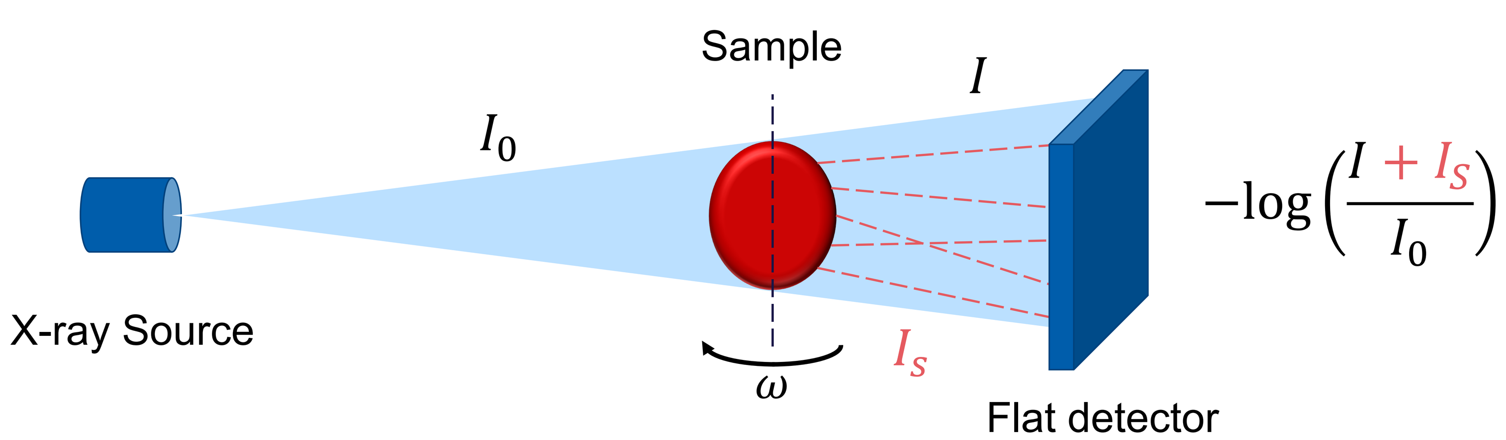
Scattering Corrections for X-ray CT using Convolutional Neural Networks

Matteo Busi*, **Christian Kehl***, **Ulrik Lund Olsen**
DTU Physics & Compute - Technical University of Denmark, Lawrence Livermore National Laboratory

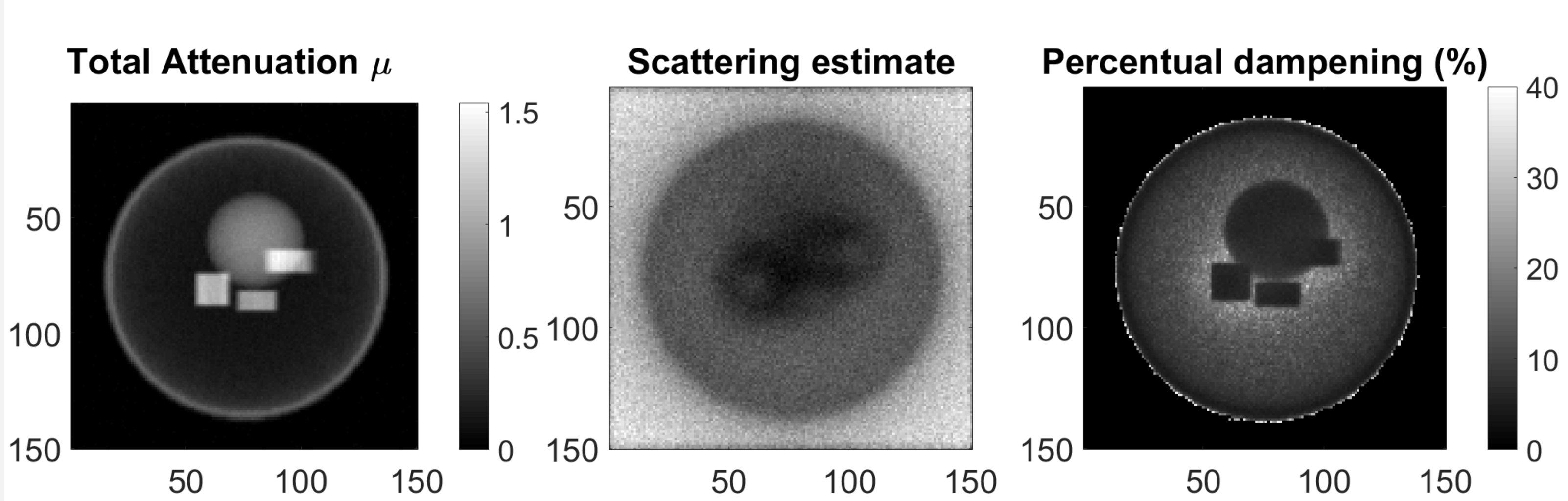
In the field of X-ray Computed Tomography (CT), a high contrast between the different materials composing the sample is crucial for the investigation, e.g. explosive detection in checked-in luggage, cancer diagnosis, quality check etc. Scattering interactions between the X-ray beam and matter yield noise in the projections (scatter) that decrease the contrast between different materials. The spatial distribution and magnitude of scatter depends on the sample features and the scanner specifics (X-ray source spectrum and magnification). Monte Carlo simulation are accepted as the gold standard of modeling the physics of the undergoing interactions, at the cost of high computational time. We trained a Convolutional Neural Network (CNN) to provide near real time scatter estimates.

MONTE CARLO SIMULATIONS PROVIDE SCATTER ESTIMATES

McXtrace [1] is a Monte Carlo (MC) software package for simulating X-ray optics, beamlines and experiments. It models the interactions undergoing CT acquisitions: photoelectric absorption, elastic scattering and inelastic scattering.

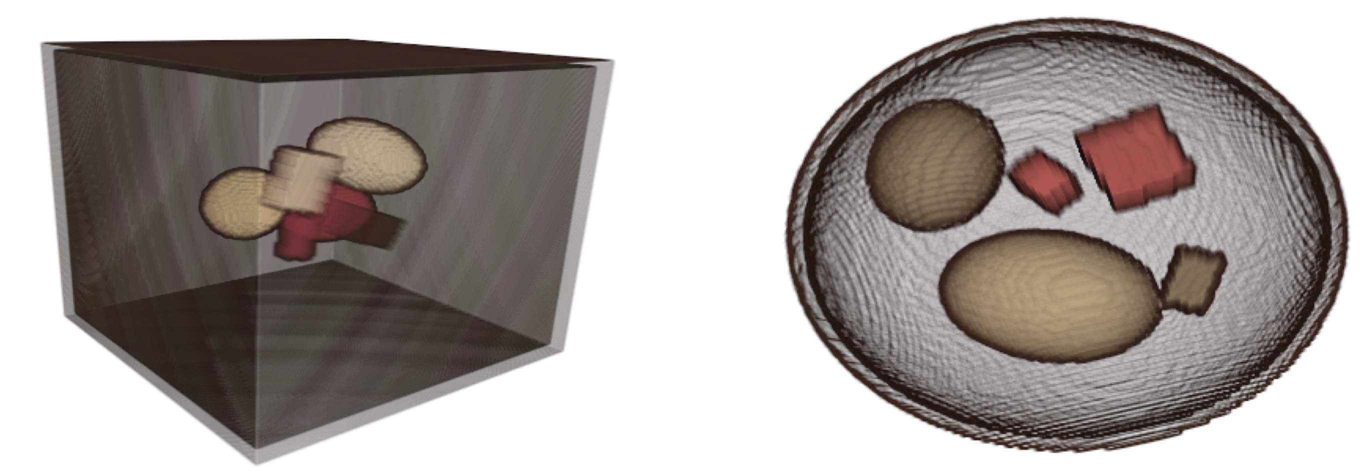


The quantity that is measured in a CT scan is the attenuation coefficient $\mu = -\log\left(\frac{I}{I_0}\right)$, that is used to distinguish between different materials. A scatter term I_s yields distortion of the measured μ. The MC simulation provides an estimate of I_s, to correct for it.



RANDOM SAMPLE GENERATOR PROVIDES TRAINING DATASET

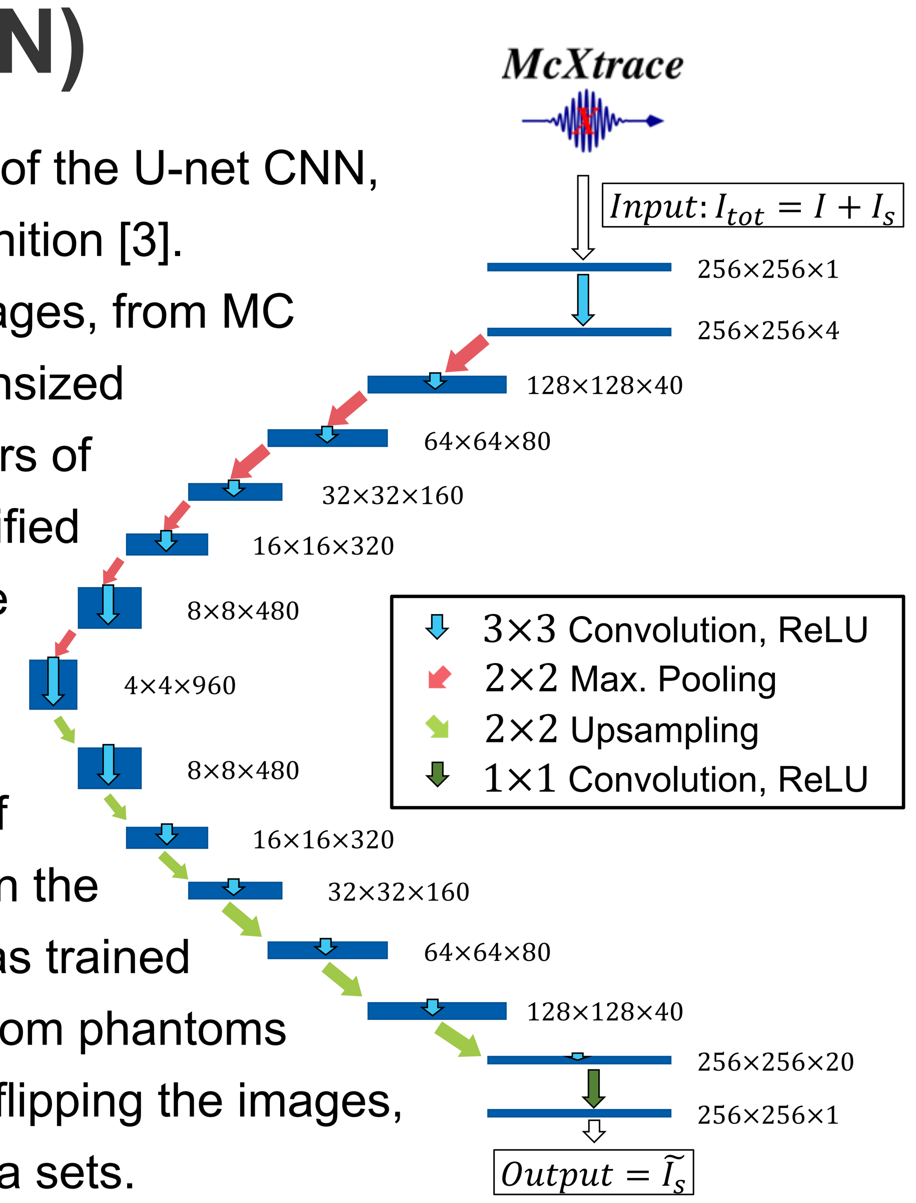
A custom implementation of the software package TomoPhantom [2], was used to generate a large amount of training datasets. The phantoms (i.e. samples) are composed of a set of ellipsoids and cuboids with random size and materials, enclosed in a constant envelope. The phantoms are imported in the MC simulation framework and their respective attenuations and scatter estimates are obtained.



Two 3D representations of the random generated phantoms. A cuboid (left) and a ellipsoid (right) envelope, containing objects with random shape, position and material.

U-NET CONVOLUTIONAL NEURAL NETWORK (CNN)

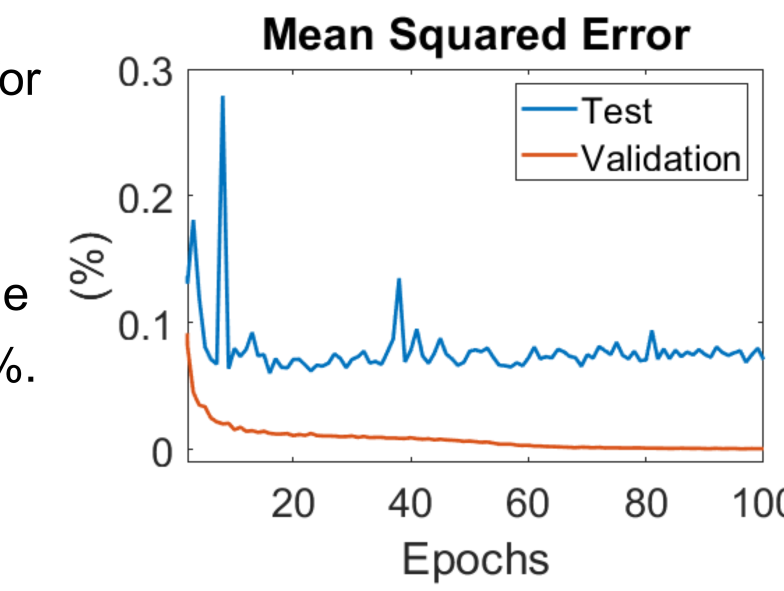
We employ a modified version of the U-net CNN, originally used for visual recognition [3]. The network receives input images, from MC simulations. The image is downsized by max. pooling through 7 layers of 3x3 convolution filters and rectified linear units (ReLU) to introduce nonlinearity. The initial image size is then restored by upsampling. The great depth of the CNN allows to capture even the smallest features. The CNN was trained with 60 projections of 100 random phantoms and 4x data-augmentation, by flipping the images, for a total of 24000 training data sets.

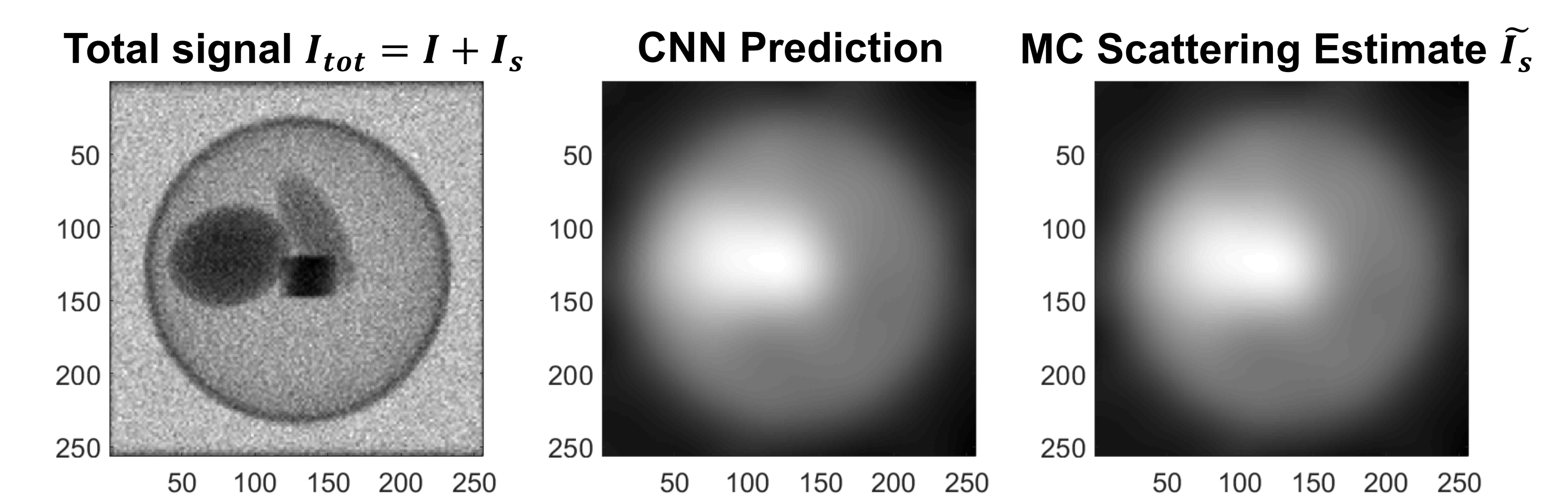


Schematic representation of the implemented Convolutional Neural Network

CNN SCATTERING ESTIMATES

The network was trained for 100 epochs using a NVIDIA Titan GPU for a total time of 6 hours. The training shows convergence of the mean squared error of test images, that the network has not seen, around 0.07%. Once trained, the network is able to provide scatter estimates at an average time of 7 milliseconds.





CNN performance: in the left frame a test input image that the network has not seen before. In the middle and right frame are respectively the scatter predicted by the CNN and the ground truth from the MC simulations.

CONCLUSIONS

This study shows promising results of the implementation of a deep convolutional neural network for near-real time scatter correction. The network, once trained provides scatter estimates that match well MC simulations, with a speed gain of several orders of magnitude.

ACKNOWLEDGMENTS

We thank NVIDIA for their GPU donation under the academic partnership program for supporting the machine learning research.

REFERENCES

[1] Bergbäck Knudsen, Erik, et al. "McXtrace: a Monte Carlo software package for simulating X-ray optics, beamlines and experiments." *Journal of Applied Crystallography* 46.3 (2013): 679-696.
[2] Kazantsev, Daniil, et al. "TomoPhantom, a software package to generate 2D–4D analytical phantoms for CT image reconstruction algorithm benchmarks." *SoftwareX* 7 (2018): 150-155.
[3] Ronneberger, Olaf, Philipp Fischer, and Thomas Brox. "U-net: Convolutional networks for biomedical image segmentation." *International Conference on Medical image computing and computer-assisted intervention*. Springer, Cham, 2015.

*Authors have equal contribution. Author contact: mbusi@fysik.dtu.dk

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.