University of Pisa
Department of Physics
PhD Course in Medical Physics

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Normalization of the PET scanner IRIS

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The PET-CT (1)

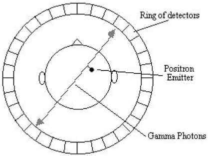
What is PET?

- Nuclear medicine scan, functional imaging technique
- Non-invasive, but it involves exposure to ionizing radiation
- Usage of radioactive isotopes: β^+-emitter

The PET-CT (2)

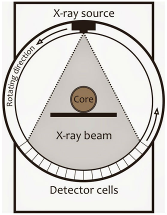
PET

- emission
- physiological information

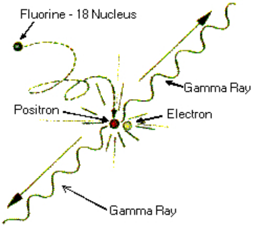


CT

- transmission
- morphological information
- attenuation coefficient



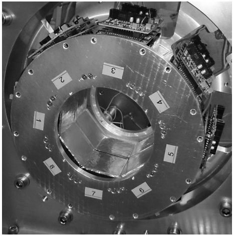
β^+ - emission

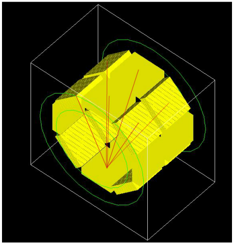


Common isotopes and their half-life in minutes

^{11}C	20.3
^{13}N	9.98
^{15}O	2.05
^{18}F	110
^{22}Na	2.6 y

IRIS





Module	System	Dataset
Crystal LYSO:Ce	Modules 16 (8 x 2)	LORs $> 2 \cdot 10^7$
Crystal size (mm3)	No. of crystals $> 10^5$	Coincidence 1 vs 6
1.6 x 1.6 x 12	Inner diameter 110.8 mm	No. pairs 48
Crystal pitch 1.69 mm	Gantry aperture 100 mm	Window (ns) 6,2
No. of Cr. 702	Axial FOV 95 mm	(2τ)
	Transaxial FOV 80 mm	

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From projection data to image

Two way to reconstruct image:

- analytic
  - deterministic
  - FBP
- iterative
  - stochastic
  - MLEM, OSEM
  - $\mathbf{y} = \mathbf{P}\mathbf{f}$

MLEM and OSEM (1)

MLEM
(Maximum Likelihood Expectation Maximization)

$$f_j^{(k+1)} = \frac{f_j^{(k)}}{\sum_i p_{ij}} \sum_i p_{ij} \frac{y_i}{\sum_l p_{il} f_l^{(k)}} \qquad (1)$$

where:

- f_j^k is the radiotracer activity in voxel j at k-th iteration;
- y_i represents the i-th pair of detectors (or LOR);
- p_{ij} contains the probability of detecting an emission from voxel site j in LOR i.

MLEM and OSEM (2)

The MLEM (or OSEM) cycle can be summarized in the following steps:

1. forward-project current image values $f_j^{(k)}$ into projection domain;
2. compare projection with measured data y_i , obtaining a correction factor;
3. back-project the correction factor into image domain for each LOR;
4. update current image estimate weighted by p_{ij} .

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Problems

In a PET scanner there are several sources of error in the quantification process, like:

- scattered photons
- random coincidences
- differences in sensitivity

Normalization in PET is the process of ensuring that all LORs joining detectors in coincidence have the right effective sensitivity.

Normalization

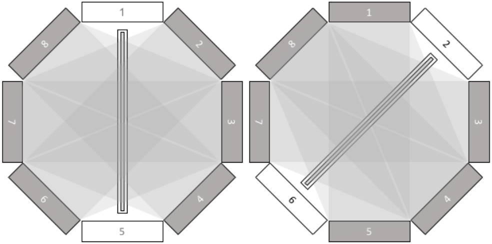
Direct

- ratio between the ideal number of coincidences and the actually measured one
- large number of counts for acceptable statical accuracy
- scatter for some phantoms

Component-based

- divides the normalization factors into detector efficiency and spatial distortion correction
- normalization factors are computed by averaging over multiple LORs
- different models for the normalization factor

The Phantom



Planar phantom: 110 x 95 x 2 mm^3 of ^{18}F

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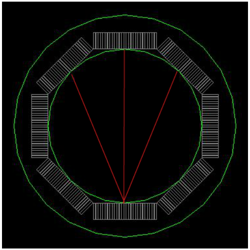
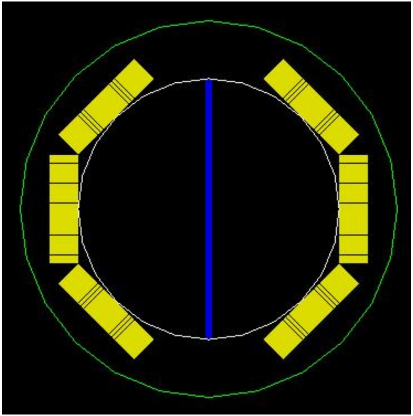
GATE 7.1

GATE: Geant4 Application for Tomographic Emission

- geometry
- physics
- digitizer
- phantom with activity



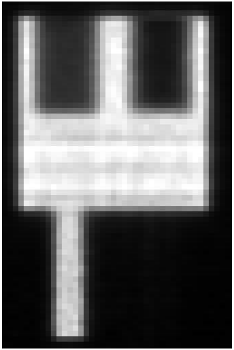
New IRIS



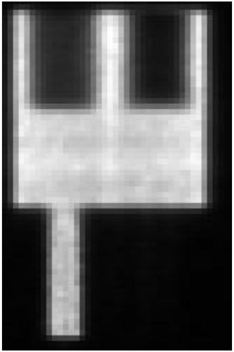
IRIS with planar phantom without 4 modules

Quality Phantom NEMA-NU4

Not normalized



Normalized



Standard mesurements: Uniformity

Not normalized	
Mean:	$5 \cdot 10^4$
Max:	$6 \cdot 10^4$
Min:	$4 \cdot 10^4$
%STD:	6

Normalized	
Mean:	$1.5 \cdot 10^4$
Max:	$1.7 \cdot 10^4$
Min:	$1.3 \cdot 10^4$
%STD:	5

Standard mesurements: Recovery Coefficient

Not normalized

	1mm	2mm	3mm	4mm	5mm
RC	0.13	0.62	0.89	0.89	0.90
%STD	9	9	7	8	7

Normalized

	1mm	2mm	3mm	4mm	5mm
RC	0.13	0.63	0.90	0.92	0.92
%STD	8	8	6	6	6

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NEXT STEPS

- Use different phantoms to normalize the LORs and study the differences in the outcome to understand which one works better with IRIS
- Investigate different normalization techniques, in particular focusing on the differences between direct and component-based normalization
- Apply the results to actual preclinical images to increase the quantification of the scanner outcome

Thank you for your attention

MLEM and OSEM: some equations

The detection of each photon pair is Poissonian:

$$p(\mathbf{y}|\mathbf{f}) = \prod_{\mathbf{i}} \mathbf{p}(\mathbf{y_i}|\mathbf{f}) = \prod_{\mathbf{i}} \mathbf{e}^{-\hat{\mathbf{y}}_\mathbf{i}} \frac{\hat{\mathbf{y}}_\mathbf{i}^{\mathbf{y_i}}}{\mathbf{y_i}!} \tag{2}$$

where: $\hat{y}_i = E[y_i] = \Sigma_j E[c_{ij}]$

$$L(\mathbf{y}|\mathbf{f}) = \sum_{\mathbf{i}} \sum_{\mathbf{j}} \mathbf{c_{ij}} \ln \mathbf{p_{ij}} \mathbf{f_i} - \mathbf{p_{ij}} \mathbf{f_i} \tag{3}$$

$$\frac{\partial E[L(\mathbf{y}|\mathbf{f})|\mathbf{y};\mathbf{f}^{(\mathbf{k})}]}{\partial f_i} = f_j^{(k)} \sum_i p_{ij} \frac{y_i}{\Sigma_l p_{il} f_l^{(k)}} \frac{p_{ij}}{p_{ij} f_j} - \sum_i p_{ij} = 0 \tag{4}$$