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Context-Aware Filtering for Direct Joint Attenuation and Scatter Correction of Whole-Body PET Images

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Purpose/Background:

In positron emission tomography (PET), attenuation and scatter corrections is necessary steps towards accurate quantitative reconstruction of the radiopharmaceutical distribution. A known characteristic of PET imaging is to have varying tracer uptakes for various patients and/or anatomical regions. However, existing deep learning-based algorithms utilize a fixed model across different subjects and/or anatomical regions during inference, which could result in spurious outputs. In this work, we present a novel deep learning-based framework for direct reconstruction of attenuation and scatter corrected PET from non-attenuation-corrected images in absence of structural information, which is able to efficiently deal with the inter-subject and intra-subject uptake variations in PET imaging.

Methods:

We propose a novel model to perform subject- and region-specific filtering through modulating the convolution kernels in accordance to the contextual coherency within the neighboring slices. This way, the context-aware convolution can guide the composition of intermediate features in favor of regressing input-conditioned and/or region-specific tracer uptakes. In particular, the neighboring slices are fed into a shared sub-network to extract the region-wise information, which is subsequently used to modify the convolution kernels in an adaptive manner. Our proposed model differs from existing methods by (1) the 3D contextual information within neighboring slices is used to adaptively modulate the kernels in specific layers and (2) the network is still in 2D manner and therefore enjoys accessing to large training instances as well as light computation cost at inference. Whole-body ^{18}F-FDG PET/CT scan data of 910 subjects were employed in this study for training and validation purposes.

Results:

The performance evaluation of our proposed context-aware network (CA-DAC) includes validation against the reference PET-CT ground truth and comparison to a conventional 2.5D UNet (UN-DAC) over a held-out test cohort consisting of 112 subjects across whole-body and 6 anatomical regions. In the whole-body, the average relative error (RE) were 2.43% ± 2.94 and -2.11% ± 2.73 for UN-DAC and CA-DAC, respectively. Also, the average absolute relative error (ARE) reduced from 14.79% ± 2.37 to 13.96% ± 2.32 for UN-DAC and CA-DAC, respectively. We also observed that CA-DAC outperformed UN-DAC by 0.71 (dB) averaged over all regions in terms of peak-signal-to-noise-ratio (PSNR). Likewise, the structural similarity (SSIM) scores averaged over all regions were improved from 0.9406 to 0.9465 using CA-DAC over UN-DAC in our evaluation

set. The coefficient of determination, denoted by R^2 was further used to quantify the goodness of fit within the joint histograms. In particular, R^2 for CA-DAC and UN-DAC was recorded as 0.982 and 0.963, respectively, indicating a better fit using the former, i.e. proposed method. Moreover, we performed a linear regression analysis by reporting the slope and intercept of the line fitted over the non-zero bins of the joint histograms. UN-DAC yielded 0.81 and 1.30 for the slope and intercepts, respectively, while CA-DAC results in 0.88 and 0.57 demonstrating an increase of 0.07 for the slope (closer to 1.0) and a decrease of 0.73 for the intercept (closer to 0.0).

Conclusion:

In this work, we introduced CA-DAC to produce attenuation-corrected PET images without requiring any anatomical information during training and inference. The novelty of the proposed network is to take advantage of context-aware convolutions to modulate the convolution kernels based on the contextual information within neighboring slices along the axial dimension for every 2D input slice. This way, the network can effectively adapt itself to the inter- and intra-subject tracer uptake variations with negligible increase in model complexity.

Enhanced Direct Joint Attenuation and Scatter Correction of Whole-Body PET Images via Context-Aware Deep Networks

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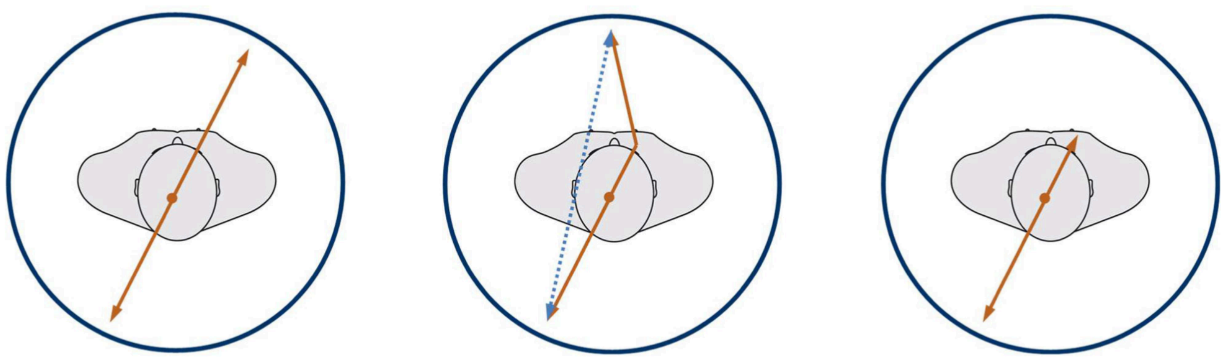
Introduction

Attenuation and Scatter Artifact in PET

- Photons may occur due to interacting with the components in the environment
  - Carry inaccurate information about the annihilation site (scatter coincidence)
  - Fall out of the energy windows and fail to be recorded by the detectors (attenuation coincidence)
- Studies reveal 40-50% of the annihilation coincidences are scattered or lost [1]



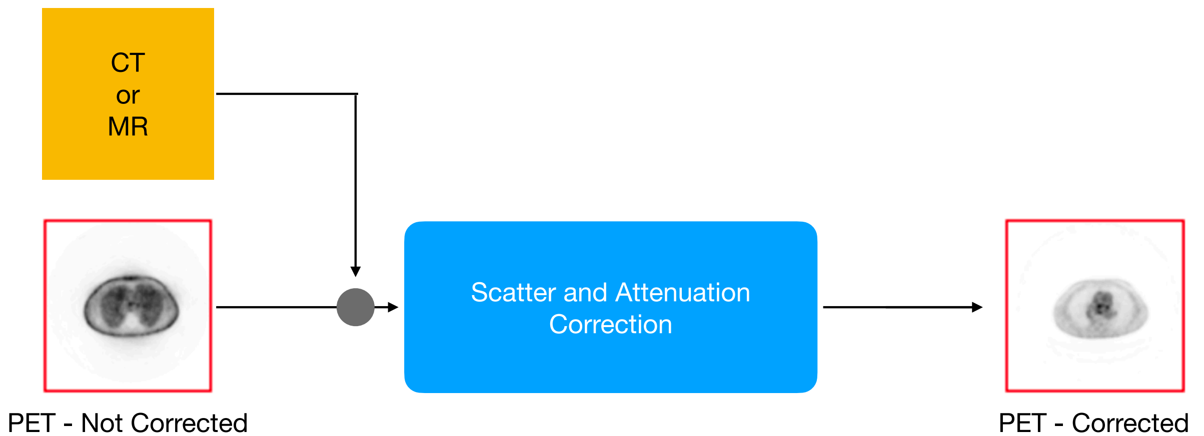
True coincidence | Scatter coincidence | Loss of coincidence

[1] Zaidi et al. “Scatter modelling and compensation in emission tomography”
[Fig] Lee et al. “A Review of Deep Learning-Based Approaches for Attenuation Correction in Positron Emission Tomography”

Introduction

Attenuation and Scatter Correction

- Anatomical information from MR/CT are used to obtain PET w/o attenuation and scatter artifacts
- PET/CT and PET/MR have their own drawback:
    - Radiation exposure
    - Unit conversion
    - Need for registration



Introduction

Direct Attenuation and Scatter Correction

- Recent works have thrived to eliminate need for anatomical information for ASC mapping

3D Slice 2D Slice Size of each slice

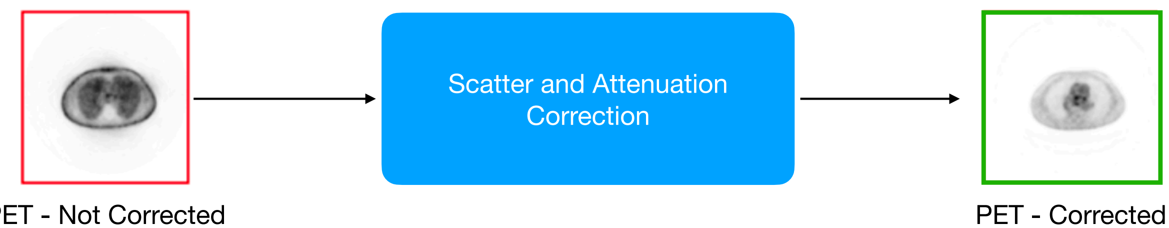
Not-Corrected $\mathscr{X} = \{X_n \in \mathbb{R}^{h \times w}\}_{n=1}^{N}$ Number of slice

Corrected $\mathscr{Y} = \{Y_n \in \mathbb{R}^{h \times w}\}_{n=1}^{N}$

ASC Mapping

$$X_n = \Phi(Y_n; \phi); \quad \forall n \in \{1,2,\ldots,N\}$$

Parameters of mapping



Introduction

Direct Attenuation and Scatter Correction

- Recent works have thrived to eliminate need for anatomical information for ASC mapping
- We use deep artificial neural network (ANN) to perform direct ASC

3D Slice   2D Slice   Size of each slice

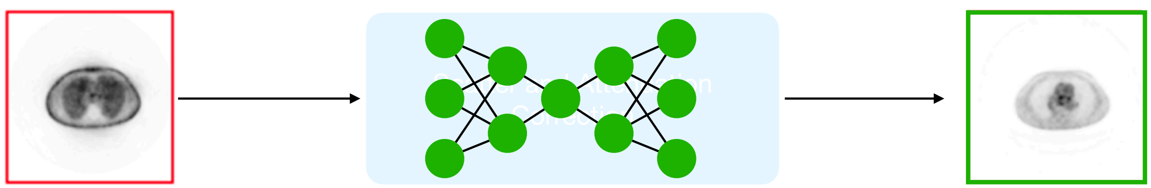
Not-Corrected $\mathcal{X} = \{X_n \in \mathbb{R}^{h \times w}\}_{n=1}^{N}$ Number of slice

Corrected $\mathcal{Y} = \{Y_n \in \mathbb{R}^{h \times w}\}_{n=1}^{N}$

ASC Mapping

$$X_n = \Phi(Y_n; \phi); \quad \forall n \in \{1,2,\ldots,N\}$$

Parameters of mapping

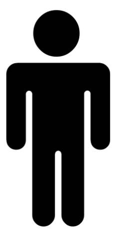
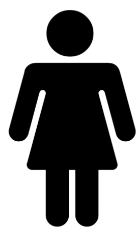
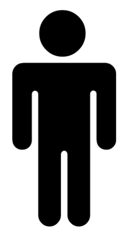
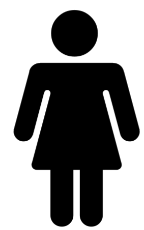


PET - Not Corrected

PET - Corrected

Data

- We collect and use a dataset of 920 subjects
- This dataset is orders of magnitude large than the ones used in previous works

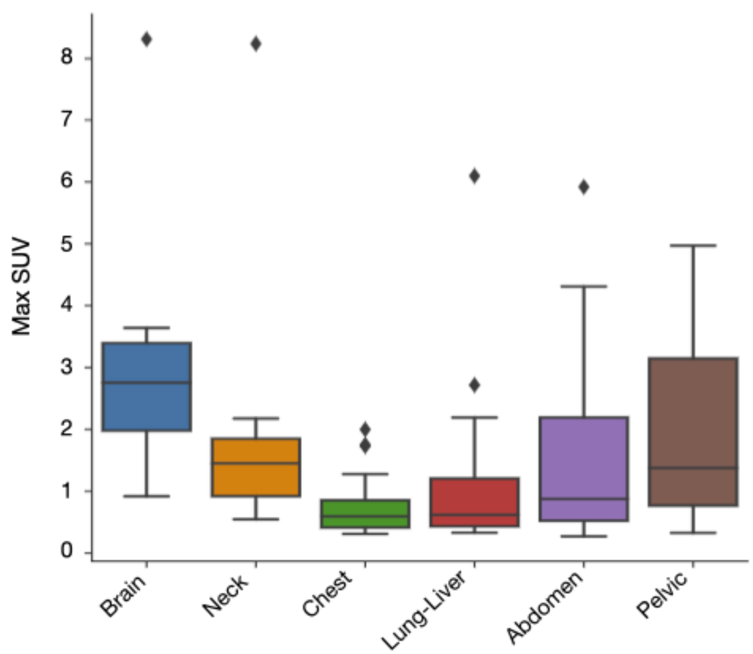
	Train		Test		TOTAL
					
Number	432	376	61	51	920
Age (year)	48 ± 18	49 ± 15	45 ± 17	50 ± 13	48 ± 16
Weight (Kg)	76.1 ± 16.4	69.5 ± 15.0	75.9 ± 14.4	71.7 ± 12.0	73.2 ± 13.1
Dose (MBq/g)	374.7 ± 55.1	369.9 ±45.3	366.4 ± 45.2	367.0 ±34.7	369.0 ± 42.7
Time (m)	60 ± 14	59 ± 10	60 ± 11	62 ± 17	60 ± 13

https://thenounproject.com/icon/male-and-female-1258540/ by Saeful Muslim

Motivation

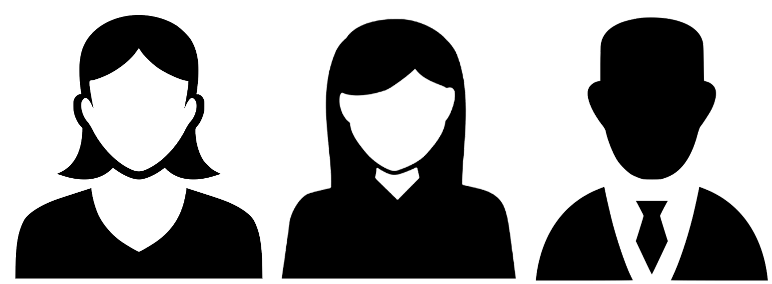
Variations in Tracer Uptake

Organs



Subjects

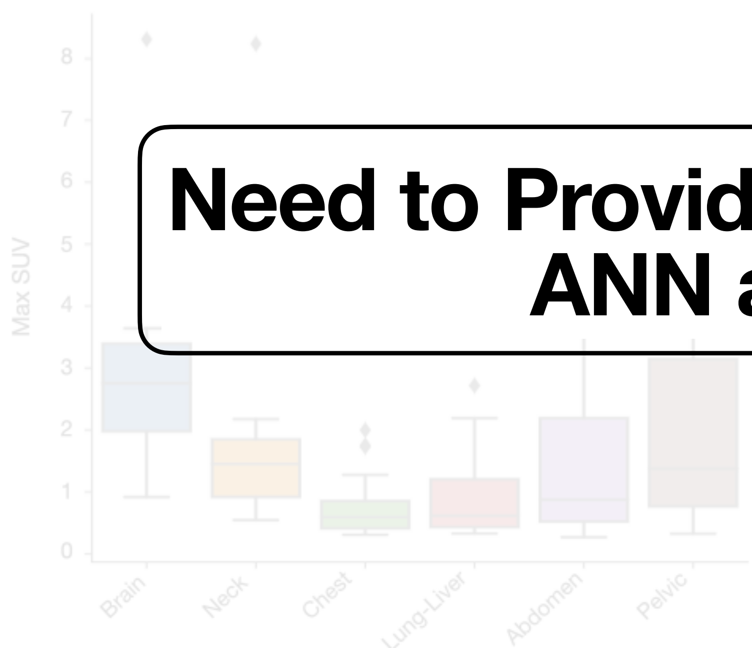
- Administered dose
- Imaging time
- Reconstruction parameters



Motivation

Variations in Tracer Uptake

Organs



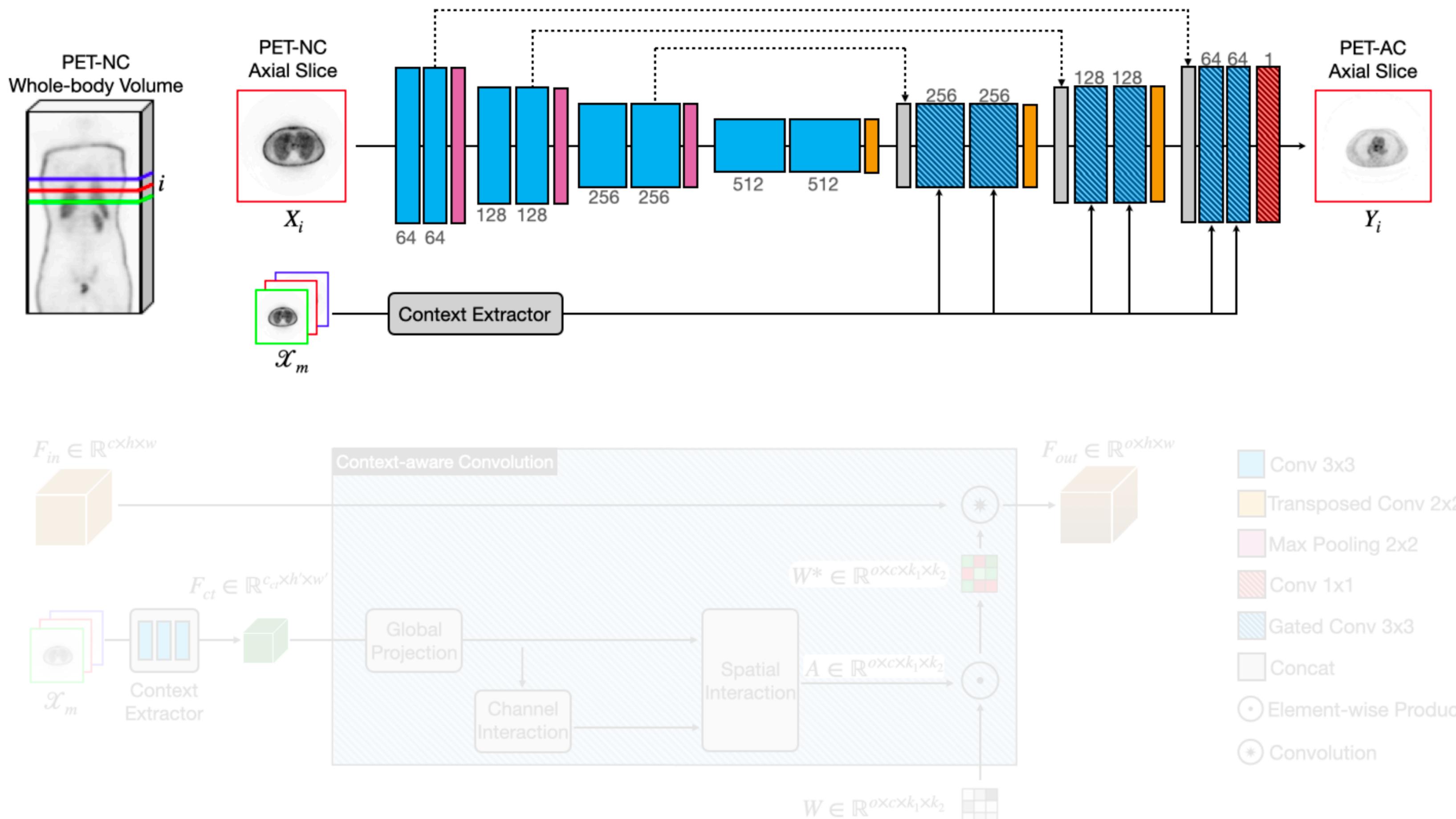
Subjects

- Administered dose
- imaging time

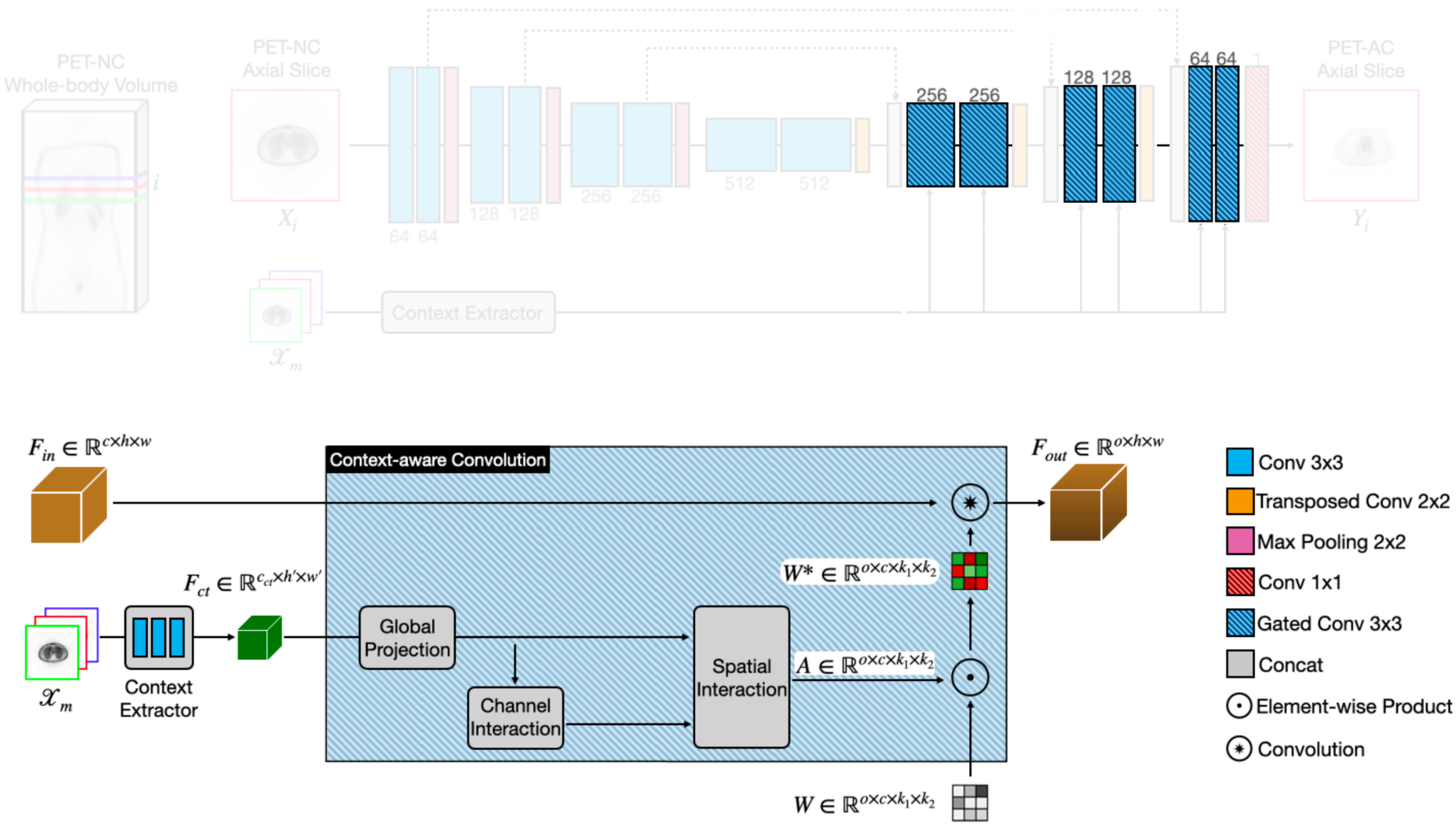
Need to Provide Enough Context to ANN at Inference

Method

Overal Architecture

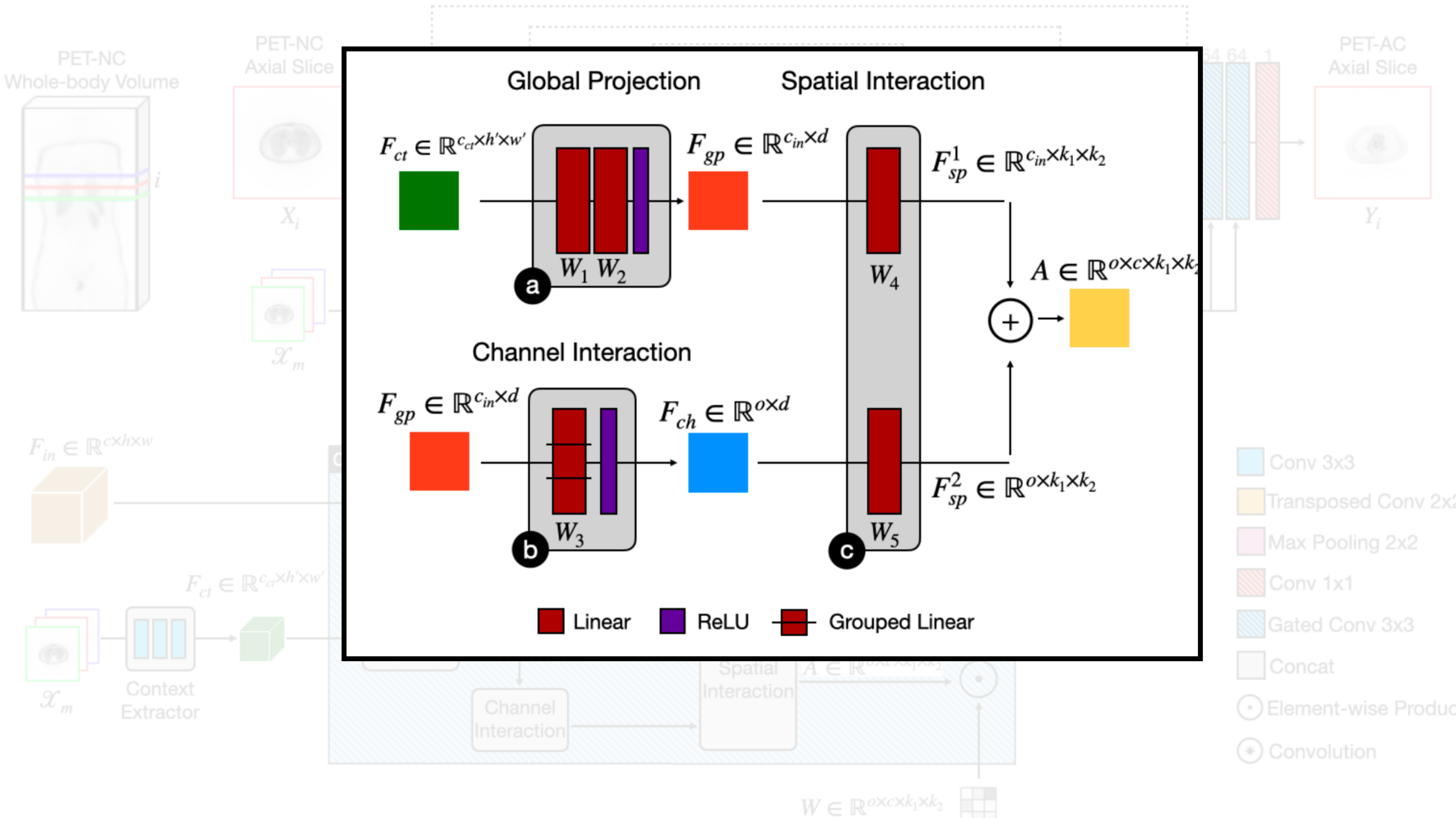


Method
Context-Aware Module



Method

Context-Aware Module



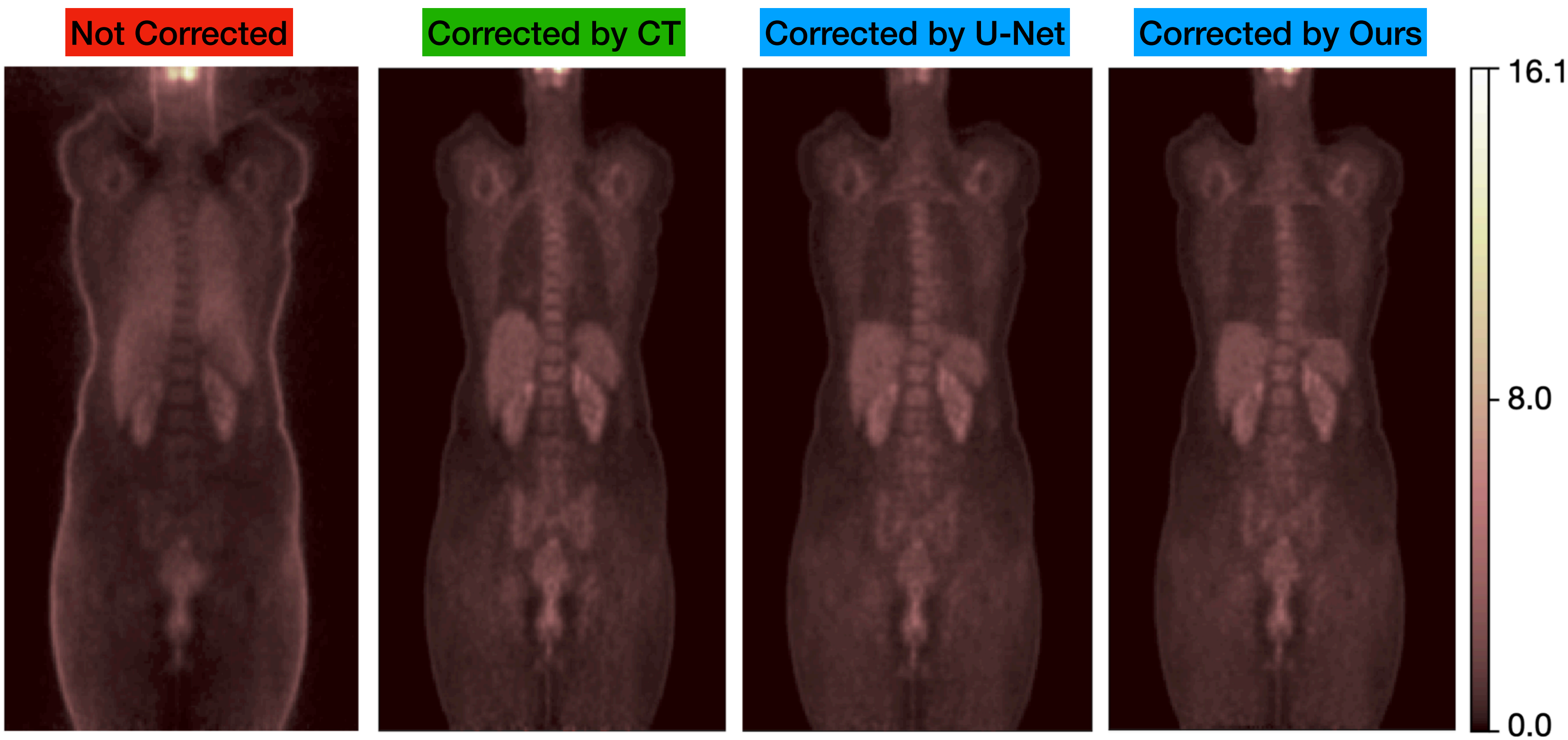
Method

Context-Aware Module

- Can effectively self-adapt itself to the inter-/intra- tracer uptake variations
- Comes with negligible increase in training parameters

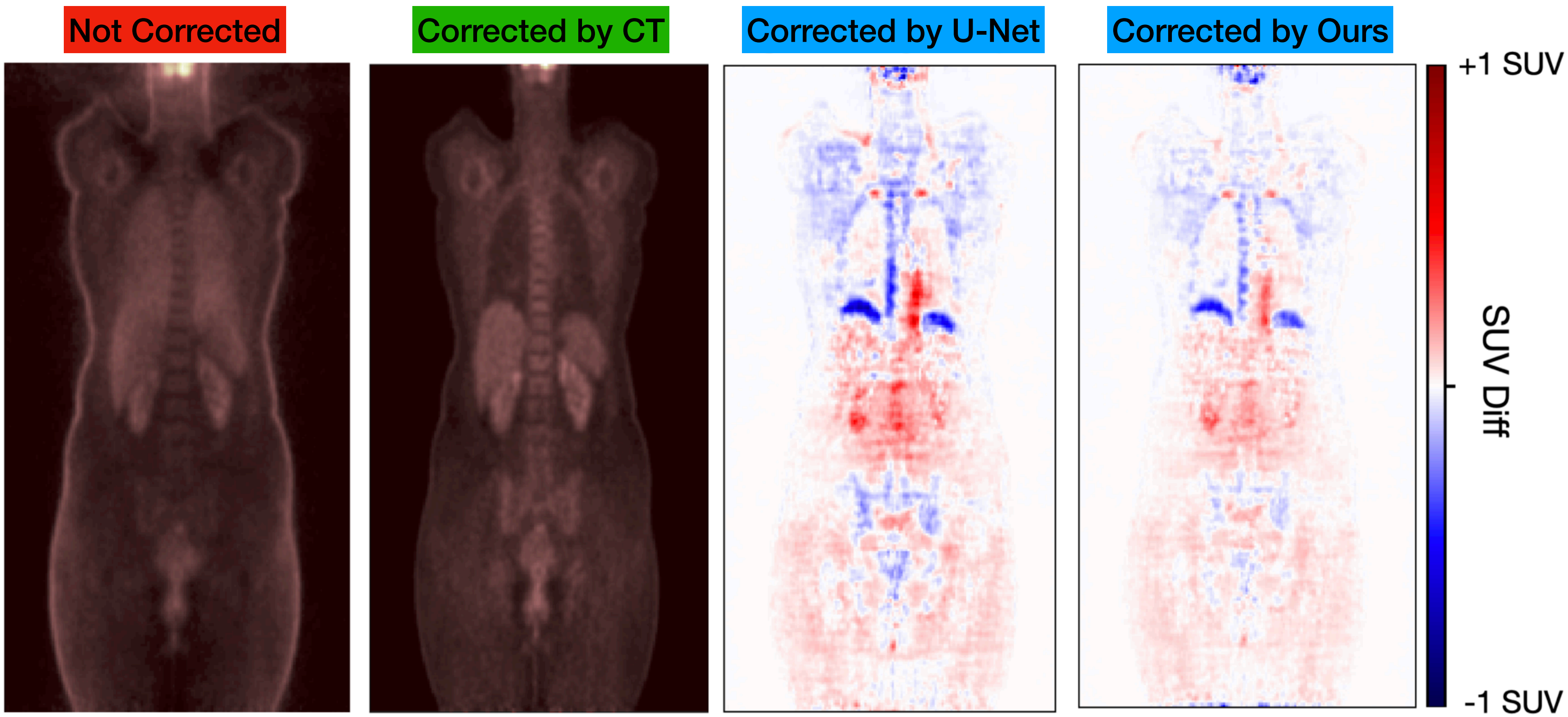
Results

Qualitative Evaluation



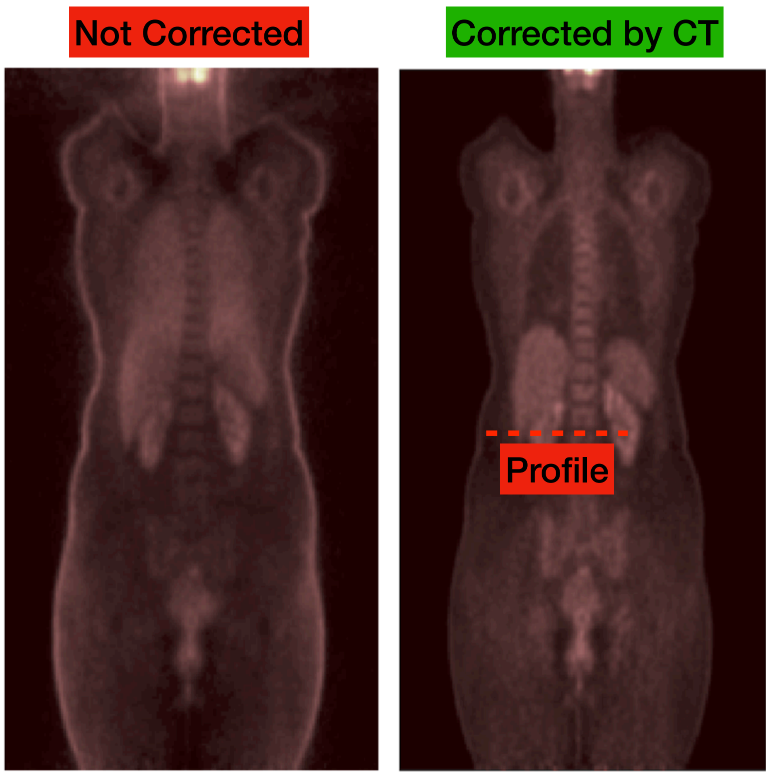
Results

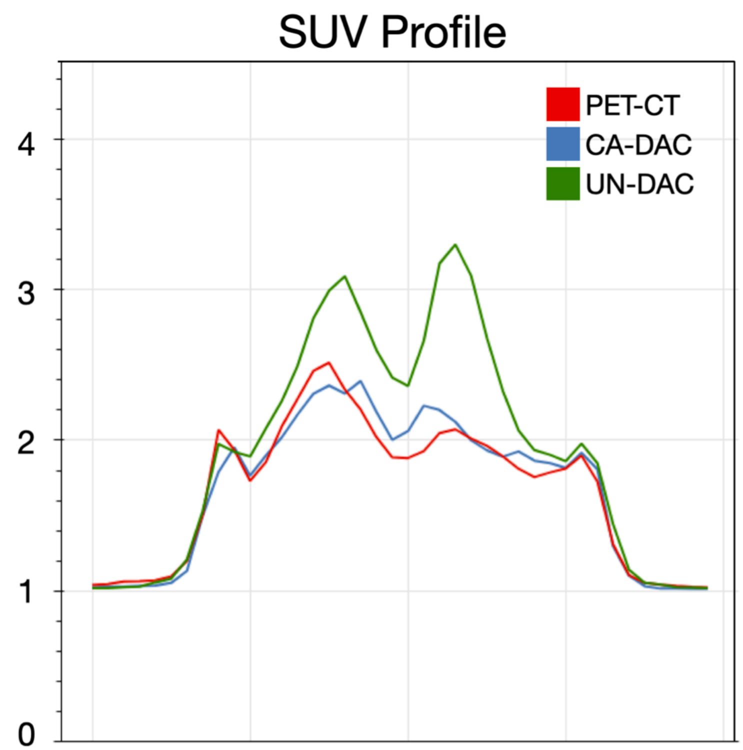
Qualitative Evaluation



Results

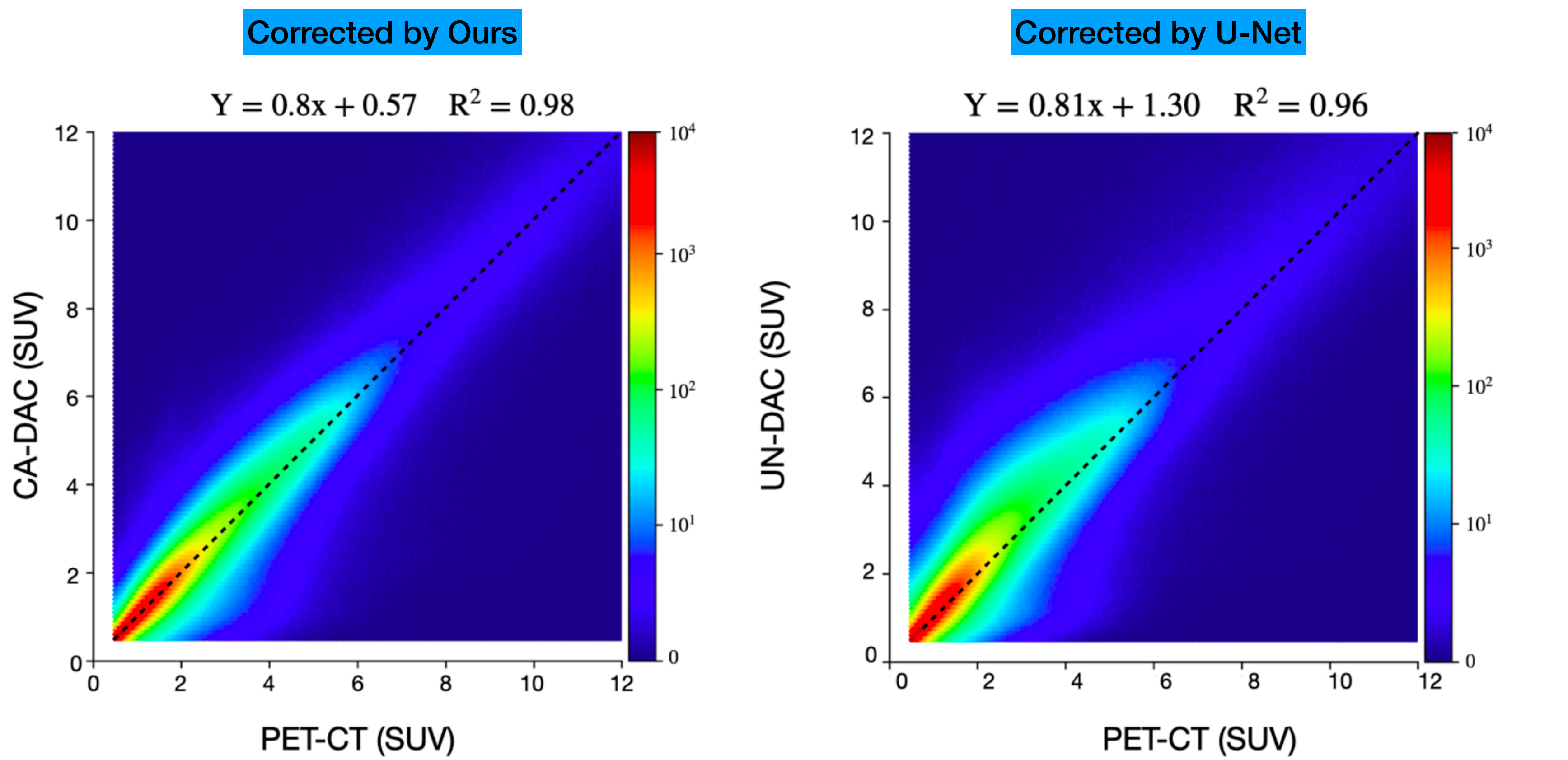
Qualitative Evaluation





Results

Quantitative - Joint Histogram

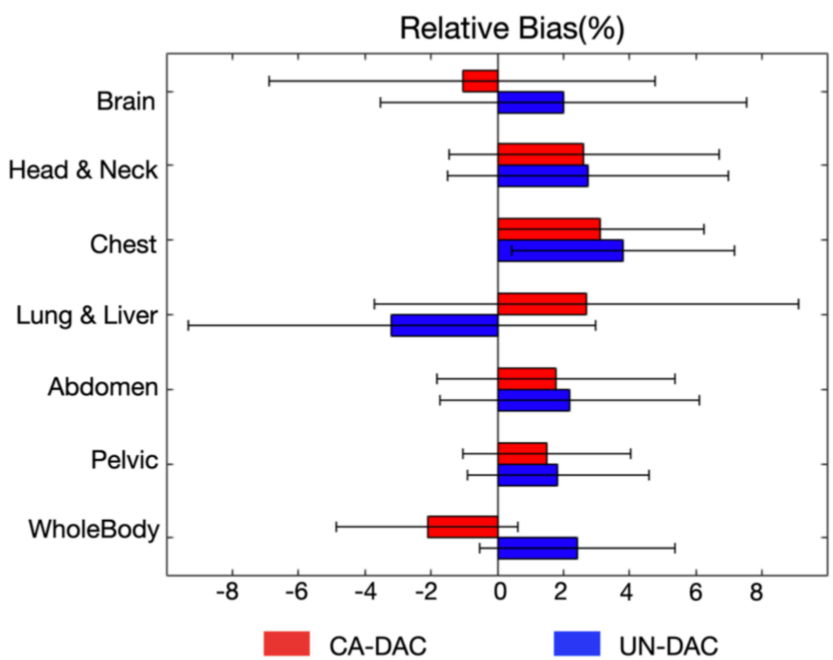


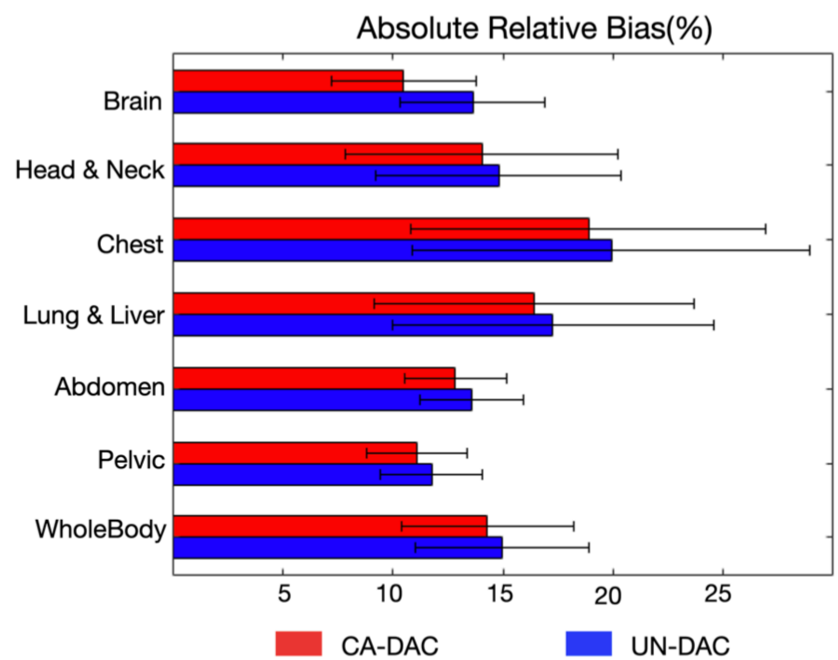
Results

Quantitative - Relative and Absolute Relative Error

- Average RE for Whole-Body
  - U-Net: 2.43 ± 2.94
  - Ours: –2.11 ± 2.73

- Average ARE for Whole-Body
  - U-Net: 14.79 ± 2.37
  - Ours: 13.96 ± 2.32

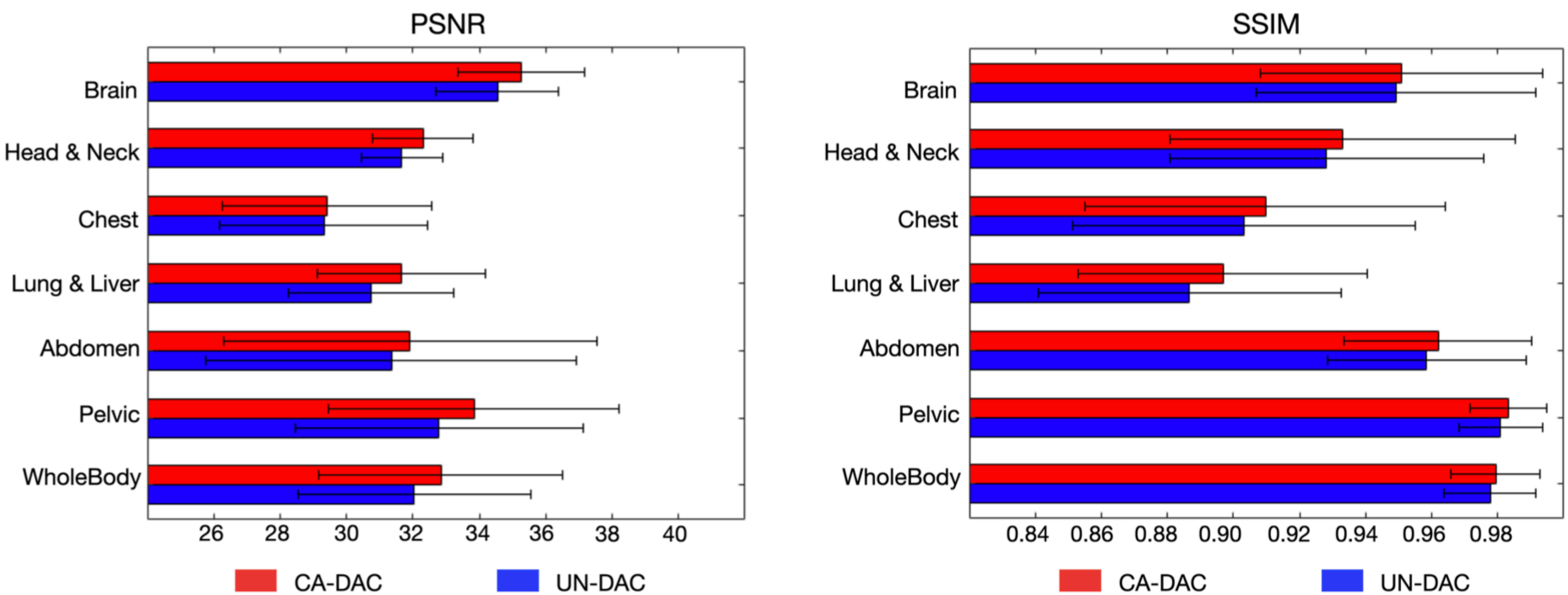




Results

Quantitative - Visual Quality Metrics

- PSNR improved by 0.71dB averaged over all regions
- SSIM improved by 0.0059 averaged over all regions



Thanks