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SJTU

Parallelization and Optimization of Laser-Plasma-Interaction Simulation Based on Kepler Cluster

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Outline

- ✓ Introduction
- ✓ Goal Proposal and Contribution
- ✓ Parallelization and Optimization
  - GPU Parallelization
  - Optimizations on GPU
- ✓ Empirical Evaluation
- ✓ Conclusion and Future Work

Laser-Plasma-Interaction Simulation

- The theoretical and experimental research on laser-matter interaction is developing very quickly.

  - Due to the progress in generating intense ultra-short laser pulse

- The code we present is a newly developed, electromagnetic, relativistic Particle-in-Cell laser-plasma-interaction simulation code.

PIC (Particle-In-Cell) Method

- The PIC method has been widely used for simulation of laser-plasma interaction and other physics simulations.

- The quality of the results achieved with this method depending on involving a large number of particles.

- Due to the possible data hazards, irregular data accesses, achieving great parallel and architectural efficiency is an extremely challenging task.

Goal, Proposal and Contribution

- Goal: Parallel and Optimize the Laser-Plasma-Interaction code on GPU cluster.

- Proposal:
  - GPU Parallelization: merged function, thread dispatching and data structure transformation
  - Optimizations on GPU: Dynamic Duplication Algorithm, mix-precision computing and a parameterized particle sorting algorithm.
  - Optimizations for MPI: GPUDirect RDMA

- Contribution:
  - Developing a series of methods to speed up the initial GPU version
  - Evaluating using GPUDirect RDMA in GPU cluster

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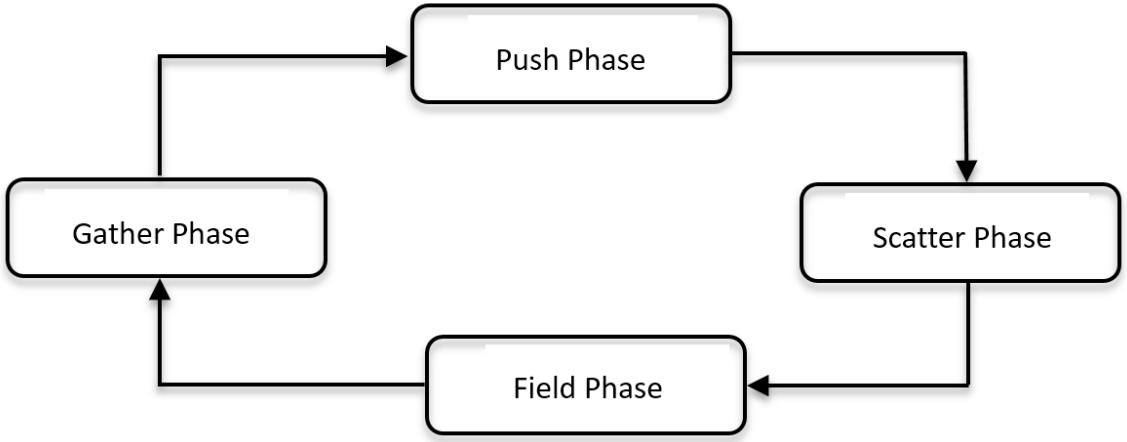
GPU Parallelization

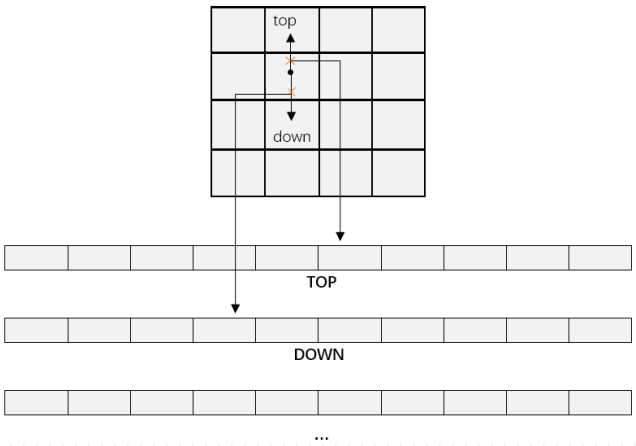
- Data structure transformation
- Merged Function



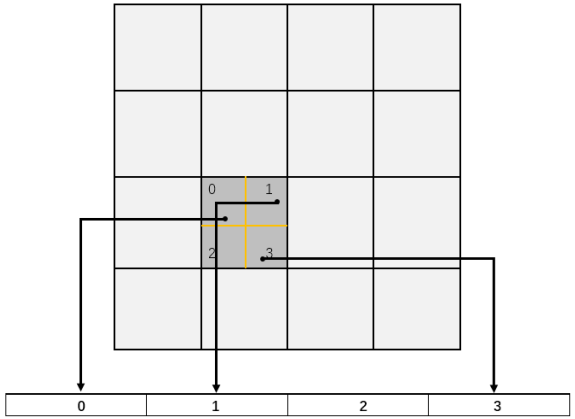
- Thread dispatching strategy
  - We assign a GPU thread to each particle location in the global particle array

Optimizations on GPU

- Duplication Method



The writing scheme when writing to different grid cells



The writing scheme when conflicts happens within the same cell

What's "Dynamic"

- Based on the fact that particles are not well distributed on the grid.

Algorithm 3: DynamicDuplication

Calculate the average number of particles each cell has, named A;
Calculate the max number of particles in a cell, named B;
For the cells that contains particles fewer than the average number A,
Make **Base_duplication_num** duplications of that cell, for those contains more particles than the average number A, Make **Base_duplication_num** × **B** / **A** duplications of the cells.

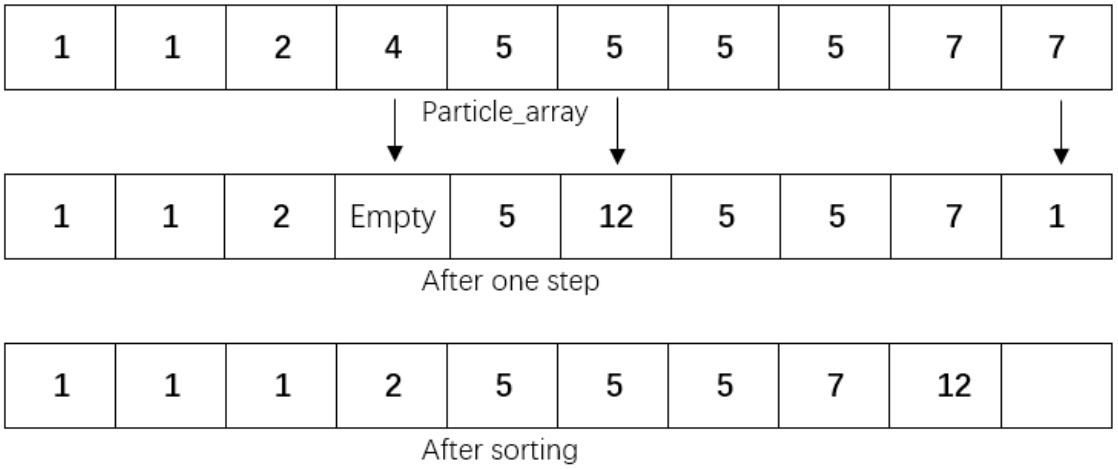
Mixed Precision Method

- Compare & Set atomic implementation is slow for the double precision method

- Do the data precision transformation work before and after the particle related data computation.

- Speed-up of 1.2x without apparent loss of accuracy.

Particle Sorting



Tune this parameter

empty_ratio = number_of_empty_locations/number_of_all_locations

- Trade off between the benefit of sorting and the overhead it brings.

CUDA-Aware MPI

- MVAPICH2
- OpenMPI
- CRAY
- SGI MPI

...

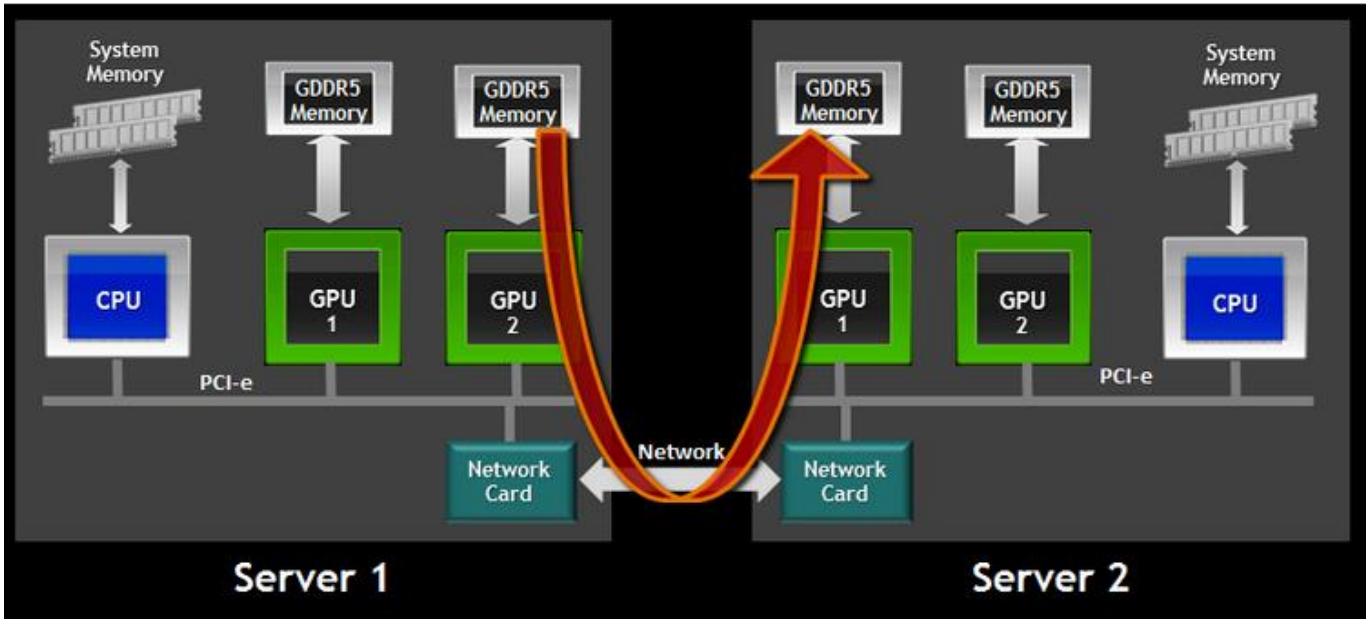
```
//MPI rank 0
cudaMemcpy(s_buf_h,s_buf_d,size,cudaMemcpyDeviceToHost);
MPI_Send(s_buf_h,size,MPI_CHAR,1,100,MPI_COMM_WORLD);

//MPI rank 1
MPI_Recv(r_buf_h,size,MPI_CHAR,0,100,MPI_COMM_WORLD, &status);
cudaMemcpy(r_buf_d,r_buf_h,size,cudaMemcpyHostToDevice);
```

```
//MPI rank 0
MPI_Send(s_buf_d,size,MPI_CHAR,1,100,MPI_COMM_WORLD);

//MPI rank n-1
MPI_Recv(r_buf_d,size,MPI_CHAR,0,100,MPI_COMM_WORLD, &status);
```

CUDA-Aware MPI + RDMA



- CUDA-Aware MPI can transparently use the GPUDirect.
- Buffers can be directly sent from the GPU memory to a network adapter without staging through host memory.

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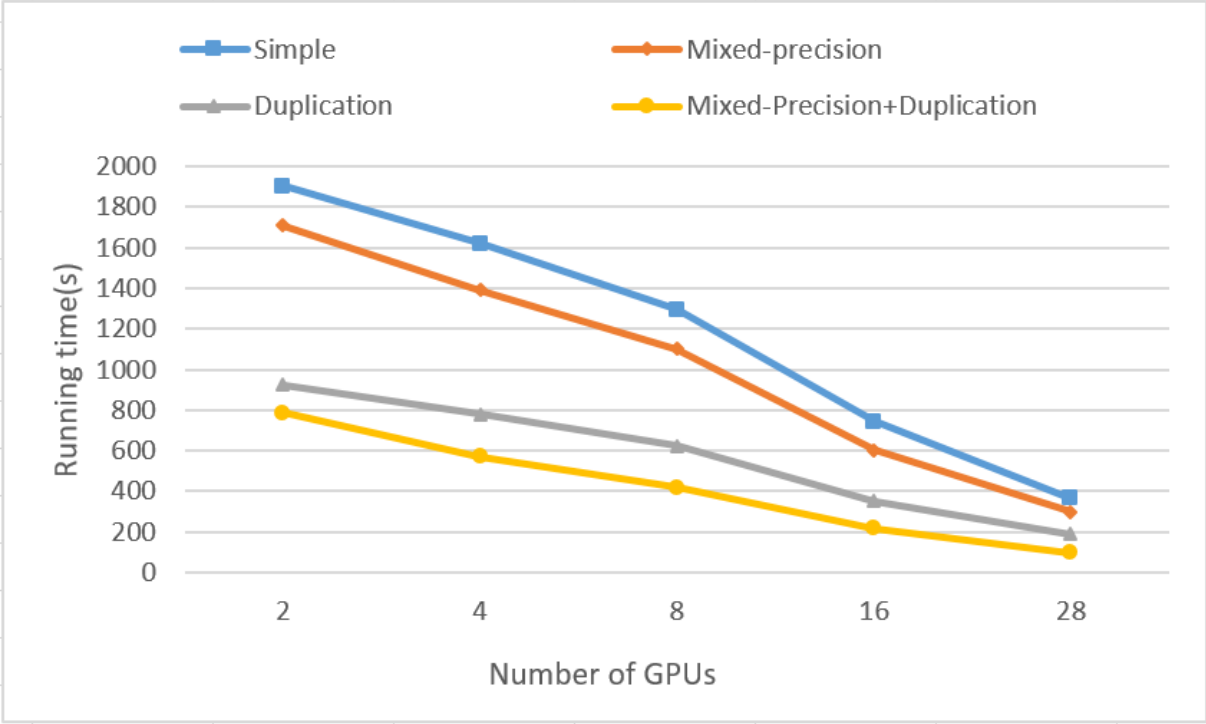
Test Bed

Experimental platform

CPU	Intel(R) Xeon(R) CPU E5-2670 @ 2.60GHz
Memory	62GB DDR3
GPU	NVIDIA Kepler K20
Compiler	NVCC 7.0 + Open MPI 1.10 + GCC 4.9.1

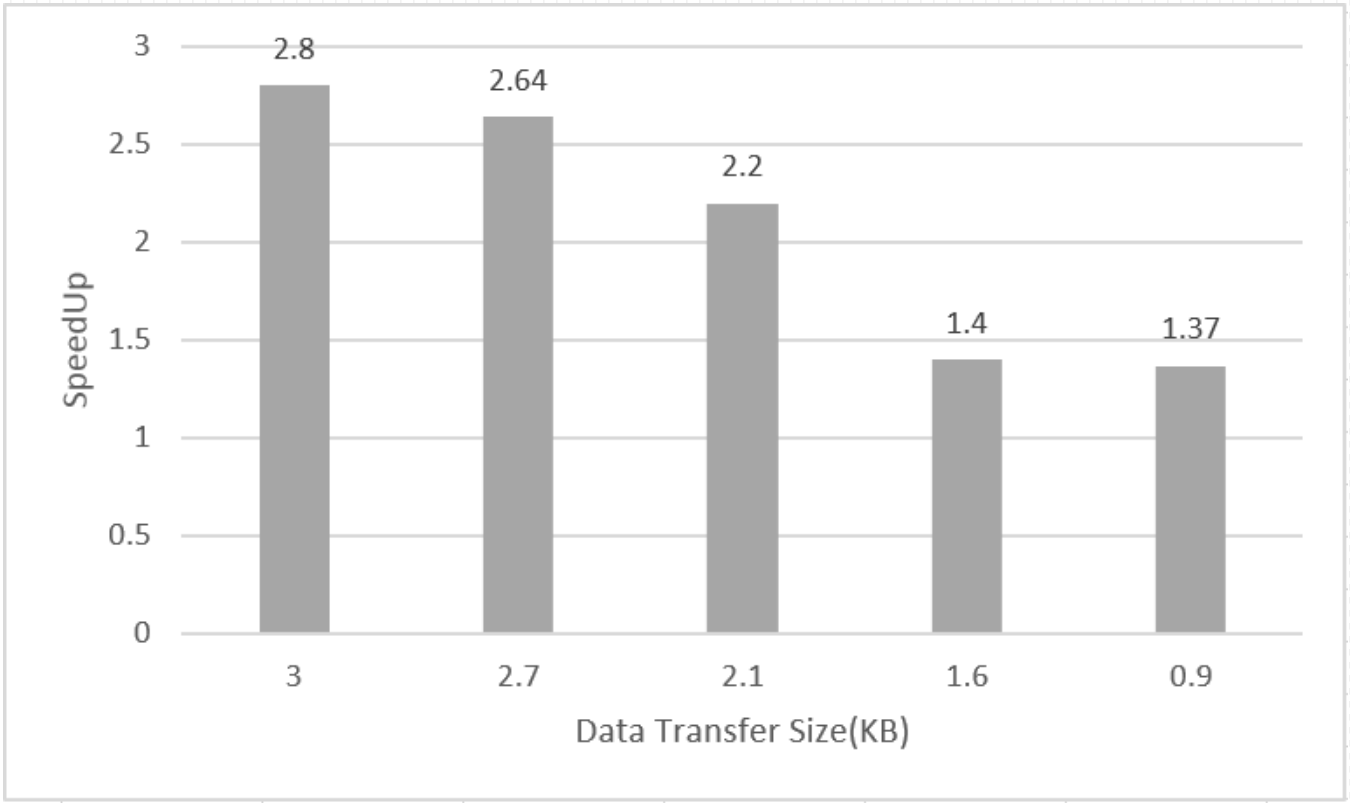
Empirical Evaluation



Baseline: initial GPU version

Combined: 3.5x

RDMA



Non-RDMA: MPI communication time + Gather Data + Scatter Data

Conclusion

- A way to implement the whole PIC Laser-Plasma-Interaction Simulation code onto GPU.
- Novel methods to accelerate the initial GPU version
- Evaluate the use of GPUDirect RDMA technique

Future Work

- Utilize GPU shared memory to store the Grid related data combined with a different GPU thread dispatching strategy.