Introduction into fMRI analysis. PsyMsc4 (Goethe 2022).

Session 1

Javier Ortiz-Tudela and Francesco Pupillo

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GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Who is this seminar for?

This is a hands-on workshop on functional Magnetic Resonance Imaging (fMRI) analysis for the PsyMSc4 at the Goethe University.

Very few assumptions are made about previous knowledge on the topic, so this workshop can be a very good entry point for complete beginners from any discipline. Also, the first introductory session could also be suited for non-scientists willing to get a broad idea into what MRI is.

What is this seminar for?

The workshops will cover **which** are the necessary and common steps when conducting fMRI research and **how** to run them with MATLAB's SPM.

The core Philosophy of the workshop is that one of the main skills that a cognitive neuroscientist should have is the ability to judge what **can** and what **cannot** be done with fMRI experiments from a conceptual level. In order to acquire such a skill, one needs to *understand* fMRI research , i.e., to know the basics of the technique itself and the logic behind the most common analysis.

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How is this seminar structured?

The workshop is structured in six sessions of about 4 hours each. Each session will be dedicated to a specific processing or analysis step.

Sessions 1 - 5 will start with **theory** and logic behind that day's step and will continue with a **hands-on exercise**. Students will select a particular dataset to use for the hands-on exercises.

Session 6 will be dedicated to **students' presentations**. Each student will prepare a short presentation (~15 minutes / ~15 slides) describing the **motivation** of the study, the **analysis** carried out, the **results** obtained and their **interpretation.**

At the end of the workshop, each student will submit an **individual brief report** (2 pages max) on the **results** obtained with their corresponding dataset and their **interpretation**.

Working in groups is allowed and even encouraged. However, the individual presentations and the reports need to be unique.

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Part I. Basics of MRI

Here are the basics of MR imaging

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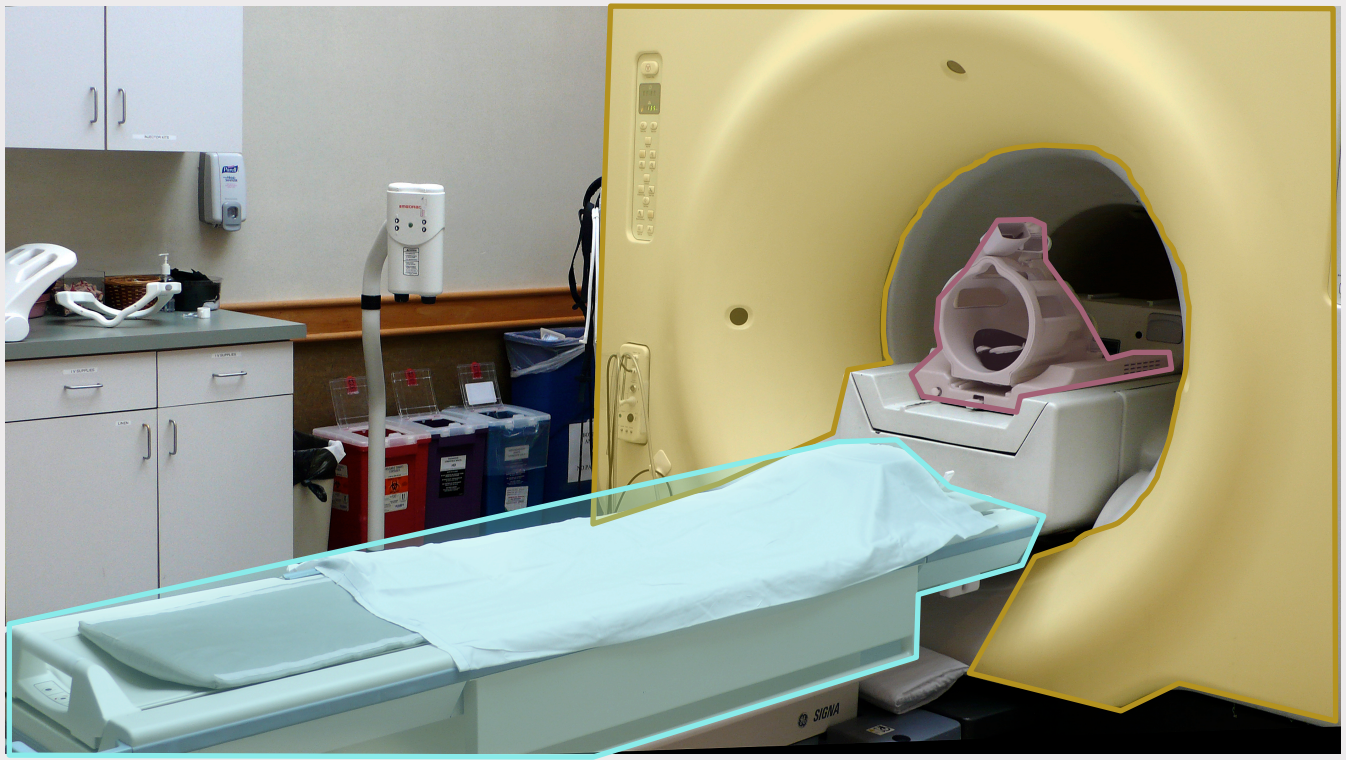
Here are the basics of MR imaging



Scanner

Coil

Bed

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Here are the basics of MR imaging

Scanner =
big magnet + radio frequency transmitter

big and **very** strong!

CAUTION!!

loud and annoying!

CAUTION!!

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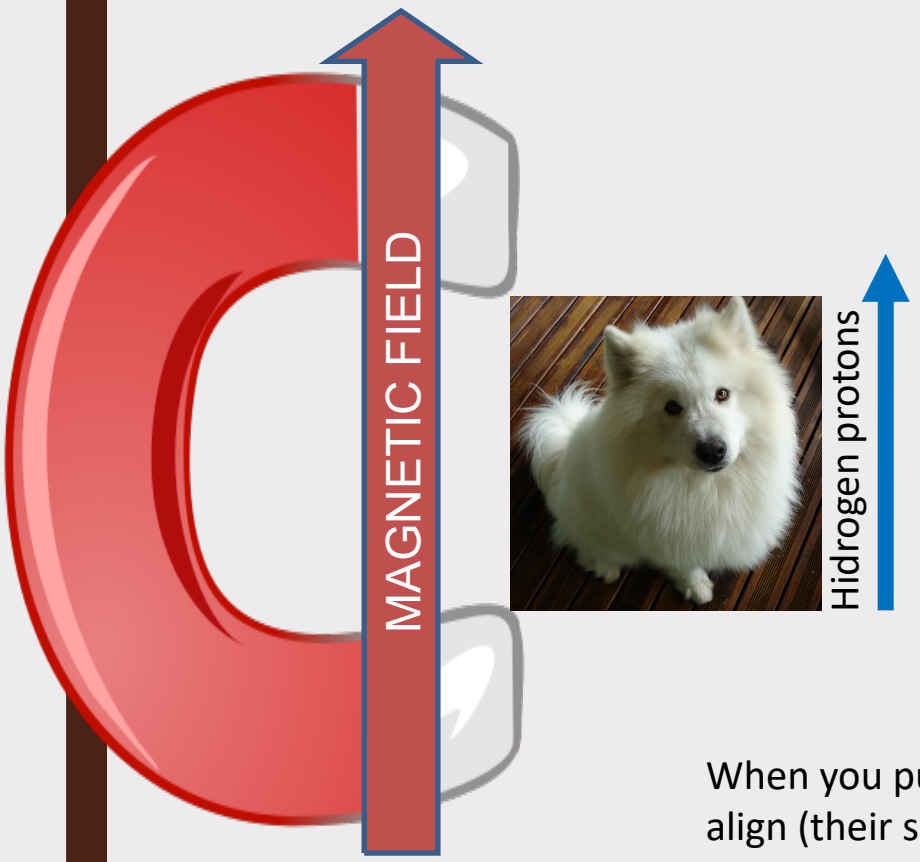
Here are the basics of MR imaging

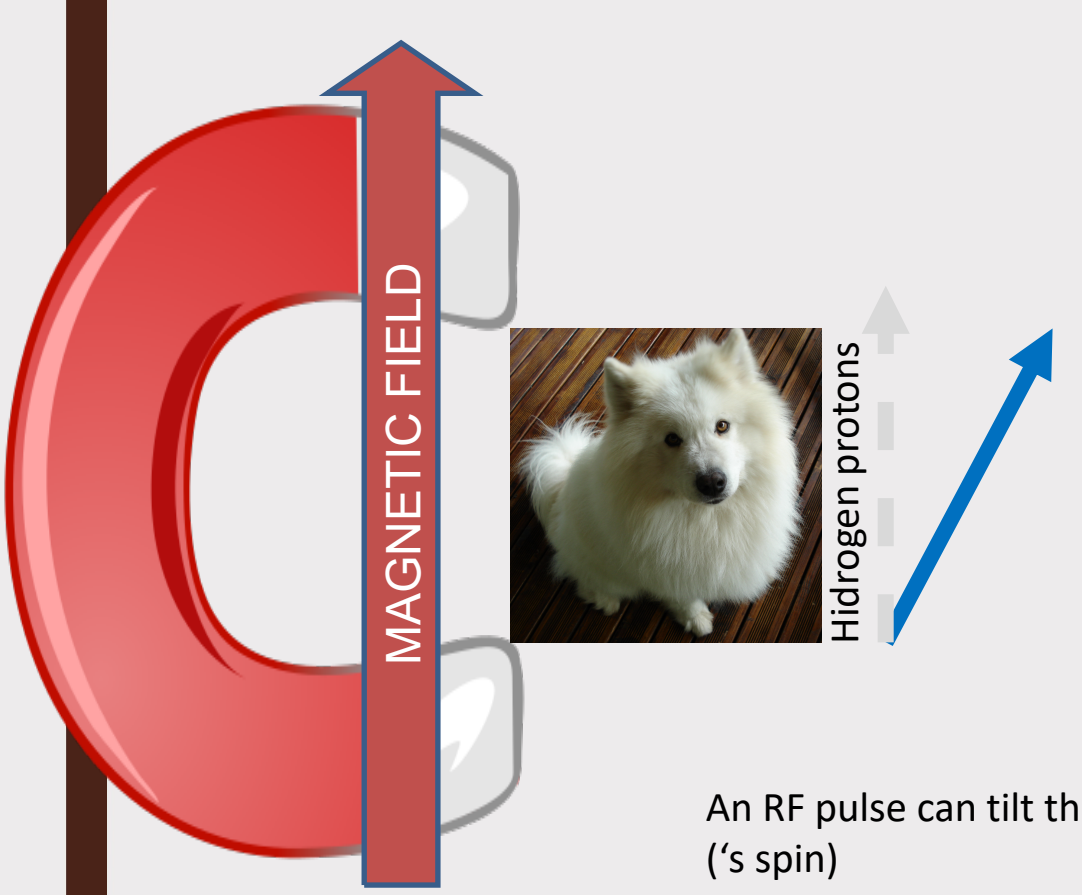
Scanner =
big magnet + radio frequency transmitter



When you put something inside a magnetic field, its H protons align (their spin) to the magnetic field.

Here are the basics of MR imaging

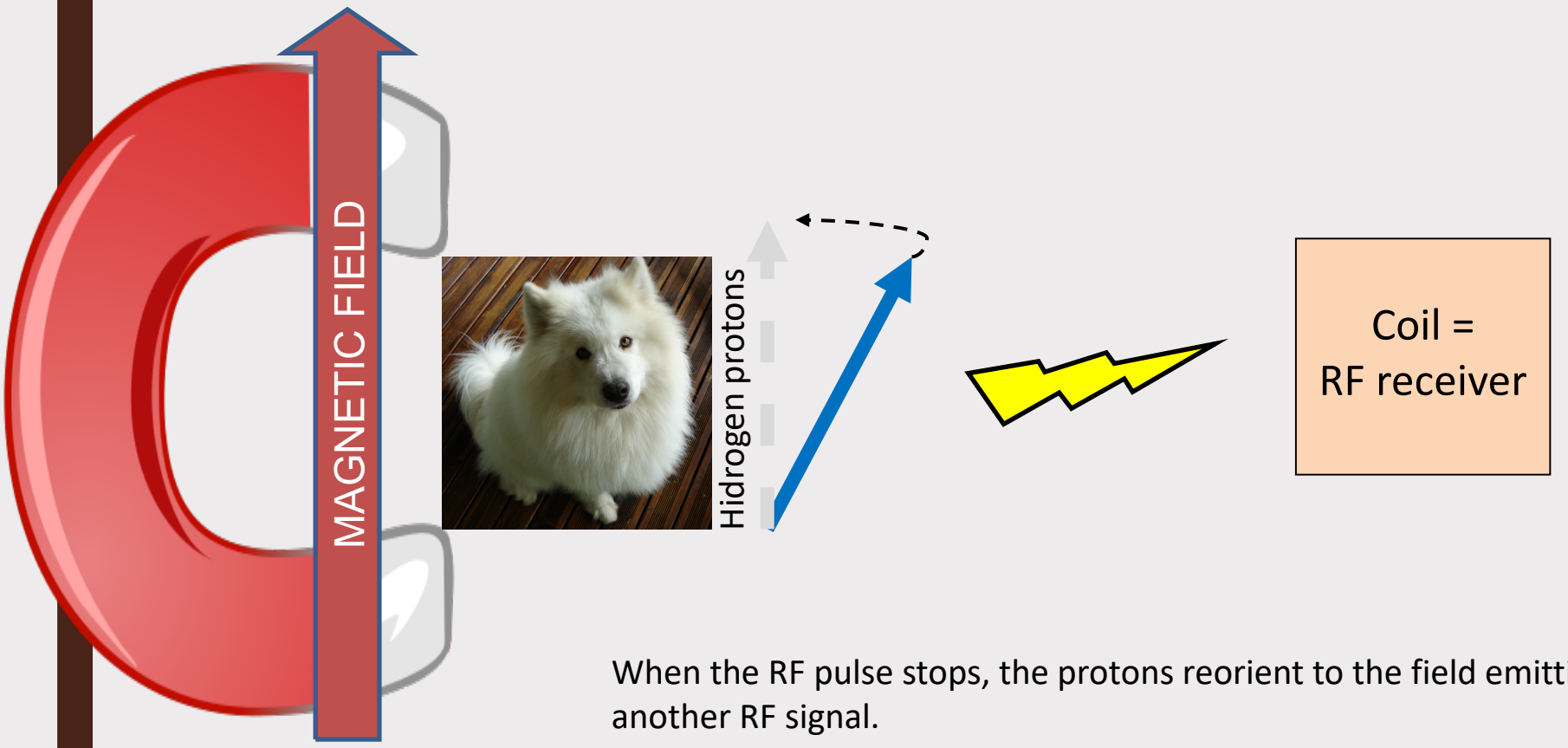
Scanner =
big magnet + radio frequency transmitter



An RF pulse can tilt the orientation of the proton ('s spin)

Here are the basics of MR imaging

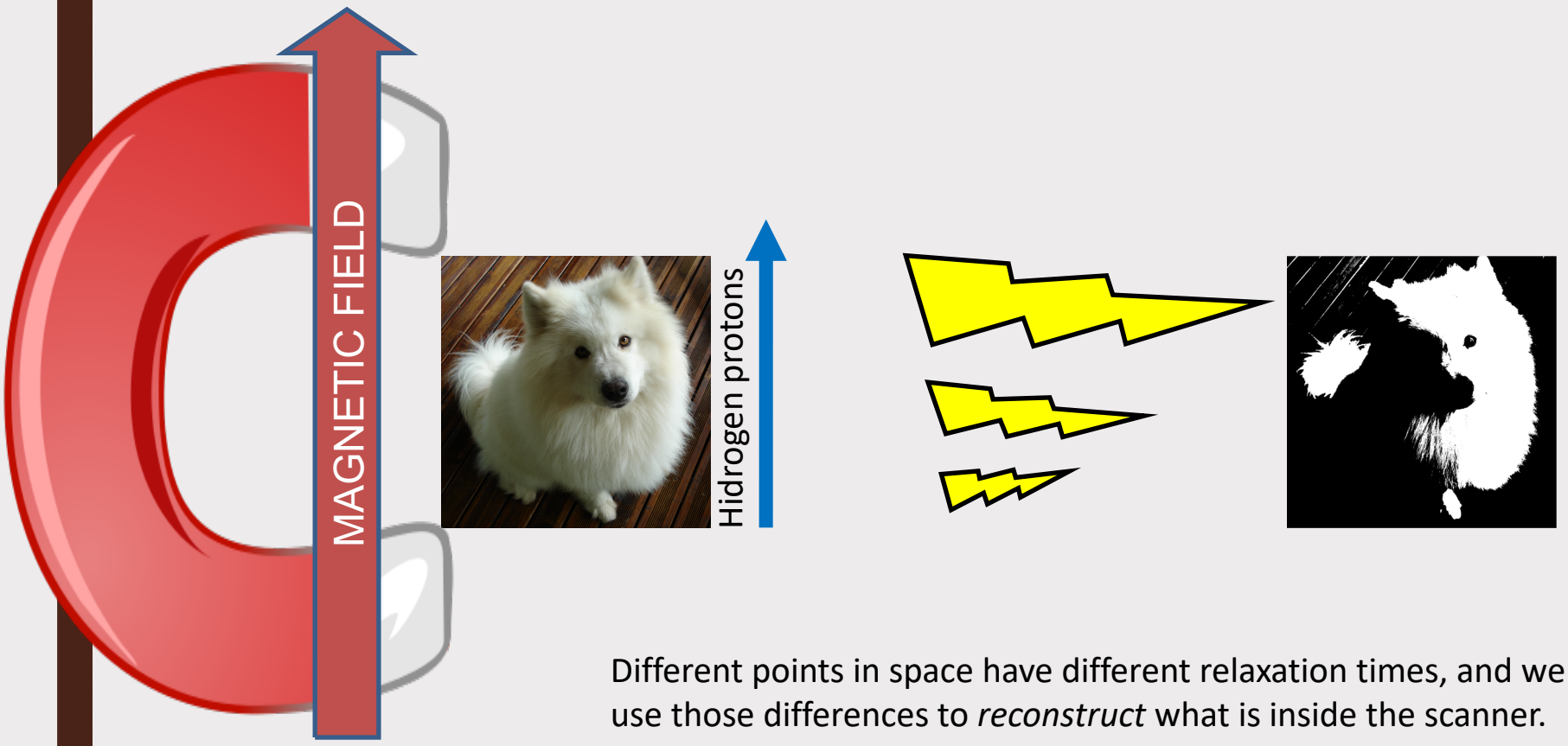
Scanner =
big magnet + radio frequency transmitter



When the RF pulse stops, the protons reorient to the field emitting another RF signal.
The time taken is known as *relaxation time*.

Here are the basics of MR imaging

Scanner =
big magnet + radio frequency transmitter



Different points in space have different relaxation times, and we can use those differences to *reconstruct* what is inside the scanner.

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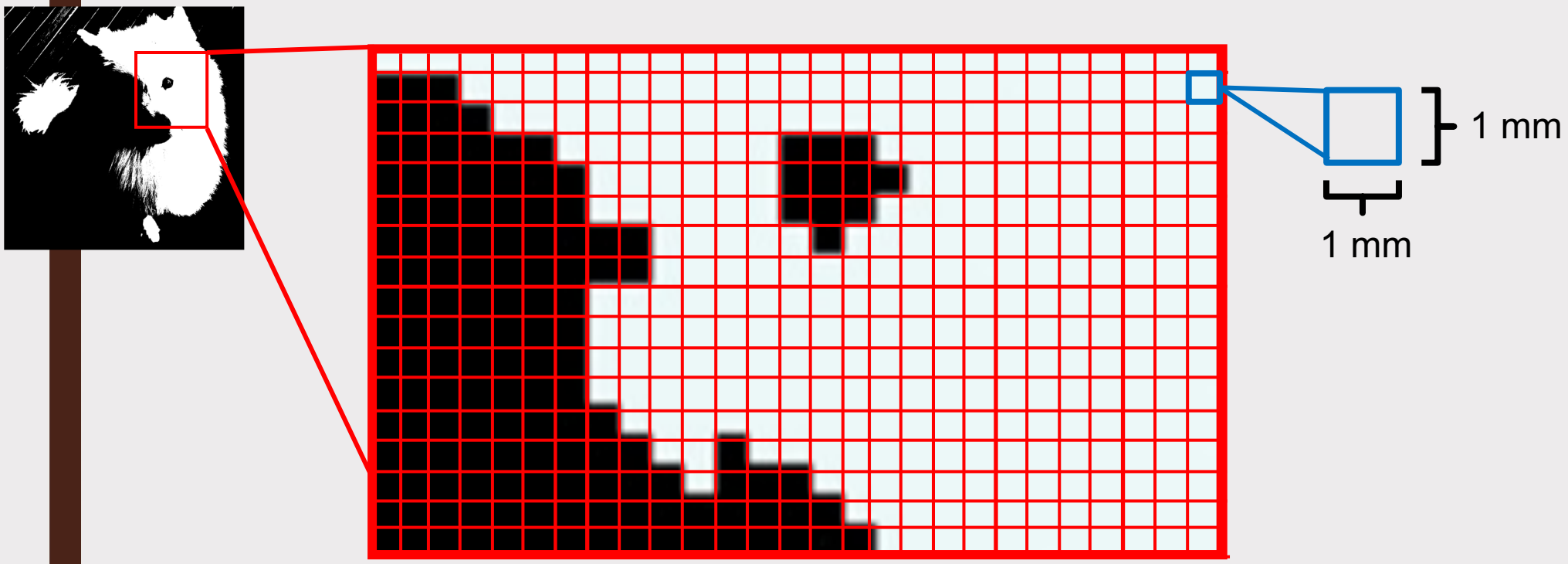
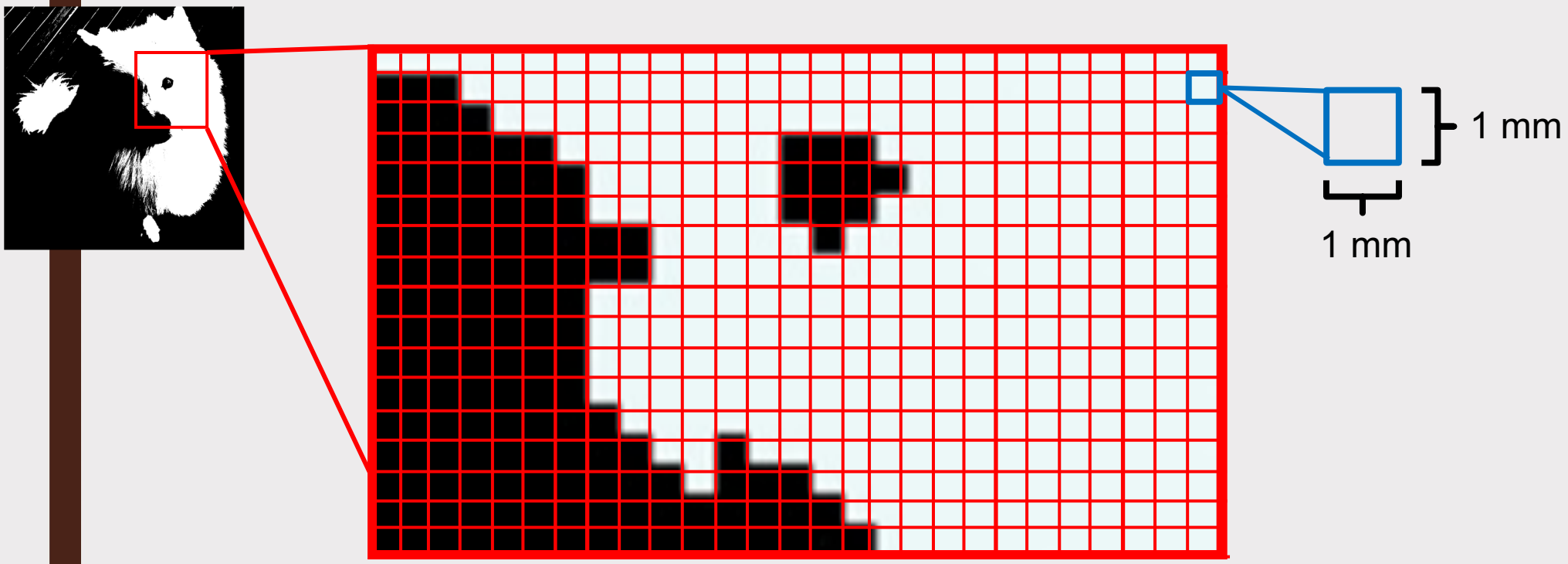
So... What are MR images?



If we zoom in, we can see that images are composed of pixels.

The size of each side of the pixel determines the image resolution (1 x 1 mm, in this example).

So... What are MR images?

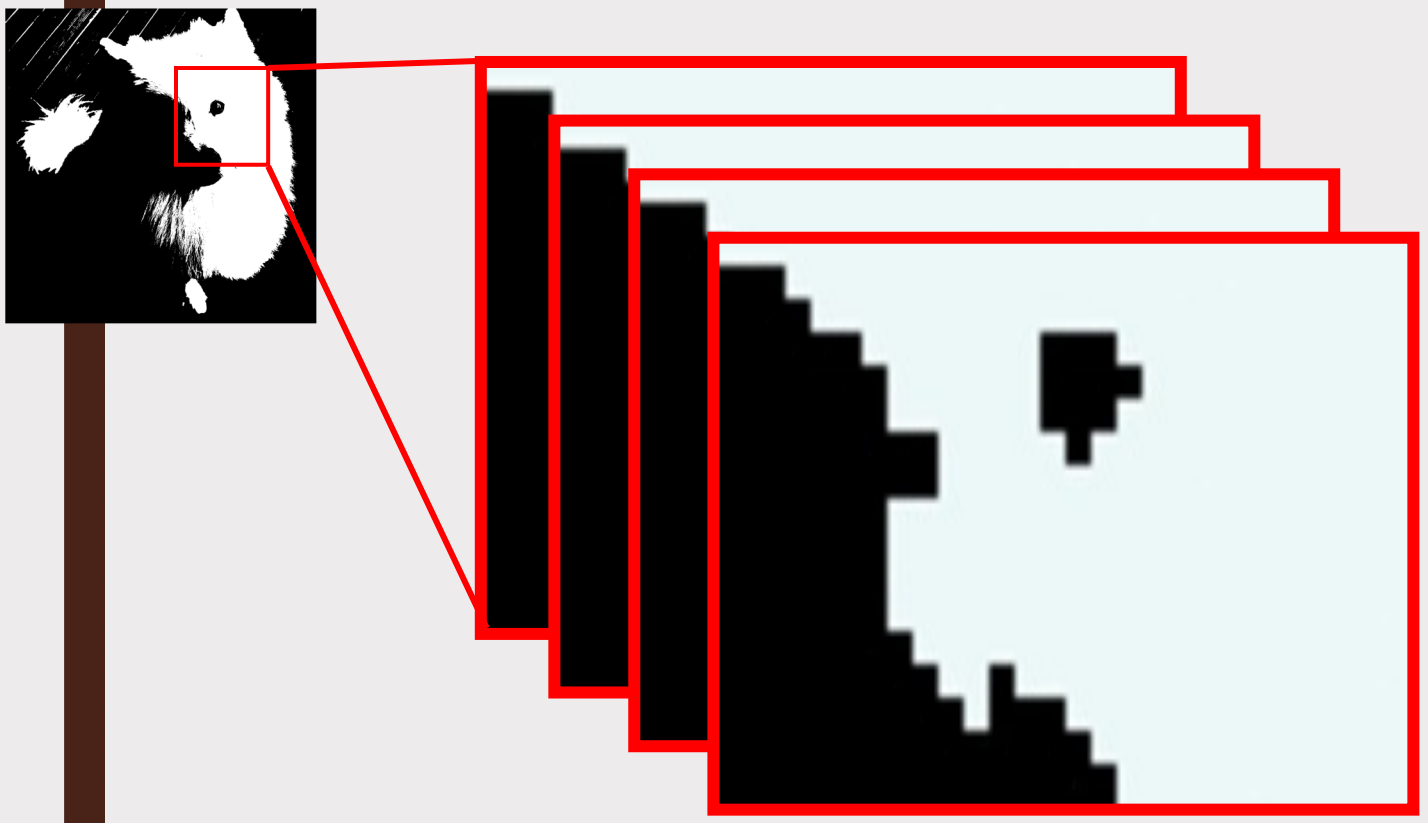


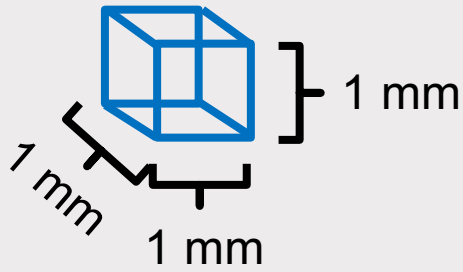
Each pixel contains one value (either 1 or 0, in this example).

0	1

The current color map assigns ”black” to 0 and “white” to 1.
But remember that the color map is arbitrary!

So... What are MR images?





When we have a 3D image, we talk about voxels (1 x 1 x 1 mm, in this example).

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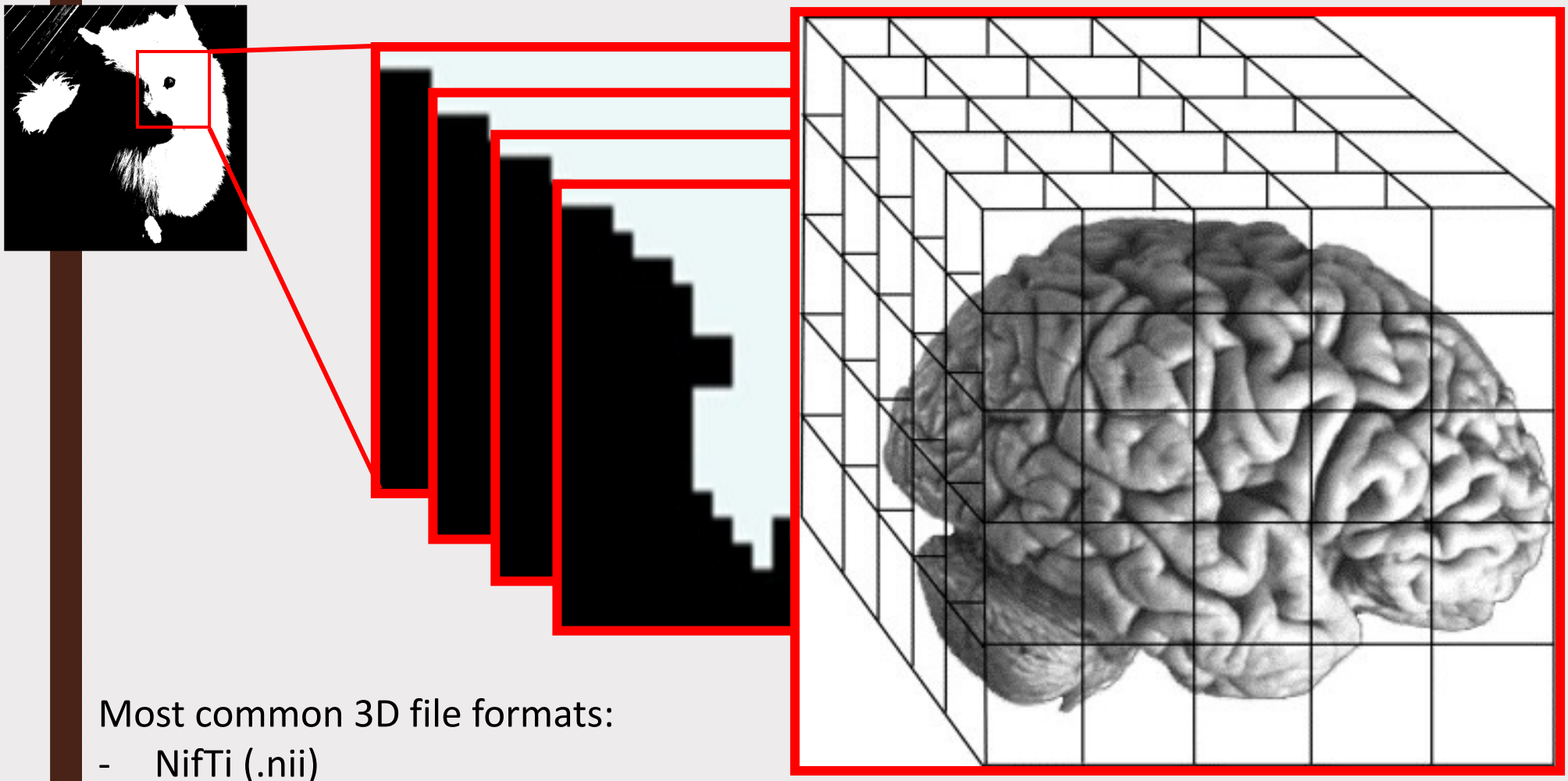
So... What are MR images?



Most common 3D file formats:

- NifTi (.nii)
- Compressed NifTi (nii.gz)

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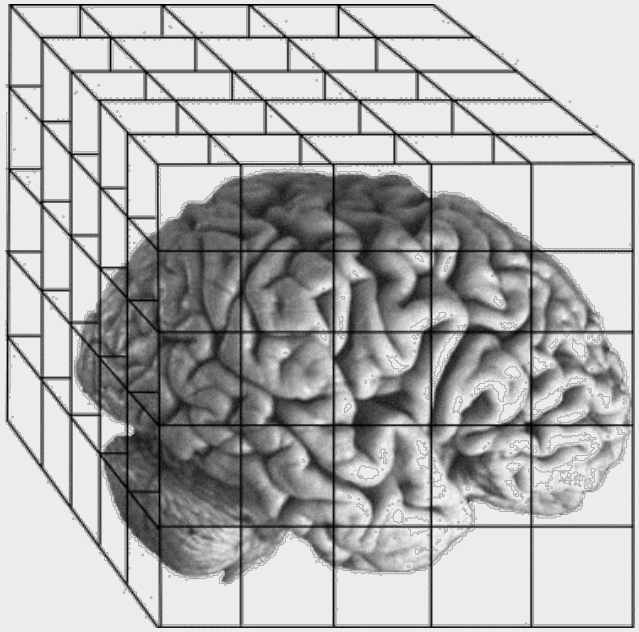
So... What are MR images?



Voxel size determines our image resolution: smaller = better.

Resolution is (partly) dependent on the strength of the magnetic field.

The **earth's magnetic field**, at the equator, is approximately 0.00005 T

Common resolutions for different strengths:

1.5 Tesla ~ **3x3x3**

3 Tesla ~ **2x2x2**

7 Tesla ~ **0.8x0.8x.0.8**

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Part I. Basics of MRI. Recap

- Scanner = magnet + RF transmitter
- MRI relies on the magnetic properties of the tissue.
- MR images are 3D “pictures” composed of voxels with one value per voxel.
- Most common 3D files: NifTi (.nii) and compressed NifTi (nii.gz).
- Spatial resolution depends on scanner strength.

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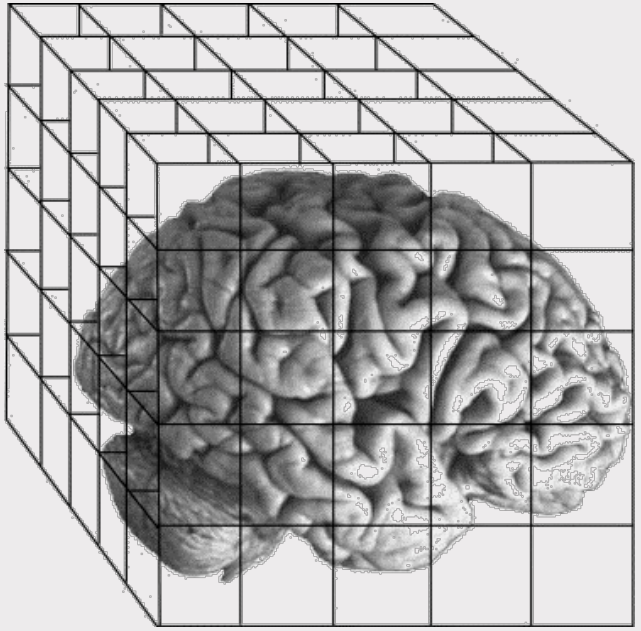
Part II. Types of MR images



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Types of MR images*

Anatomical images

Functional images

*For the purpose of this seminar only these two types will be covered since they are essential for standard fMRI analysis.

Types of MR images

Anatomical images (T1w)

Differences in signal strength caused by different tissue types.

Aim:
Structure
Feats:
Good spatial resolution.
Task free.
Slow acquisition
(~5 min full brain)

Functional images

Types of MR images

Anatomical images

Functional images (T2*)

Aim:
Activity
Feats:
"Good" time resolution.
Measures blood flow.
Task sensitive.
Fast acquisition
(~2s full brain)

Differences in signal strength caused by distortions in the magnetic field.

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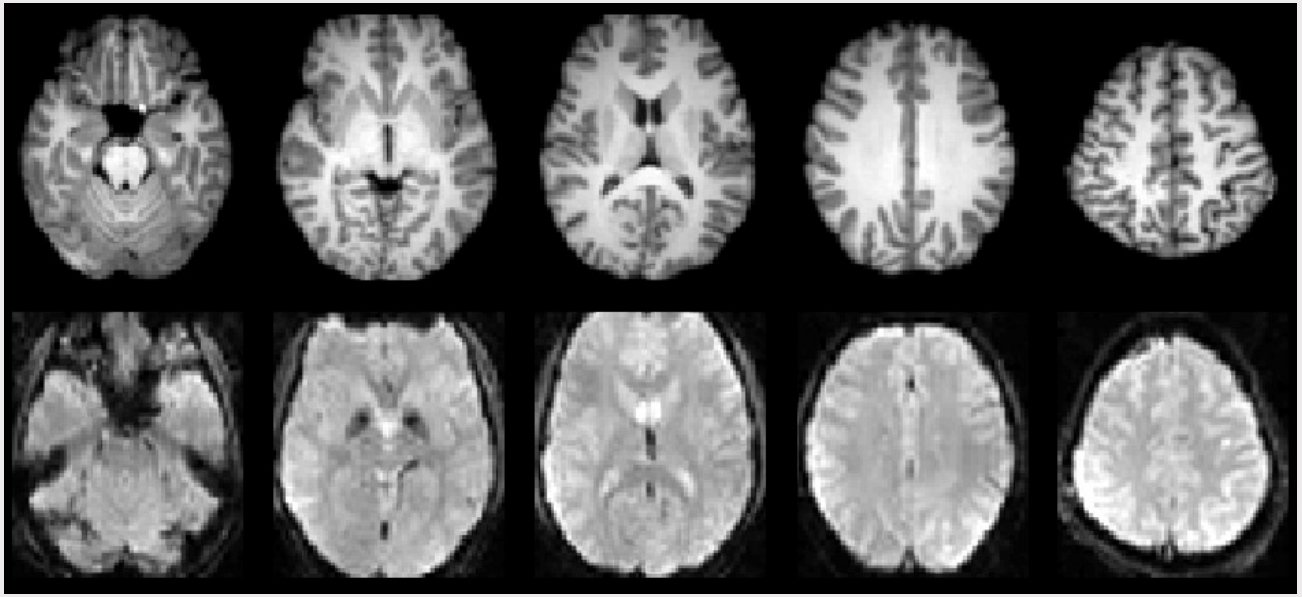
Types of MR images

Anatomical images

Functional images



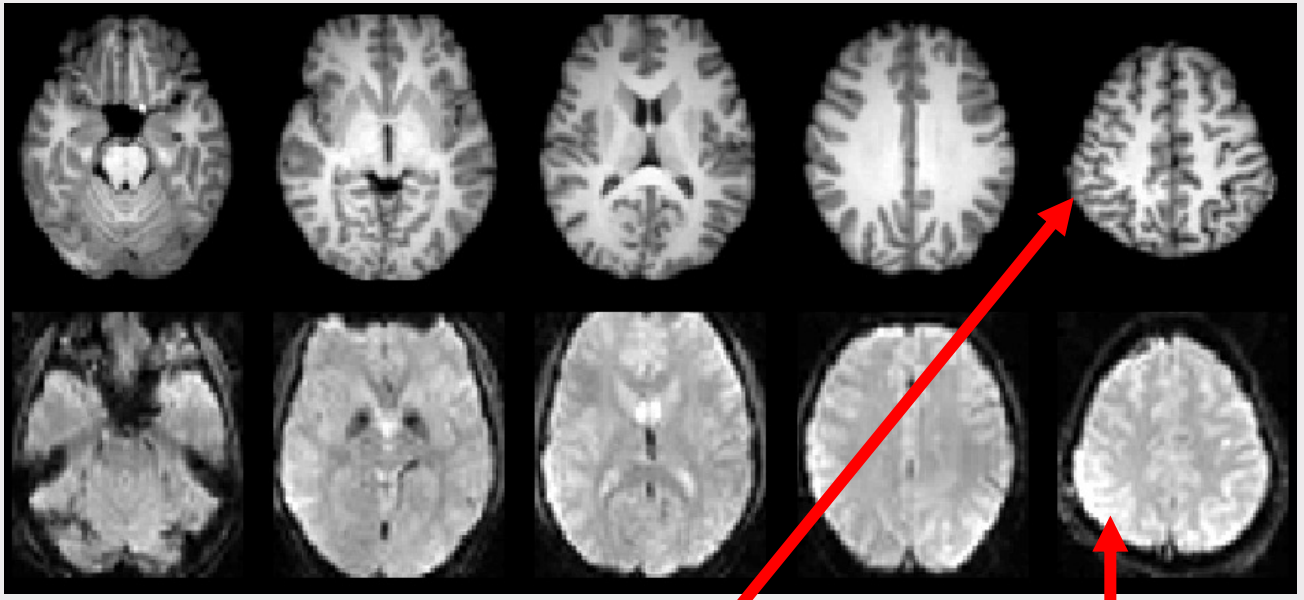
How to distinguish them?

Inverse contrast!

Types of MR images

Anatomical images

Functional images



How to distinguish them?

Inverse contrast!

T1w:
Grey matter – dark
White matter - bright

T2:
Grey matter – bright
White matter - dark

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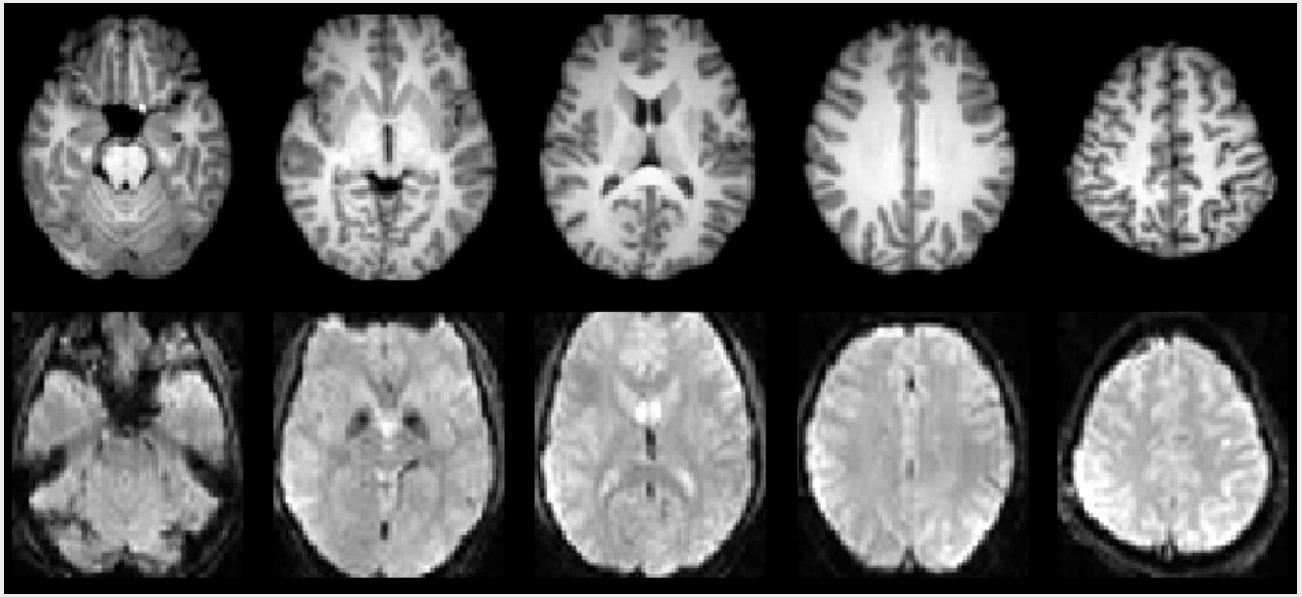
Types of MR images

Anatomical images

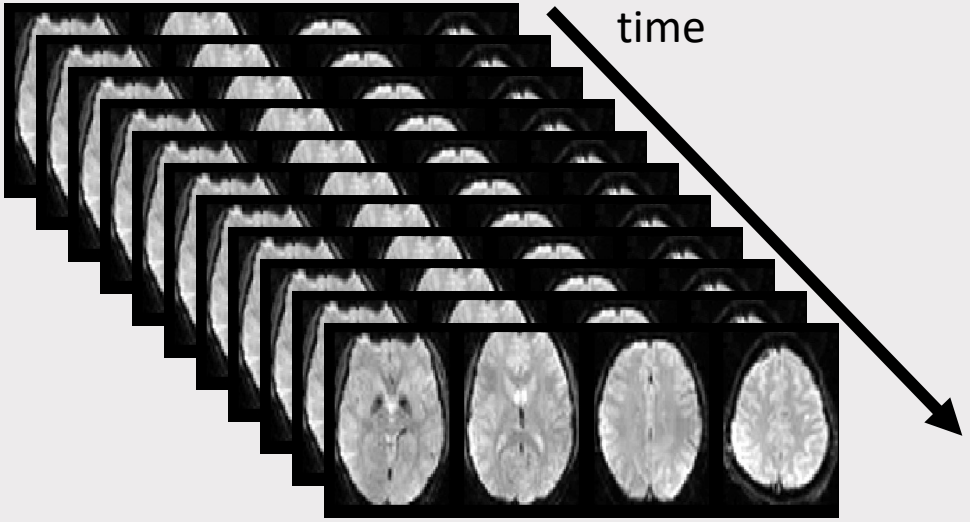
Functional images



How to distinguish them?

Functional images have (usually) lower spatial resolution.

Gain in time resolution!



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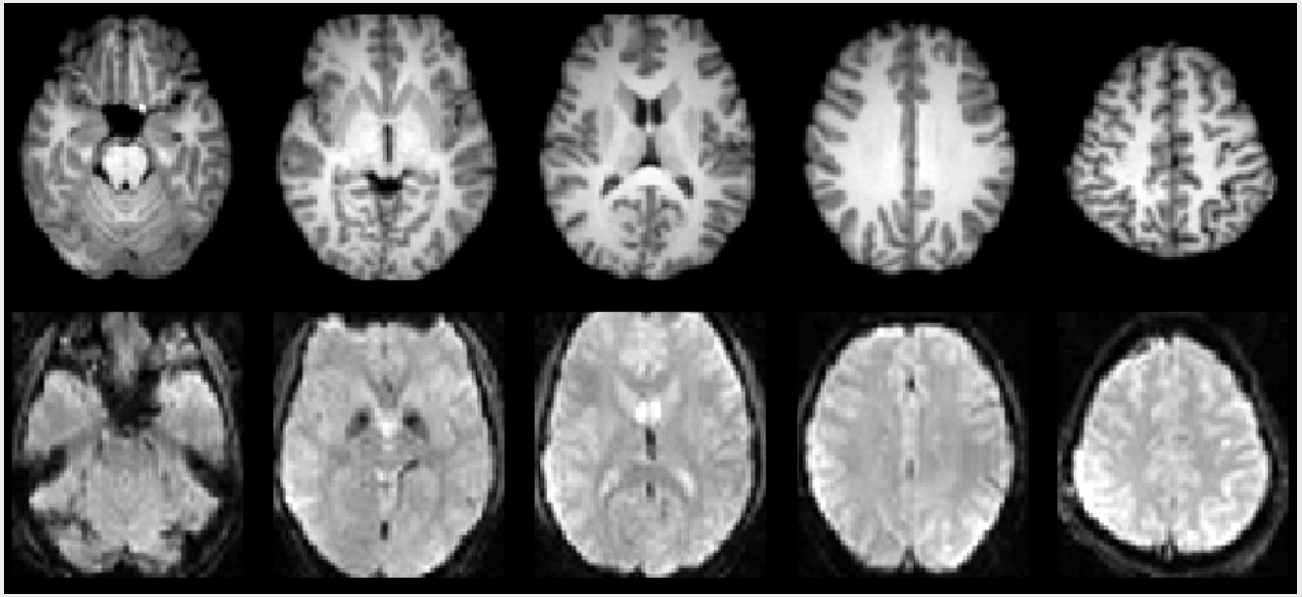
Types of MR images

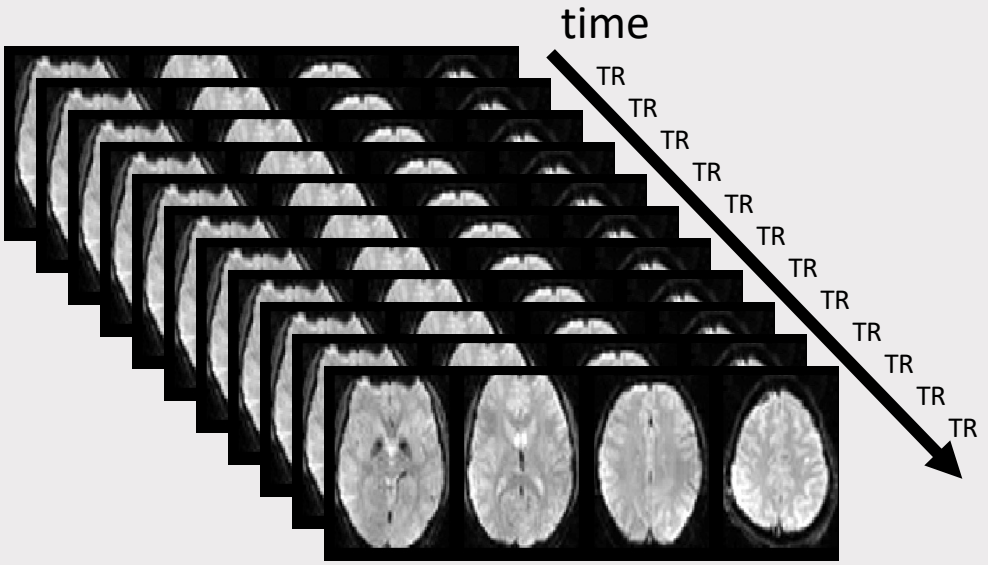
Anatomical images

Functional images



How to distinguish them?

TR = time to sample the entire field (to collect one brain volume).



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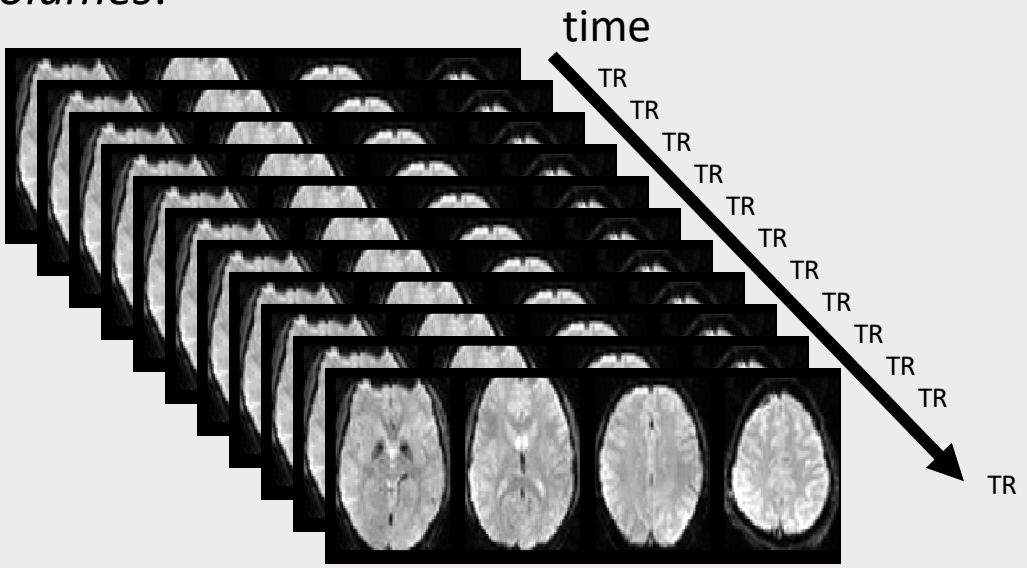
Types of MR images. Functional images

Functional runs. What are they?

Noise due to scanner drift accumulates over time so collecting images for *too long* will cause your images to look bad.

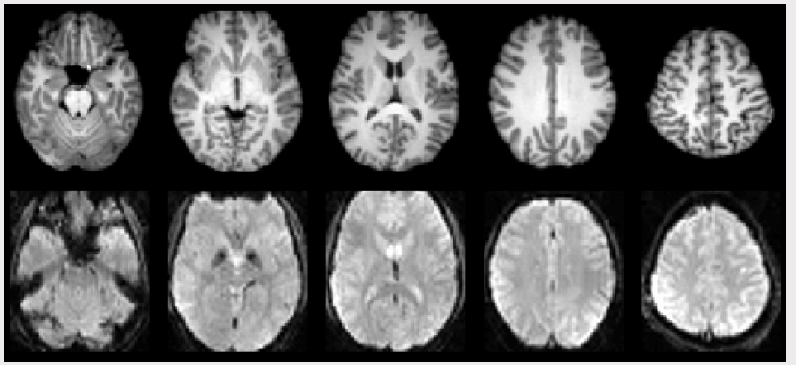
Solution: divide your task into shorter blocks, i.e., runs.
Aprox. run duration: ~10 minutes (adults) / ~6 minutes (children).
Max duration: 15 minutes (ideally shorter).
Run duration is often measured in *volumes*.



Part II. MR images types. Recap

Key ideas.

- MR images can be roughly grouped into **anatomical** and **functional** images.
- Anatomical images (usually one volume) have higher spatial resolution than functional images (usually several volumes).
- TR = time to collect one brain volume.
- Runs = blocks of recording time.



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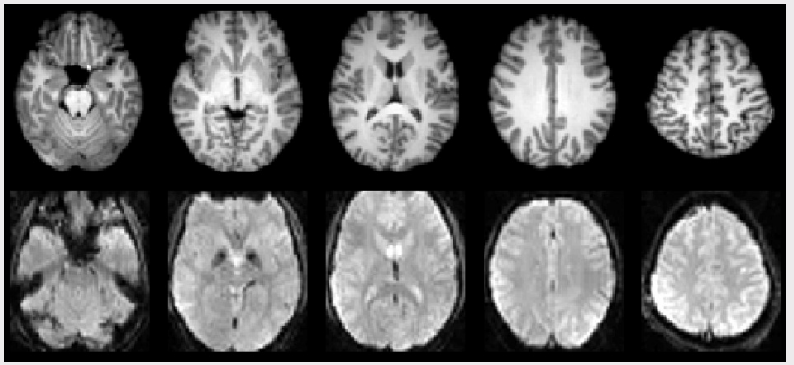
Part III. Image preprocessing



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Preprocessing.

Why?

MR images as a *reconstruction* problem > This process is never perfect.

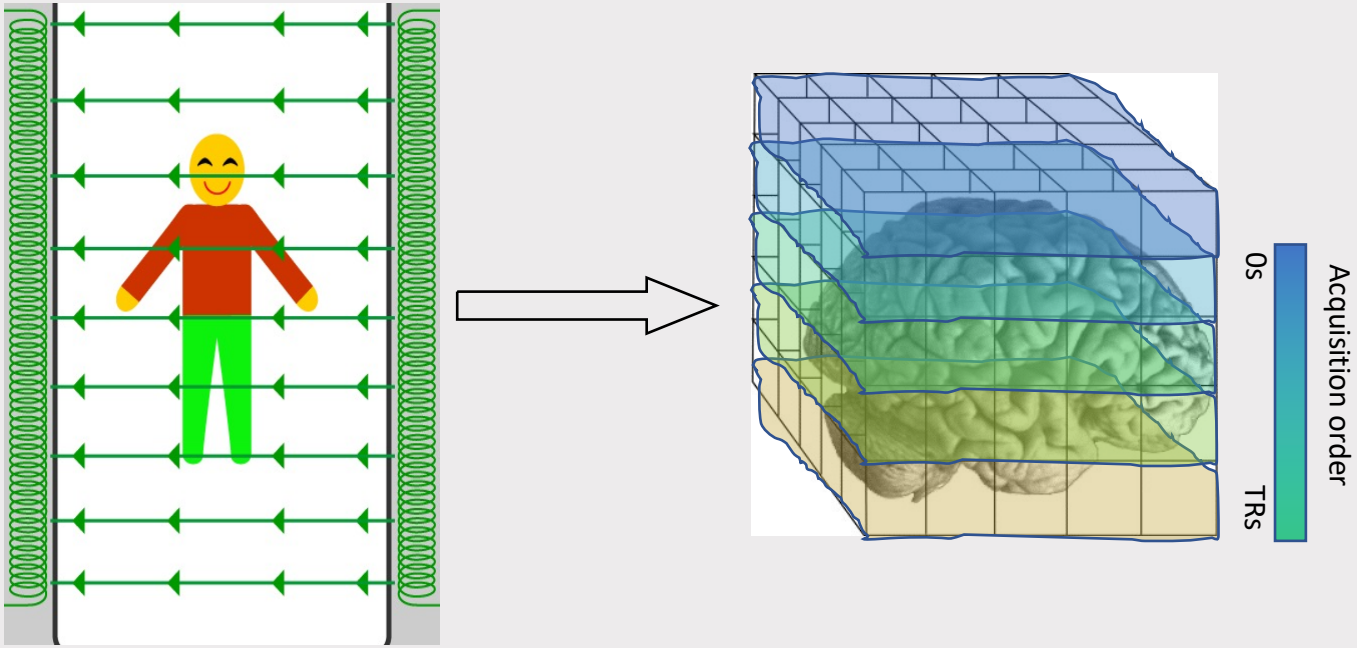
Distortions in MR images can be grouped in two types: temporal and spatial.

Preprocessing.

Why?

MR images as a *reconstruction* problem > This process is never perfect.

Distortions in MR images can be grouped in two types: **temporal** and spatial.



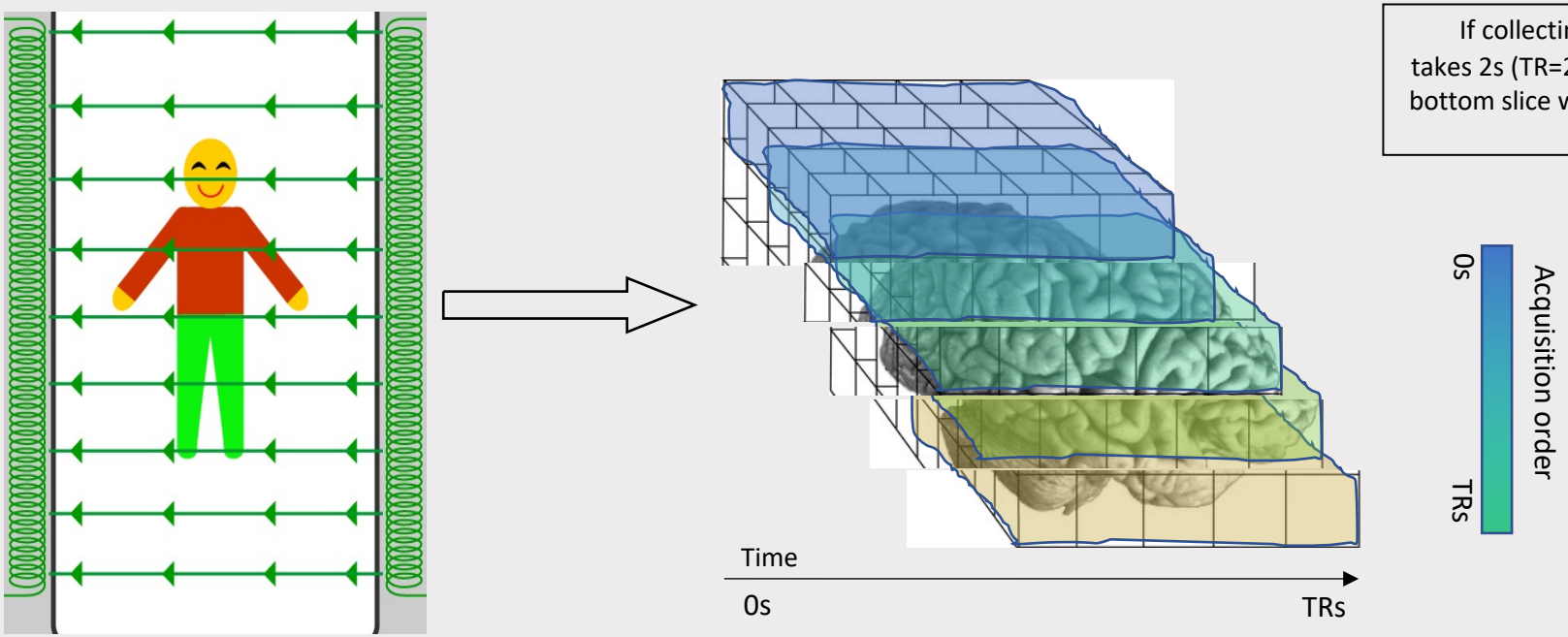
If collecting this entire volume takes 2s (TR=2s), it means that the top slice was acquired ~2 after the bottom one!

Preprocessing.

Why?

MR images as a *reconstruction* problem > This process is never perfect.

Distortions in MR images can be grouped in two types: **temporal** and spatial.



Preprocessing.

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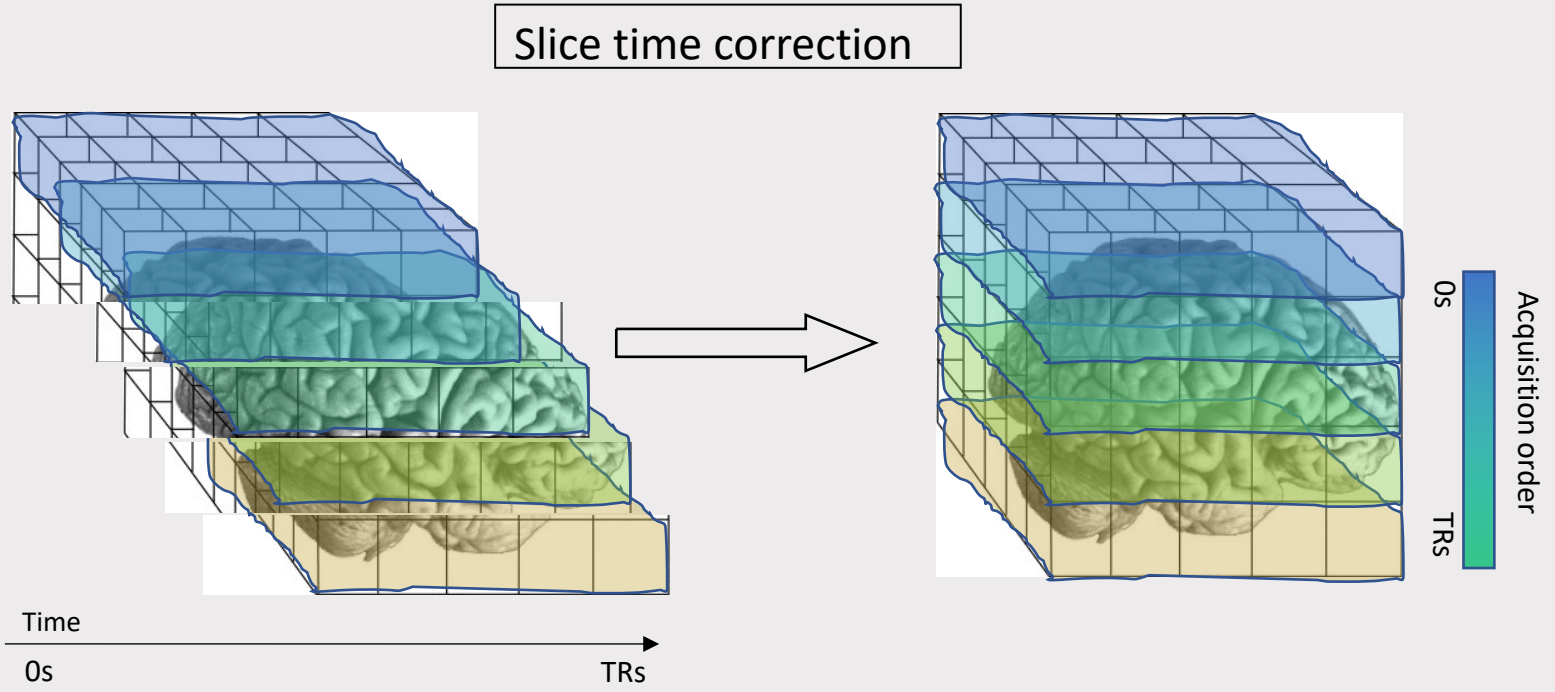


Preprocessing.

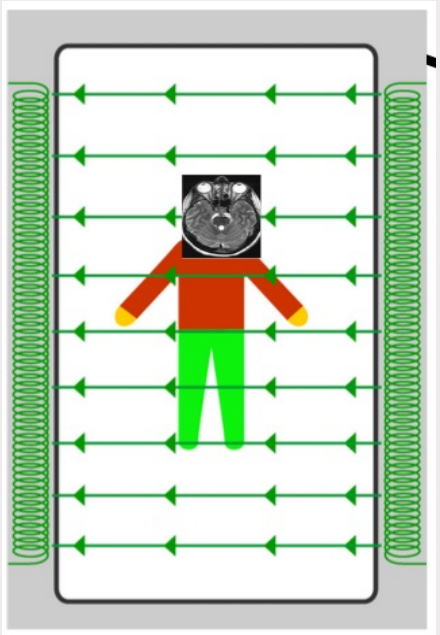
Why?

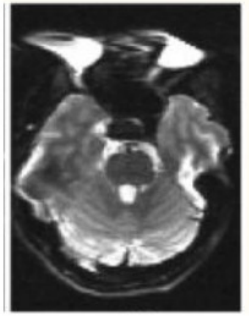
MR images as a *reconstruction* problem > This process is never perfect.

Distortions in MR images can be grouped in two types: temporal and **spatial**.

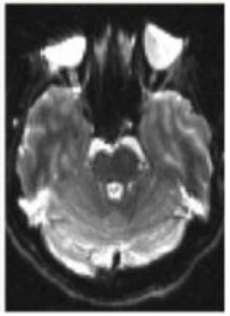
Magnetic field inhomogeneities

"*Magnetic field inhomogeneities, caused by susceptibility differences at tissue/air and tissue/bone interfaces, result in significant geometric and intensity distortions. The challenge of reducing these field inhomogeneity effects arises from their spatial dependence. Data from different spatial locations are corrupted to different degrees, with the amount of corruption determined by the local magnetic field environment.*" (Gholipour, et al., 2011).





Right-Left



Anterior-Posterior

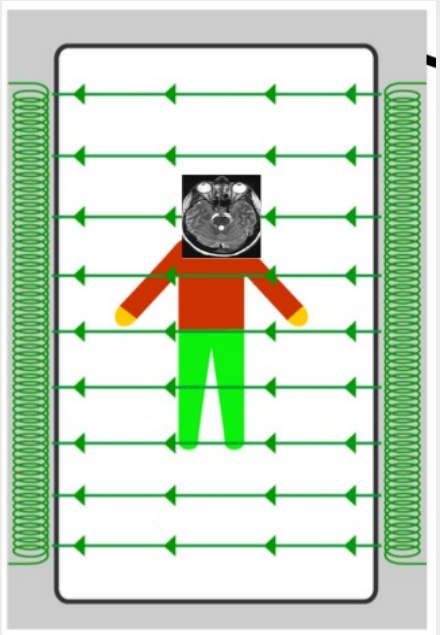
Preprocessing.

Why?

MR images as a *reconstruction* problem > This process is never perfect.

Distortions in MR images can be grouped in two types: temporal and **spatial**.

Magnetic field inhomogeneities

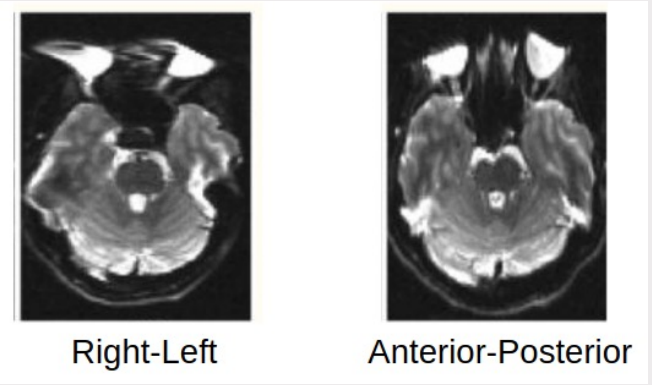


While some minor field inhomogeneity can be corrected by (automatic) shimming, much of it cannot…

Two main approaches to tackle the resulting distortions:

- Field map, i.e., acquiring a map of the magnetic field

- Blip up – blip down, i.e., acquiring an image in the inverted phase - encoding direction (Holland, Kuperman, & Dale, (2010).



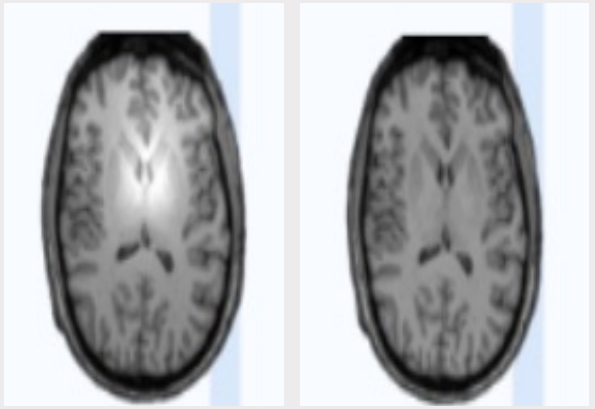
Preprocessing.

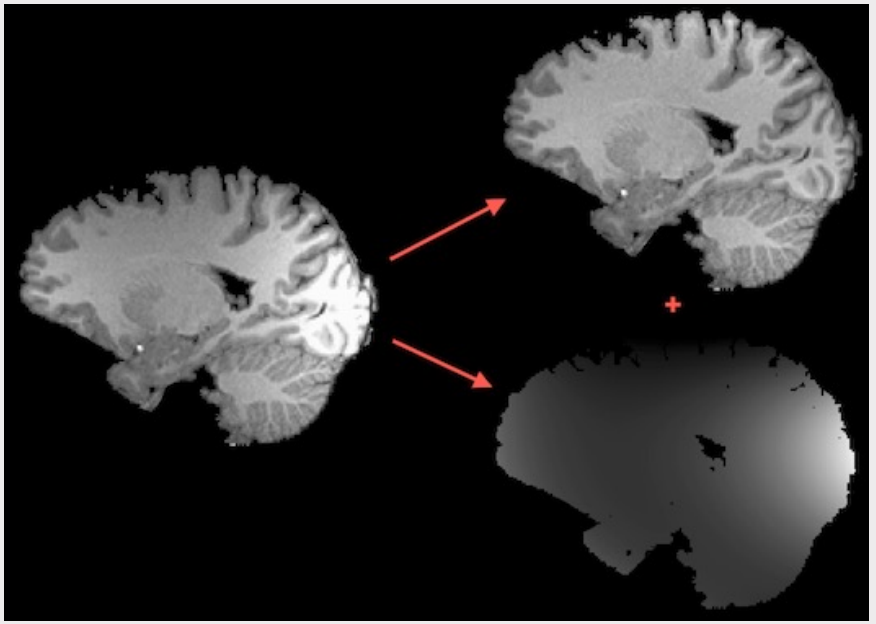
Why?

MR images as a *reconstruction* problem > This process is never perfect.

Distortions in MR images can be grouped in two types: temporal and **spatial**.

Intensity inhomogeneities

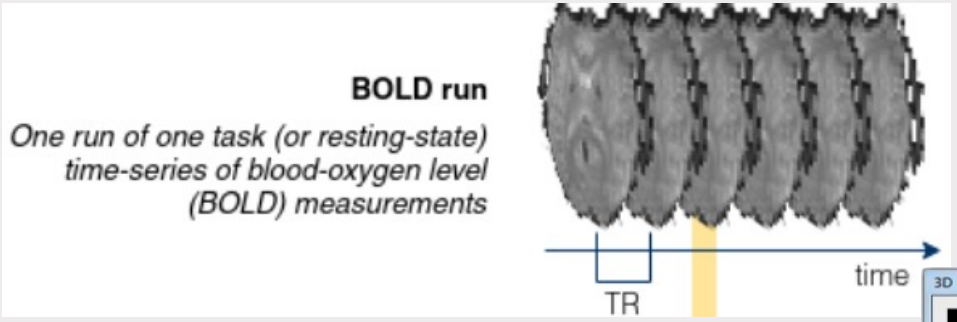


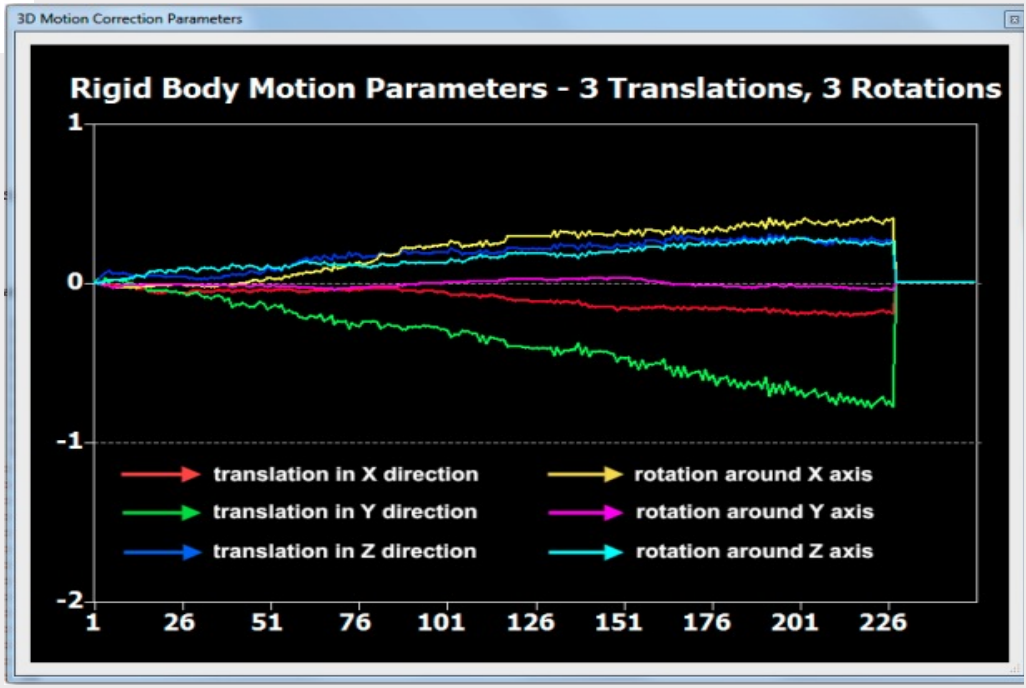


Preprocessing.

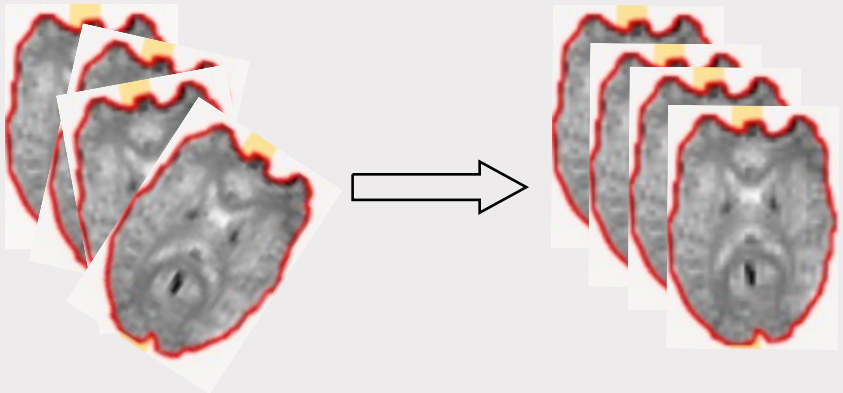
Why?

Functional MR images are recorded *over time* > Participants move!





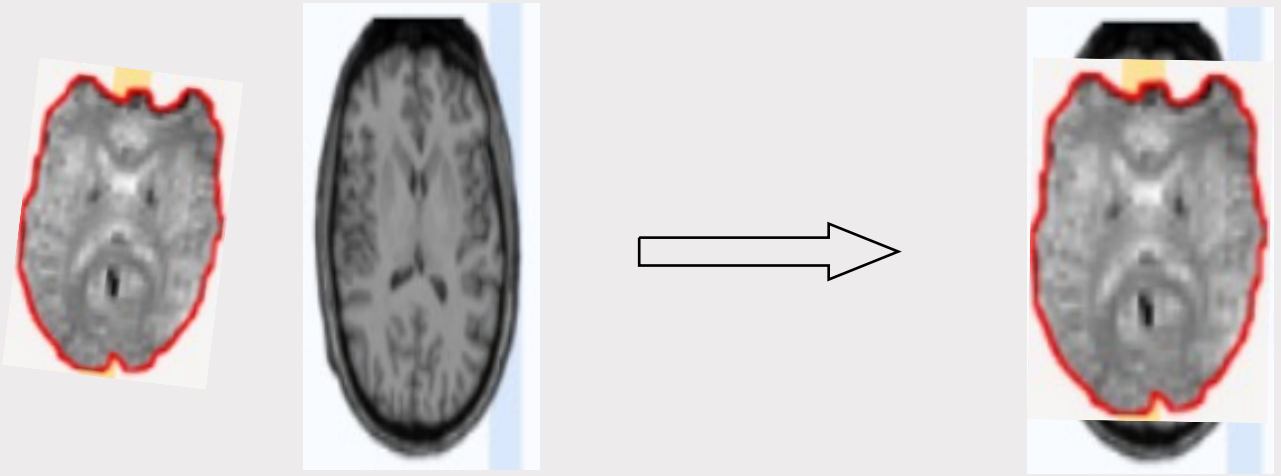
Volumes need to be re-aligned!



Preprocessing.

Why?

Anatomical and functional MR images are recorded *at different time points* and with *different sequences* > Volumes need to be **registered** to each other!



Preprocessing.

Why?

MR images are recorded for *multiple individuals* > Participants have different brain shapes!

We might want to have a common **space** for all of them.

Preprocessing.

Why?

MR images are recorded for *multiple individuals* > Participants have different brain shapes!

Common spaces:

- Native
- MNI
- Sample specific

Part III. Image preprocessing. Recap

Key steps.

- Slice-time correction
- Magnetic field distortions
- Intensity inhomogeneities
- Motion correction
- Registration
- Normalization

Part III. Image preprocessing. Recap

Key steps.

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How to do this?

- **fMRIprep** (https://fmriprep.org)
- SPM
- FSL
- BrainVoyager
- … and more

How to run fMRIPrep on your own:https://gitlab.com/ortizTud/neuroim-methods#010321-tutorial-on-fmriprep-ortiz

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Let's get practical.

Software needed:
MATLAB 2018 or later (https://www.mathworks.com/)
SPM12 (https://www.fil.ion.ucl.ac.uk/spm/software/spm12/)
ITK-Snap 3.8.0 (http://www.itksnap.org/)

Data needed:

Know our repository:
https://github.com/ortiztud/fmri_analysis_intro

All the steps involved in preprocessing take a while to complete (up to several hours sometimes!)

We have already preprocessed all the images with fMRIPrep. You can find them under *~/<project_folder>/preproc_data/fmriprep/*

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