Modeling and Simulation schemes in Radiography/ CT

Koushik Viswanathan
Dr. Krishnan Balasubramanian

Center for Non-Destructive Evaluation
Indian Institute of Technology, Madras

January 12, 2010

Outline

Were going to look at two schemes pertaining to X-ray radiography and CT

Outline

Were going to look at two schemes pertaining to X-ray radiography and CT

- Data reconstruction involving Computed Tomography, mainly dealing with reconstruction of 2D cross-sections from X-ray projections

Outline

Were going to look at two schemes pertaining to X-ray radiography and CT

- Data reconstruction involving Computed Tomography, mainly dealing with reconstruction of 2D cross-sections from X-ray projections
- Forward simulation to simulate radiography/ tomographic imaging on CAD models

Outline

Were going to look at two schemes pertaining to X-ray radiography and CT

- Data reconstruction involving Computed Tomography, mainly dealing with reconstruction of 2D cross-sections from X-ray projections
- Forward simulation to simulate radiography/ tomographic imaging on CAD models
- All of this is done **ENTIRELY** on commodity graphics hardware!

Simulations on GPUs

- Graphics Processing Units are capable of large-scale parallel processing

Simulations on GPUs

- Graphics Processing Units are capable of large-scale parallel processing
  - Low-end GPUs contain around 32 shader cores

Simulations on GPUs

- Graphics Processing Units are capable of large-scale parallel processing
  - Low-end GPUs contain around 32 shader cores
  - Available high end cards feature upto 480 cores

Simulations on GPUs

- Graphics Processing Units are capable of large-scale parallel processing
  - Low-end GPUs contain around 32 shader cores
  - Available high end cards feature upto 480 cores
  - Intel's next-gen processor will have 16 cores

Simulations on GPUs

- Graphics Processing Units are capable of large-scale parallel processing
  - Low-end GPUs contain around 32 shader cores
  - Available high end cards feature upto 480 cores
  - Intel's next-gen processor will have 16 cores
- Two approaches to parallelization, namely multi-core processing (reconstruction) and traditional GPGPU techniques (forward simulation)

Simulations on GPUs

- Graphics Processing Units are capable of large-scale parallel processing
  - Low-end GPUs contain around 32 shader cores
  - Available high end cards feature upto 480 cores
  - Intel's next-gen processor will have 16 cores
- Two approaches to parallelization, namely multi-core processing (reconstruction) and traditional GPGPU techniques (forward simulation)
- Drawbacks with GPUs

Simulations on GPUs

- Graphics Processing Units are capable of large-scale parallel processing
  - Low-end GPUs contain around 32 shader cores
  - Available high end cards feature upto 480 cores
  - Intel's next-gen processor will have 16 cores
- Two approaches to parallelization, namely multi-core processing (reconstruction) and traditional GPGPU techniques (forward simulation)
- Drawbacks with GPUs
  - No double precision support (though that is changing)

Simulations on GPUs

- Graphics Processing Units are capable of large-scale parallel processing
  - Low-end GPUs contain around 32 shader cores
  - Available high end cards feature upto 480 cores
  - Intel's next-gen processor will have 16 cores
- Two approaches to parallelization, namely multi-core processing (reconstruction) and traditional GPGPU techniques (forward simulation)
- Drawbacks with GPUs
  - No double precision support (though that is changing)
  - Low clock speeds (unlikely to change soon)

Image reconstruction schemes

Image-reconstruction

- Most commonly used techniques include Filtered Backprojection and Algebraic Reconstruction algorithms

Image-reconstruction

- Most commonly used techniques include Filtered Backprojection and Algebraic Reconstruction algorithms
- Typical implementations on a standard PC require approx. 20 seconds for around 0.5 degree projections

Image-reconstruction

- Most commonly used techniques include Filtered Backprojection and Algebraic Reconstruction algorithms
- Typical implementations on a standard PC require approx. 20 seconds for around 0.5 degree projections
- Reconstruction done layer-by-layer, full 3D Feldkamp reconstruction takes much longer due to larger datasets

Our implementation

Our Reconstruction algorithms are implemented using a large-scale multi-threading scheme with *NVidia*'s *CUDA* API

Our implementation

Our Reconstruction algorithms are implemented using a large-scale multi-threading scheme with *NVidia*'s *CUDA* API

- 2D FFT is done initially on the CPU due to problems with double precision handling

Our implementation

Our Reconstruction algorithms are implemented using a large-scale multi-threading scheme with *NVidia*'s *CUDA* API

- 2D FFT is done initially on the CPU due to problems with double precision handling
- After pre-filtering on the CPU, the image is transferred onto the GPU for backprojection

Our implementation

Our Reconstruction algorithms are implemented using a large-scale multi-threading scheme with *NVidia*'s *CUDA* API

- 2D FFT is done initially on the CPU due to problems with double precision handling
- After pre-filtering on the CPU, the image is transferred onto the GPU for backprojection
- For a large number of projections, Backprojection is computationally the most intensive step

Our implementation

Our Reconstruction algorithms are implemented using a large-scale multi-threading scheme with *NVidia*'s *CUDA* API

- 2D FFT is done initially on the CPU due to problems with double precision handling
- After pre-filtering on the CPU, the image is transferred onto the GPU for backprojection
- For a large number of projections, Backprojection is computationally the most intensive step
- Done massively in parallel, spawn one thread per projection

Our implementation

Our Reconstruction algorithms are implemented using a large-scale multi-threading scheme with *NVidia*'s *CUDA* API

- 2D FFT is done initially on the CPU due to problems with double precision handling
- After pre-filtering on the CPU, the image is transferred onto the GPU for backprojection
- For a large number of projections, Backprojection is computationally the most intensive step
- Done massively in parallel, spawn one thread per projection
- This technique scales very well with modern GPUs

Quick comparisons

No of projections	CPU implementation (sec)	GPU implementation (sec)
100	3.623	0.132
200	7.609	0.197
300	11.630	0.263
400	15.567	0.323
500	19.388	0.381

Forward simulation schemes

Fundamental algorithm

- Use Ray tracing, more commonly termed ray-casting, since only primary rays are followed through the medium

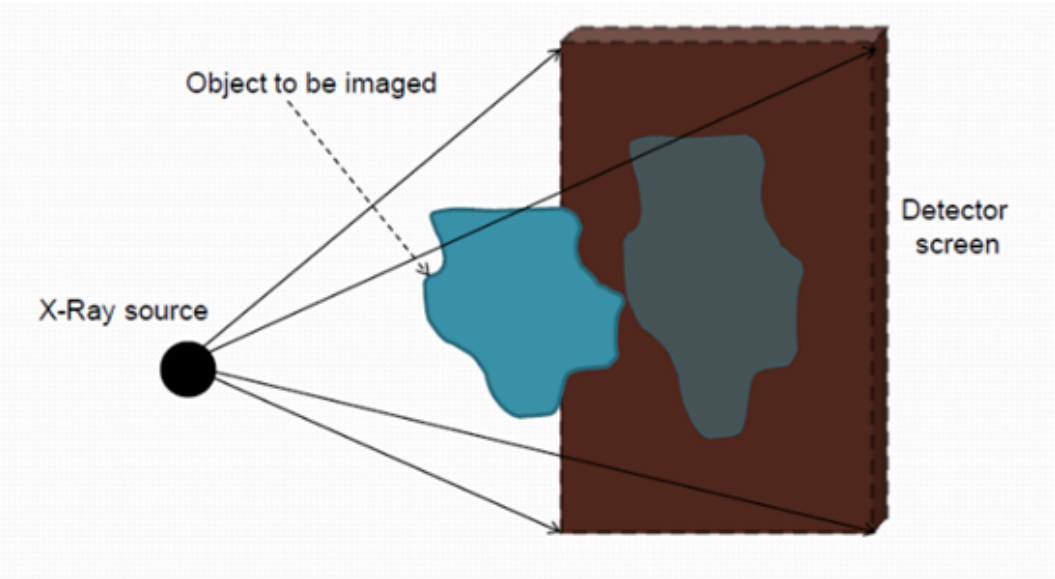
Fundamental algorithm

- Use Ray tracing, more commonly termed ray-casting, since only primary rays are followed through the medium
- Spawn one ray per detector pixel, going from the source to the deteector, through the medium

Fundamental algorithm

- Use Ray tracing, more commonly termed ray-casting, since only primary rays are followed through the medium
- Spawn one ray per detector pixel, going from the source to the deteector, through the medium
- Depending on the requirements, a triangulated mesh or a voxel mode is used

Fundamental algorithm



$$N(E) = N_0(E)\Delta\Omega\prod_i \exp[-\mu_i(E)x_i]$$

$$= N_0(E)\Delta\Omega\exp\left[\sum_i -\mu_i(E)x_i\right].$$

Possible optimizations

Ray-tracing optimization has been treated extensively, several techniques have been proposed

Possible optimizations

Ray-tracing optimization has been treated extensively, several techniques have been proposed

- Spatial sub-division techniques esp. Octrees and KD Trees

Possible optimizations

Ray-tracing optimization has been treated extensively, several techniques have been proposed

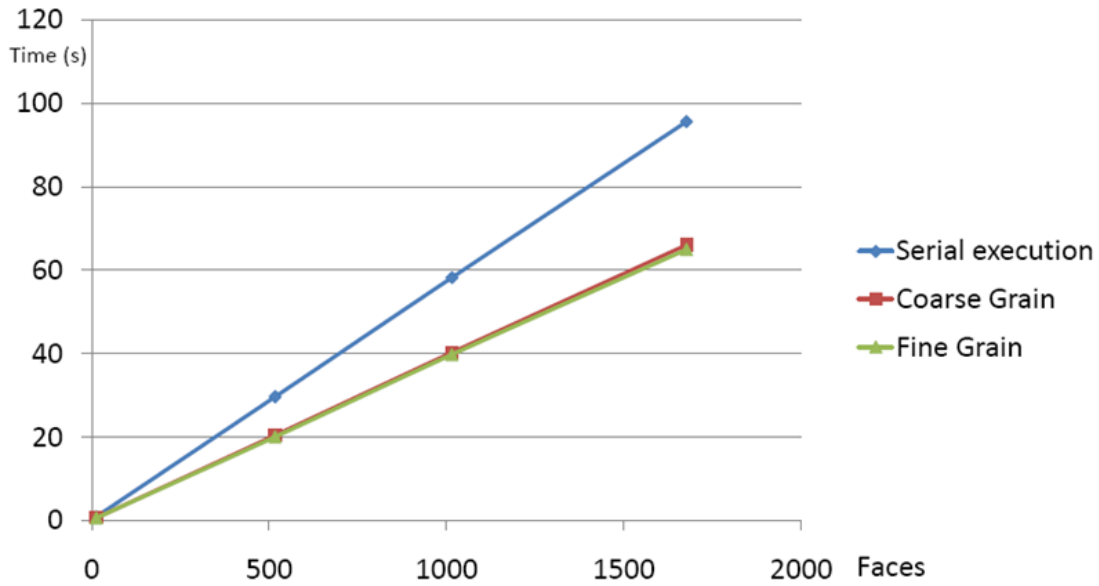
- Spatial sub-division techniques esp. Octrees and KD Trees
- Intersection tests can be reduced using Bounding Volume Hierarchies

Possible optimizations

Ray-tracing optimization has been treated extensively, several techniques have been proposed

- Spatial sub-division techniques esp. Octrees and KD Trees
- Intersection tests can be reduced using Bounding Volume Hierarchies
- Parallel processing involving parallel ray-tracing algorithms

Parallel Processing tests



Our algorithm

We went back to the drawing board and reworked the basic law evaluation

Our algorithm

We went back to the drawing board and reworked the basic law evaluation

- Developed a new algorithm to evaluate the Beer-Lambert law

Our algorithm

We went back to the drawing board and reworked the basic law evaluation

- Developed a new algorithm to evaluate the Beer-Lambert law
- Instead of following ray-tracing based techniques, we developed a rasterization based algorithm

Our algorithm

We went back to the drawing board and reworked the basic law evaluation

- Developed a new algorithm to evaluate the Beer-Lambert law
- Instead of following ray-tracing based techniques, we developed a rasterization based algorithm
- Intensity of every detector pixel computed in parallel, we make GPUs do what they were meant to do!

Very promising results

- Other groups around the world have tackled this problem, but our algorithm works faster than all of the results reported so far

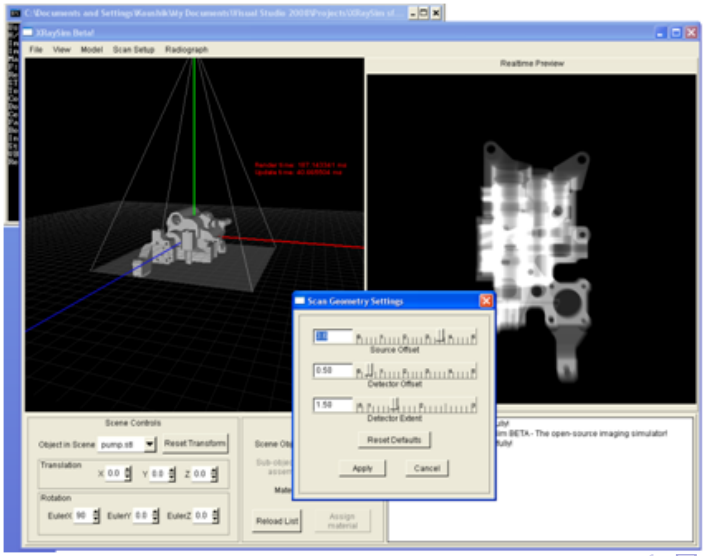
Very promising results

- Other groups around the world have tackled this problem, but our algorithm works faster than all of the results reported so far
- Works on any consumer-grade hardware, only OpenGL 2.0 support needed!

Triangle count	CPU computation (ms)	GPU computation (ms)
53582	70.07	0.41
72353	79.56	0.44
96967	87.58	0.44
154349	116.65	0.52
178690	156.71	0.58
871415	470.83	1.34

XRaySim

- Open source Radiography/ Computed Tomography simulation tool
- Developed from scratch at the Center for Non-Destructive Evaluation, IIT Madras
- Seamless integration with commercial CAD packages through standard data exchange formats



Thank you for your attention!
Questions/ enquiries are welcome