Imperial College London

MRC Clinical Sciences Centre

PET Quantification using STIR

STIR User's Meeting

Charalampos Tsoumpas, PhD
King's College London

Hammersmith
Imanet

PET Quantification

Image elements should correspond to concentration of the injected radiotracer

What corrections are necessary for it:

- Attenuation
- Scatter
- Motion
- Randoms
- Normalization
- Dead Time

Overview of the talk

PET Quantification using STIR:

3D Scatter Correction

Parametric Reconstruction

Theory

How to use

Examples

Limitations & Future Work

3D Scatter Correction

Single Scatter Simulation - SSS

The scatter probabilities are estimated by Klein-Nishina formula for each possible scatter point in the transmission image.

$$P_{AB} = \int_{\substack{scatter\\volume}} \left(\frac{\sigma_{AS}\sigma_{BS}}{r^2_{AS} r^2_{BS}} \right) (P_{ASB} + P_{BSA}) dS$$

$$P_{ASB} = \varepsilon_{AS}(E) e^{-\int_A^S \mu(E,l)dl} \int_A^S \lambda(l) \frac{d\mu(E,S,\theta)}{d\Omega} e^{-\int_S^B \mu(E',l)dl} \varepsilon_{BS}(E')$$

$$P_{BSA} = \varepsilon_{BS}(E) e^{-\int_B^S \mu(E,l)dl} \int_B^S \lambda(l) \frac{d\mu(E,S,\theta)}{d\Omega} e^{-\int_S^A \mu(E',l)dl} \varepsilon_{AS}(E')$$

Compensation for multiple and out of the FoV scattering

Each plane of the scatter estimation is scaled by an appropriate factor

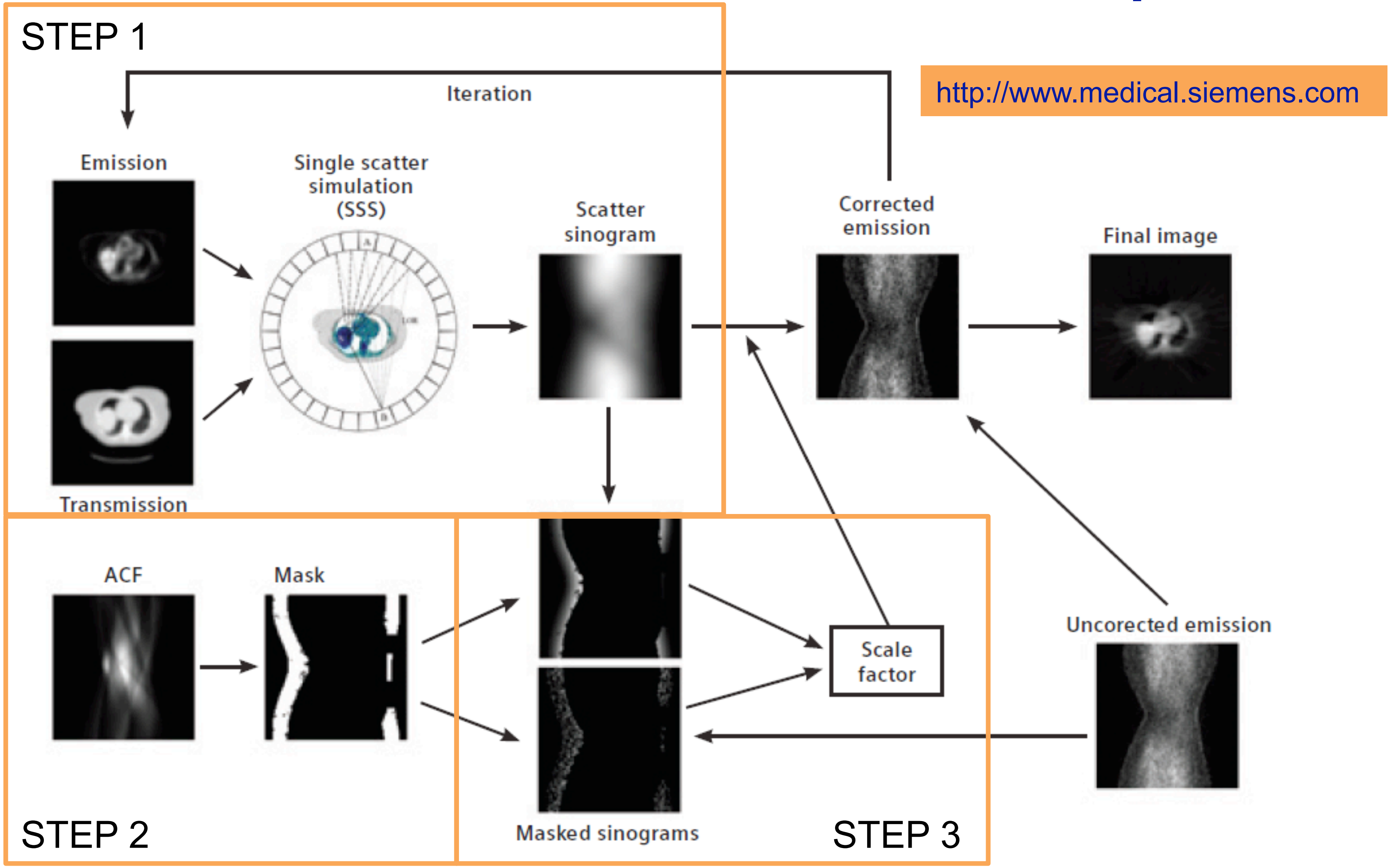
Watson CC *et al*. “A single-scatter simulation technique for scatter correction in 3D PET” *Fully 3D Image Recon in Radiology & Nucl Med*. 1996

Implementation in STIR

Scatter Buildblock classes and relative files

ScatterEstimationByBin	sample_scatter_points
scatter_estimate_for_one_scatter_point	integral_scattpoint_det
cached_factors	scatter_estimate_for_all_scatter_points
estimate_scatter	upsample_and_fit_scatter_estimate
create_tail_mask_from_ACFs	scale_single_scatter

Scatter Correction in 4 steps



Watson CC “New, Faster, Image-Based Scatter Correction for 3D PET” *IEEE Trans. Nucl. Sci.* 47 (4) 1587-1594, 2000

STIR How To: Scatter Correct

STEP 1: `estimate_scatter scatter.par`

```
attenuation_threshold :=.01
random :=0
use_cache :=1
energy_resolution :=.22
lower_energy_threshold :=350
upper_energy_threshold :=650

activity_image_filename := ${ACTIVITY_IMAGE}
density_image_filename := ${DENSITY_IMAGE}
density_image_for_scatter_points_filename:=${LOW_RES_DENSITY_IMAGE}
template_proj_data_filename :=  ${TEMPLATE}

output_filename_prefix :=${OUTPUT_PREFIX}


End Scatter Estimation Parameters:=
```

STIR How To: Scatter Correct

STEP 2: `create_tail_mask_from_ACFs`

```
--ACF-filename <projdata>
--ACF-threshold <number (1.01)>
--output-filename <projdata>
--safety-margin <0>
```

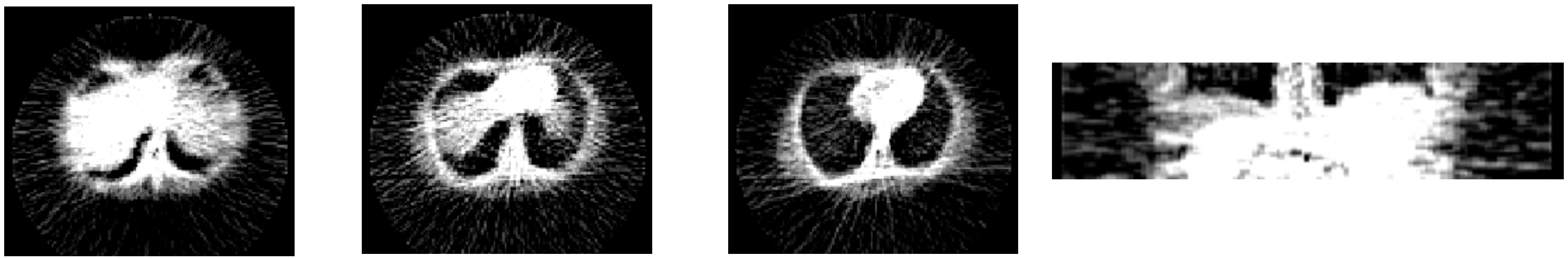
STEP 3: `scale_single_scatter`

```
--min-scale-factor <number>
--max-scale-factor <number>
--remove-interleaving <1|0>
--half-filter-width <number>
--output-filename <filename>
--data-to-fit <filename>
--data-to-scale <filename>
--weights <filename>
```

STEP 4: Remove Scatter Estimate and repeat steps (1) and (3).
Then, average the two scatter estimates.

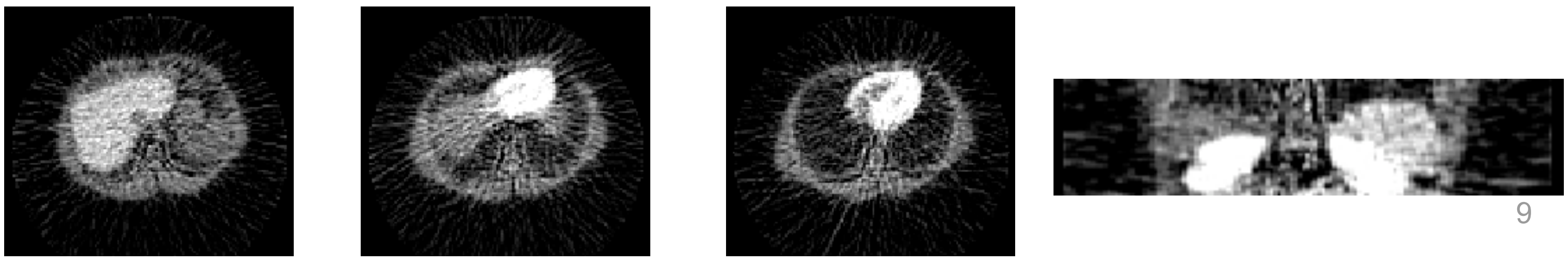
Phantom Results

Not corrected



Corrected with SSS

SimSET total scatter corrected



Implementation in STIR

- Current Limitations - Potential Optimizations:
  - Three separate executables: merge all in one
  - Upsampling for oblique sinograms is handled in a simple way: (pseudo)-inverse SSRB

- Potential Extensions
  - ToF scatter correction
  - Scatter estimation for List Mode data

Relevant Literature

- Tsoumpas C *et al.* “Evaluation of the Single Scatter Simulation Algorithm Implemented in the STIR Library” 2004 IEEE NSS-MIC, Rome.
- Aguiar P *et al*. “Assessment of scattered photons on the quantification of small animal PET studies” *EANM*, Athens, Greece, 2006.
- Dikaios N “Scatter correction in 3D PET”, MSc Thesis, Patras, Greece, 2006.
- Polycarpou I “Evaluation of Scatter Correction Approaches in PET”, MSc Thesis, King’s College London, 2009.

Overview

PET Quantification using STIR:

3D Scatter Correction

Parametric Reconstruction

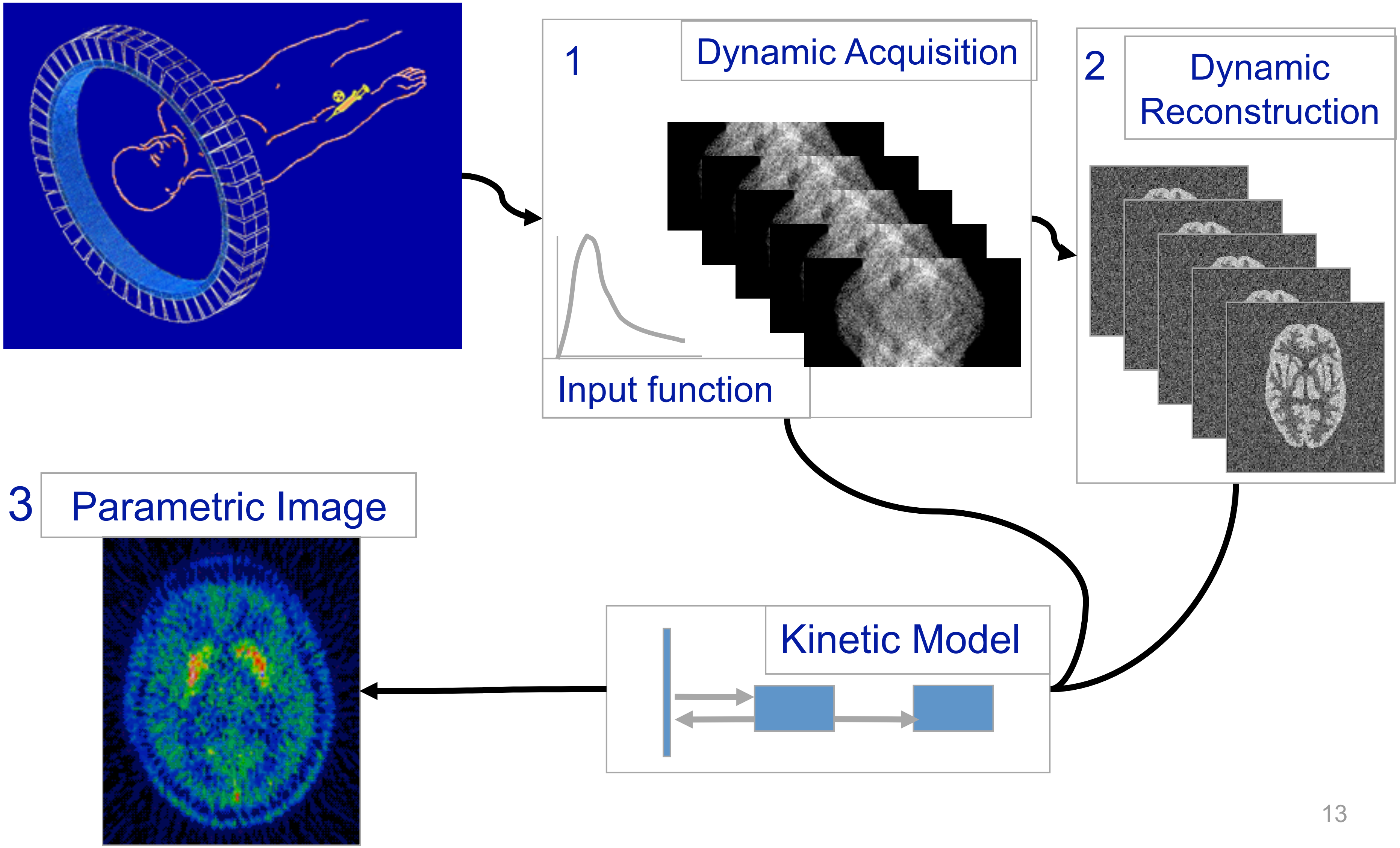
Theory

How to use

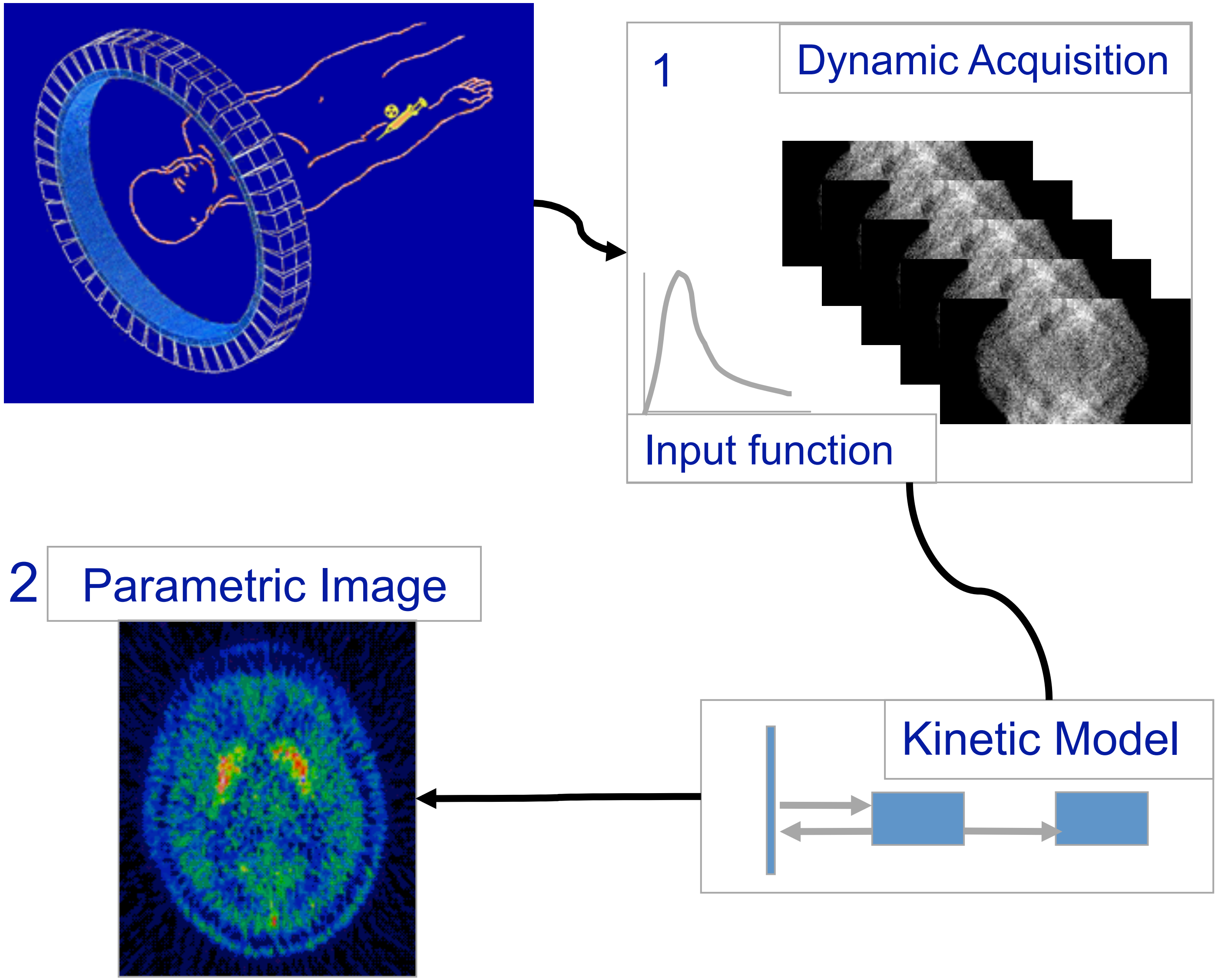
Examples

Limitations & Future Work

Quantitative dynamic studies



Parametric Reconstruction



Why Direct Reconstruction?

- Image Reconstruction: FBP does not offer high resolution and quality parametric images, thus OSEM would be preferable. However, the statistical properties of the reconstructed images are not well approximated with normal distribution for OSEM (*Foundations of Image Science, Barrett & Myers*).

- Kinetic Modelling: Assume Normal Distribution of emission images within repeated measurements.

Parametric Reconstruction

An iterative algorithm based on OSEM that integrates the kinetic model in reconstruction

$$K_{vk}^{(n+1)} = K_{vk}^{(n)} \frac{1}{\sum_{b,f} P_{bvf} M_{kf}} \sum_{b,f} P_{bvf} \left(\frac{Y_{bf}}{\sum_{\tilde{k},\tilde{v}} P_{b\tilde{v}f} (K_{\tilde{v}\tilde{k}}^{(n)} M_{\tilde{k}f}) + S_{bf} + R_{bf}} M_{kf} \right)$$

K: Kinetic Parameter
M: Linear Kinetic Model Matrix
S, R: Scatter and Random Sinograms
P: System Matrix (including scanner geometry, attenuation, normalisation etc.)
Y: Projection Data
b, f, v, k: notations for sinogram, bins, time frames, voxels, kinetic parameter

C. Tsoumpas, F.E. Turkheimer, K. Thielemans, "Study of direct and indirect parametric estimation methods of linear models in dynamic positron emission tomography." *Med Phys*, 2008.

Implementation in STIR

Modelling Buildblock classes and relative classes

`ParametricDiscretisedDensity`

`KineticModel`

`KineticParameters`

`PatlakPlot`

`ModelMatrix`

`PlasmaSample/PlasmaData`

`PoissonLogLikelihoodWithLinearKineticModelAndDynamicProjectionData`

`DynamicProjData`

`DynamicDiscretisedDensity`

`POSMAPOSL/POSSPS`

STIR How To: Modelling

Indirect Patlak Plot

Example for Reference Tissue

```
Patlak Plot Parameters:=

time frame definition filename:=time.fdef
starting frame := 23
calibration factor := 1
scale factor := 1
blood data filename :=  ref.roi
; In seconds
Time Shift := 0
In total counts := 0
In correct scale := 1

end Patlak Plot Parameters:=
```

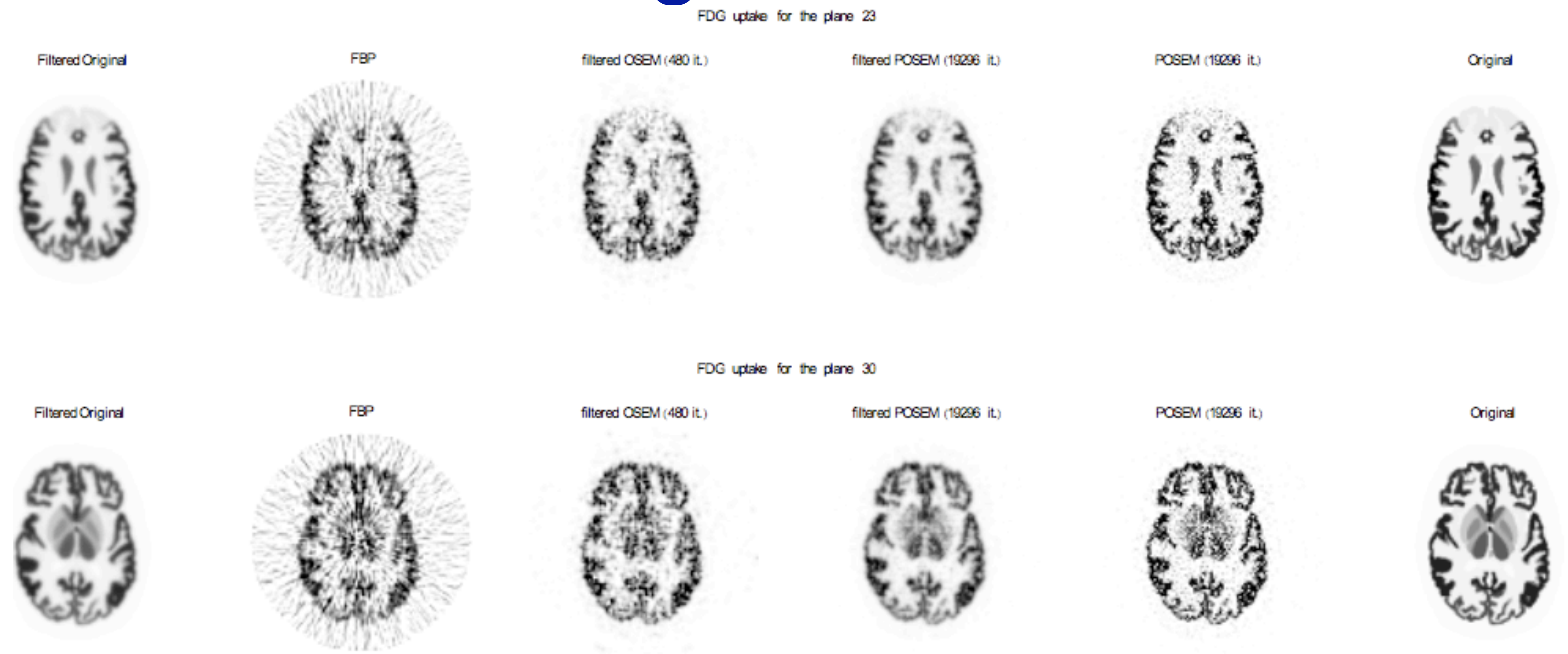
Example for Plasma Input Function

```
Patlak Plot Parameters:=

time frame definition filename:=time.fdef
starting frame := 23
calibration factor := 1942
scale factor := 1
blood data filename :=  plasma.tac
; In seconds
Time Shift := 15
In total counts := 0
In correct scale := 1

end Patlak Plot Parameters:=
```

Direct Reconstruction (POSMAPOSL or POSSPS)

```
objective function
type:=PoissonLogLikelihoodWithLinearKineticModelAndDynamicProjectionData
```

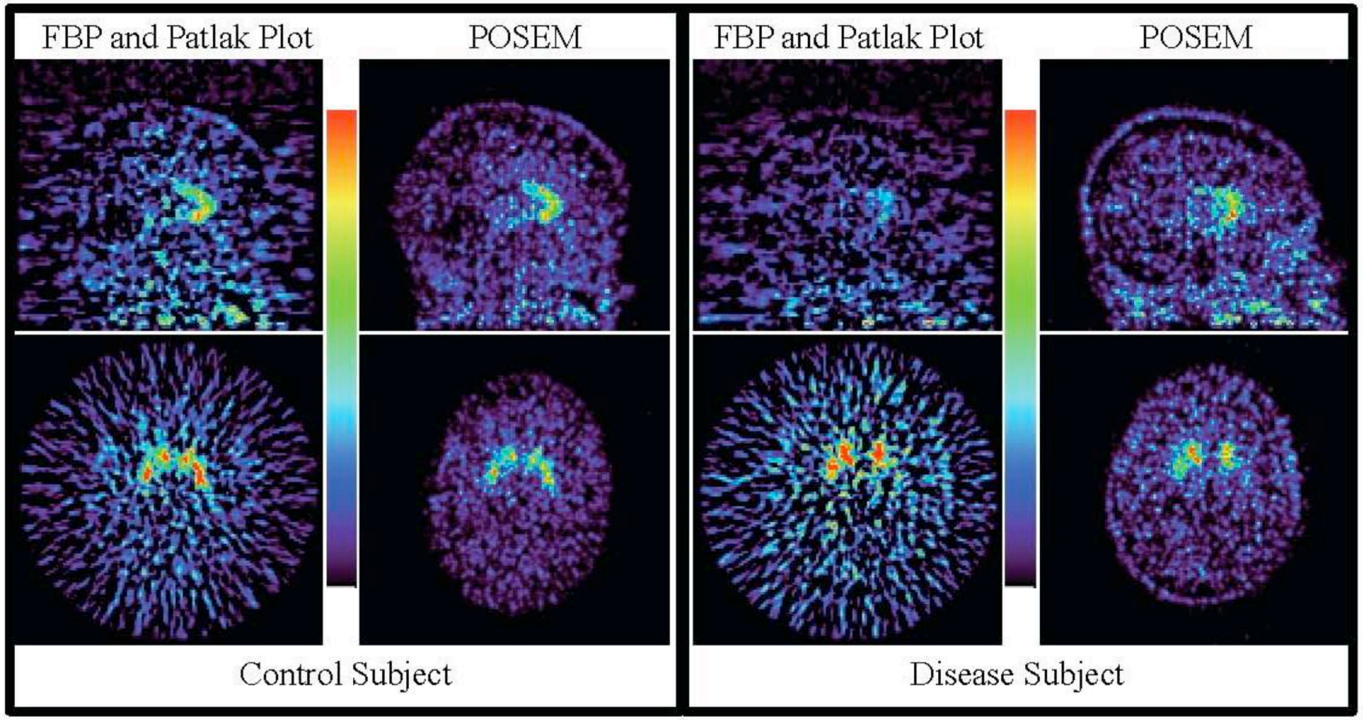
Comparison of converged images of a single realization



Two transaxial planes of the phantom images for one noise realization for the FDG uptake reconstructed with the different methods. Inverse grey scale was used ranging from 0 to the maximum of the original parametric planes. (Note that the last 96 POSEM iterations were performed with PMLEM)

Tsoumpas C, PhD Thesis, Imperial College London, 2008

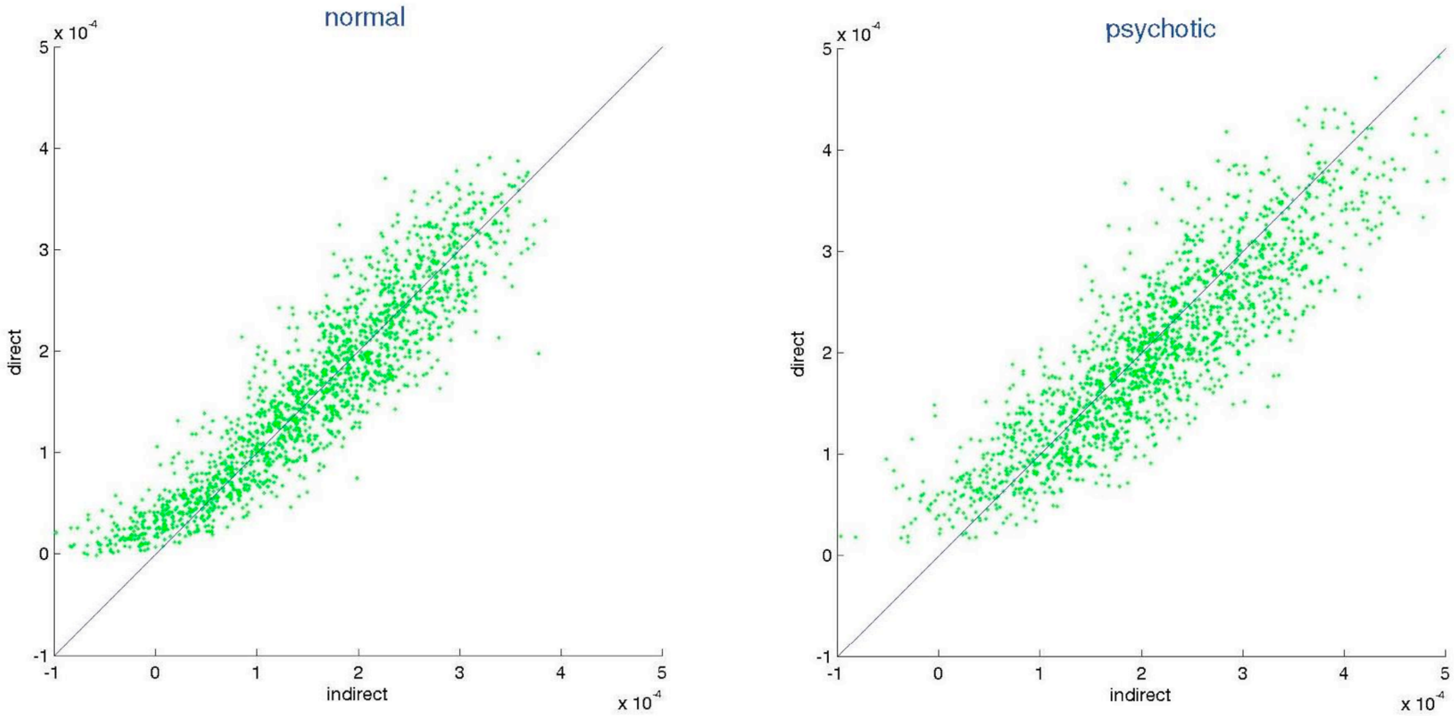
Example of an FDOPA study



Comparison of parametric maps for a patient and a healthy volunteer on a large axial FoV and high sensitivity PET scanner.

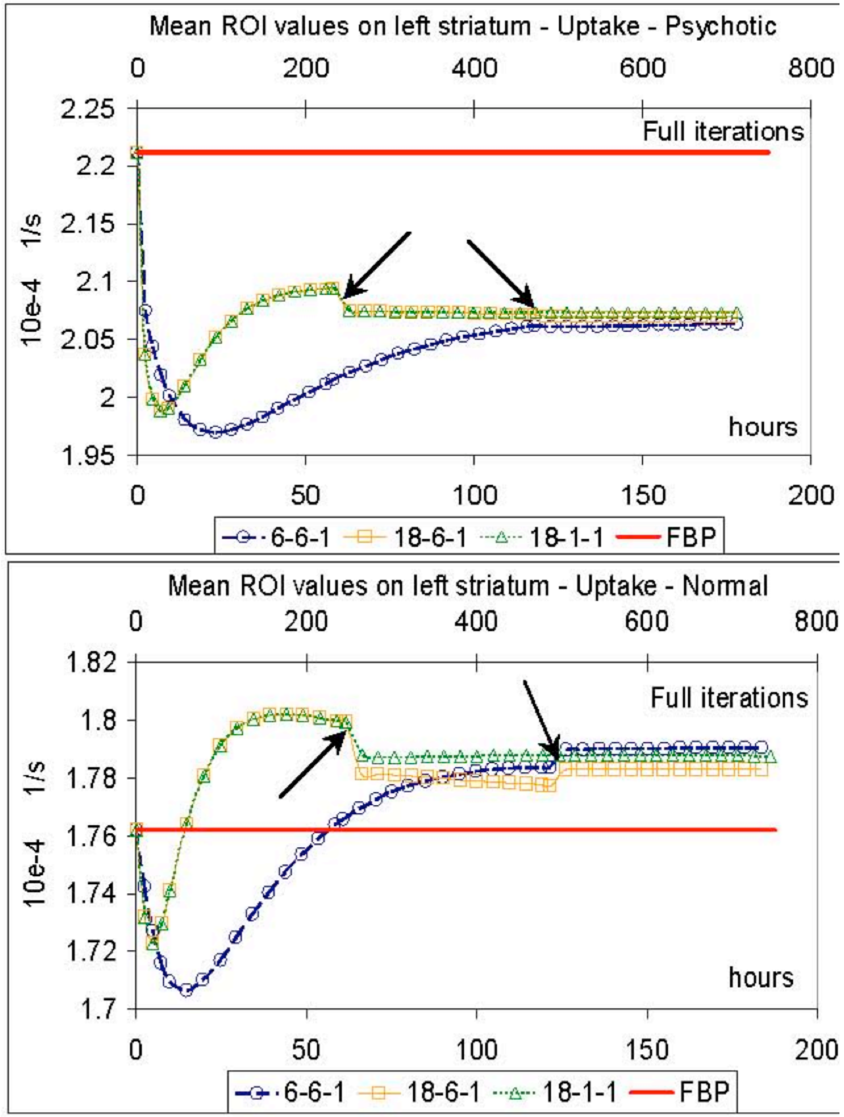
Angelis GI, MRes Thesis, Imperial College London, 2008

Quantitative Comparison



Voxel-wise scatter plots comparing the quantitative values in the left and right striatum for a normal (left side) and an abnormal (right side) subject.

Need for Speed



The mean ROI values (left) and standard deviation (right) for the tracer uptake on the left striatum are presented for a psychotic (up) and a normal (down) study. Three different descending subsets schemes are presented.

G. Angelis, *et al. WMIC*, Nice, France, 2008.

Implementation in STIR

- Current Limitation:
  - Compilation only by defining the NUM_PARAMS as preprocessor variable
- Possible Optimization:
  - POSMAPOSL could use less fwd-projection steps
  - Much faster convergence using alternates steps direct reconstruction (Wang and Qi, 2009 TMI)
- Potential Extensions
  - Straight integration of other algorithms
  - Additional temporal basis (e.g. Spectral Analysis, B-Splines)
  - List-Mode based direct reconstruction

PET Quantification

What next?

- Motion Correction
- *Randoms*
- *Normalization*
- *Dead Time*

However, details from the scanner manufacturers are not easily accessible.

Acknowledgments

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