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Research Article

Parallel Computing for LURR of Earthquake Prediction

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The LURR theory is a new approach for earthquake prediction, which achieves a good result within China mainland and some regions in America, Japan, and Australia. However, the expansion of the prediction region leads to the refinement of its longitude and latitude and the increase of the time period. This requires more and more computations and volume of data reaching the order of GB, which will be very difficult for a single CPU. In this paper, adopting the technology of domain decomposition and parallelizing using MPI, we developed a new parallel tempospatial scanning program.

1. Introduction

The Load-Unload Response Ratio (LURR) Method, which is invented by Professor Yin [1], has achieved successful result in earthquake prediction within China mainland as well as some other regions in America, Japan, and Australia [2–4].

From the solid mechanics, the constitutive relation (stress-strain curve) is a comprehensive description of the mechanical behaviors of any materials. A typical stress-strain curve for focal media (rock) is shown in Figure 1. For more universality, in Figure 1 the ordinate denotes general load P instead of stress σ and the abscissa is the general response R to load P instead of strain ε. If the load acting on the material increases monotonously, the material will experience the regimes of elastic, damage and failure or destabilization. The most essential characteristic of the elastic regime is its reversibility; that is, the positive process and the contrary process are reversible. In other words, the loading modulus and the unloading one are equal to each other. Contrary to the elastic regime, the damage regime is characterized by irreversible process. Hence the loading response is different from the unloading one, or the loading modulus is different from the unloading one. This difference indicates the deterioration of material due to damage (Yin et al. [5, 6]). LURR is defined according to this difference. P and R are the load and response of a system, respectively; if P has a small change ΔP resulting in a small change to R of ΔR, then we can define X as

$$X = \lim_{\Delta P \to 0} \frac{\Delta R}{\Delta P}. \tag{1}$$

This is so called the response ratio, and LURR is defined as

$$Y = \frac{X^+}{X^-}, \tag{2}$$

where X^+ and X^- are response ratio during loading and unloading. As shown in Figure 1, when a system is in a stable or linear state, $X^+ \approx X^-$ then $Y \approx 1$. When a system lies beyond the linear state, $X^+ > X^-$ and $Y > 1$. Hence, Y can be used as a criterion to judge the degree of stability of a system.

In LURR theory, Y is defined directly by the seismic energy as follows: $Y = (\sum_{i=1}^{N^+} E_i^m)_+ / (\sum_{i=1}^{N^-} E_i^m)_-$, where E denotes seismic energy, which can be calculated according to the Gutenberg-Richter formula, the sign "+" means loading and "−" unloading, $m = 0$ or 1/3 or 1/2 or 2/3 or 1. When $m = 1$, E^m is exactly the energy itself; $m = 1/2$, E^m denotes the Benioff strain; $m = 1/3$, 2/3, E^m represents the linear scale and area scale of the focal zone, respectively; $m = 0$, Y is equal to N^+/N^-, where N^+ and N^- denote the number of earthquake occurred during the loading and unloading durations, respectively [2]. Since the preparation

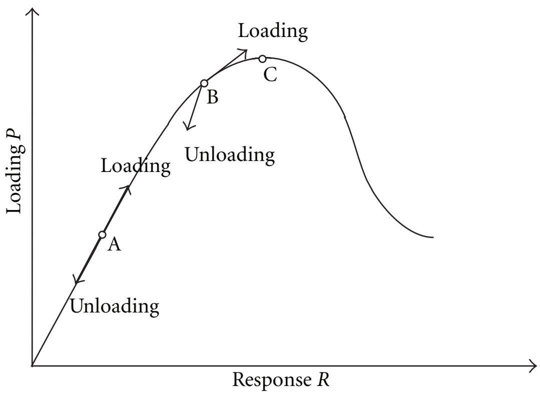

Figure 1: Constitutive relation of systems.

and occurrence process of earthquakes are controlled not only by deterministic dynamical law but also affected by stochastic or disorder factors, Zhuang and Yin [7] studied the influence of random factors on LURR in order to judge whether a high Y value can be considered an earthquake precursor at a specified confidence level. They gave the critical value of LURR Y_c that depends on the number of earthquakes at different specified confidence levels. For instance, at the confidence level of 90%, Y_c is equal to 3.18 if the number of earthquakes in the time and space window is 20, which means that Y should be equal to or greater than 3.18 when the number of earthquakes is 20. For the confidence level of 99%, Y_c is 7.69 if the number of earthquakes in the specific time and space window is 20. The greater the earthquake number is the lower is the Y_c (critical LURR).

In this paper, we give the critical region of LURR by Y/Y_c instead of Y at a confidence level of 99%.

With the expansion of the prediction region, the refinement of its longitude and latitude, and the increase of the time period, the computation overburden will be very high, and the volume of data reaches the order of GB, which will be very difficult for a single CPU to deal with. In this paper, a new method was introduced to solve this problem. Adopting the technology of domain decomposition and parallelizing using MPI, we developed a new parallel tempo-spatial scanning program based on Yin's previous work.

2. Algorithm Formula

In previous work [8], we analyzed the algorithm, and the tempospatial scanning program of LURR is optimized. To calculate the distance between a location and epicenter takes the longest time in the whole procedure. This distance is two points' distance of great-circles on the spherical surface. The following formula can be used in the procedure to calculate the distance:

$$d = R_e \times \sqrt{\cos^2(\mathrm{lat}_z) + \cos^2(\mathrm{lat}_c) - 2\cos(\mathrm{lat}_z)\cos(\mathrm{lat}_c)\cos(\mathrm{lon}_z - \mathrm{lon}_c) + (\sin(\mathrm{lat}_z) - \sin(\mathrm{lat}_c))^2}, \tag{3}$$

where R_e is the Earth's radius, lon_c and lat_c are longitude and latitude of the epicenter, and lon_z and lat_z are longitude and latitude of the assigned location, respectively. The latitude and longitude are transformed from the angle value to the radian value. We discover that sine and cosine of latitude or longitude are independent between the assigned location and the epicenter mutually. Thus, these trigonometric functions can be calculated in advance.

Another time consuming operation is the calculation of assigned location's loading or the unloading response in the earthquake regions. The following equation is used

$$E = \sqrt{10^{(11.8+1.5M)}} = 10^{(11.8+1.5M)/2} = 10^{5.9+0.75M}, \tag{4}$$

where M is Richter magnitude scale. E must be computed once for each location in the earthquake spatial regions. In the present procedure, the LURR is only related to Richter magnitude scale, namely, LURR of an earthquake is a constant and needs to be calculated once only.

3. Parallel Computing

Based on MPI (Message Passing Interface) library, we parallelized computing of temporal and spatial scanning of LURR. The actual spatial region is divided into small spatial regions, each of which is computed by one processor. There are many different methods to partition the actual spatial region, such as, and block distribution, cyclic distribution, block-cyclic distribution.

3.1. Domain Decomposition Method. In domain decomposition method, macrotasking scheme is used, which divides the spatial scope into small regions. Considering the data independency and parallelism, any two neighboring region are not overlapped, the communication on the boundary is also reduced.

3.2. Data Reduction. The data of each step of longitude and the latitude scanning to be computed are recorded, and a great deal of data need high-frequency storage, which will spend large amounts of communication time dealing with the data reduction. In order to solve this problem, many temporary files are opened to record data by each processor separately. Once all processes are finished, the output documents are then written by one main processor.

4. Performance Testing

On the platform DeepComp 7000 Cluster, we have tested the LURR for China mainland with a time period from January 1, 1990, to December 31, 2004, with the spatial precision for

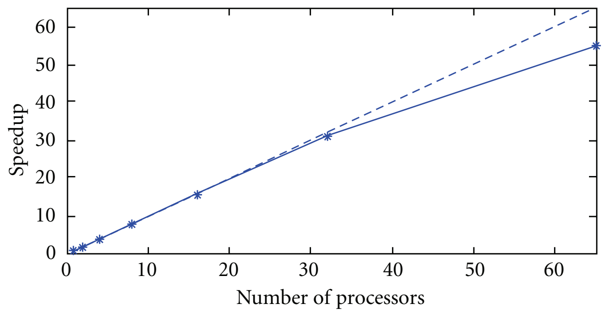

Figure 2: Speedup.

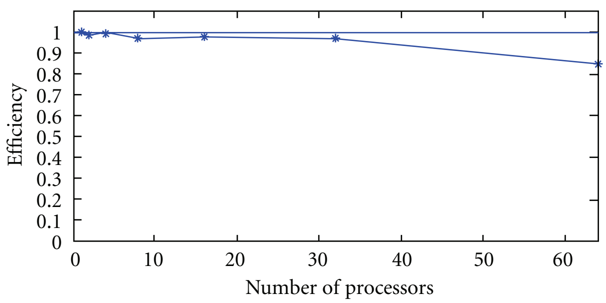

Figure 3: Parallel efficiency.

scanning being 0.01 degree. The speedup of this program is shown in Figure 2 and the parallel efficiency is shown in Figure 3. From the results we can see that the parallel efficiency is near 100% when the number of processors is less than 32. Although the parallel efficiency decreases because of the communication cost when the number of processors goes up to 64, which is a common problem for almost all parallel program, the speedup and parallel efficiency are still very high.

5. Conclusion

With the capability of supercomputer, we can do numerical simulation for the actual situation of earthquake preparation, the bullwhip effect, and cascade phenomenon from micro, small, medium, big to especially big seismic events; find the forming process and mechanism of large destructive earthquake; further improve the accuracy of time, space, and magnitude for earthquake prediction through temporal-spatial scanning of China mainland with multidimension, multiparameter, and multiepoch. Since earthquake prediction requires a valid-time computation, one should complete the calculations in a short time. In addition, this program requires less computation power that makes it less dependent on high performance computer and decreases running cost.

Acknowledgments

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