Medical Image Processing for Interventional Applications

Energy-Resolving Imaging

Online Course – Unit 18

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Topics

X-ray Projections From Energy-Resolving Detectors

Monochromatic Material Decomposition

Joint Bilateral Filter

Summary

- Take Home Messages
- Further Readings

X-ray Spectrum

- X-ray radiation is typically polychromatic.

- For different materials, the amount of absorbed photons is depending on the photons‘ energy.

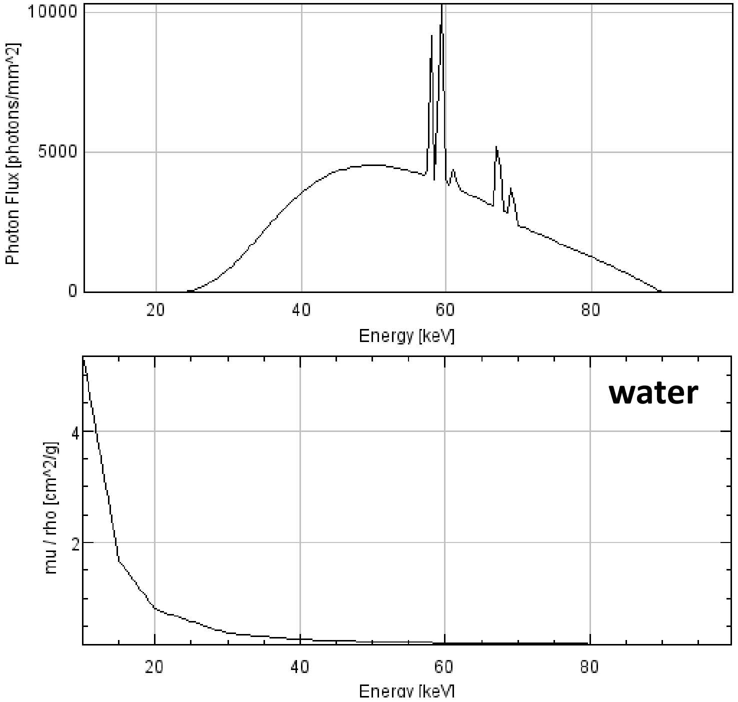

Figure 1: Example for a spectrum of bremsstrahlung (top), and the absorption spectrum of water (bottom)

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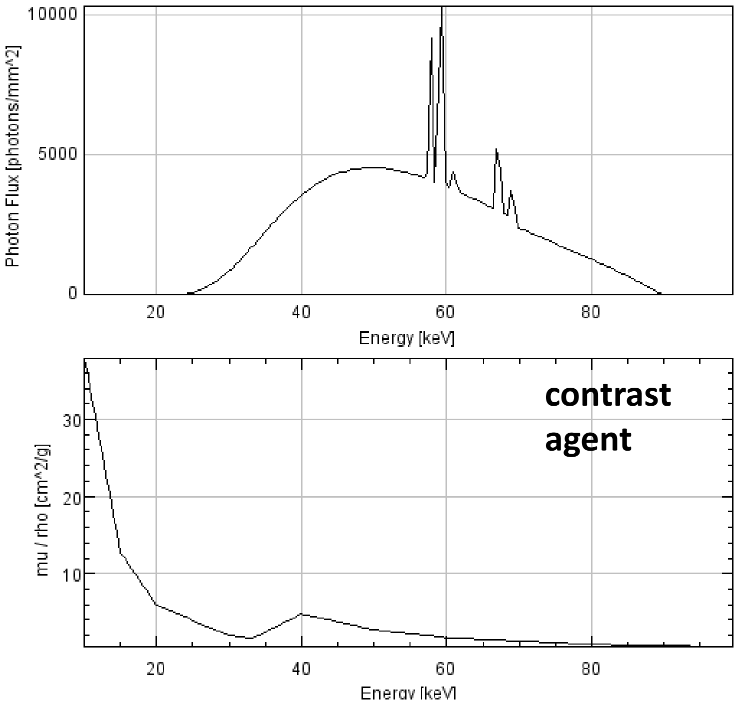

Figure 2: Example for a spectrum of bremsstrahlung (top), and the absorption spectrum of a contrast agent (bottom)

X-ray Projection

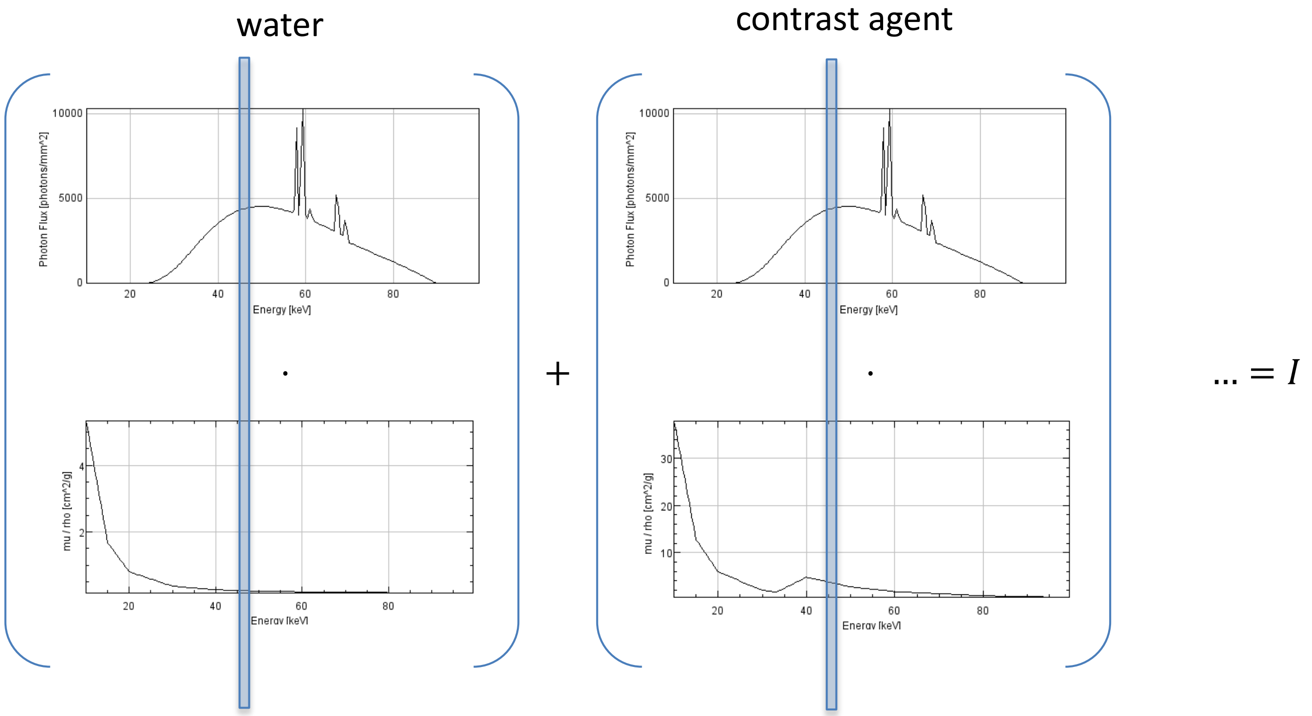

Figure 3: An X-ray projection is the combined result of remaining photons after material dependent absorption.

Energy-Resolving Detectors

- Recent detectors can measure energy levels of X-ray radiation.

- Photons can be distinguished between energies.

- This yields so-called **bins**.

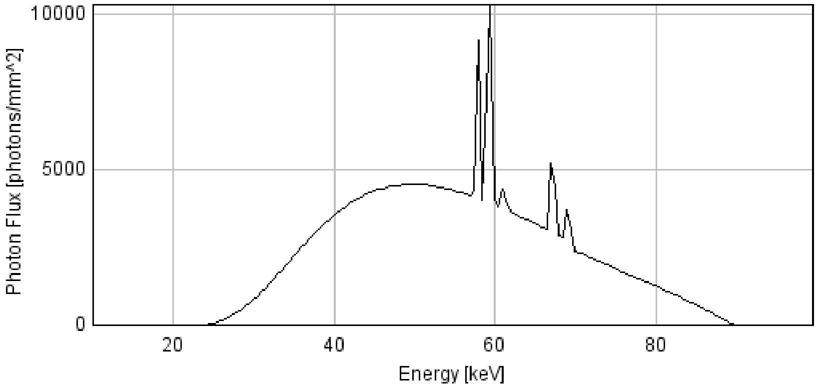

Figure 4: Spectrum subdivided into three energy bins

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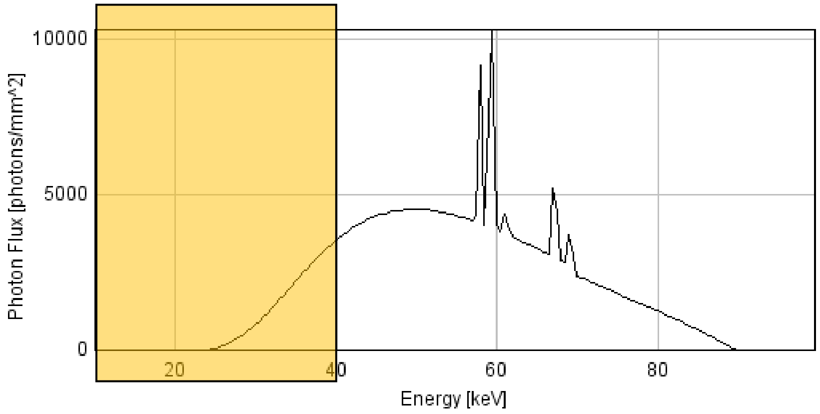

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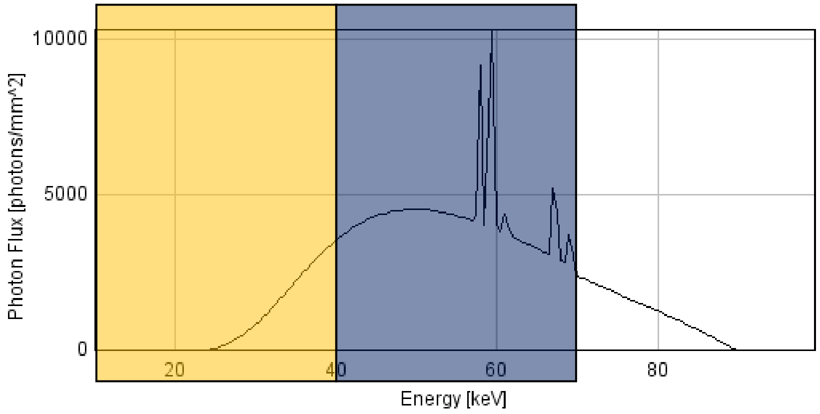

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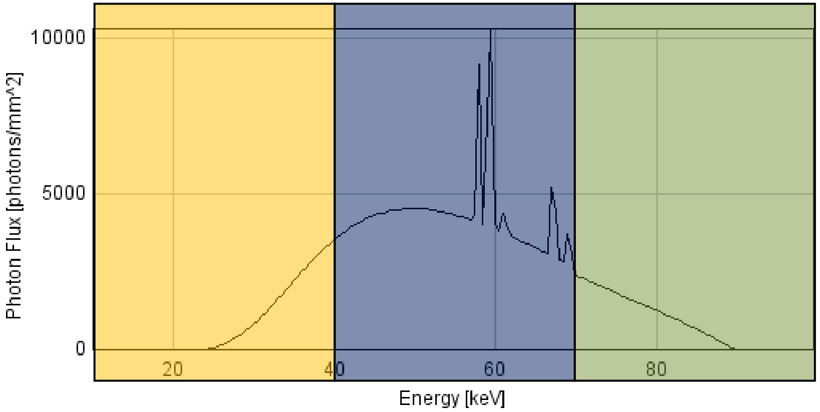

Figure 4: Spectrum subdivided into three energy bins

Simulation

Material images as input:

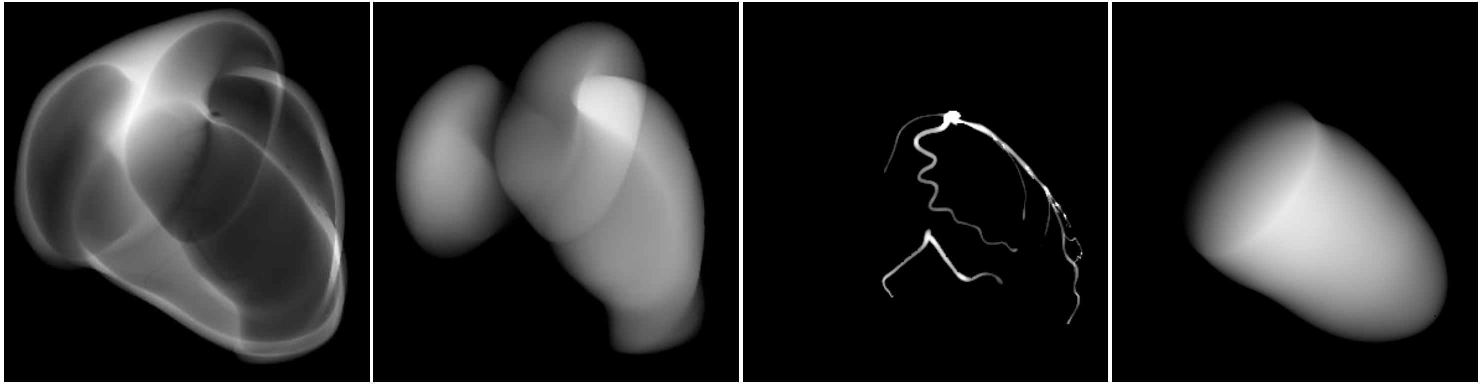

Figure 5: **Myocardium** (left), **blood** (middle left), **Ultravist 370** (middle right), blood of **left ventricle** (right)

Simulation

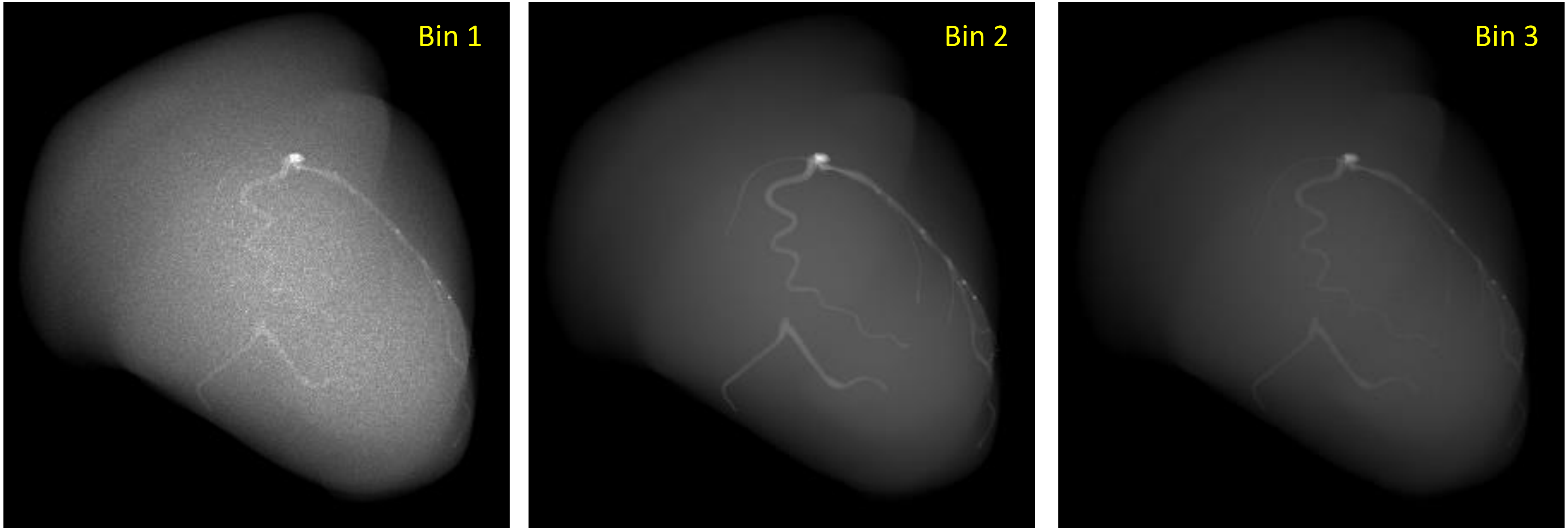

Figure 6: Energy-resolved images, bins 1-3 from left to right, (generated using CONRAD)

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Monochromatic Material Decomposition (Firsching et al., 2008)

Assumption: Bins I_b effectively contain a single energy measurement b.

- The material dependent absorption at energy b is $\mu(b, j)$ for a material listed by index j.

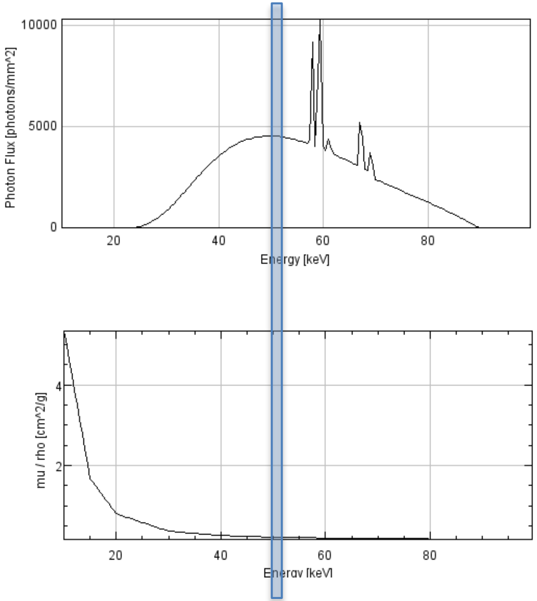

Figure 7: A single energy for a certain bin (top) and its according absorption coefficient (bottom)

Monochromatic Material Decomposition (Firsching et al., 2008)

Assumption: Bins I_b effectively contain a single energy measurement b.

- The material dependent absorption at energy b is $\mu(b,j)$ for a material listed by index j.
- A measured value is equal to the integral over all materials j:

$$I_{0b}e^{-\sum_j \mu(b,j)l_j} = I_b,$$

$$\sum_j \mu(b,j)l_j = -\ln\frac{I_b}{I_{0b}},$$

$$\sum_j \mu(b,j)l_j = q_b.$$

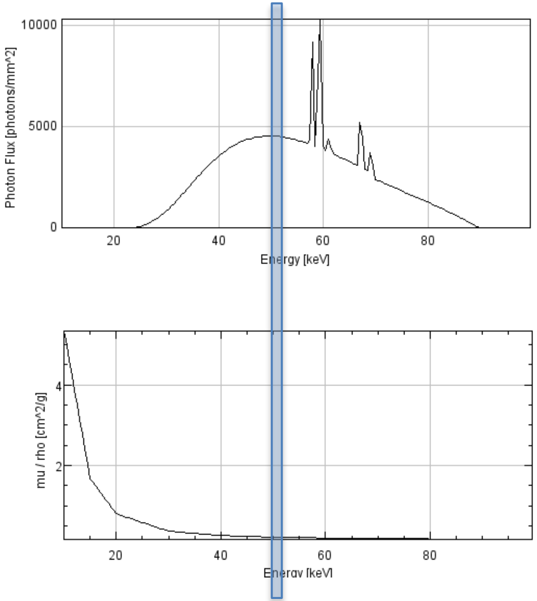

Figure 7: A single energy for a certain bin (top) and its according absorption coefficient (bottom)

Monochromatic Material Decomposition

- There is only a certain number N of materials:

$$\sum_{j=1}^{N} \mu(b,j) l_j = q_b \, .$$

- Formulation in matrix notation for N materials:

$$\begin{pmatrix} \mu(b,1) \\ \vdots \\ \mu(b,N) \end{pmatrix}^T \begin{pmatrix} l_1 \\ \vdots \\ l_N \end{pmatrix} = q_b,$$

$$\boldsymbol{\mu}_b^T \boldsymbol{l} = q_b.$$

Monochromatic Material Decomposition

- Formulation in matrix notation for N materials:

$$\boldsymbol{\mu}_b^T \boldsymbol{l} = q_b$$

$$\begin{pmatrix} \boldsymbol{\mu}_1^T \\ \vdots \\ \boldsymbol{\mu}_M^T \end{pmatrix} \boldsymbol{l} = \begin{pmatrix} q_1 \\ \vdots \\ q_M \end{pmatrix}$$

$$\boldsymbol{M}\boldsymbol{l} = \boldsymbol{q}$$

- Solution using pseudoinverse:

$$\boldsymbol{l} = \boldsymbol{M}^+ \boldsymbol{q}$$

Monochromatic Material Decomposition

- To determine the decomposition of N materials, at least N bins are required.
  - → At least as many bins as number of materials are required.
- A decomposition is only possible if the rank of $\boldsymbol{M}$ is greater or equal to N.
  - → Basic materials must not be linearly dependent.

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Denoising with Joint Bilateral Filter (Lu et al., 2015)

- Sum bins to create guidance image:

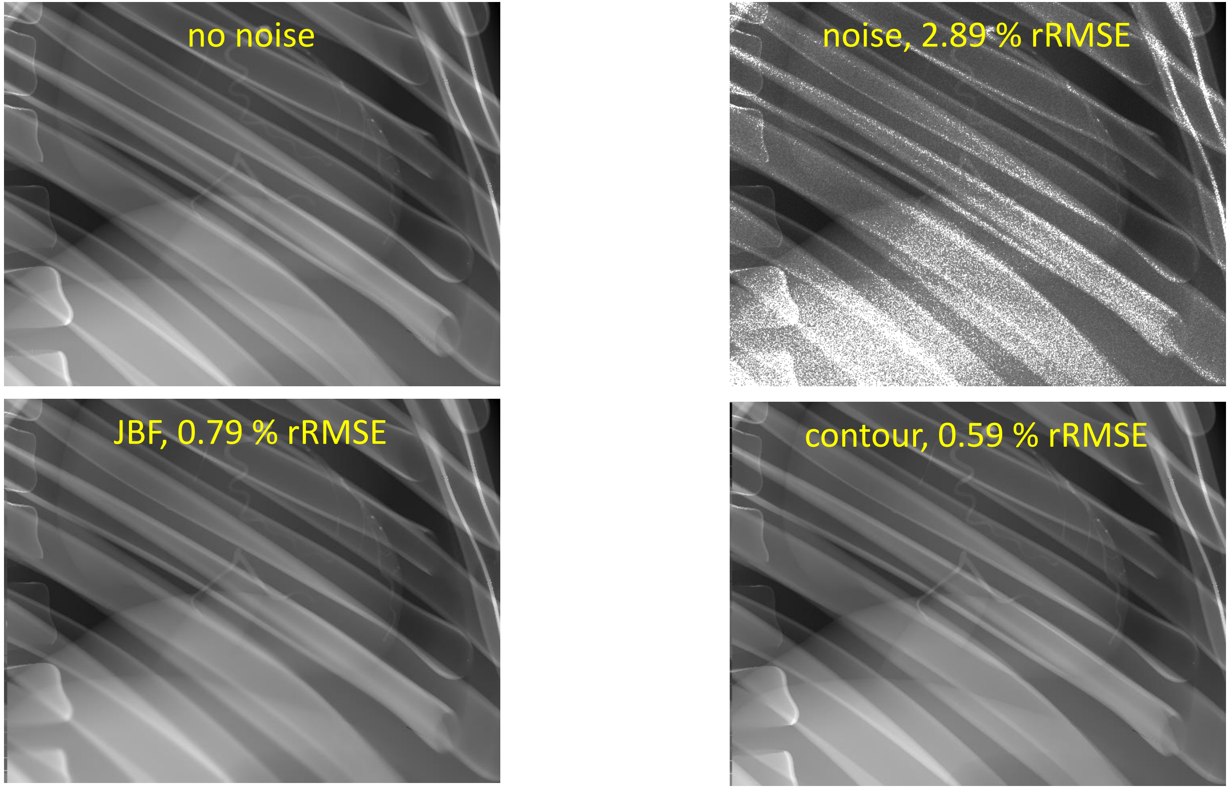
$$I(x,y) = \sum_b I_b(x,y)$$

- Use bilateral filter:
  - Spatial kernel → Gaussian $G_s(\boldsymbol{x}, \boldsymbol{x}')$ with σ_s chosen like in normal bilateral filter
  - Range kernel → Gaussian $G_I(\boldsymbol{x}, \boldsymbol{x}')$ with σ_I determined using the guidance image I
- Contour-aware filtering (angiography):

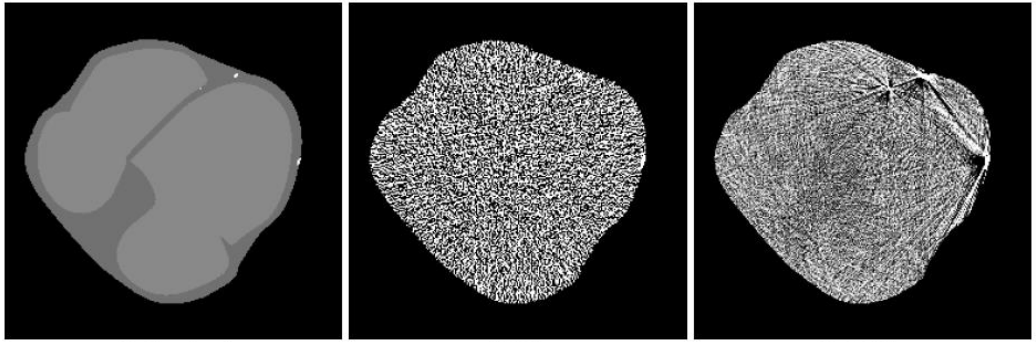
$$\sigma_I(x,y) = \bar{I}(x,y)z, \qquad z = \left(1 - \frac{I_2}{I_1}\right)$$

  - $\bar{I}$ is the guidance image filtered with an average filter.
  - z is determined such that a certain contrast difference $D = I_1 - I_2$ is preserved.

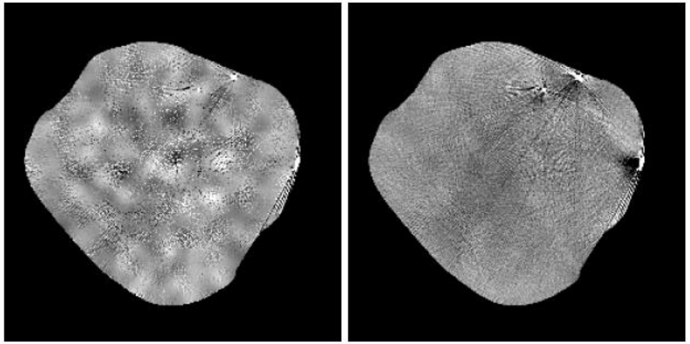
Results



Reconstructions (Manhart et al., 2014)



(a) Ground truth (b) Noise (c) JBF Filter



(d) Noise + ID-JBF (e) JBF + ID-JBF

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- With energy-resolving detectors projections are acquired for different parts of the radiation energy spectrum.
- This information is binned and can be used to decompose the volume into different materials.
- Denoising is an application of a joint bilateral filter which makes use of energy-binned projection data.

Further Readings

- Markus Firsching et al. “Material Resolving X-ray Imaging Using Spectrum Reconstruction with Medipix2”. In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 591.1 (June 2008), pp. 19–23. DOI: 10.1016/j.nima.2008.03.017
- Yanye Lu et al. “Projection-Based Denoising Method for Photon-Counting Energy-Resolving Detectors”. In: *Bildverarbeitung für die Medizin 2015: Algorithmen - Systeme - Anwendungen. Proceedings des Workshops vom 15. bis 17. März 2015 in Lübeck*. Ed. by Heinz Handels et al. Berlin, Heidelberg: Springer Berlin Heidelberg, 2015, pp. 137–142. DOI: 10.1007/978-3-662-46224-9_25
- Michael Manhart et al. “Guided Noise Reduction for Spectral CT with Energy-Selective Photon Counting Detectors”. In: *Proceedings of the Third CT Meeting*. Ed. by Frédéric Noo. Salt Lake City, UT, USA, June 2014, pp. 91–94