New developments in analytical calculation of first order scattering for 3D complex objects

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The principle of the analytical calculation of first order scattering used in our simulation code named VXI (Virtual X-ray Imaging) is based on a double ray-tracing [1]. The first step consists in realizing a ray-tracing from the X-ray source point to each point of the object (an elementary volume in practice) including attenuation effect in the primary beam. This calculation gives the number of photons and their direction arriving on each voxel. A voxel acts as a secondary source which properties accord to the physics of X-ray scattering (Compton and Rayleigh) [2]. The second step of the ray-tracing is then done from each voxel of the object in the direction of each pixel of the detector, taking into account the attenuation along the scattering path (fig. 1)

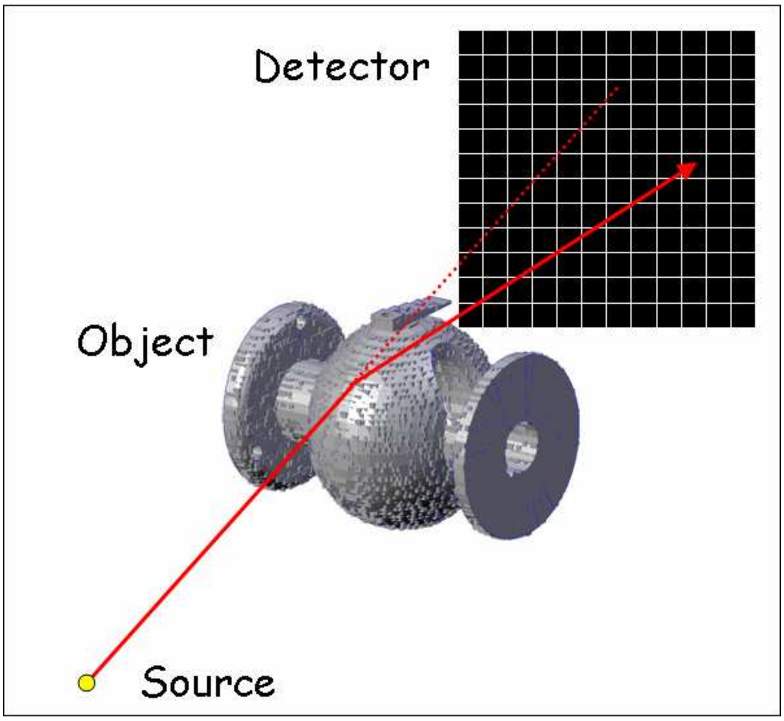
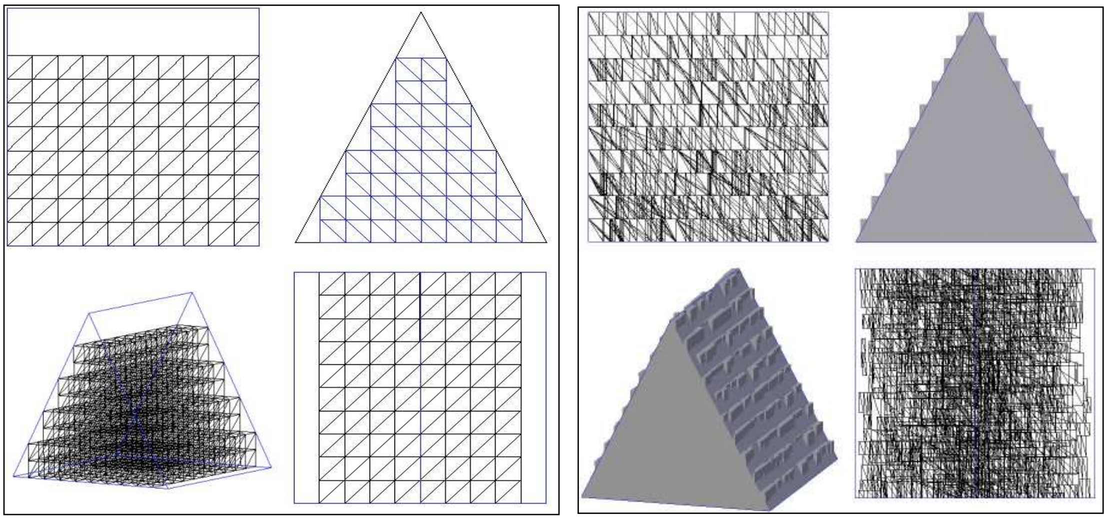


Fig. 1 Principle of first order scattering analytical simulation

To simulate a 3D complex object, the first problem consists in realizing an automatic 3D sampling of the object. This is done by using an octree-based method optimized for

deterministic scattering computation. The basic octree method consists in dividing recursively the volume of the object in decreasing-size voxels until each of them is completely included under the surface of the sample [3] [4].
First, we can see figure 2a that the object volume is then always under evaluated.
This is a problem because the scattering phenomenon strongly depends on the real volume of the object [5].
The second problem is that artefacts due to sampling effects can occur in synthesis images.
These two particular aspects are taken into account in our simulation code and an optimized octree-based method has been specially developed for this application.

To respond to the first problem, our 3D sampling algorithm may accept voxels on the surface of the sample under conditions defined by the user.
The second problem is treated in generating a random sampling instead of a regular one.
The example of the 3D sampling using the octree-based method (figure 2a) becomes, after improvements, this viewed in figure 2b.



(a) (b)

Fig. 2: a) 3D sampling example using the basic octree method. b) 3D sampling example using the optimized octree method.

The algorithm developed for 3D sampling is easily configurable, fast (about a few seconds maximum), robust and can be applied to all object shapes (thin, massive). The sampling time depends on the number of facets of the object (the CAD model of an object is defined by a set of facets describing its surface) and of course the number of voxels chosen. As an example, for the gate shown on figure 3 and containing 5500 facets, the 100000 voxels are obtained in 7 seconds.
The whole algorithm dedicated to first order analytical scattering computation, including ray-tracing, scattering physics and 3D sampling has been compared to GEANT4 Monte Carlo code in the aim to validate our method and our algorithms. Results of this comparison are given on figure 4. It shows the transmission image (uncollided) and the scattering images obtained for Rayleigh and Compton effects.

Using VXI, such images (200^2 pixels) need 7 hours to be calculated while GEANT4 need 75 days for the same calculation. Note that we didn't search to optimize GEANT4 code to reduce

Monte Carlo computation time but VXI will be always faster. On the other hand and by opposition to VXI, GEANT4 gives information on all effects appearing inside the sample (ie X-ray fluorescence, multiple scattering, etc …).
As said before, VXI is a deterministic code and then no noise appears in the images but it can be added afterwards if needed.

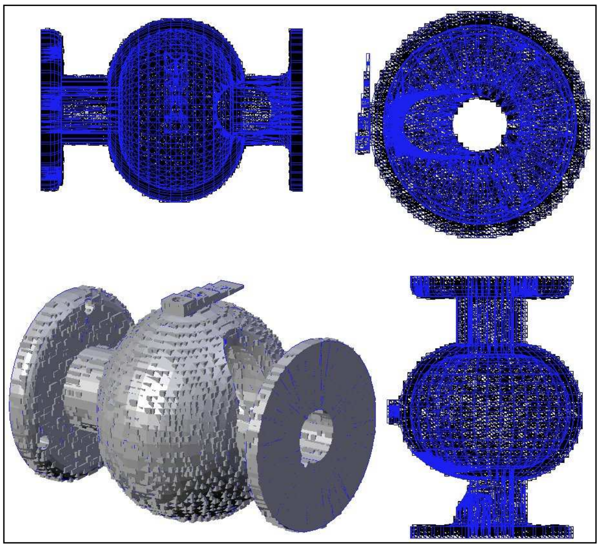


Fig.3: CAD model of a gate. The surface is described by a triangular mesh containing around 5500 facets. 3D sampling algorithm gives 100000 voxels in 7 seconds.

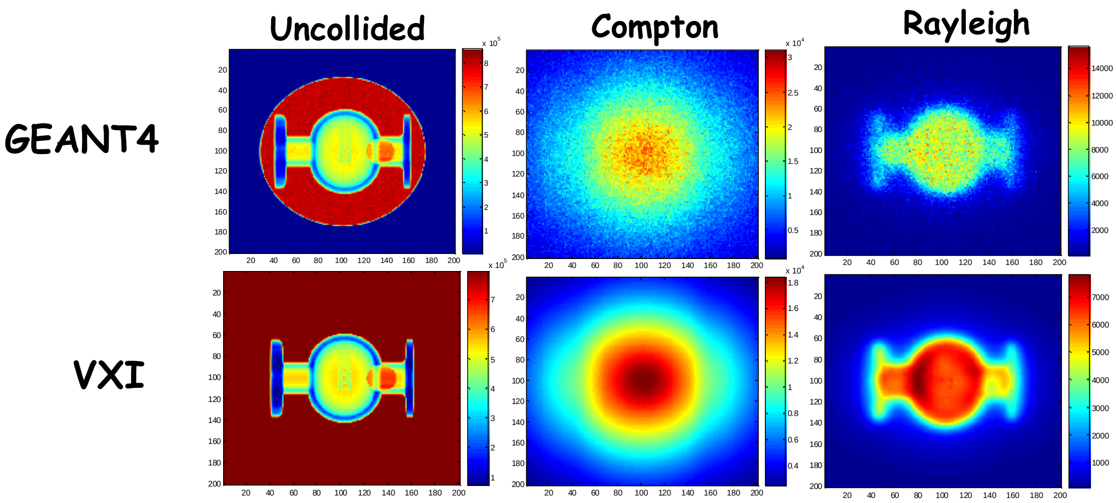


Fig.4: Comparisons between GEANT4 and VXI (Compton and Rayleigh images represent the first order scattering only)

In conclusion, deterministic simulation of first order scattering is possible on complex objects, by mean of a dedicated 3D sampling algorithm. For a lot of practical cases, the first order scattering is sufficient to approach reality. In this case, VXI gives results without noise, without major artifacts and in a very fast way comparing on Monte Carlo method.

References

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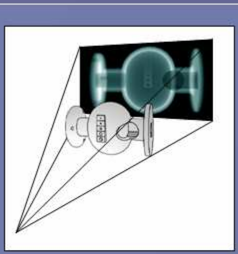

First order scattering analytical computation

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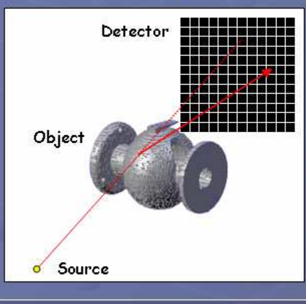
Principle

Calculation principle of scattered X-ray consists in ray-tracing from a point source to each point of an object, acting as a secondary source. Those points emit Compton or Rayleigh X-rays in the detector pixels direction. For this reason, we need a 3D sampling of the scattering object.



Theory elements

Scattering photon contribution is computed from classical models based on differential cross section (DCS)

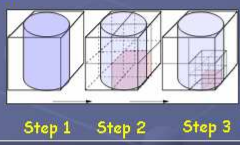
- $DCS_{Rayleigh} = DCS_{Thomson} \times FF^2(E,\theta,Z)$
- $DCS_{Compton} = DCS_{Klein-Nishina} \times SF(E,\theta,Z)$

FF and SF are the atomic form factor and the incoherent scattering function respectively

3D Sampling

Method: use of octrees principle

- Each voxel is recursively subdived in 8 same size sub-voxels
- Division process is stopped when the voxel is completely inside the object

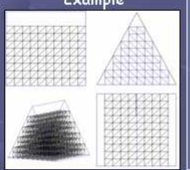


Octree method

Advantages
- 3D sampling of complex geometry
- Low input computation time for sampling

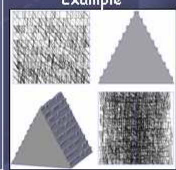
Drawbacks
- the sampled volume and therefore the scattering contribution is under evaluated

Example



Optimized based octree method for scattering

Example



- Scattered contribution strongly depends on the total sampling volume
  - Adjustment of the sampling volume vs real volume
- Reduction of under sampling of the scattering functions
  - Random sampling

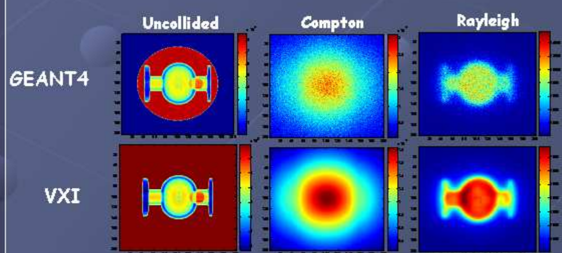
3D complex sample

3D Sampling computation time
- Depends on the number of facets of the object
- Depends on 3D sampling parameters

Example (5470 facets) :
- ~30.000 voxels: 3,5 s
- ~50.000 voxels: 4,5 s
- ~100.000 voxels: 7 s

Comparison: VXI vs GEANT4

Simulation parameters
- Material: aluminium
- Energy: 150 keV
- Detector: 200x200 pixels



Number of histories: 90.10^6 photons
Simulation time: ~1800 h (75 days)

Number of voxels: 164.000 voxels
Simulation time: ~7 h

Conclusion

Configuration of 3D sampling is easy. The algorithm we have developed is fast, robust, adaptable and coherent with the physics laws of interactions. Results obtained with the 3D sampling are accurate and without major artifacts.

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