Parallel Seismic 2-D Reverse Time Migration

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Abstract— In Oil and Gas industries, Reverse Time Migration (RTM) has become a powerful technology in seismic imaging for complex subsurface structures, because of the quality and integrity of the images it provides. But computational cost of RTM is high. In case of RTM, program run times are long, i.e. total number of CPU cycles are more and it requires large amount of disk space. This hinders its practical success. To accelerate computing, parallelization can be used which can be implemented by using Message Passing Interface (MPI) and OpenMP on multicore computers, for forward modelling and reverse time extrapolation. MPI is used to exploit core-level parallelism and OpenMP to exploit thread-level parallelism.

On the daily basis practical use of serial implementation of RTM is not possible. We implemented RTM parallelly by using MPI and OpenMP so that we can achieve better performance.

Keywords—*Reverse Time Migration,High Performance Computing, MPI, OpenMP*

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I. INTRODUCTION

Now a days there is increasing demand of processing speed and high speed performance therefore High Performance Computing has emerged as most conventional computing method. HPC is a method of accumulating power that conveys much high performance than a typical computer to solve a much larger problem. As advanced problems and research activities are needed to be tackled HPC has proven to be conventional method for solving the problems. High Performance Computing is practiced for solving advanced problems and conducting research activities through modelling, simulation and analysis. The need of HPC increases day by day as the demand of more computational power, more than available increases.

HPC finds its use in various multidisciplinary fields due to its high speed computing. Some of the fields in which HPC is used are Geographical data, Climate modeling, Biosciences, Seismic data processing and many others

A. Motivation

From studies and analysis of past several decades oil and gas industry is continuously trying to balance the need of imaging rapidly and meticulously i.e. rapid imaging and imaging with utmost care is being tried to achieve by the industry. Cost of drilling a dry well and cost of finding any reserves are high which drives the need for meticulous due to poor imaging for former and the need for quick imaging for the later. As there is need of reducing these costs the industry depends on high performance computing clusters and increase in compute power to have faster and accurate imaging. It is known that the seismic people have huge data sets and time-consuming algorithms to create subsurface images to drive the drill decisions, as a result processing time is increased and HPC finds its way to be used effectively. In seismic modelling, the most computational part is of seismic migration that consumes about 90% of the computational time, this computational time can be reduced by high performance computing.

Reverse Time Migration (RTM) is one of the high quality migration method that demands the most computational power in seismic exploration. Crucial drilling decisions are to be taken for the oil and gas industries therefore RTM is considered the most advanced technique by these industries. It is essential to exploit parallelism at all the levels for RTM to become a feasible solution to obtain a complex geological image.

II. BACKGROUND

A. Seismic Data Processing

To manipulate the acquired seismic data into an image that gives details of the subsurface structure is considered to be main objective of Seismic Data Processing. The five main methods to acquire seismic data are:

1) Positioning
2) Seismic Energy Source
3) Data Recording
4) Data Processing
5) Data Interpretation

The seismic data which is to be acquired involves transmission of acoustic energy to the Earth’s surface and recording the reflected waves from the surface. These reflections can be processed to produce Synthetic image of Earth’s subsurface.

In seismic reflection, elastic waves using an energy source like vibroseis or dynamite are sent to the Earth’s surface. Some of the energy waves are reflected while rest are refracted by various layers of Earth’s surface. Geophone in case of land and hydrophones in case of water are the receivers which record the reflected waves. Geophones convert ground motion to electrical signals whereas hydrophones convert pressure changes to electrical signals. The responses of the receivers are recorded to data storage device. Various techniques like modelling, migration, inversion, etc. are used to process the acquired data. Geologist or geophysicist interpret the processed data.

B. Seismic Migration

The main objective of seismic migration is to remodel the reflectivity of Earth’s surface from the recorded seismic data. The seismic data recorded by the receivers are the superposition of the seismic waves from all directions in the terrain. Thus the recorded reflections are not only from the surface just below the receivers but also from the far geological formations. Seismic Migration refers to the process in which the seismic events are geo-metrically relocated to the location the event occurred rather than to the location where it was recorded.

C. Reverse Time Migration

The type of Seismic Depth Migration that solves fundamental acoustic wave equation is referred to as Reverse Time Migration. Wave Equation is used by RTM in time domain. All elastic properties that makes it difficult to apply and requires tremendous amount of computational power are accounted by Elastic implementation. Therefore, acoustic wave equation is used to propagate the wavefield.

The RTM is a wavefield continuation method in time that simulates all kinds of waves. RTM consists of two basic steps:

1) Numerical Propagation:

The numerical propagation of the wavefield is further divided into two steps:

a. Source wavefield: The source wavefield is propagated forward in time starting from t=0 from the source signal
b. Receiver wavefield: The receiver wavefield is propagated backward in time from the received signals at the surface.

2) Imaging:

Source and receiver wavefields are cross correlated with the imaging condition to create the final subsurface image.

To propagate the source wavefields forward in time with computational scope from t=0 to t=maxtime and store the resulting wavefields(t,x) in timesteps consistent with the sampling rate dt is the key idea behind RTM. The recorded data is used as input to backward propagate the wavefield from t=maxtime to t=0 and stored in r(t,x).

The final image is given by:

$$I(x) = \sum_{t=0}^{maxtime} s(t,x)r(t,x)$$

D. MPI and OpenMP

MPI is a standard message-passing interface for applications and libraries running on concurrent computers with logically distributed memory. It is a communication protocol that supports point-to-point and collective communication. In MPI, data movement is carried out by moving data from address space of one process to the address space of another process through cooperative operations.

OpenMP is an application programming interface that supports shared memory programming. OpenMP is similar to multithreading where master thread forks slave threads that perform specific tasks. OpenMP can be used to achieve task-level as well as data-level parallelism.

III. PROPOSED SYSTEM

After studying RTM, few points to consider:

RTM consists of three main steps: Forward modeling, Reverse time extrapolation and Cross-correlation. Here, cross-correlation is performed on results obtained from forward modeling and reverse time extrapolation as a result we need to save the results of forward modeling as well as reverse time extrapolation. As seismic data sets are very large upto 100,000 shots at 0.1-1 GByte per shot, large disk space is required to store results. The main HPC challenge is to transfer these huge data from disk to memory. We need to handle this data for processing, interpretation and visualization.

In RTM, the seismic waves which are being propagated are modeled using wave equation which needs to be applied twice. Firstly, in forward modeling where assumptions are made about the characteristics of the seismic source and its variations in subsurface velocity which results in forward wavefields. With the help of seismic traces recorded by geophones and assumed velocity model, the observations are reversed in time and back propagated using the same wave equation resulting in receiver wavefields. Finite Difference Method (FDM) is used to propagate all wavefields in space and time. To ensure meaningful and correct results time and space needs to be discritized into small grid intervals. As Partial Differential Equation is used in time and space, the FDM approximates the future values for all the derivations. Also to obtain reliable results, RTM requires high-order approximations for all derivatives. These reasons define why the RTM kernel is inherently compute intensive.

From the earlier days, it was the standard practice to write the forward wavefield to the disk. Then, cross-correlate this stored source wavefields with the receiver wavefields in the subsequent step. This cross-correlation was the basis of the imaging condition. This method gave appropriate subsurfaces images but couldn’t succeed much as multiple TB data was difficult to fetch. The urge to write the forward wavefields to disk and re-read them during cross-corelation with receivers wavefields results in disk I/O as the significant bottleneck.

A. Problem Defination

It may take days or even months to execute, when RTM is executed on single core machine. Also, if it executed on multicore architecture, it is of not much use if designed serially. Designing the code parallel using MPI and OpenMP to reduce the execution time is the main goal. MPI is used for communication between the nodes and OpenMP is used for multithreaded, shared-memory parallelism. The combination of shared memory (OpenMP) and message passing (MPI) parallelisation paradigms within the same application can provide more efficient parallelisation strategy. Core-level parallelism is achieved using MPI and thread-level parallelism is achieved using OpenMP.

The implementation of MPI and OpenMP will give the estimation of the overheads and use of OpenMP will remove some of the overheads like data movement, false sharing and contention.

B. Proposed System

In the proposed system we are going to design the Reverse Time Migration code. This will include propagating the source wavefields forward in time from t=0 to $t=t_{max}$. Then storing the resultant wavefields and applying reverse time extrapolation by backward propagating the receiver wavefields from $t=t_{max}$ to t=0 and saving the results. The final RTM image will be obtained by cross-correlating the source and receiver output wavefields.

In this scenario we will use parallel programming to divide large problem into subtasks and solve it concurrently. For that OpenMP and MPI will be used. RTM algorithm will be implemented for 2D multiple shots. Here source locations will be calculated and divided among different processors using MPI i.e. master will divide the task among workers. All the workers will propagate the source and receiver wavefields concurrently. The master node will collect the final result from all the workers using MPI_Reduce to get the final migrated image. To ensure parallelism within the nodes OpenMP will be used to divide the work among each core.

C. Implementation Result

Input:

The Input data is the Sigbee model is 9.144 km (30 000 ft) in depth and 24.384 km (80 000 ft) in length. The model contains 7.62 m (25 ft) grid spacing that have 11.43 m (37.5 ft) lateral grid spacing. The grid contains 1201 data points in Z direction and 3201 data points in X direction.

The code is executed on an Intel core i5-2400 CPU @ 3.10 GHz processor with 2 GB RAM with no. of cores and threads equal to 4

Figure 1 shows the input Sigbee velocity model

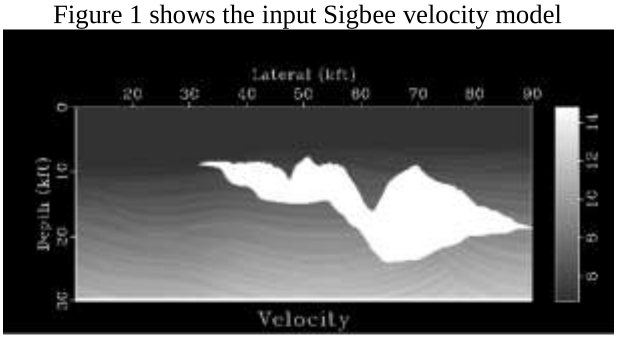

Figure 1: Velocity Model

Figure 2 shows the density model

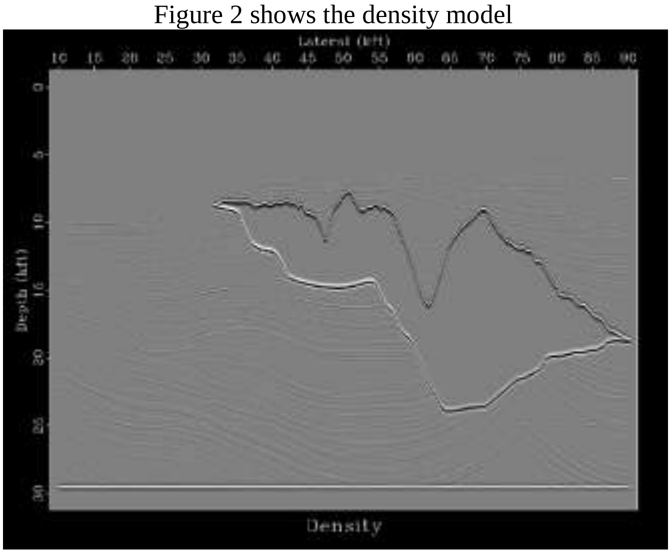

Figure 2: Density model

The resultant output RTM image obtained by forward and reverse propagation of the Sigbee model is shown in figure 3.

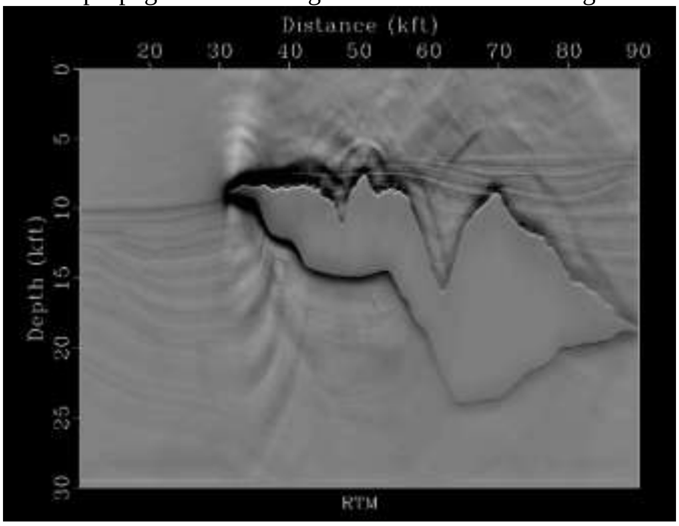

Figure 3: RTM output image

D. Intel VTune Amplifier Result Analysis

Here Intel VTune Amplifier is used to analyse and identify how effectively the program uses CPU, memory and floating-point operation hardware resources. It is a component of Intel Parallel Studio used for analysis of local and remote target systems.

Table 1 shows the time taken by the algorithm to execute.

Elapsed Time	115.588s
CPU Time	420.440s
Total Thread Count	4

Table 1: Time taken to execute code

Here, the total elapsed time is *115.588s* which is the clock time and includes waits. The CPU time is *420.440s*, which is higher than the elapsed time and is due to the fact that the program is being executed on a multi-core processor and the CPU time is the summation of time taken by all the cores.

IV. CONCLUSION

RTM algorithm when executed in parallel with MPI and OpenMP on Intel Core i5 took approximately 1.92 minutes to execute i.e. such data consuming and time consuming applications can be run on a normal desktop with utmost efficiency when executed in parallel.

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