Topic 4 – Quantitative Validation

IBSim-4i 2020

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13th Aug 2020

Quantitative Validation

- Simulating an image relies on a Beer-Lambert law implementation;
- Solving the Beer-Lambert law relies on Linear Attenuation Coefficients; ()
- is not known for given incident energies;
- is computed using Mass Attenuation Coefficients (/) and material density ().
- **Are the values used in gVirtualXRay accurate?**
  - Compare values computed in gVirtualXRay with those from the literature.
- **Are the Beer-Lambert law implementations accurate?**
  - Compare values computed in gVirtualXRay with theoretical ones.
- **Are the simulated images accurate?**
  - Compare images computed using gVirtualXRay with those using a state-of-the-art Monte Carlo software, e.g.

Density for Different Materials (human tissues) from the Literature

Density for Different Materials (human tissues) computed by gVirtualXRay

Mass Attenuation Coefficients

- Any tissue can be described by its Hounsfiled Unit (HU):

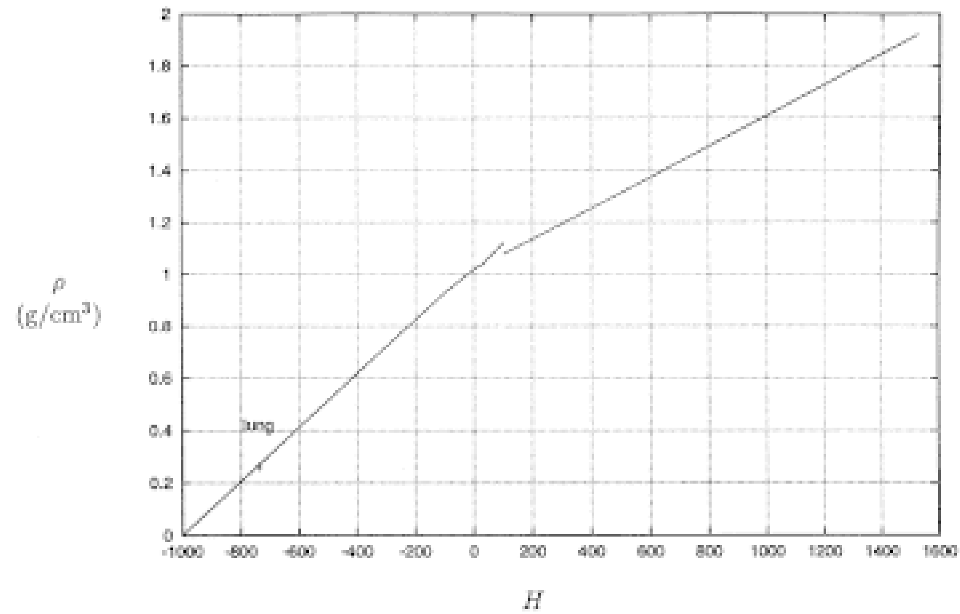


Image from W. Schneider, T. Bortfeld, and W. Schlegel, "Correlation between CT numbers and tissue parameters needed for Monte Carlo simulations of clinical dose distributions," Physics in Medicine & Biology, vol. 45, no. 2, p. 459, 2000. doi:10.1088/0031-9155/45/2/314

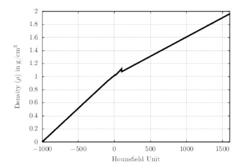


Image from `http://gvirtualxray.sourceforge.net/validation/validation_02/density.php`

- HU(material) = 1000 x ((material) - (water)) / (water)

- Given a HU value for any simulated object;
  - If (water) is known for any energy,
  - then (material) for any HU and for any energy can be computed:
    - ⋆ (material, E) = (water, E) x (1 + HU(material)/1000)
- Mass attenuation coefficients (/) for various human tissues can be found in the literature;
- The density () for various human tissues can be found in the literature.
- **Linear attenuation coefficients can therefore be computed for various human tissues** and
- **used to solve the Beer-Lambert law**

Mass Attenuation Coefficients: Tissue, Soft (ICRU-44)

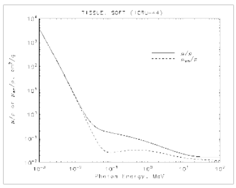
- 

  Image from ***https://physics.nist.gov/PhysRefData/XrayMassCoef/ComTab/tissue.html***

- (water) from literature is provided at given energies only: Interpolation needed for missing energies

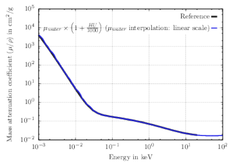
  - 

    Image computed with gVirtualXRay using linear interpolation

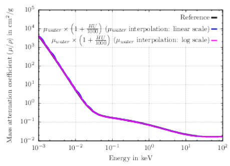
  - 

    Image computed with gVirtualXRay using interpolation in the log scale

Mass Attenuation Coefficients: Bone, Cortical (ICRU-44)

-

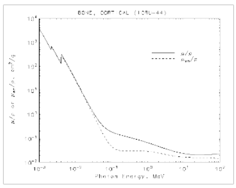


Image from ***https://physics.nist.gov/PhysRefData/XrayMassCoef/ComTab/bone.html***

- (water) from literature is provided at given energies only: Interpolation needed for missing energies

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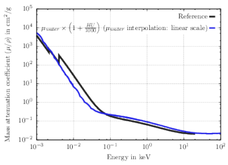
  

  Image computed with gVirtualXRay using linear interpolation

  –

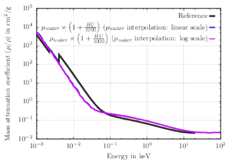
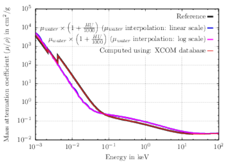
  

  Image computed with gVirtualXRay using interpolation in the log scale

Not a good match as the peaks are not visible in (water)

- 

This is now a good match

Going back to previous slide

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- **Are the values used in gVirtualXRay accurate?**
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- **Are the values used in gVirtualXRay accurate?**
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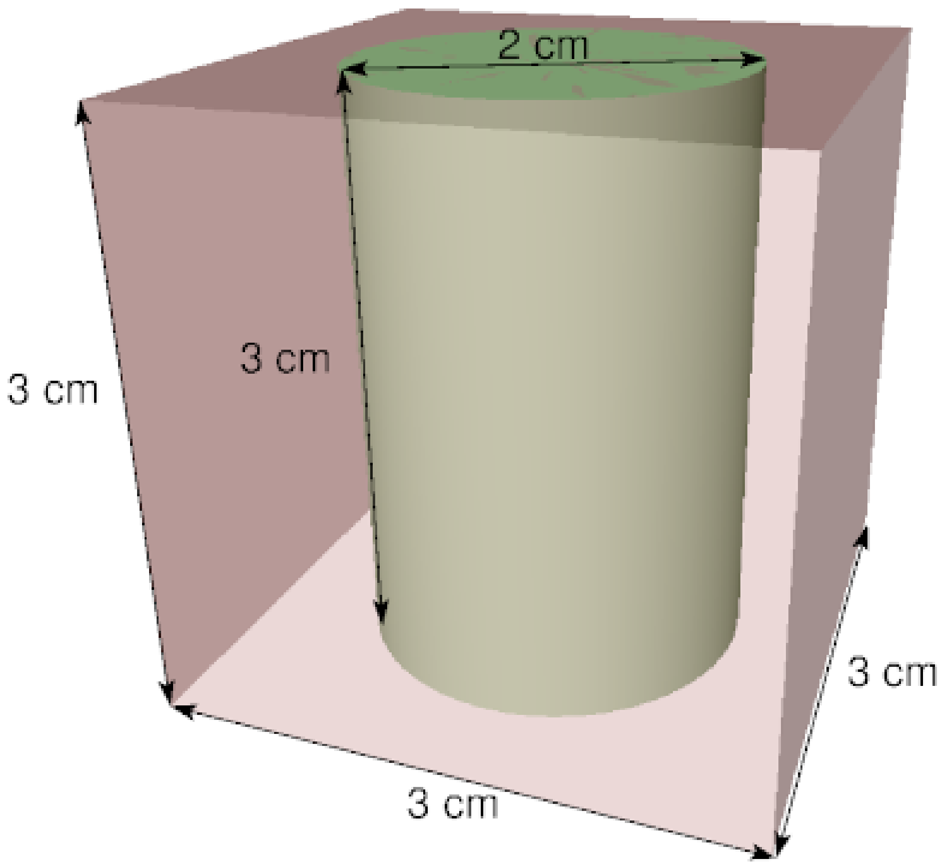
  - **YES**

More testing

- **Are the Beer-Lambert law implementations accurate?**
  - Compare values computed in gVirtualXRay with theoretical ones.
- **Are the simulated images accurate?**
  - Compare images computed using gVirtualXRay with those using a state-of-the-art Monte Carlo software, e.g.

Test case

- Simulated object



Simulated object

- Cube: edge length of 3 cm, made of soft tissue (HU = 52).
- Cylinder: height of 3 m, diameter of 2 cm, made of bone (HU = 1330).

- Incident beam:

N: number of photons	E: energy (in MeV)
10	0.1
20	0.2
10	0.3

Beer-Lambert Law: Polychromatism Case

- Use material properties from the literature;
- The energy, Iout, (in MeV) transmitted orthogonally throw the middle of cube and cylinder should be:

- Iout = Iout(0.1) + Iout(0.2) + Iout(0.3), with
- Iout(0.1) = 10 x 0.1 x e-(3.346E-01 x 2 + 1.799E-01 x 1)
- Iout(0.2) = 10 x 0.1 x e-(2.361E-01 x 2 + 1.443E-01 x 1)
- Iout(0.3) = 10 x 0.1 x e-(2.008E-01 x 2 + 1.249E-01 x 1)
- Iout = 4.359

- On GPU, the energy, Ioutgpu, is: 4.353.
  - The relative error is:
  - |Iout - Ioutgpu| / Iout = 0.1%

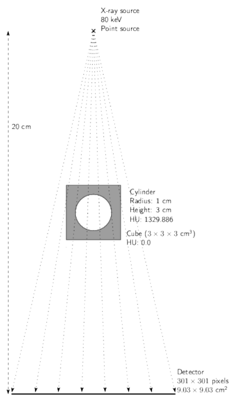
Gate vs. gVirtualXRay

We simulate a test case twice:

- Using a Monte Carlo method for particle physics implemented in GATE;
- Using our GPU implementation.

GATE is an opensource software developed by an international collaboration. Its focus is on Monte Carlo simulation in medical imaging and radiotherapy. GATE makes use of the Geant4 libraries. Geant 4 is CERN's Monte Carlo simulation platform dedicated to particle physics in nuclear research. CERN is the European Organization for Nuclear Research.

Gate vs. gVirtualXRay: Point Source



Simulation parameters

Normalised cross-correlation (NCC) = 99.747%

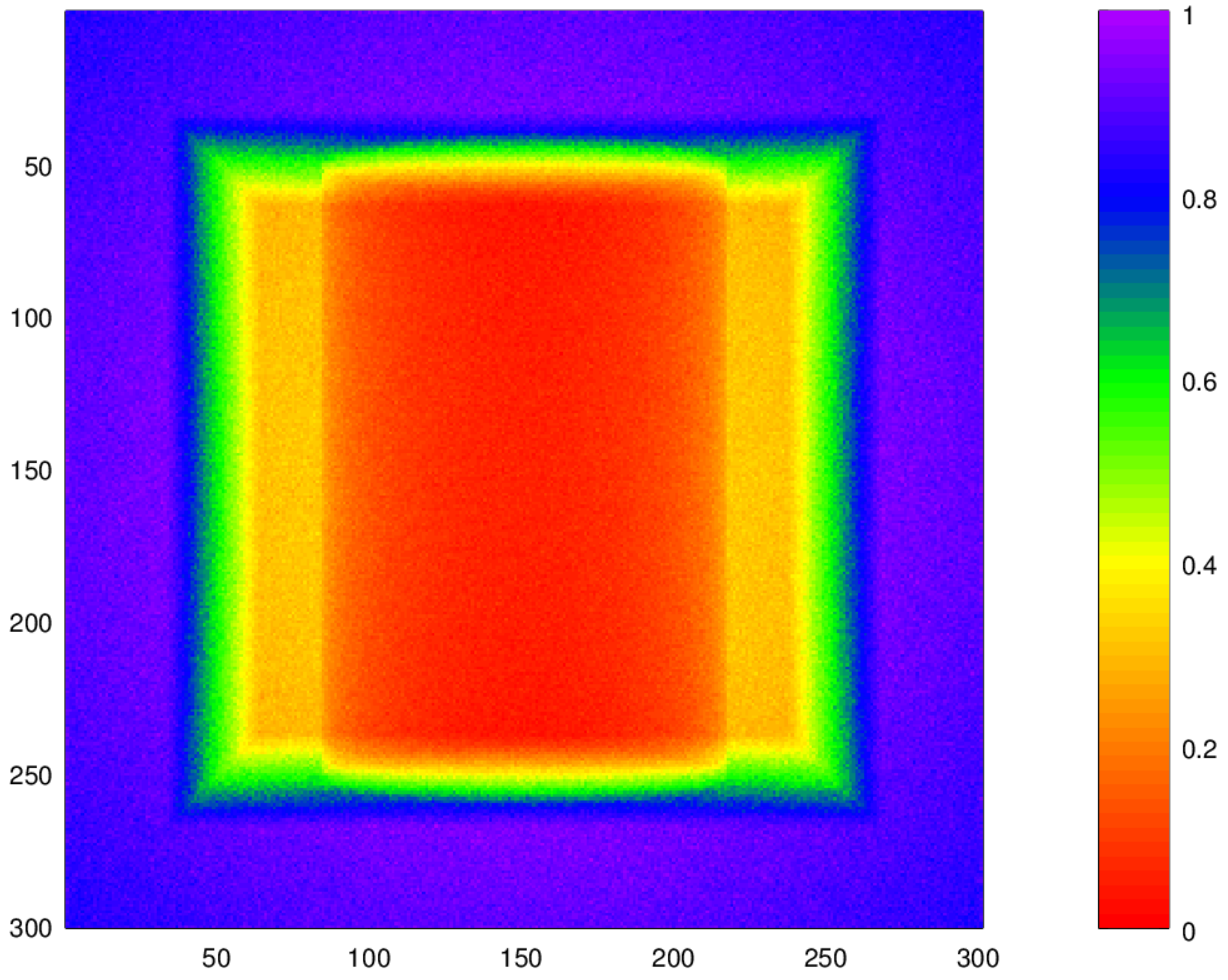


Image computed with GATE (2 weeks of computations on supercomputer)

Gate vs. gVirtualXRay: Uncentered Source

The source is translated by a vector: -5.0 0.5 0.5 cm

Normalised cross-correlation (NCC) = 99.656%

Gate vs. gVirtualXRay: Cube Source

The source is a 1x1x1 cm cube.

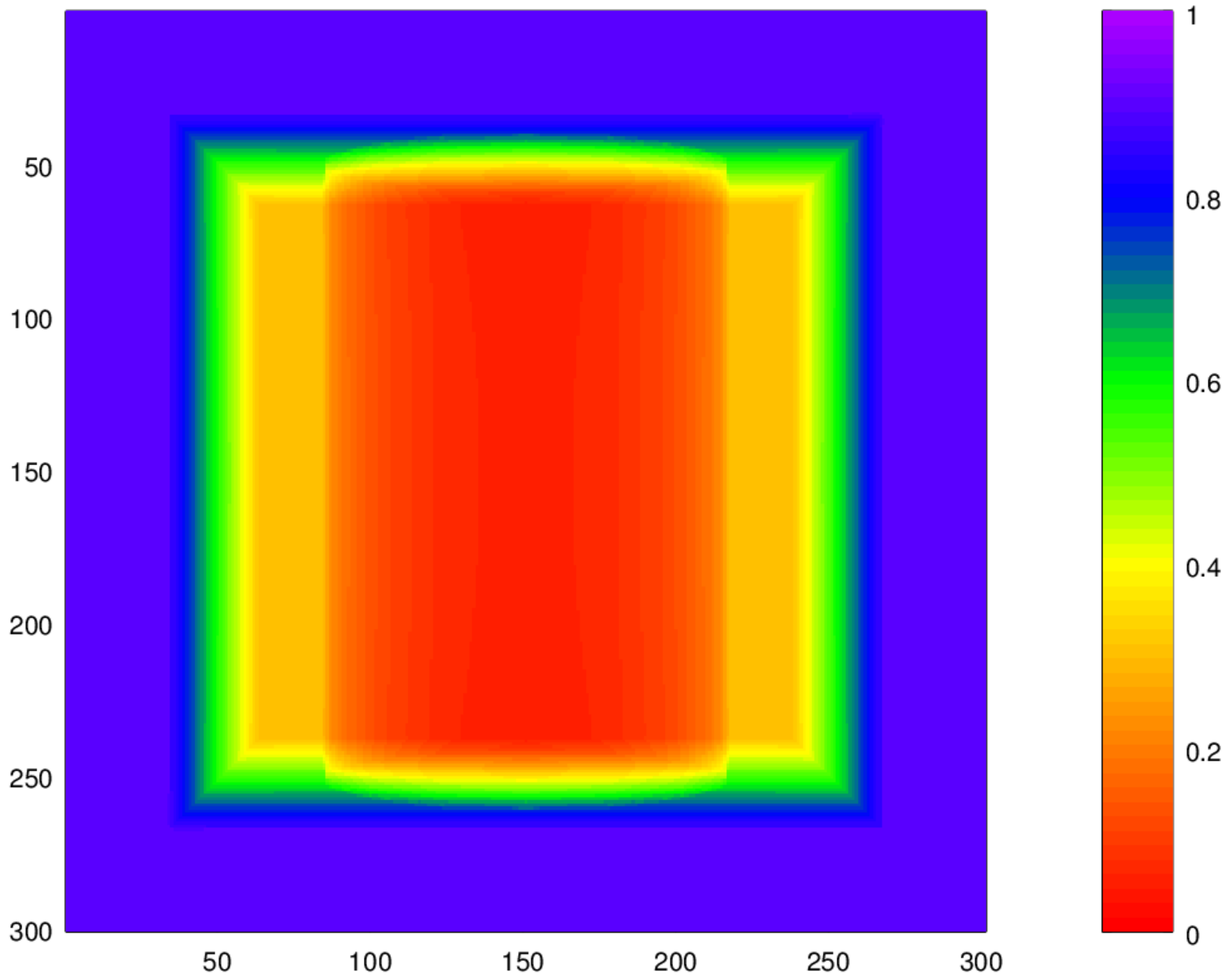
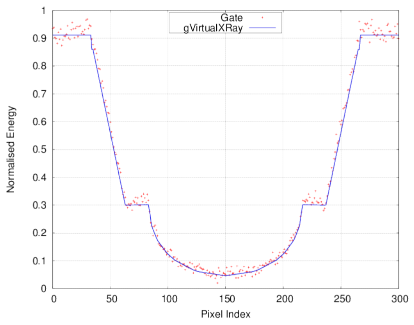


Image computed with gVirtualXRay (less than 1 sec. of computations on GPU)

Normalised cross-correlation (NCC) = 99.743%

Unit tests

- More validation test available, see `http://gvirtualxray.sourceforge.net/validation/validation_tests.php`
- To check that your system provides the results you expect,
- Run the unit tests



Profiles

– See next topic

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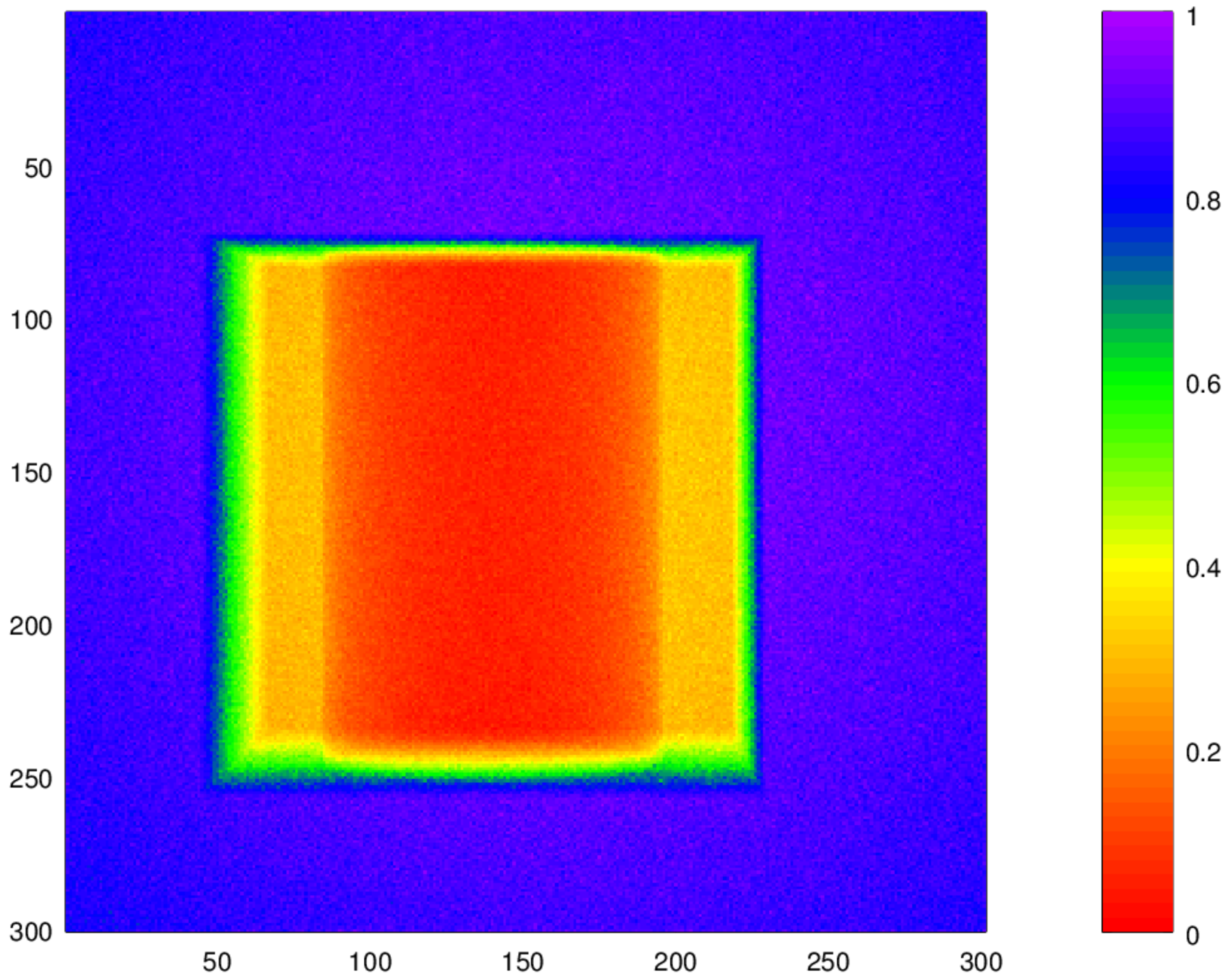
Click here



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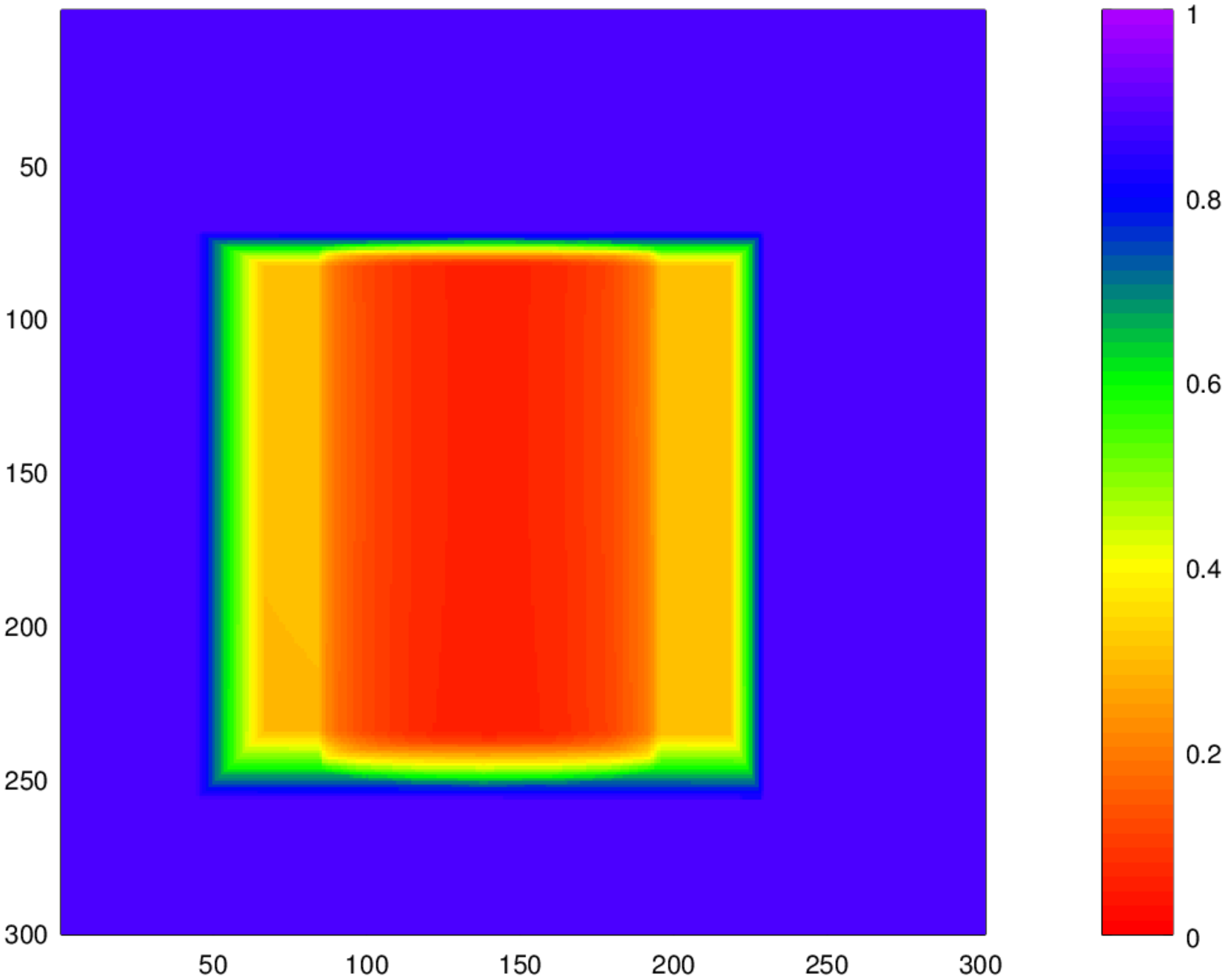
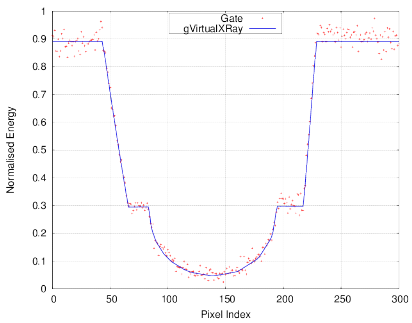
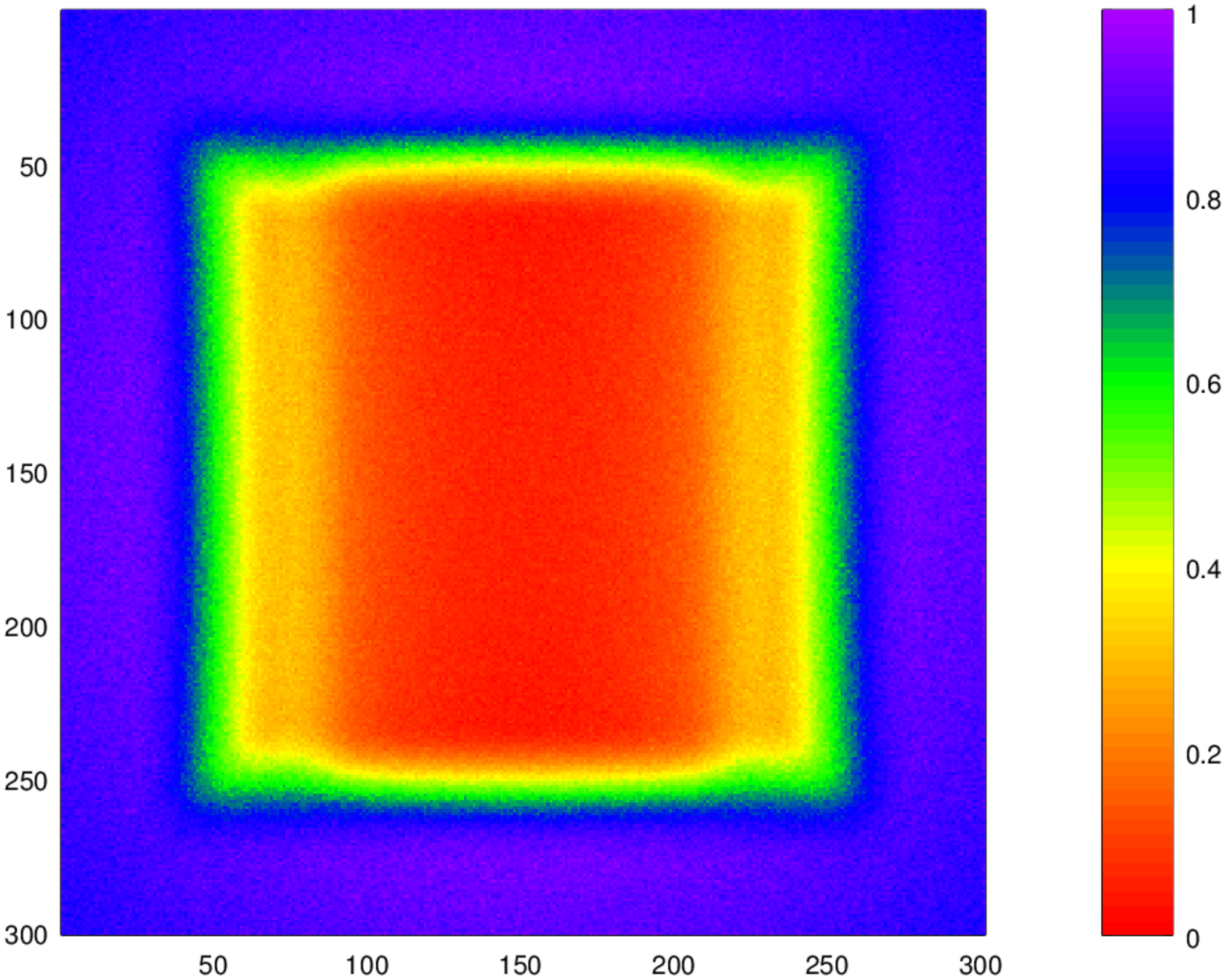


Image computed with gVirtualXRay (less than 1 sec. of computations on GPU)


Gate
gVirtualXRay
Normalised Energy
Pixel Index
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300

Profiles



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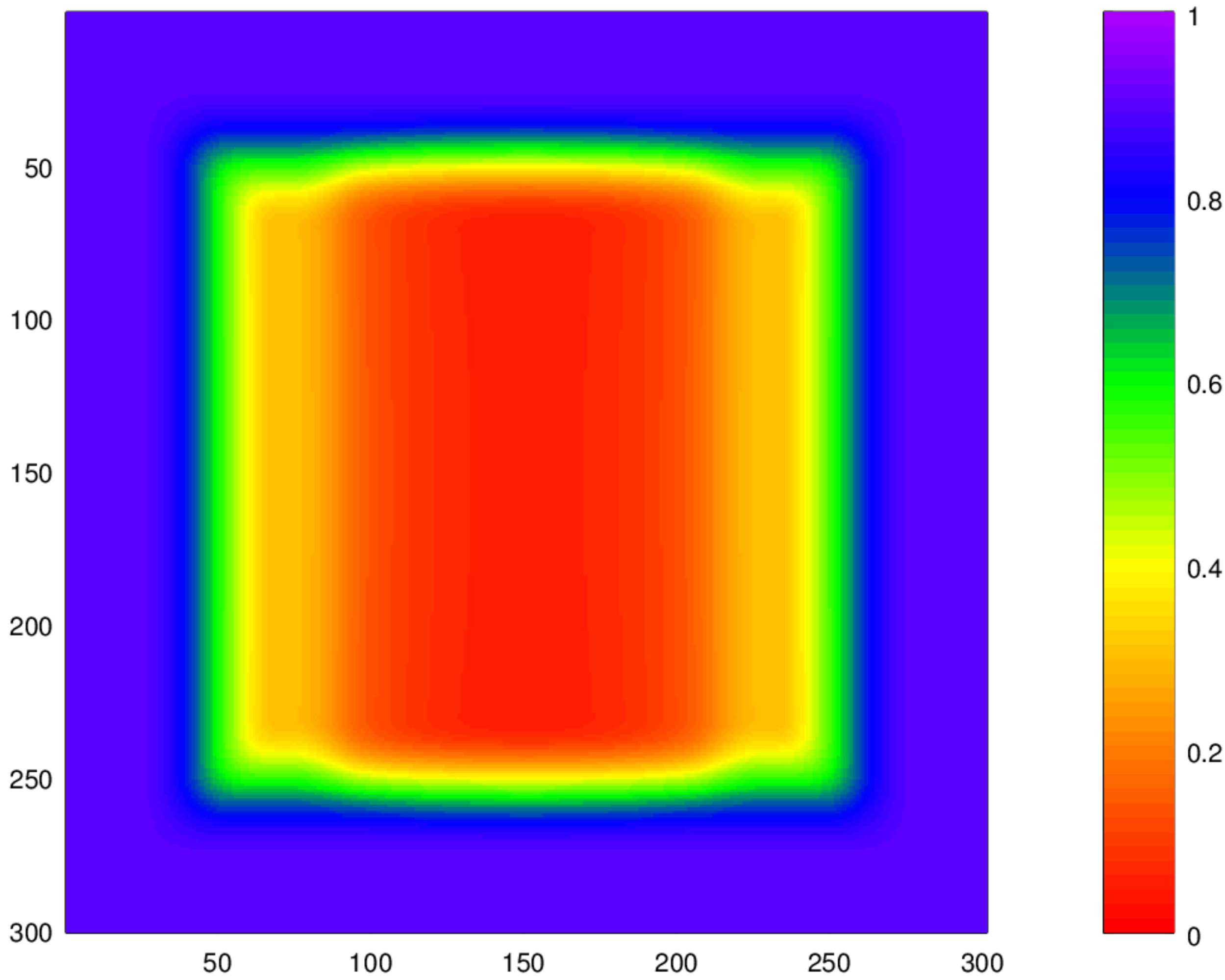
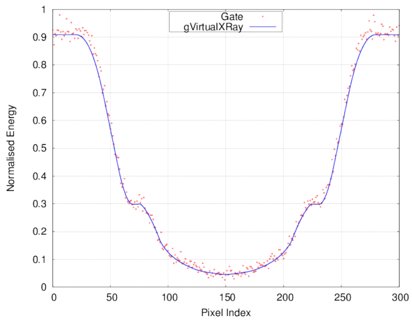


Image computed with gVirtualXRay (less than 1 sec. of computations on GPU)


Gate
gVirtualXRay
Normalised Energy
Pixel Index
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300

Profiles