Parallel 2D Pre-Stack Imaging On PARAM Padma

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Summary

Obtaining high-resolution images of the underground geological structures using seismic reflection data in prestack or poststack domain is crucial for exploration of oil and gas deposits. In petroleum industry, seismic migration is one of the most compute intensive steps in seismic data processing sequence. It accurately images the reflected and diffracted energy and aids in delineating the structural features of the underground geological formations. Migration techniques are highly compute and input/output (I/O) intensive and therefore requires high performance computing. In the last decade the development of parallel distributed computing platforms, related system software and programming environments have made it possible to use parallel codes for high resolution imaging. Centre for Development of Advanced Computing (C-DAC), Pune has developed the OpenFrame architecture for scalable parallel computing applications. Various seismic migration algorithms have been developed and implemented for imaging purposes. In this presentation we will discuss the parallel implementation achieved on C-DAC's PARAM Padma platform for two totally different 2D pre-stack migration algorithms. In both cases parallelisation has been done using MPI message passing environment and MPI I/O for parallel file reading and writing. The first algorithm is Finite difference based depth migration in frequency - space domain (ω-x depth migration) and the second one is based on integral or summation approach migration in time (Kirchhoff time migration). The benchmarking results for both the algorithm clearly shows that large-scale problems can be solved by implementation of highly efficient and scalable codes. These codes can be easily ported across cluster of workstations.

Introduction

Seismic imaging is a form of echo-reconstructive technique based on experiments, in which a certain earth volume is illuminated by an explosive or vibratory source, and the backscattered energy by the inhomogeneties of the medium is recorded on the surface in digital form. The inhomogeneties act as reflecting surfaces, which cause signal echoing; the echoes are then recorded at the surface and processed through a "computational lens" defined by a propagation model to yield an image of the inhomogeneties. Seismic Migration is a wave equation based technique that attempts to remove all the distortions from the reflection records by migrating events to their true spatial locations. Migration technique positions dipping and diffracted events observed on seismic section to their true positions in the subsurface resulting in an image, which has greater spatial resolution. It is quite logical to term migration as an inverse process in which recorded events are propagated back to the corresponding reflector locations.

There are many ways to migrate seismic data. The numerical techniques employed can generally be separated in three broad categories, namely: summation or integral methods such as Kirchhoff migration (Schneider, 1978); finite difference methods (Claerbout, 1976, 1985); and transform methods such as *f-k* migration (Stolt, 1978; Gazdag, 1978; Gazdag and Sguazzero, 1984). All these migration methods make use of some approximation to the scalar wave equation.

The choice of a migration method to a particular data set depends upon the complexity of the velocity model. Migration methods (*f-k* migration) that are computationally fast can only accommodate velocity variations with depth. Other methods, e.g. Kirchhoff method, finite difference method, PSPI (Phase Shift Plus Interpolation) method, can also handle lateral velocity variations, but require large computational resources in terms of speed, memory and I/O.

Migration can be performed in time or in depth. In the presence of strong lateral velocity variations, time migration followed by time to depth conversion does not image the reflected energy to its true subsurface position. Depth migration is essential in these cases. Depth migration compensates for ray bending, lateral velocity pull-ups and structure. A natural advantage of depth migration is that the output image is displayed in depth and therefore can directly be utilized for geologic interpretation.

Migration can be carried out in prestack or poststack domain. The poststack methods are applied to stacked data and are based upon the exploding reflector concept. Prestack migration methods are applied to data before stack and based on downward continuation of the wavefield (Claerbout, 1985). As the common-midpoint stack does not correctly stack dipping event, poststack migration cannot image the dipping event correctly. Though, it is cheaper in terms of computation but inferior to the prestack migration.

Parallel computing

As already mentioned that the migration techniques are highly intensive in terms of computing. So a natural way to circumvent this situation, is to use parallel computing in which a large number of processors are connected in parallel and are programmed to work simultaneously on a given problem. Thus parallel computing environment provides much higher computation rates. Parallelism is essentially a process of performing tasks concurrently. The most commonly used method of parallel programming, which we have also implemented, is message passing or some variant of message passing. In the basic 'message passing', the processors coordinate their activities by explicitly sending and receiving messages. In all parallel processing algorithms, data must be exchanged between cooperating tasks. Message Passing Interface (MPI) is the most common message-passing library used for exchange of data. The main advantages of establishing message-passing interfaces are portability and ease of use.

As far as the parallel strategy for seismic imaging is concerned there are two types of approaches: function parallelism and data parallel approach. In the function parallel approach, portions of the code are distributed among the processors, while in data parallel case, subsets of the data or model space are distributed among the processors for parallel computation, which runs identical codes on these subsets. For parallelizing most of the seismic migration methods, data parallel approach is the most suitable one.

The parallel implementation is analogous to a Client – Server system, where there is one server with multiple clients. One can also think of it as a Master – Worker system, where the master works as the manager and assigns tasks to his workers. The job of the master is to provide the required parameters and data to all the workers and distribute workload properly, so that idle time of worker is minimized. Also, at the end the master should collect the finished work from all the workers, compile it and store it in a proper manner. One of the processor acts as master and worker tasks are assigned to different processor. In another approach, the master can also be a worker after distributing the data, which is termed as latency hiding in parallel computing literature (Pacheco, 1997).

Migration algorithms on PARAM padma

Among many approaches to perform migration in prestack data, here, in this paper we will show implementation of two prestack migration techniques, namely pre-stack 2D Kirchhoff time migration and 2D frequency-space depth migration. First is, integrating the wave field along the diffraction surfaces/curves in time domain and the other one is downward continuation of the wavefield in depth domain. The parallel implementation of these algorithms will be carried out on PARAM series of parallel computing systems. The latest member of this series, PARAM Padma, is the next generation high performance scalable computing cluster, with a peak computing power of one teraflop (1TF). The effectiveness of the methods will be demonstrated by applying it to synthetic seismic data.

2D Pre-stack Kirchhoff time migration

One of the main advantages with Kirchhoff migration is the fact that it is less addicted to regularity than any other wave equation based migration, which follows finite – difference method for solution of wave equation. It can accommodate irregular sampling and even non-planar data acquisition. It gives good performance with steep dip angles and moderate performance on lateral and vertical change of velocity. Kirchhoff migration performs badly in low signal to noise ratio. In this method, the amplitudes are summed along the diffraction hyperbola and the result is placed at its apex (Schneider 1978). A straightforward summation of amplitudes is carried out along the hyperbolic trajectory whose curvature is governed by the velocity function. Assuming a horizontally layered velocity model, the velocity function used to compute the travel-time trajectory is the RMS velocity at the apex of the hyperbola. The lateral extent of the diffraction hyperbola (aperture) in the summation process is also a crucial parameter in the migration process (Rastogi et.al., 2002)

Kirchhoff migration method can be described by the integral solution to the scalar wave equation (Berkhout, 1980; Schneider, 1978; Berryhill, 1979; and Bancroft 1998). In pre-stack Kirchhoff time hyperbolic trajectory time is calculated for the migration of a point in the subsurface, is the sum of travel time from source to that point and that point to the receiver. Here, we have used fixed aperture width for migration, which is a distance from both side of a migration location. A criterion is defined for the selection of input traces from different shot gathers for migration. If the offset of the trace lies within the offset cutoff limit and the midpoint of the trace should fall within the +/- aperture distance from the migration location then that trace is added for the output migration location after applying some factor (Yilmez, 1987). In the present implementation of the algorithm, for migrating an output location whole data volume has to be searched to select the required traces for summation.

Parallel Implementation

Parallelization of Kirchhoff migration algorithm exhibits the inherent parallelism in terms of migration locations, as the migration of first location doesn't depend

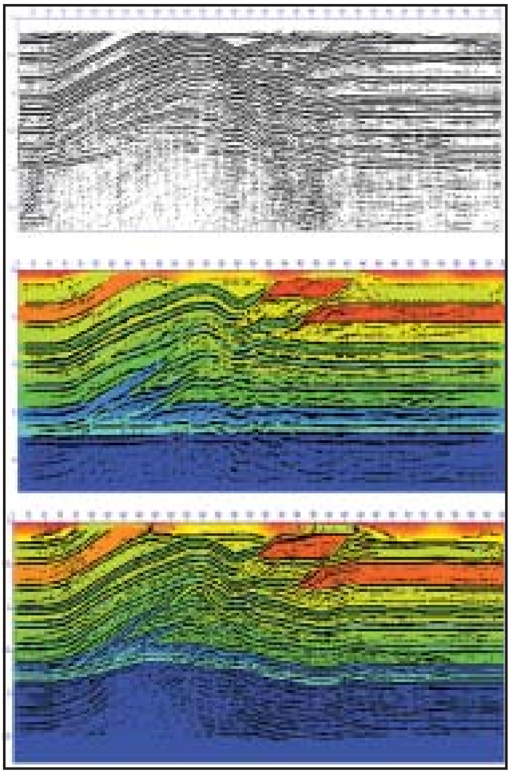

Fig.1 : (a) Zero-offset section of a line from 3D volume of SEG/EAGE overthrust model. (b) The same line after 2D ω-x pre-stack depth migration. (c) The same line after 2D Pre-stack Kirchhoff time migration results.

on migration previous or side wise locations. Therefore, the data parallel approach is used here and the loop over output location is parallelized. It is a SPMD (Single Program Multiple Data) approach, where the program running on all the processors is same but data is different. All the processors calculate their output locations and read the corresponding data and velocity files, calculates the aperture distance, perform migration and write the migrated section into the output file. MPI I/O is used for reading and writing input data, velocity data and output data. Parallel implementation of this algorithm on PARAM Padma can be easily understood by a flow chart as shown in the Figure 2.

2D Pre-stack Depth Migration in *ω-x* domain

Most of the wave equation based migration methods comprise of two steps, extrapolation and imaging. In the extrapolation step the wavefield is downward continued using some form of the acoustic wave equation. Basically extrapolation involves the numerical reconstruction of wavefield at depth or traveltime depth (in the case of time migration), from the wavefield recorded at the earth's surface. Imaging is a process that allows one to obtain the local reflection strength from the extrapolated data in depth or traveltime depth (time migration) and create an image of the subsurface reflectors. At each depth the image is formed at t = 0. The extrapolation of the wavefield can be carried out in t-x, *ω-x* domain. Here we are describing the implementation of migration in *ω-x* domains for pre-stack data. For 2D pre-stack depth migration, the extrapolation equation in ω-x domain is a parabolic partial differential equation (Claerbout, 1985) consisting of a diffraction term and a thin lens term. The thin lens term, which accounts for lateral velocity variations, is usually ignored in time migration. The diffraction term is numerically solved by the method of splitting, which is the basis for the onepass approach. In pre-stack ω-x depth migration the extrapolation is achieved by double downward continuation of source and receivers one after the other. Crank - Nikolson finite difference scheme (Mitchell and Griffiths, 1981) with absorbing boundary conditions on the sides of the model is used for the solution. The thin lens term is solved analytically. Imaging is the summation of all the frequencies at t=0 for each depth.

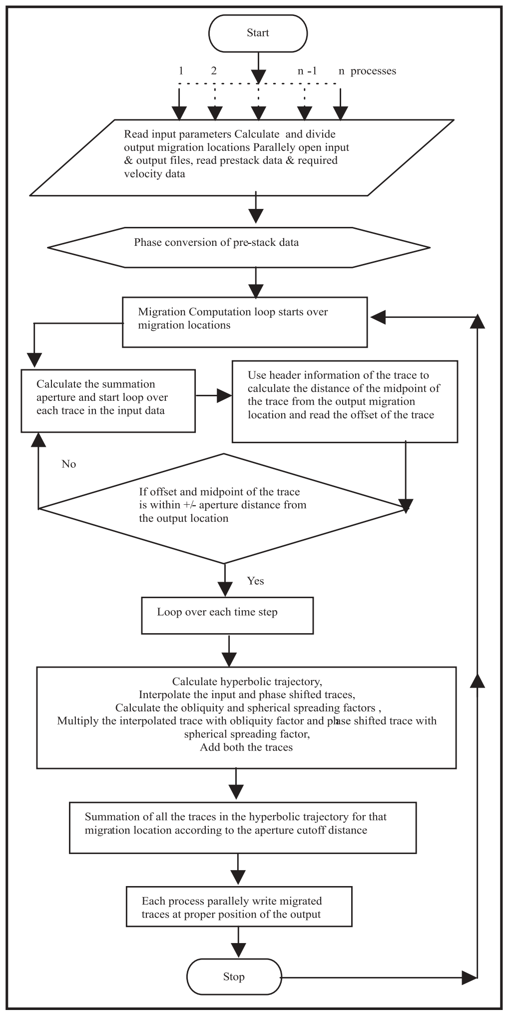

Fig. 2: The parallel program flow of 2-D Kirchhoff Pre-stack Time migration.

Parallel Implementation

The pre-stack depth migration algorithm in ω-*x* domain is inherently parallel in terms of frequencies. The parabolic approximation of the wave equation in frequency-space domain has decomposed the wave field into monochromatic plane waves that are propagating downwards. Therefore, each frequency harmonic can be extrapolated in depth independently on each processor and there is no need of inter-task communication. One can introduce parallel task allocation into each frequency harmonic component with the ultimate goal to have as many processors as frequencies. This approach is also data parallel parallelisation but it is using MPMD (Multiple program multiple data) model Here, after reading all the required parameters, the Master (processor with rank 0) 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 in a sequential manner and after that the migration algorithm runs through the depth steps. The required velocity data for each depth step is sent to the Workers in the depth loop. Also the migrated data from all the Workers for that depth is collected by Master, imaged and stored on the disk (Phadke et al., 1998). At each depth step all frequency components after extrapolation are summed up (Imaging Condition) to give the migrated image. The summation is carried out by automatic merging using MPI_Reduce. Flow chart for parallel implementation of finite difference migration is given in Figure 3.

Results and discussion

The output of any Migration process is a seismic section that shows the structural details of the subsurface in true sense. The stacked seismic section before migration, though it shows the subsurface structure, is often misleading and sometimes gives rise to some spurious prospective subsurface structure. That is why migration is an essential and crucial step of Data Processing in the petroleum exploration. To show the efficiency and efficacy of our developed parallel migration algorithms, we migrated one pre-stack line of the 3D data set of SEG/EAGE (1997) Overthrust model on PARAM Padma (a cluster of workstations of 1 TF peak performance). The dataset consists of 97 lines, 401 CDPs per line and 350 time samples per trace with 8 msec sampling interval. In depth migration algorithm the wavefield was downward continued by 187 depth steps with 25m depth interval. In time migration has been performed on 621 migration location 25m apart in x direction. Figure 1(a) shows the zero-offset section for one of the lines, which is migrated here. 2D pre-stack (Clearbout, 1985, Yilmez, 1987) migrated sections for the line using ω-x depth migration and Kirchhoff time migration are depicted in the Figures 1(b) and 1(c). In all the migrated section, the velocity model is superimposed to show the accuracy of the algorithms. Figures 4 and 5 show the execution times as a function of number of processors for 2D ω-x pre-stack Depth migration and Kirchhoff pre-stack Time migration respectively.

Scalability and Speedup

Efficiency of any parallel application depends on its scalability with increasing number of processors. Execution timing and speedup graphs of pre-stack FD depth and Kirchhoff time migration algorithm are shown in Figure 4 and 5 respectively on PARAM Padma. The execution time graph shows how the time for execution of a given problem changes with the increase in the number of CPUs used to solve the problem. As is clearly seen in the execution-timing graph, depth has larger computations than time migration. So, for any given number of processors ω-x depth migration has better computations to communication ratio. This explains why it has better speedup graph than that of Kirchhoff time migration.

Conclusions

In this paper we have demonstrated two different

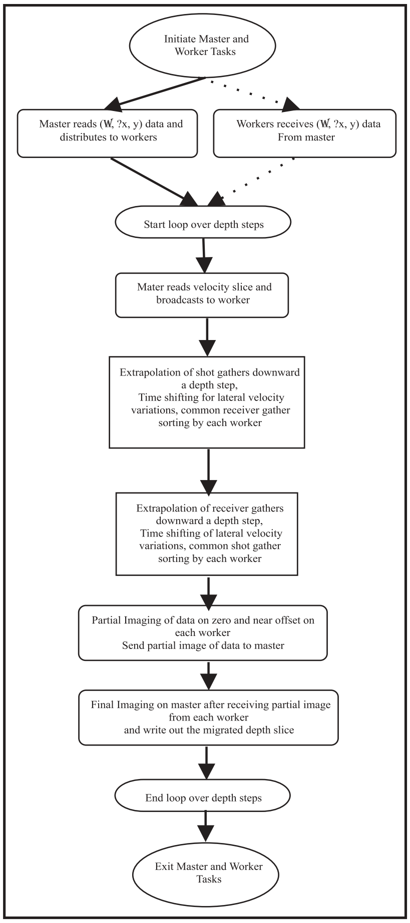

Fig. 3: The parallel program flow of 2-D ω-x Pre- stack Depth migration.

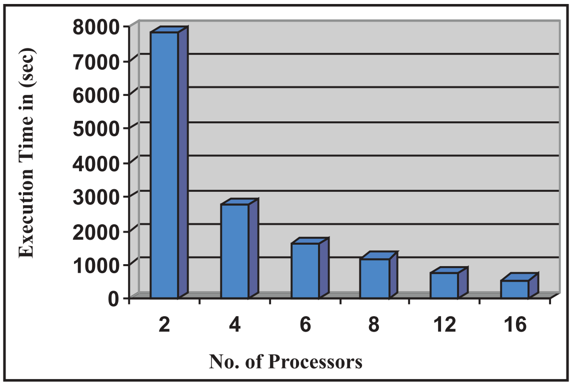

Fig.4 : The Execution timings of 2-D ω-x Pre-stack Depth migration.

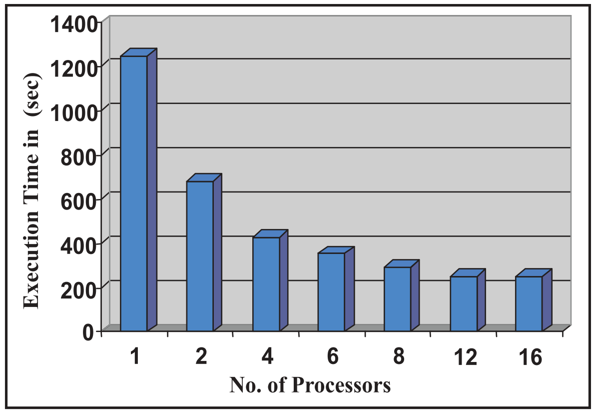

Fig.5: The Execution timings of 2-D Kirchhoff Pre-stack Time migration.

2D pre-stack migration algorithms in depth and time domain for seismic imaging on a parallel-distributed computer enviornment. The developed migration algorithms are highly efficient as shown in the Figures 1(b) and (c). The algorithms are also highly scalable on parallel computing systems as evident from the execution time graphs. For the current problem size, Kirchhoff migration algorithm is not scaling up beyond 12 processor see figure 5, because for migrating one location a processor has to search the data volume for suitable traces before it goes for trace summation. So, in this present implementation of Kirchhoff migration, I/O time increasing with number of processors increase than the actual computation time. Also because of parallel I/O there is absolutely no communication required among the preocessors. The second algorithm is highly scalable with the increasing number of processors and shown almost linear speedup as evident form the execution time graphs in figure 4. Both pre-stack migration codes (Finite Difference and Kirchhoff) are inherently parallel in different domains and therefore it is possible to write efficient parallel codes. The performance graphs clearly demonstrate this claim. Parallel computing has made it possible to apply such techniques to large real data sets on a routine basis.Also, from the migrated sections of the Figures 1, one may observe, which is in fact proven fact that the depth migration gives much more realistic subsurface image, though it is expensive than pre-stack time migration.

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