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THE PARALLEL STRATEGY OF A LARGE SCALE SIMULATION ABOUT TEN MILLIONS NODES TO RESERVOIR WITH MULTIPLE LAYERS

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Abstract. Aim at large scale fine reservoir numerical simulation application research on Shenwei computer, the multilayer two dimension two phase parallel software transplanted successfully and a large scale integral simulation about ten millions nodes were realized in the environment of Shenwei parallel computer. The whole preconditioning alternating Schward and another many improved algorithm, the parallel optimal methods about coefficient matrix and saturation calculation made the parallel efficiency increased effectively about multilayer two dimension two phase parallel software. Especially the deep research about the communication and load-balanced technology fitting for Shenwei computer make the parallel function of the software to large scale increase. The multilayer two dimension two phase parallel software transplanted and the parallel computer resource of homegrown Shenwei high behavior parallel computer with 112 CPUs was to simulate the production history of 12 sandgroups of the second Shahejian in second block of Shengtuo. The simulation scale is 10 millions nodes and the time exhausted is about 5 hours which satisfies the application requisition of reservoir simulation. This verifies the reliability and stability of the software and makes the whole parallel efficiency to 79%. It is first time to bring out the independent copyright reservoir simulation parallel software with satisfactory back and forth processing function in homegrown Shenwei computer. Especially the application of the whole preconditioning alternating Schward region decomposition algorithm, the deep research of load-balanced technology and the large scale application etc. are all innovative.

Key Words. reservoir simulation, parallel calculation, model, speedup

1. Foreword

High-behavior computer is usually used for large scale parallel calculation in fields of national defence, meteorology and air/space technology, etc. In July, 2000, homegrown Shenwei computer, a huge computer system, came into the world. It is very suitable for such calculation. The key of reservoir numerical simulation is to solve large-scale sparse linear algebraic equation group-formed from large-scale partial differential one, which needs mass of time. But it is a kind of parallel calculation which can be done on various parallel computers. In this paper, parallelization of reservoir numerical simulation and its application has been studied using ShenWei computer and the multilayer two dimension two phase parallel software (developed by ourselves). Also parallel strategy and parallel optimization is probed with good effects. The simulation scale is 10 million blocks and the time exhausted is about 5 hours.

2. Characteristics of Shenwei computer

Shenwei computer is a home-developed, huge computer system used for large scale parallel processing. Considering users' requirements, it is designed to be a super parallel processing system with multiple instruction-flows/data-flows. It is characterized with fast calculation speed, large memory capacity, high efficiency, rich software collocation with completed function and good PFK, friendly interface which is easy to study and use, stable and reliable function which makes maintenance and re-assembling convenient. It is made up of host computer system, front end, disk array and software with main system of isomorphism ,distributing sharing, framework of planar grid- cubicle-net and 384 CPU. The highest calculation speed of this system amounts to 384 billion times per second.

3. Parallelization of multilayer two dimension two phase software

Multilayer two dimension two phase parallel software is adapt to numerical simulation of terrestrial facies, layered, low-saturation, water-flooded sandstone reservoir. According to features of such reservoir, synchronous parallelization of interlayer and intralayer is adopted using region decomposition algorithm on Shenwei computer.

3.1. Parallel strategy. In terms of characteristics of Shenwei computer, the key technical strategy of software parallelization mainly aims to tackle two problems as follows. The first is how to realize large scale simulation and the second is how to make multilayer two dimension two phase software fit to high behavior and huge parallel computer. To solve the former problem, distributing-sharing storage techniques are adopted and for the latter one, multilevel parallelization is used.

3.1.1. Design of distributing-sharing storage manner. Distributing-sharing is one of storage manners usually used by MPP. It can be classified into two categories: Cache or non-Cache. In the former system, one CPU should visit local Cache firstly before visiting other CPU. If local Cache can not be reach, then it can visit a remote CPU. While in latter system, one CPU can visit a remote CPU directly to obtain contents he wants. In terms of contents which are modified frequently by many CPU, the efficiency of Cache distributing-sharing will be higher than that of non-Cache one. In terms of contents which are not modified frequently by many CPU, the efficiency of Cache distributing-sharing will be much more higher. In this study, sharing data should be visited and modified only during major process process, so Cache distributing-sharing will be more effective. Distributing-sharing storage technique is designed and applied.

Without distributing-sharing storage, the largest simulation scale of Shenwei computer with 512M main store capacity will be about 3.5 4 million blocks . If 4 CPU–each with 256M distributing-share capacity-are adopted, totally 1G capacity will be obtained. Then the largest simulation scale will be increased dramatically and amount to 10 11 million nodes. Furthermore, If 16 such CPU are adopted, the largest simulation scale will be above 40 million blocks. The application of distributing-share is an effective method to enlarge storage capacity. Thus, different simulation scales can be realized.

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3.1.2. Multilevel parallelization strategy. This study deals with two kinds of parallelization–intralayer and interlayer. They can be used synchronously in the same program. So how to organize these two parallelization manners are very important.

In terms of interlayer parallelization, the whole program includes two unparallelized parts (bottom hole pressure calculation and indexes determination), which should be done through a maste-rcontrol process process, as well as two parallelized parts (pressure and saturation calculation). While in terms of intralayer parallelization, the generation of coefficient matrix can not be parallelized and also needs a process which can bear main process process.

In order to improve efficiency of interlayer parallelization, dynamic scheduler is adopted to provide task to each process. That is, there is a main process (dynamic scheduler) which is responsible for providing data needed by each parallelized process; the parallelized processs should notify main process after they finish the calculation; then main process will distribute another task (if exists) to them or inform them of rest (if no tasks left). Due to such characteristics, dynamic scheduler can not participate in interlayer parallelized calculation. Otherwise its efficiency can not be guaranteed. If all the conditions above are satisfied, dynamic scheduler algorithm will be optimum choice for interlayer parallelization.

To sum up, the main model which includes interlayer and intralayer parallelization is made up of processs of three levels

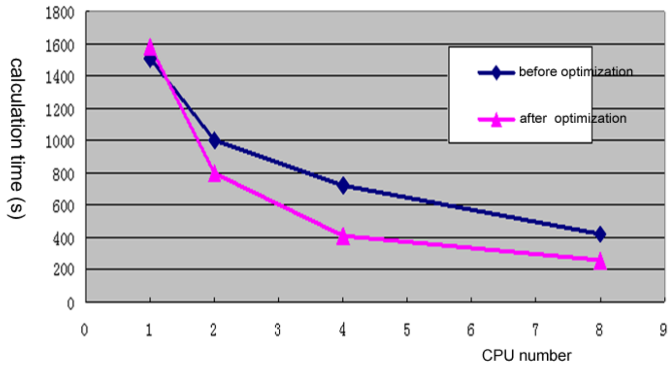
(1) Master-control process: it is responsible for calculation which can not be parallelized, and as the same tine, it acts as the scheduler for interlayer parallelization.
(2) Intralayer main process: it is responsible for receiving for layer data from mastercontrol process, coefficient matrix calculation and division into pieces of coefficient matrix, transition of such pieces to intralayer sub-processes, collection of calculation results from sub-processes and determining the astringency of these results, calculation of saturation, and sending the calculated data to mastercontrol process.
(3) Intralayer sub-processs: they are responsible for incept of data from intralayer main process, calculation of pressure and sending the calculated data back to intralayer main process.

3.2. Parallel optimization.

3.2.1. Load-balanced optimization. Load-balanced optimization is the chief matter in software parallelization. In terms of multilayer two dimension two phase model, calculation load of different layers may be different dramatically in different time-step/iterated sub-timestep even in the same timestep due to geological heterogeneity or diversity of producing degree between them.

(1) Processing flow of dynamic load-balanced
Hereunder, algorithm flow will be introduced taken interlayer parallelized calculation of pressure and saturation as an example. On the assumption that KC layers remain to be calculated, there are KC tasks. In case that (n+1) CPU participates in this calculation, there should be 1 mastercontrol process responsible for distributing these tasks. For the mastercontrol

FIGURE 1. Comparison diagram of time during pressure calculation before and after load-balanced optimization.



process, data needed by each layer during iteration and calculation should be gotten ready after completion of bottom hole pressure calculation. Then it should distribute one layer-data needed during calculation-to each subprocess and wait for information of fulfillment from them immediately followed by incept of calculated data. If there are tasks left, that is, there still exists layers needed to be calculated, it will send data of those layers to the sub-processs who have finished their former tasks until all the layers are calculated. While sub-processs are responsible for incept of data from mastercontrol process, calculation of these data and sending back the calculated results.

(2) Analyses of dynamic load-balanced effects
In order to evaluate dynamic load-balanced effects, model of real reservoir in second block of Shengtuo oilfield has been studied. In this model, there are 17 simulated layers with the scale of 2.6 million nodes and 26 of calculation time-step. From Fig.1, time during pressure calculation before load-balanced optimization is compared with that after optimization. After dynamic scheduler is adopted, the parallel efficiency of 2 CPU will amount to 1.0 and that of 4 CPU to 0.97, similar to linear acceleration. But because of 17 simulated layers, efficiency of 8 CPU will drop to about 0.77 due to one layer will be left after each CPU finished calculation of two layers, which will make the whole calculation time be relatively longer. However, this efficiency is still much higher than that (0.45) before parallelization.

3.2.2. Communication optimization. Communication and I/O are the key factors which can affect program behavior. In this program we discussed, mass of communication exists, making communication optimization more important. During the whole parallelization, communication load focus mainly on process of tasks distributing from mastercontrol process to sub-processs and of intralayer parallelization/interlayer iteration. The load of the former process is very heavy and can not be replaced by other manners.

(1) Communication optimization of load-balanced algorithm

Intralayer mastercontrol process should take over calculation results of all the intralayer sub-process besides pressure calculation through iteration. At the same time, it should process the calculated pressure results of each PCU, resulting in new values. If the values are not convergent, it should transmit them back to CPU for recalculation. This additional work makes the intralayer mastercontrol process be another bottle-neck during intralayer parallelization. In case that each sub-process can finish its pressure processing independently, the efficiency may be improved largely. The reasons are as follows: first, load of mastercontrol process will be lighten due to data incorporation of each sub-process, which is concentrated on it before, is distributed to sub-processs themselves; second, communication load will be reduced dramatically. In original program, sub-processs should transmit pressure field of the whole layer to mastercontrol process each time after completion of intralayer iteration and the former should broadcast the new pressure field produced through incorporation back to the latter. While in optimized algorithm, these two transmitting process are replaced by boundary communication whose communication-load is much less. Thus, the whole pressure field is sent to mastercontrol process only when the calculated data are convergent. In the latter algorithm, load-balance is considered to the largest degree and the work of sub-processs is almost equivalent to that of mastercontrol process.

(2) Effects analyses of communication optimization

Effects of communication optimization are test using the same test model as load-balance. After optimization, time using for iteration calculation will reduce 1/3 than before and speedup will be enhanced correspondingly. Due to communication optimization algorithm is mainly used to tackle problems occurred during intralayer parallelization, the effects will be more obvious if simulated scale and CPU number adopted increased.

4. Analyses of application example

The 1–2 sandgroups of second Shahejian in second block is located in west-south flank of eastern high in Shengtuo oilfield. Controlled by boundary faults in the east and north, it spreads as a fan to west-south. It is a layered sandstone reservoir with high permeability, serious heterogeneity, mid-high viscosity, low saturation and positive rhythm. Here the oil-bearing area of 20.9km2 and OOIP is 397.1 million t, with edge water.

4.1. Prescription test of mid-large scale simulation. In practice, mid-large scale simulation with 1 3million nodes is mostly required and should be a primary target of application test. Models (2.88 million nodes) of second block in Shengtuo are tested respectively when CPU numbers adopted are 1, 8, 16 and 32 to determine optimum CPU number. The major test results are listed in following Table 1. From this table, it is obvious that the efficiency can be improved using parallel calculation and the whole time used can drop to about 1.5 hours from 5.4 hours when series program is adopted with parallel efficiency of pressure calculation to be 84.6%.

4.2. Simulation of largest scale and its prescription test. Simulation of largest scale and its prescription test are very important. Models of second block in Shengtuo are tested respectively when simulation nodes are 6.5 or10 million and when adopted modes are interlayer parallel or mixed parallel, resulting in

TABLE 1. Time used for large scale simulation

CPU number	The whole calculation time (s)	Generation of coefficient matrix(s)	Pressure calculation (s)	Saturation calculation (s)	Indexes calculation (s)
1	19421.0	406.6	12949.6	1226.4	1083.9
8	6266.3	55.6	1913.3	160.4	1228.5
16	5554.4	41.1	1752.1	138.3	1046.0
32	5272.0	56.9	1015.0	199.9	1085.2

determination of largest simulation scale with reasonable prescription as follows: it will be 6.5 million nodes when interlayer parallel is adopted with exhausted time about 6 hours, while it can amount to 10 million nodes when mixed parallel is adopted with 112 CPU and the exhausted time is about 5 hours.The technology using for this scale simulation is introduced above.

5. Conclusions

Parallelization processing of reservoir numerical simulation is the effective way for its large-scale application and calculation. For different simulation of different reservoirs, different parallel strategies and methods should be adopted. Communication and load-balance are the main problems faced by parallel efficiency. In terms of parallel software, its simulation scale and calculation efficiency and elapse time are the key factors to determine whether it can be applied widely or not.

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