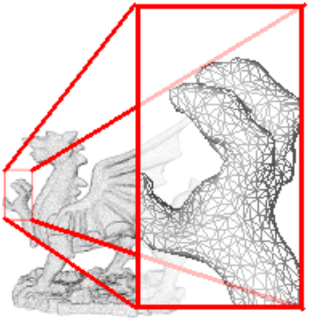
What is gVirtualXray (gVXR)?

Alberto Corbi, Franck Vidal, Francisco Albiol, Alberto Albiol

- API (application programming interface)
- relying on the **Beer–Lambert law**
- to simulate X-ray images in realtime on a GPU (graphics processor unit)
- using triangular meshes.
- Re-implementation as opensource since 2013.



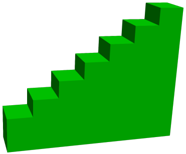
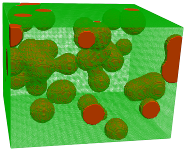
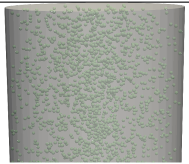
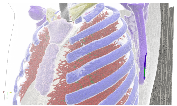
Implementation

- R&D started in the early 2000s, VXI by Nicolas Freud[1] (INSA-Lyon), and
- Its port on GPU when they became programmable (Bangor University, 2007);
- Not a ray tracer, but a rasterizer!
- Implemented in C++ using OpenGL
- Wrapper for python, R, Ruby, Tcl, C#, Java, and GNU Octave

[1] Freud et al., "Fast and robust ray casting algorithms for virtual X-ray imaging".

What can we scan?

- Surface mesh from files (all common formats are supported, inc. STL)
- Multi-part models using multiple different materials
- Volume meshes (INP files from Abaqus, EXPERIMENTAL)
- Implicit modeling (organic-looking n-dimensional isosurfaces)
- Customisable built-in phantoms

Welsh dragon	Step wedge	Foam	Geometric shapes	Lungman
				

Main simulation parameters

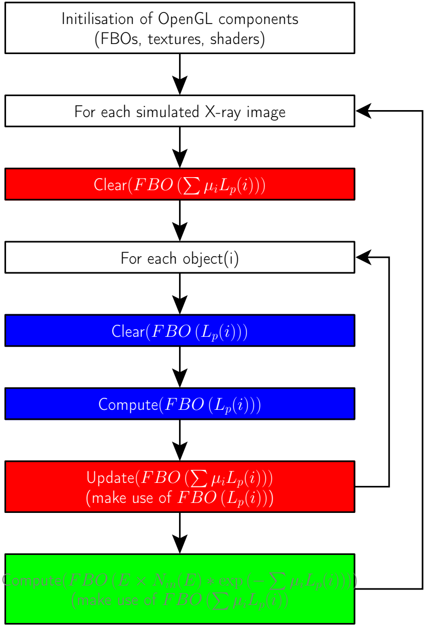
- Parallel beams, point sources, focal spots
- Mono/Poly chromatic spectra
  - including kV and beam filtration
- Photon noise (calibrated on Geant4/Gate)
- Impulse response of detectors
- Scintillation
- Flexible material composition
- Interactive 3D visualization

Text in red marks components validated against Monte Carlo simulations

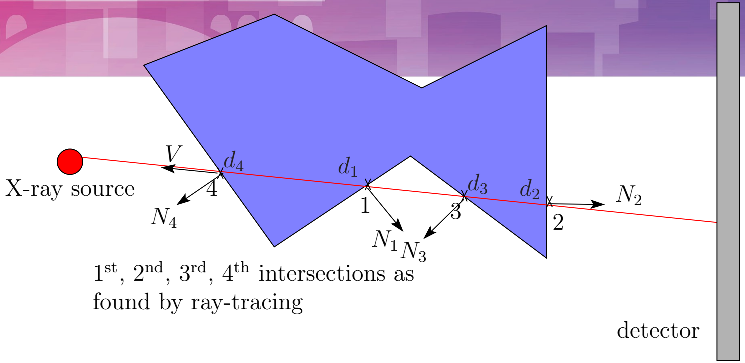
Multipass Rendering Pipeline

$$pixel = E \times N_{out}$$
$$= E \times N_{in}(E) \exp\left(-\sum_i^I \mu_i L_p(i)\right)$$

- Needs 3 FBOs with high-dynamic range capability for off-line rendering:
- For each object of the scene:
  1. Compute $L_p(i)$;
  2. Update results of $\sum \mu_i L_p(i)$.
- For the final image only:
  1. Compute N_{out};
  2. (Optional when only direct display is needed).



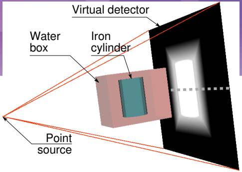
Path Length: L-Buffer



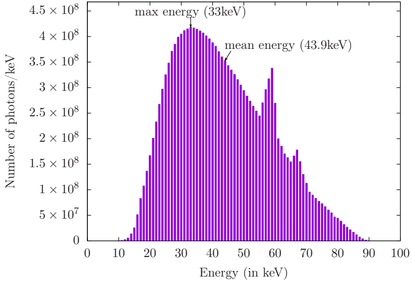
- Intersection sorting is not needed!
- By convention normals are outward;
- A ray penetrates into an object when the dot product between the view vector (V) and the normal vector (N_i) at the intersection point is positive;
- It leaves an object when the dot product is negative.

Adding the Beam Spectrum

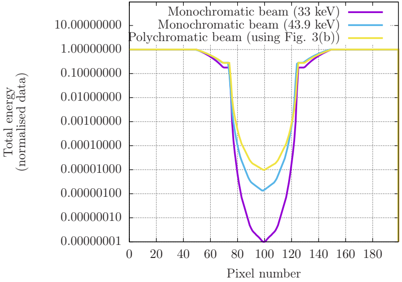
$$pixel = \sum_j E_j \times N_{in}(E_j) \exp\left(-\sum_i \mu_i(E_j, \rho, Z) d_i\right)$$



Set up.



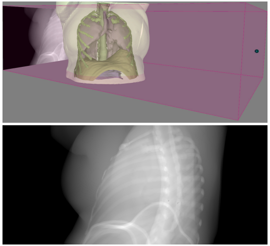
Polychromatic beam spectrum for 90kV X-ray tube peak voltage.



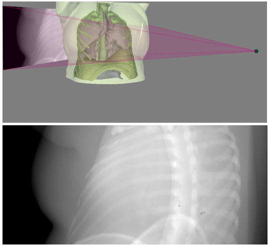
Intensity profiles.

Simulation with Different Source Shapes[3]

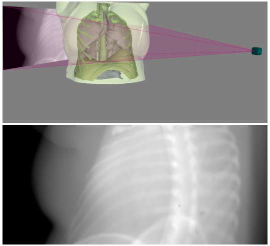
$$pixel = \sum_{k} \sum_{j} E_j \times N_{in}(E_j) \exp \left(- \sum_{i} \mu_i(E_j, \rho, Z) d_i(k) \right)$$



(a) Parallel beam.



(b) Infinitely small point source.



(c) 1^3mm source.

[3] Franck P. Vidal and Villard, "Development and validation of real-time simulation of X-ray imaging with respiratory motion".

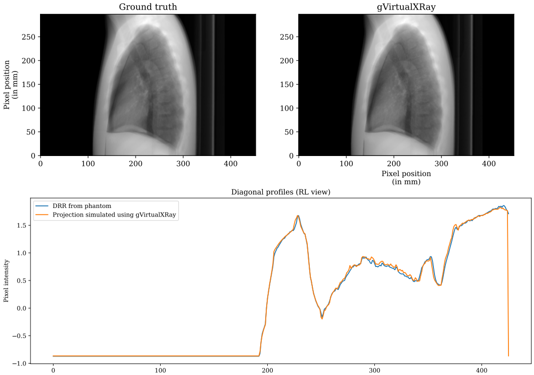
Final model

$$pixel(x,y) = \sum_u \sum_v PSF(u,v) \times \sum_k \sum_j \mathbf{R}(E_j) \times$$
$$\text{Poisson}\left(N_{in}(E_j)\ \exp\left(-\sum_i \mu_i(E_j,\rho,Z)\ d_i(k, x-u, y-v) \right) \right)$$

- PSF is the impulse response of the detector, a low-pass filter;
- $\mathbf{R}(E_j)$ is the energy response of the detector, a lookup table to mimic scintillators.

Is gVXR validated?[4]

- Against state-of-the art Monte Carlo simulation, namely Geant4/Gate
- Against DRRs computed from experimental data acquired with a clinically utilized device



MAPE: 1.76%, ZNCC: 99.66%, SSIM: 0.98

[4] Pointon et al., "Simulation of X-ray projections on GPU: Benchmarking gVirtualXray with clinically realistic phantoms".

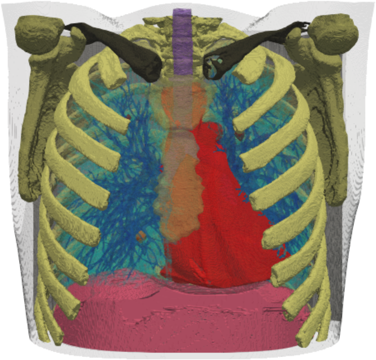
- Choose an anthropomorphic phantom;
- Scan it with a clinically utilised device;

128-slice Somatom Definition Edge (Siemens Healthcare, Erlangen, Germany)

[a] Franck Patrick Vidal and Tugwell-Allsup, *CT scans, 3D segmentations, digital radiograph and 3D surfaces of the Lungman phantom*.

Digital twining

- Choose an anthropomorphic phantom;
- Scan it with a clinically utilised device;
- Segment and mesh the CT volume[a];

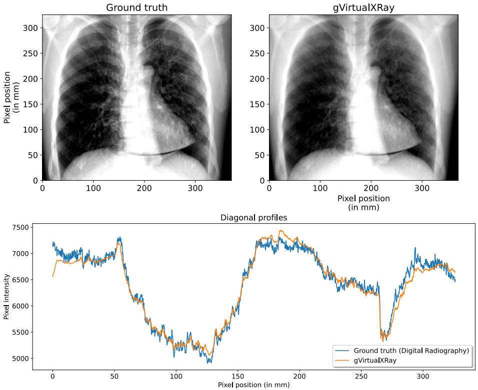


[a] Franck Patrick Vidal and Tugwell-Allsup, *CT scans, 3D segmentations, digital radiograph and 3D surfaces of the Lungman phantom*.

Digital twining

- Choose an anthropomorphic phantom;
- Scan it with a clinically utilised device;
- Segment and mesh the CT volume[a];
- Take radiographs with a clinically utilised device;
- Calibrate the simulation.

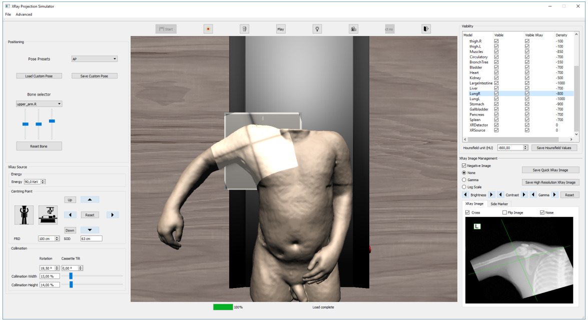
[a]Franck Patrick Vidal and Tugwell-Allsup, *CT scans, 3D segmentations, digital radiograph and 3D surfaces of the Lungman phantom*.



MAPE: 1.56%, ZNCC: 98.91%, SSIM: 0.94

Education

1. Virtual reality (VR) using
2. Desktop applications

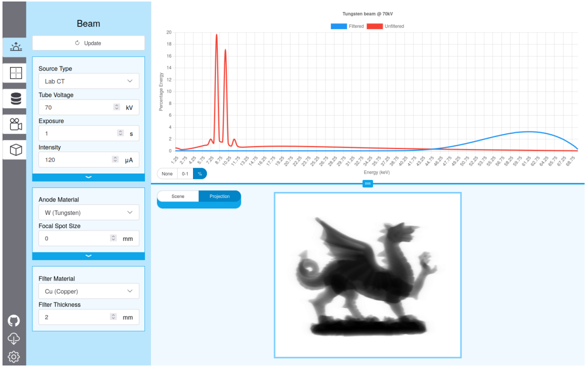


Radiography teaching by Sújar et al.

Education

1. Virtual reality (VR) using
2. Desktop applications
3. Modern Web-based GUI

https://webct.io/



by Mitchell et al.

Education

1. Virtual reality (VR) using
2. Desktop applications
3. Modern Web-based GUI
4. Containerisation & Programming
   - Distance learning of medical imaging
   - Cohort of $\sim$ 100 students per year
   - for 6 years

docker

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X-ray imaging virtual online laboratory for engineering undergraduates

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Abstract
Distance learning engineering students (as well as those in face-to-face settings) should acquire a basic background in radiation–matter interaction