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PARALLEL COMPUTING IN SEISMIC DATA PROCESSING

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ABSTRACT
Parallel Processing, the method of having many small tasks solve one large problem, has emerged as a key enabling technology in modern computing. Most seismic problems carry an inherent parallelism and parallel computing is the only way to achieve improvements of several orders of magnitude in computer performance. In this article we have disused the parallel implementation of seismic migration and modelling algorithms.

Key Words: Parallel Computing, Seismic Migration, Seismic Modelling, Wave equation.

INTRODUCTION
Seismic Data Processing occupies a significant role in the exploration of oil and natural gases. Over the last two decades the computational requirements of the SDP activities have grown up many folds due to the increase in the data volume as well as the development in the mathematical algorithms. Three dimensional data acquisition has become routine as it has become necessary to look at the minor details of the underground geology.

Wave equation based methods (Phadke et.al., 1998) are gaining more and more popularity in recent years as they provide finer detailed geological features than other conventional methods as well as they preserve amplitude information. Advanced techniques are distinguished primarily by their use of wave equation. The most common advanced techniques include seismic migration and forward modelling. Finite difference methods are most suitable for migration and modelling as they offer most direct solution to the problem in terms of the basic equation and initial and boundary conditions.

By nature most seismic problems carry an inherent parallelism in subdivision by source, receivers, frequency or wave number. Indeed the problem decomposition in several domains is possible. With the change in demand it has become very difficult for a processing facility build around a serial architecture machine to cope up with increase in data volume. The I/O problems are better solved in parallel processing. The wave equation based methods are computationally more expensive but suitable for parallelization. The seismic processing industries all over the world have found parallel processing as the only solution to the challenges in probing the earth's interior for natural resources.

PARALLEL SEISMIC MIGRATION
The wave equation based seismic migration has become popular in recent years as it provides finer geological details. ω - x seismic migration is an advanced technique based on wave equation and uses finite differences. It has several advantages over conventional methods as it takes care of lateral velocity variations, can tolerate larger velocity errors, accurate upto 70 degrees and can handle dips upto 90 degrees. But it is computationally very intensive. The migration algorithms in

ω - x domain are inherently parallel in terms of frequencies. This favours us to take up the challenge of highly compute intensive nature of ω-x migration on a parallel architecture machine.

The migration method comprises of two steps *viz.* extrapolation and imaging. The extrapolation of the wavefield is carried out with a one-way wave extrapolation equation. The derivation of one-way wave equation begins with a constant density acoustic wave equation

$$\frac{\partial P^2}{\partial x^2} + \frac{\partial P^2}{\partial y^2} + \frac{\partial P^2}{\partial z^2} = \frac{1}{v^2(x, y, z)} \frac{\partial P^2}{\partial t^2} \tag{1}$$

A Fourier transformation with respect to x, y, z and t gives us the 3D dispersion relation

$$k_z = \pm \frac{\omega}{v} \sqrt{1 - \frac{v^2 k_x^2}{\omega^2} - \frac{v^2 k_y^2}{\omega^2}} \tag{2}$$

By keeping only the negative square root term and taking an inverse Fourier transform with respect to z, we obtain one-way wave equation in 3D

$$\frac{\partial P}{\partial z} = -i \frac{\omega}{v} \left(\sqrt{1 - \frac{v^2 k_x^2}{\omega^2} - \frac{v^2 k_y^2}{\omega^2}} \right) P \tag{3}$$

One way wave equation in ω-x domain is derived by first approximating the square root and then taking an inverse Fourier transform with respect to x and y. (Brown, 1983) suggested to approximate the square root term in (2) by

$$R = \sqrt{1 - X^2} + \sqrt{1 - Y^2} - 1 \quad \text{where,} \quad X = \frac{k_x v}{\omega} \quad \text{and} \quad Y = \frac{k_y v}{\omega} \tag{4}$$

and an approximation to (4) (Bunks, 1992) is given by

$$R = \rho - \frac{\beta X^2}{1 - \alpha X^2} - \frac{\beta Y^2}{1 - \alpha Y^2} \tag{5}$$

where ρ, α and β will be determined by solving an optimisation problem. For 45 degree approximation $\alpha = 0.25$ and $\beta = 0.50$. Now substituting (5) in (2) and using the definition of retarded wavefield equation (Claerbout, 1985), we obtain the one-way depth extrapolation equation in 3D

$$\frac{\partial Q}{\partial z} = -i\omega \left\{ \frac{\rho}{v(x,z)} - \frac{1}{\bar{v}(x,z)} \right\} Q + \left(i \frac{\beta k_x^2 \frac{v}{\omega}}{1 - \alpha k_x^2 \frac{v^2}{\omega^2}} \right) Q + \left(i \frac{\beta k_y^2 \frac{v}{\omega}}{1 - \alpha k_y^2 \frac{v^2}{\omega^2}} \right) Q \tag{6}$$

The first term on the right hand side is called thin lens term and the other two terms are called differaction terms. Thin lens term has a straightforward analytic solution, whereas diffraction terms are solved by finite difference method using a splitting technique. The splitting method for solving the diffraction term is also called onepass migration method. This method works very well for handling strong lateral velocity variations.. For the one pass method the field is downward continued alternately along the x and y directions for each depth step. The differential equations in ω-x domain for downward continuation in x and y directions are given by

$$\left(1+\frac{\alpha v^2}{\omega^2}\frac{\partial^2}{\partial x^2}\right)\frac{\partial Q}{\partial z}-i\frac{\beta v}{\omega}\frac{\partial^2 Q}{\partial x^2}=0 \tag{7}$$

$$\left(1+\frac{\alpha v^2}{\omega^2}\frac{\partial^2}{\partial y^2}\right)\frac{\partial Q}{\partial z}-i\frac{\beta v}{\omega}\frac{\partial^2 Q}{\partial y^2}=0 \tag{8}$$

The imaging part is the summation of all the frequencies at t=0 at each depth step.

$$P(x,y,z,t=0)=\sum_{\omega}P(x,y.z,\omega) \tag{9}$$

IMPLEMENTATION OF ω-x MIGRATION

The stacked data is first Fourier transformed with respect to time and stored in frequency sequential format. Only the required number of frequencies are stored after Fourier transformation. The frequency band width to be used for migration is determined from spectral analysis of the input traces. This forms the input data to the depth migration code. In addition to this a proper velocity depth model is also required. The parallel implementation is analogous to Master-Worker system. After reading all the required parameters, the Master determines the number of frequencies and frequency bandwidth to be assigned to each Worker. Then it reads and sends the frequency data to the designated Worker. Then the migration algorithm runs through the depth steps. The required velocity data for that depth step is sent to the Workers. Also the migrated data from all the Workers for that depth is collected by Master, imaged and stored on the disk. A flow chart of this algorithm is shown in Figure 1. The figure only shows one Master task and one Worker task, but in reality there are many Worker tasks. All the Worker tasks communicate with Master task in an identical fashion as shown in the figure 1.

PARALLEL SEISMIC MODELLING

A basic problem in theoretical seismology is to determine the wave response of a given model to the excitation of an impulsive source by solving the wave equations. In scalar approximation, the acoustic wave equation may be solved to evaluate the waveform but only compressional waves are considered. A more complete approach is to study the vector displacement field using the full elastic wave equation for modelling both P-waves and shear waves. However, important wave properties such as attenuation and dispersion require a more sophisticated set of equations.

For implementation of seismic modelling algorithms we have used a domain decomposition scheme. First, the problem domain is divided into subdomains that are assigned to separate processors. Figure 2(a) shows an example of the division of problem domain into four subdomains. Depending upon the number of available processors and the problem, one can divide the problem domain into any number of subdomains. we are using a nine point difference star for MacCormack method (Phadke & Bhardwaj, 1997, 1998), the calculation of the wavefield at an advanced time level for any grid point, requires the knowledge of the wavefield at 9 grid points of the current time level. For grid points along the boundaries of the subdomain, the information about the neighbouring grid points comes from the adjacent subdomains. Therefore after each time step the subdomains have to exchange wavefield data. Figure 2(b) shows the required memory space for each 2D array of the subdomain and the communication between two adjacent subdomains. The data in the darker region is sent to the lighter region of the neighbouring subdomian using message passing calls.

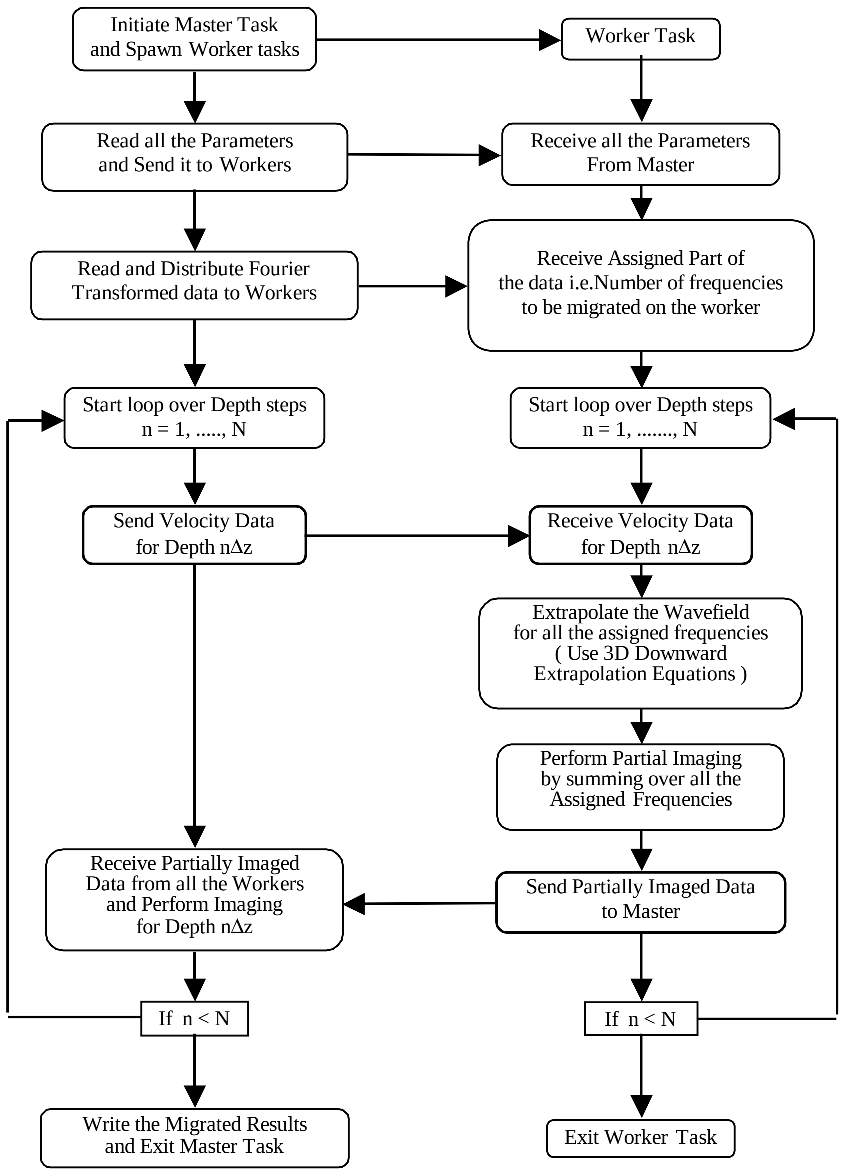

Figure 1 :Flowchart of the ω-x migration algorithm

In the parallel implementation of the modelling codes there is a master task and there are number of worker tasks. The main job of master task is to divide the model domain into subdomains and distribute them to worker tasks. The worker tasks perform time marching and communicate after each time step. As demanded by the user the snapshot and synthetic seismogram data are collected by the master and written out on the disk.

(a) (b)

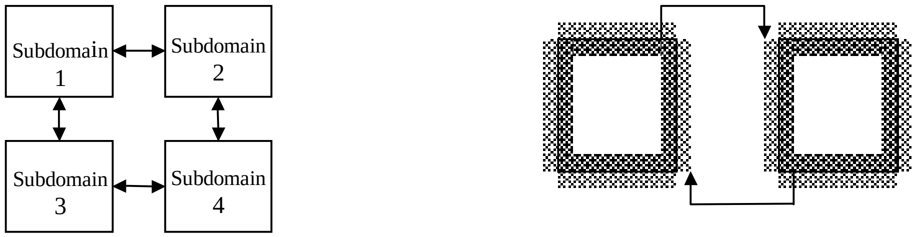

Figure 2: (a) Decomposition of model domain into subdomains (b) Communication between two adjacent tasks

NUMERICAL EXAMPLE

We have tested the parallel codes by generating a synthetic data using forward modelling and depth migrating it. The velocity model used for generating the synthetic data is shown in Figure 3. The model comprises of a weathered layer on top of a dipping layer and a graban like structure. Synthetic seismograms were calculated for this model for 46 source positions with a source interval of 50m and a receiver interval of 25m. A higher order (Mac-Cormack method) finite difference modelling algorithm based upon acoustic wave equation was used with a grid spacing of 5m. A Ricker wavelet with a dominant frequency of 30Hz was used as the source function.

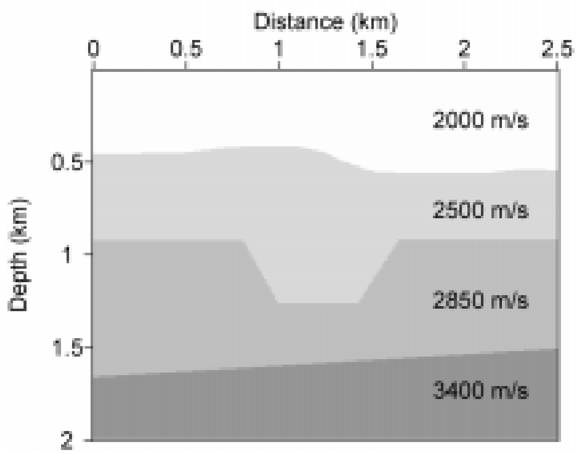

Figure 3: Velocity model used for the generation of synthetic data set

A CDP stacked section of the synthetic data set is shown in Figure 4. Next this stacked data set was migrated using the ω-x 2D depth migration algorithm. Depth migrated section is shown in figure 5. For both, modelling and migration examples presented in this paper we have used 16 processors of PARAM 10000.

CONCLUSION

The numerical example shows the accuracy of the results. Various seismic migration and modelling algorithms have been implemented on PARAM series of parallel computers. Parallel processing enables us to use one-pass approach for 3D seismic migration (both in depth and time) which has several advantages over conventional two pass approach while providing more accurate results. We have made use of these implementations for successful processing of various real data sets from oil industry as well as research institutions. Parallel computing helps us in taking up the challenges of complexities of high resolution mathematical algorithms and large volume of data sets. It also takes much lesser time as compared to the sequential processing. Parallel implementations have been done using PVM (Parallel Virtual Machine) & MPI (Message Passing Interface) message passing libraries. This enables the portability of the software across various parallel machines.

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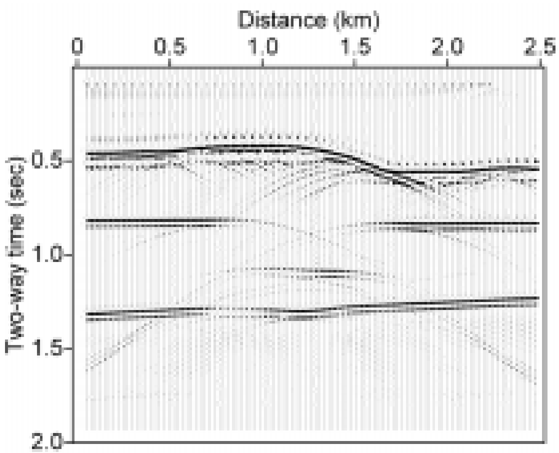

Figure 4: A CDP stacked section of the synthetic data set.

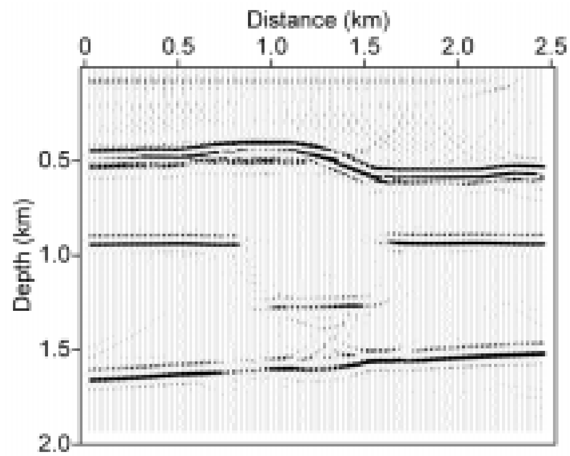

Figure 5: The migrated seismic sections