Deep Learning-Based Real-Time Estimation of Patient Dose Distributions for Various Medical CT Scan Protocols

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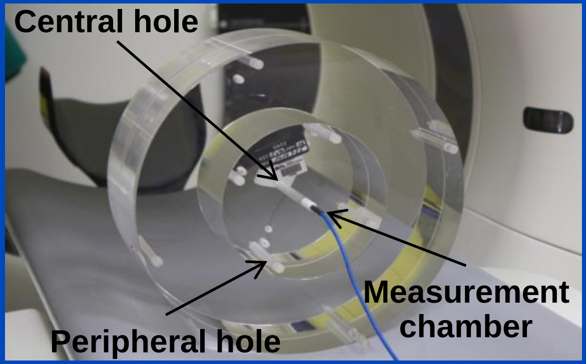
Motivation

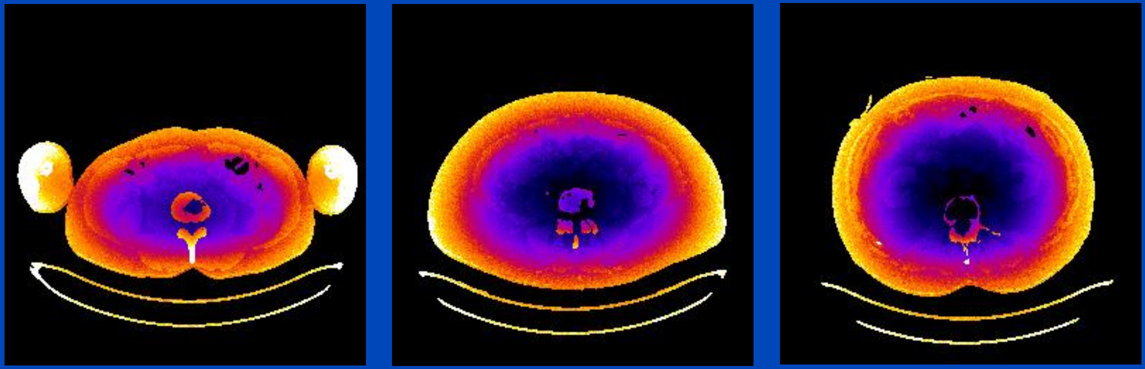
- Potential risk associated with the radiation exposure
- Report the administered patient dose for each CT scan
- Conventional metrics for dose estimation are based on phantom measurements which don’t reflect the patient’s anatomy

  → Rough estimate of the actual patient dose

32 cm CTDI Phantom (L)



Thorax and abdomen phantom for adults



Same CTDI, different dose distribution

Dose values in air voxels are set to zero (black).

Patient-Specific Dose Estimation

- Accurate solutions:
  - Gold standard: Monte Carlo (MC) simulation

  → Accurate but computationally expensive

- Fast alternatives:
  - Application of look-up tables using MC simulations of phantoms[1]
  - Analytic approximation of CT dose deposition[2]

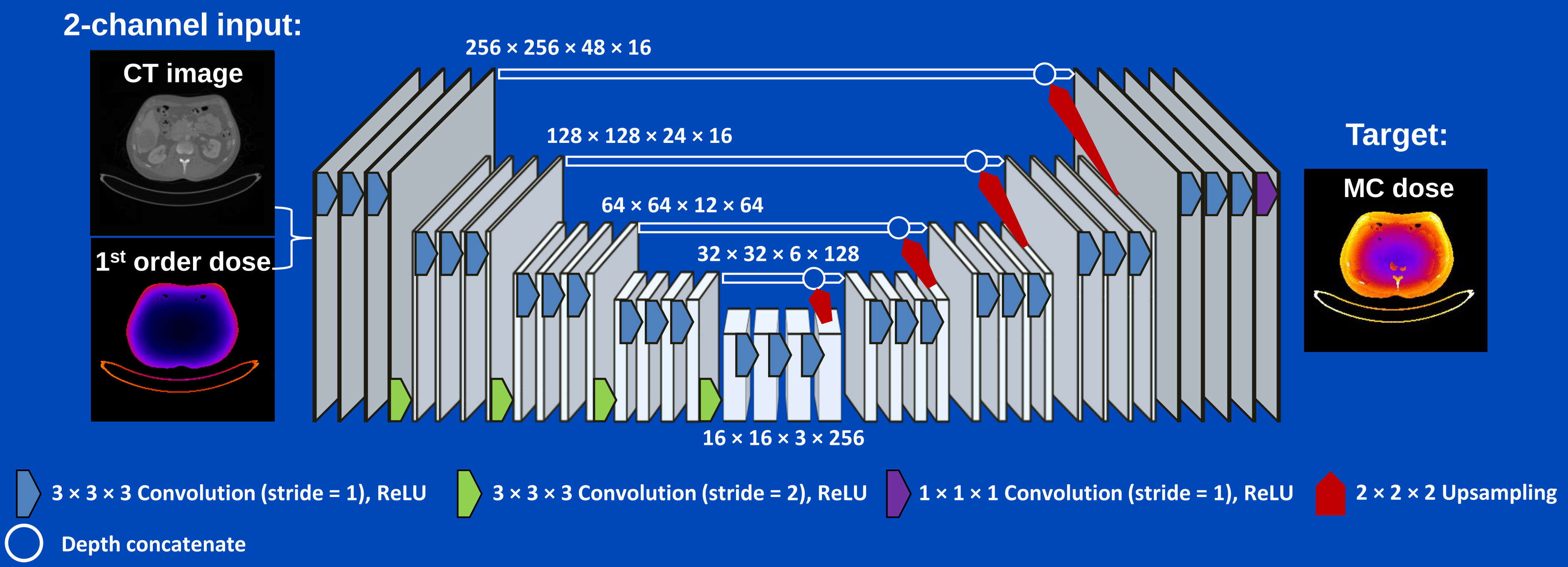
  → Fast but less accurate

→ How to be fast and accurate?

[1] A. Ding et al., “VirtualDose: a software for reporting organ doses from CT for adult and pediatric patients”, Phys. Med. Biol. 60, 2015.
[2] B. De Man, “Dose reconstruction for real-time patient-specific dose estimation in CT”, Med. Phys. 42, 2015.

Deep Dose Estimation (DDE)

- Model
  - 3D U-net with two channel input (CT image and first-order dose estimate)
  - Target: Monte Carlo simulation



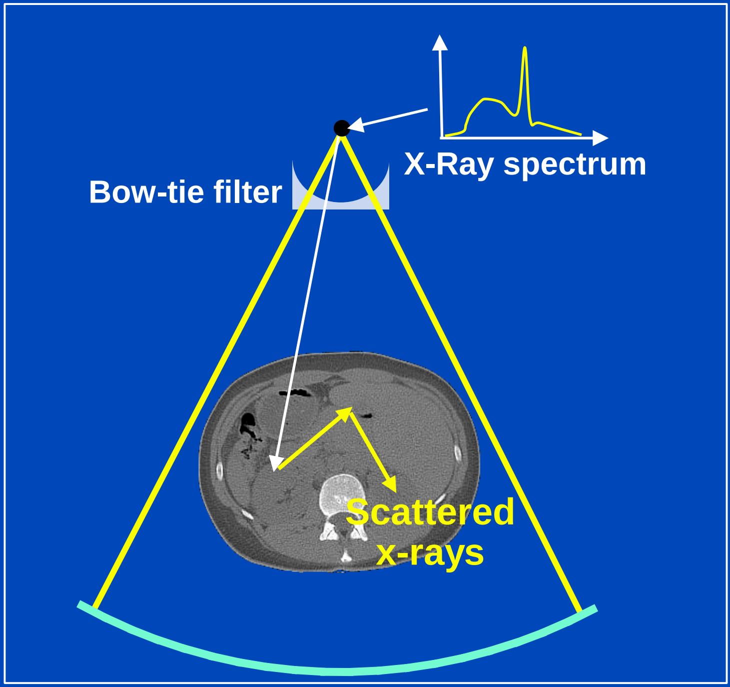
J. Maier, E. Eulig, S. Dorn, S. Sawall, and M. Kachelrieß. Real-time patient-specific CT dose estimation using a deep convolutional neural network. Proc. IEEE MIC 2018.

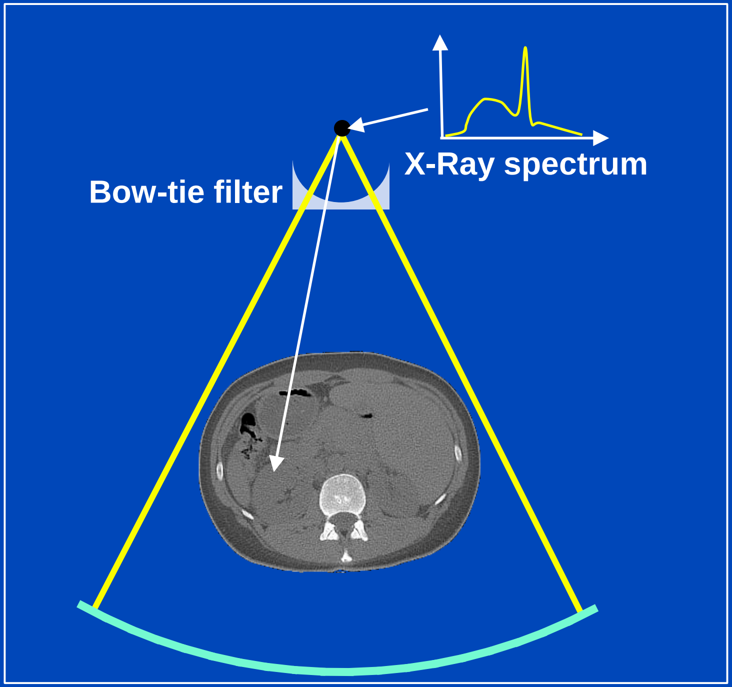
Deep Dose Estimation (DDE)

First-order dose estimate

Monte Carlo:
Calculation of the complete photon trajectory through different tissues including scatter interactions.
→ Slow

First-order dose:
Only direct rays are considered.
Only a single material (water) is considered.
→ Fast



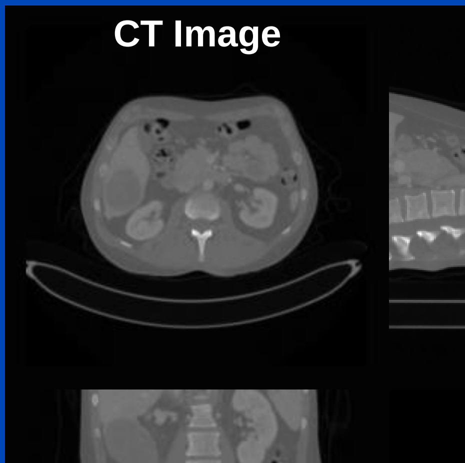


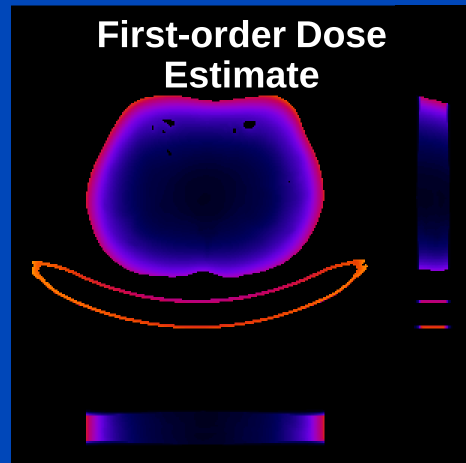
Data Generation

- Simulation of 5191 CT scans of 35 patients assuming the geometry of the Simens Somatom Flash CT scanner
- Always simulating a FOD and MC dose estimate on a 256×256×128 voxel grid with an isotropic voxel size of 2 mm
- The simulations have been performed with
  - Different acquisition protocols (circular and spiral, pitch 0.0 and 1.0)
  - Different z-positions (thorax, abdomen, and pelvis)
  - Different tube voltages (80 kV, 100 kV and 120 kV)
  - Bow-tie filtration (on / off)
  - Tube current modulation (TCM) (on / off)
- 28 patients are used for training, 7 for validation

Results

120 kV, circle scan, no bow-tie, no TCM



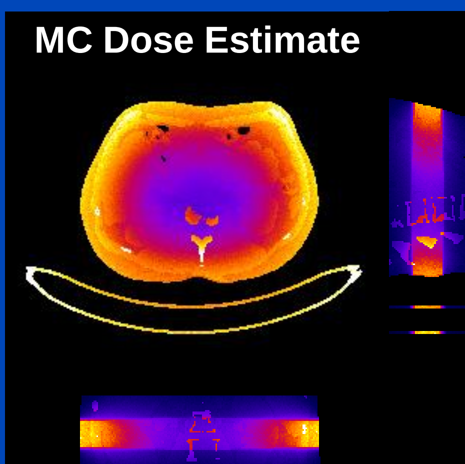


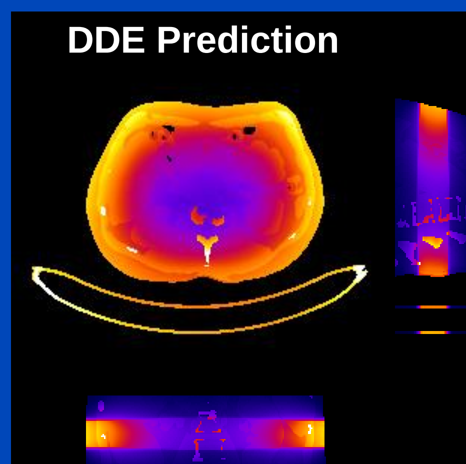
	MC	DDE
128 slices	40 min	0.25 s

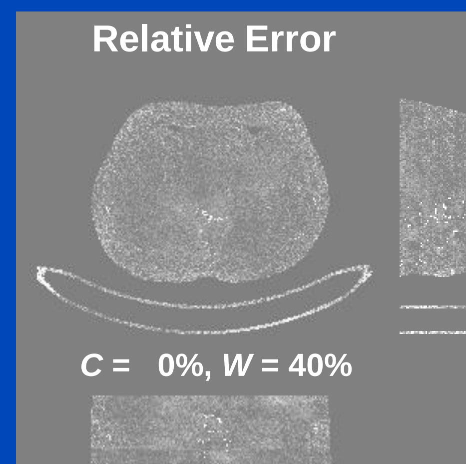
MC uses 16 CPU kernels
DDE uses one Nvidia Geforce RTX 2080TI GPU

DDE training took 3 days for 65 epochs, on 5191 samples, 48 slices per sample

MAPE = 4.79%

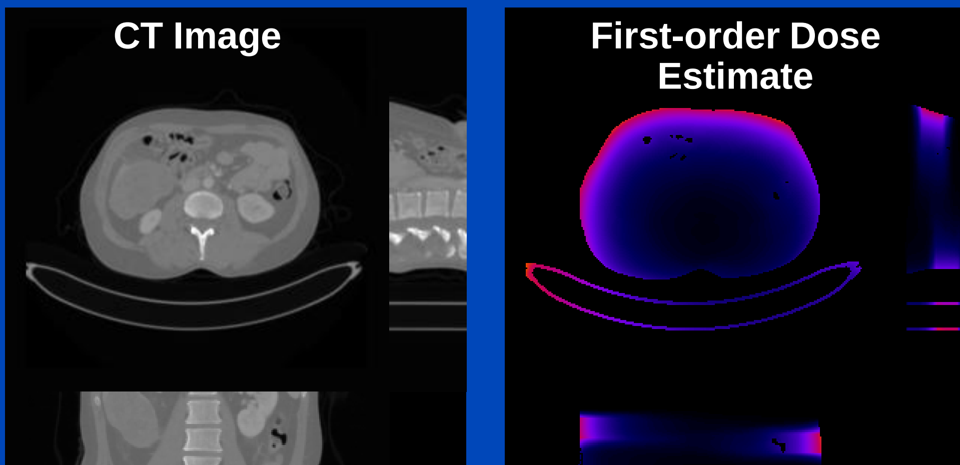






Results

120 kV, spiral scan, no bow-tie, no TCM

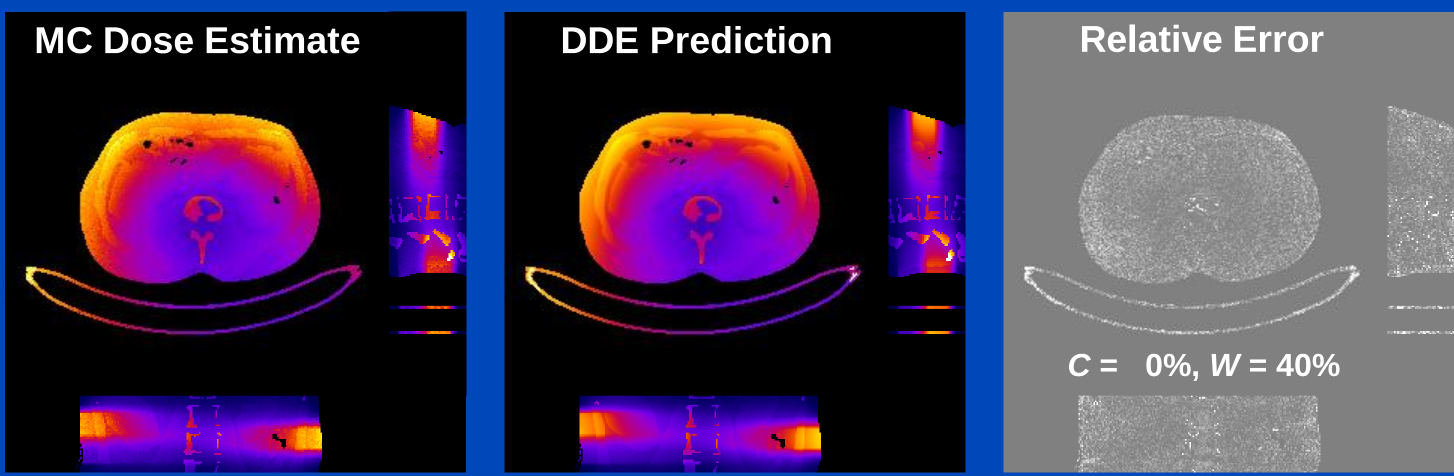


	MC	DDE
128 slices	40 min	0.25 s

MC uses 16 CPU kernels
DDE uses one Nvidia Geforce RTX 2080TI GPU

DDE training took 3 days for 65 epochs, on 5191 samples, 48 slices per sample

MAPE = 4.30%



Results

Analysis for Different Tube Voltages

Testing / Trainig	80 kV	100 kV	120 kV
80 kV	**6.72**	19.94	32.02
100 kV	31.36	**5.74**	13.7
120 kV	51.9	18.03	**5.34**
All Data	15.78	9.08	11.52

MAPE [%]

→ Train each tube voltage separately rather than all data together

Conclusions

- The DDE method is able to derive accurate dose estimates for the circle and the spiral trajectory in different parameter configurations.
- This also holds true outside of the z-collimation where the first-order dose is zero.
- Training each tube voltage separately produces better results than training all data together.
- After the network is trained we are able to process a 256×256×48 voxel volume with a 2 mm voxel size in 250 ms.

Thank You!

Job opportunities through DKFZ’s international Fellowship programs (marc.kachelriess@dkfz.de).
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