Reverse Time Migration Algorithm

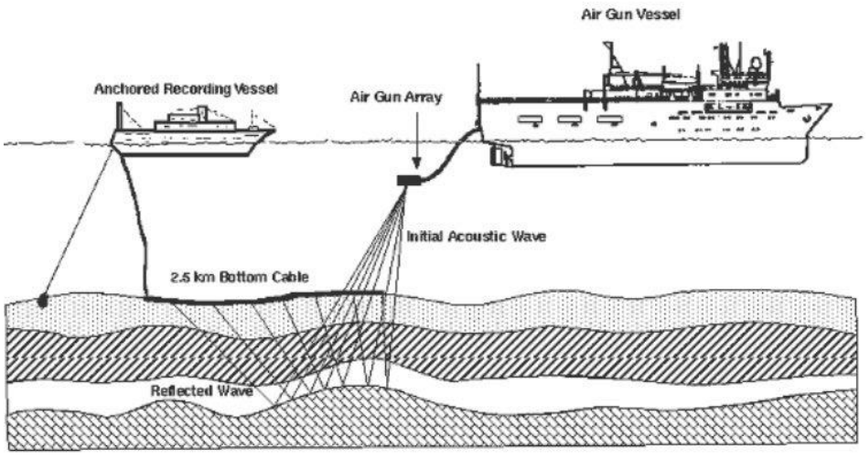
What is seismic exploration:

The purpose of the seismic exploration is to understand the constitution of the interior earth as much as possible. As we know, it is impractical or even impossible to penetrate the earth and put your camera there to capture the image, other indirect approaches are used to attain the similar or same result. These approaches include seismological measurement, electromagnetic measurement and gravity measurement. As these approaches are indirect, they usually give an analyze or indication of the measured result. Some tools, such as computers, are required as part of the analyze and the capability of the tools may be the bottleneck of the analyze. For example, in the past, with the poor computational performance of the computer, the data in only a small region and in a low resolution could the seismologists analyzed due to the limited computing power. As the Moore's Law indicates that the number of transistors double every 18 months, the computer gains much more computing power than before. Some seismological methods, which are computationally-demanding, seems not practical in the past, can be implemented by utilizing the advanced technology today. One of the most useful but computationally-demanding algorithm, **Reverse Time Migration algorithm**, also comes into reality. Reverse Time Migration is an algorithm of seismic migration. And seismic migration is one of the most important part of seismic exploration, and more specifically, seismic imaging. By seismic migration, the constitution of the interior earth could be imaged, sketching, for example, the water, rocks, gas, oil, faults etc in the subsurface.

General Process of Seismic Exploration:

Seismic exploration, as one of the background knowledge of this thesis, is explained in this section. Figure sea_floor_seismic shows a typical scenario of a marine based seismic exploration. The vessel will inject waves periodically by the air gun. The waves just injected will spread in all direction quickly until it penetrate different media, such as rocks, ands, gas, or oil beneath the water, where the waves will reflect back or refract through another medium. The reflected waves, or those refracts first, then reflected waves would be recorded by a large array of Geo phones. In figure sea_floor_seismic, another smaller ship shows up, dragging a cable which contains an array of sensors to record the reflected signals. Geophysics data processing then follows the process of recording the signals. First of all, multiple steps should be applied to perform the preprocessing. For example, use the bandpass filter to remove the noise. And last of all, is the migration step to reconstruct the image of subsurface. The detail of how the data are processed is not the topic of this project, so I won't explain it.

Sea_floor_seismic image:



Reverse Time Migration :

The algorithm is somehow complicated but I am just explain it briefly it takes the results of the waves which come from the earth's surface. They have three dimension(X and Y) and also time of propagation. Using some calculation which includes integral they find the results. The algorithm could be implemented by some for loops. It had backward and forward part. The whole algorithm for two dimension(X-Y) is :

Forward propagation : send the waves

Backward propagation : resend the waves

Receiver propagation : get the waves

All of them require integrals and derivations which are implemented by using time as a time step in some for loops. The input is 3 dimensional arrays which is the point on the earth surface and the time propagation for it. I just implement the forward propagation as the other parts are somehow the same and use the same algorithm for parallelism. The algorithm contains 4 for loops first loop is because of 5 dimension that we have in total (remember is it is a derivation so we have to go through all dimensions) then we have to go through the time step and then x and y. So we have 4 for loops.

The real algorithm is for the forward part :

NOTE: We need some weights in order to have more realistic results. The weights are from a real calculation which was written in a paper.

```
for ( num = 0 ; num < 5 ; num++ ){
for ( t = 5 ; t < NUM-5 ; t++ ){
for ( x = 0 ; x < NUM ; x++ ){
for ( y = 0 ; y < NUM ; y++ ){
output[t*(NUM)+x*NUM+y] = weight[0]*input[t*(NUM)+x*NUM+y]+ weight[1]*(input[(t-1)*NUM+x*NUM+y] + input[(t+1)*NUM+x*NUM+y])
+ weight[2]*(input[(t-2)*NUM+x*NUM+y] + input[(t+2)*NUM+x*NUM+y])+ weight[3]*(input[(t-3)*NUM+x*NUM+y] + input[(t+3)*NUM+x*NUM+y])
+ weight[4]*(input[(t-4)*NUM+x*NUM+y] + input[(t+4)*NUM+x*NUM+y])+weight[5]*(input[(t-5)]*NUM+x*NUM+y + input[(t+5)*NUM+x*NUM+y]);
}
}
}
}
}
```

I implemented the above algorithm by **pthreads, MPI and OpenMP** in order to use threads for doing the loops.

For both of them I parallel the X loop. Because the X loop would be better for parallelism as it has more iteration and we can change the order of for loops in the way that X loop contain y loop and T loop.

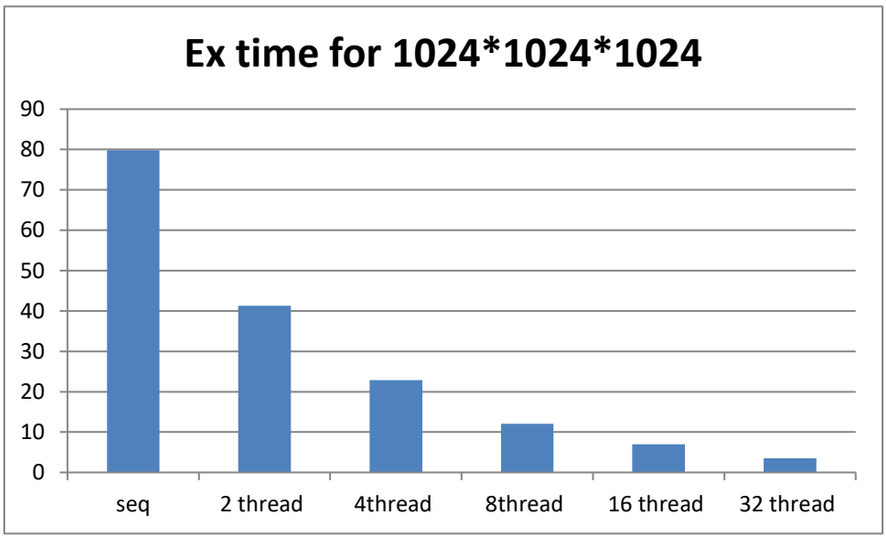
In pthread the implementation is in a way that each thread has a chunk of X iteration the chunks are the number of surface points divided by number of threads. The code attached in appendix.
In mpi is the same each processor in MPI work on a chunk of X iteration.

The difference in pthreads and MPI is on their barriers and how they pass works so the results should be near but not exactly the same.

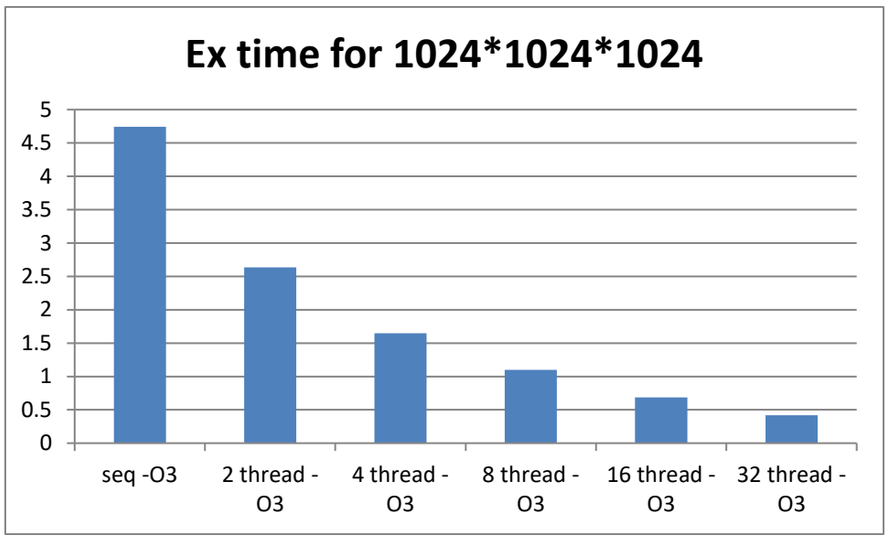
For the OpenMP the results are so near to MPI as the difference of them not affected my algorithm because the difference of this algorithms is in **OpenMP** is a way to program on shared memory devices. This means that the parallelism occurs where every parallel thread has access to all of your data. But **MPI** is a way to program on distributed memory devices. This means that the parallelism occurs where every parallel process is working in its own memory space in isolation from the others. So as my code have no dependencies in data and local variables so the results are near. I attached the OpenMP code.

The results are calculated for 1024 inputs. Input is 1024*1024*1024 dimension. Also the Excel file is in uploaded files.

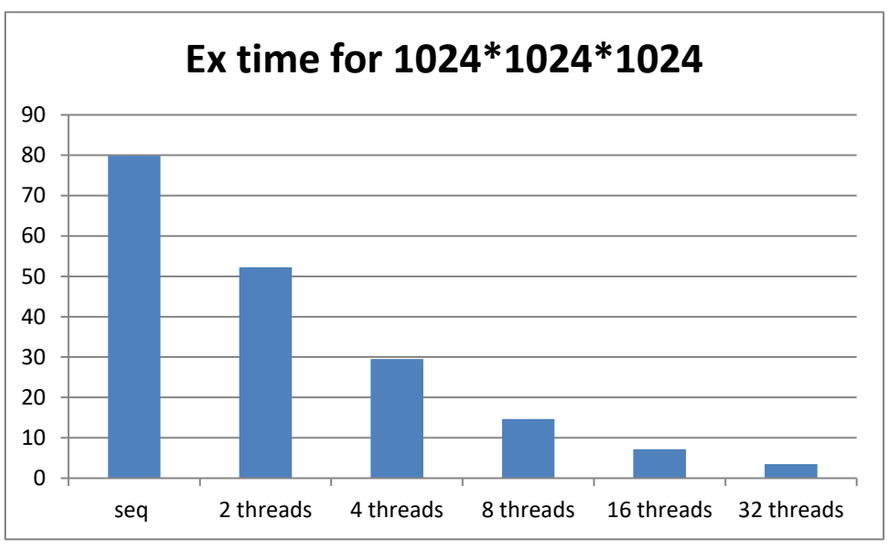
PTHREAD without any optimization tag:



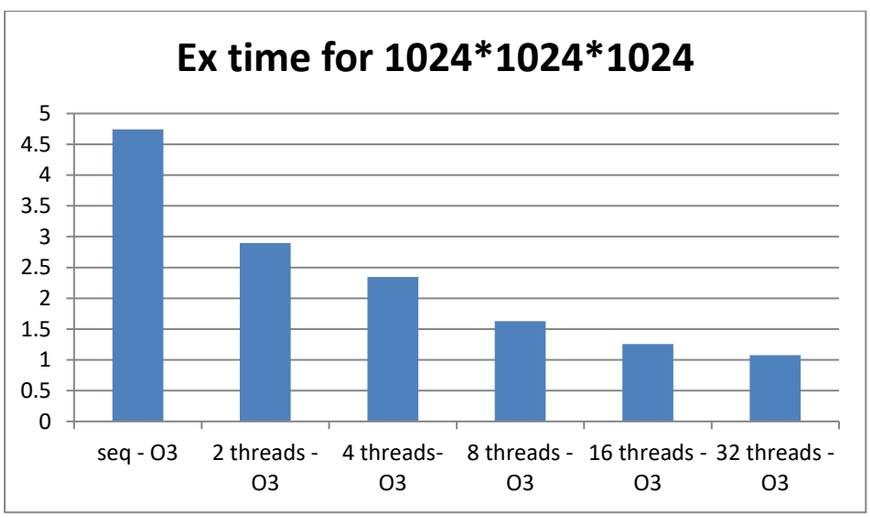
PTHRAED with O3 optimization:



MPI without optimization flags:



MPI with O3 flag:



The results for all three methods in comparison: