LIÈGE université
GIGA
CRC Human Imaging

hMRI toolbox developments

Past, present & future!

fnrs
LA LIBERTÉ DE CHERCHER

Christophe Phillips
for the whole hMRI toolbox team

Prehistory…

Originally “Voxel-Based Quantification”, aka. VBQ toolbox

- Some code from 2008 (C. Hutton on `B1map`), then “bits and pieces” added.
- 1st release (public?) in 2011, around Draganski et al.
- Started versioning (with SVN) in 2014(?), around Callaghan et al.

Original contributors (from names in code)

- J. Ashburner, E. Balteau, B. Draganski, G. Helms, C. Hutton, F. Kherif, A. Lutti, C. Phillips, N. Weiskopf

Draganski *et al.*, https://doi.org/10.1016/j.neuroimage.2011.01.052
Callaghan *et al.*, https://doi.org/10.1016/j.neurobiolaging.2014.02.008

History

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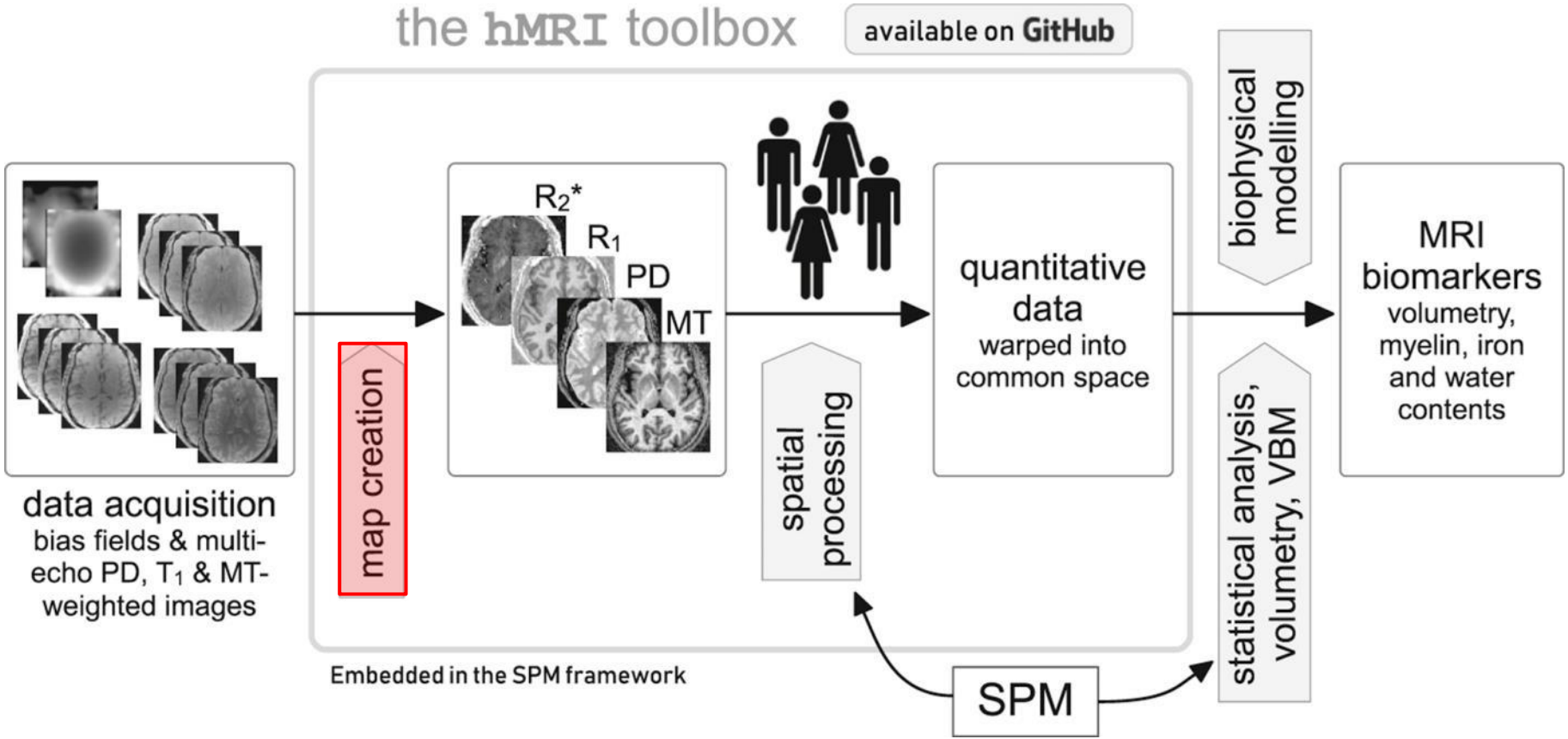
More contributors

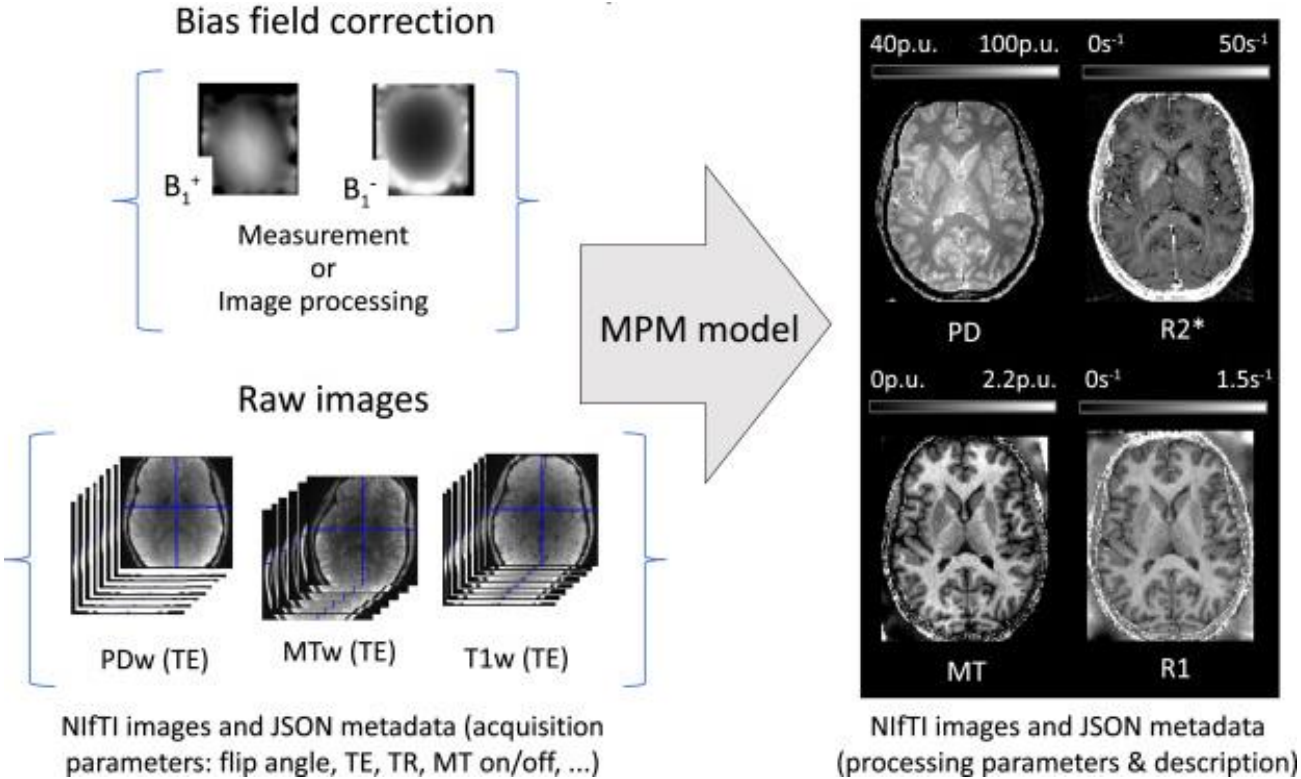
- J. Ashburner, E. Balteau, B. Draganski, G. Helms, C. Hutton, F. Kherif, A. Lutti, C. Phillips, N. Weiskopf
- E. Reimer, L. Edwards, P. Scheibe, M. F. Callaghan, B. E. Ugurcan, T. Leuritz, N. Beliy, *et al.*

Tabelov *et al.*, https://doi.org/10.1016/j.neuroimage.2019.01.029
Callaghan *et al.*, https://doi.org/10.1016/j.dib.2019.104132

hMRI toolbox and SPM



MPM (Multi-Parameter Mapping) Protocol & Maps creation



Tabelov *et al.*, https://doi.org/10.1016/j.neuroimage.2019.01.029

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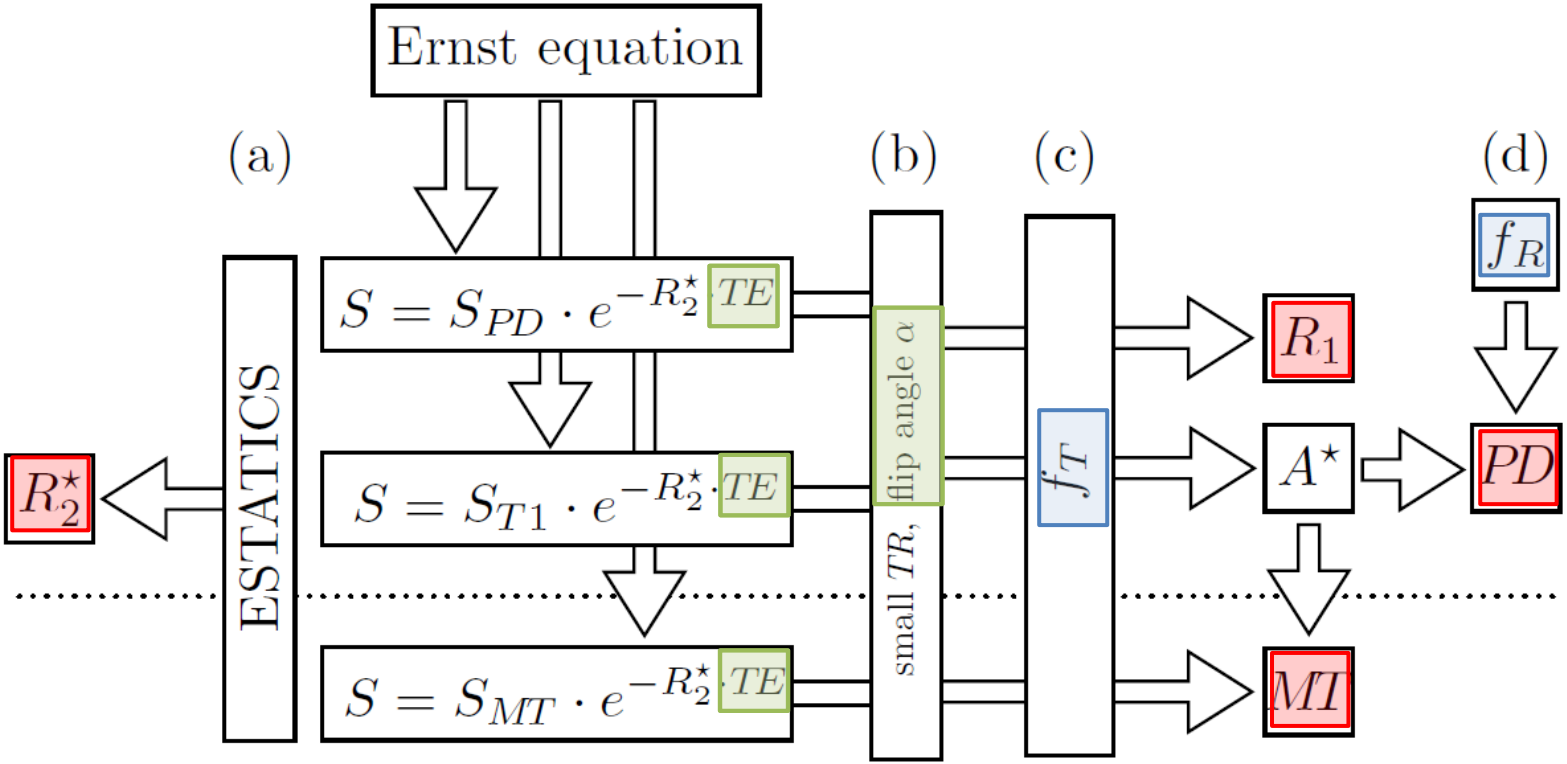


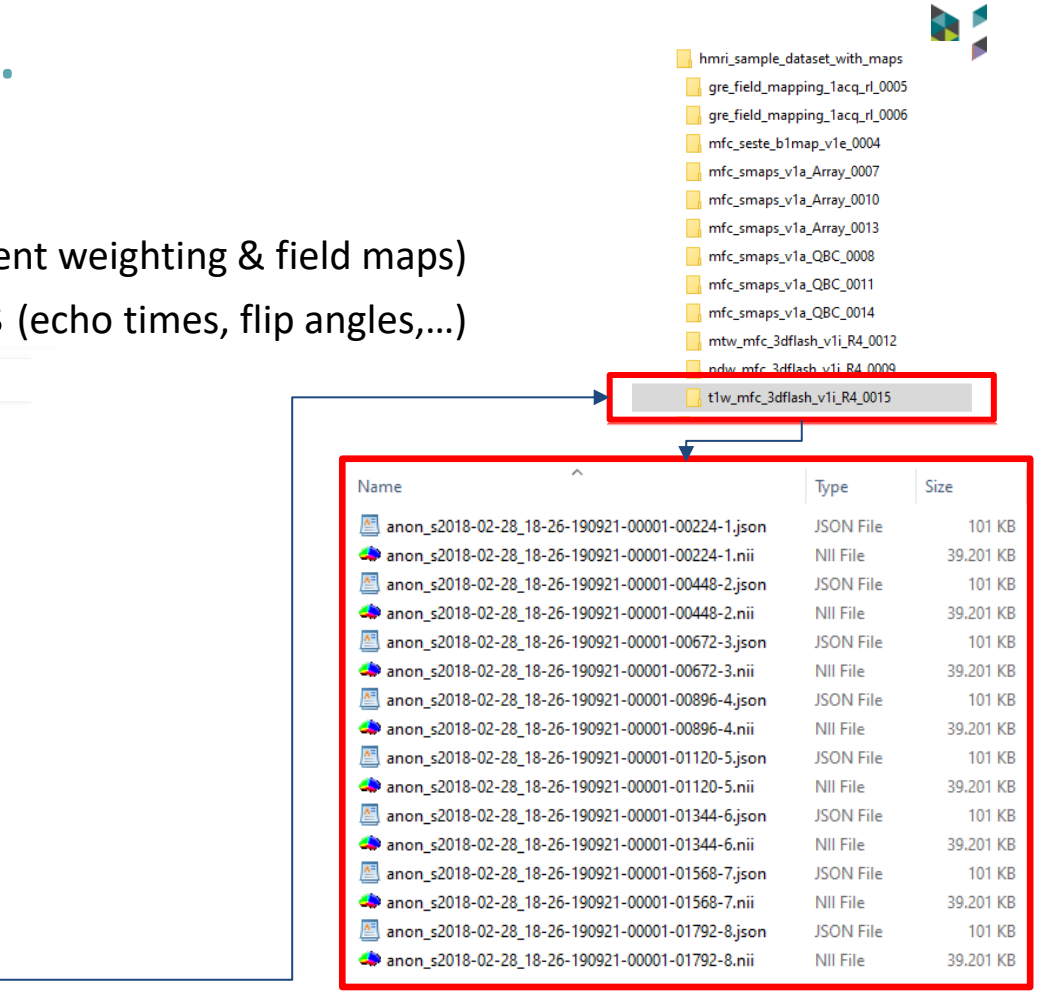
Weiskopf *et al.*, https://dx.doi.org/10.3389%2Ffnins.2013.00095

Raw data are messy…

qMRI relies on

- multiple series of images (different weighting & field maps)
- specific acquisition parameters (echo times, flip angles,…)

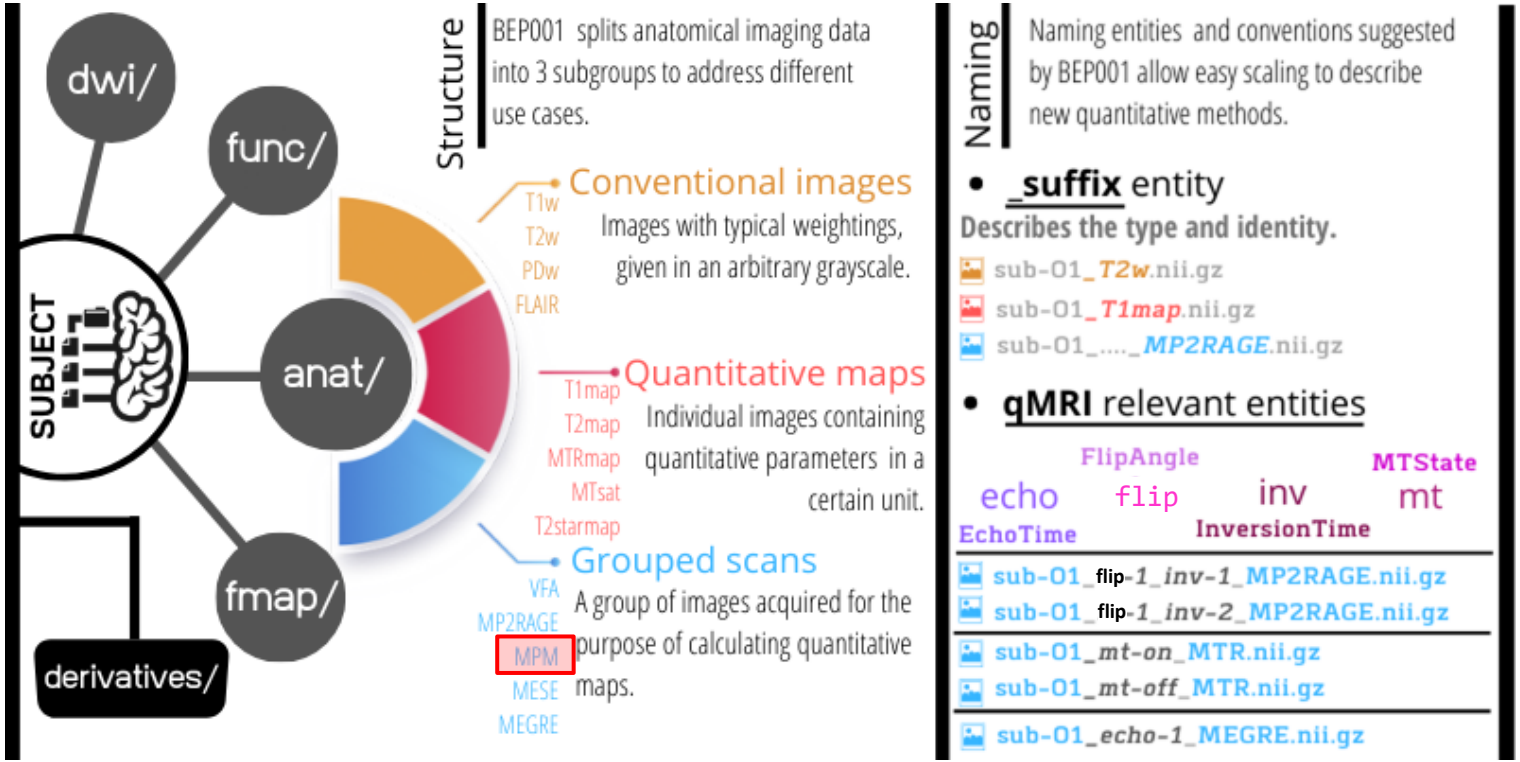
Image Series No.	Sequence Name	Description
4	mfc_seste_b1map_v1e	B_1^+ Mapping Data
5	gre_field_mapping_1acq_rl	B_0 Mapping Magnitude
6	gre_field_mapping_1acq_rl	B_0 Mapping Phase Difference
7	mfc_smaps_v1a_Array	Net Receive Sensitivity Mapping of Array
8	mfc_smaps_v1a_QBC	Net Receive Sensitivity Mapping of Body Coil
9	pdw_mfc_3dflash_v1i_R4	Lower flip angle multi-echo FLASH
Participant moved to new position via primary rotation about z		
10	mfc_smaps_v1a_Array	Net Receive Sensitivity Mapping of Array
11	mfc_smaps_v1a_QBC	Net Receive Sensitivity Mapping of Body Coil
12	mtw_mfc_3dflash_v1i_R4	FLASH acquisition with MT pre-pulse
Participant returned to approximate alignment with the original position		
13	mfc_smaps_v1a_Array	Net Receive Sensitivity Mapping of Array
14	mfc_smaps_v1a_QBC	Net Receive Sensitivity Mapping of Body Coil
15	t1w_mfc_3dflash_v1i_R4	Higher flip angle multi-echo FLASH



Callaghan *et al.*, https://doi.org/10.1016/j.dib.2019.104132

BIDS, with qMRI extension…

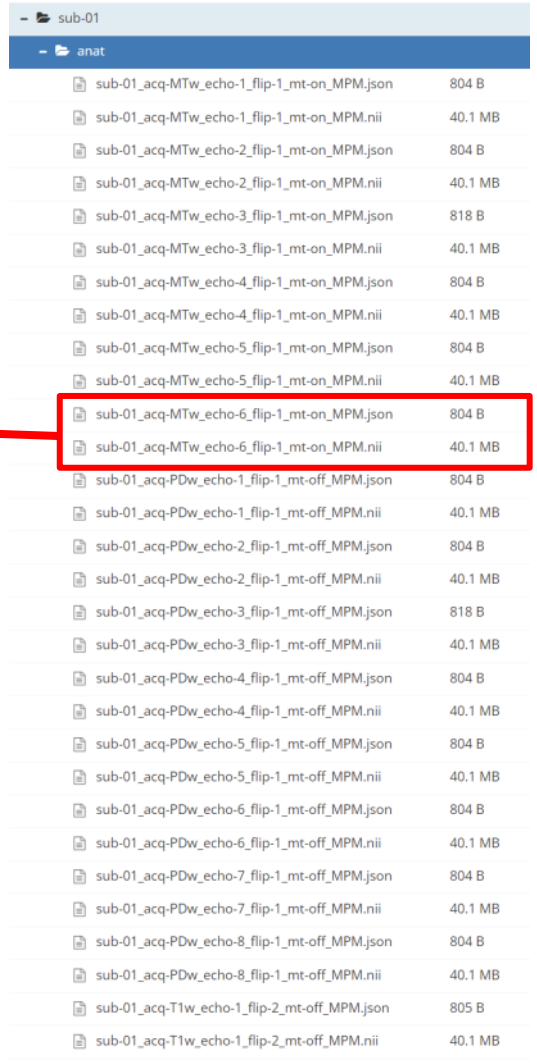
Brain Imaging Data Structure

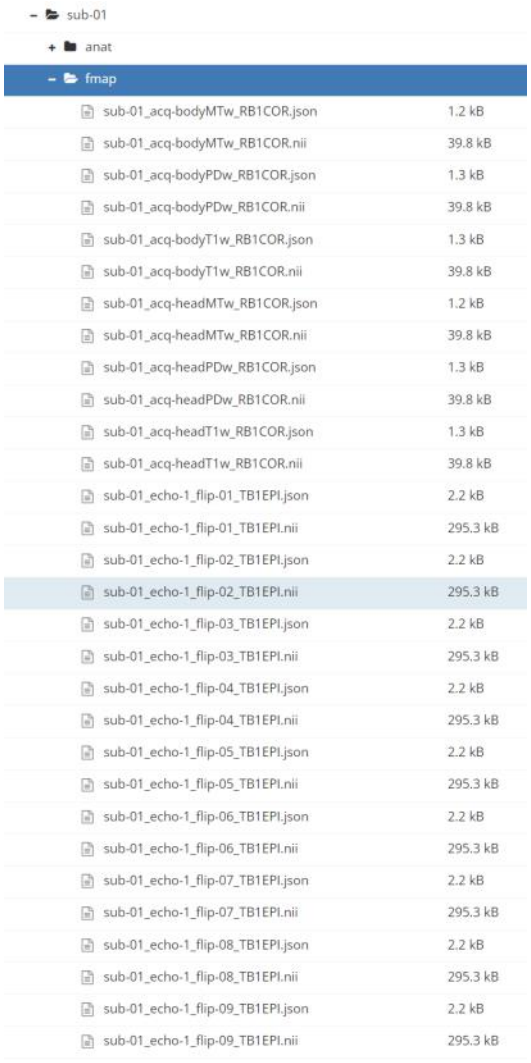


Karakuzu *et al.*, https://doi.org/10.1101/2021.10.22.21265382

Raw data sorted…


```
{
  "Manufacturer": "SIEMENS ",
  "ManufacturersModelName": "Prisma_fit",
  "DeviceSerialNumber": "167025",
  "StationName": "MRC35437",
  "MagneticFieldStrength": 3,
  "ScanningSequence": "RM",
  "SequenceName": "fl3d_1i3d6",
  "PulseSequenceDetails": "mtw_mfc_3dflash_v1i_R4",
  "RepetitionTimeExcitation": 0.025,
  "EchoTime": 0.0092,
  "FlipAngle": 6,
  "MTState": 1,
  "NumberShots": 1,
  "PhaseEncodingDirectionSign": 1,
  "history": {
    "procstep": {
      "descrip": "dicom to nifti import",
      "version": "spm_dicom_convert.m - version 6899 - SPM12 (12.3)",
      "procpar": []
    },
    "input": {
      "filename": "AnonymousFileName",
      "history": []
    },
    "output": {
      "imtype": "ORIGINAL\\PRIMARY\\M\\ND ",
      "units": "a.u."
    }
  }
}
```

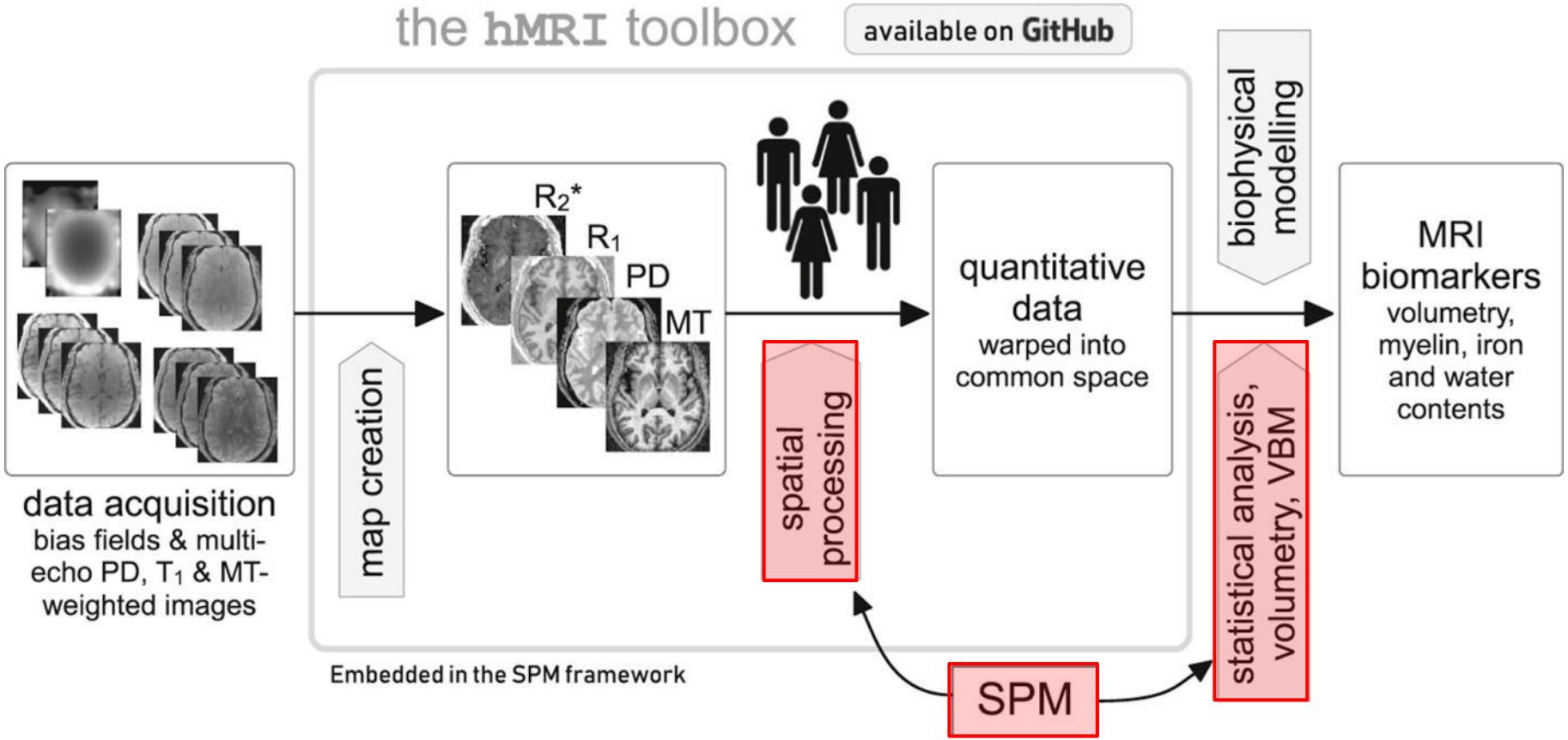





“BIDSme” tool

Beliy *et al.*, https://doi.org/10.21105/joss.05575 &
https://github.com/CyclotronResearchCentre/bidsme

hMRI toolbox and SPM



SPM embedding

- Spatial processing:
  - Unified Segmentation, Normalization & DARTEL
    ➔ wrapping around SPM,

    MatlabBatch GUI tailored for qMRI… but same SPM functions called !
  - Smoothing & mask creation
    ➔ specific tools for quantitative maps
- Statistics & inference
  ➔ standard univariate RFX analysis (but issue of multiple GLMs?)

Tissue-weighted smoothing & masks

$$\widehat{s_{ij}} = \frac{g * (w_j s_{ij})\ m_{TPM}}{g * w_j} m_j$$

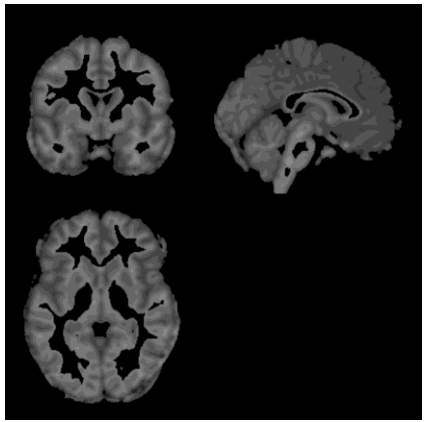
s_{ij} = signal of ith map from jth subject

g = Gaussian smoothing kernel

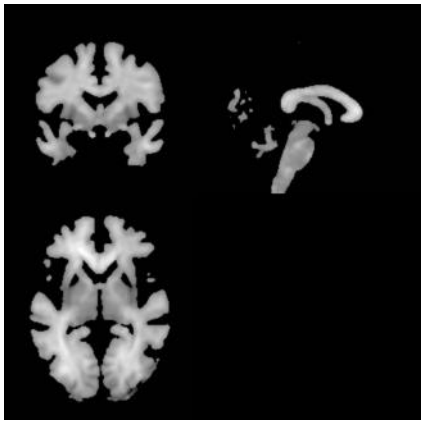
w_j = $J_{\Phi j} t_{\Phi j}$

= modulated warped posterior probability tissue map

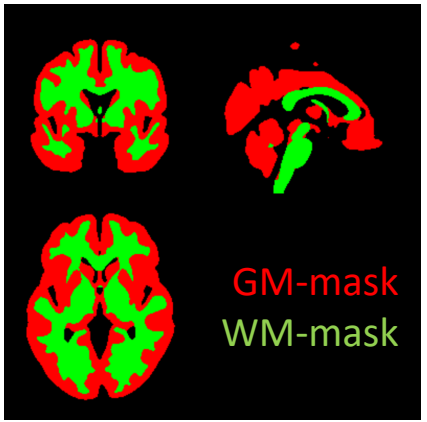
m_{TPM}/m_j = *a priori* (TPM-based) mask /subject's tissue mask



MTsat GM-smoothed



MTsat WM-smoothed



⚠ Note: Float vs. Integer data ➔ different implicit masking in GLM ! ⚠

Ongoing story…

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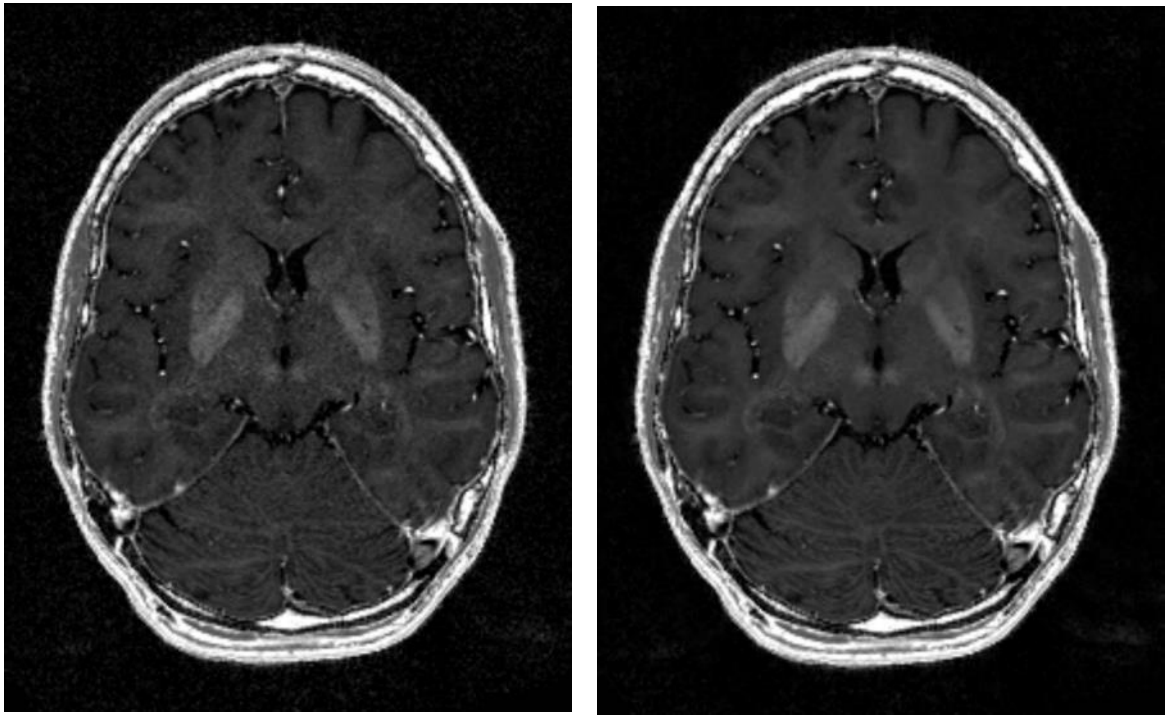
Release of v1.0.0, *planned for early October 2025*

- Presentations at OHBM & ESMRMB conferences
- New features: *denoising*, *error maps*, *quality index weighted RFX*, *compilation & Neurodesk integration*

Novelty #1: denoising tool

Publicly available denoising methods implemented in Java

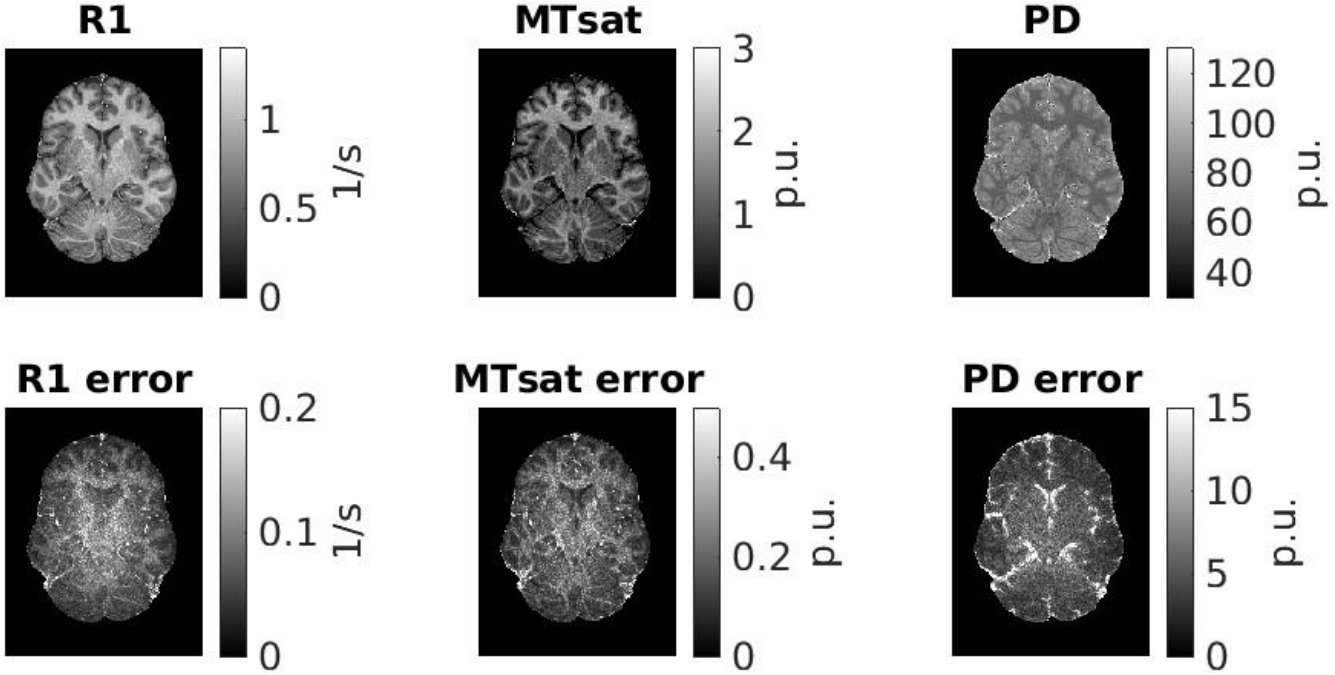
➔ interfaced in hMRI toolbox MatlabBatch GUI (thanks to a Java-Matlab interface)



R2s output: obtained from PDw, T1w, MTw of toolbox demo data (*left*) and the same data first denoised in the with the 'LCPCA-denoising' (*right*)

Edwards *et al.*, https://tinyurl.com/2w4dv3yk

Novelty #2: error maps output



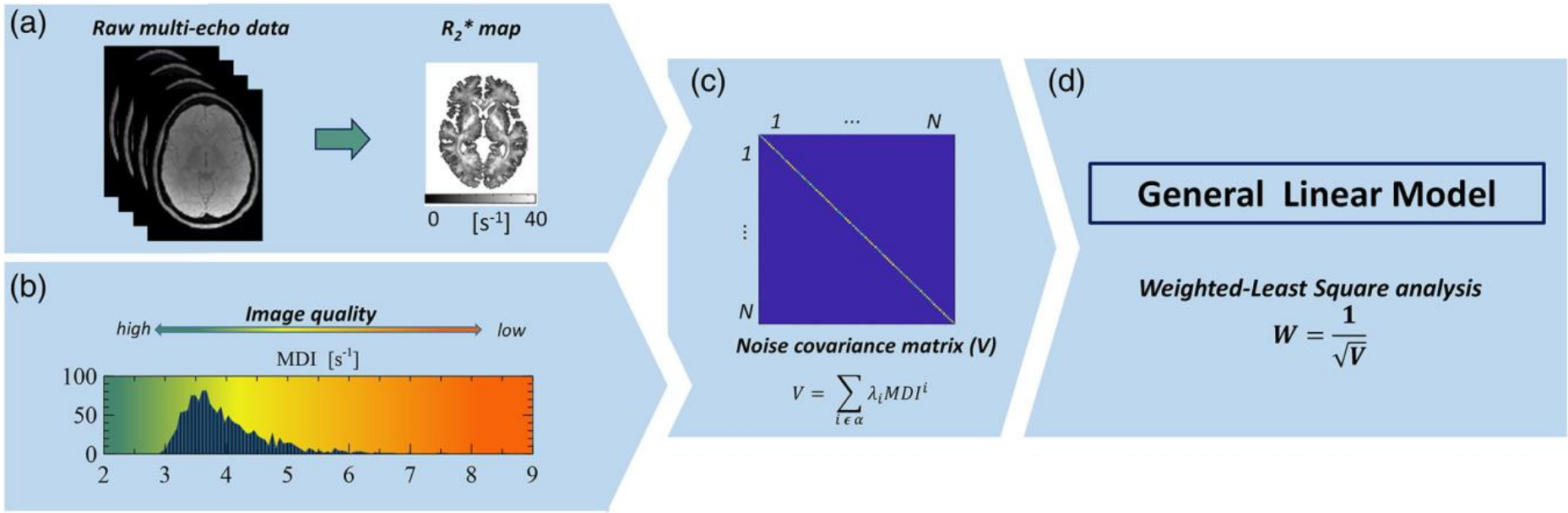
Error maps created from demo dataset

+ additional submodule ('Combine two successive hmri datasets')

➔ robust combination of quantitative maps from successive acquisitions

Mohammadi *et al.*, https://doi.org/10.1016/j.neuroimage.2022.119529

Novelty #3: QUIQI (Analysis of QUantitative Imaging data using a Quality Index)

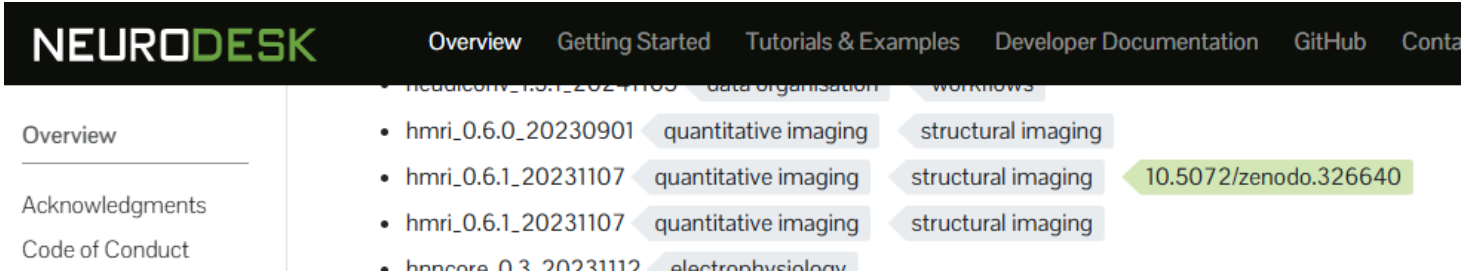


Quality index, e.g. Motion Degradation Index, used to model noise covariance matrix of the GLM (ReML)

➔ QUIQI restores homoscedasticity of the residual noise distribution

Lutti *et al.*, http://dx.doi.org/10.1002/hbm.25767

Novelty #4: compilation & Neurodesk



- Standalone alone version ➔ no reliance on Matlab instalation
- Neurodesk integration ➔ combination with any other tool

Future stuff…

Objectives

- More advanced acquisition techniques & quantitative maps
  ➔ see Nick's presentation
- Better and easier to use reconstruction tools
  ➔ data curation: image organisation + parameter extraction
  ➔ BIDS standard, to be extended/stretched ?
- Improved image processing
  ➔ *spatial* and *statistics*

Future stuff…

Improved image *spatial* processing

- Segmentation:

  uni-/multi-channel, parameter definition, lesion/abnormalities, extented TPM or region specific,…

- Warping:

  DARTEL ➔ SHOOT ?

- Smoothing:

  tissue-weighted vs T-SPOON (“tissue-specific, smoothing-compensated” for DWI)

  ➔ To be applied to other modalities (DWI/NODDI, PET,…)?

Lorio *et al.*, https://doi.org/10.1016/j.neuroimage.2016.01.062
Lee *et al.*, https://doi.org/10.1016/j.neuroimage.2008.09.041

Future stuff…

Improved *statistical* inference

- 4 maps/subj, smoothed for GM/WM ➔ 8 smoothed maps/subj ➔ 8 GLMs ➔ 8 inferences per contrast
- Potential issues
  - multiple comparison ➔ increased risk of false positives?
  - distributed effect ➔ lack of sensitivity ?

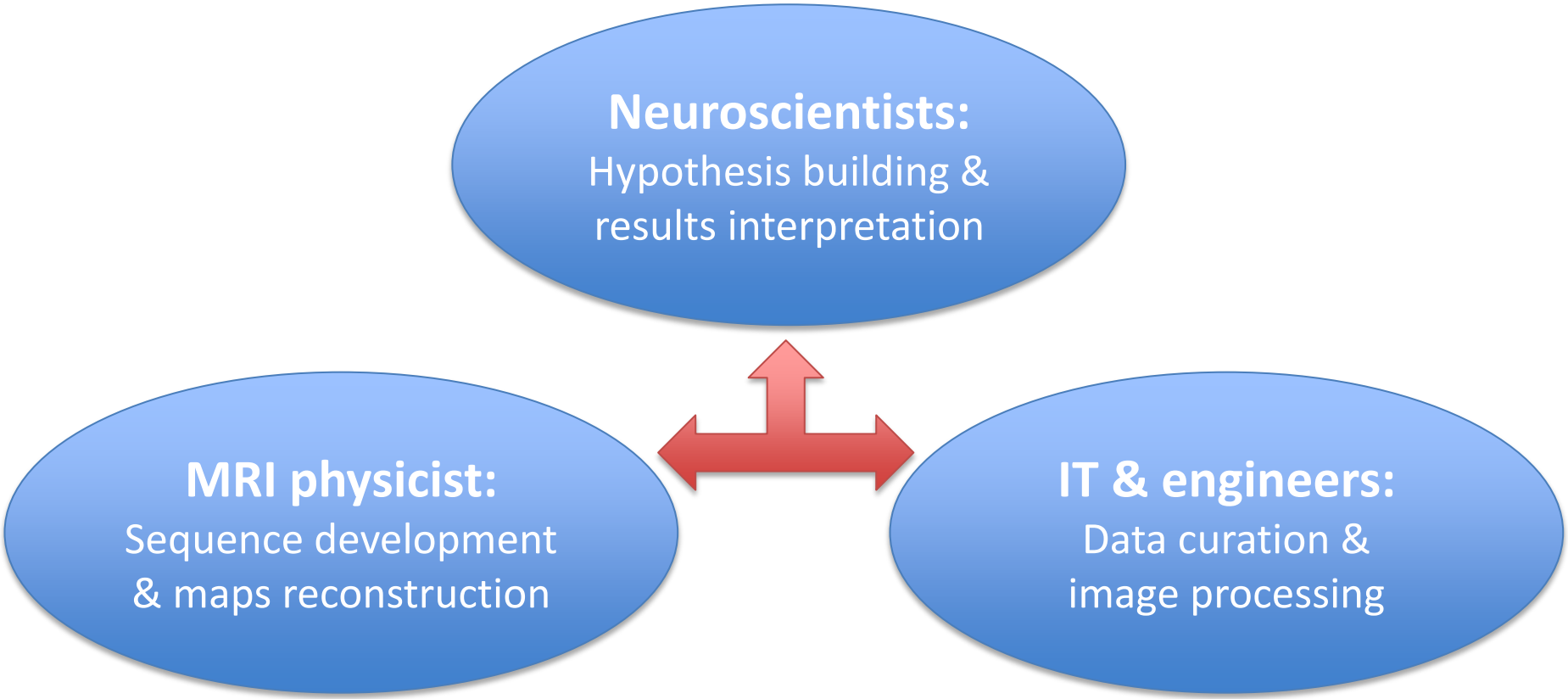
Go for MANOVA for 4 maps, for GM and WM separately?

e.g. MSPM tool (by Gyger et al. from F. Kerith's team), applied on qMRI ageing data (from Callaghan et al. 2014)

➔ more significant voxels in "previously unseen" regions

Gyger *et al.*, https://doi.org/10.1016/j.neuroimage.2021.117895
https://github.com/LREN-CHUV/MSPM
Moallemian *et al.*, https://doi.org/10.1101/2023.10.19.23297253

Conclusion



Each field has his own constraints and interests!

Thank you for your attention…

And to all who (unknowingly or not) provided images and slides