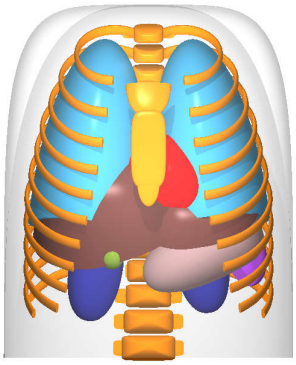
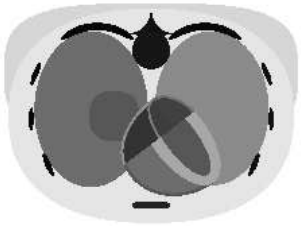
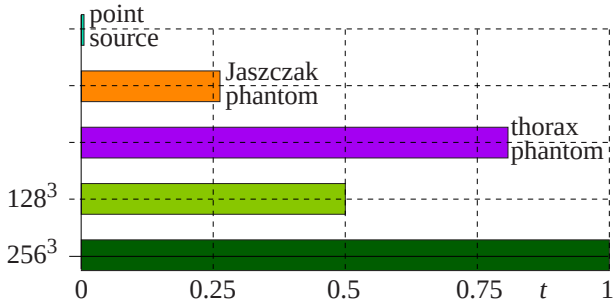
Analytical Versus Voxelized Phantom Representation for 3D Monte Carlo

Background: Monte Carlo simulations in nuclear medicine, with accurately modeled photon transport and high quality random number generators, require precisely defined and often detailed phantoms as an important component in the simulation process. Contemporary simulation models predominantly employ voxel driven algorithms, but analytical models offer important advantages. We discuss the implementation of ray-solid intersection algorithms in analytical superquadric-based complex phantoms with additional speed-up rejection testing for use in nuclear medicine imaging simulations, and make comparisons with voxelized counterparts. Comparisons are made with well known cold rod:sphere and anthropomorphic phantoms. For these complex phantoms, the analytical phantom representations are nominally several orders of magnitude smaller in memory requirements than voxelized versions. Analytical phantoms facilitate constant distribution parameters. As a consequence of discretizing a continuous surface into finite bins, for example, time dependent voxelized phantoms can have difficulties preserving accurate volumes of a beating heart. While there is virtually no inaccuracy associated with path calculations in analytical phantoms, the discretization can negatively impact the simulation process and results. Discretization errors are apparent in reconstructed images of cold rod:sphere voxel-based phantoms due to a redistribution of the count densities in the simulated objects. These problems are entirely avoided in analytical phantoms. Voxelized phantoms can accurately model detailed human shapes based on segmented CT or MRI images and have been shown to be more appropriate if the effects of complex protuberances between internal organ structures are under investigation, but analytical phantoms offer advantages in time and accuracy for evaluation and investigation of imaging physics and reconstruction algorithms in a straightforward and efficient manner.





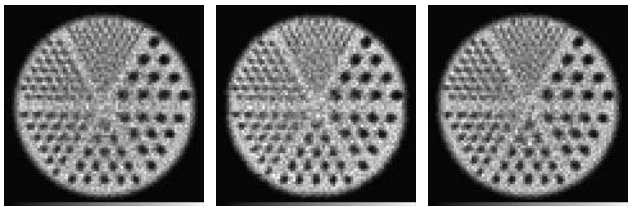
Analytically defined thorax phantom and transverse image if its voxelized (256^3) counterpart



Computational time requirements for 100,000 photon histories (without scatter)

Memory demand of the 3D/4D anthropomorphic torso phantom in kBytes (uncompressed)

	Analytic	128^3	256^3
3D	12	2,048	16,384
4D (16 frames)	64	32,786	262,144



Analytic 256^3 128^3

A visual comparison of these Jaszczak phantom images shows that the closest agreement to the true phantom geometry seems to be given by the voxelized phantom with 128^3 voxels.The corresponding profile has significantly exaggerated extrema compared to the profiles of the other results which are quite similar.Obviously, this cannot be the case. The reason for the misleading interpretation of the simulation results can be found in discretization errors.

Painting by Rembrandt "Anatomy Lesson of Dr. Tulip"

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