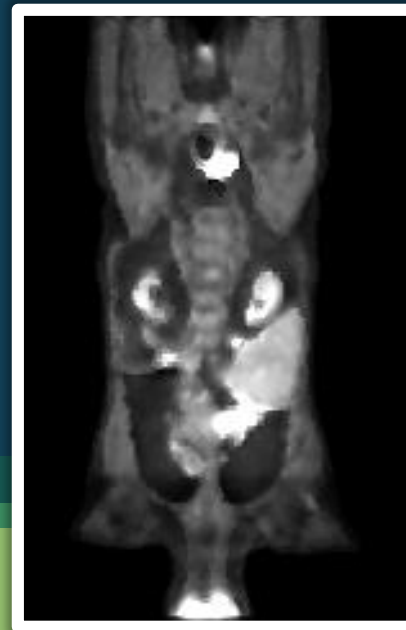


Presenter: **Dóra Varnyú**

Consulent: **László Szirmay-Kalos, BME-IIT**

Improving PET Imaging With Guided Filtering



SZÉCHENYI 2020



HUNGARIAN
GOVERNMENT

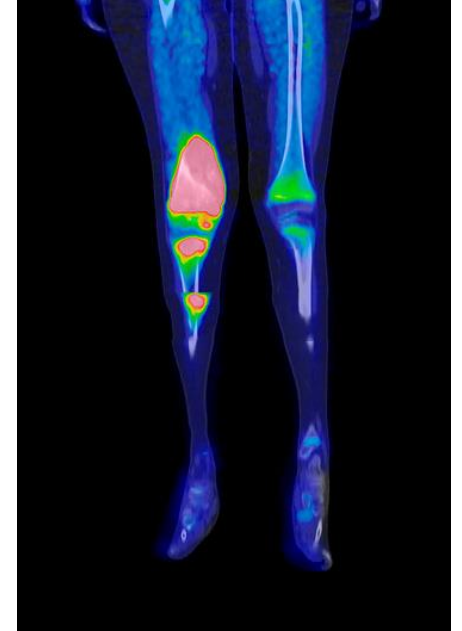
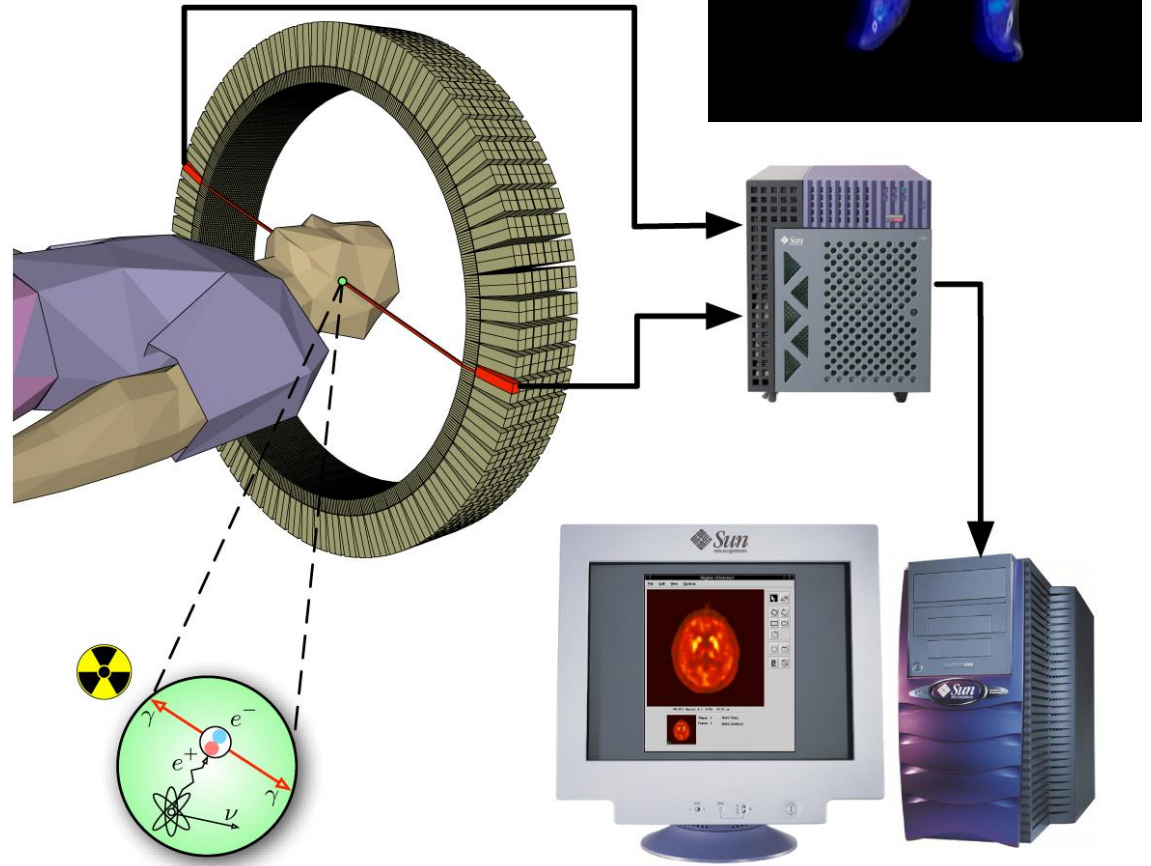
European Union
European Social
Fund



INVESTING IN YOUR FUTURE



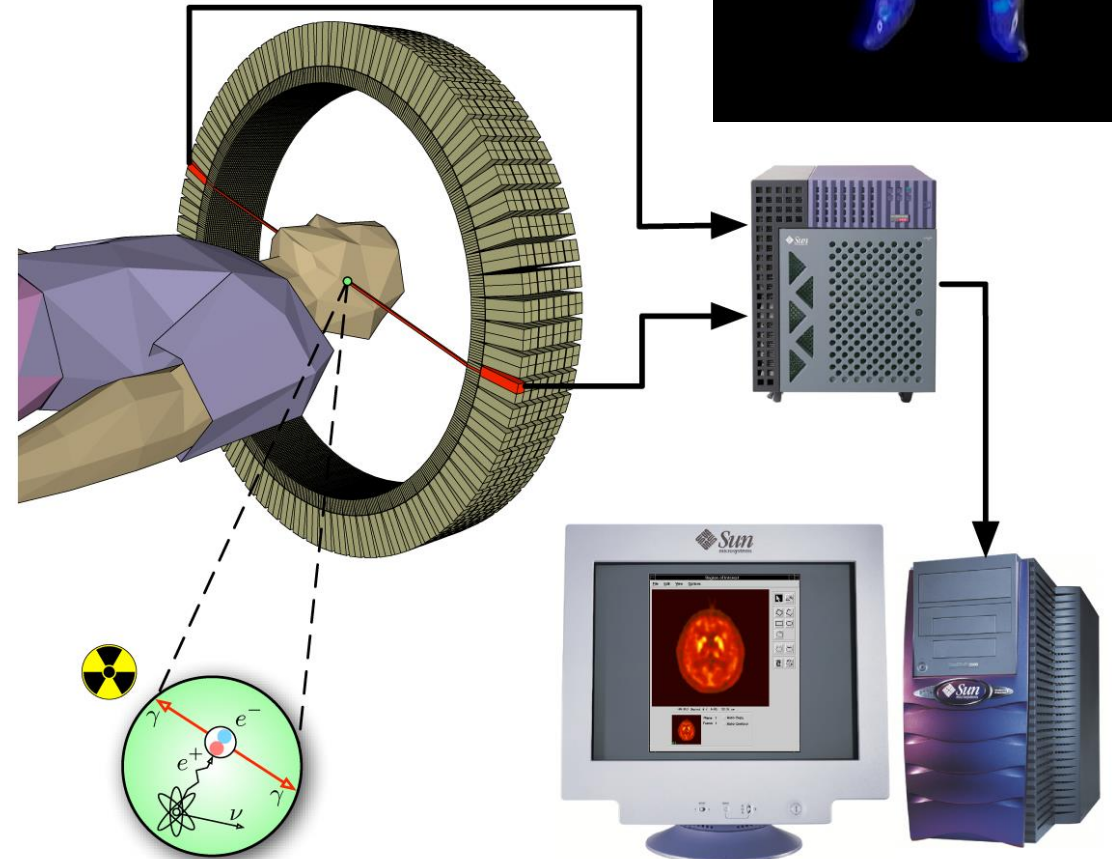
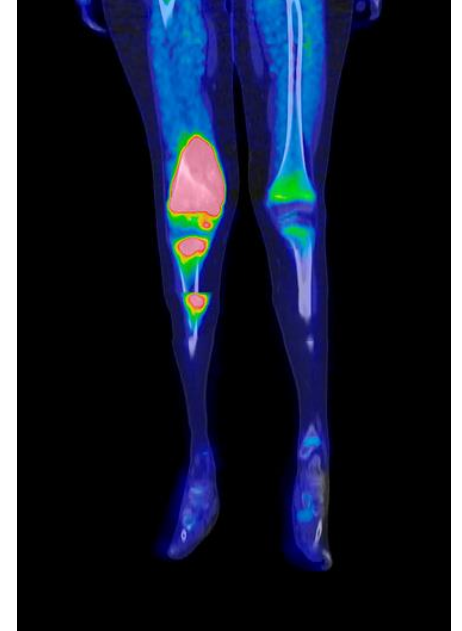
Positron Emission Tomography (PET)





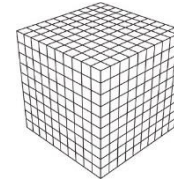
Positron Emission Tomography (PET)

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



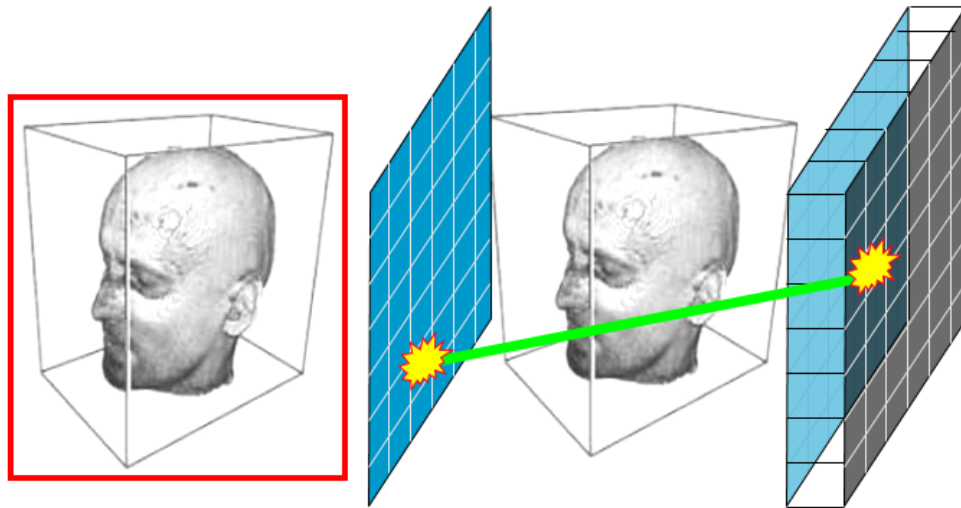


PET reconstruction

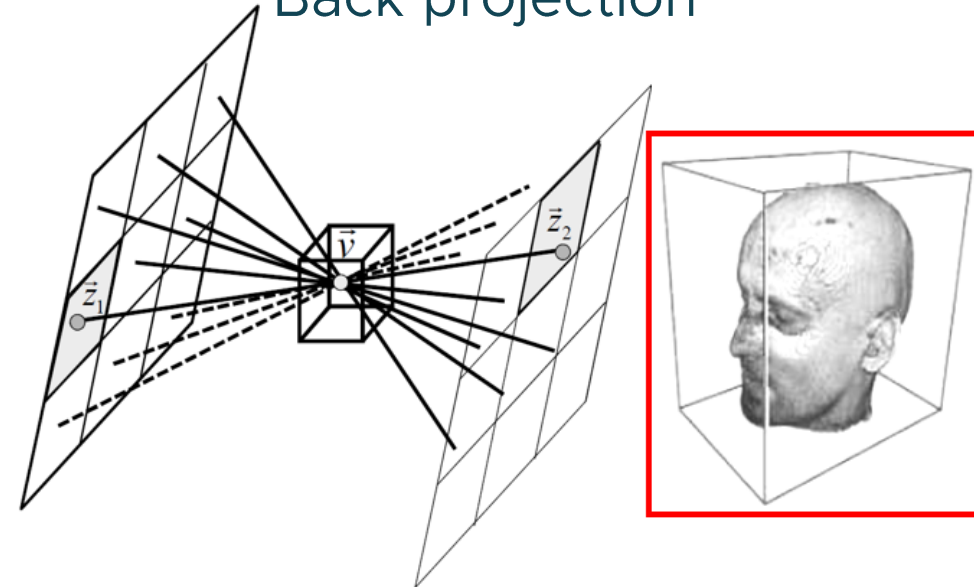


homogeneous 3D voxel grid

Distribution estimation → Expected hit count
Forward projection



Measured hit count → Corrected distribution estimation
Back projection



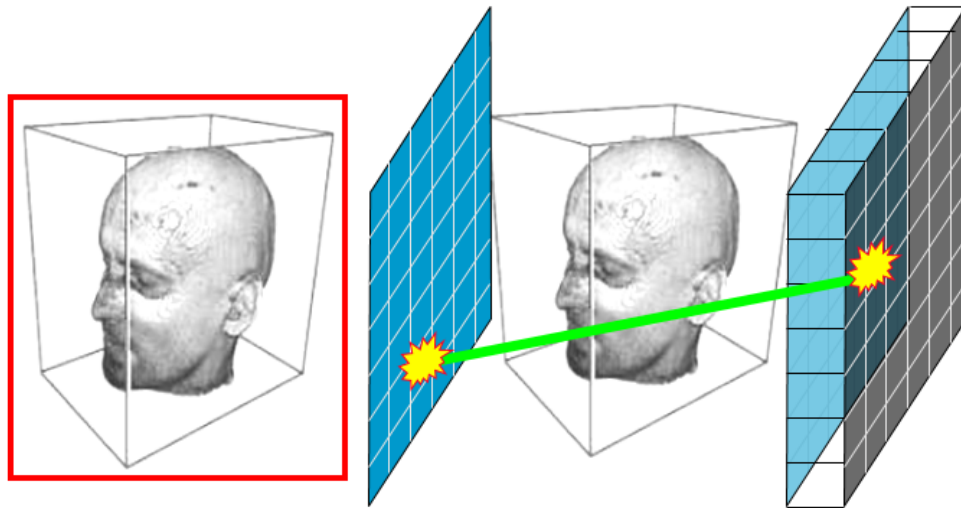
10-100 iterations



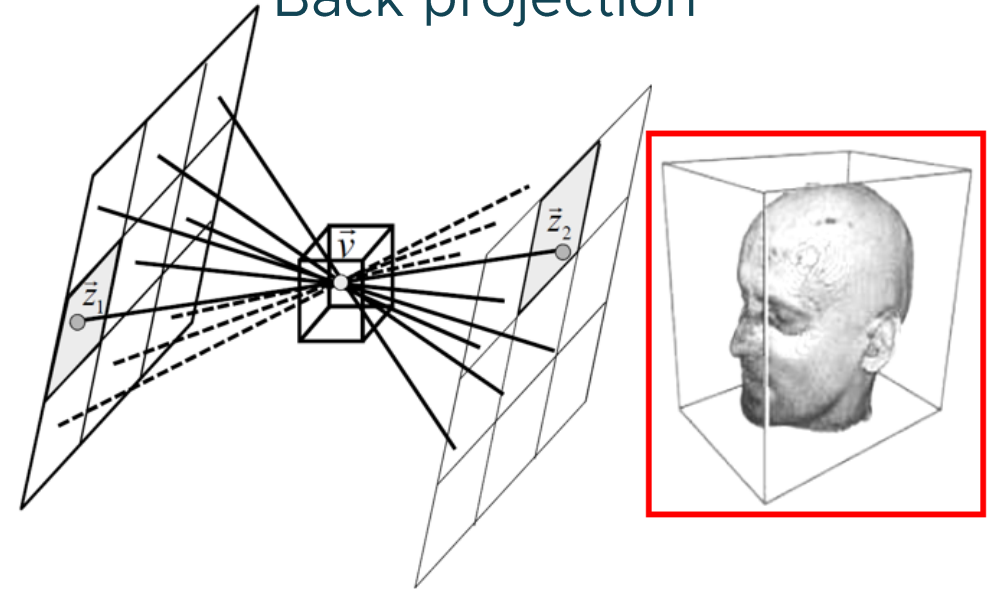
PET reconstruction

static $\leftrightarrow$ dynamic reconstruction

Distribution estimation $\rightarrow$ Expected hit count
Forward projection



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



10-100 iterations

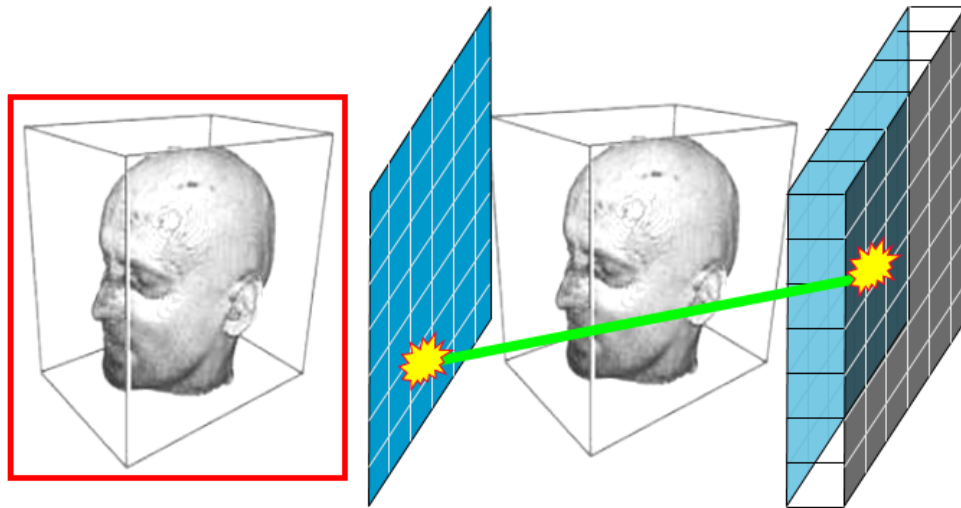


PET reconstruction

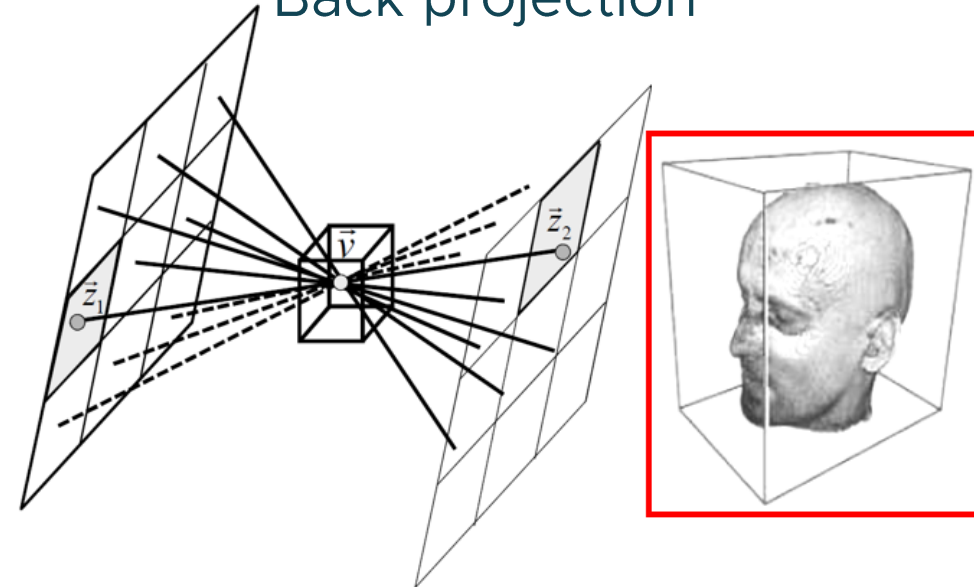
static $\leftrightarrow$ dynamic reconstruction

- spectral model
- two-tissue compartment model

Distribution estimation $\rightarrow$ Expected hit count
Forward projection



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

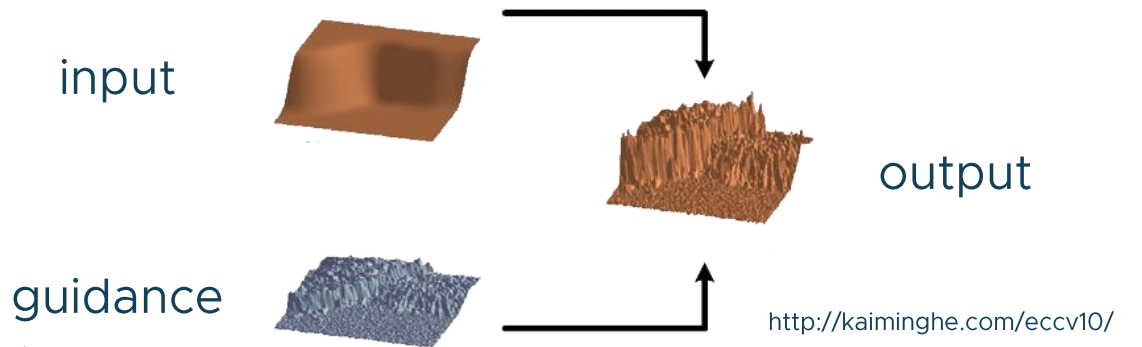
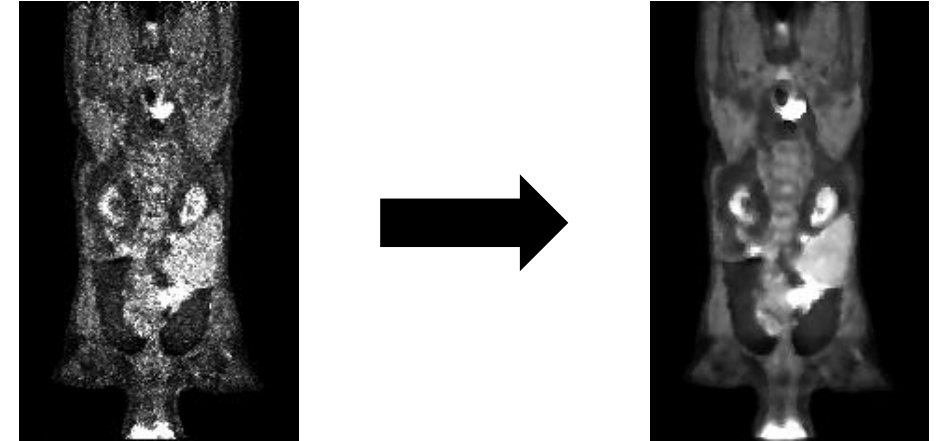


10-100 iterations



Problem statement

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

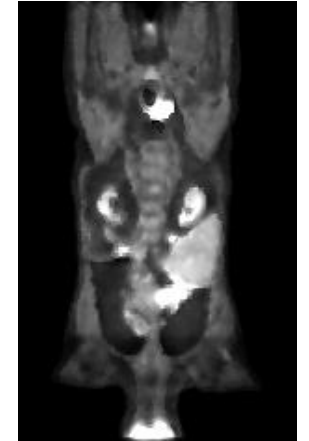
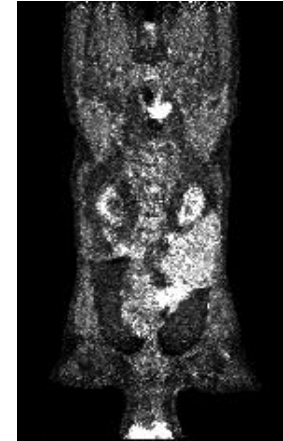


¹ He, K., Sun, J. & Tang, X., 2013. Guided Image Filtering. IEEE transactions on pattern analysis and machine intelligence, 6, Volume 35, pp. 1397-1409.



Problem statement

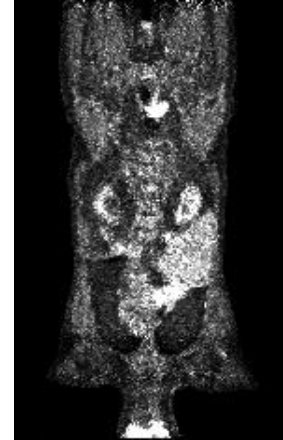
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Problem statement

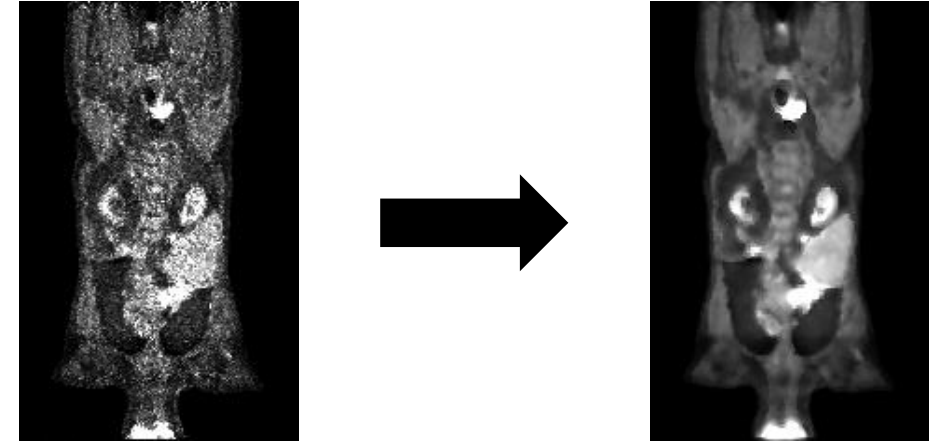
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Problem statement

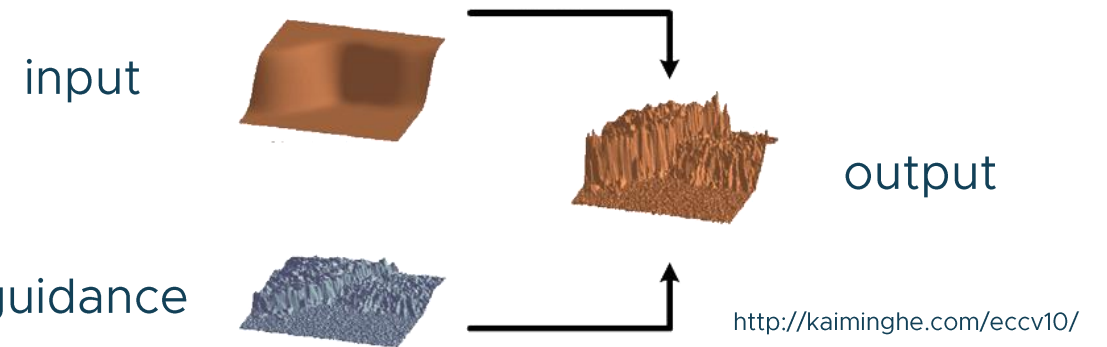
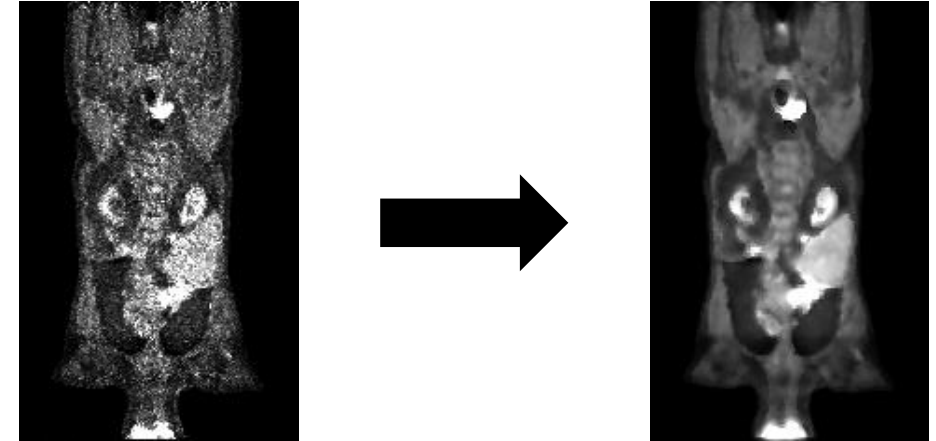
- High noise → misdiagnosis
- Noise filtering!
 - method of sieves
 - post-reconstruction filtering





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
- 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.



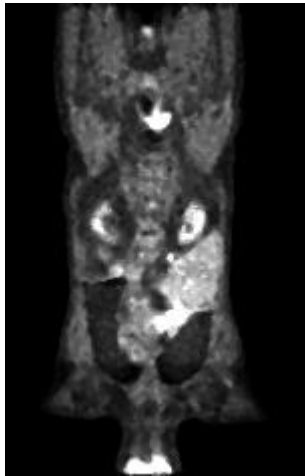
Alternative filters



Alternative filters

1. Median

middle of the values listed in
ascending order



output

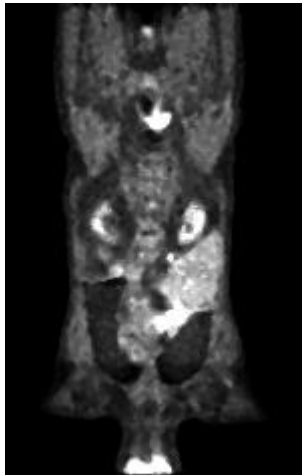


Alternative filters

Gaussian function: $g(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \cdot e^{-\frac{x^2}{2\sigma^2}}$

1. Median

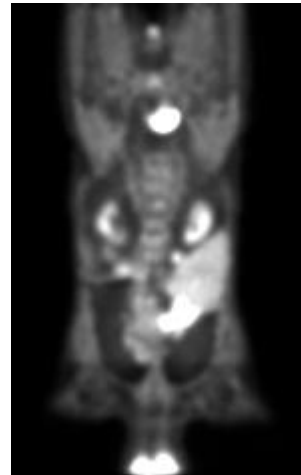
middle of the values listed in ascending order



output

2. Gaussian

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



output

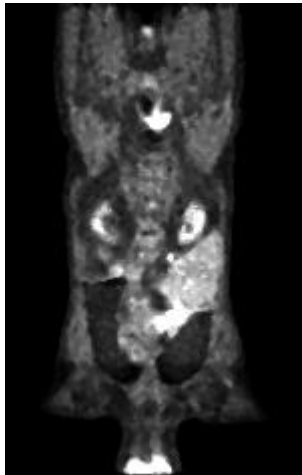


Alternative filters

Gaussian function: $g(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \cdot e^{-\frac{x^2}{2\sigma^2}}$

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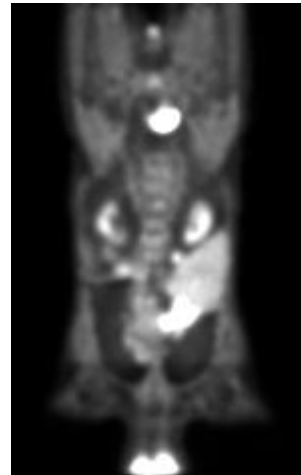
middle of the values listed in ascending order



output

2. Gaussian

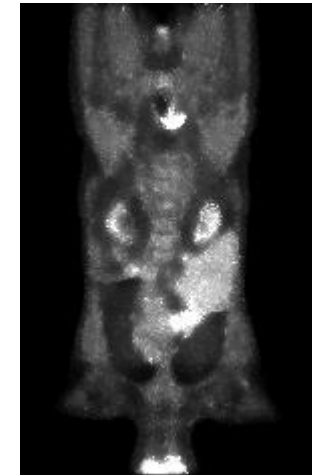
$$Q_k = \frac{\sum_{i \in \omega_k} P_i \cdot g(\|i - k\|)}{\sum_{i \in \omega_k} g(\|i - k\|)}$$



output

3. Bilateral

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



output

Noise reduction with guided filtering

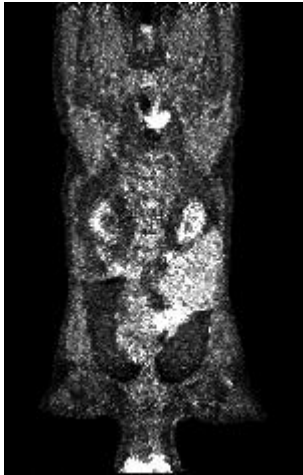
For static reconstructions



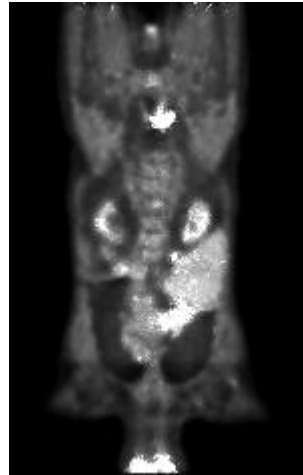
Choice of guidance

1. Input

the input itself is the controller



guidance



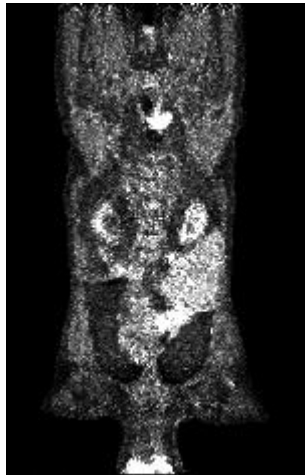
output



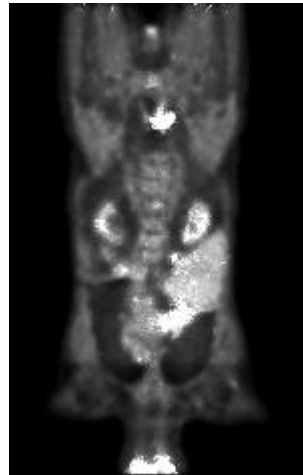
Choice of guidance

1. Input

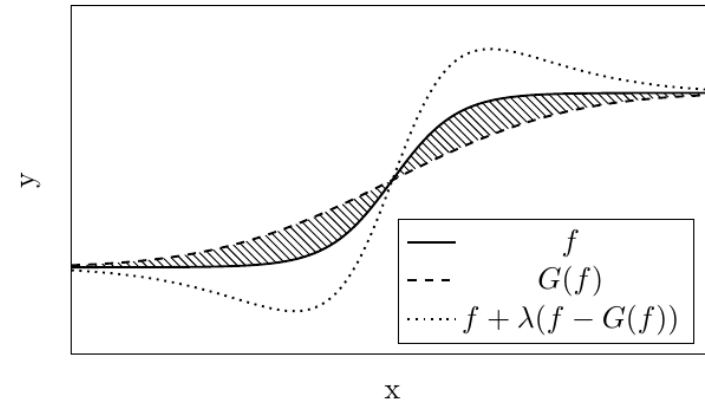
the input itself is the guidance



guidance



output

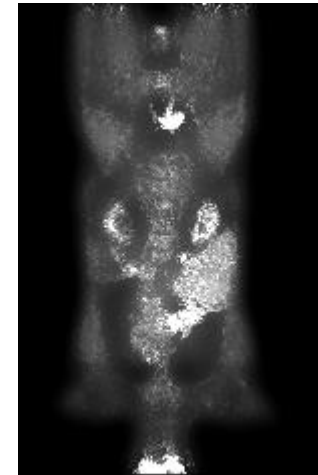


2. Enhanced input

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



guidance



output

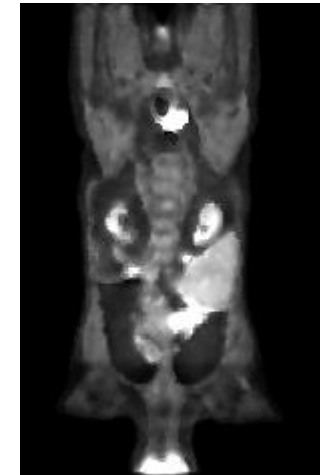
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anatomical image
↙ ↘

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



guidance



output

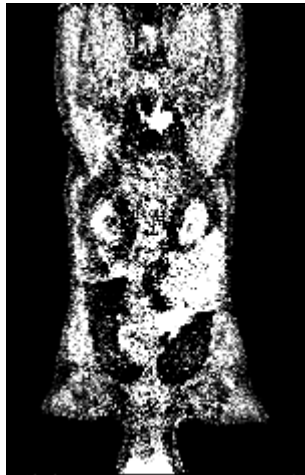


Choice of guidance

5. Dual channel guidance

Channel 1: enhanced input

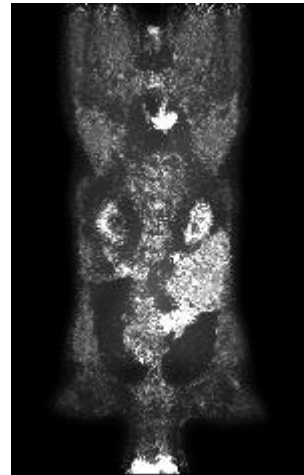
Channel 2: anatomically guided input



guidance
channel 1



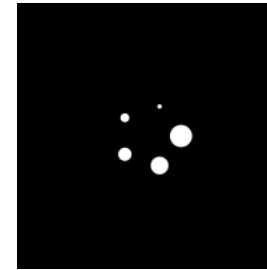
guidance
channel 2



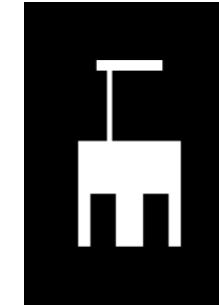
output



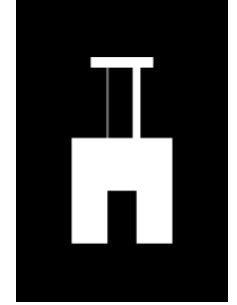
Choice of guidance



axial



coronal



sagittal

preclinical small rodent phantom
NEMA NU 4-2008

5. Dual channel guidance

Channel 1: enhanced input

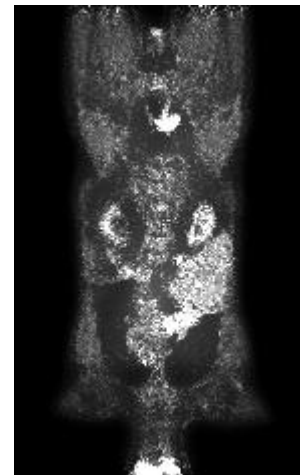
Channel 2: anatomically guided input



guidance
channel 1

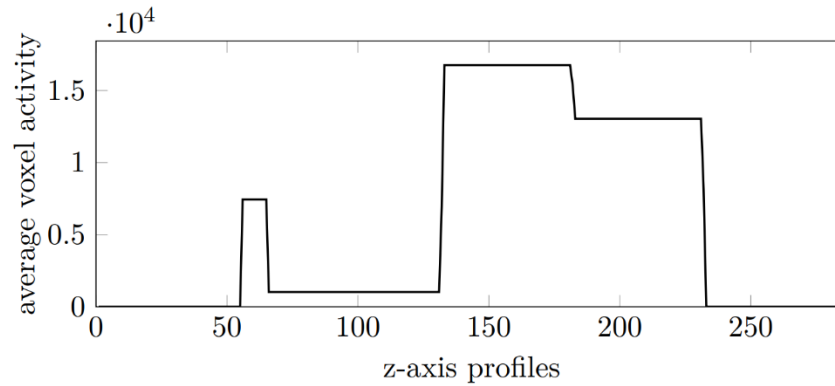
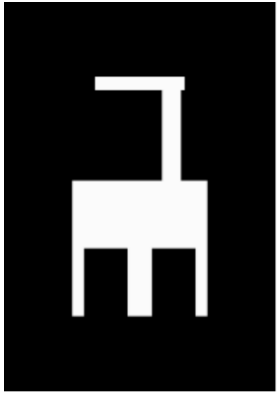


guidance
channel 2

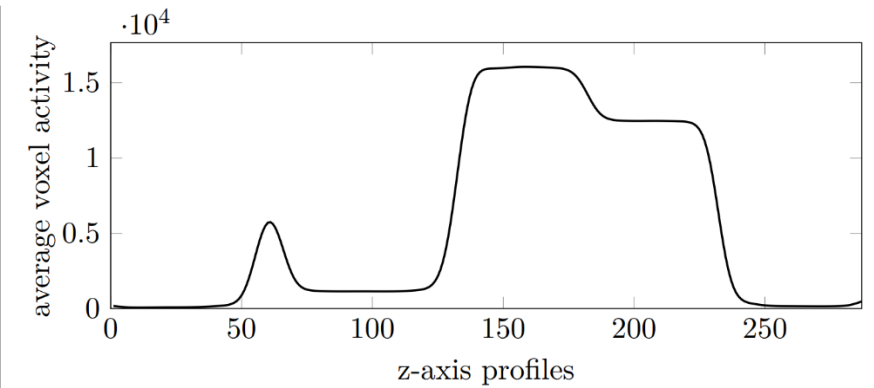


output

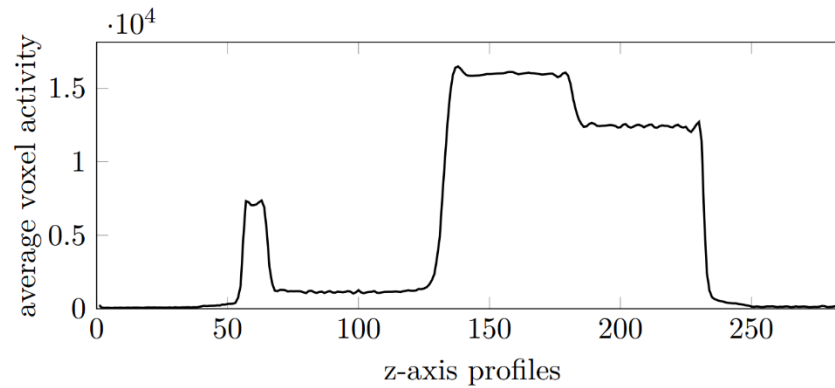
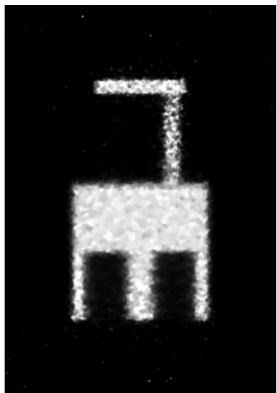
z-axis profiles



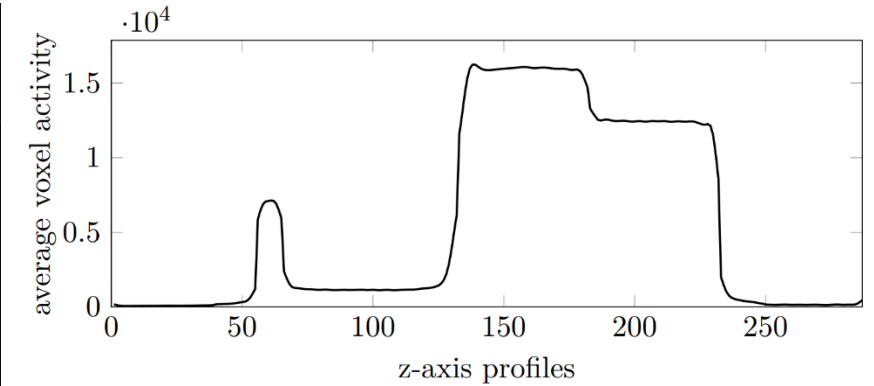
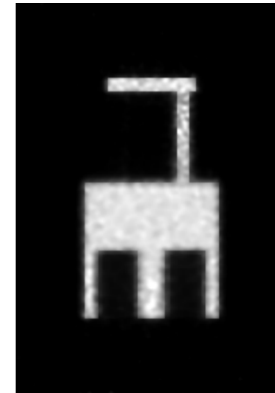
reference



with Gaussian filtering



without filtering

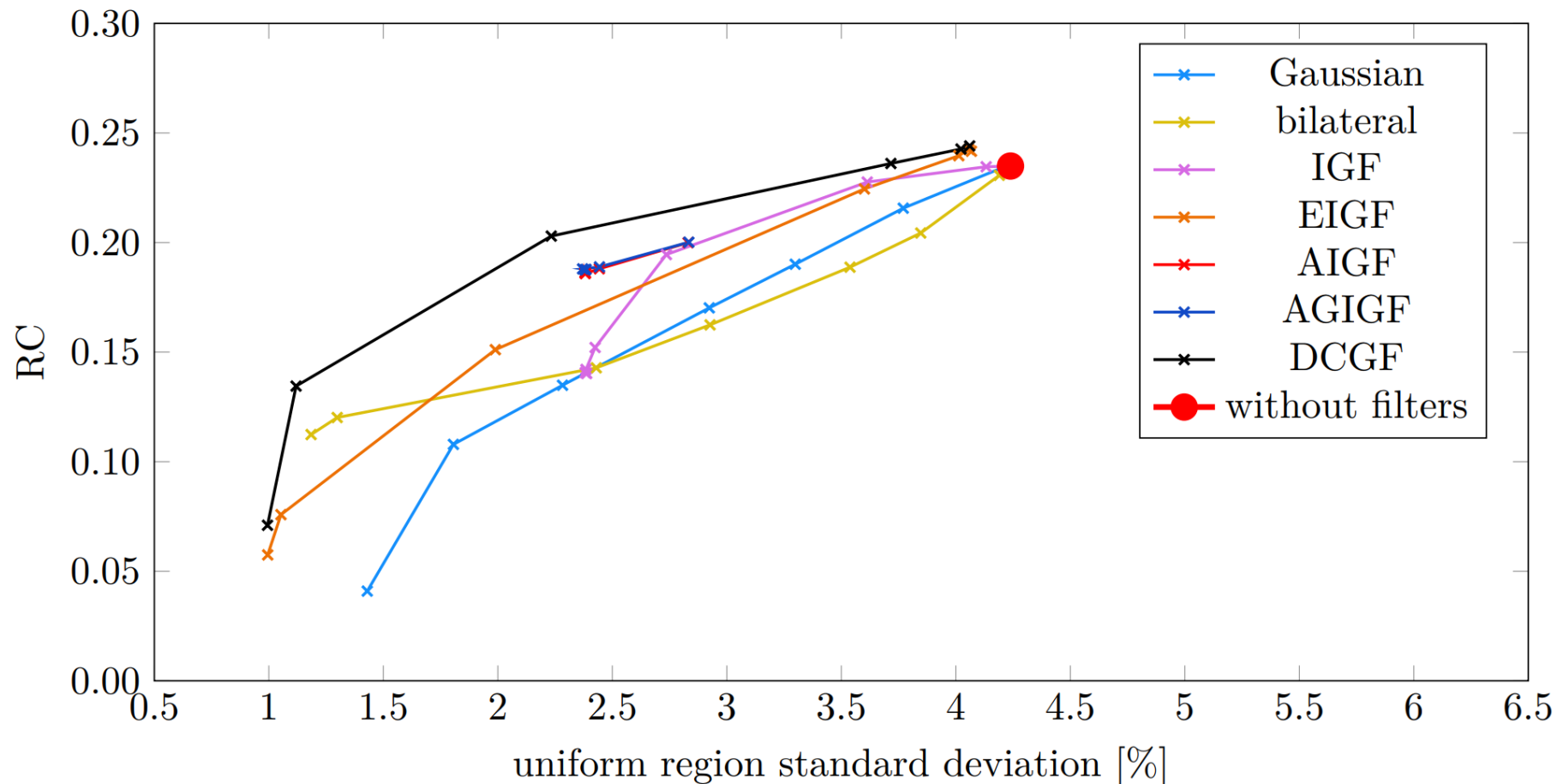


with anatomically guided input guided filtering

Recovery Coefficients

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

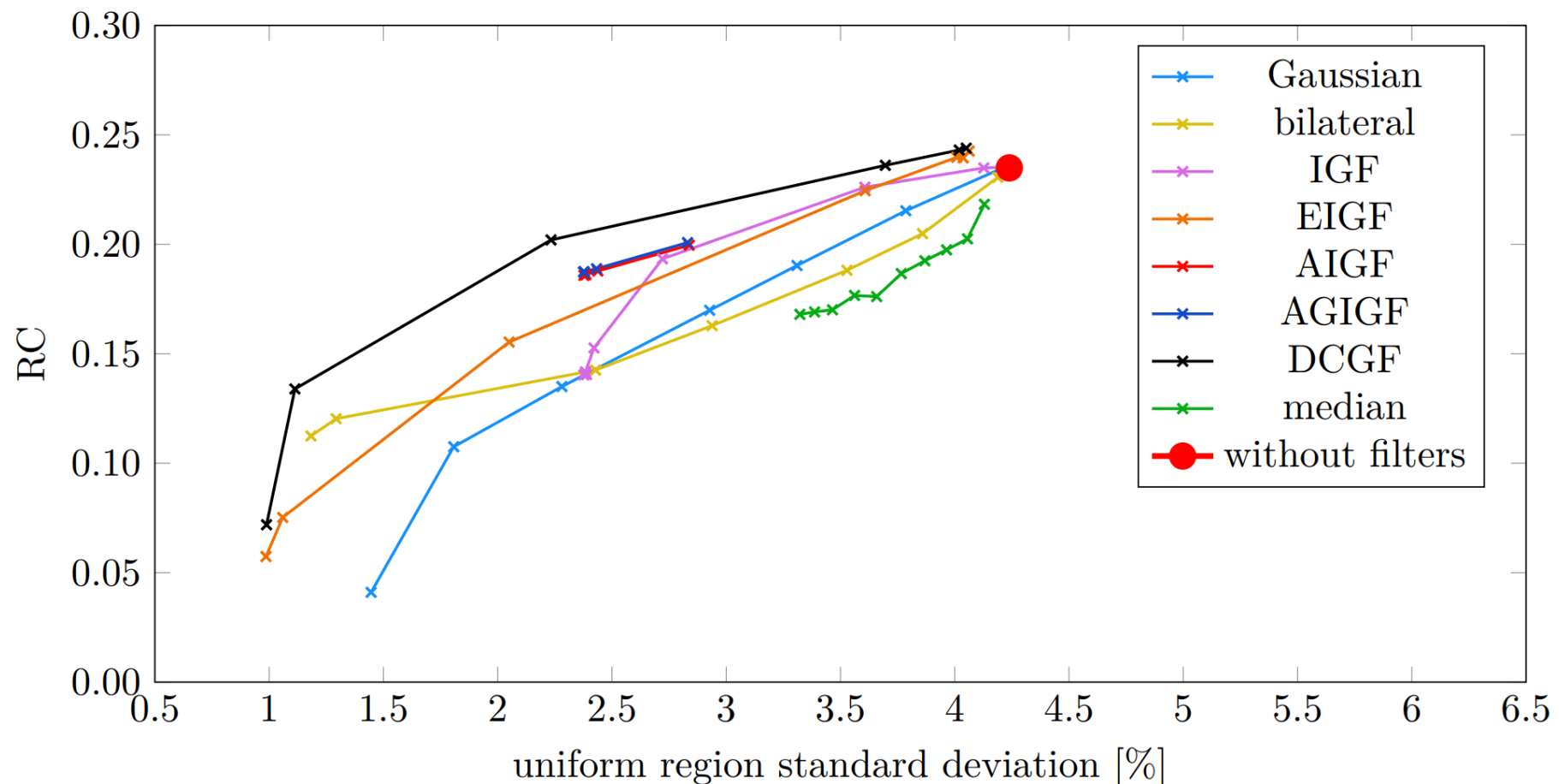
Performing filtering after each iteration



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**

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- Guidance?
 - guidances listed for static reconstructions

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

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 - **image of the static reconstruction**: sum of the activity images of all frames³

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?

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

- Guidance?
 - guidances listed for static reconstructions
 - **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.

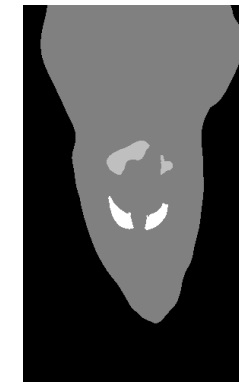
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E.g. in case of 9 frames the first channel is the sum of the activity images of frames 1-3, the second channel is of frames 4-6, and the third channel is of frames 7-9
- Rat phantom
 - 4 regions: body, lung, striatum, cerebellum
 - 1800 second simulation,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



axial



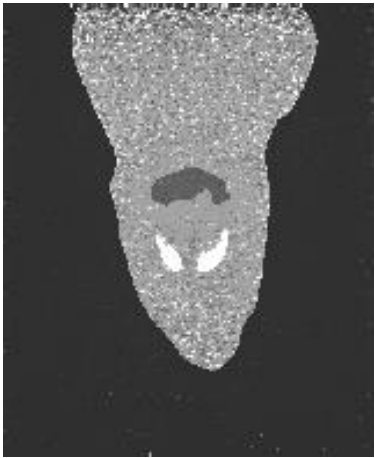
coronal



sagittal

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

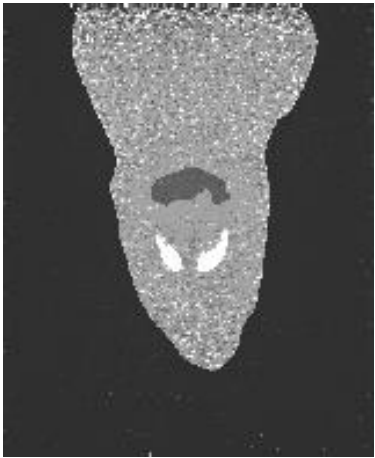
Results using two-tissue compartment model



without filters

Results using two-tissue compartment model

activity filtering



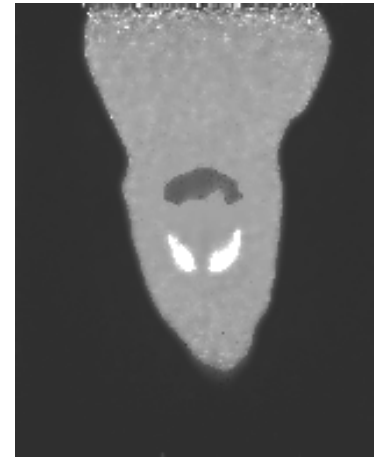
without filters



anatomically guided
input guided filtering



static reconstruction
guided filtering

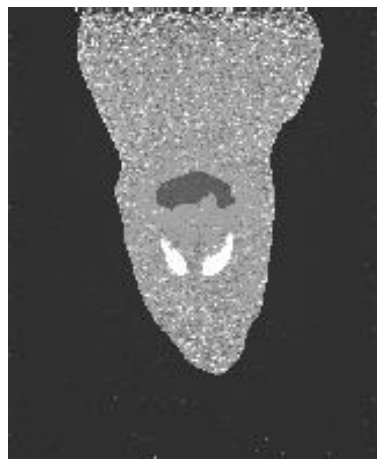


triple channel
guided filtering

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

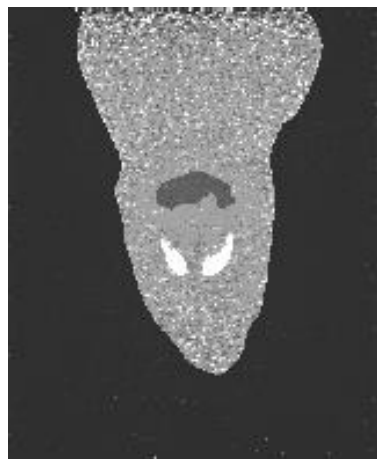
X

not applicable for
exponential parameters!



activity filtering

parametric filtering



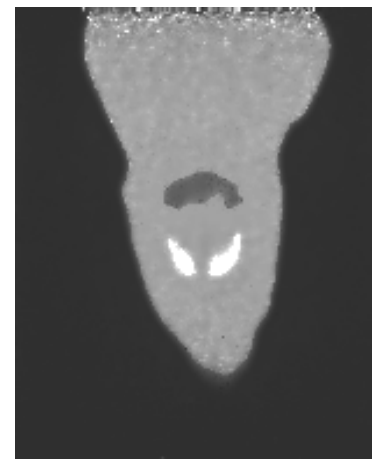
without filters



anatomically guided
input guided filtering



static reconstruction
guided filtering



triple channel
guided filtering



static reconstruction
guided parametric filtering

Results using spectral model

Performing filtering
only after last iteration



without filters

Results using spectral model

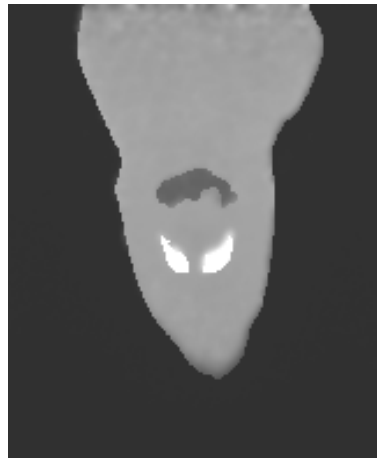
Performing filtering
only after last iteration

activity filtering

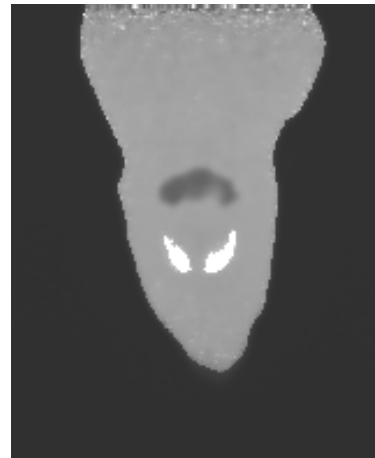
parametric filtering



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



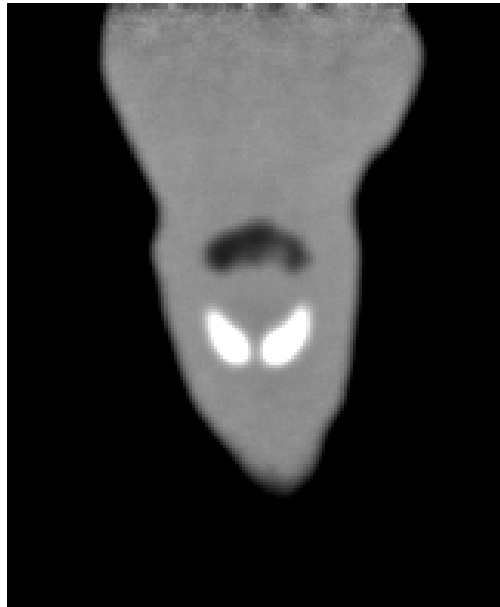
triple channel guided
parametric filtering

Partial Volume Correction with Guided Filtering

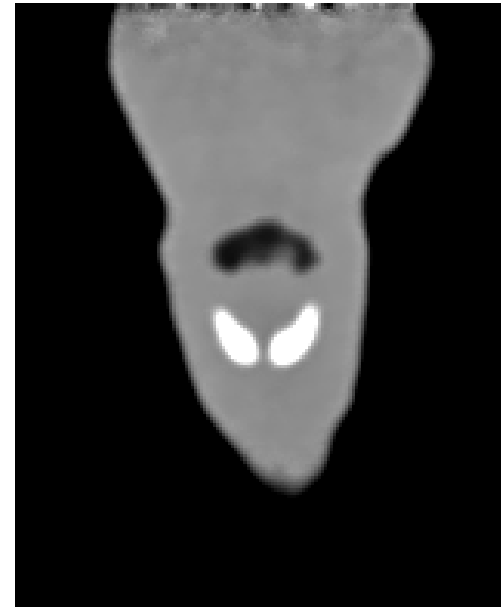
- the partial volume effect mathematically corresponds to convolution with the PSF
PSF (point spread function): response to a point activity source

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PSF (point spread function): response to a point activity source
- 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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- Comparison of guided filtering with other filtering methods:
RC of the proposed dual channel guidance is more favorable than the other tested filters.

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

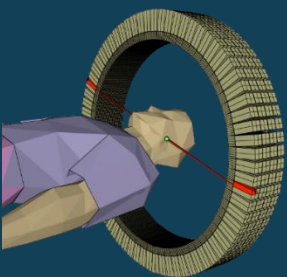
Application of guided filtering in static PET reconstruction

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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.

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.*

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



Thank you for your attention!

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