Using PC-cluster for 3D finite-difference seismic modeling

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1.Introduction
   Authors are developing 3D viscoelastic finite-difference method as the one of the computation methods for strong ground motion simulations. Computation time and memory requirement are two important issues in the application of finite-difference method to large-scale 3D seismic modeling. Parallel computation can solve the problem of computation time and the memory requirement simultaneously in the large-scale finite-difference seismic modeling. However, traditional parallel computers have been highly expensive and not so many researchers can use such parallel computers. In order to calculate large-scale model with common PCs, we have been built PC-cluster.

2.Outline of the PC-cluster
   Our system consists of 8 dual CPU PCs connected with 100BASE Ethernet. We can add several PCs if necessary. An ordinal switching HUB is used for connecting all PCs. The Windows2000 is used as operating system and MPI is used as message passing library.
   Table 1 shows the result of a benchmark test. The test is so called 'Himeno benchmark test' in which finite-difference solution of Poisson equation is iteratively calculated by Jacobi's method. Our PC-cluster recorded 1.1GFLOPS with 16 CPUs in the benchmark test.

3.Parallel computation in O(2,4) staggered grid finite-difference scheme
   The finite-difference method based on the second-order accurate in time, forth-order accurate in space, staggered grid scheme. A viscoelastic modeling is based on the Standard Linear Solid. Memory variables are introduced to eliminate the convolution in the viscoelastic constitutive relation.
   Figure 1 shows the boundary of CPUs for a forth-order accurate in space finite-difference scheme. The figure shows three additional grids are needed on the boundary. If we divide the velocity model in only one direction, the number of grids on divided edge increases (# of CPUs -1)*3. Figure 2 shows the rate of increase against the number of CPUs and the number of grids on divided edge.

4.Computation time
   Figure 3 summarizes the computation time for the simulation of strong ground motion using the PC-cluster. The calculation is viscoelastic and one SLS is used. In the figure 3, horizontal axis indicates the number of CPUs and vertical axis indicates the computation time used for one cell and one step (dt). dt is normalized by the number of CPUs used in the calculation. dt is defined as,

   dt = (total CPU time * # of CPUs) / (#of cells * # of time steps).

   Figure 3 shows the dt is about 4 micro-sec regardless of the number of CPUs and cells. It indicates that the computation time for message passing is not significant if we choose appropriate number of CPUs.
   We can estimate the computation time for larger simulation with the dt.

   Total CPU time = (dt * # of cells * # of time steps) / # of CPUs

   4 micro-sec of dt is the case of viscoelastic calculation with a SLS. If we calculate elastic model or if we use faster CPUs, computation time can be reduced.
   For example, if we calculate a 450 by 900 by 70 km model as a natural earthquake simulation with minimum grid spacing of 200m, the number of grids is about 2250 by 4450 by 100 with irregular grid spacing method and total number of grids is about 1G. The memory requirement for this computation is about 80GB, and the simulation should be divided into 40CPUs, because the Windows can handle 2GB by a CPU. Consequently, computation time for 200sec wave propagation (about 16383 steps) can be estimated as 19 days using the above equation.

表－1　姫野ベンチマークテスト実行結果と参考値

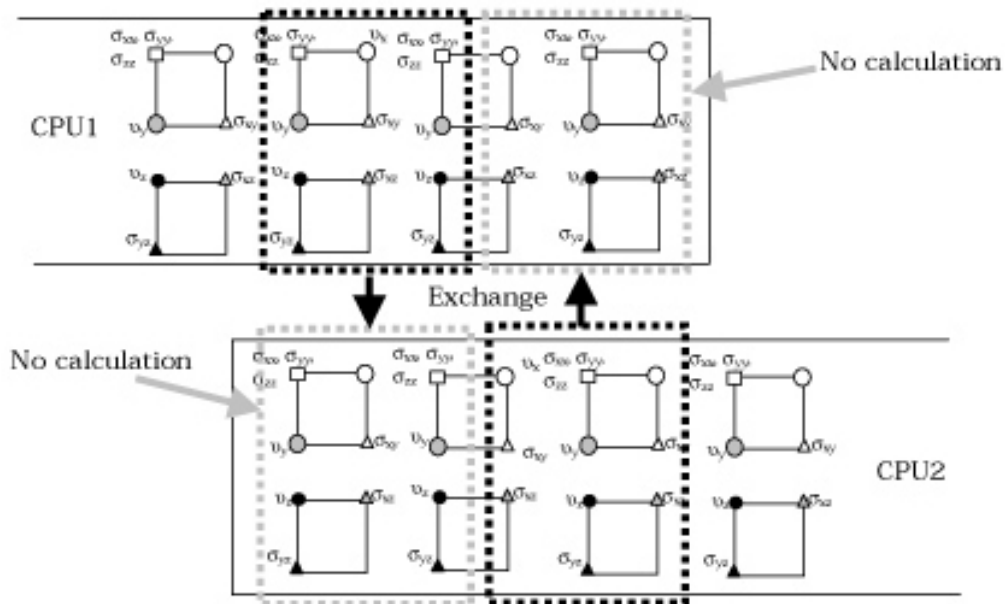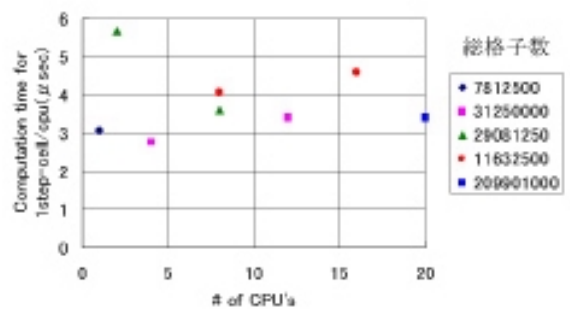| 使用した CPU 数		計算時間	実測速度	参 考 値		
PC クラスタ	1 CPU	38.53 秒	130.92 MFLOPS	NEC SX4/2C	(1 CPU)	1237.80 MFLOPS
	2 CPU	26.64 秒	189.33 MFLOPS	SGI Origin2000	(16 CPU)	3399.00 MFLOPS
	4 CPU	14.39 秒	350.59 MFLOPS	日立 SR2201	(64 CPU)	3586.95 MFLOPS
	8 CPU	8.15 秒	619.19 MFLOPS	富士通 VPP700E	(16 CPU)	7986.84 MFLOPS
	16CPU	4.55 秒	1108.43 MFLOPS	Compaq Alpha	(64 CPU)	10644.58 MFLOPS

図－1　並列計算におけるデータ交換の概念図（空間四次近似の場合）。
　　　　灰色の点線で囲んだ範囲は計算を行わない。
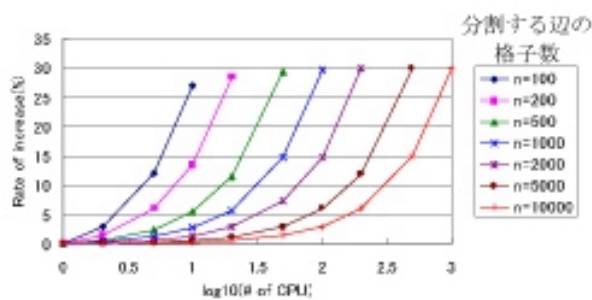
図－2　並列計算による総格子数の増加割合　　　図－3　1セル・1ステップの計算時間（1CPU 換算）