X-ray phase-contrast simulations of fibrous phantoms using GATE

J. Sanctorum[1], J. De Beenhouwer[1], J. Sijbers[1]

[1]imec-Vision Lab, Department of Physics, University of Antwerp, Belgium

Introduction

In recent years, the overall importance of x-ray phase-contrast imaging (XPCI) techniques has grown substantially due to their ability to generate contrast in a range of situations where traditional absorption imaging falls short. Fibrous and porous materials, found in for example advanced composites, such as fibre reinforced polymers, and biological structures, such as dentinal tubules in teeth, are of particular interest for XPCI, as information about their microstructure can be revealed even below the system's spatial resolution. This is done by exploiting the so-called dark-field contrast (DFC) [1], generated by x-ray scatter in the specimen. When it comes to developing new acquisition and reconstruction techniques for XPCI-CT, as well as optimizing the system and components design, Monte Carlo (MC) simulations are a valuable tool for benchmarking and testing. Here, we present the practical implementation of a set of tools within the GATE [2] framework that extend its functionality, paving the way for grating-based differential phase contrast (DPC) simulations.

Methodology

Simulation flow: As proposed in [3], the simulation pipeline is split up in two parts. Initially, MC simulations are performed with GATE for modeling the photon interactions, followed by numerical wavefront propagation using MATLAB. The intermediate transformation from photons to wavefront can be done using ROOT [4]. Tracking phase effects in GATE requires the implementation of two additional features: **(1)** x-ray refraction using Snell's law and **(2)** assigning an optical path length to each photon trajectory. Both processes are determined by the complex refractive index of the material and were incorporated in the GATE source code.

GATE
Photon-phantom interactions
- New photon property: optical path
- New GATE-process: refraction
- Collect photons at virtual detector

ROOT
Photon to wave transition
- Discretise virtual detector plane
- Assign complex amplitude to photons
- Sum amplitudes of coinciding photons

MATLAB
Numerical wavefront propagation
- Apply phase grating
- Perform Fresnel propagation
- Apply analyzer grating
- Phase stepping

Advantages:
- **effective decoupling** of interactions and subsequent wavefront propagation;
- **flexible choice** of wavefront sampling parameters after performing MC.

Limitations:
- intermediate **output size** depends on number of simulated photons and can therefore become large irrespective of final image size;
- additional **time** due to intermediate step.

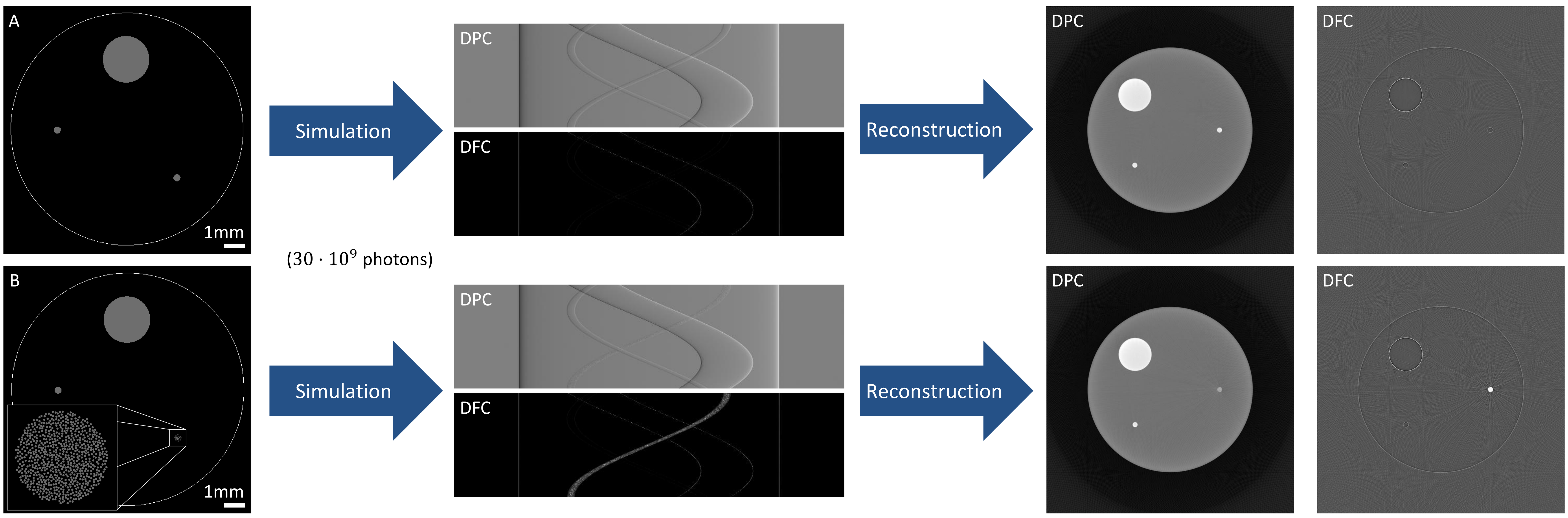
Alternative flow: When flexibility is not an issue, it is desirable to ommit the intermediate step. Therefore, we also propose an alternative scheme, where the intermediate transition step is fully integrated in the first step. The direct wavefront generation was implemented in the GATE source code.

GATE
Photon-phantom interactions + photon to wave transition

MATLAB
Numerical wavefront propagation

Demonstration

The simulated phantom is a cylindrical volume containing either three homogeneous cylinders (version A) or two such cylinders and one bundle of smaller cylinders, mimicking a fibre bundle (version B). Tomographic reconstruction is performed with the **ASTRA toolbox** [5].



References

[1] Pfeiffer, F., et al., *J. Appl. Phys.*, **105(10)**, 102006, (2009)
[2] Santin, G., et al., *IEEE Trans. Nucl. Sci.*, **50(5)**, 1516-1521, (2003)
[3] Peter, S., et al., *J. Synchrotron Radiat.*, **21(3)**, 613-622, (2014)
[4] Brun, R., et al., *Nucl. Instrum. Meth. Phys. Res. A*, **389(1-2)**, 81-86, (1997)
[5] van Aarle, W., et al., *Opt. Express*, **24(22)**, 25129, (2016)

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Contact: jonathan.sanctorum@uantwerpen.be