High Performance Computation by Graphics Processor Unit Technology for Geophysical Seismic Signal Processing*

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Introduction

The main goal of Earth exploration is to provide the oil and gas industry with knowledge of the Earth's subsurface structure to detect where oil can be found and recovered. To do so, large-scale seismic surveys of the Earth are performed, and the data recorded undergoes complex iterative processing to extract a geological model of the Earth. The data is then interpreted by experts to help decide where to build oil recovery infrastructure. Non-Stationary statistical Geophysical Seismic Signal Processing (GSSP) is of paramount importance for imaging subsurface geological structures and is being used all over the world to search for petroleum deposits and to probe the deeper portions of the Earth to enhance R/P ratio of nations with a view to fuel security of the world.

Imaging of the subsurface is a nonlinear inverse problem which plays the role of optical lens. The key challenge that the oil industry must face for hydrocarbon exploration requires the development of state-of-the-art technologies to image the subsurface precisely and reconstitute the three-dimensional structure of the Earth. The use of seismic reflections is one of these essential and strategic methods. Reflection imaging is key to seismic exploration because it is used as the basis on which geoscientists leave no stone unturned in the quest of new giant oil and gas reservoirs. The industry has seen a revolution in the ability to process seismic data and to build an increasingly accurate image of the Earth’s structure.

Seismic Depth imaging and High performance computing are both key components of this revolution. Indeed the fast evolution of computers has enabled the development of specialized algorithms allowing the processing of increasingly large volumes of data generated by seismic acquisitions. High performance computing based on General Purpose Graphics processing units GPU technology (GPGPU) is an important direction of developments to meet the requirements of large scale computing in the petroleum industry. The massively parallel intrinsic nature of seismic data allows the geophysicist to develop very efficient algorithms. Recent progress both on interconnect topology and new accelerating technology (FPGA, GPGPU, CELL) open new R&D directions to rectify and pacify the limits of computation. Graphics processing units (GPUs) have evolved into a very attractive hardware platform for general purpose computations due to their extremely high floating-point processing performance, huge memory bandwidth and their comparatively low cost. The rapid evolution of GPUs in performance, architecture, and programmability can provide application potential beyond their primary purpose of graphics processing. High-end GPUs typically deliver performance of at least one order of magnitude higher compared to that of the CPU, while at the same time equipped up to 1 GB of GPU main memory. This commodity graphics hardware can become a cost-effective, highly parallel platform to solve scientific problems. The GPU performance of basic linear algebra operations typically is one order of magnitude higher compared to that of a current CPU. Hence, already a minimally invasive approach to instrumenting a CPU state-of-the art direct solver for large sparse systems of linear equations results in considerable speed-up. Using the GPU-enhanced solver for interior point optimization, a speed-up factor up to 6.5 could be observed compared to the original 64-bit precision code. Using a GPU as co-processor, a comparatively small effort is needed to remarkably improve the performance of a basic ingredient of scientific computing such as a solver for sparse systems of linear equations. Selecting algorithms for GPU implementation can be difficult, especially without experience in GPU programming. In our seismic processing sequence, there are several important considerations. For example, the algorithms we port to the GPU are part of an industrial application already running in parallel on a large cluster. Therefore, our goal is an application running on the same kind of cluster but with graphics cards installed in every node. Furthermore, a significant part of the application that deals with all cluster parallelization and efficient data management cannot be changed to accommodate the GPU programming model.

Advantages of GPU Computing

General Purpose GPU technology already can use a graphics card for general computing, not only to draw image. The floating-point operation performances reach trillion per second, namely correspond to ten times faster than the x86 CPU. But GPU itself is not a general purpose chip and can proceed some specific tasks through graphics application program interface (API), such as 3D romance, thus GPU had no means of processing general purpose computing yet. The appearance of GPU general purpose computing technique is directed to utilize the powerful computational ability of GPU for speeding up general tasks, due to the characteristic of high parallelism and density computing. Compared with GPU, the CPU is designed for low latency and complicate control, so it has little computing unit and low bandwidth; on the other hand, GPU is a processor with Single Instructor Multiple Data (SIMD) and includes enormous processing unit and very high bandwidth to DRAM. These features give GPU great potential to parallel processing and high density computing that it is valuable to expend GPU computing technique in the oil and gas industry. Combined with GPU computing technology, pre-stack time migration has been improved efficiently. Further considering the cheap price and huge market, GPU can be characterized by small size, saving power and portable. So your pre-stack datasets can be migrated by your desktop or personal computer with GPU. Other huge time consuming algorithm, such as the pre-stack depth migration, can be transplanted onto GPU. That means a new developmental stage is coming for 3D seismic data pre-stack imaging and multifarious mass data preparation.

Supercharging Seismic Processing with GPUs

In the oil and gas industry, seismic data processing has become an essential tool in the energy production workflow. By employing the latest software and hardware, raw seismic data can be used to create revealing images of the geological structure of the Earth's subsurface. These can then be used by geoscientists to find the most likely places to drill for oil and gas. Because of the enormous volumes of data generated by seismic exploration, the speed and accuracy of transforming the data into images is directly related to the amount of compute power that is available. At the heart of these calculations is vector processing, which attracted early developers of seismic data processing to seek out vector-based machines. Following the rise of high-performance computing clusters, the industry rewrote all their codes to run on standard commodity hardware. But as the demand for real-time seismic analysis grows and as both power and space become issues in the datacenter, the oil and gas industry is looking at more compute-dense, energy-efficient solutions. Especially within the past couple of years, there has been growing interest in coprocessor acceleration, which uses FPGAs, GPUs, Cell processors, and Clear Speed boards to perform the most compute-intensive parts of seismic processing. One company that is offering solutions along these lines is Houston-based Headwave Inc., a company that sells software tools for seismic analysis. They are one of the first vendors to use GPGPU (general-purpose computation on GPUs) for commercial purposes. Headwave is employing NVIDIA GPUs to filter and visualize multi-terabytes of raw seismic trace (prestack) data. The latest graphics devices offer as much as 500 gigaflops of processing power.

Deep Views with Prestack Software

Headwave has developed the first highly accelerated, prestack visualization and computation software package. While prestack has long been used for AVO (Amplitude versus Offset) and RMO (Residual Moveout) analysis, the interpretation process used has been arduous. With multi-fold gathers, interpreters have struggled to get a clear overview of what was going on.

Volumetric visualization means the data is seen as a volume in space. Moreover, the data is seen in context. Each gather is associated with the poststack trace generated from the gather. This makes it easy to relate individual prestack traces to the poststack, additionally gather flatness (NMO quality), muting quality, and RMO quality are easily seen. Even a Hyper Cursor can be used to see the prestack info at a special location. In this way, the viewer can walk through the prestack volume and inspect all traces at a given offset, or each gather in a given volume. Having assured oneself and the group that the data processing results are as expected, now the power of volumetric visualization can be fully utilized. The user can easily adjust the transparency of the prestack data volume.

Prestack Horizon Picking

Picking a horizon in poststack data is commonplace, it is not so common to pick a horizon in prestack data, and even less common to use a poststack horizon to seed the prestack pick. The picked prestack horizon can be used to map various attributes. Attributes such as horizon curvature, time delta (the difference from the time of the event at offset 0 to the time of the event at offset n), trace count (how many traces of the gather contributed to the poststack trace), Gaussian curvature, or others can be derived or loaded and mapped onto the prestack horizon. The user can step through the entire poststack volume viewing the prestack horizons associated with that inline. At any point the attribute being displayed may be changed and the stepping continued.

Imperfect Prestack Data and AVO

With the computational power now available through Headwave, corrections can be applied, interactively, on the desktop. Maybe additional filtering would help, or maybe it needs a minor velocity tweak and a test of the stacking parameters to optimize the poststack trace or improve AVO calculations. This is all possible. Stacking can be done either on the full volume, or on a selected probe. Since the probe is a subset of the entire data volume, stacking can be performed quickly. Sometimes the prestack data will not have a mute applied or the applied mute needs adjustment. In Headwave the mute parameters can be tested. They can be designed on the prestack data gathers and the stacked result directly inspected. As previously discussed, partial stacks are also possible, and quickly accomplished. What is good for 3D is even better for 4D. Full use of prestack 4D data lets users easily see changes, changes in a horizon for sure, but even more, changes in volumes. Volumetric visualization gives visual pop to reservoir changes: it evaluates reservoir response with time lapse seismic. Multiple datasets can easily be merged for comparisons, delta calculations, and more.

Seismic Processing

The goal of seismic processing is to convert terabytes of survey data into a 3D volume description of the Earth’s subsurface structure. Because the velocity field is initially unknown, we generally start by assuming a rather simple velocity model. Then the migration process gives us a better image of the Earth’s subsurface that allows us to refine the velocity field. This iterative process finally converges toward our best approximation to the exact Earth reflectivity model. At the end of the processing, the 3D volume of data is far cleaner and easier to understand. Some attributes can be extracted to help geologists interpret the results. Typically the impedance of the media is one of those attributes, as well as the wave velocity, the density, and the anisotropy. Figure 3 gives an overview of what the data looks like before and after the processing sequence. Also shown is an attribute map representing the wave velocity at a particular depth of the seismic survey. Different rock types have different velocities, so velocity is a good indicator to look for specific rocks such as sand. In the particular case of Figure 3c, low velocities (in blue) are characteristic of sand, here from an old riverbed. As a rock, sand is very porous and is typically a good target to prospect for oil.

GPU Acceleration of 2D-DWT Image Compression in MATLAB with CUDA

Acceleration of 2D wavelet-based data (image) compression on MATLAB with CUDA. It is obvious that the diagnostic materials (mostly as a certain type of image) are increasingly acquired in a digital format. Therefore, the common need to daily manipulate huge amounts of data brought about the issue of compression within a very less stipulated amount of time. Attention will be given to the acceleration processing flow which exploits the massive parallel computational power offered by the latest NVIDIA graphics processor unit (GPU). It brings a compute device that can be programmed using a C-like language using CUDA, (Compute Unified Device Architecture). At the same time, a number of attractive features can be exploited for a broad class of intensive data parallel computation tasks. The final part of discussion outlines possible directions towards future improvements of compression ratio and processing speed.

Conclusion

Novel technology for the oil and gas industry is based on GPU processing. With the advent of GPU processing on a single graphics card or even in clusters, its interactive prestack visualization and computational tools are available today for large, very large, and extremely large datasets. Before the drilling takes place, HPC has a key role to play in two aspects of the modern exploratory survey: data processing and image analysis. The first entails interpretation of acoustic data into a 3D map of the acoustic impedance of the Earth’s subsurface. Depending on the area surveyed, this data processing can take months, or up to a year. When complete, interfaces between various rock types can be resolved. Once the acoustic impedance data has been processed into a 3D matrix, the analysis can begin. Geophysicists in the oil and gas industry are seeking more accurate images of what lies beneath the Earth. In order to find what's been buried for millions of years, OpenGeoSolutions uses a technique called “spectral decomposition”, specifically to reveal geological information that goes beyond classic seismic resolution and detection. The quality of the data produced by this technique is improved when large regional datasets are processed, but more importantly when that data is 'inverted', allowing it to be translated into real geological structures.

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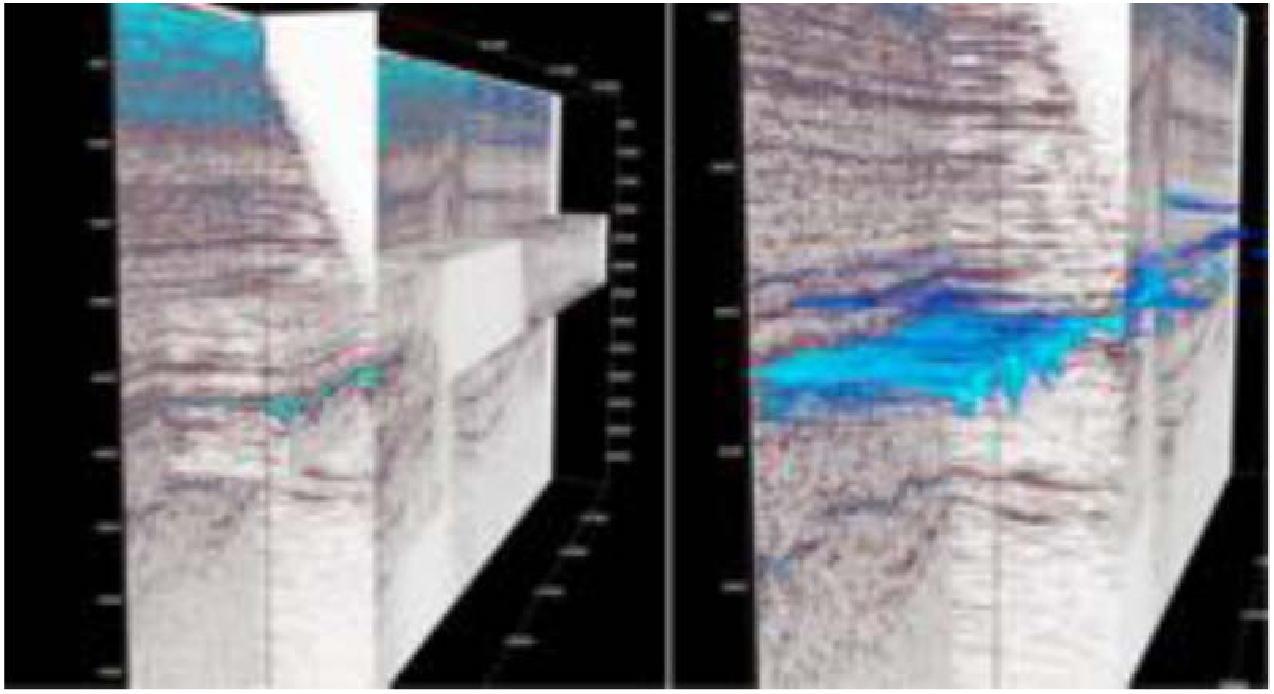

Figure 1. Two views of the same inline and associated prestack data. On the left a gather is displayed and a prestack probe is also shown for the inline data. On the right, the probe has had the shader modified to make all but the trough peaks transparent (blue = trough) in the probe. The nature of the far offset booming is clear, and from the gather data, a revisiting of the muting of the prestack data might be in order (http://www.headwave.com).

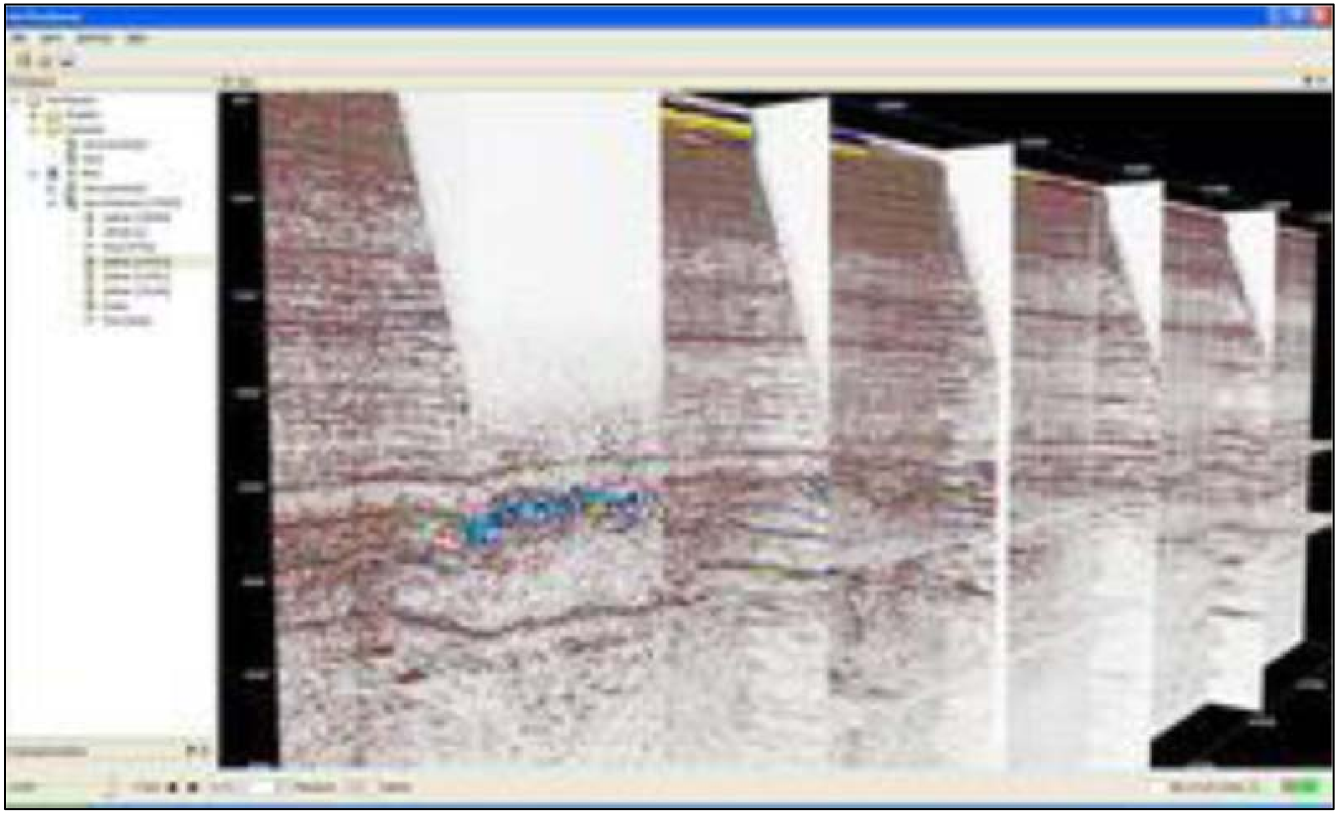

Figure 2. Here are four 36-fold gathers and a prestack probe displayed together with the poststack inline; two time horizons are displayed as well. This display is next to impossible in a 2D display mode (http://www.headwave.com).

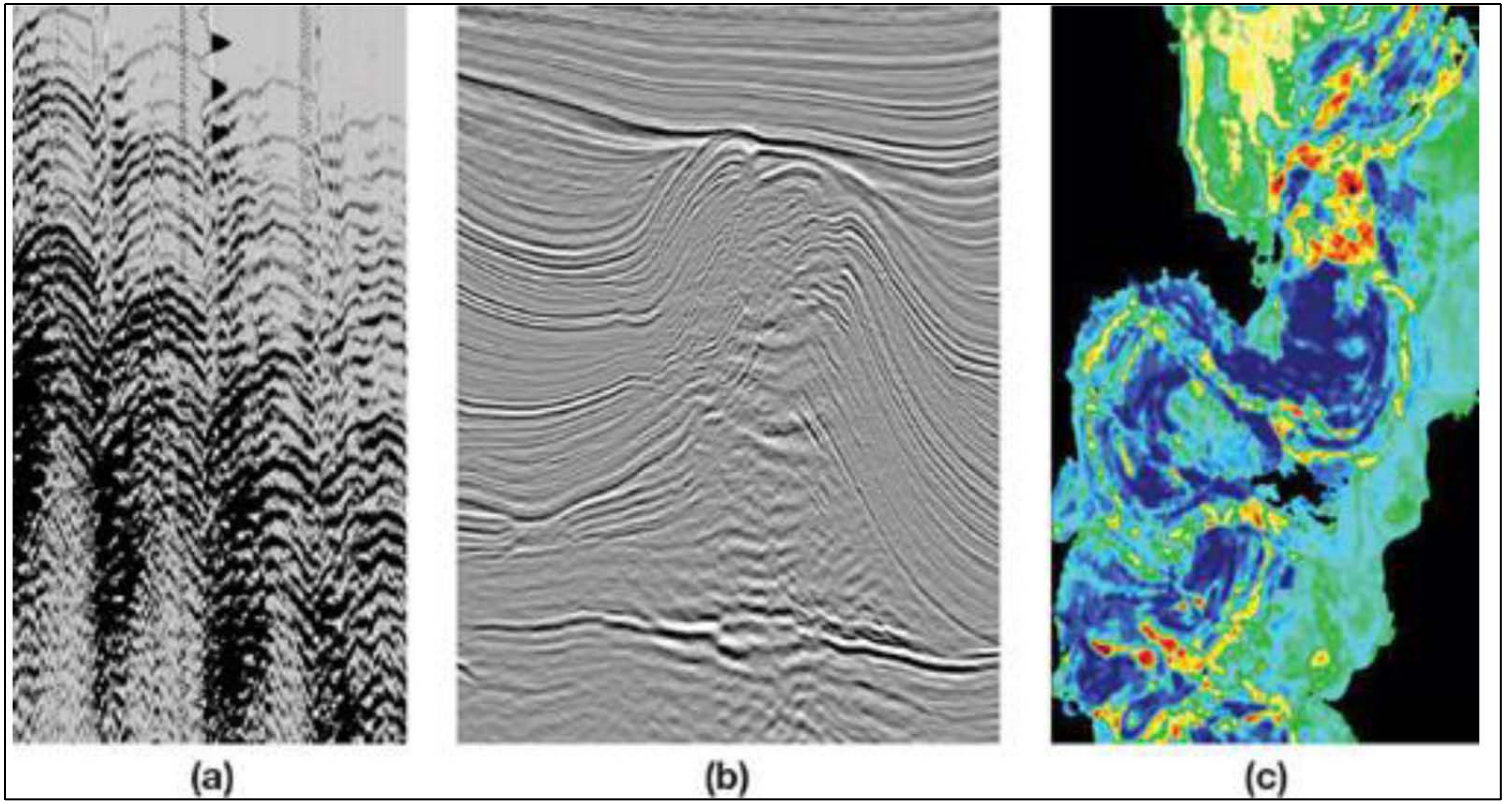

Figure 3. A seismic processing example (http://www.developer.nvidia.com).