Parallel execution of Mie scattering events

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To simulate the radiation transport in different media we have implemented an algorithm based on Mie theory. The algorithm is both executable on CPUs and GPUs. Using GPUs the execution time can be reduced significantly without loss of exactness.

1 Introduction

Mie theory describes the scattering of electromagnetic waves on spheroidal particles whose diameter is smaller compared to the wavelength of the incident radiation. A variety of computer algorithms exist to calculate scattering parameters. Despite the exactness of these algorithms they lack computational speed.

Therefore the simulation of radiation transport in a medium can be a time consuming task. To our best knowledge no attempt has been made to adapt algorithms to parallel processors like programmable graphics adapters.

We implemented a parallel algorithm to calculate perpendicular ($i_\perp$) and parallel ($i_{||}$) polarization of scattered waves from which other scattering parameters can be derived. This facilitates simultaneous tracking of particular waves in scattering media. Our code can be invoked from scripting languages like Matlab. It can be invoked from high level languages like C/C++ and is executable on conventional processors as well. We tested our approach using Monte Carlo simulations. The results correspond to reference implementations.

We have shown that execution time can be reduced significantly compared to sequential approaches.

2 Methods

2.1 Exactness of simulations

Artificial angular distributions can be generated from theoretical predictions. An arbitrary number of simulated events can be computed with lower and varying statistics by the procedure described below. The method is useful to study the sense of realism of Monte Carlo simulations.
From the angular distribution $i_{||}$ (or equivalently $i_\perp$) the normalized cumulative distribution function $I_{||,j}$ is calculated:

$$I_{||,j} = \frac{\sum_{i=0}^{j} i_{||,i}}{\sum_{i=0}^{n} i_{||,i}}$$

where n is the number of scattering angles (typically 181) and $I_{||,j}$ is in the Interval [0;1]. To generate Monte Carlo events, we select N times an angle θ_i according to

$$\theta_i = I_{||}^{-1}(r)$$

where $I_{||}^{-1}$ is the inverse cumulative distribution and r is a uniformly distributed random number. Since N is the number of simulated events, varying N can control the counting statistics. In practice $I_{||}^{-1}$ cannot be calculated, so for each random number r we select angle θ_i for which the condition

$$I_{||,i} \le r \le I_{||,i+1}$$

is fulfilled.

2.2 Execution time

The execution time has been measured using an

- Intel Core i5, 2,67 GHz, 8 GB RAM and a
- NVIDIA GeForce GTX 470

with Ubuntu 12.04 LTS and Matlab 2012a.

Every setup for the benchmark has been run 50 times. The mean value of 50 runs has been used for the results. This method has been chosen to exclude statistical fluctuations.

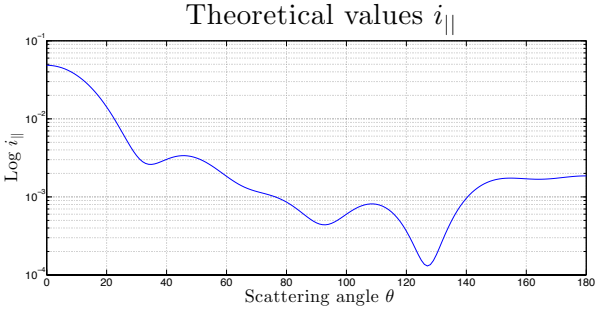

Fig. 1 *$i_{||}$ according to Mie theory.*

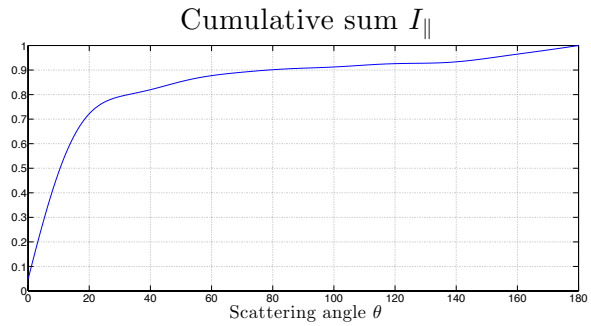

Fig. 2 *Cumulative sum of $i_{\|}$.*

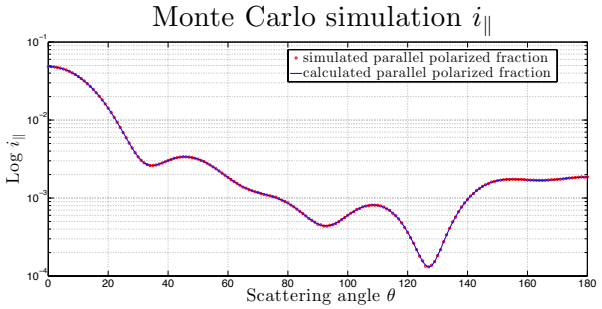

Fig. 3 *N = 50 x 10^6 Monte Carlo events computed according to the cumulative sum of $i_{\|}$.*

3 Results

3.1 Exactness

Figure 3 shows that the simulated scattering angles are distributed in accordance with the theoretical prediction. N was chosen large enough to suppress statistical fluctuations. For smaller N one expects larger fluctuations, which is typical for Monte Carlo simulations.

Table 1 shows the fraction between the theoretical and the simulated values of $i_{\|}$. Due to forward scattering statistical fluctuations are small for scattering angles up to (say) 20°.

3.2 Execution time

The results shown in figure 4 consider the computation time only. The time needed for setting up Monte Carlo simulation and generation of uniform distributed random numbers has not been considered.
Our results show speedup factors of 344 for the given setting of 100 photons being scattered 100.000 times.

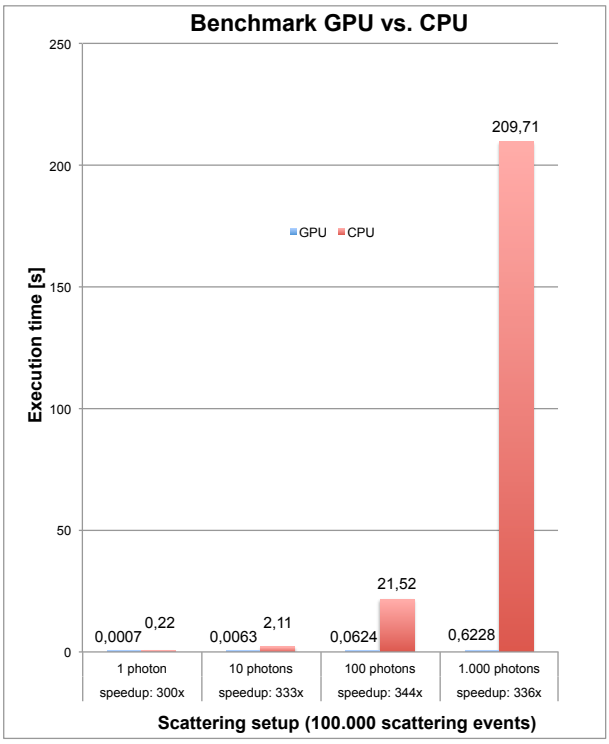

Fig. 4 *Benchmark results.*

θ	$i_{\|,theor}$	$i_{\|,sim}$	$i_{\|,theor}$ / $i_{\|,sim}$
0°	4,852E-02	4,864E-02	1,002
45°	3,373E-03	3,365E-03	0,998
90°	4,653E-04	4,473E-04	0,962
135°	4,886E-04	4,697E-04	0,962
180°	1,859E-03	1,826E-03	0,982

Tab. 1 *Quality of simulated results.*

4 Conclusion

We have shown that programmable graphics hardware can significantly decrease the computation time for Mie scattering events. No approximation was used to generate the results. As shown in Figure 3 and Table 1, we adhere to the results from Bohren and Huffman [1].

References

[1] Craig F. Bohren and Donald R. Huffman. *Absorption and Scattering of Light by Small Particles*. Wiley-VCH, April 1998. p. 477