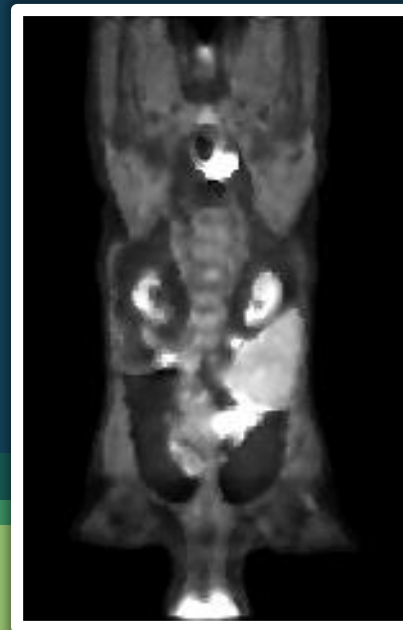
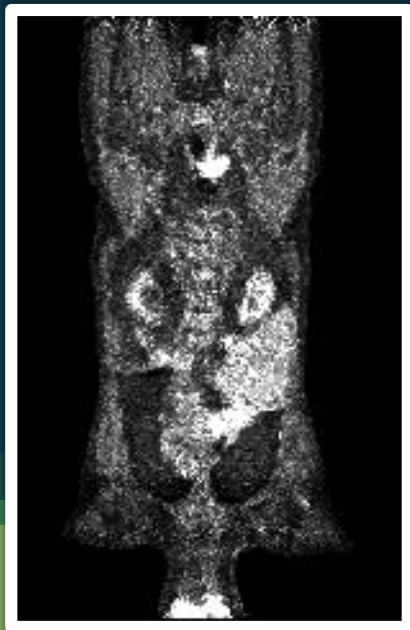


Dóra Varnyú, László Szirmay-Kalos
Budapest University of Technology and Economics, Hungary

Improving Positron Emission Tomography with Guided Filtering



SZÉCHENYI 2020



HUNGARIAN
GOVERNMENT

European Union
European Social
Fund

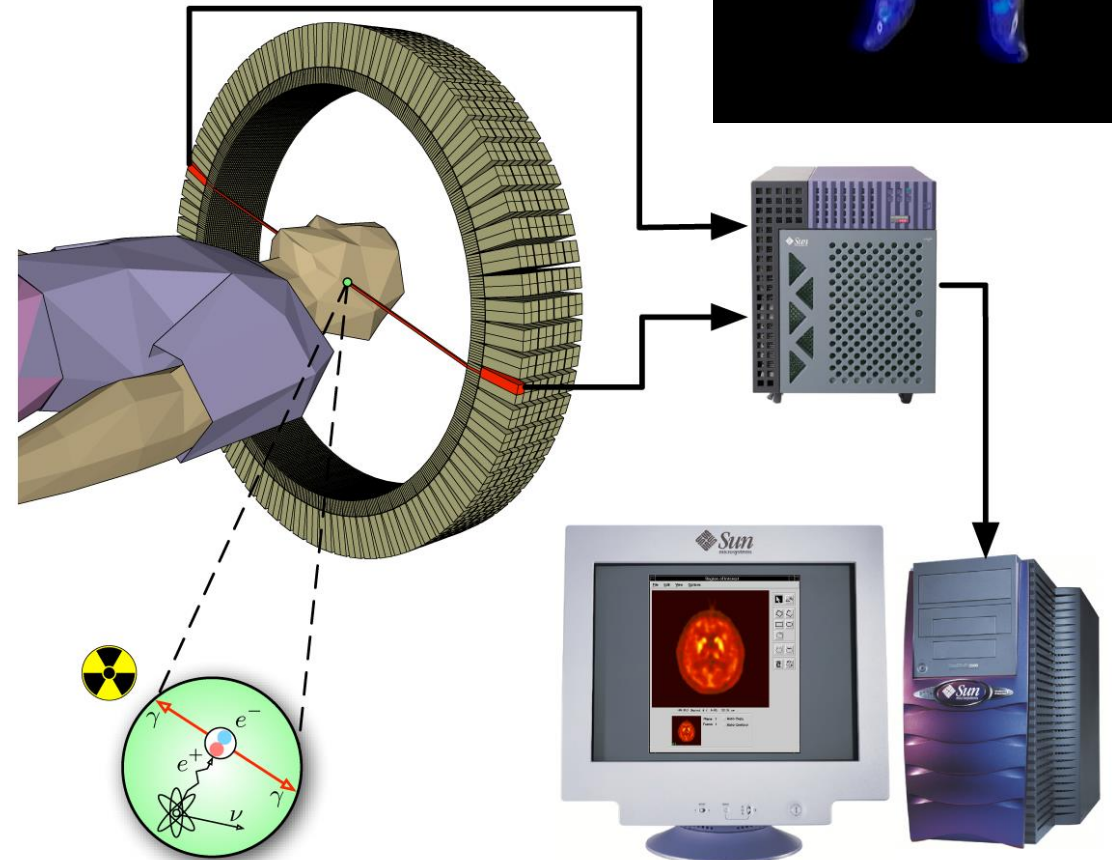
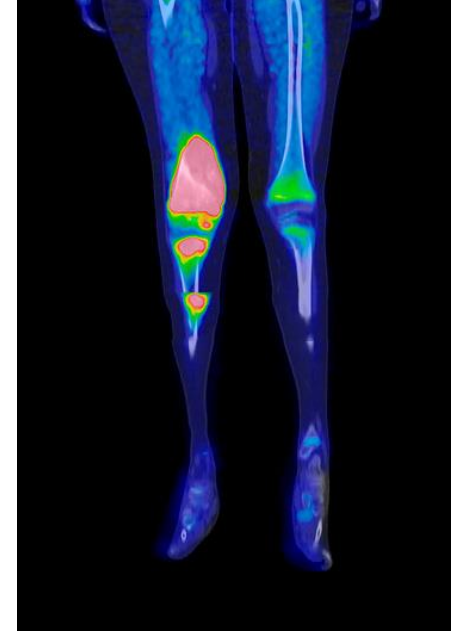


INVESTING IN YOUR FUTURE



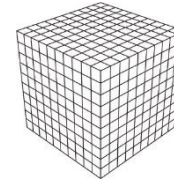
Positron Emission Tomography (PET)

- Tumor
- Coronary Artery Disease
- Alzheimer's disease
- Epilepsy
- Parkinson's disease



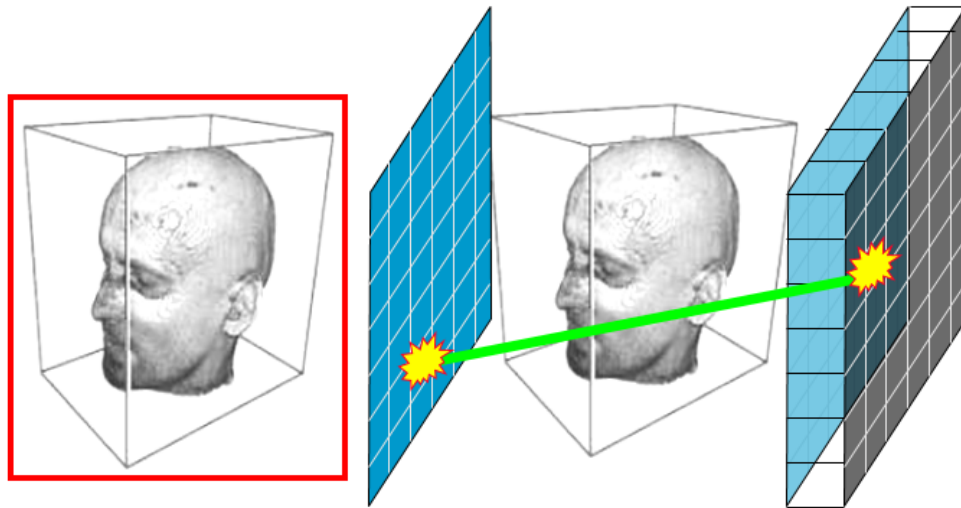


PET reconstruction

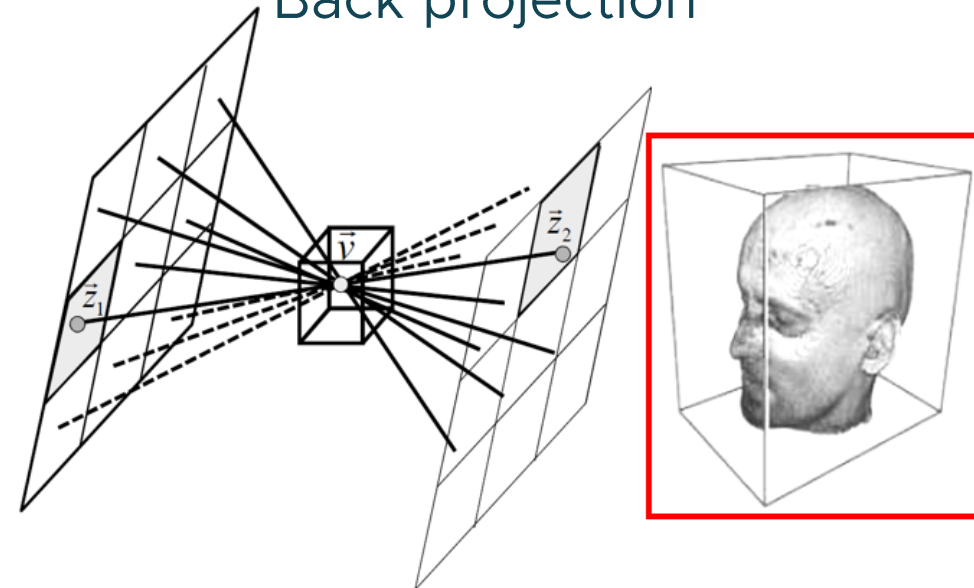


homogeneous 3D voxel grid

Distribution estimation → Expected hit count
Forward projection



Measured hit count → Corrected distribution estimation
Back projection



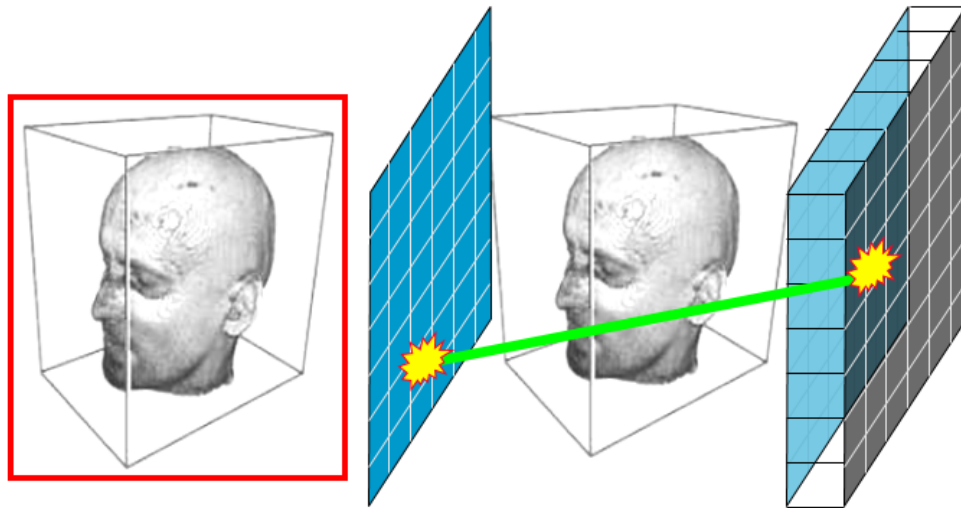
10-100 iterations



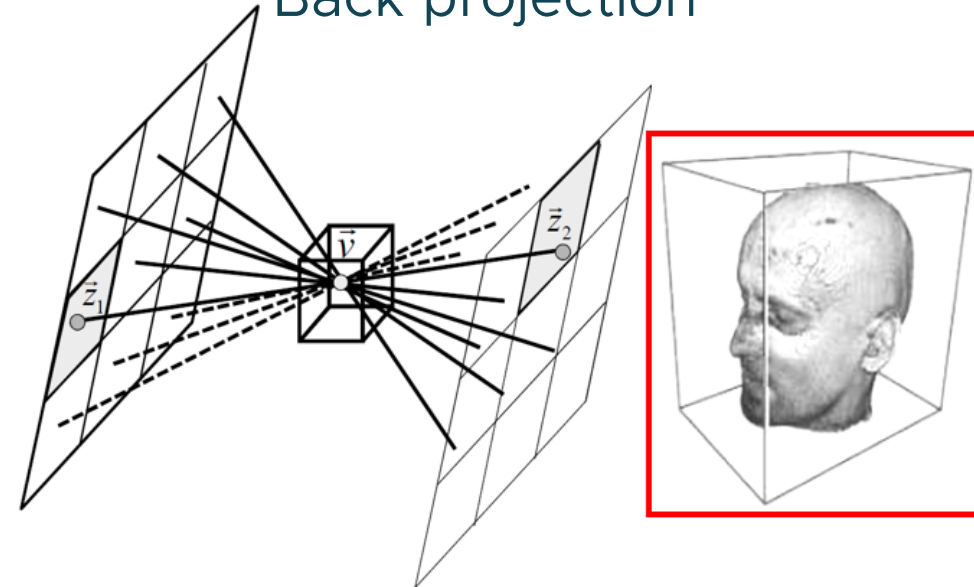
PET reconstruction

static $\leftrightarrow$ dynamic reconstruction

Distribution estimation $\rightarrow$ Expected hit count
Forward projection



Measured hit count $\rightarrow$ Corrected distribution estimation
Back projection



10-100 iterations



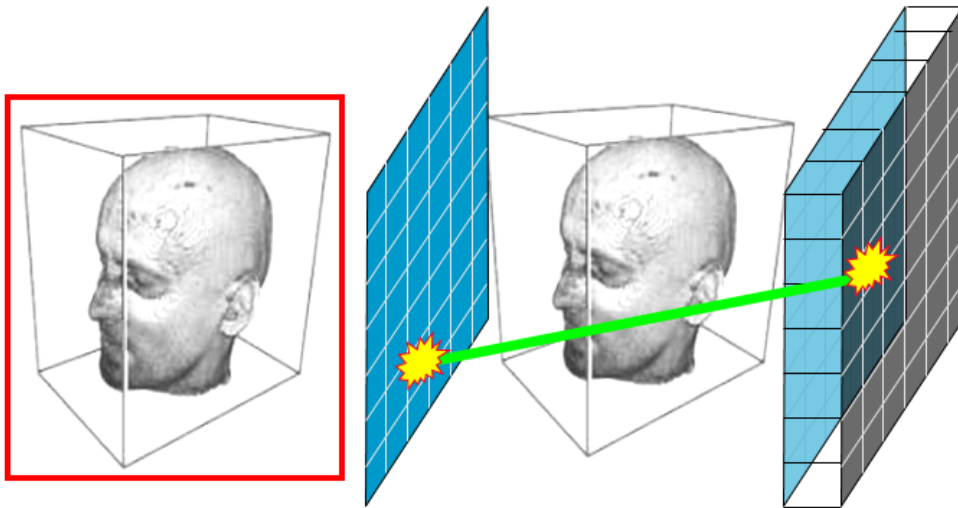


PET reconstruction

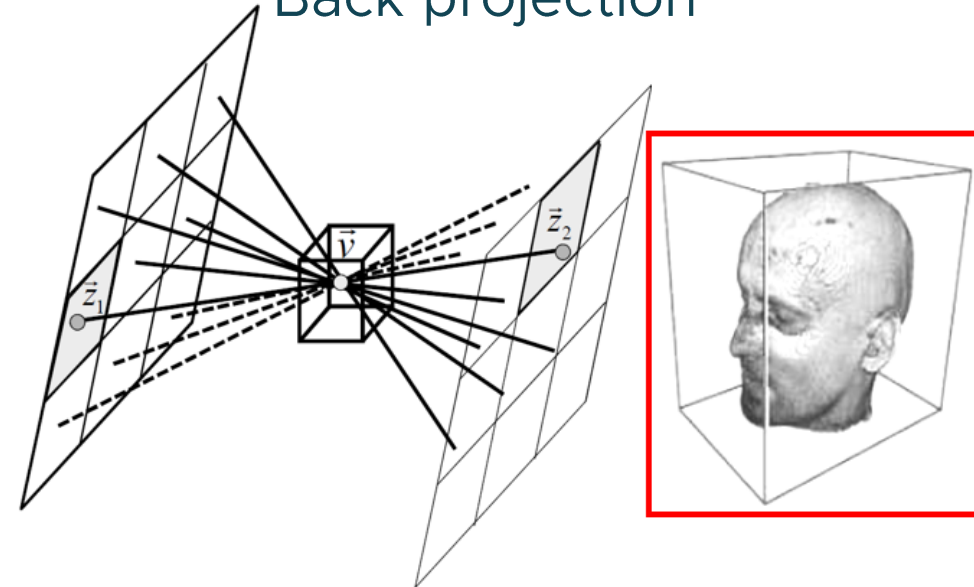
static $\leftrightarrow$ dynamic reconstruction

- spectral model
- two-tissue compartment model

Distribution estimation $\rightarrow$ Expected hit count
Forward projection



Measured hit count $\rightarrow$ Corrected distribution estimation
Back projection

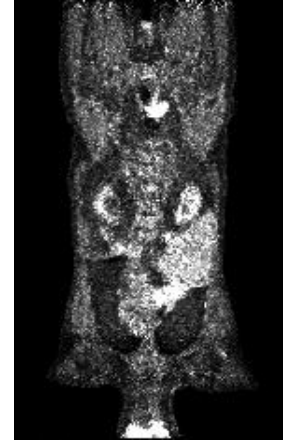


10-100 iterations



Problem statement

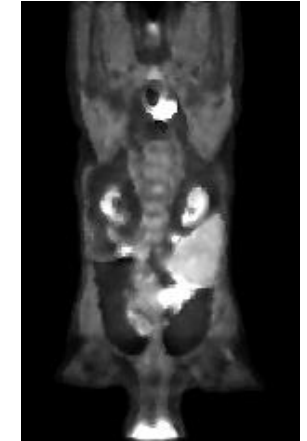
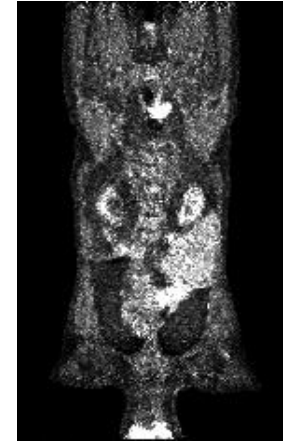
- High noise → misdiagnosis





Problem statement

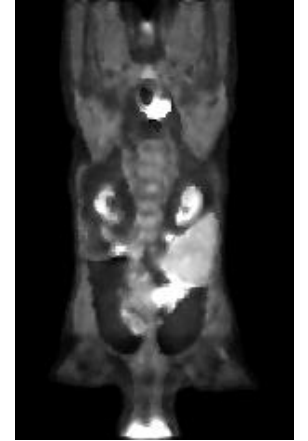
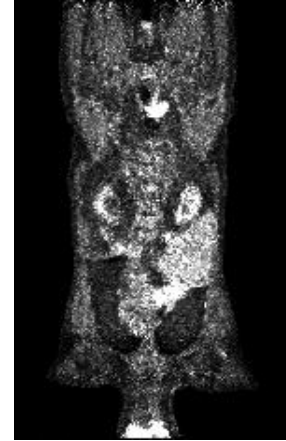
- High noise → misdiagnosis
- Noise filtering!





Problem statement

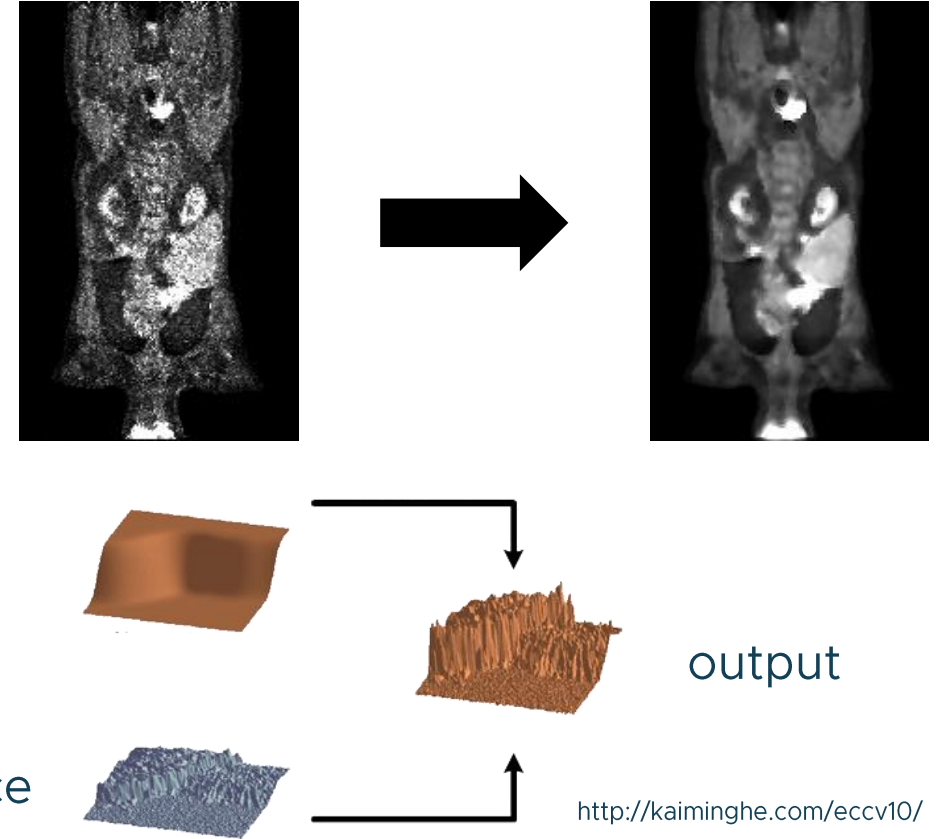
- High noise → misdiagnosis
- Noise filtering!
 - method of sieves
 - post-reconstruction filtering





Problem statement

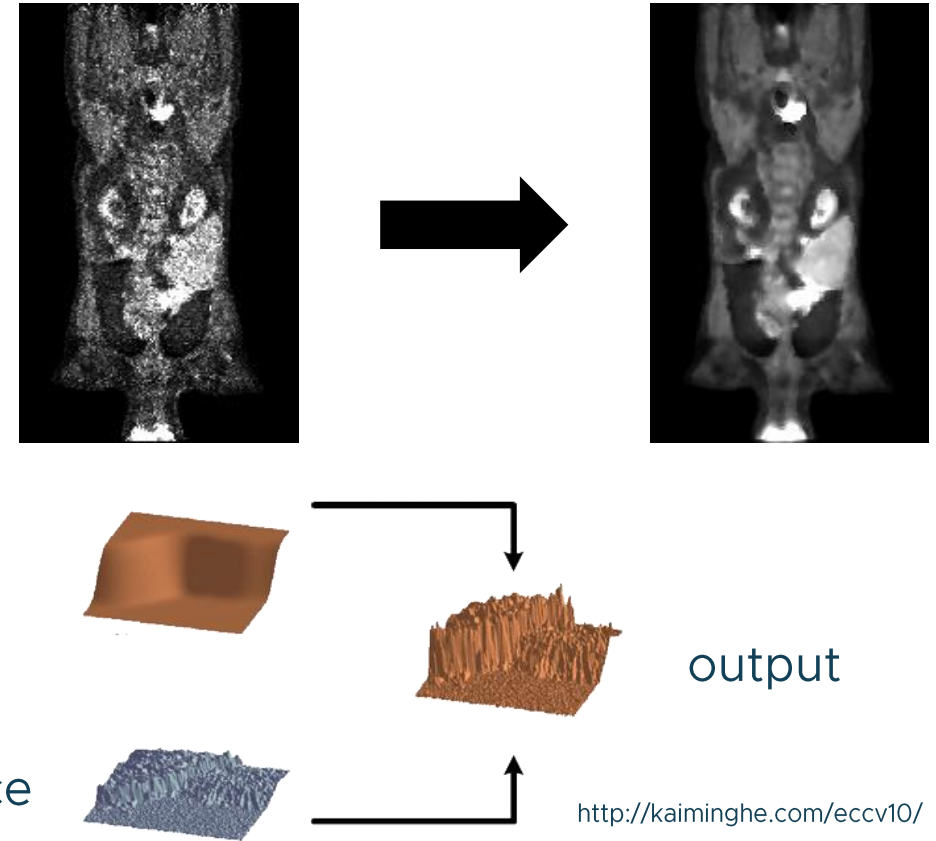
- High noise → misdiagnosis
- Noise filtering!
 - method of sieves
 - post-reconstruction filtering
- **guided filter**¹
 - fast, edge-preserving smoothing operator
 - edge enhancement using CT/MRI imaging



¹ He, K., Sun, J. & Tang, X., 2013. Guided Image Filtering. IEEE transactions on pattern analysis and machine intelligence, 6, Volume 35, pp. 1397-1409.

Problem statement

- High noise → misdiagnosis
- Noise filtering!
 - method of sieves
 - post-reconstruction filtering
- **guided filter**¹
 - fast, edge-preserving smoothing operator
 - edge enhancement using CT/MRI imaging
- GPU-acceleration



¹ He, K., Sun, J. & Tang, X., 2013. Guided Image Filtering. IEEE transactions on pattern analysis and machine intelligence, 6, Volume 35, pp. 1397-1409.

Noise reduction with guided filtering

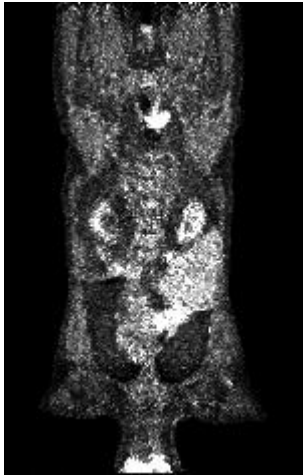
For static reconstructions



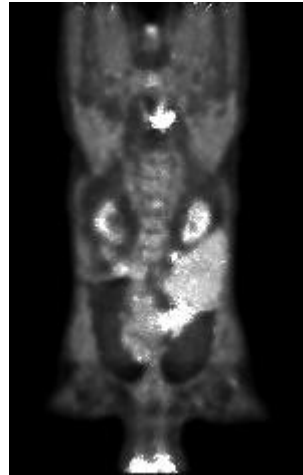
Choice of guidance

1. Input

the input itself is the guidance



guidance



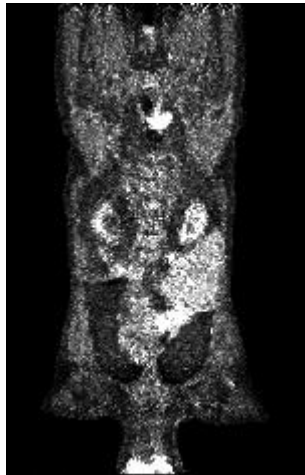
output



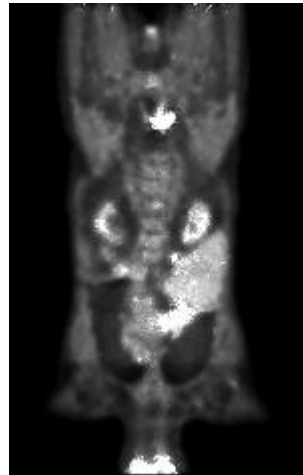
Choice of guidance

1. Input

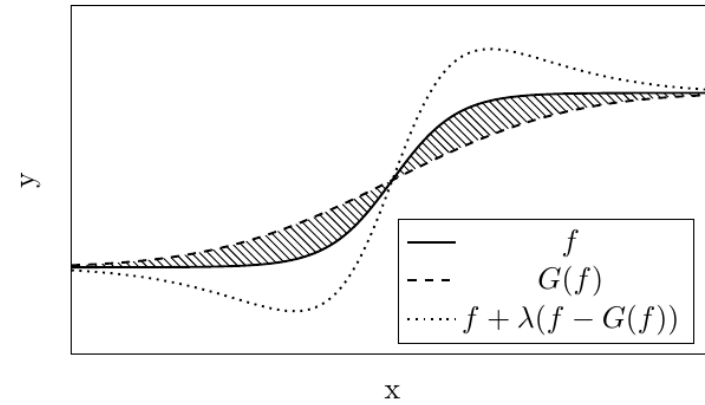
the input itself is the guidance



guidance



output

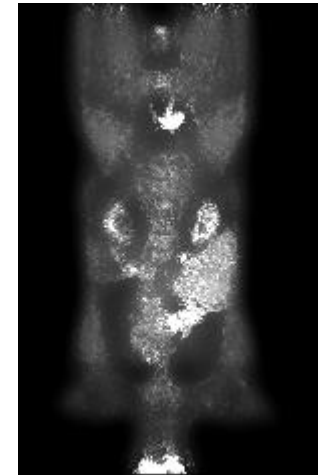


2. Enhanced input

Gaussian + high-boost filtering



guidance



output



Choice of guidance

3. Anatomical image from CT/MRI imaging



guidance



output



Choice of guidance

3. Anatomical image from CT/MRI imaging

4. Anatomically guided input
guided bilateral filtering² of the input
using the anatomical image as guidance

guidance



output

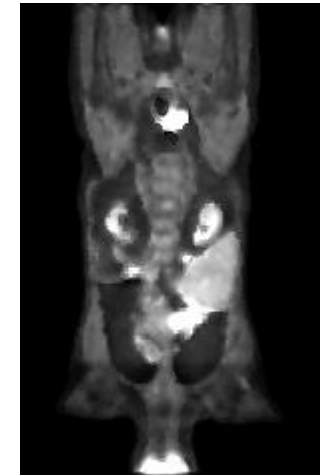
$$Q_k = \frac{\sum_{i \in \omega_k} P_i \cdot g(\|i - k\|) \cdot g(\|A_i - A_k\|)}{\sum_{i \in \omega_k} g(\|i - k\|) \cdot g(\|A_i - A_k\|)}$$

anatomical image
↙ ↘

4. Anatomically guided input guided bilateral filtering² of the input using the anatomical image as guidance



guidance



output

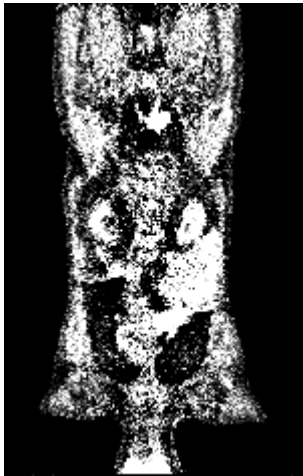


Choice of guidance

5. Dual channel guidance

Channel 1: enhanced input

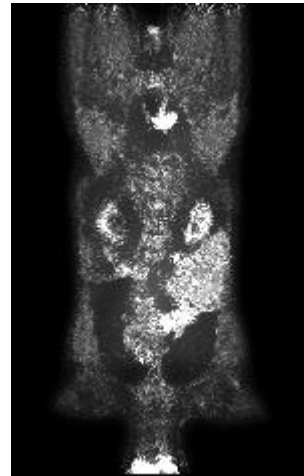
Channel 2: anatomically guided input



guidance
channel 1



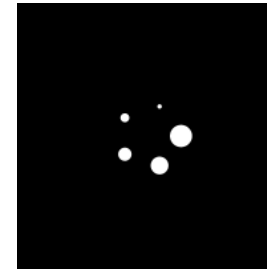
guidance
channel 2



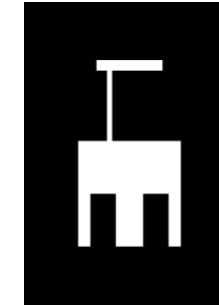
output



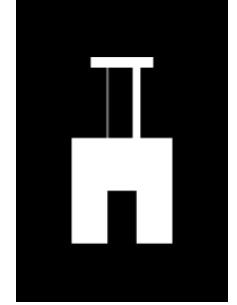
Choice of guidance



axial



coronal



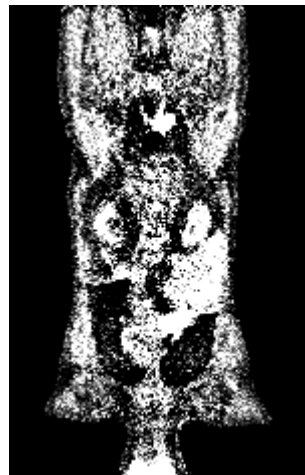
sagittal

preclinical small rodent phantom
NEMA NU 4-2008

5. Dual channel guidance

Channel 1: enhanced input

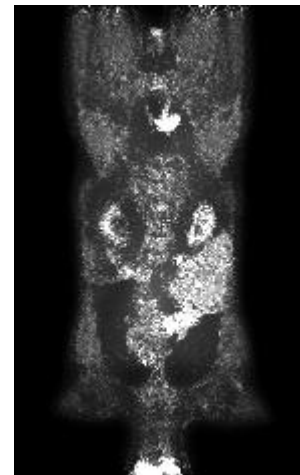
Channel 2: anatomically guided input



guidance
channel 1



guidance
channel 2

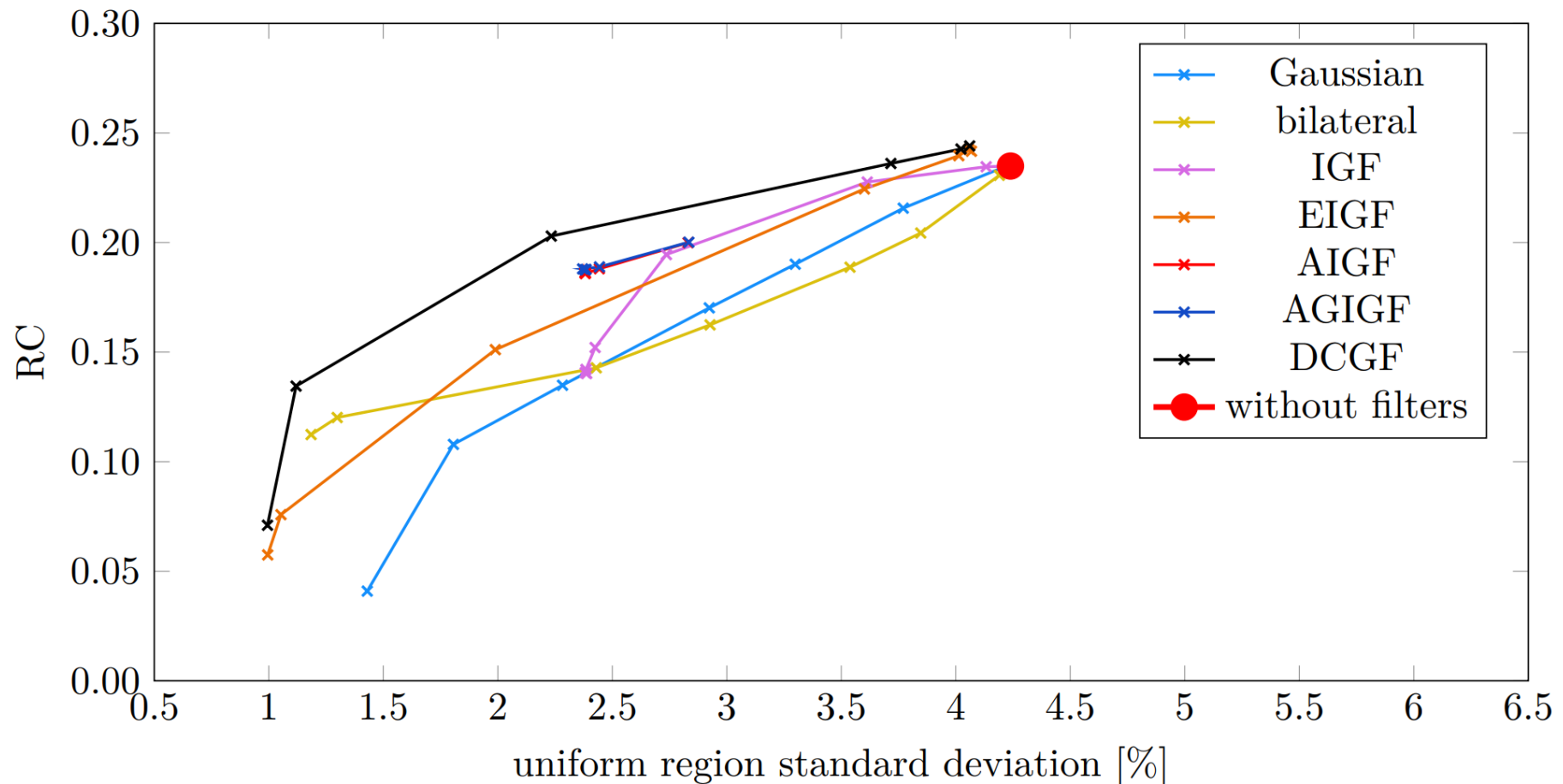


output

Recovery Coefficients

Recovery Coefficient (RC): $\frac{\text{reconstructed activity}}{\text{real activity}}$

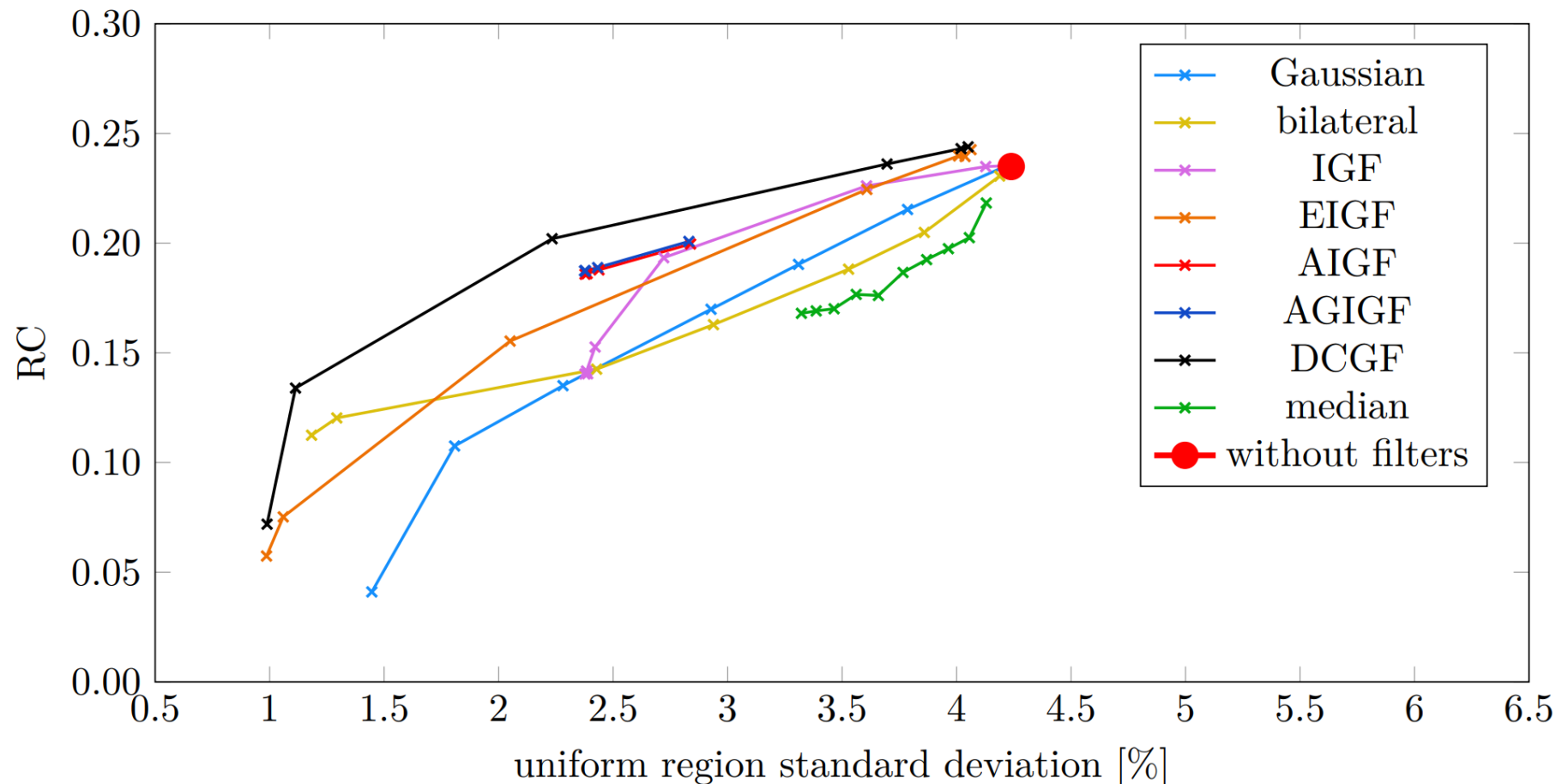
Performing filtering after each iteration



Recovery Coefficients

Recovery Coefficient (RC): $\frac{\text{reconstructed activity}}{\text{real activity}}$

Performing filtering only after last iteration





Runtime

NVIDIA TITAN V graphics card

$200 \times 200 \times 287$ voxels

How many seconds is the runtime of the filters
at different kernel window sizes?

r	median	Gaussian	bilateral	IGF	EIGF	AIGF	AGIGF	DCGF
1	0.0410	0.0089	0.3535	0.4857	0.6030	0.5097	0.6584	1.2466
2	1.0632	0.0090	0.3533	0.4865	0.6048	0.5091	0.6580	1.2488
3	9.2433	0.0092	0.3542	0.4867	0.6034	0.5093	0.6582	1.2464
4	44.4551	0.0094	0.3596	0.4880	0.6041	0.5095	0.6581	1.2462
5	178.0231	0.0096	0.3754	0.4867	0.6034	0.5092	0.6585	1.2468
6	478.2444	0.0098	0.4003	0.4866	0.6052	0.5100	0.6581	1.2465
7	1116.0873	0.0101	0.4322	0.4861	0.6038	0.5095	0.6587	1.2462
8	2308.0518	0.0103	0.4767	0.4859	0.6055	0.5098	0.6582	1.2473
9	4412.3638	0.0105	0.5293	0.4860	0.6044	0.5095	0.6581	1.2517
10	7911.3560	0.0107	0.5968	0.4868	0.6031	0.5097	0.6580	1.2454

For dynamic reconstructions

- What should we filter?

activity filtering $\leftrightarrow$ **parametric filtering**

- What should we filter?
 - activity filtering** $\leftrightarrow$ **parametric filtering**
- Guidance?
 - guidances listed for static reconstructions

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3. Lu, L. et al., 2014. Dynamic PET denoising incorporating a composite image guided filter. s.l., s.n., pp. 1-4.

- What should we filter?

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 - **image of the static reconstruction**: sum of the activity images of all frames³
 - **grouping of frames**: 3 groups $\rightarrow$ **triple channel guidance**
E.g. in case of 9 frames the first channel is the sum of the activity images of frames 1-3, the second channel is of frames 4-6, and the third channel is of frames 7-9

3. Lu, L. et al., 2014. Dynamic PET denoising incorporating a composite image guided filter. s.l., s.n., pp. 1-4.

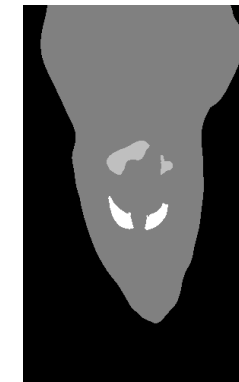
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E.g. in case of 9 frames the first channel is the sum of the activity images of frames 1-3, the second channel is of frames 4-6, and the third channel is of frames 7-9
- Rat phantom
 - 4 regions: body, lung, striatum, cerebellum
 - 1800 second simulation, divided into 9 frames



axial



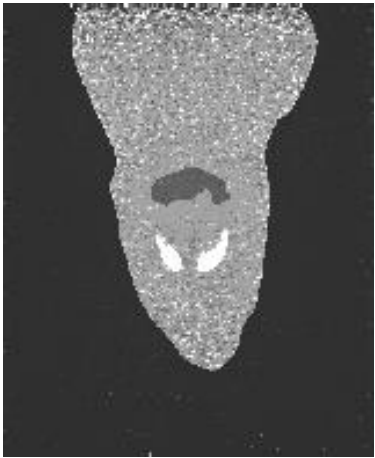
coronal



sagittal

3. Lu, L. et al., 2014. Dynamic PET denoising incorporating a composite image guided filter. s.l., s.n., pp. 1-4.

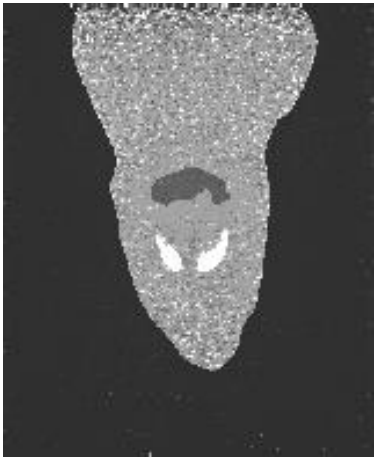
Results using two-tissue compartment model



without filters

Results using two-tissue compartment model

activity filtering



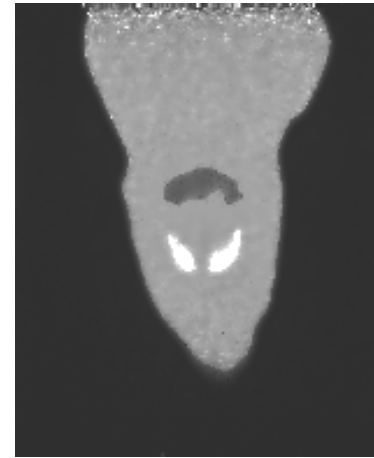
without filters



anatomically guided
input guided filtering



static reconstruction
guided filtering

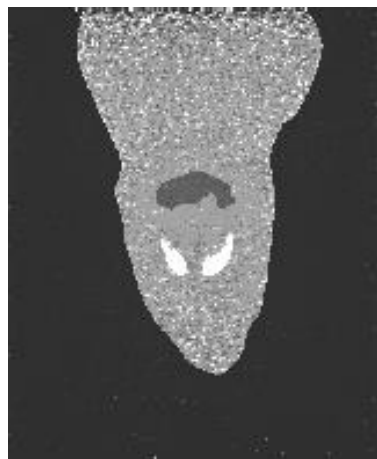


triple channel
guided filtering

Results using two-tissue compartment model

activity filtering

parametric filtering



without filters



anatomically guided
input guided filtering



static reconstruction
guided filtering



triple channel
guided filtering



static reconstruction
guided parametric filtering

Results using two-tissue compartment model

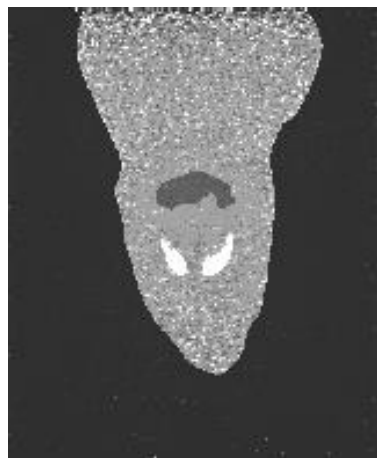
X

not applicable for
exponential parameters!



activity filtering

parametric filtering



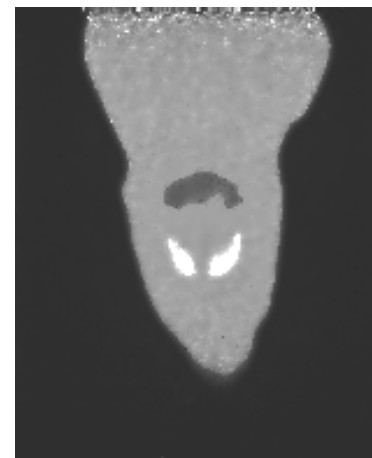
without filters



anatomically guided
input guided filtering



static reconstruction
guided filtering



triple channel
guided filtering



static reconstruction
guided parametric filtering

Results using spectral model



without filters

Results using spectral model

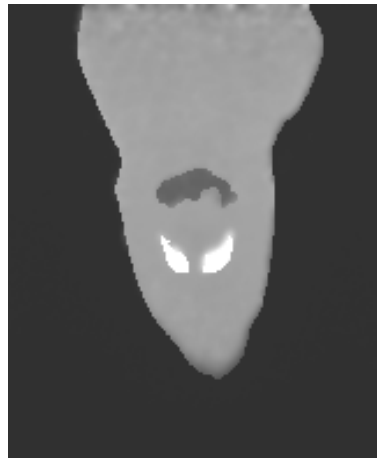
Performing filtering
only after last iteration

activity filtering

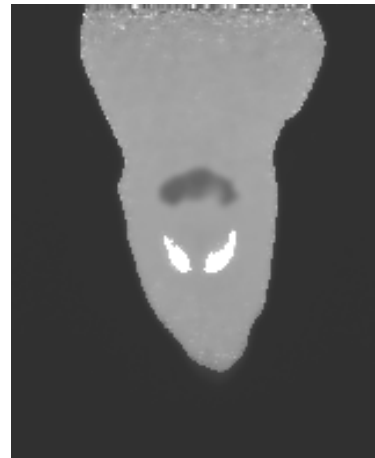
parametric filtering



without filters



anatomically guided
input guided filtering



static reconstruction
guided filtering



triple channel
guided filtering



triple channel guided
parametric filtering

Results using spectral model

Performing filtering
after each iteration

activity filtering

parametric filtering



without filters



anatomically guided
input guided filtering



static reconstruction
guided filtering



triple channel
guided filtering



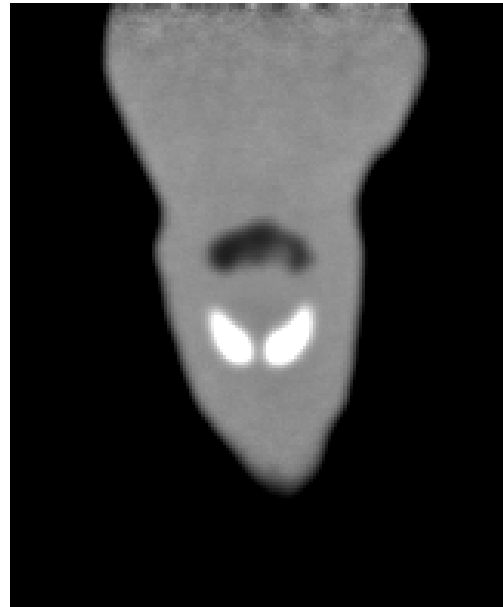
triple channel guided
parametric filtering

Partial Volume Correction with Guided Filtering

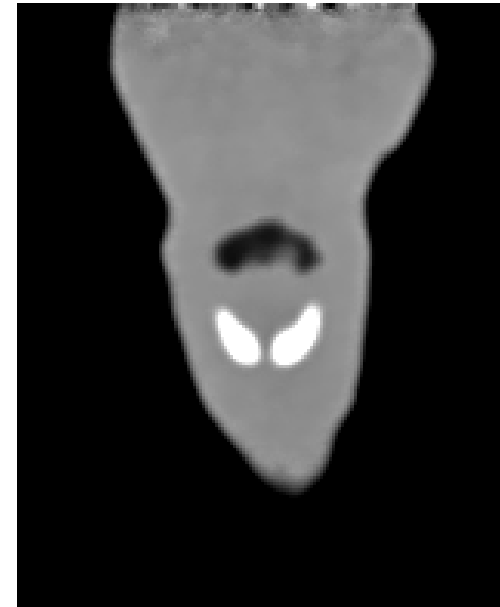
- the partial volume effect mathematically corresponds to convolution with the PSF
PSF (point spread function): response to a point activity source

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- proposal: minimize $\|(PSF * Q) - P\|$ instead of $\|Q - P\|$

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PSF (point spread function): response to a point activity source
- proposal: minimize $\|(PSF * Q) - P\|$ instead of $\|Q - P\|$



without correction



with correction



My contributions

Application of guided filtering in static PET reconstruction

- Definition of guidances:
Enhanced input, anatomically guided input, dual channel.
- Comparison of guided filtering with other filtering methods:
RC of the proposed dual channel guidance is more favorable than the other tested filters.



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Improving existing guided filtering methods for dynamic PET reconstruction

- Definition of a new guidance: *triple channel.*
- Elaboration of the concept of parametric filtering.
- Comparison of activity and parametric filtering:
 - *In case of activity filtering, the triple channel guidance performs best.*
 - *If the anatomical segmentation is known, parametric filtering produces just as good results as activity filtering, but more efficiently.*



My contributions

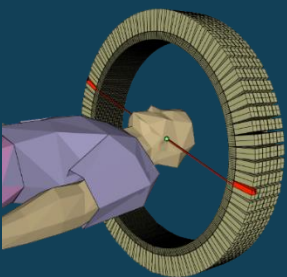
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Development of an effective, guided-filter-based partial volume correction technique



Thank you for your attention!

Noise reduction with guided filtering was supported by the ÚNKP-19-1 New National Excellence Program of the Ministry for Innovation and Technology.



Partial volume correction with guided filtering has been supported by the European Union, co-financed by the European Social Fund (EFOP 3.6.1-16-2016-00014, Research, Development, and Educational Integration of Disruptive Technologies in the Field of E-mobility; EFOP-3.6.2-16-2017-00013, Thematic Fundamental Research Collaborations Grounding Innovation in Informatics and Infocommunications).



European Union
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Fund



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