Motion-Corrected PET Reconstruction with the Synergistic Image Reconstruction Framework (SIRF)

Richard Brown

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1 Introduction

SIRF

- Open-source platform for PET/MR reconstructions
  - Designed for researchers
  - Matlab, python, C++

- Wrappers around existing software, providing interchangeable packages for reconstruction.
  - STIR for PET reconstruction
  - Gadgetron for MR reconstruction

  - … for motion correction?

NiftyReg

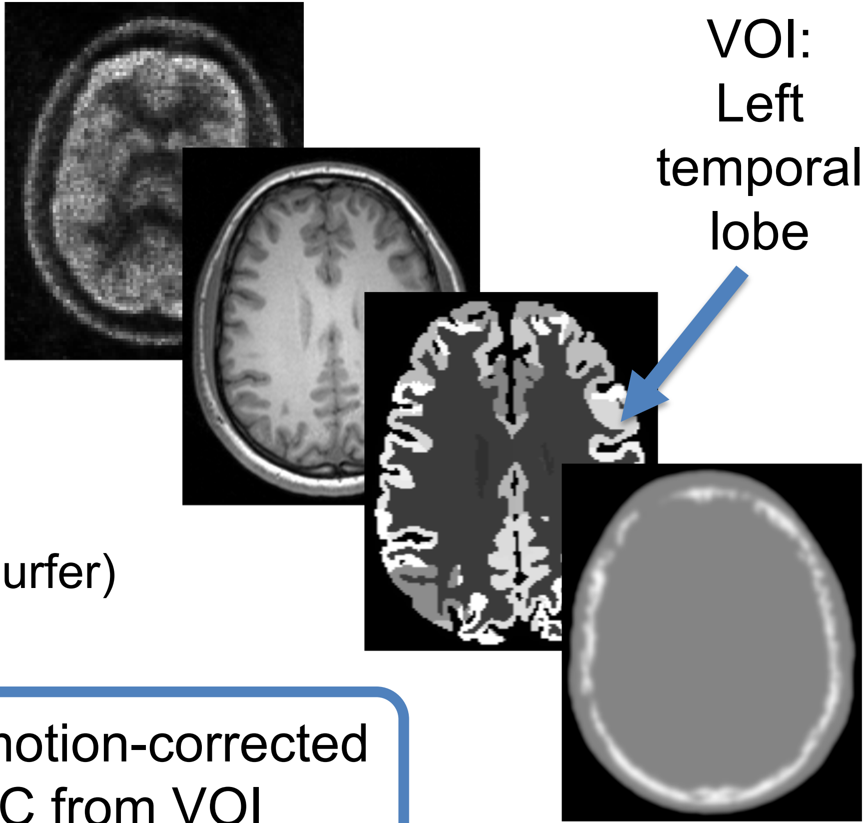
- Open-source registration tool
  - Rigid and affine registrations with *aladin*
  - Non-rigid registrations with *f3d*
  - Resampling functionality

- SIRFReg
  - Accessible from Matlab, python and C++

SIRFReg: Example used throughout presentation

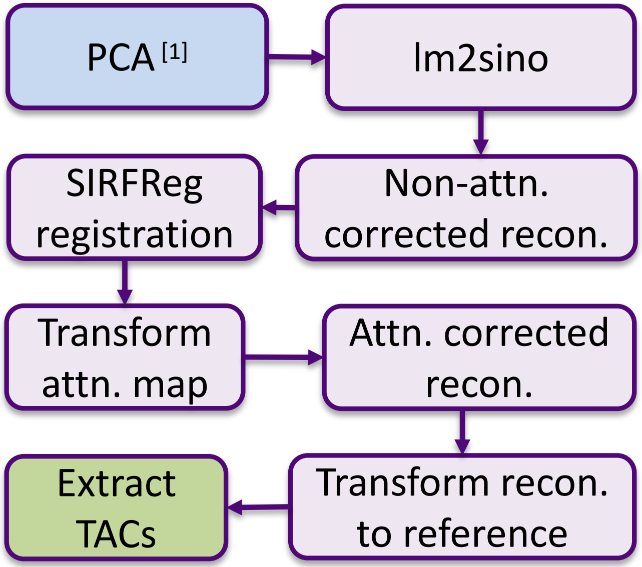
Example

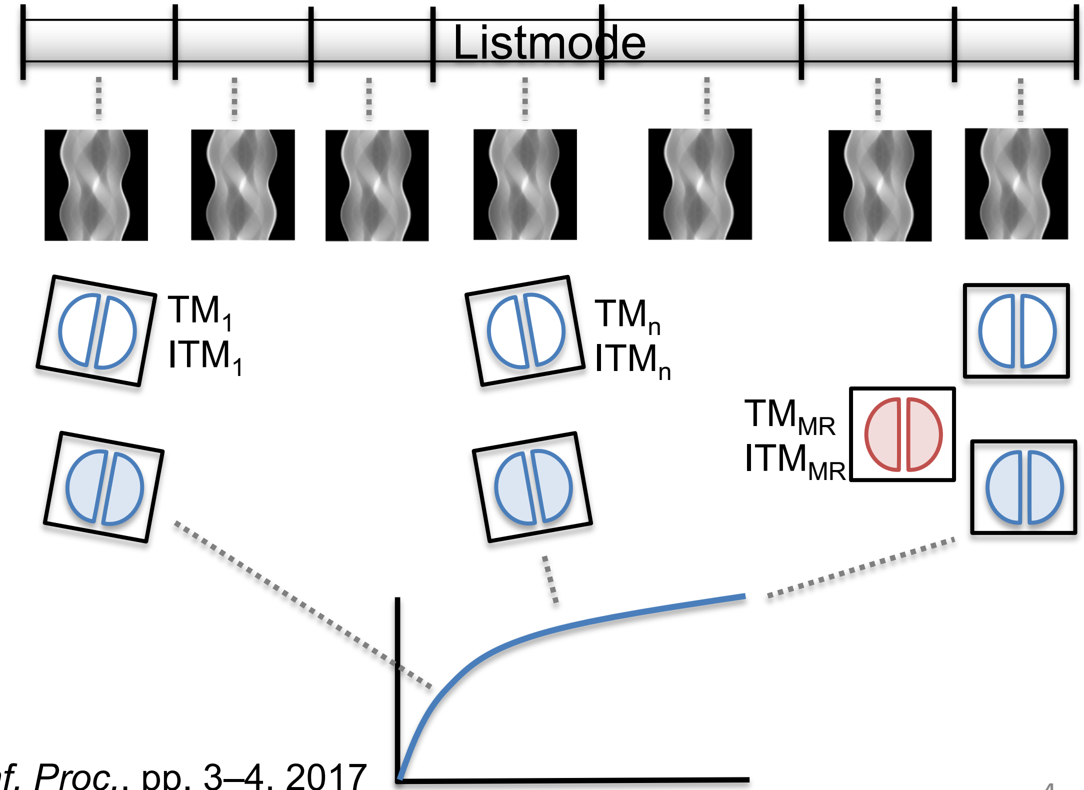
- Brain FDG epilepsy study acquired with Siemens Biograph mMR
- **PET:** listmode data and associated normalisation files
- **MR:**
  - MPRAGE
    - MR-based parcellation (FreeSurfer)
  - MRAC (from UTE)



Goal: Perform frame-by-frame motion-corrected reconstruction to extract TAC from VOI

Workflow





[1] Rashidnasab *et al.*, *IEEE PSMR Conf. Proc.*, pp. 3–4, 2017

Registration

Deformation & displacement images

```
reg = mSIRFReg.NiftyAladin();
reg.set_reference_image_filename(ref_file);
reg.set_floating_image_filename(flo_file);
reg.set_parameter_file(param_file);
reg.update();
reg.save_transformation_matrix(TM_file);
reg.save_inverse_transformation_matrix(ITM_file);
reg.save_warped_image(warped);
```

Aladin = Rigid/Affine

Usage identical with Matlab and Python

2 Motion correction

Results 1/2

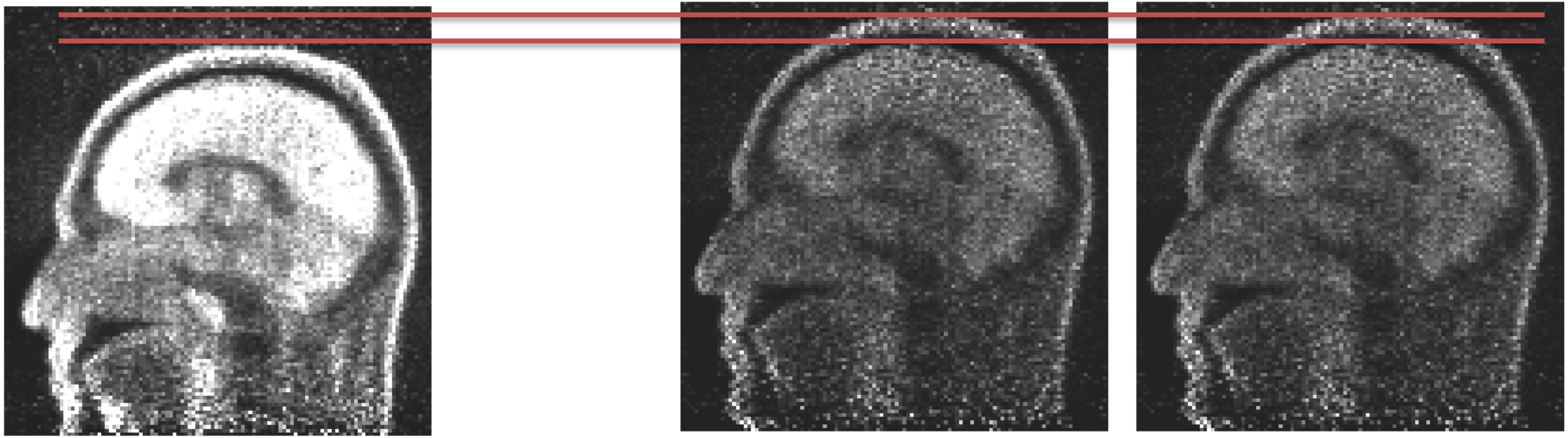
28 frames (2700 s)

f22 (750-900 s)

Ref: f25 (1500-1950 s)

MC workflow

NMC workflow



MRAC

NAC

2 Motion correction

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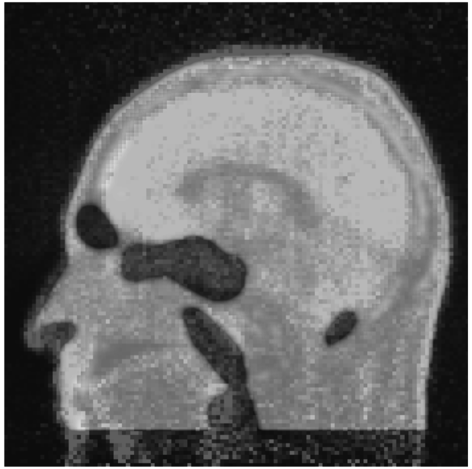
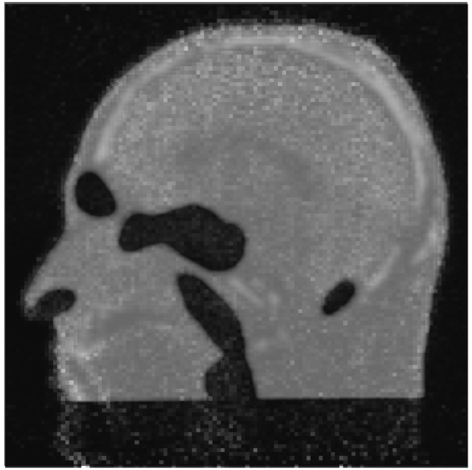
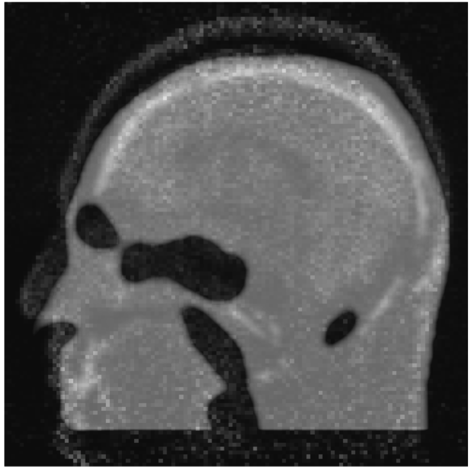


MRAC

MC workflow



NMC workflow



NAC

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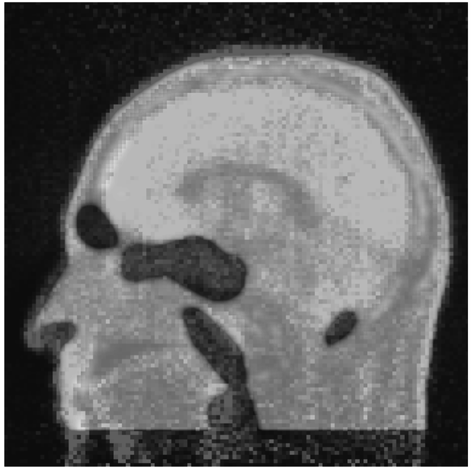
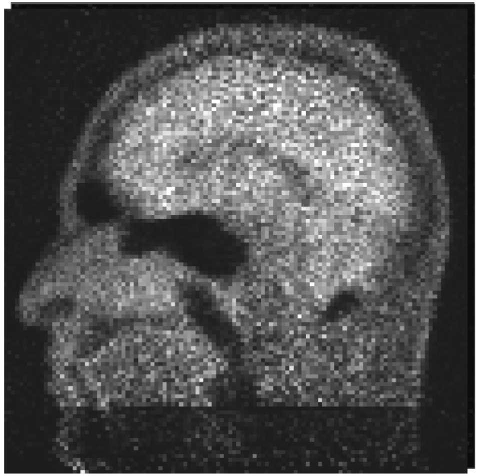
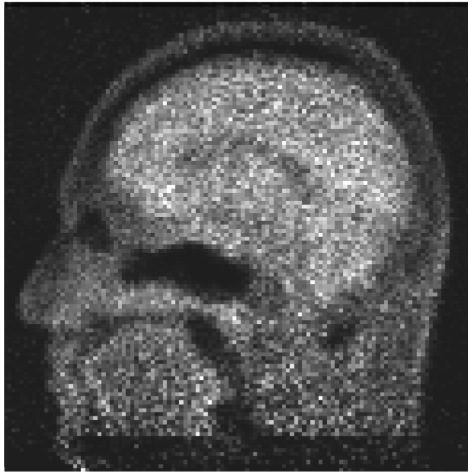


MRAC

MC workflow



NMC workflow



AC

2 Motion correction

Results 1/2

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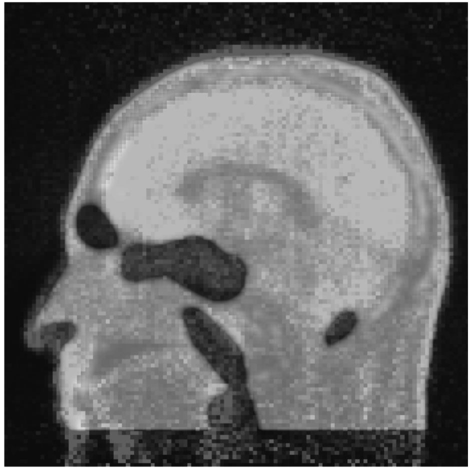
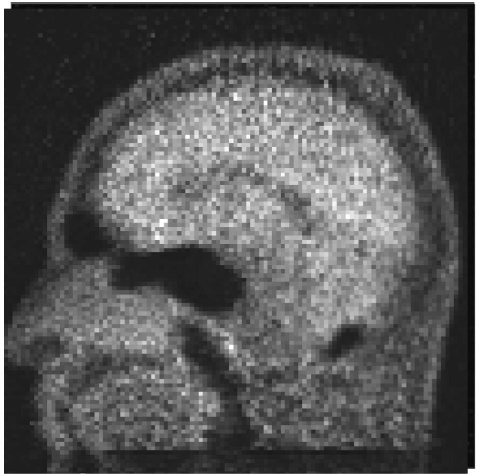


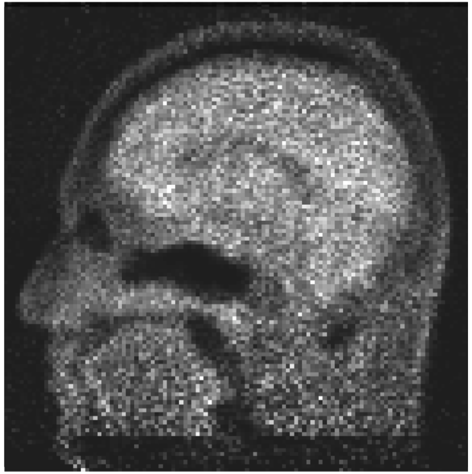
MRAC

f22 (750-900 s)

MC workflow



NMC workflow



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2 Motion correction

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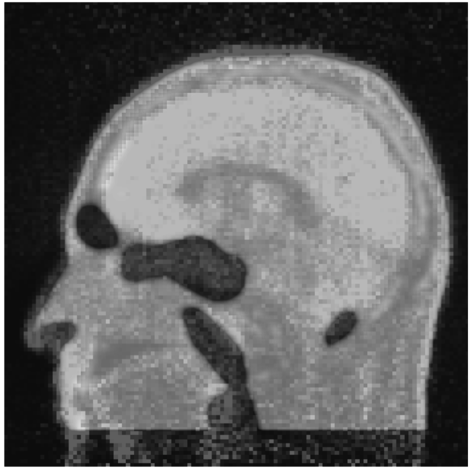
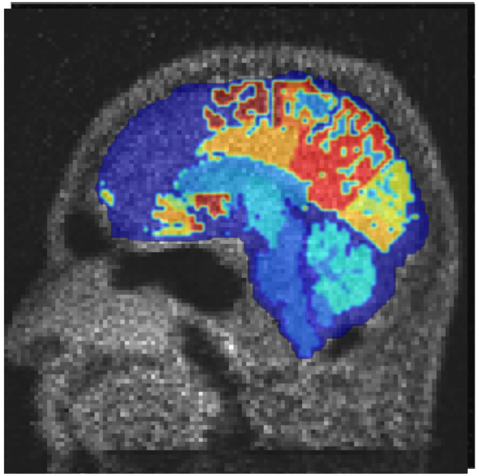
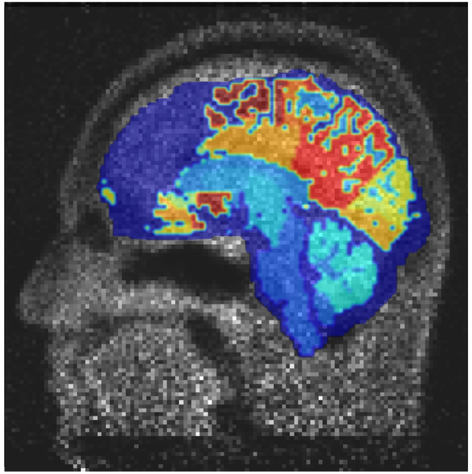


MRAC

MC workflow



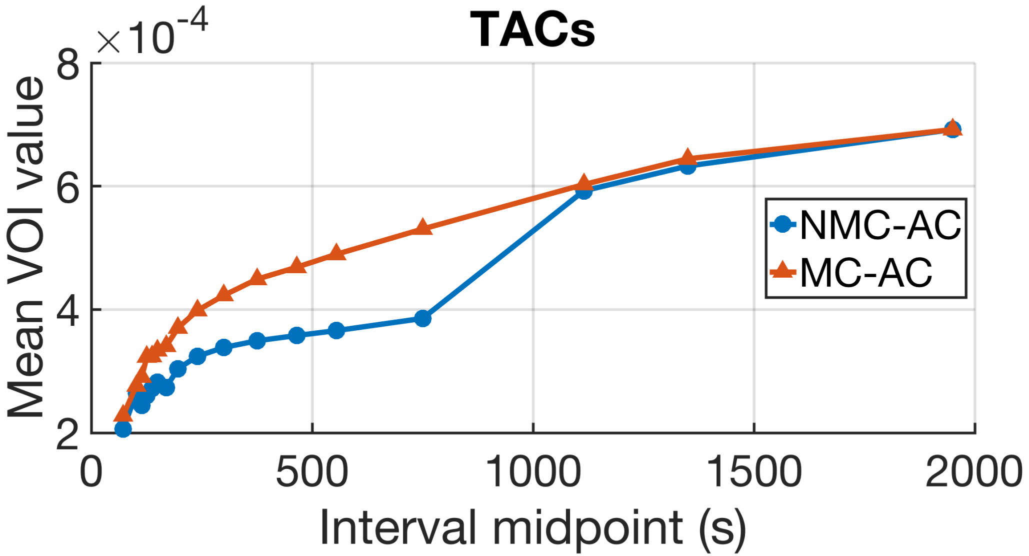
NMC workflow



AC

2 Motion correction

Results (2/2)



Now that PET & MR aligned: anatomical priors?

Introduction

- Anatomical prior [2] → similar features expected in reconstructed PET and anatomical (MR) images
- Regularisation term to reduce noise in reconstructed PET image whilst preserving edges
    - Minimised when gradients of anatomical and reconstructed images match
- [3] discusses benefit of anatomical priors for epilepsy FDG studies

[2] Ehrhardt MJ *et al.*, *IEEE Trans Med Imaging*, 2016
[3] Baete K *et al.*, *IEEE Trans Med Imaging*, 2004

Formulation

$$\boldsymbol{u} = \underset{\boldsymbol{u} \geq 0}{\operatorname{argmax}} [\mathcal{L}(\boldsymbol{y}|\boldsymbol{u}) - \beta \hat{\boldsymbol{\kappa}}^2 \mathcal{R}(\boldsymbol{u}, \boldsymbol{v})]$$

$$\mathcal{R}(\boldsymbol{u}, \boldsymbol{v}) = \sqrt{\alpha^2 + |\nabla \boldsymbol{u}^2| - \langle \nabla \boldsymbol{u}, \xi \rangle^2}, \ \xi = \frac{\nabla \boldsymbol{v}}{\sqrt{|\nabla \boldsymbol{v}|^2 + \eta^2}}$$

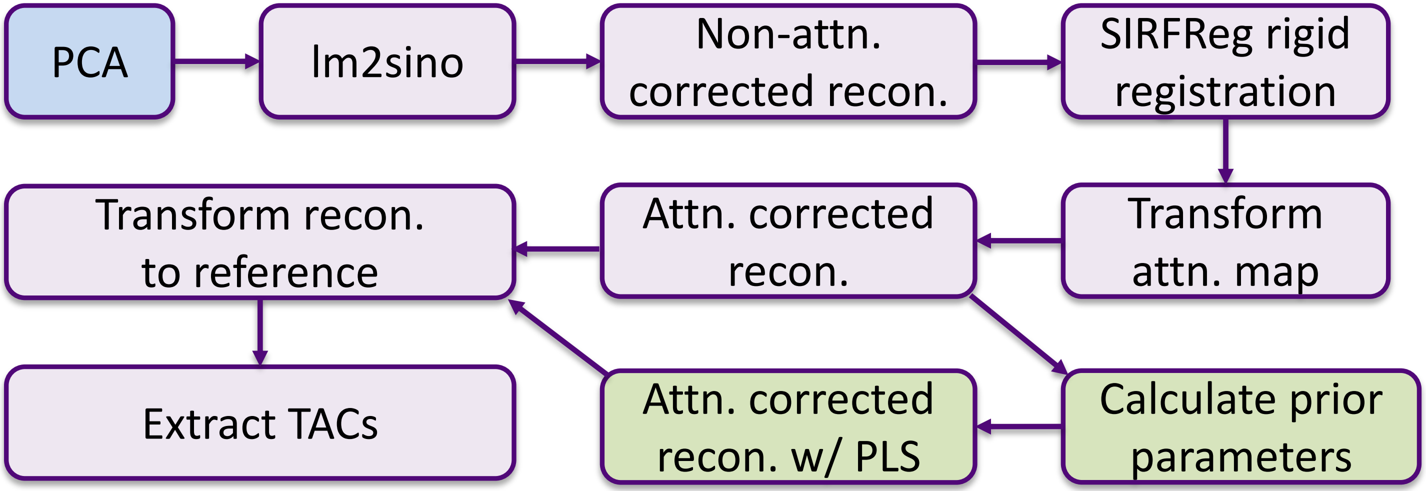
Strength of regularisation needs to change as fn. of intensity → $\boldsymbol{\kappa}$

- Uniform resolution of regularisation
  - Can use constant β

[4] Fessler JA, Rogers WL., *IEEE Trans Image Process,* 1996
[5] Y.-J. Tsai *et al.*, *IEEE NSS/MIC Conf. Proc.*, 2017

PLS workflow

- α and $\boldsymbol{\kappa}$ calculated from AC reconstruction

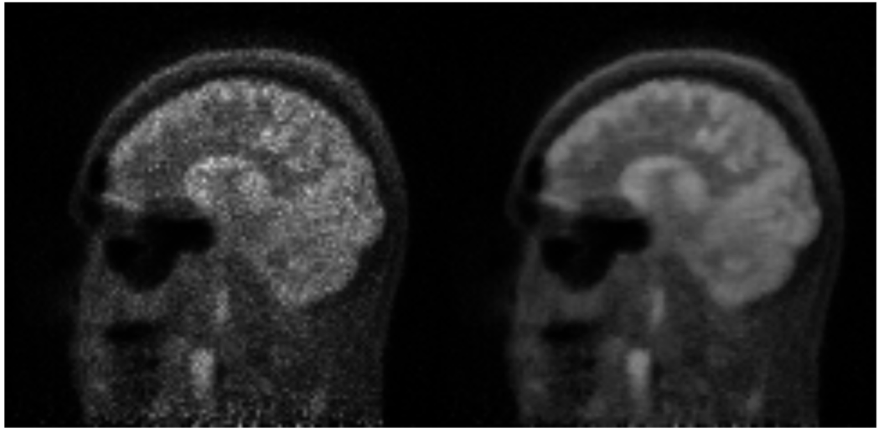


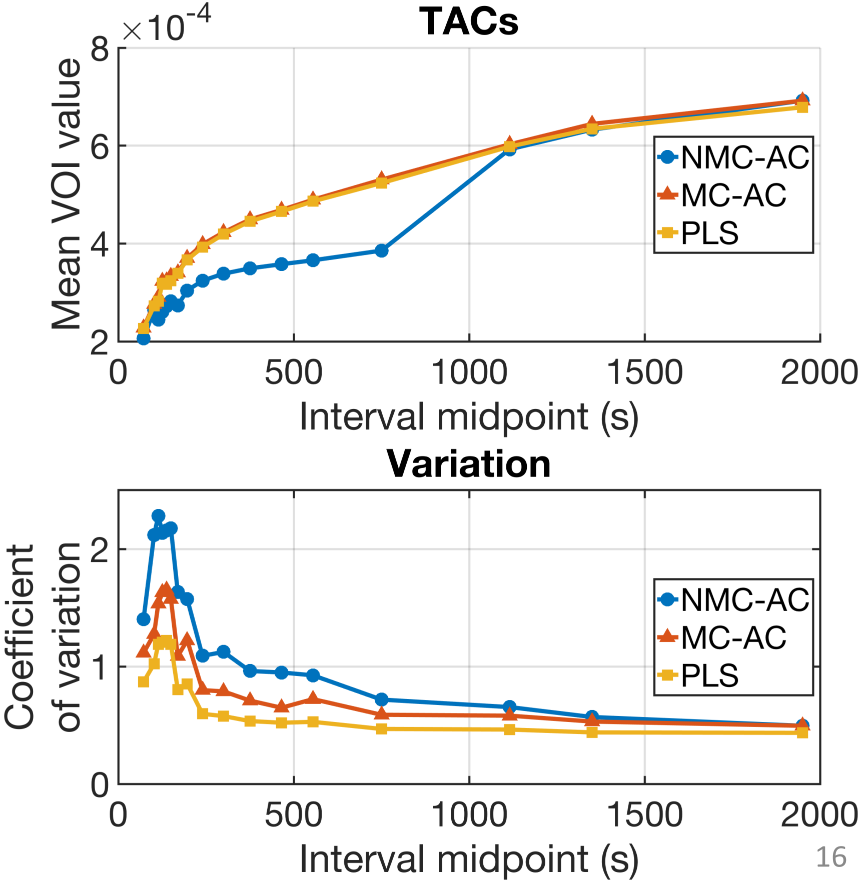
Parallel level sets prior

```
prior=mSTIR.PLSPrior();
prior.set_alpha(alpha);
prior.set_eta(eta);
prior.set_beta(penalisation_factor);
prior.set_kappa_file(kappa_file);
prior.set_anatomical_file(MR_file);
obj_fn = mSTIR.make_Poisson_loglikelihood();
obj_fn.set_prior(prior);
```

3 Parallel level sets prior

PLS prior results





Conclusion

- SIRF – open-source PET/MR reconstruction framework

- For motion correction – registration package (NiftyReg) incorporated
    - Available in SIRF v1.2

- Example of simple frame-by-frame motion correction with an anatomical prior
    - Initial steps for performing motion-corrected reconstructions from within the same framework

- Future work into other uses of motion correction
    - Parametric reconstructions
    - Gated (+dynamic) data

Acknowledgements

- Kris Thielemans
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- Evgueni Ovtchinnikov
- Edoardo Pasca
- Casper da Costa-Luis
- Brian F. Hutton
- Charalampos Tsoumpas

3 Parallel level sets prior

UCL

$$\boldsymbol{u} = \underset{\boldsymbol{u} \geq 0}{\operatorname{argmax}}[\mathcal{L}(\boldsymbol{y}|\boldsymbol{u}) - \beta \hat{\boldsymbol{\kappa}}^2 \mathcal{R}(\boldsymbol{u}, \boldsymbol{v})]$$

$\boldsymbol{v}$: MR image

$$\mathcal{R}(\boldsymbol{u}, \boldsymbol{v}) = \sqrt{\alpha^2 + |\nabla \boldsymbol{u}^2| - \langle \nabla \boldsymbol{u}, \xi \rangle^2}, \; \xi = \frac{\nabla \boldsymbol{v}}{\sqrt{|\nabla \boldsymbol{v}|^2 + \eta^2}}$$

TV

$$\hat{\boldsymbol{\kappa}}^2 = \boldsymbol{A}^t \left(\frac{\boldsymbol{y}}{(\boldsymbol{A}\boldsymbol{u}_{AC} + \boldsymbol{r})^2} \right) \boldsymbol{A1}$$

Approximation of Hessian

[2] Ehrhardt MJ *et al.*, *IEEE Trans Med Imaging*, 2016.
[3] Y.-J. Tsai *et al.*, *IEEE NSS/MIC Conf. Proc.*, 2017.

Kappa images

Varies across image **and** timeframe