TRANSPLANT AND OPTIMIZE OPENFOAM ON SUNWAY TAIHULIGHT SUPERCOMPUTER

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Sunway TaihuLight is the world's first supercomputer with peak performance over 100PFlop/s. It was composed with over 40K "SW26010" chips. "SW26010" is a novel architected many-core processor, with 4 managing cores (MPE) and 256 computing cores (CPE) all integrated on a single chip. OpenFOAM is one of the most popular open CFD softwares, but written with millions C++ lines and based on an unstructured mesh and data layout. Transplanting and Optimizing OpenFOAM on Sunway TaihuLight was necessarily valuable and challengeable.
The present work reports the porting and comprehensive optimization of OpenFOAM on the Sunway TaihuLight supercomputer. The most important problem while transplanting is that the "wmake" build tool was found to some extent only suitable for shared-library type compiling. Since it is more reliable on Sunway system using static-library type building, a script-based archiving method was used to enable static library support. The optimizations were carried out from two levels – the process level using MPI and the sub-process level many-core parallelization, in which architecture aware acceleration technics, problem oriented strategies, as well as algorithm upgrades were involved.

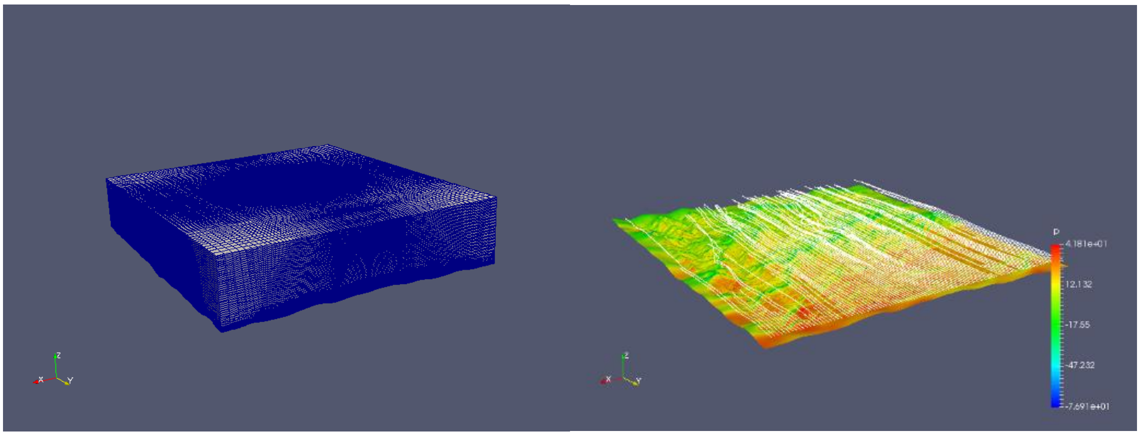

Figure 1: The test case
A wind field, with an about 30 km × 30 km square terrain and an about 7.5 km vertical height to the atmosphere, was under consideration. The domain was discretized with about 50 million unstructured mesh (left). A steady velocity and pressure distribution is to be calculated (right).

Table 1: Test case solving setup

Governing equation	Incompressible Navier-Stokes
Algorithm	SIMPLE family
Variables	ux, uy, uz, p
Orthogonality correction number	1
Velocity equation solver	ILU preconditioned PBiCG
Pressure equation solver	GAMG with Gauss smoother
Turbulence model	k-epsilon

The case used for performance test was a wind field shown as **Figure 1**, and the key solving configurations were listed in **Table 1.** Boundary conditions are obtained from meteorological observations and weather simulations in real applications. **Figure 2** shows the main measures taken in optimization, and corresponding accumulated effects. First, a problem oriented mesh partition was implemented in place of the default "scotch" partition method for unstructured meshes. Then, in order to achieving more efficient memory access, the whole-chip memory was disabled after getting rid of data gathering to main process by post-processing function objects. Manual caching with pre-calculated array stamps was used in the flux and source term computations in the finite volume discretization and the algebra equation formations. For the sparse matrix-vector multiplication (SpMV) kernel "Amul" and "ATmul", matrix reordering strategies was taken to reduce the random data fetching. Despite the flux and matrix related calculations, there are still a large number of vector operations along the execution process. Manual coding respectively would be time consuming and prone to bugs. A series of vector acceleration interfaces were developed, with which a single vector kernel can be accelerated by no more than several dozens of lines, about 10 to 100 times less than respective coding. Apart from accelerations and optimizations on codes itself, algorithms for linear system solver were also upgraded. In the "GAMG" solver of OpenFOAM, the Gauss iteration is mostly used for smoothing, and the ILU preconditioner is frequently adopted together with the "PBiCG" solver. However, Gauss iteration and ILU are algorithmically of a limited degree of parallelism. By extending a new Chebyshev smoother and matching a diagonal preconditioner to a new stabilized conjugate gradient (CG) solver, the degree of parallelism was released with little overhead and similar convergence.

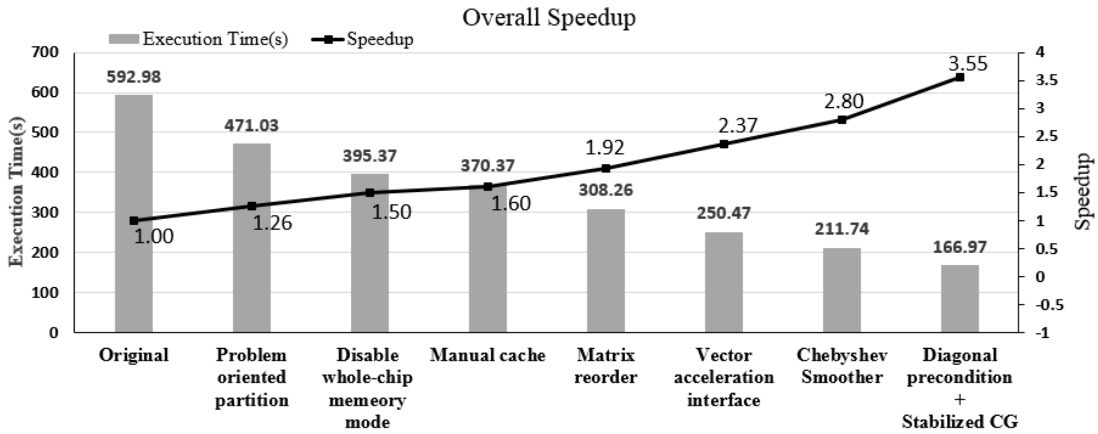

Figure 2: The overall speedup

The speedup is observed in steady wind field case, configured with 50 million unstructured mesh, using 256 core groups on Sunway TaihuLight. Detailed case setups can be found in **Table 1**. The pillars illustrate the "Execution Time" reported by OpenFOAM after 40 SIMPLE iterations. Effects are accumulated. The solid line shows the speedup converted from the "Execution Time" result.

Finally upto 3.55 times' overall speed up was achieved compared to the original version. The performance per one core group on Sunway - there are 4 core groups on a single SW26010 processor - is about 1.18 times of that on a prevailing Intel x86 core at present state. CFD simulations with OpenFOAM are now routines on Sunway system, helping best-in-class companies select wind fun location and predict wind power generation.

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