Performance Improvement of Calculation of Static Magnetic Field of Micromagnetic Simulator Using Supercomputer FX10

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Background

Micromagnetic simulator is used for analyzing dynamic behavior of magnetization. However, calculation of static magnetic fields among a huge number of small nanosized cells, into which simulation model discretizes simulated field, is time consuming.

Purpose

We used the supercomputer FX10 at the University of Tokyo to investigate possibility of using parallelizing methods to decrease calculation time.

- Parallelization of the message passing interface (MPI) with MPI_Allgather() for CPU-to-CPU communications with various directions of parallelization in its three-dimensional (3-D) model.
- Comparing three parallelizing methods for communication among CPUs, namely MPI, multithread parallelization with OpenMP, and Open MP/MPI hybrid parallelization.

Calculation methods

Landau-Lifshitz-Gilbert equation

$$(1+\alpha^2)\frac{d\vec{M}}{dt} = -\gamma\vec{M}\times\left(\vec{H}_{eff}-\alpha\vec{H}_{st}\right) - \frac{\gamma}{M_s}\vec{M}\times\left\{\vec{M}\times\left(\alpha\vec{H}_{eff}+\vec{H}_{st}\right)\right\}$$

$\vec{M}$: magnetization vector t : time

γ : gyro magnetic constant α : damping constant

$\vec{H}_{eff}$: effective field vector (sum of external, anisotropy, exchange, and static field) $\vec{H}_{st}$: spin-torque field vector

Static magnetic field equation

$$\begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix} = \sum_{cell} \begin{bmatrix} S_{xx} & S_{xy} & S_{xz} \\ S_{yx} & S_{yy} & S_{yz} \\ S_{zx} & S_{zy} & S_{zz} \end{bmatrix} \cdot \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix}$$

$H_a(a{:}x,y,z)$: static magnetic field

$S_{ab}\ (b{:}x,y,z)$: structure factor depending on shape of cell and distance of cell-to-cell

M_a: magnetization

FFT(Fast Fourier Transform)

$$H(k) = S(k)\cdot M(k)$$

$H(k)$: static magnetic field $S(k)$: structure factor

$M(k)$: magnetization k : frequency

FFT in X and Y directions are sequentially performed.

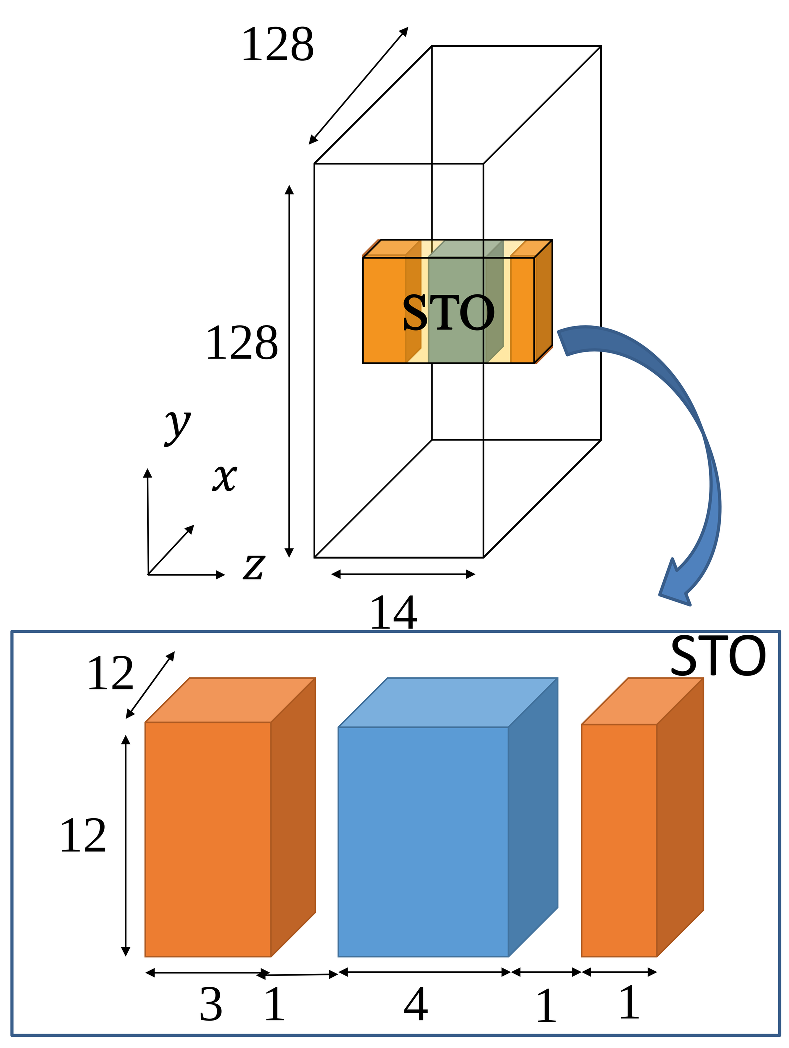

Fig. 1: Simulation model of STO.

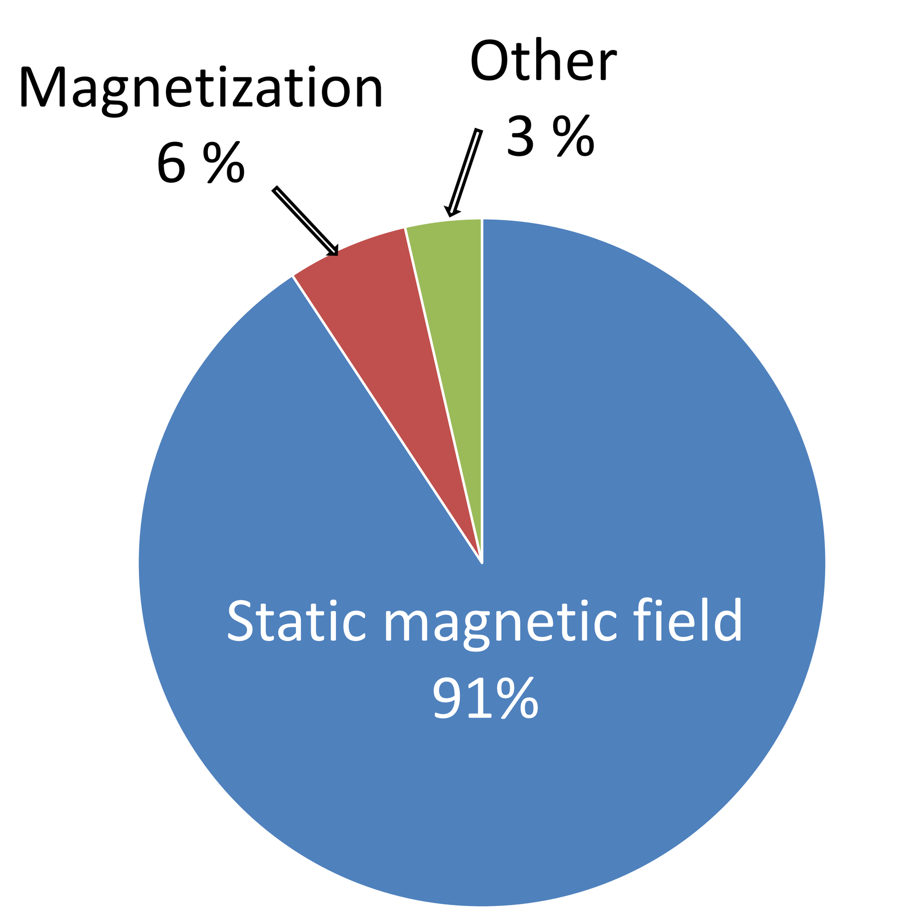

Fig. 2: Breakdown of calculation time in LLG simulator.

Subscript of 3-D array is [i][j][k], elements of [i], [j], and [k] are termed the first, second and third elements, respectively.

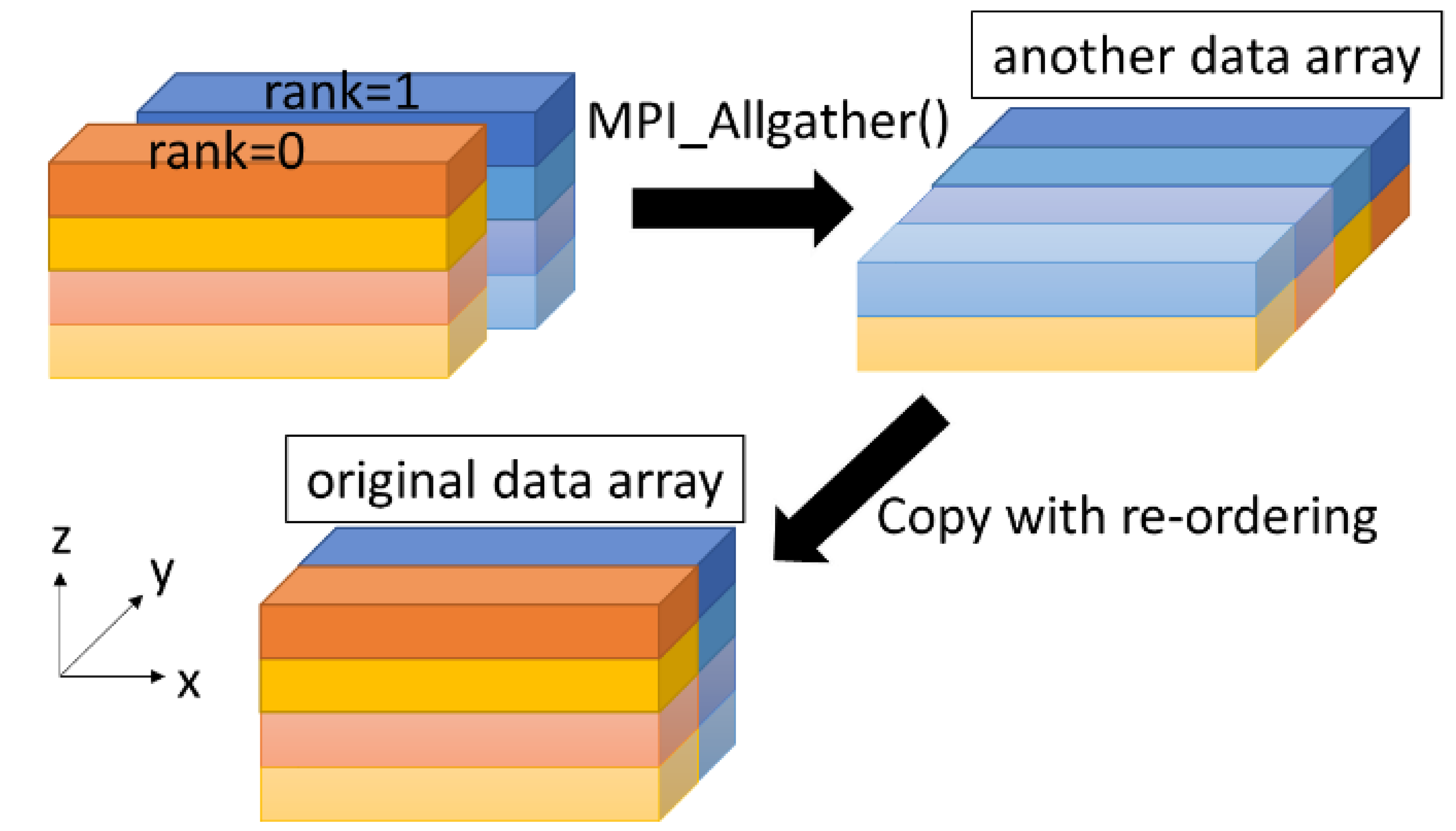

Fig. 3: Schematic of data array for MPI parallelization in second and third element using MPI_Allgather().

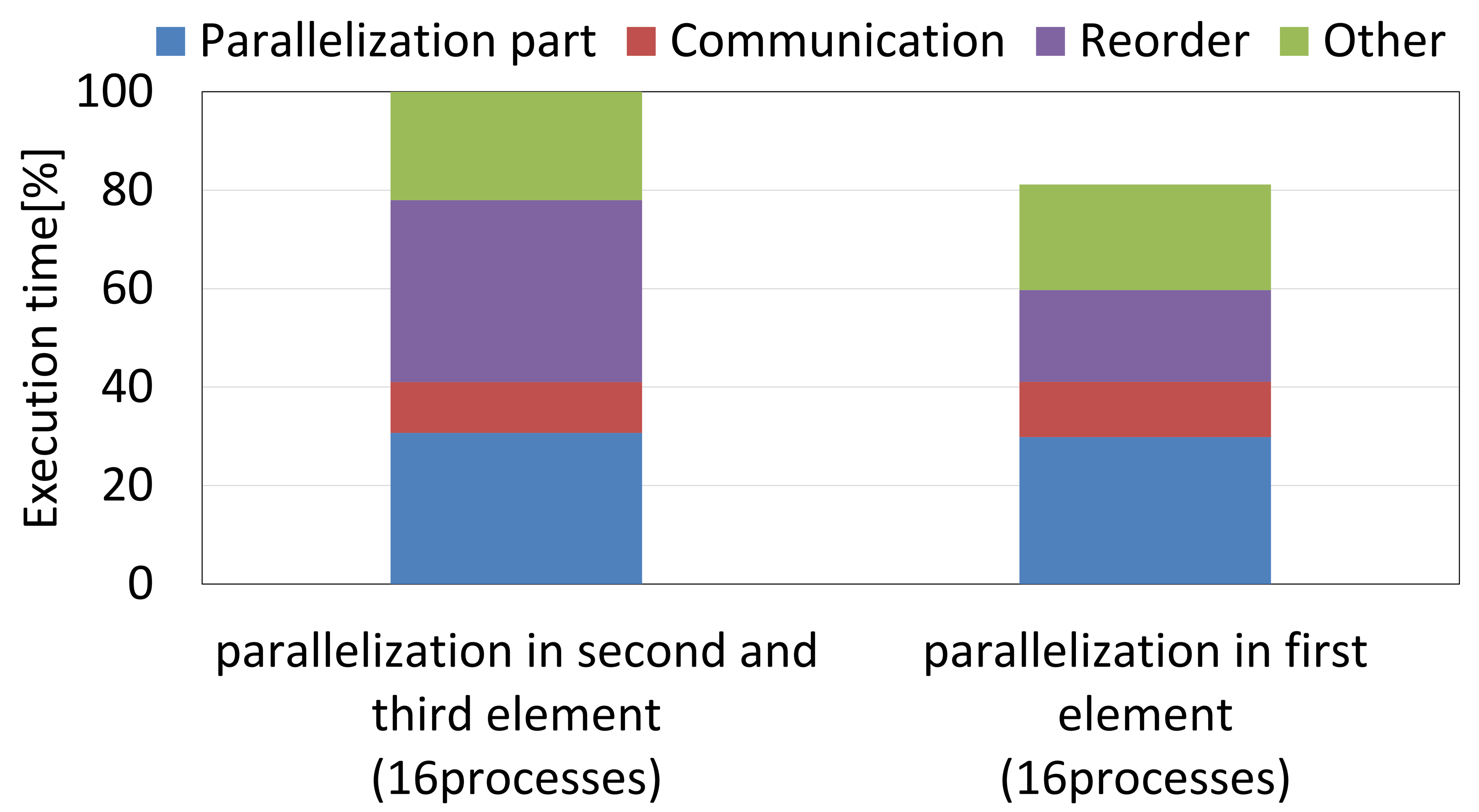

Fig. 4: Comparison between conventional and improvement methods in breakdown of execution time in MPI_Allgather().

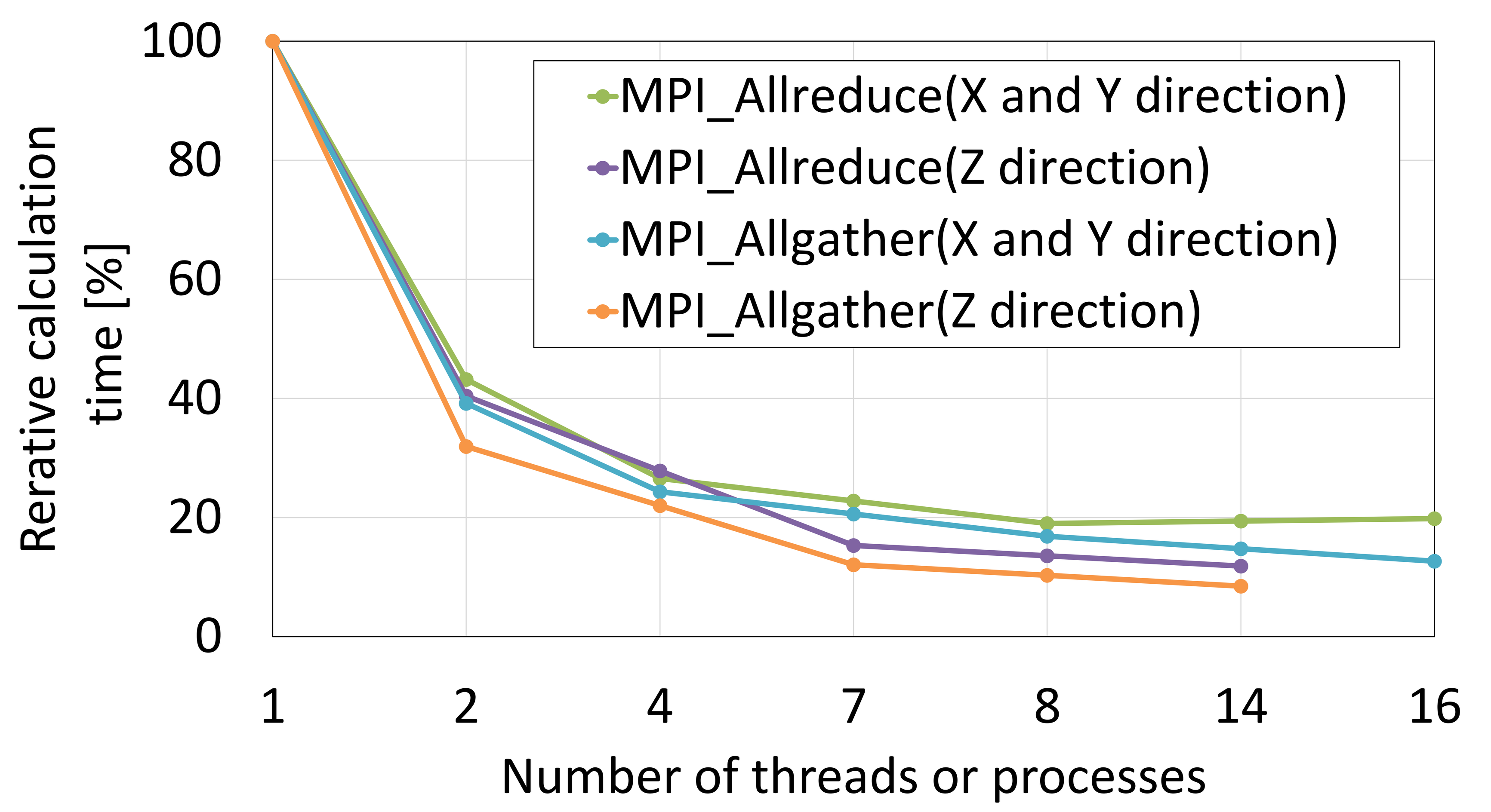

Fig. 5: Relationship between number of processes and calculation time in MPI.

Conclusions

- Parallelization in Z-direction is faster than those in the X-and Y-directions.
- Calculation time can be decreased by parallelizing the first element of data array.
- Calculation time can be reduced by applying hybrid parallelization using MPI with MPI_Allgather() in Z-direction (without FFT) and OpenMP in X- and Y-directions (with FFT for static magnetic field and magnetization).

ACKNOWLEDGMENTS

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