Fast Monte Carlo Photon Transport Simulations for Heterogeneous Computing Systems

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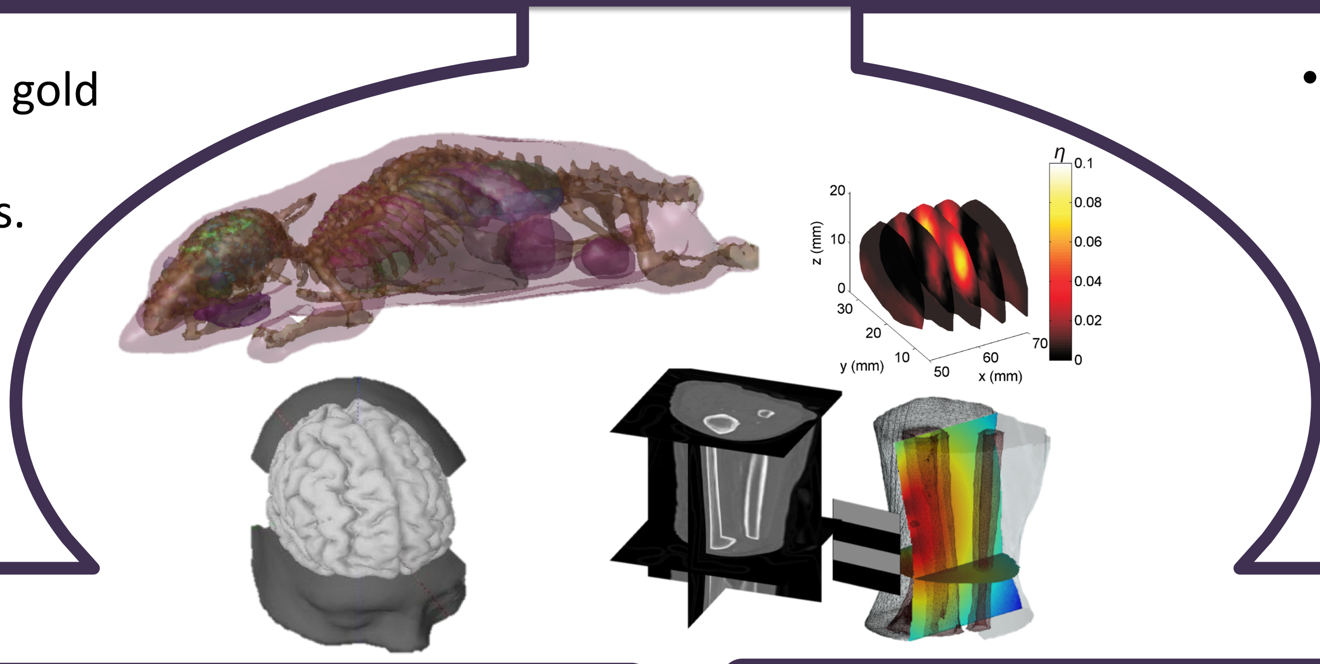
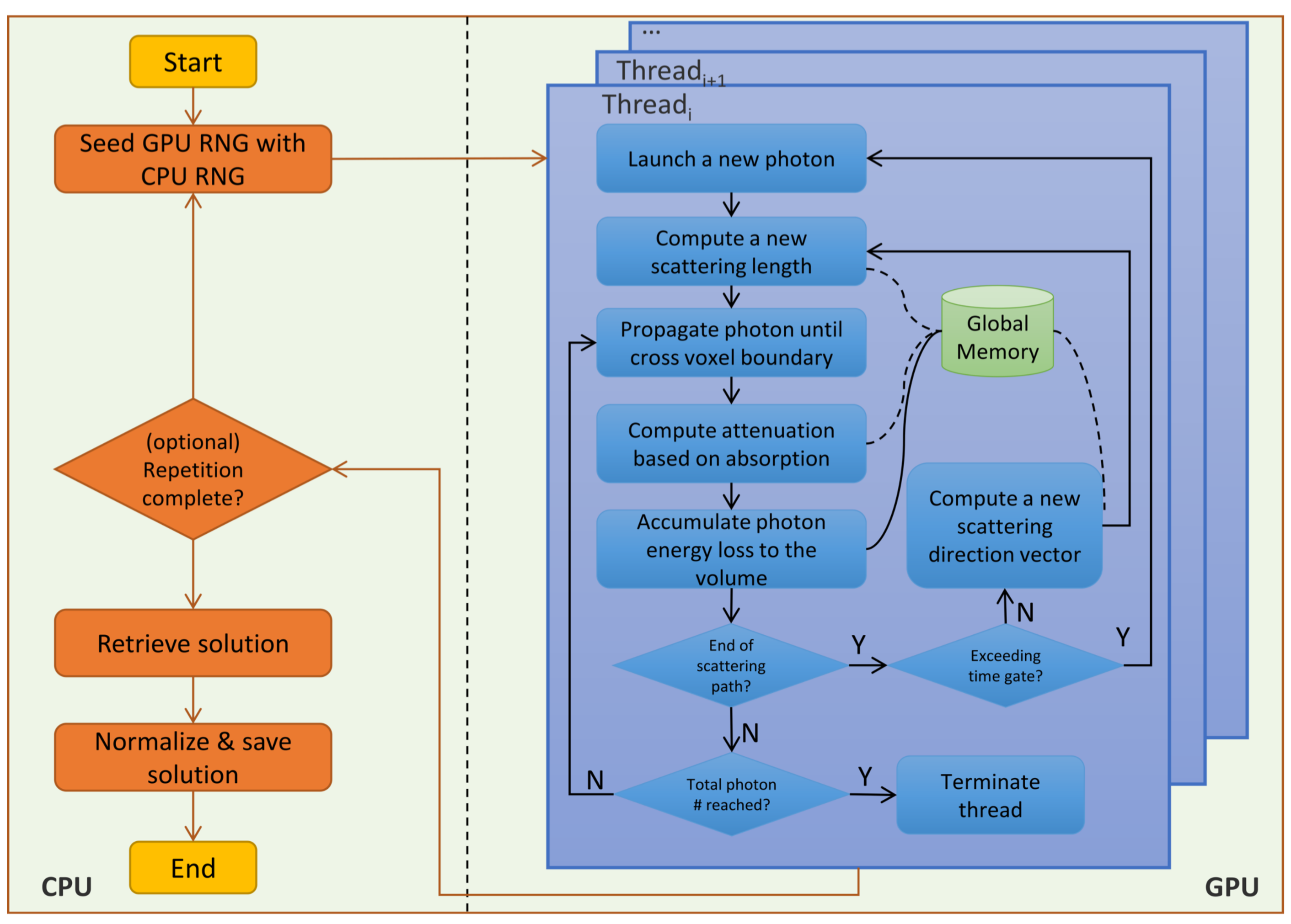
Motivation

- Monte Carlo (MC) method is considered as the gold standard for modeling light propagation inside complex media, such as human brains or bones.
- Due to its computational complexity, sequential execution can easily take up to several hours.

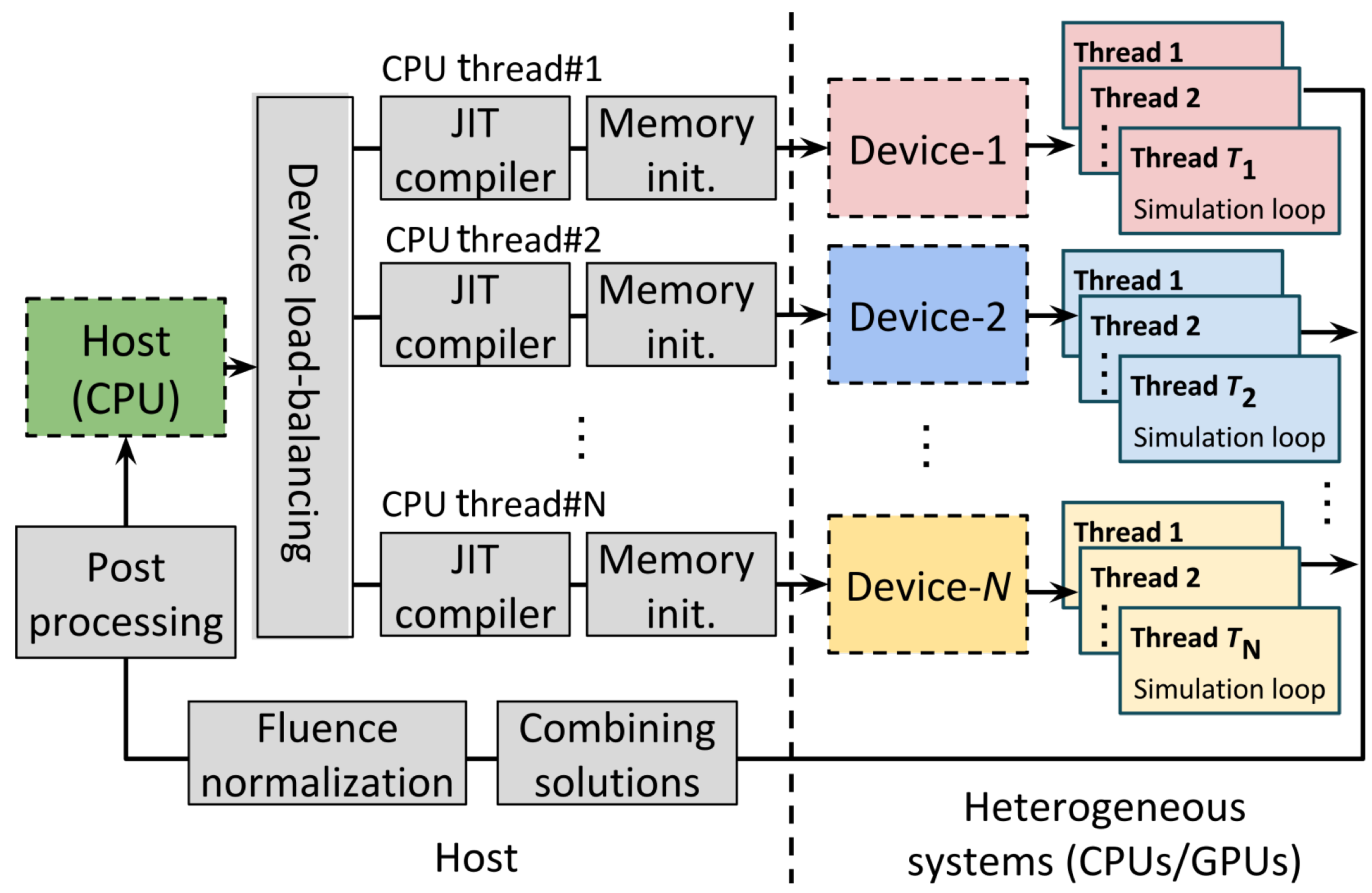


- Leveraging Graphics Processing Units (GPUs), we can significantly reduce the simulation time.
- For scalability and portability, we have developed a fast Monte Carlo photon transport simulation framework in OpenCL for heterogeneous computing systems.

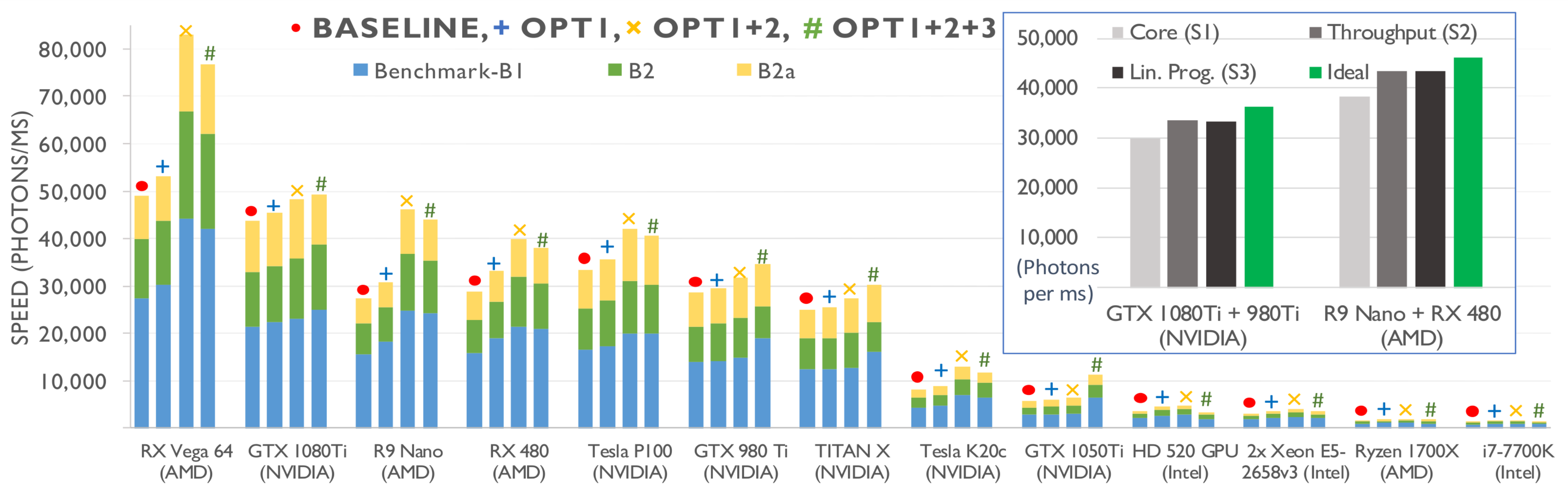
Algorithm



Implementation



Evaluation



Benchmark1	RX Vega 64	GTX 1080Ti	R9 Nano	RX 480	Tesla P100	GTX 980 Ti	Titan X	Tesla K20c	GTX 1050 Ti	HD 520 GPU	2x Xeon E5 2658v3	Ryzen 1700X	i7-7700K
Cores	4096	2816	4096	2304	3584	2816	3072	2496	768	24	24	8	4
Throughput(photons/ms)	44307	24994	24845	21372	19968	18875	16069	6897	6472	2757	2391	1151	1024
Throughput(photons/ms) Per Core	11	9	6	9	6	7	5	3	8	115	100	144	256
Thermal Design Power(Watt)	295	250	175	150	300	250	250	225	75	15	210	95	91
Throughput(photons/ms) Per Watt	150	100	142	142	67	76	64	31	86	184	11	12	11

Optimizations
- ❑ OPT1: Native Math
- ❑ OPT2: Balanced Threads
- ❑ OPT3: Simplify control flow

Benchmarks
- ❑ B1: No reflection
- ❑ B2: Reflection with nonatomic operations
- ❑ B2a: Reflection with atomic operations

Load-partitioning strategies
- ❑ S1: Number of stream-processors
- ❑ S2: Estimated device throughput
- ❑ S3: Linear-programming solution

Results

- GPUs excel in MC simulations with many less powerful cores. The Intel HD 520 GPU reports the highest power efficiency.
- Optimization schemes achieve a 56% performance improvement on average on AMD GPUs, 20% on Intel CPUs/GPUs, and 10% on NVIDIA GPUs.
- Efficient load-partitioning strategies, based on the device throughput and linear-programming models, achieve higher throughput vs. core-based approach.

References

- L Yu, F Nina-Paravecino, D Kaeli and Q Fang. "Scalable and massively parallel Monte Carlo photon transport simulations for heterogeneous computing platforms." Journal of Biomedical Optics 23, no. 1 (2018): 010504.
- Source code for MCXCL, http://mcx.space/mcxcl

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