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Comparison of Kokkos and CUDA Programming Models for Key Kernels in the Monte Carlo Transport Algorithm

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Introduction

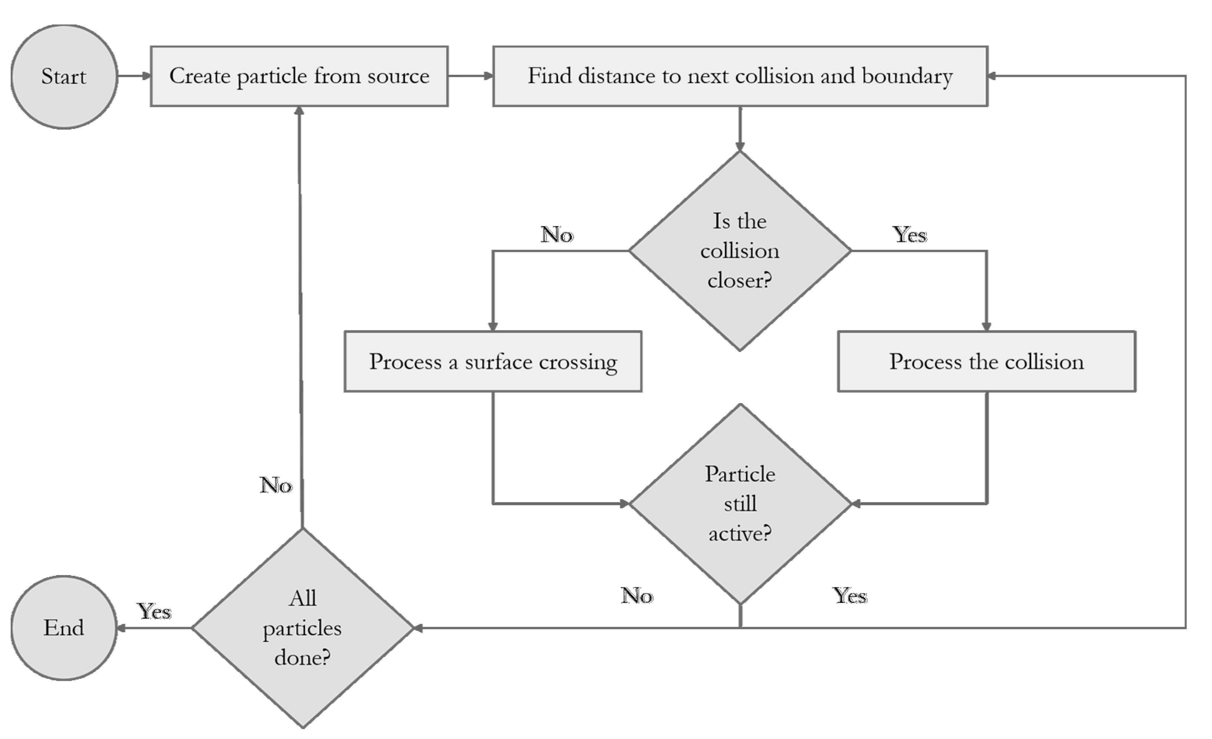
GOAL: Assess effectiveness of the Kokkos programming model for Monte Carlo particle transport on the GPU

- Kokkos is a programming model for performance portability across manycore devices including GPUs
- CUDA is a programming model explicitly designed for NVIDIA GPUs
- CUDA has direct access to features such as constant memory and warp shuffle that can improve performance

Monte Carlo Transport Algorithm

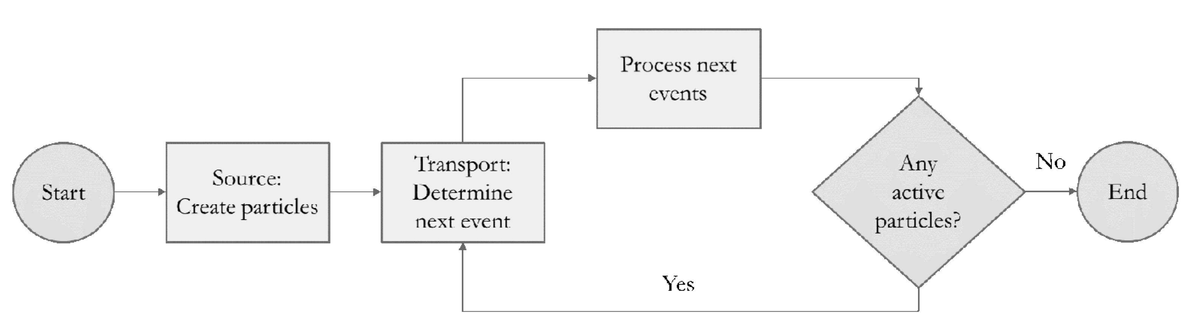
History-Based Transport Algorithm

- Traditional approach used by most production codes
- GPU implementation fully defined within one Big Kernel



Event-Based Transport Algorithm

- Novel approach that reduces divergence on GPUs
- GPU implementation requires multiple kernels



Event-Based Photon Attenuation

- Photon attenuation can be implemented with only three kernels as no events need to be processed

Source Kernel	• Creates all photons from a common source definition
Transport Kernel	• Identifies which photons are absorbed and which ones escape
Tally Kernel	• Counts the total number of photons that escaped

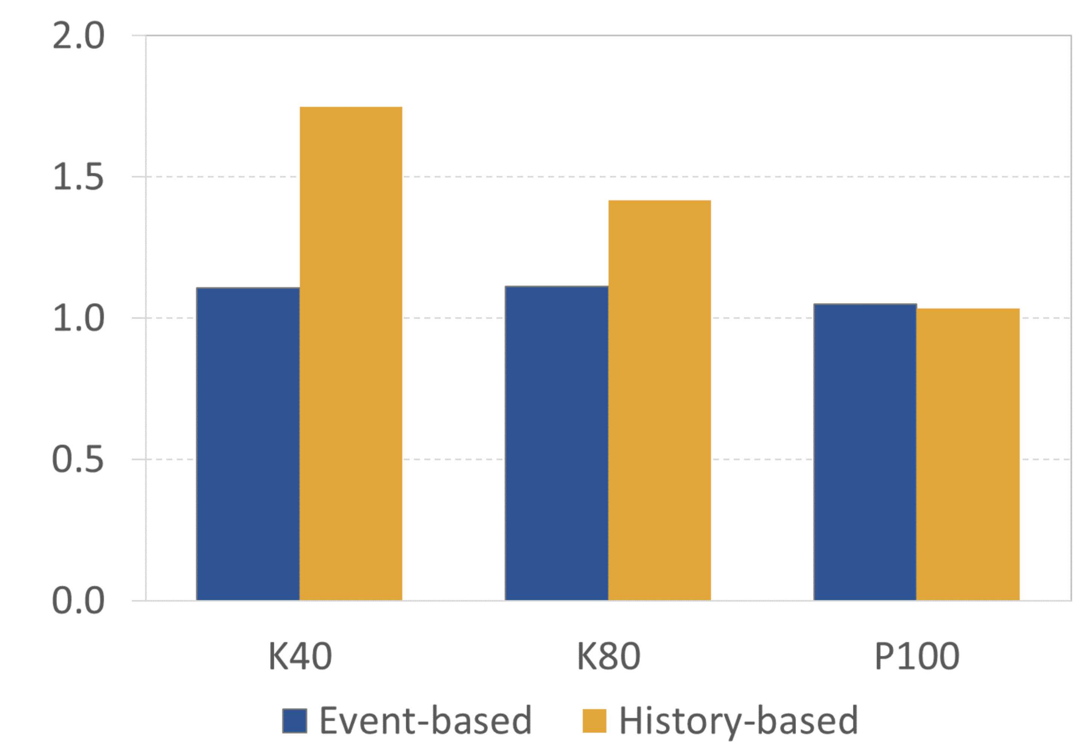
Performance Tests

- 1D photon attenuation problem with 32-bit integer escape tally for 10^8 particle histories
- Compared history-based and event-based algorithms
- Repeated tests on Tesla K40, Tesla K80, and Tesla P100
- All timing data is an average of ten independent runs

General Results

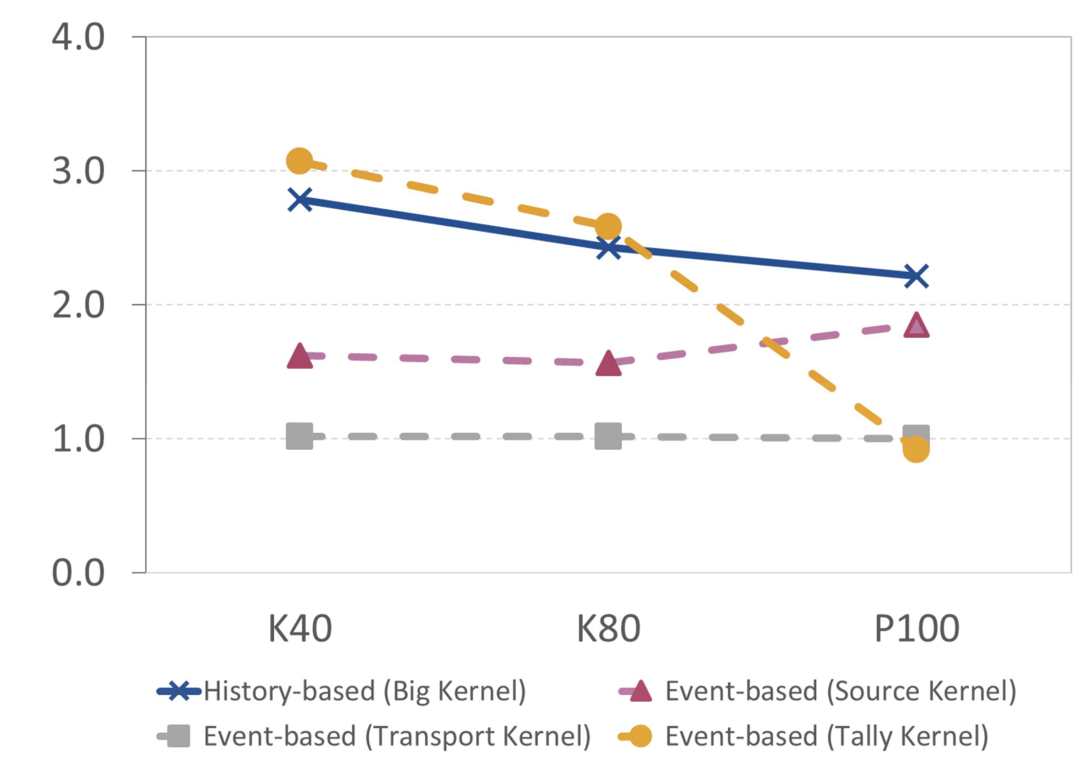
Average Speedup of CUDA over Kokkos (Total Runtime)

- Kokkos was more effective for event-based transport than for history-based transport



Average Speedup of CUDA over Kokkos (Key Kernels)

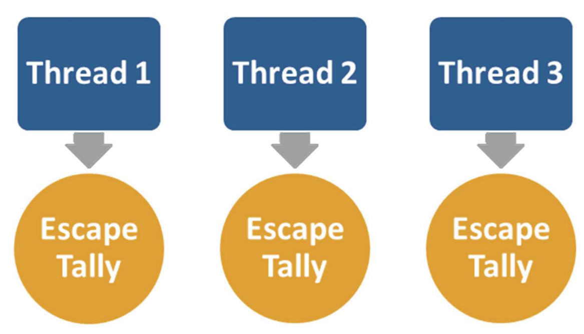
- Only the Transport Kernel had similar runtimes between the Kokkos and CUDA versions
- CUDA was consistently faster for the Source Kernel due to its effective use of constant memory



Tally Kernel

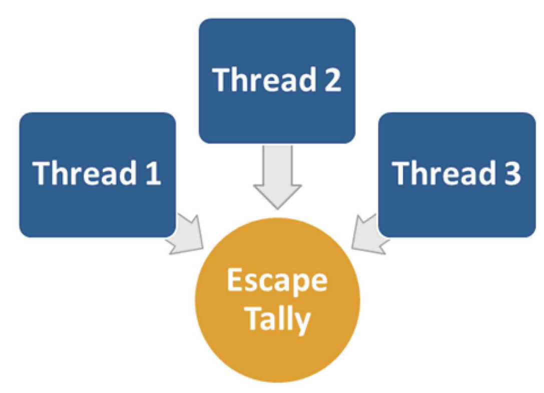
Tally Replication

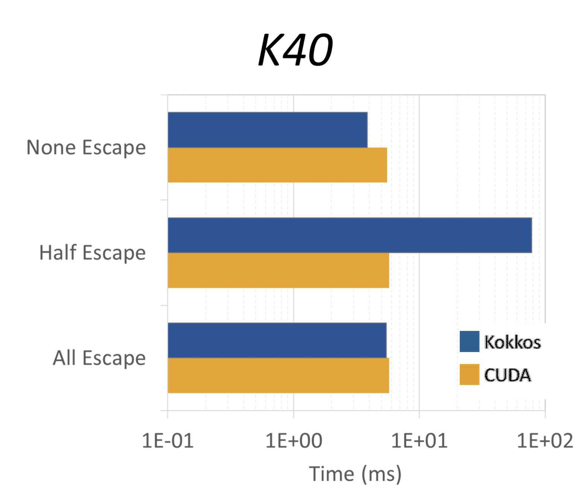
- Kokkos and CUDA had similar runtimes for the Tally Kernel when tallies were replicated



Atomics

- Kokkos with atomics was faster if no photons escaped because no atomic operations were needed
- CUDA's warp shuffle was 14x faster on the K40 when half the photons escaped



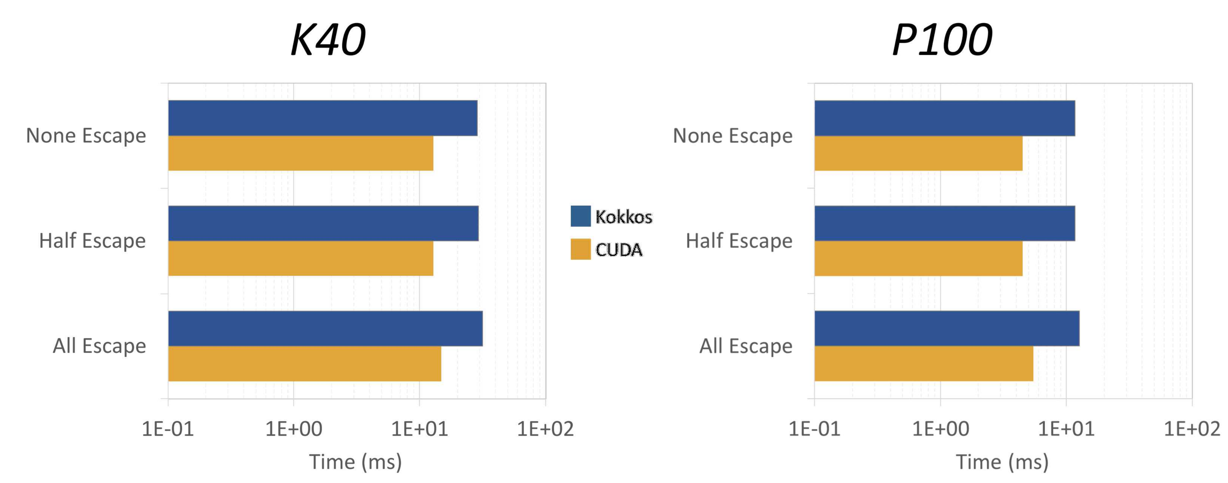


Big Kernel

- Kokkos version of the Big Kernel was slower than the CUDA version for all variations considered
- Direct access to CUDA features is more important for history-based transport

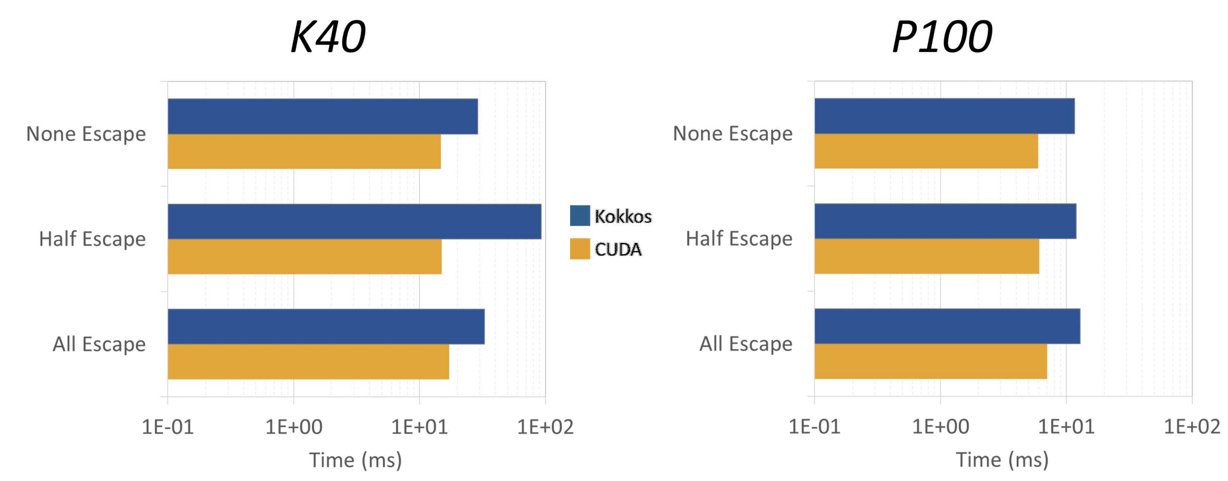
Big Kernel with Tally Replication

- Kokkos is slower because the Big Kernel needs too much data for Kokkos to use constant memory



Big Kernel with Atomics

- Kokkos was 6 times slower on the K40 when half the photons escape due to using atomics for tallying instead of warp shuffle



Conclusions

- Total runtime using Kokkos was competitive with CUDA in most cases – especially on the Tesla P100
- Direct access to CUDA's constant memory and warp shuffle features noticeably improved performance for the Big Kernel, Source Kernel, and Tally Kernel
- Kokkos performance could be improved by restructuring the code to get indirect access to CUDA features hidden under the abstraction
- Future work will compare Kokkos and CUDA on a more complex Monte Carlo transport problem

Acknowledgements

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