Duke ELECTRICAL & COMPUTER ENGINEERING

Rapid X-ray Imaging Simulation with OptiX

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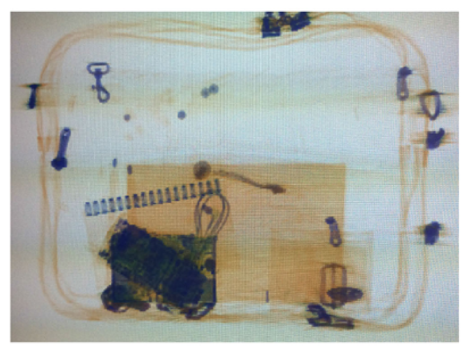
Motivation

- X-ray imaging systems are ubiquitous, non-invasive inspection tools used in transportation security.
- We are currently investigating information-theoretic methods for analyzing X-ray threat detectability and system performance.
- In order to provide sufficient statistical data for this exploration of X-ray detectability, millions of X-ray images of benign and threat-containing bags must be analyzed. This would be extremely time-consuming to acquire via actual X-ray machines.
- A rapid simulation tool is therefore required to generate high-quality, simulated X-ray images from plausible bag descriptions.

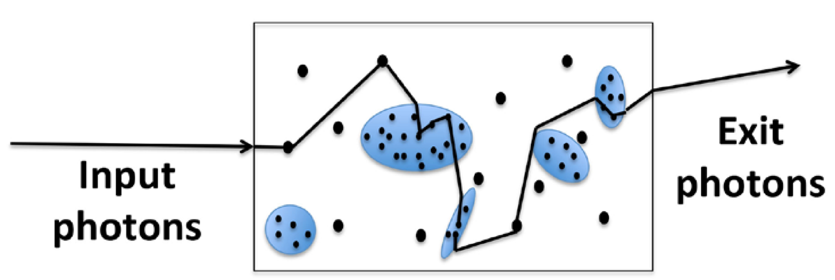
X-ray baggage scanner



Example of bag radiography

Challenges in Rapid X-ray Imaging Simulation

- Most existing X-ray imaging simulation tools exploit Monte Carlo methods:



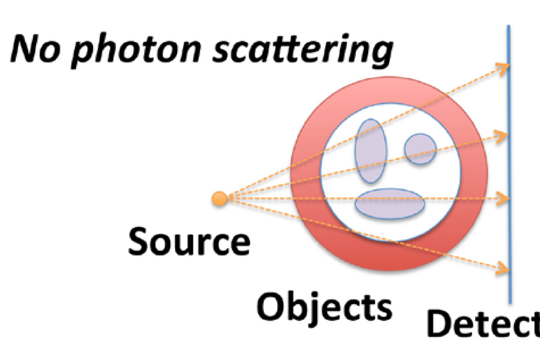
✔ The most accurate simulation of underlying physics
✗ High computational cost

- This approach is not sufficiently rapid for our purposes.

X-ray Imaging Simulation Strategy

- To achieve the required speed, we needed to leverage the decades of advancement in computer graphics and ray-tracing.

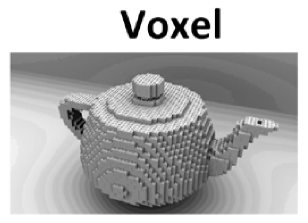
Rapid X-ray Imaging — deterministic approach



- Model photon absorption
  - Ray tracing
  - BEER's Attenuation law

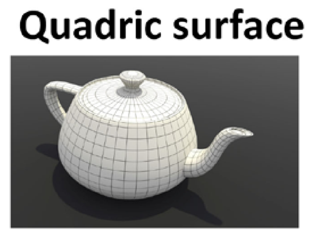
Main descriptor for 3D model

Voxel



✔ Natively volumetric
✗ Resource intensive

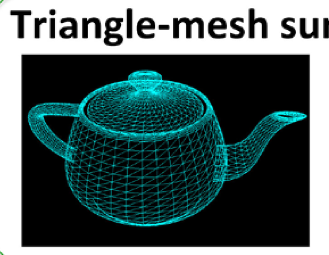
Quadric surface



✔ Simpler ray tracing algorithm
✗ Complicated when describing details; not volumetric

Model used

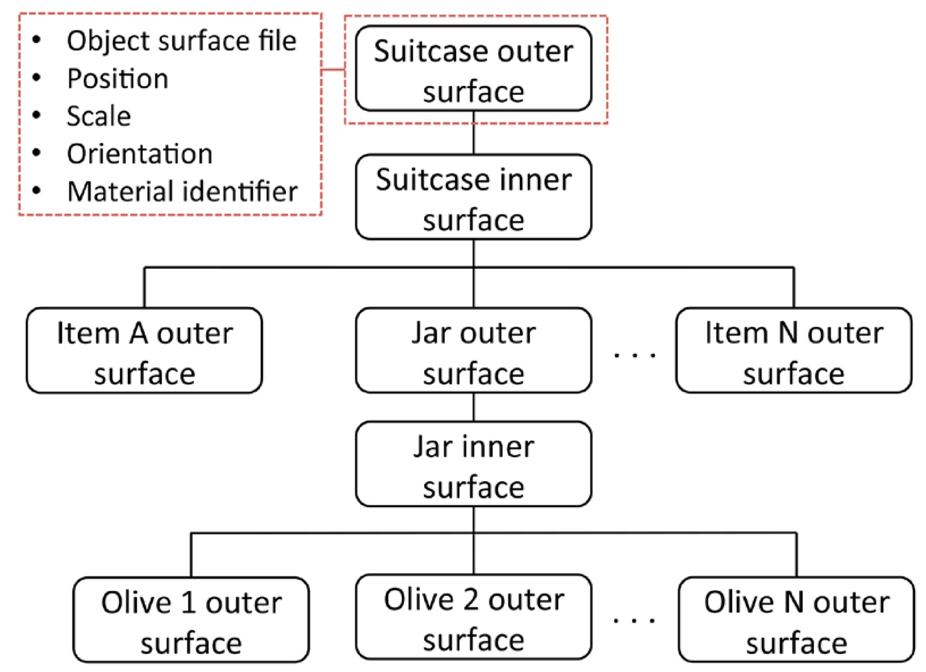
Triangle-mesh surface



✔ Low resource requirements
✗ Not inherently volumetric

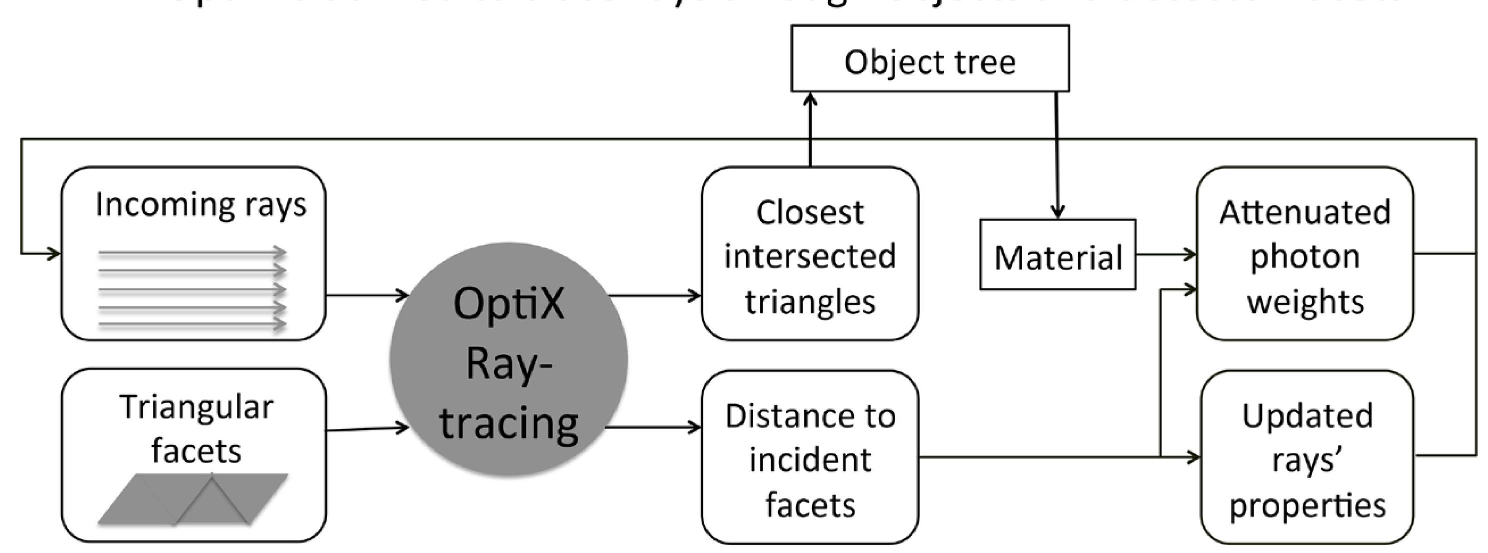
Volumetric Representation using Surfaces

- X-ray simulation requires volumetric information, but triangle-meshes describe surfaces.
- Surfaces can represent boundaries between homogeneous materials, yielding volumetric information.
- Storing surface metadata as a tree allows us to track the current material interaction.
- Tree structures potentially speed up ray-tracing by limiting the number of triangles that incoming rays may intersect.

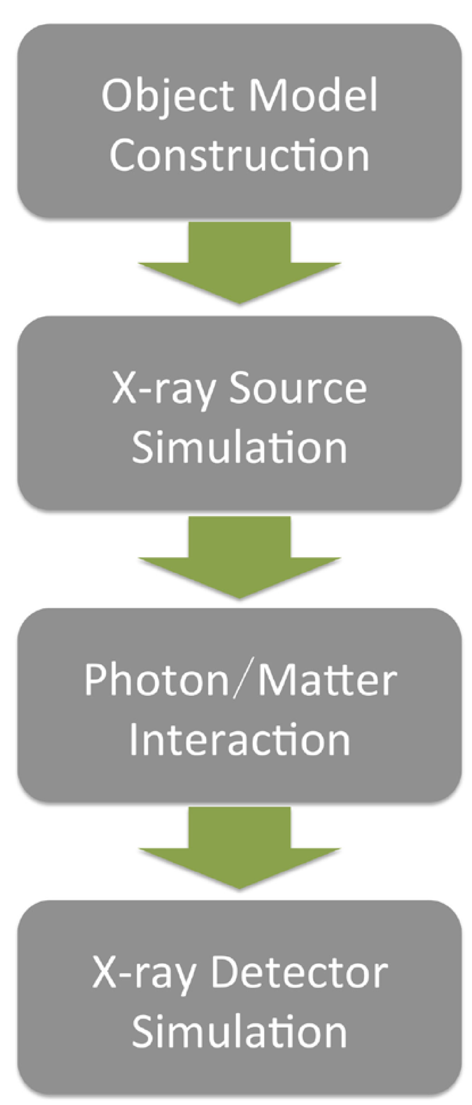


Ray-Tracing with OptiX

- Each ray is treated independently, making it a natural fit for GPU implementation.
- NVIDIA OptiX is utilized to trace rays through objects and detector facets.

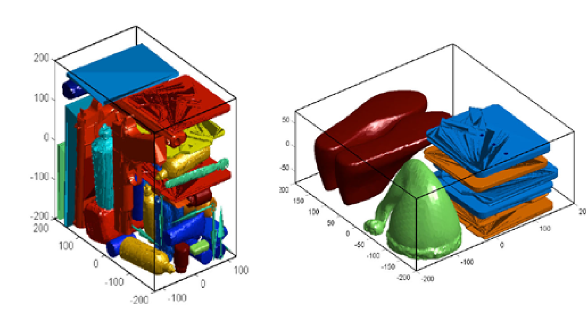


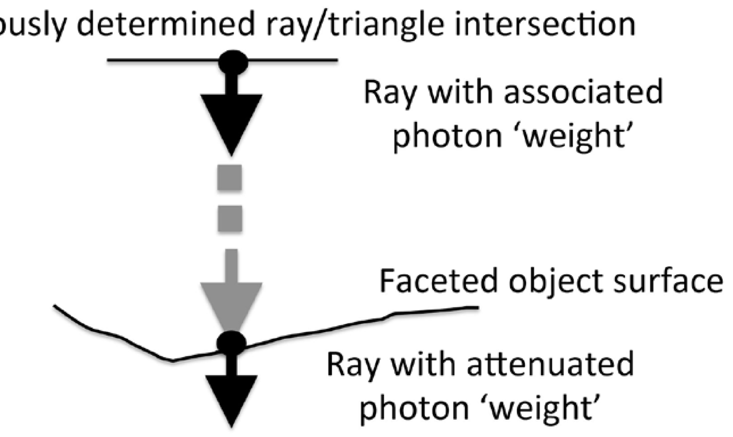
X-ray Imaging Pipeline

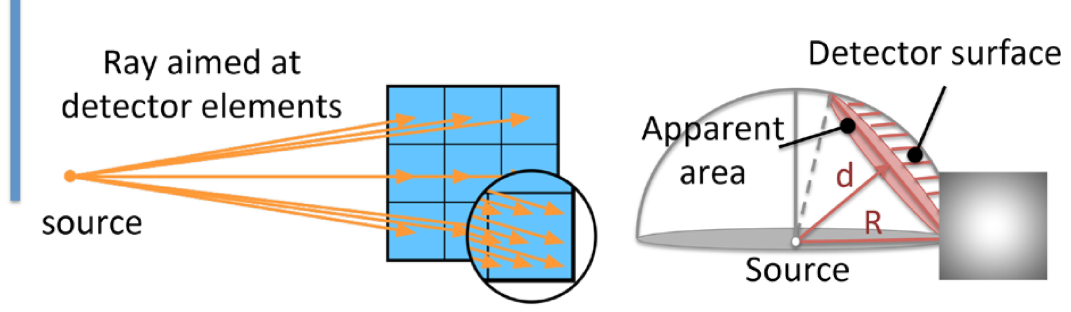


Object models

Random bag generator







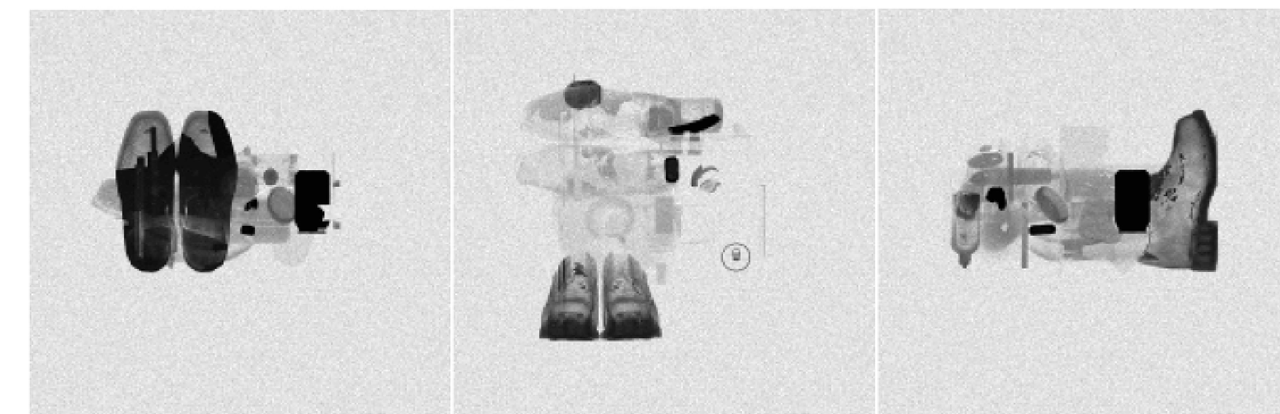
Detector over sampling possible

Photon weights of ray scaled by solid angle of detector area

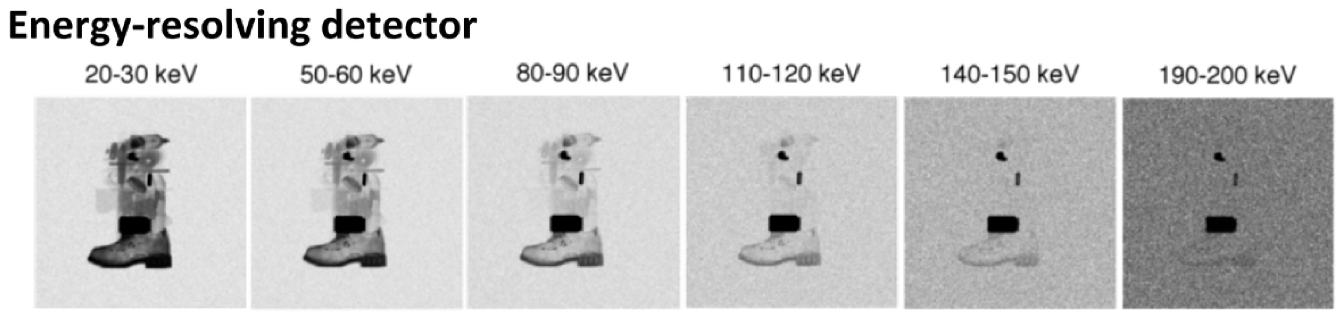
Results

Simulated projections:
(Total of 45 objects consisting of 300k triangular facets)

Counter detector — 3 orthogonal views



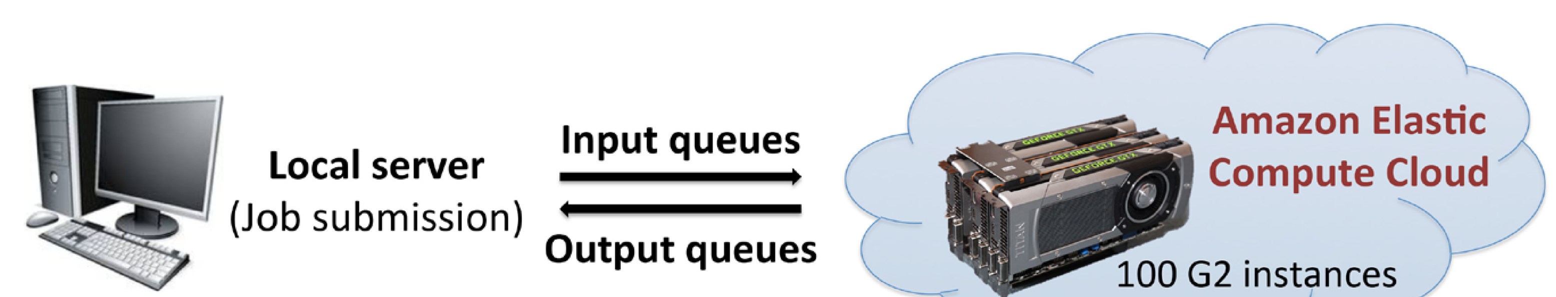
Energy-resolving detector



Timing and cost:

- A single machine with a GTX 770 card can simulate images from more than 5000 bags in an hour.
- Implementation time is linear in number of rays, facets and GPU instances.
- Further computational improvement has been observed with cloud-based computing platforms.

# of Detector Elements	Approx. Time for 1M bags	Approx. Cost for 1M bags
200 (counting)	2 hours	$ 130
200 (energy)	2 hours	$ 130
200 × 200 (counting)	7 hours	$ 455
200 × 200 (energy)	16 hours	$ 975



G2: Xeon E5-2670 Processors & GRID K520 GPU w/ 1536 CUDA cores and 4GB video memory

Conclusions

- Introduced a rapid GPU-based pipeline for simulation of X-ray transmission imaging.
- High-performance OptiX API used for ray-tracing computations.
- High-fidelity X-ray photo-absorption measurements can be simulated over a broad energy domain (20-200 keV).
- By using a cloud-based GPU computing platform, 1 million realistic bag projections can be delivered in approximately 2 hours with 100 GPUs.

Acknowledgements

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