MRC Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

fMRI analysis

Dace Apšvalka
[Datza]

@dcdace dcdace.net

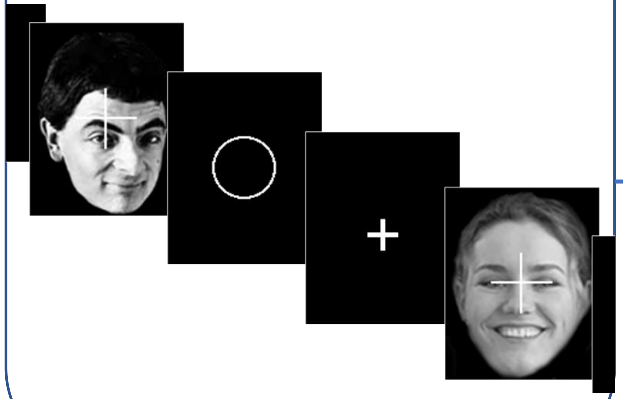
- Sep, 2022

Materials

GitHub https://github.com/dcdace/COGNESTIC-fMRI

Famous vs **Unfamiliar** faces are processed differently in the brain

Design an experiment

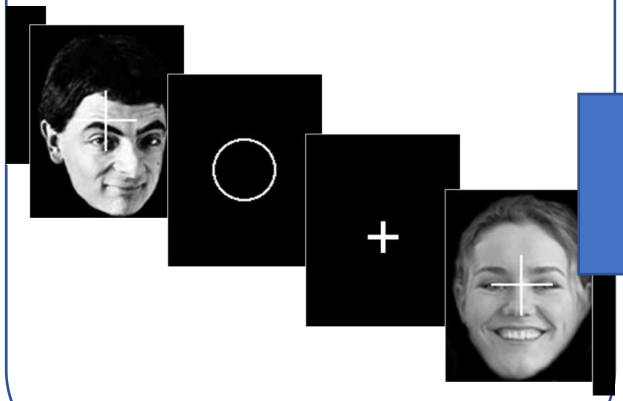


Collect the MRI data

What do we do now?

Famous vs **Unfamiliar** faces are processed differently in the brain

Design an experiment

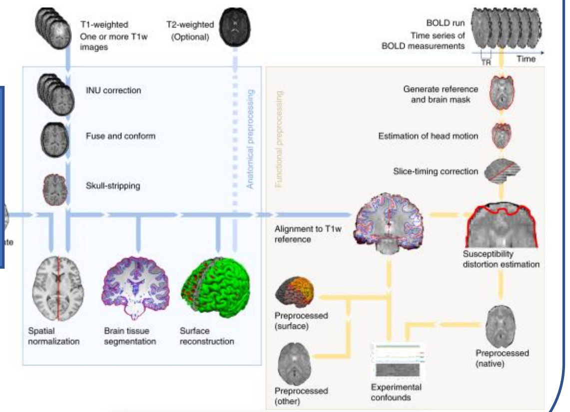


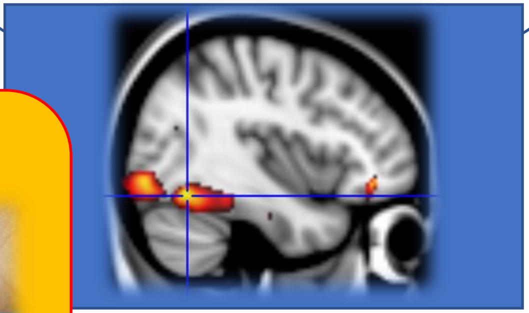
Stimuli
Timing

Collect the MRI data

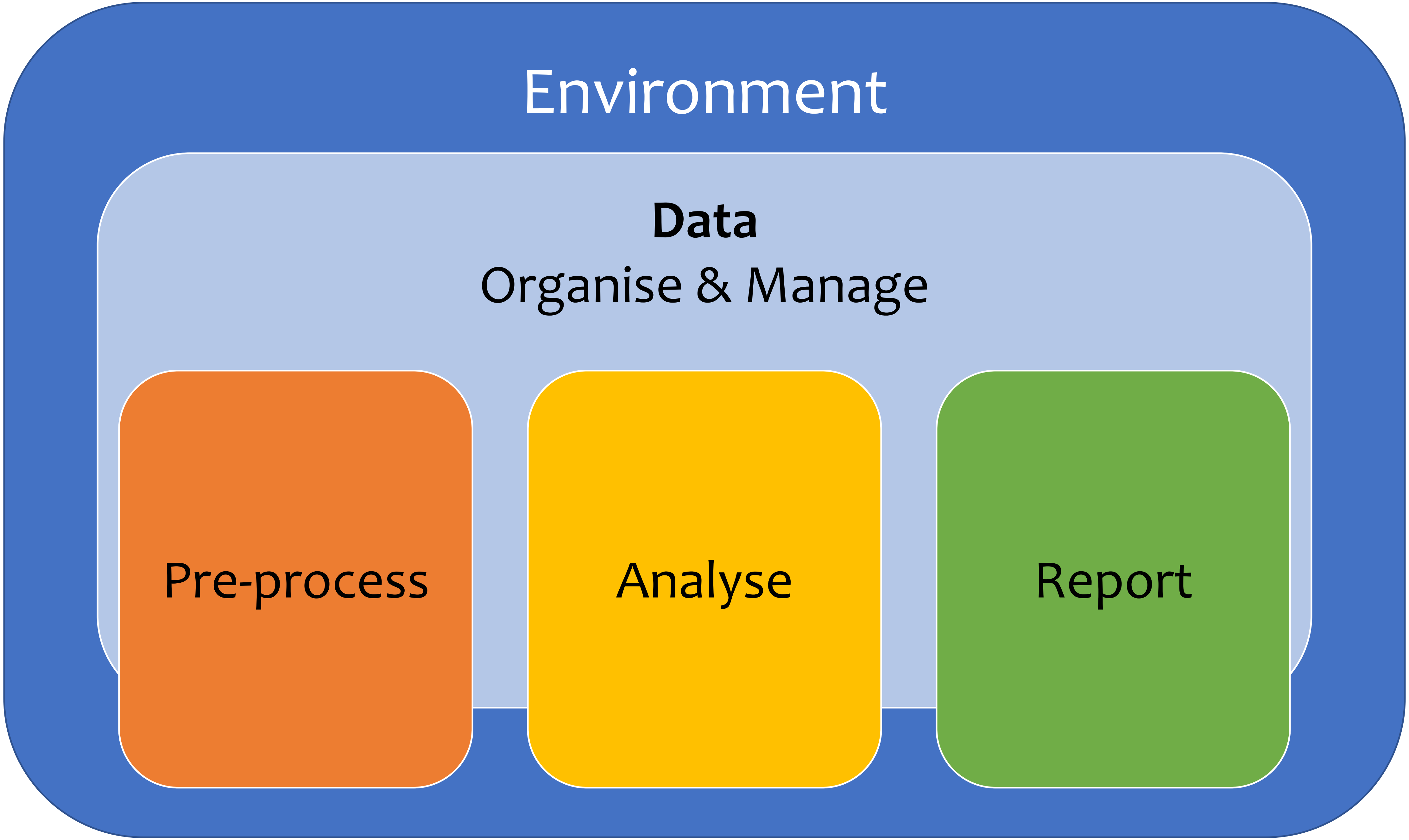
Anatomical image
Functional images
Event details

Pre-process & Analyse





The final push


Environment
Data
Organise & Manage
Pre-process
Analyse
Report

Example Dataset

https://openneuro.org/datasets/ds000117/versions/1.0.5

www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN

SUBJECT CATEGORIES

» Electroencephalography -EEG

» Brain imaging

» Functional magnetic resonance imaging

» Cognitive neuroscience

A multi-subject, multi-modal human neuroimaging dataset

Daniel G. Wakeman[1,2] & Richard N. Henson[2]

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/.

Received: 07 April 2014

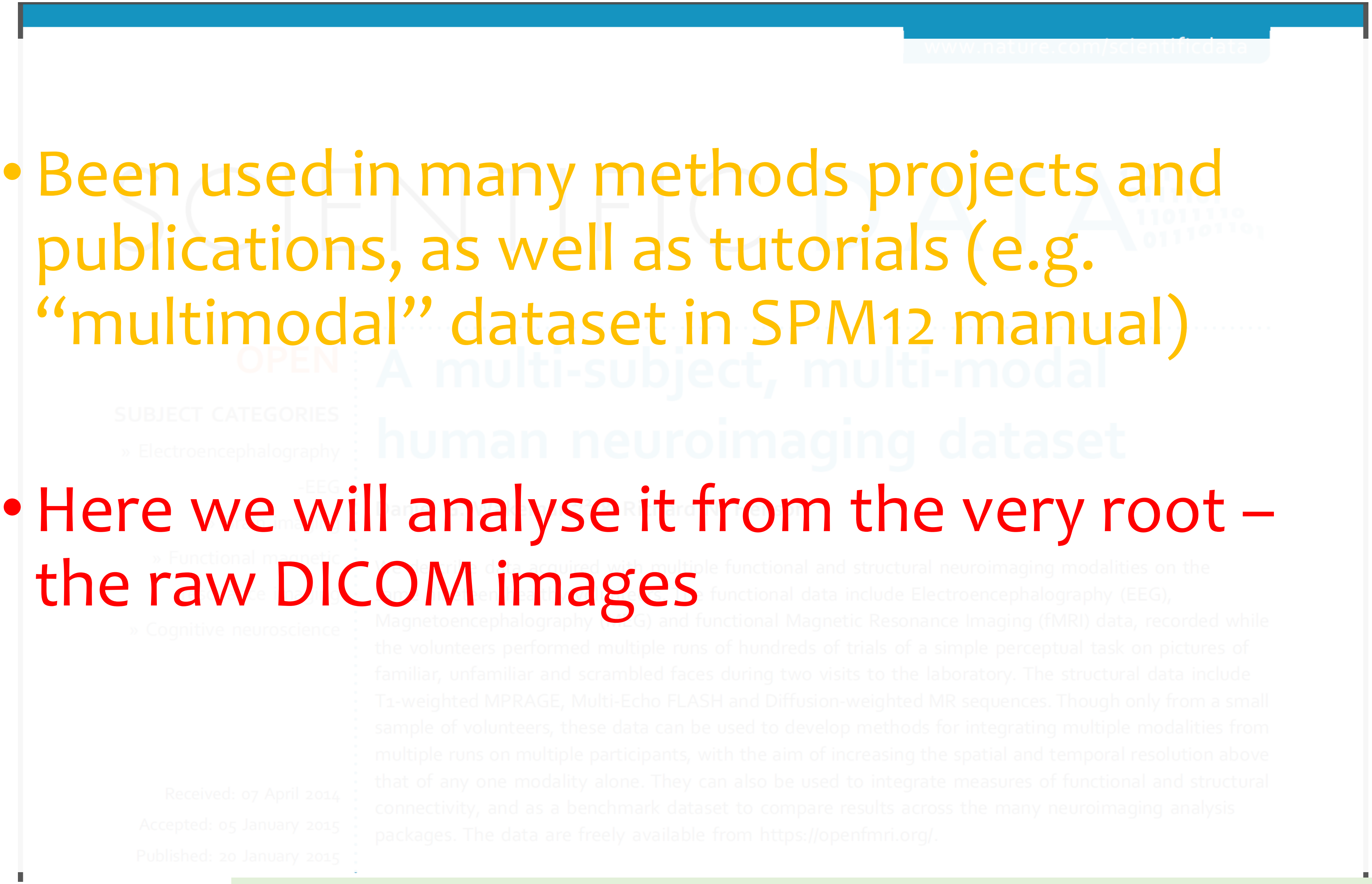
Accepted: 05 January 2015

Published: 20 January 2015

Wakeman & Henson (2015), *Scientific Data*, http://www.nature.com/articles/sdata20151

Example Dataset

https://openneuro.org/datasets/ds000117/versions/1.0.5



www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN

SUBJECT CATEGORIES

» Electroencephalography

» Cognitive neuroscience

A multi-subject, multi-modal human neuroimaging dataset

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/.

Received: 07 April 2014

Accepted: 05 January 2015

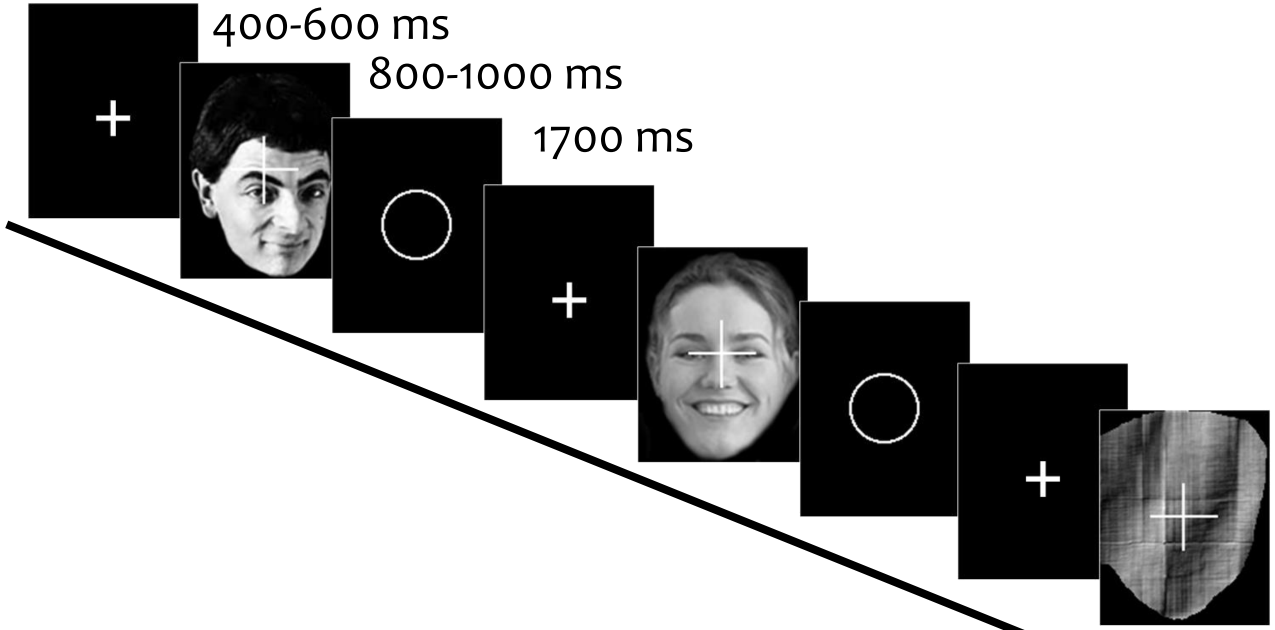
Published: 20 January 2015

- 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

Wakeman & Henson (2015), *Scientific Data*, http://www.nature.com/articles/sdata20151

Experiment: Face Recognition



N = 16 subjects

Stimuli: 3 types of greyscale face images:

- ~150 x Famous
- ~155 x Unfamiliar
- ~150 x Scrambled

Task: Judge face symmetry

Environment

Let’s see the 01_Analysis_Environment.ipynb notebook

Environment

Data

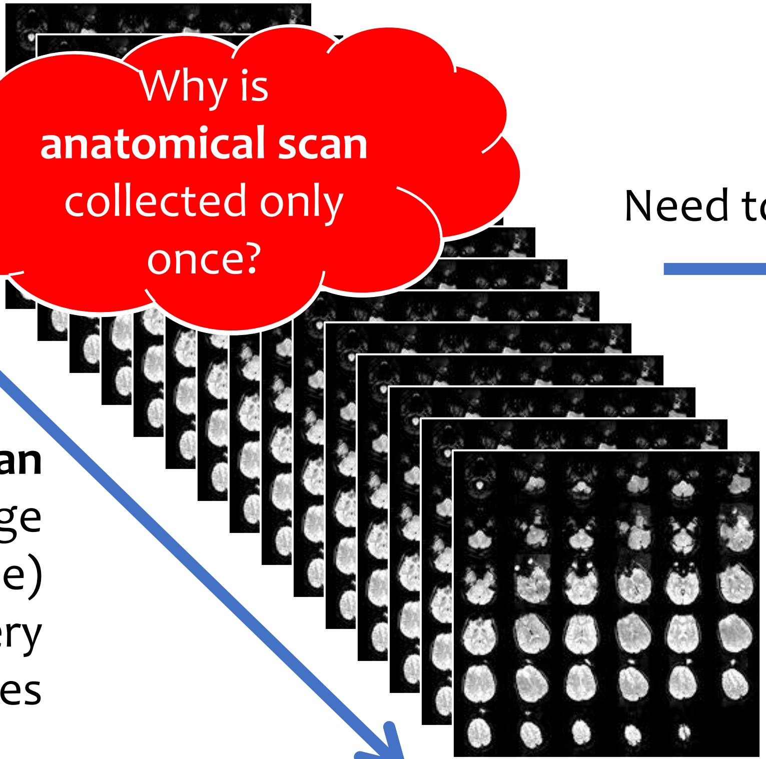
Organise & Manage

fMRI file formats

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

Collect the data

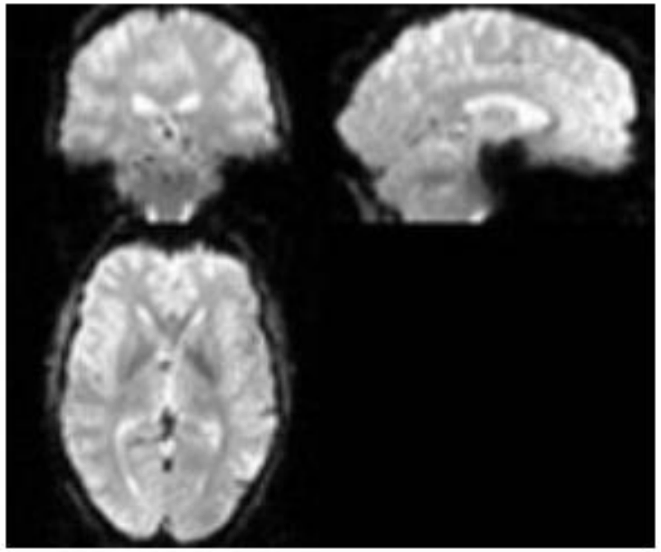
- **DICOM** - **D**igital **I**maging and **Com**munications in **M**edicine (.dcm)
  - Raw data standard for storing and communicating medical images
  - Contains a **header** (meta data) and the actual **image** itself
  - A separate file for each **slice** (2D format)



Why is **anatomical scan** collected only once?

functional scan
A brain image
(slice-by-slice)
selected every
2s > 100 times

Need to convert to **NIfTI**



- **NIfTI** – **N**euro**i**maging **I**n**f**ormatics **T**echnology **I**nitiative (.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)

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

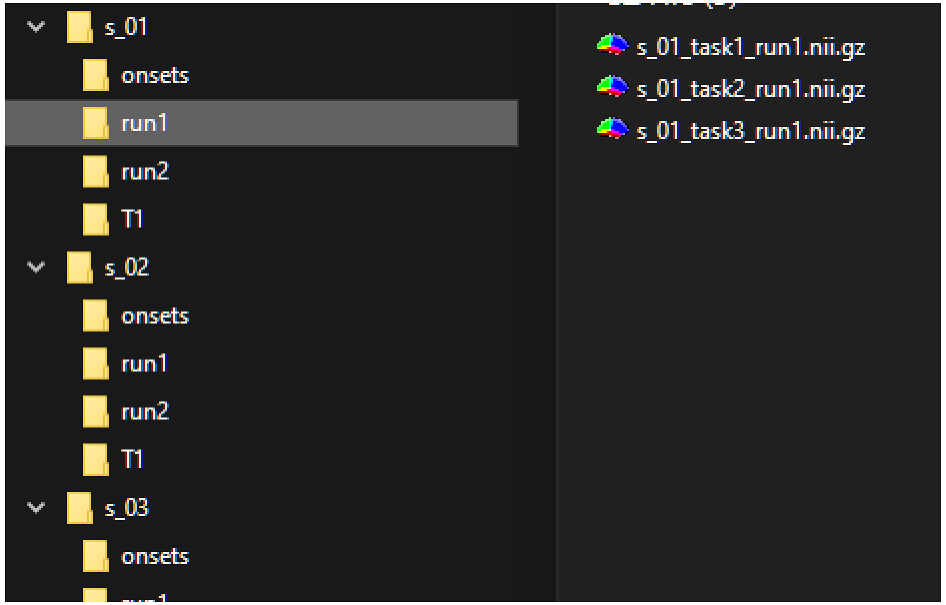
How should we organise our files?

File organisation

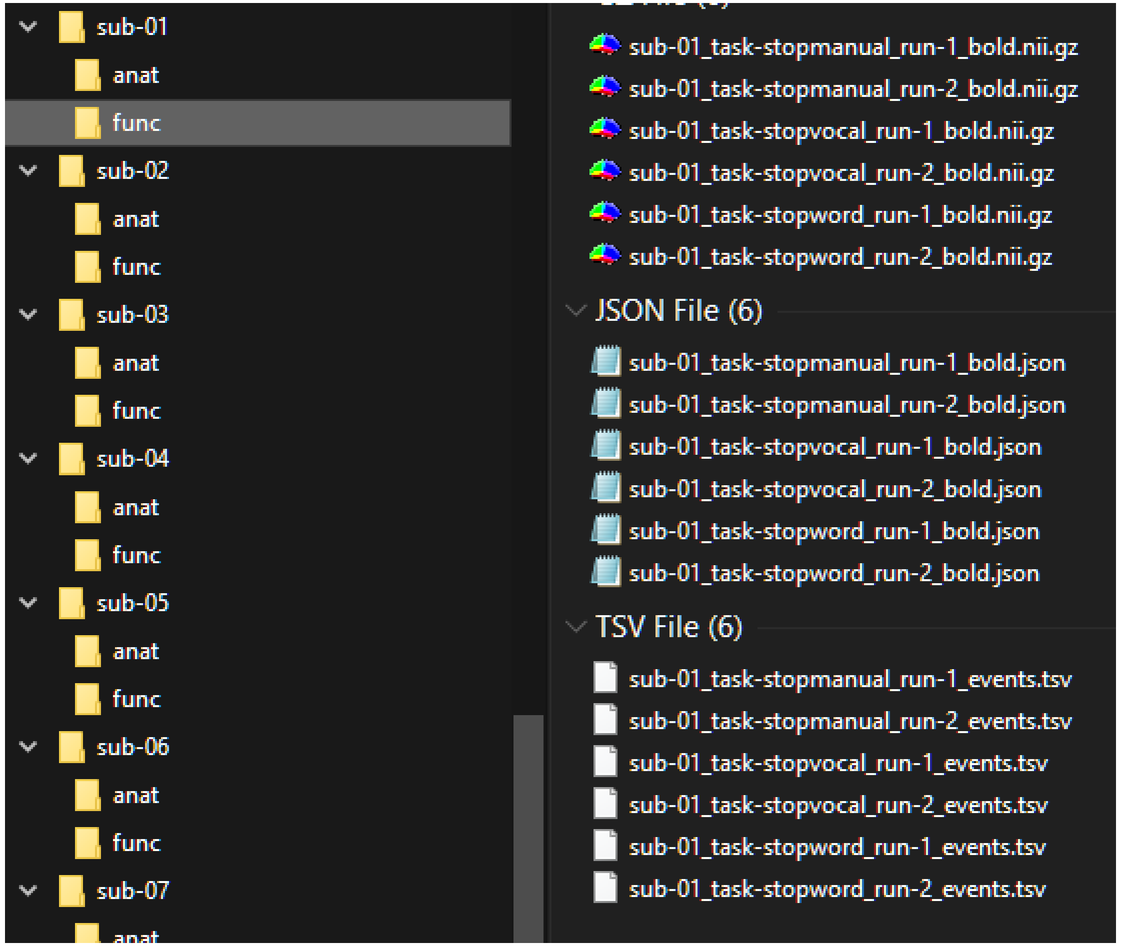
fMRI terminology

- 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

BIDS BRAIN IMAGING DATA STRUCTURE

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. Gorgolewski[1], Tibor Auer[2], Vince D. Calhoun[3,4], R. Cameron Craddock[5,6], Samir Das[7], Eugene P. Duff[8], Guillaume Flandin[9], Satrajit S. Ghosh[10,11], Tristan Glatard[7,12], Yaroslav O. Halchenko[13], Daniel A. Handwerker[14], Michael Hanke[15,16], David Keator[17], Xiangrui Li[18], Zachary Michael[19], Camille Maumet[20], B. Nolan Nichols[21,22], Thomas E. Nichols[20,23], John Pellman[6], Jean-Baptiste Poline[24], Ariel Rokem[25], Gunnar Schaefer[1,26], Vanessa Sochat[27], William Triplett[1], Jessica A. Turner[3,28], Gaël Varoquaux[29] & Russell A. Poldrack[1]

Received: 18 December 2015
Accepted: 19 May 2016
Published: 21 June 2016

PLOS | COMPUTATIONAL BIOLOGY

RESEARCH ARTICLE

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

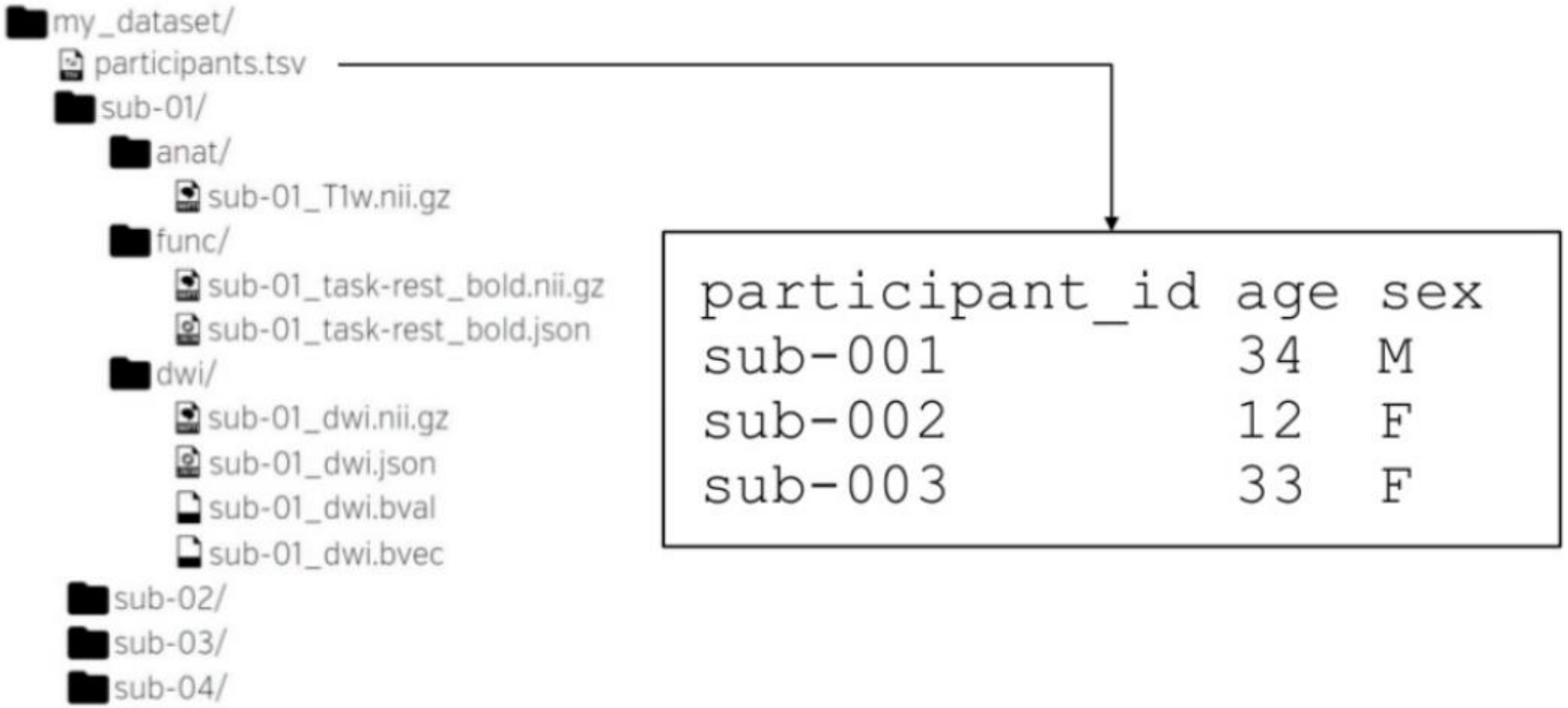
Krzysztof J. Gorgolewski[1]*, Fidel Alfaro-Almagro[2], Tibor Auer[3], Pierre Bellec[4,5], Mihai Capotă[6], M. Mallar Chakravarty[7,8], Nathan W. Churchill[9], Alexander Li Cohen[10], R. Cameron Craddock[11,12], Gabriel A. Devenyi[7,8], Anders Eklund[13,14,15], Oscar Esteban[1], Guillaume Flandin[16], Satrajit S. Ghosh[17,18], J. Swaroop Guntupalli[19], Mark Jenkinson[2], Anisha Keshavan[20], Gregory Kiar[21,22], Franziskus Liem[23], Pradeep Reddy Raamana[24,25], David Raffelt[26], Christopher J. Steele[7,8], Pierre-Olivier Quirion[15], Robert E. Smith[26], Stephen C. Strother[24,25], Gaël Varoquaux[27], Yida Wang[6], Tal Yarkoni[28], Russell A. Poldrack[1]

BIDS

- **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

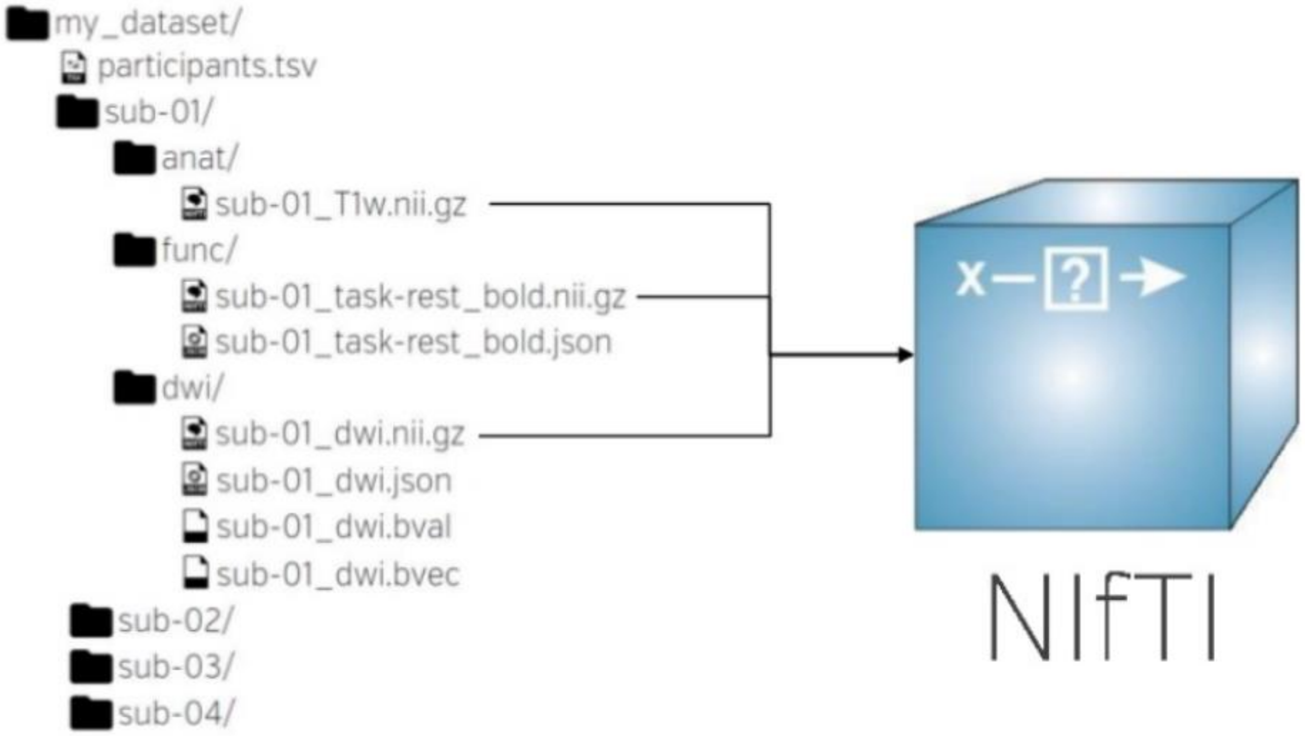
BIDS

- Contains participant information



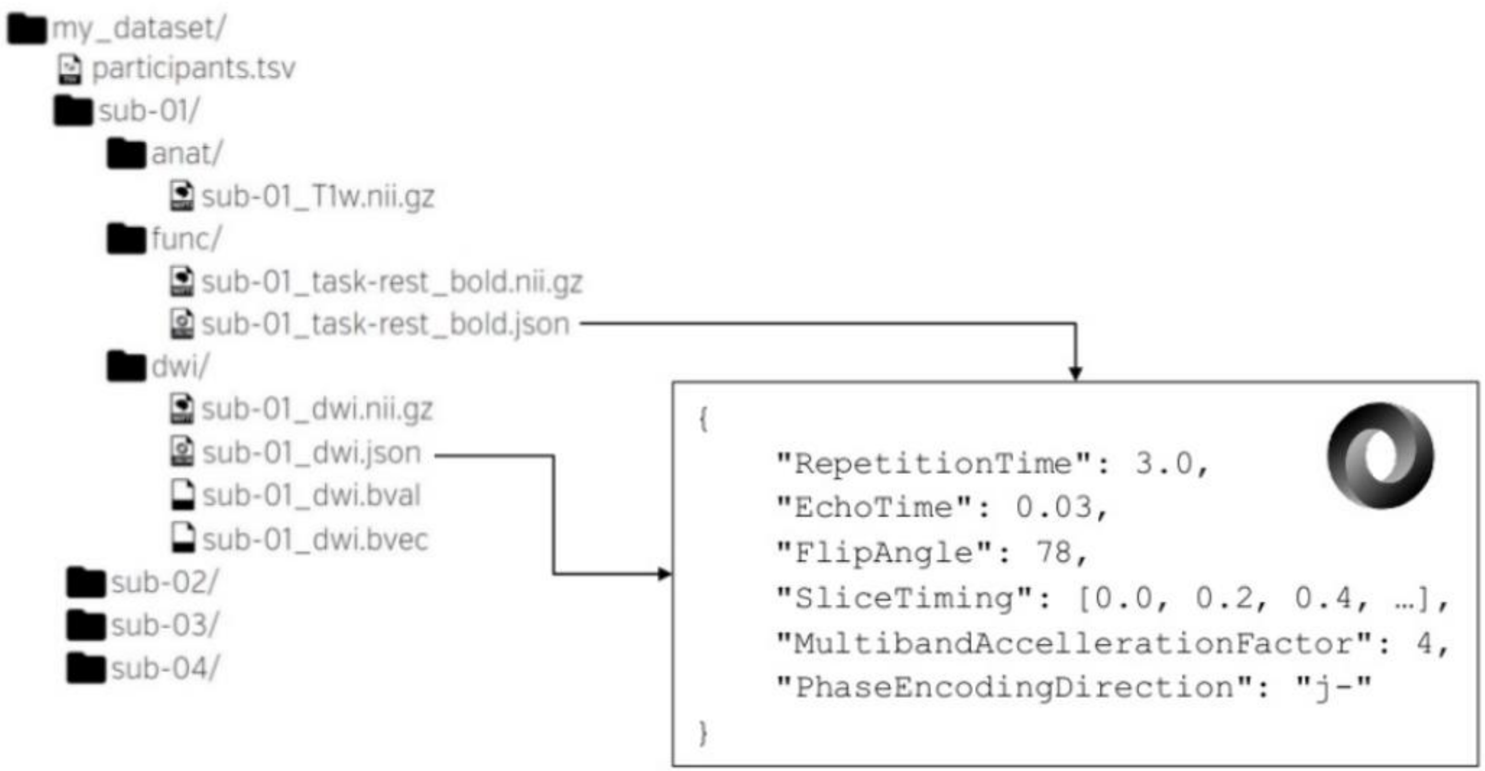
BIDS

- Contains data files: neuroimaging/behaviour



BIDS

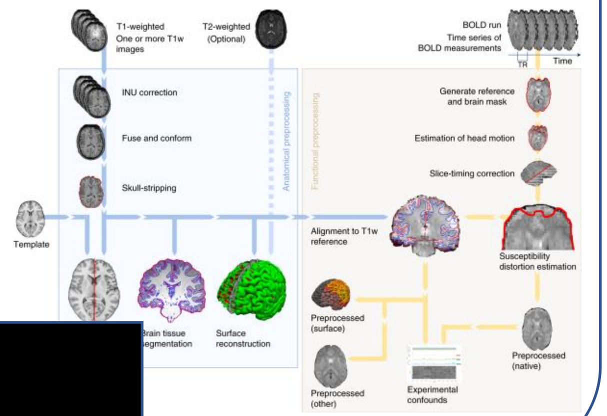
- Contains study specific JSON files: sequences & paradigm



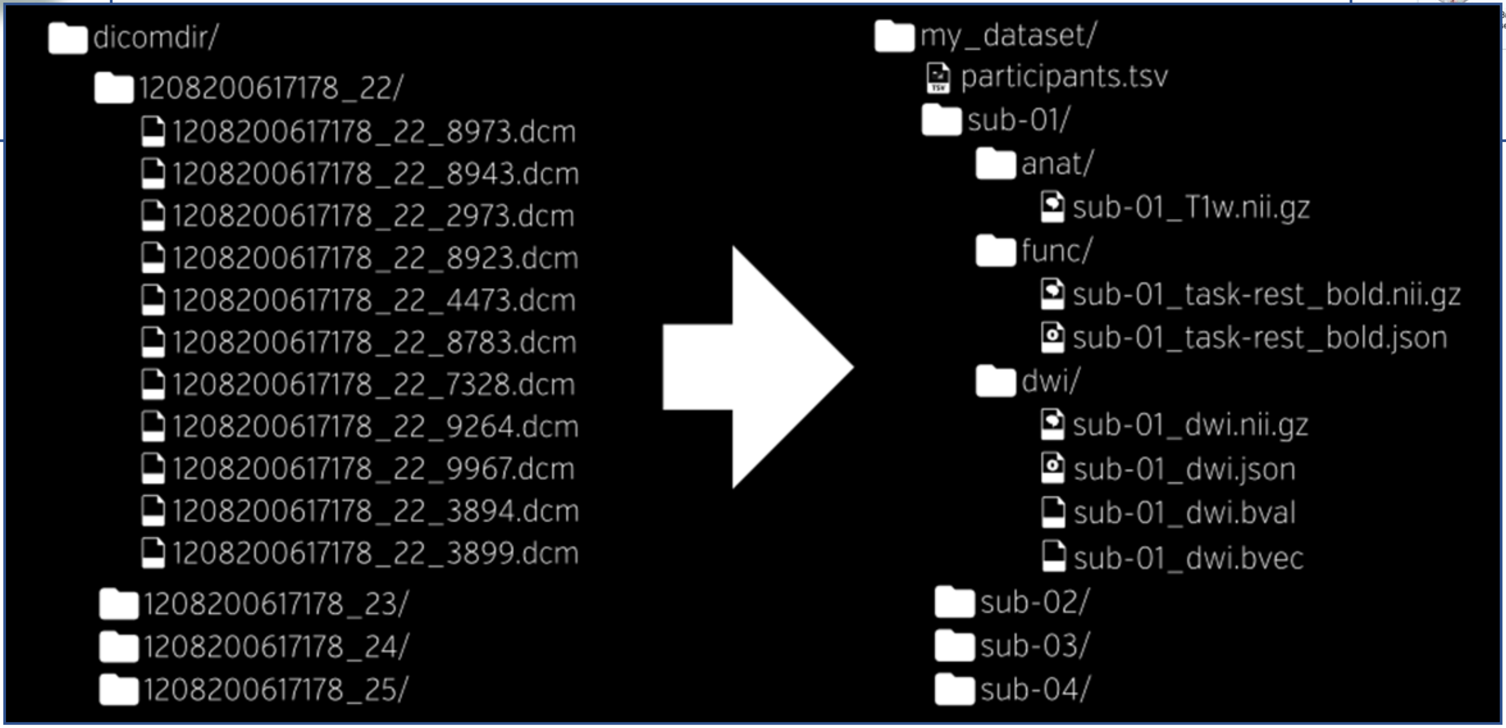
BIDS

Collect the data

Pre-process & Analyse



Many BIDS converters available

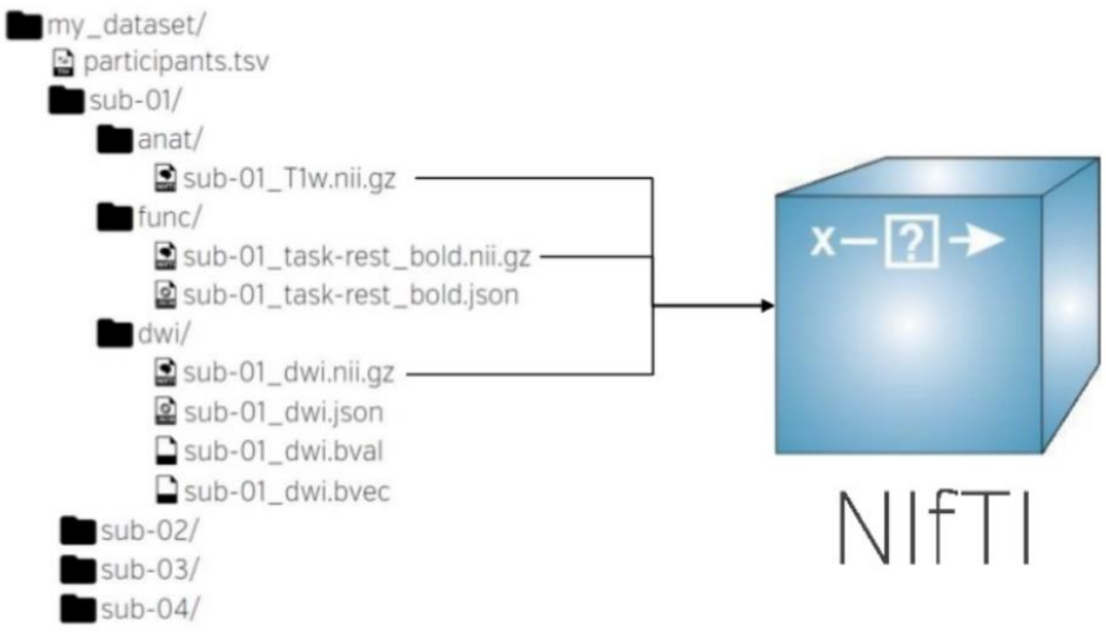


Environment

Data

Organise & Manage

Let’s see the 02-fMRI_Data_Management.ipynb notebook



Imaging data content

MRI data structure

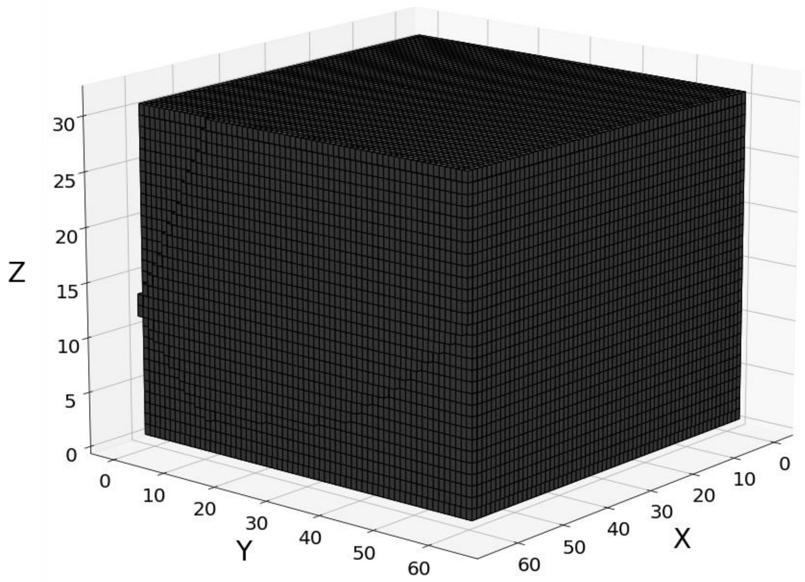
A 3D or 4D arrays of numbers

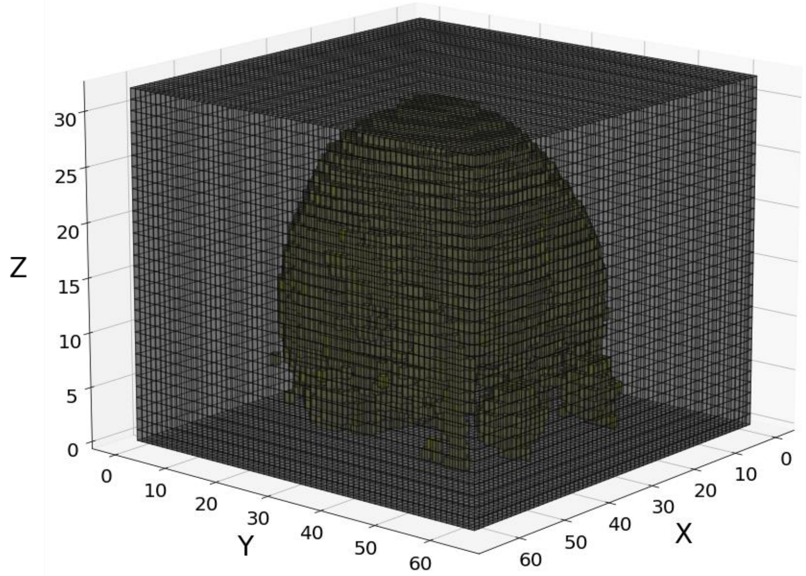
```
([[[ 0.,  0.,  0., ...,  0.,  0.,  0.],
   [ 0.,  0.,  0., ...,  0.,  0.,  0.],
   [ 0.,  0.,  0., ...,  0.,  0.,  0.],
   ...,
   [ 0.,  0.,  0., ...,  0.,  0.,  0.],
   [ 0.,  0.,  0., ...,  0.,  0.,  0.],
   [ 0.,  0.,  0., ...,  0.,  0.,  0.]],

  [[ 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.]],

  ...,
```

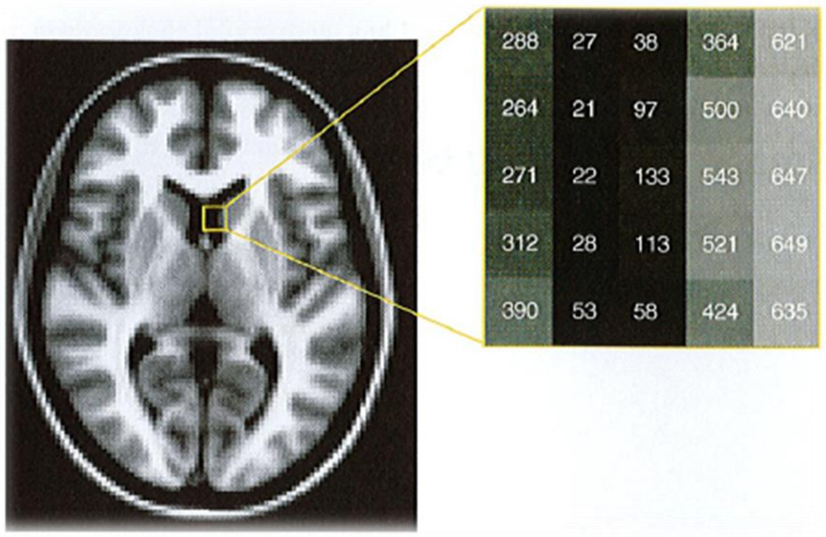
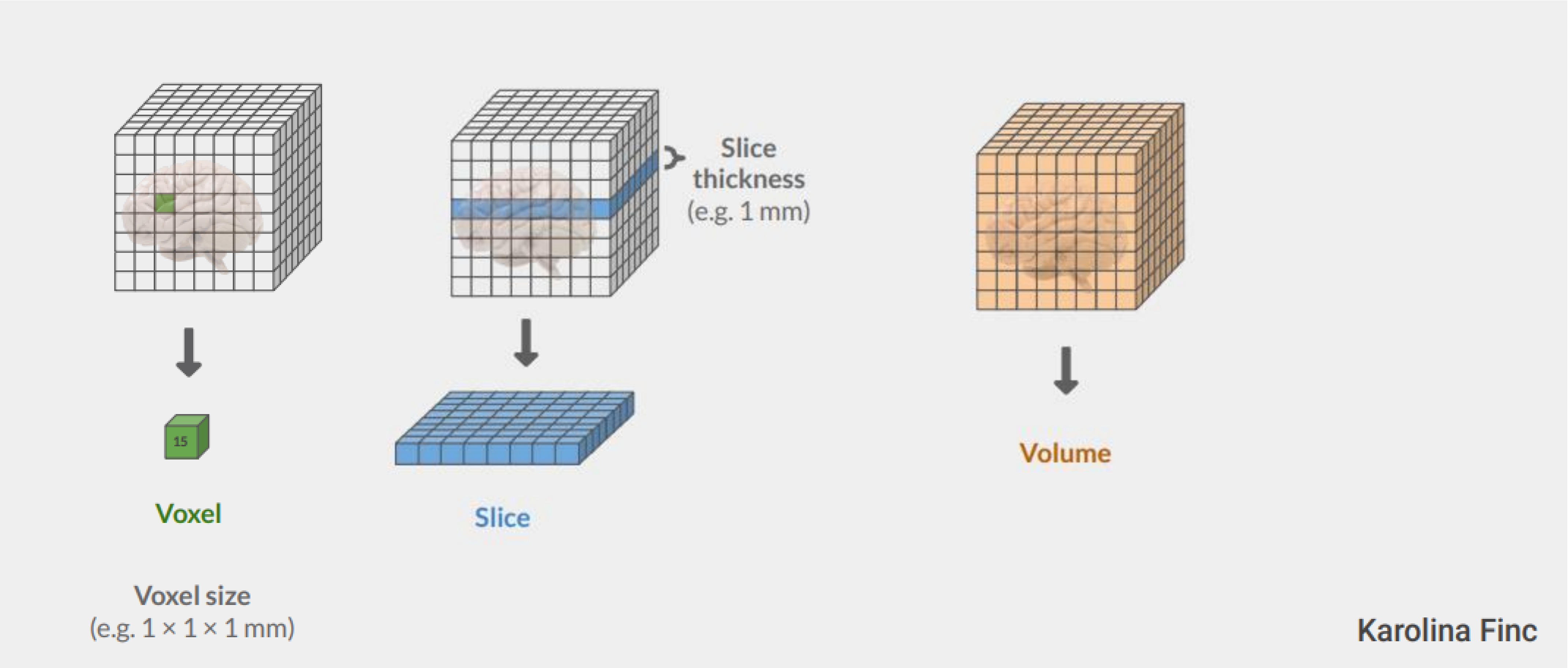


Image from Poldrack et al., 2011

MRI data structure

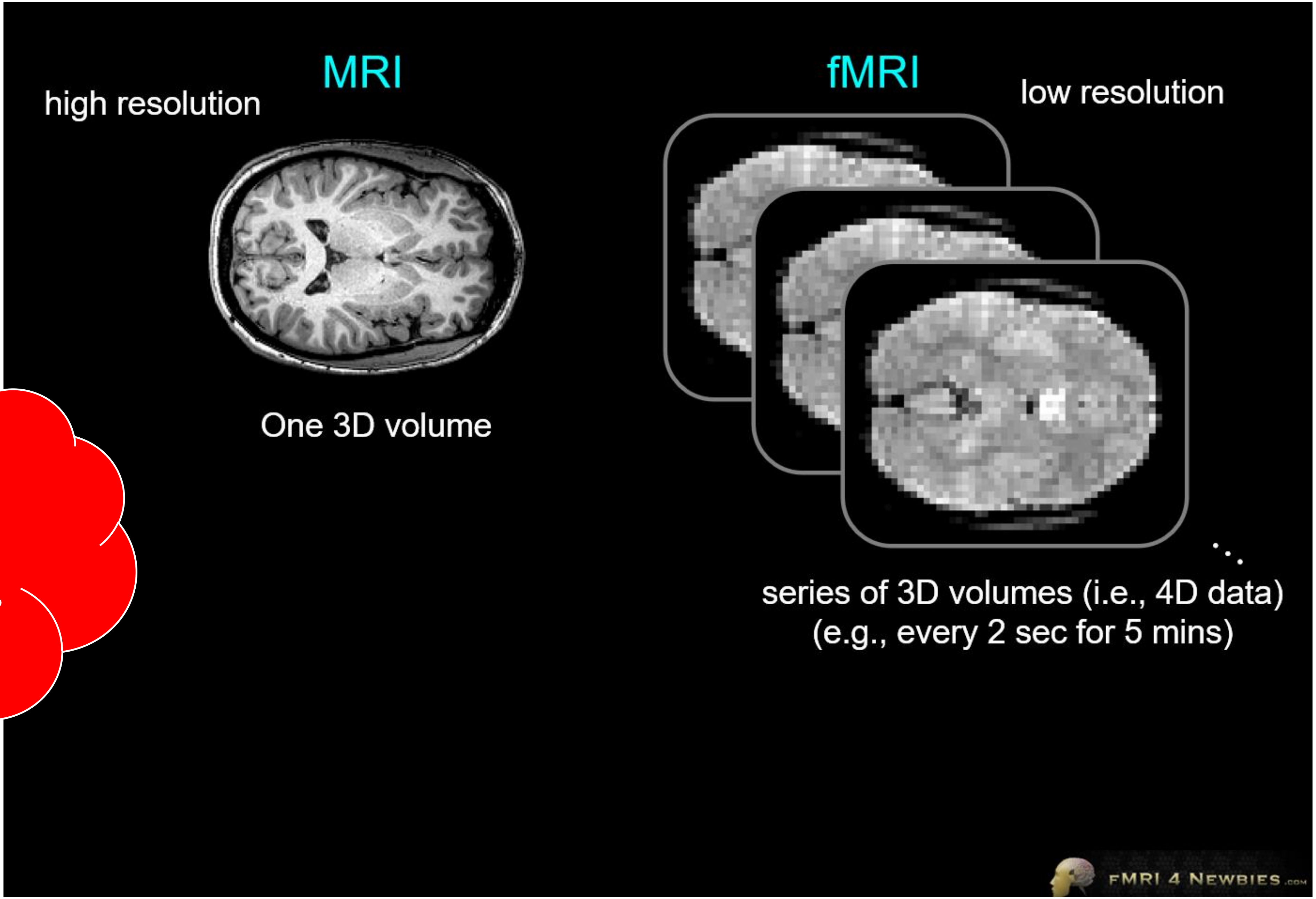


MRI data

MRI data

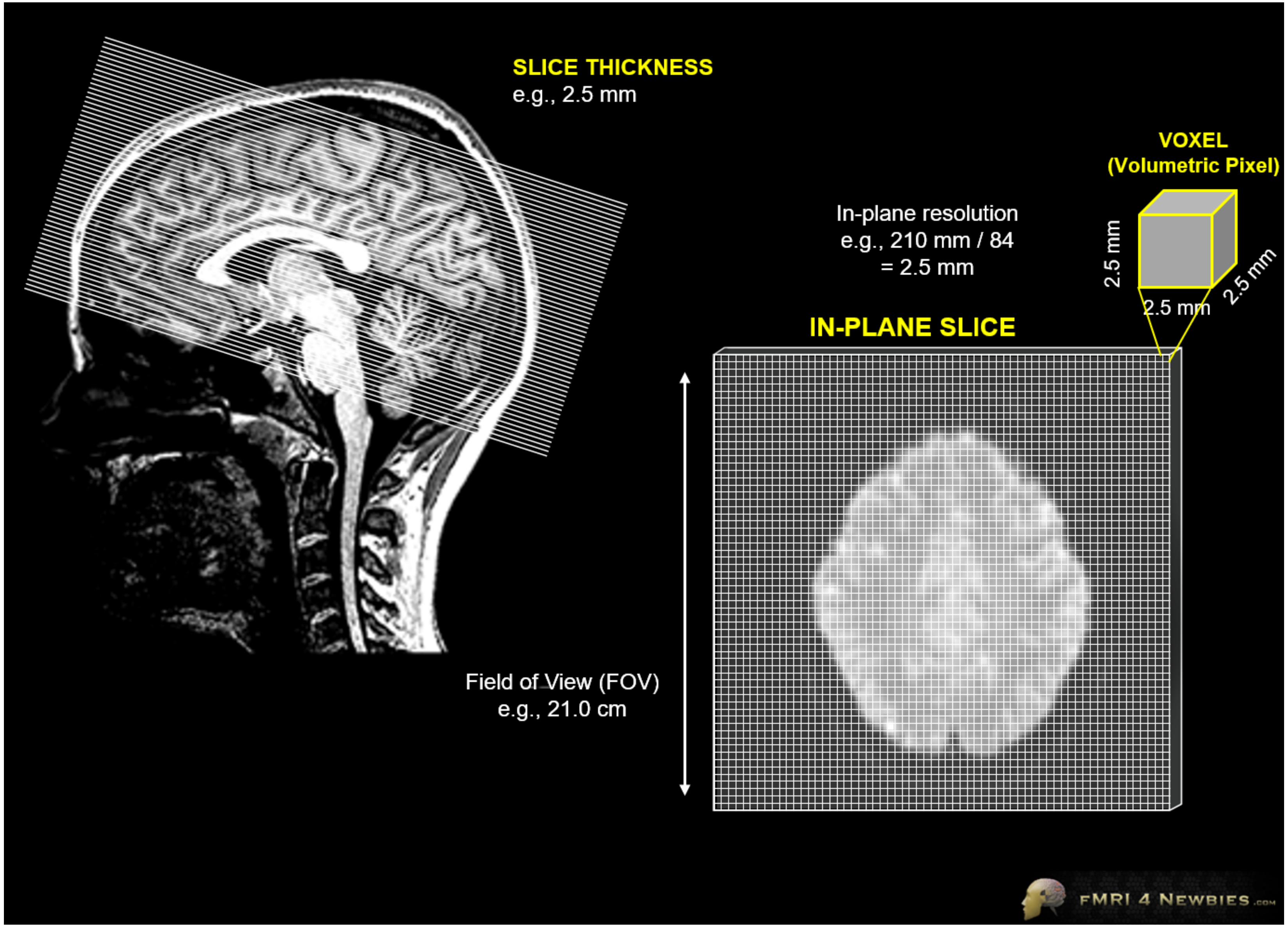
What determines the resolution?

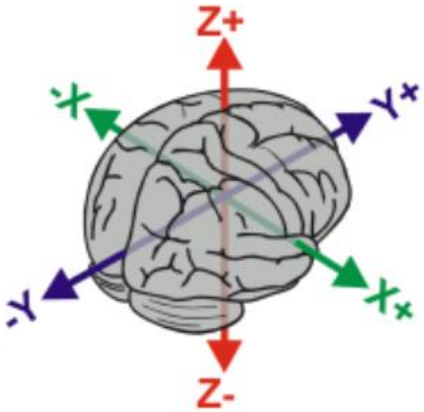
Why can't we acquire the functional images with higher resolution?

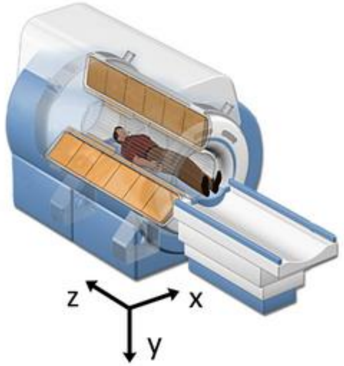


fMRI data

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

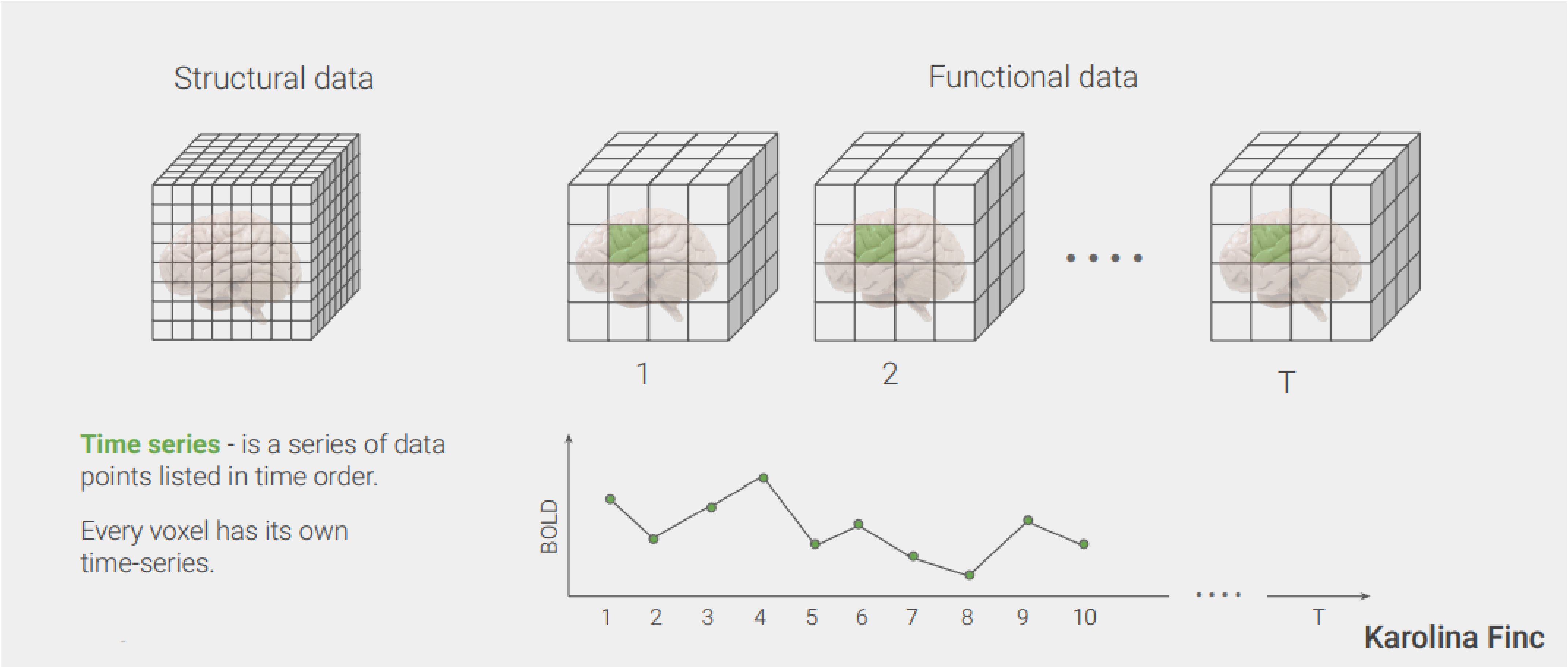






- Temporal resolution (TR) usually 1.5-3s
- Modern sequences allow acquiring multiple slices at the same time
- Typically 30-50 slices acquired
- More slices = longer TR

MRI data structure



Environment

Data

Organise & Manage

Let’s check the Hands-On_02_Neuroimaging_data_manipulation notebook