
RT: 2250 ET: 2.98
FS: 3
MR
LittleEndianImplicit
Images: 55/192
Series: 2
```



MRC-CBU
TrioTim
26-August-2009 9:51:26

Zoom: 491%
WL: 352 WW: 759

[illegible]

DICOM: Functional

DICOM browser		Search...
All patients (Patients: 1, Images: 208)		
CBU909038		
CBU Neuroimaging(MR: 1 series)		
CBU_DWPEP_BOLD210		
	1.3.12.1.1107.5.2.32.35119.200908260959346867944	
	1.3.12.1.1107.5.2.32.35119.20090826095936845386	
	1.3.12.1.1107.5.2.32.35119.20090826095936731331	
	1.3.12.1.1107.5.2.32.35119.20090826095936868365	
	1.3.12.1.1107.5.2.32.35119.200908260959428686564	
	1.3.12.1.1107.5.2.32.35119.200908260959446855523	
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	1.3.12.1.1107.5.2.32.35119.200908260959506875051	
	1.3.12.1.1107.5.2.32.35119.200908260959526863598	
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	1.3.12.1.1107.5.2.32.35119.200908261000046843481	
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	1.3.12.1.1107.5.2.32.35119.200908261001106770191	
	1.3.12.1.1107.5.2.32.35119.200908261001126740631	
	1.3.12.1.1107.5.2.32.35119.200908261001146628781	
	1.3.12.1.1107.5.2.32.35119.200908261001166776511	
	1.3.12.1.1107.5.2.32.35119.200908261001186764451	
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	1.3.12.1.1107.5.2.32.35119.2009082610012267378	

CBU090938
MR09029
4-September-1983 M
CBU Neuroimaging
CBU DWEPI BOLD210

V
V

R

```
ST: 3 SL: -50.170833
RT: 2000 ET: 30
FS: 3
MR
LittleEndianImplicit
Images: 1/208
Series: 3
```

AS

PI

MRC-CBU
TrioTim
9 9:59:31

26-August-2009 9:59:31

L

Zoom: 327%

WL: 743 WW: 1555

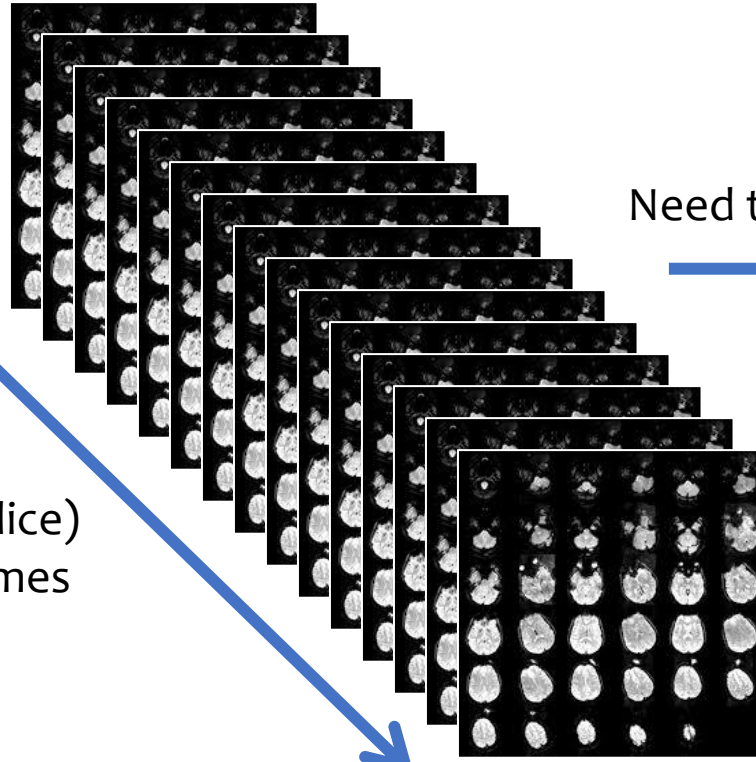
[illegible]

Anatomical (T1w) image & Functional (T2*/BOLD) image

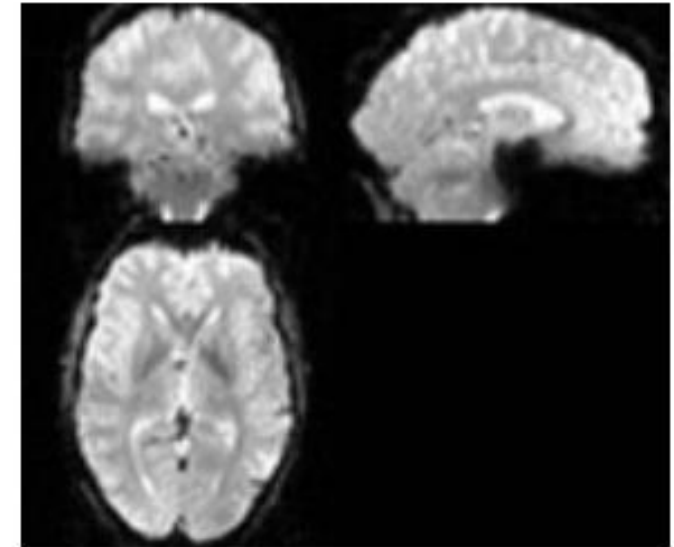
Collect the data



DICOM format



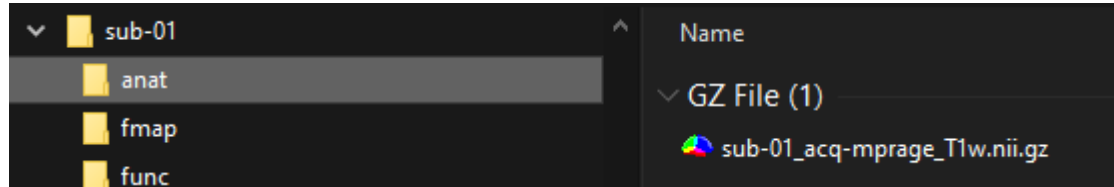
Need to convert to NIfTI



functional scan

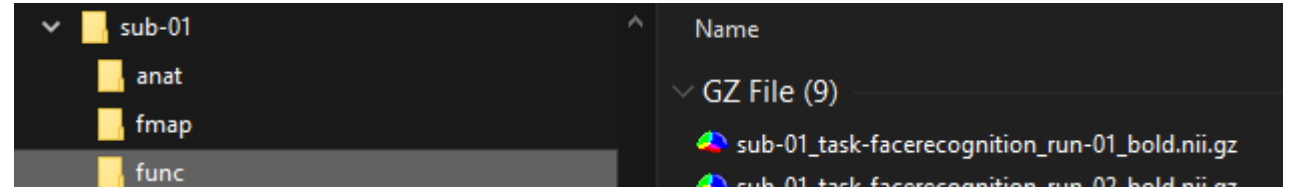
A brain volume (slice-by-slice)
scanned every 2s > 100 times

Anatomical (T1w) scans



3D file

Functional (T2*/BOLD) scans



4D file

- **NIfTI – Neuroimaging Informatics Technology Initiative (.nii, .nii.gz)**
 - Standardised representation of **brain images**, cross-platform, cross-software
 - Contains **header** and **image**
 - 3D or 4D files (all slices/volumes in a single file)
- **DICOM vs NIfTI**
 - All medical vs brain images
 - 2D layer files vs 3D/4D files
 - More vs less metadata
 - When converting DICOM to NIfTI need to be aware of that and save all metadata that might be needed
- **DICOM to NIfTI**
 - Several tools are available
 - For example **dc~~m~~2~~n~~iix** Python package

Collect the data



Anatomical (T1w) image & Functional (T2*/BOLD) image

- sub-01_T1w.nii
- sub-01_run-01_bold.nii
- sub-01_run-02_bold.nii
- sub-02_T1w.nii
- sub-02_run-01_bold.nii
- sub-02_run-02_bold.nii
- ...
- sub-100_T1w.nii
- sub-100_run-01_bold.nii
- sub-100_run-02_bold.nii
- and even more files (more sessions and tasks)

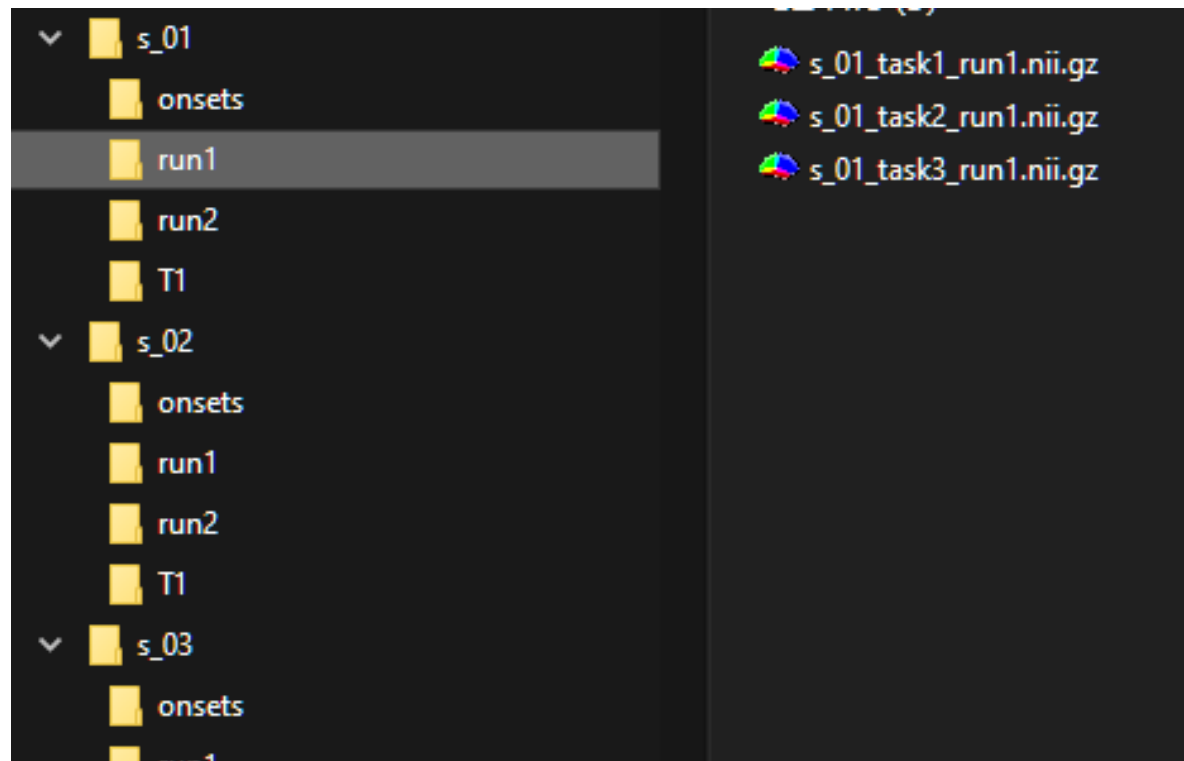
How should we
organise our files?

File organisation

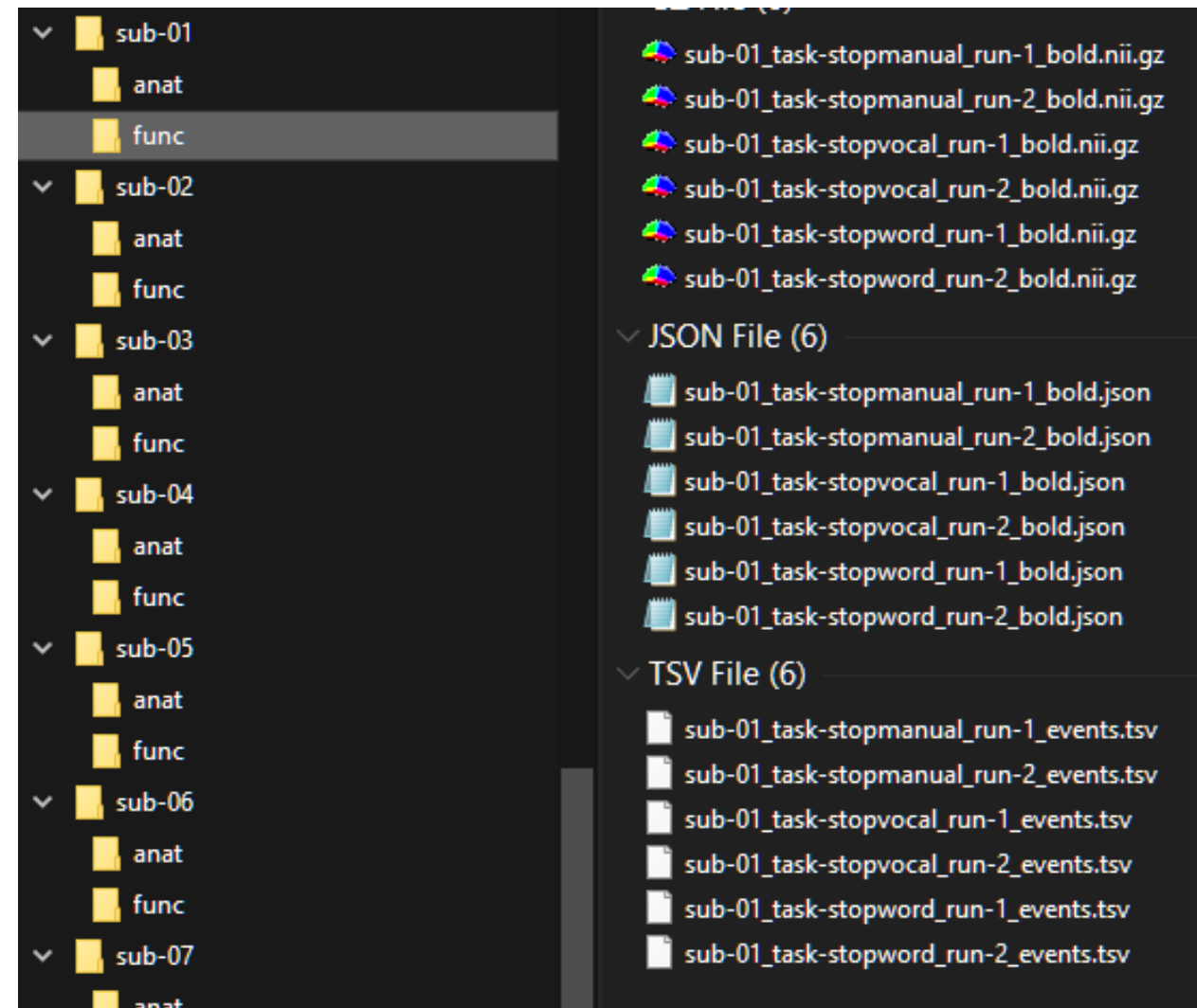
fMRI terminology

- **Session**
 - The time that the subject enters the scanner until they leave the scanner. This will usually include multiple scanning runs with different pulse sequences, including anatomical, functional, etc. Participant can be invited for a follow up session, next day or even later. That will then be Session 2.
- **Run**
 - A period of temporally continuous data acquisition using a single pulse sequence. Functional acquisitions are often split into multiple runs (5-10min) with brief breaks in between.
- **Volume**
 - A single 3D image acquired as part of a run. There is 1 anatomical volume and > 100 functional volumes.
- **Condition**
 - A set of task features that are created to engage a particular mental state. E.g., look at faces (condition 1), or look at houses (condition 2).
- **Trial**
 - A temporally isolated period during which a particular condition is presented, or a specific behaviour is observed. E.g., the first occurrence of the 'faces' condition is trial_1, the second occurrence is trial_2.
- **Event**
 - A trial can consist of multiple subunits. E.g., viewing faces trial may include pressing a button if you saw this face in the previous trials. Or working memory task may contain encoding, delay, retrieval. These subunits are labelled as 'events' and the 'trial' is defined as an overarching task.
- **Block (or an 'epoch')**
 - A temporarily contiguous period when a subject is presented with a particular condition.

Example 1



Example 2



fMRI data management



- **Problems with heterogeneity in data management**
 - Difficult for others (and you!) to understand your data and keep track of changes
 - Scripts have to be adapted (can't be easily reused)
 - Huge effort to automate workflows and no way to automatically validate data sets
 - Sharing data becomes a hustle

Wouldn't it be much easier if everybody organised the files in the same way?

fMRI data management



- A standardised way for organising & describing neuroimaging data

Brain Imaging Data Structure - **BIDS**



Stanford | Center for Reproducible
Neuroscience

- Documentation: <https://bids-specification.readthedocs.io/en/latest/>



SCIENTIFIC DATA

OPEN

SUBJECT CATEGORIES

» Data publication and
archiving
» Research data

The brain imaging data structure, a format for organizing and describing outputs of neuroimaging experiments

Krzysztof J. Gorgolewski¹, Tibor Auer², Vince D. Calhoun^{3,4}, R. Cameron Craddock^{5,6}, Samir Das⁷, Eugene P. Duff⁸, Guillaume Flandin⁹, Satrajit S. Ghosh^{10,11}, Tristan Glatard^{7,12}, Yaroslav O. Halchenko¹³, Daniel A. Handwerker¹⁴, Michael Hanke^{15,16}, David Keator¹⁷, Xiangrui Li¹⁸, Zachary Michael¹⁹, Camille Maumet²⁰, B. Nolan Nichols^{21,22}, Thomas E. Nichols^{23,24}, John Pellman⁵, Jean-Baptiste Poline²⁴, Ariel Rokem²⁵, Gunnar Schaefer^{1,26}, Vanessa Sochat²⁷, William Triplett¹, Jessica A. Turner^{3,28}, Gaël Varoquaux²⁹ & Russell A. Poldrack¹

Received: 18 December 2015

Accepted: 19 May 2016

Published: 21 June 2016

RESEARCH ARTICLE

BIDS apps: Improving ease of use, accessibility, and reproducibility of neuroimaging data analysis methods

Krzysztof J. Gorgolewski^{1*}, Fidel Alfaro-Almagro², Tibor Auer³, Pierre Bellec^{4,5}, Mihai Capota⁶, M. Mallar Chakravarty^{7,8}, Nathan W. Churchill⁹, Alexander Li Cohen¹⁰, R. Cameron Craddock^{11,12}, Gabriel A. Devenyi^{7,8}, Anders Eklund^{13,14,15}, Oscar Esteban¹, Guillaume Flandin¹⁶, Satrajit S. Ghosh^{17,18}, J. Swaroop Guntupalli¹⁹, Mark Jenkinson², Anisha Keshavan²⁰, Gregory Kiar^{21,22}, Franziskus Liem²³, Pradeep Reddy Raamana^{24,25}, David Raffelt²⁶, Christopher J. Steele^{7,8}, Pierre-Olivier Quirion¹⁵, Robert E. Smith²⁶, Stephen C. Strother^{24,25}, Gaël Varoquaux²⁷, Yida Wang⁶, Tal Yarkoni²⁸, Russell A. Poldrack¹





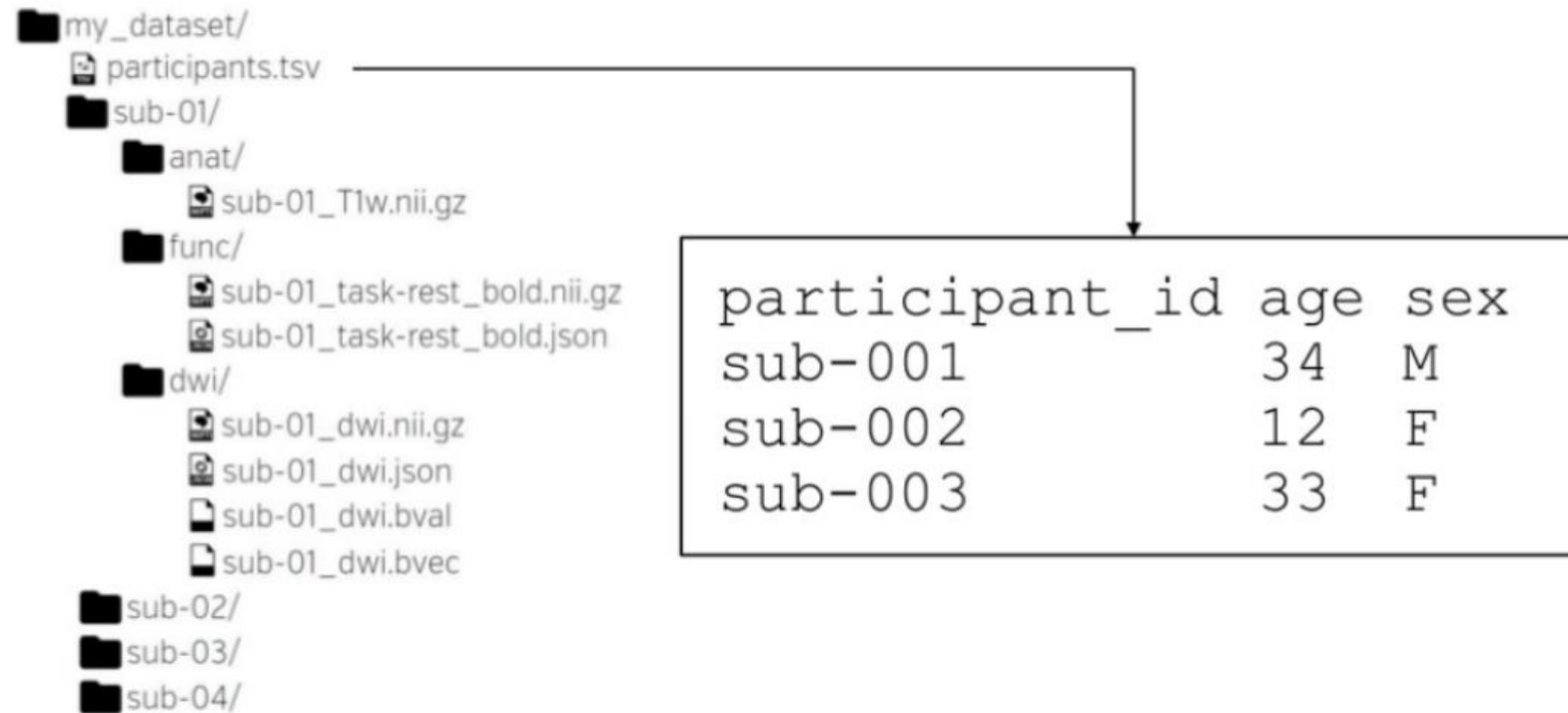
- **Benefits of BIDS**

- Easy for other people to work on your data (for collaborations or contract changes)
- Growing number of data analysis software packages that understand BIDS
- Databases, such as OpenNeuro and LORIS etc., accept and export datasets organised according to BIDS
- Validation tools that can check your dataset integrity and let you easily spot missing values



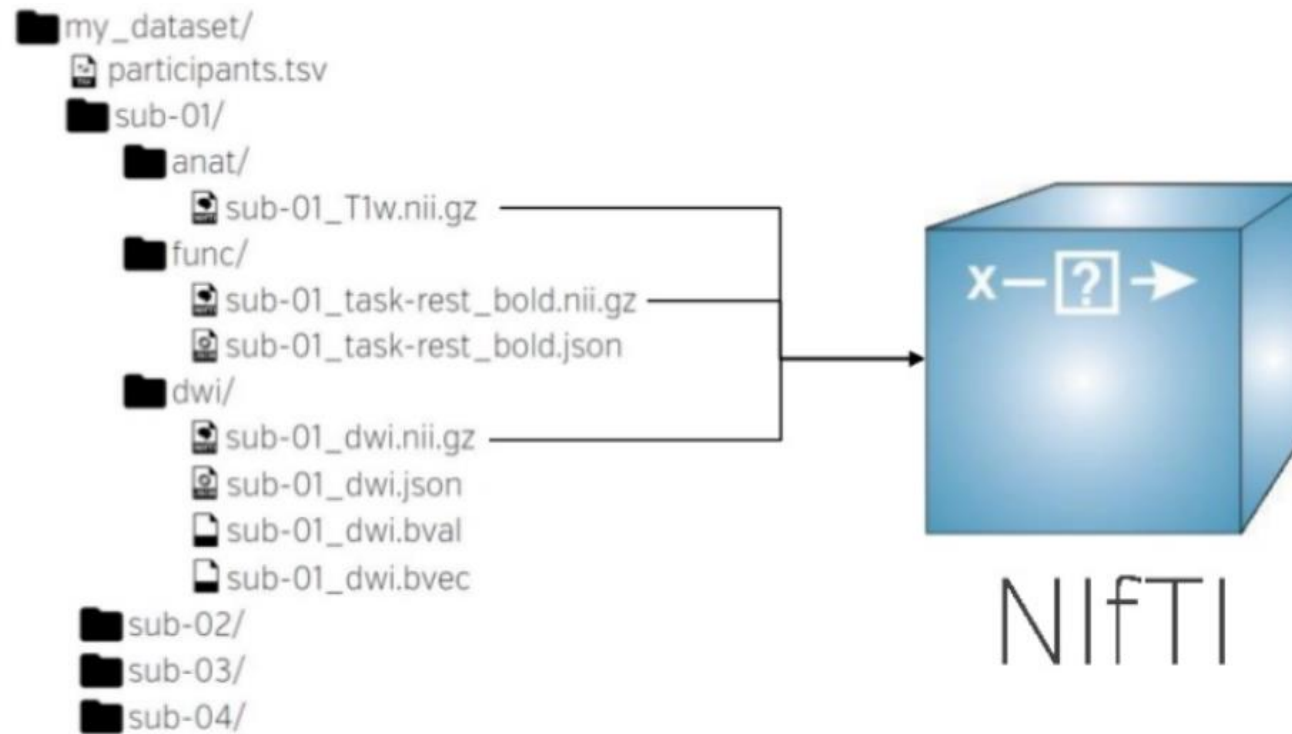
BIDS

- Contains participant information



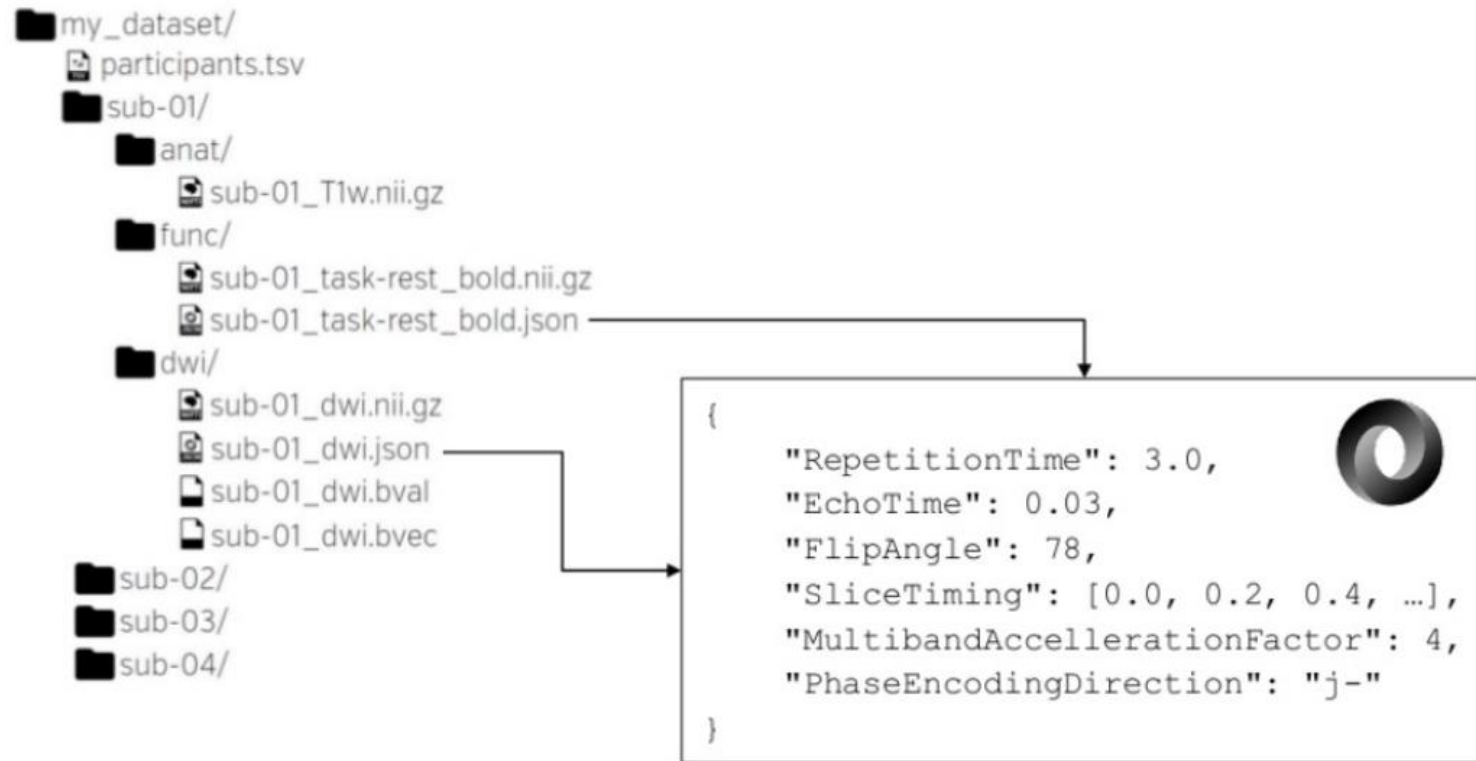
BIDS

- Contains data files



BIDS

- Contains study specific JSON (metadata) files



DICOM → BIDS

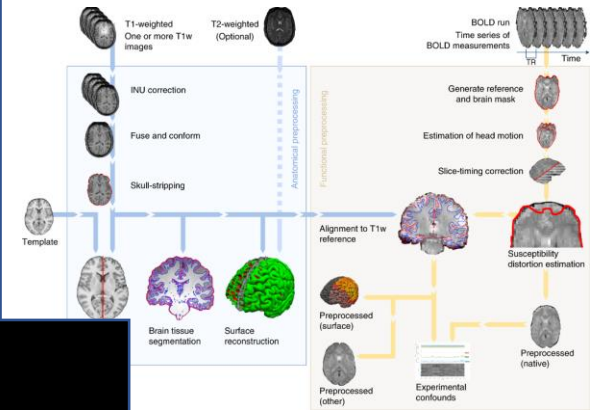
Collect the data



Many BIDS converters available

HeuDiConv (Heuristic **D**icom **C**onversion)
provides sophisticated and flexible creation of BIDS datasets.

Pre-process & Analyse



Environment

Data Organise & Manage

Let's see the [02-fMRI_Data_Management.ipynb](#) notebook

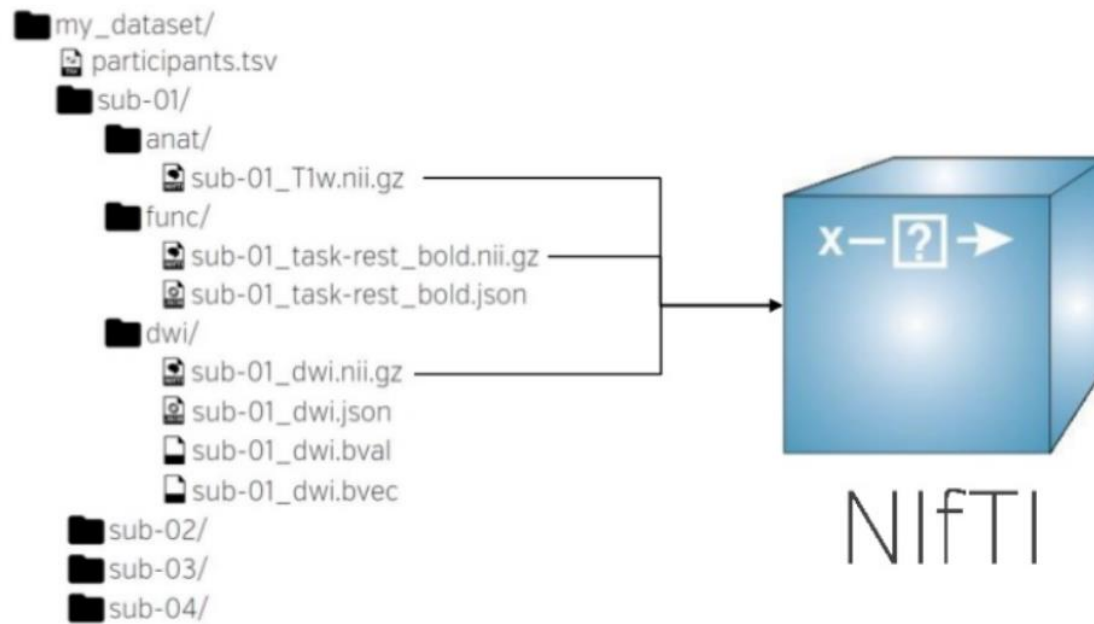


Explore **BIDS** dataset structure with **PyBIDS**

- Interactive notebook
 - https://github.com/dcdace/fMRI_training



Hands-On_01_PyBIDS.ipynb

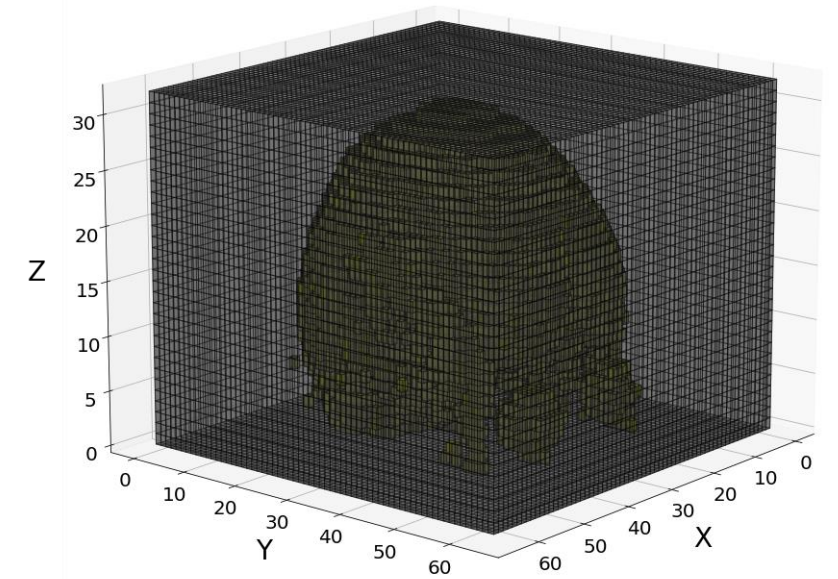
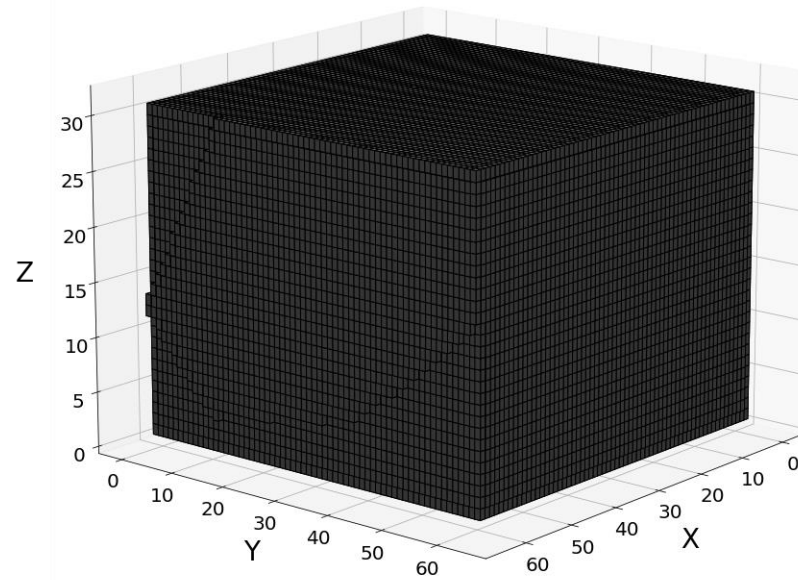


Imaging data content

MRI data structure

A 3D or 4D arrays of numbers

```
([[[ 0.,  0.,  0., ...,  0.,  0.,  0.],  
  [ 0.,  0.,  0., ...,  0.,  0.,  0.],  
  [ 0.,  0.,  0., ...,  0.,  0.,  0.],  
  ...,  
  [ 0.,  0.,  0., ...,  0.,  0.,  0.],  
  [ 0.,  0.,  0., ...,  0.,  0.,  0.],  
  [ 0.,  0.,  0., ...,  0.,  0.,  0.]],  
 [[ 0.,  0.,  0., ...,  0.,  0.,  0.],  
  [ 0., 25., 23., ..., 23., 32.,  0.],  
  [ 0., 28., 21., ..., 25., 25.,  0.],  
  ...,  
  [ 0., 26., 24., ..., 40., 20.,  0.],  
  [ 0., 44., 28., ..., 30., 21.,  0.],  
  [ 0.,  0.,  0., ...,  0.,  0.,  0.]],  
 [[ 0.,  0.,  0., ...,  0.,  0.,  0.],  
  [ 0., 28., 26., ..., 31., 29.,  0.],  
  [ 0., 32., 30., ..., 22., 21.,  0.],  
  ...,  
  [ 0., 27., 24., ..., 31., 30.,  0.],  
  [ 0., 30., 23., ..., 37., 22.,  0.],  
  [ 0.,  0.,  0., ...,  0.,  0.,  0.]],  
  ...],  
  ...]
```



MRI data structure

A 3D or 4D arrays of numbers – intensity values

```
([[[ 0., 0., 0., ..., 0., 0., 0.],
     [ 0., 0., 0., ..., 0., 0., 0.],
     [ 0., 0., 0., ..., 0., 0., 0.],
     ...,
     [ 0., 0., 0., ..., 0., 0., 0.],
     [ 0., 0., 0., ..., 0., 0., 0.],
     [ 0., 0., 0., ..., 0., 0., 0.]]],

 [[ 0., 0., 0., ..., 0., 0., 0.],
  [ 0., 25., 23., ..., 23., 32., 0.],
  [ 0., 28., 21., ..., 25., 25., 0.],
  ...,
  [ 0., 26., 24., ..., 40., 20., 0.],
  [ 0., 44., 28., ..., 30., 21., 0.],
  [ 0., 0., 0., ..., 0., 0., 0.]]],

 [[ 0., 0., 0., ..., 0., 0., 0.],
  [ 0., 28., 26., ..., 31., 29., 0.],
  [ 0., 32., 30., ..., 22., 21., 0.],
  ...,
  [ 0., 27., 24., ..., 31., 30., 0.],
  [ 0., 30., 23., ..., 37., 22., 0.],
  [ 0., 0., 0., ..., 0., 0., 0.]]],

 ...,
```

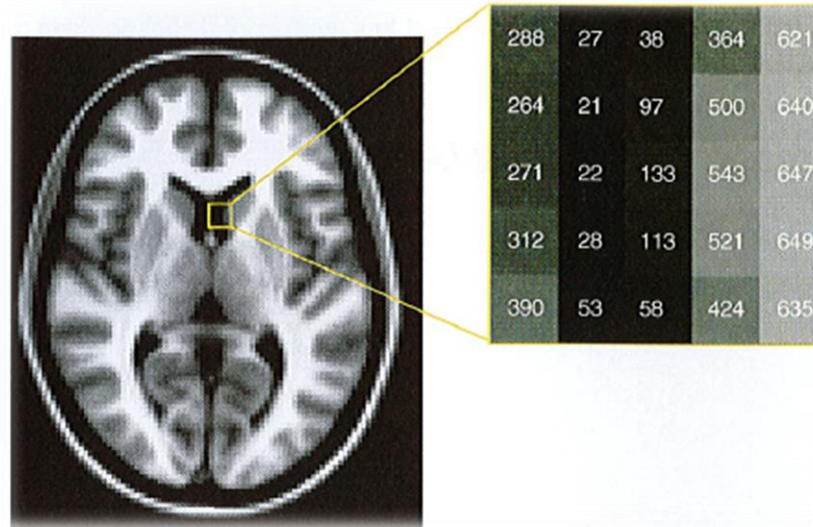
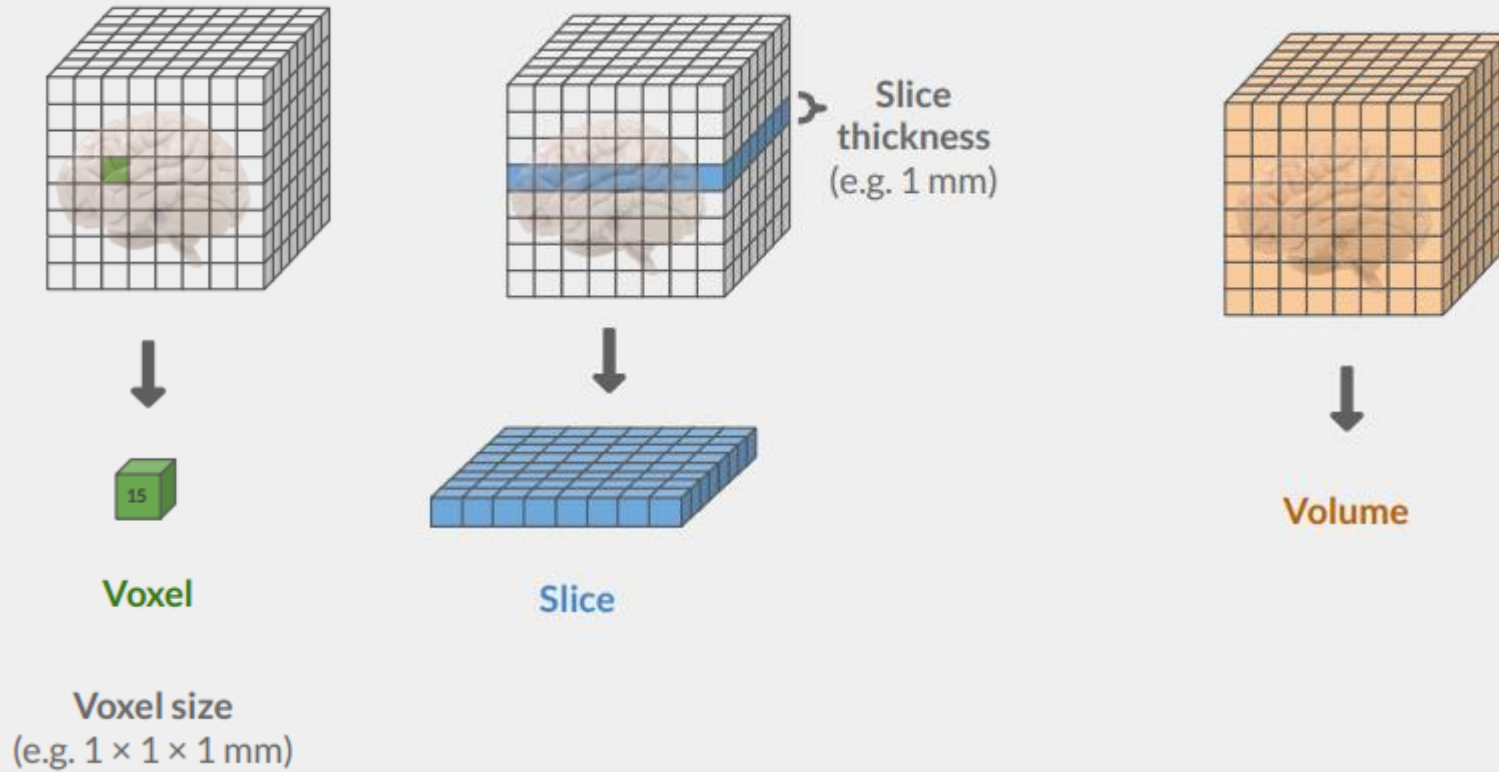


Image from Poldrack et al., 2011

MRI data structure



Karolina Finc

MRI data

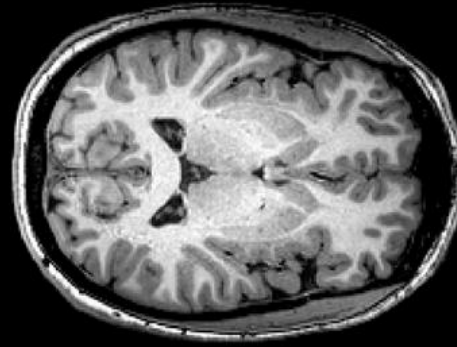


MRI data

What determines the resolution?

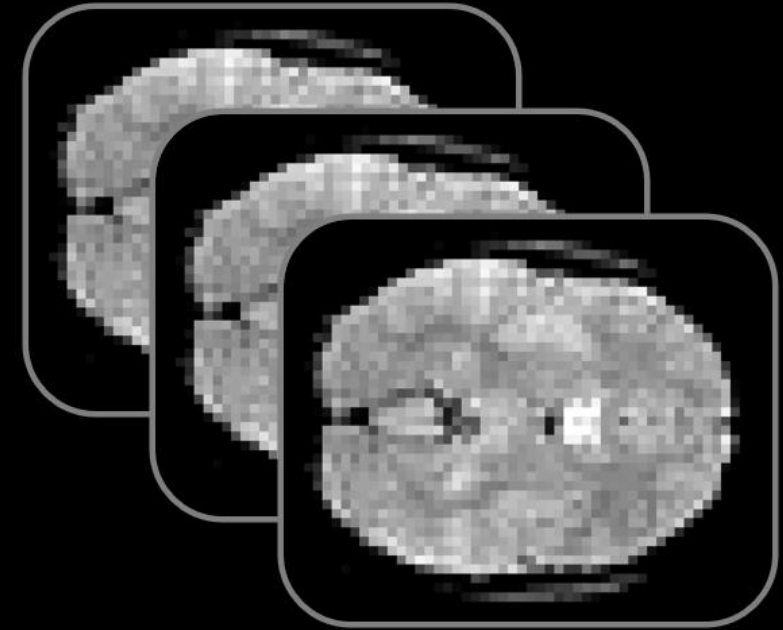
Why can't we acquire the functional images with higher resolution?

high resolution **MRI**



One 3D volume

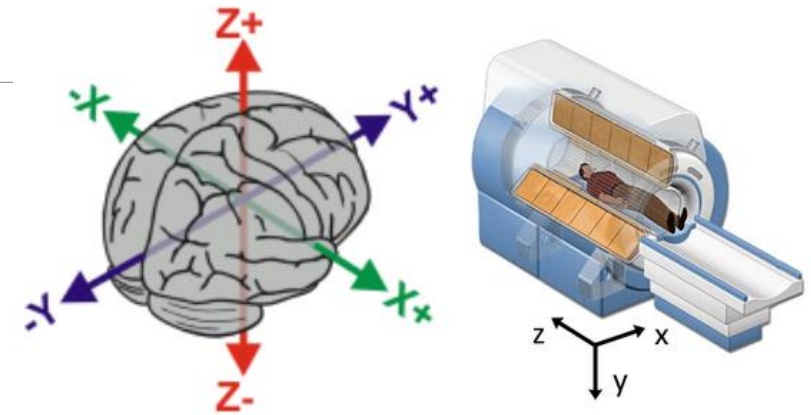
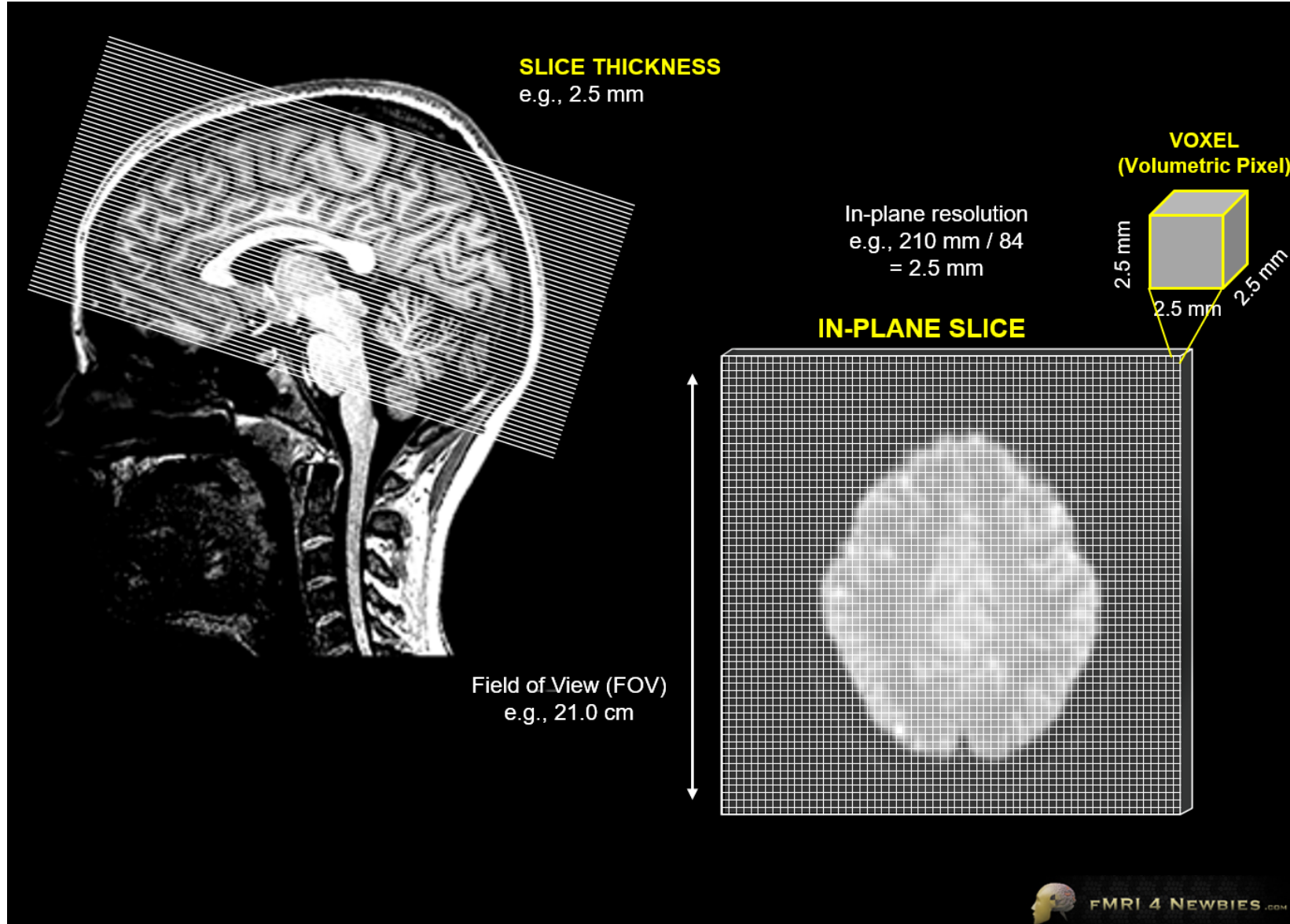
fMRI low resolution



...
series of 3D volumes (i.e., 4D data)
(e.g., every 2 sec for 5 mins)

fMRI data

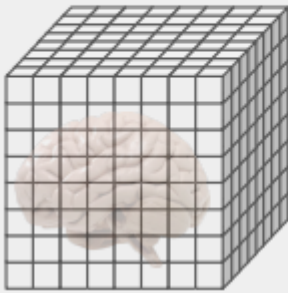
- Acquired in slices (usually axial; z-axis)



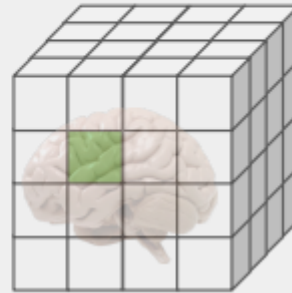
- Temporal resolution (TR) usually 1.5-3s
- Modern sequences allow acquiring multiple slices at the same time
- Typically 30-50 slices acquired
- More slices = longer TR

MRI data structure

Structural data



Functional data

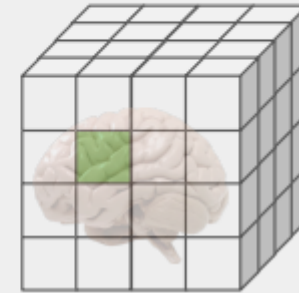


1



2

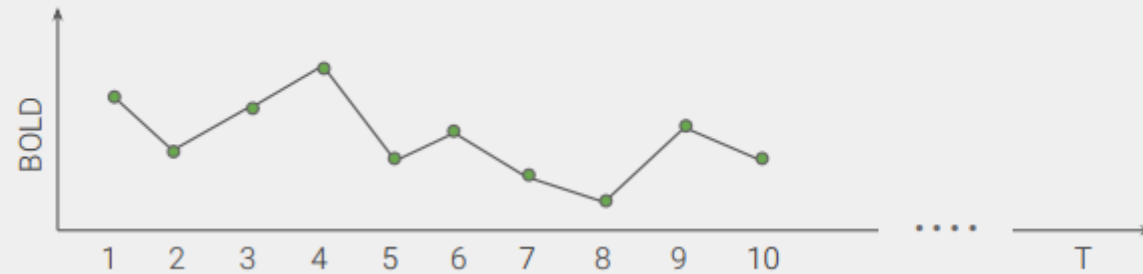
...



T

Time series - is a series of data points listed in time order.

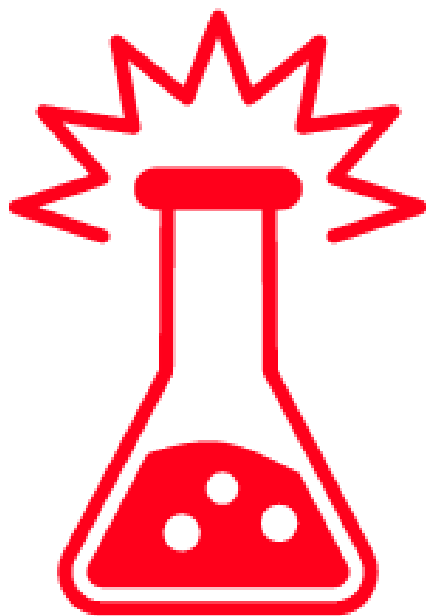
Every voxel has its own time-series.



....

T

Karolina Finc



MRI data content & manipulation



NiBabel

Access a cacophony of neuro-imaging file formats



Nilearn:

Statistics for NeuroImaging in Python

- Interactive notebook
 - https://github.com/dcdace/fMRI_training



Hands-On_02_Neuroimaging_data_manipulation.ipynb