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Seismic Attributes Extraction Based on GPU

Zhang Guang-Zhi, Chen Lei+ and Ye Duan-Nan

College of Geo-resource and Information, China University of Petroleum (East China)

Qingdao 266555, China

Abstract—In oil and gas exploration, the seismic data can provide the information of the earth's subsurface structure and detect where oil can be found and recovered. To get a geological model of the earth, the complex iterative processing is being done. So, the need for computing power increases with the oil and gas exploration and development. And the new high-performance computing (HPC) technologies are used in seismic processing. We use NVIDIA's CUDA programming language to accelerate seismic attributes extraction technology. By comparing the same work in the CPU and GPU, GPU is about 6 times faster, it shows that GPU can effectively shorten the processing time.

Keywords-parallel-speedup; GPU; CUDA; seismic data processing; seismic attributes

1. Introduction

With the continuously development in three-dimensional seismic exploration technology, seismic data resulted from it is also increasing. To process these vast amounts of data, not only high performance computing equipment, but also a large amount of time is required. Along with the constant expansion in the scale of traditional computer cluster, the cost of construction, operation and maintenance continue to rise [1]. On the other hand, to level up the system performance has been constrained to some extent. To accelerate processing speed and reduce processing period, a new high performance computing technology must be found.

GPU computing performance has been developing rapidly in the past decade. At present, the computing performance of a high-end GPU can be equivalent to a high-performance computer cluster system, with much larger computing power than the main stream CPU. The GPU has such a powerful computing power because it devotes more transistors to data processing instead of flow control. Traditionally GPU are only used in graphic processing, the application fields have been limited. However, the GPU computing power soon attracted people's attention, and they began to apply GPU in general-purpose computing other than graphic processing, such as data processing, scientific computing and so on. Now, more and more scientific researchers start to learn and make use of GPU.

GPU particularly suitable for compute-intensive and highly parallel computing [2], GPU could be several times or even a hundred times faster in application of calculating, Seismic attributes extraction fits in this characteristics. Compared with CPU, GPU usually has larger memory bandwidth and more execution units, and GPU possesses higher cost-effective compared with equally priced CPU. Therefore, compared with CPU, extraction of seismic attributes using the GPU has great advantages.

2. What is the Gpu and Cuda

+ Corresponding author.
E-mail address: hnxygs2006@163.com

The concept of GPU is first proposed by NVIDIA in 1999, when the GeForce-256 graphic processing chip was released. GPU is a concept relative to CPU. It is the abbreviation of Graphics Processing Units. As the core of graphics card, GPU determines the quality and performance of a graphics card. GPU can do part of CPU' work, which reduces dependence on CPU.

Launched by NVIDIA, CUDA is a hardware and software system which takes GPU as the parallel computing device [3]. CUDA makes the GPU, which used to focus on graphic processing, also applies to data processing and scientific computing fields. CUDA does not need the help of a graphics API, use C language to develop, which makes the developer get familiar with CUDA programming quickly. The CUDA programming model applies CPU+GPU heterogeneous programming, which takes CPU as host and GPU as coprocessor or namely device. In this model, the CPU is responsible for handling the strong logic and serial computing, and GPU could do the parallel processing parts that can be highly threaded. So, the code based on GPU can be divided into two parts: one is host code which is executed on the CPU; the other is executed on the GPU and called device code. At present, in addition to support the standard CUDA C language, the CUDA also support FORTRAN, Java and other programming languages, it will support more programming languages in the future, which makes more and more people could take advantage of GPU easily.

The CUDA C language is similar to C language, but this does not mean CUDA C language is equal to C language. The following is a CUDA C language example:

```
// Kernel definition
__global__ void VecAdd(float *A, float *B, float *C)
{
   int i=threadIdx.x;
   C[i]=A[i]+B[i];
 }
int main( )
{
    …
    // Kernel invocation with N threads
    VecAdd<<<1,N>>>(A,B,C);
}
```

In this example, "VecAdd<<<1,N>>>(A,B,C)" completed a call to kernel function. The parameter in "<<<… >>>" represent the execution parameter of kernel function, and it is used to explain the number of thread and how thread is organized. The parameter in parenthesis is the parameter of function.

There are two important concepts in CUDA: one is thread, the other is memory. Only by understanding the thread and memory structures in the GPU, the parallel computing power of GPU can be brought into play.

3. to Understand Cuda

3.1. Thread Hierarchy

In the CUDA architecture, the smallest unit of program execution is thread, several threads form a block, and the blocks which perform the same program may form a grid. Threads in the same block share the same piece of shared memory, and can perform synchronized action very quickly. The number of thread in a block is limited. Because of the thread in different block can not access a same shared memory, there is no direct communication or synchronized action between different block. The relation among grid, block, and thread is shown in figure 1.

3.2. Memory Hierarchy

Device memory is classified into multi-processor on-chip memory (including shared memory and registers), and off-chip memory (including global memory, constant memory and texture memory). Thread executed on the device may access the DRAM (Dynamic Random Access Memory) and on-chip memory units through the memory space which shown in figure 2 only.

Each thread owns a register and local memory. Threads in the same block shares a shared memory. Besides, threads in a same grid share a global memory, a constant memory and a texture memory.

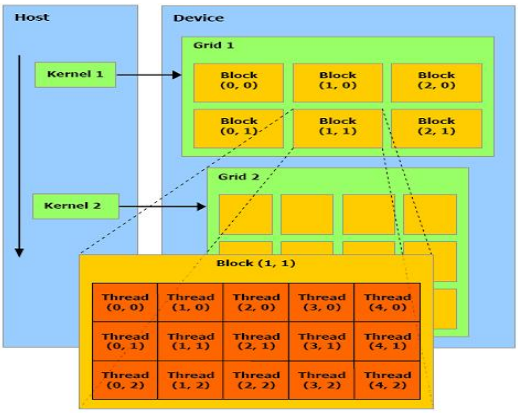

Fig.1. Thread Hierarchy.

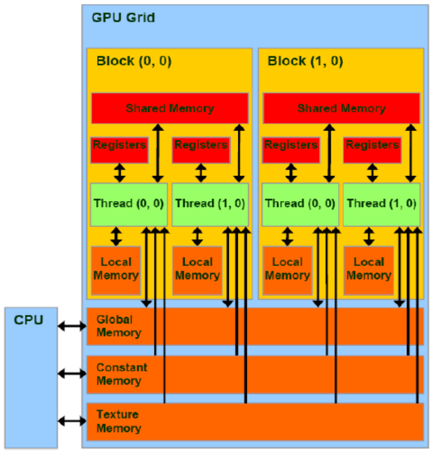

Fig.2. Memory Hierarchy.

The speed of On-chip memory access is very high, and the access speed of shared memory equals to register without memory conflict situations. The registers are attached inside the Multiprocessor, and they are allocated by the device and can not be directly used by program. The constant and texture memory in off-chip memory is read only for thread, but was buffered. If there is no access conflict, the access speed of the two kinds of memory is equal to the registers. The global memory has the largest capacity and bandwidth, but the latency is too long. If each thread in a block access to continuous global memory, the latency will be covered.

Global, constant and texture memory can optimize accordingly to different memory usage. Texture memory offers different addressing modes and data filters for some specific data. Threads could access dynamic random access memory on the device and on-chip memory through a group of memory space in different areas.

4. Seismic Attributes Based on Complex Trace Analysis

Seismic attributes are specific measurements of geometric, kinematic, dynamic, or statistical features derived from seismic data [4]. Seismic attributes is a description and quantitative characteristics of seismic data [5], it is a subset of all the information of raw seismic data, different seismic attributes reflect different subsets of geological information. In many seismic attributes, some attributes is sensitive to a particular reservoir environment, some of them are beneficial to the underground anomalies which is difficult to detect, and some others can be used directly for hydrocarbon detection.

The seismic attribute technology can extract more useful information which is hidden in the seismic data, and increases efficiency in using original seismic data; at the same time, it improves the level of seismic technology of the oil industry.

4.1. Complex Seismic Trace Analysis

The complex seismic trace analysis technology became the most important tool for seismic attribute technology in 1970s. Take seismic trace as the real part, and Hilbert transform of the seismic trace as the imaginary part, and they constitutes a complex seismic trace, which is the basis of complex seismic trace analysis. Based on complex seismic trace analysis generated three basic instantaneous attributes (instantaneous amplitude, instantaneous phase, and instantaneous frequency), customarily referred to as the "three instantaneous attributes". The three instantaneous attributes generated many other relative attributes. In this paper, three instantaneous attributes and relative seven attributes are extracted, the computational equations of the ten attributes as follows.

Complex trace analysis treats a seismic trace $f(t)$ as the real part [6], and $g(t)$ as the imaginary part, so the complex seismic trace can be represented as $F(t) = f(t) + ig(t)$.

Define $E(t)$ as instantaneous amplitude, also called envelop, $\gamma(t)$ as instantaneous phase, $\omega(t)$ as instantaneous frequency, $\sigma(t)$ as instantaneous bandwidth, $na(t)$ as cosine of instantaneous phase, $\overline{\omega}(t)$ as frequency weighted envelop, $thin\_bed(t)$ as thin bed, $E'(t)$ as first derivative of envelop, $E''(t)$ as second derivative of envelop, and $q(t)$ as Q factor.

4.2. Equations Used to Compute Seismic Attributes

$$E(t) = \sqrt{f^2(t) + g^2(t)} \tag{1}$$

$$\gamma(t) = \arctan[g(t)/f(t)] \tag{2}$$

$$\omega(t) = \frac{d[\gamma(t)]}{dt} \tag{3}$$

$$E'(t) = d[E(t)]/dt \tag{4}$$

$$E''(t) = d[E'(t)]/dt \tag{5}$$

$$na(t) = \cos[\gamma(t)] \tag{6}$$

$$\bar{\omega}(t) = \sum_T [E(t)\omega(t)] / \sum_T E(t) \tag{7}$$

$$thin\_bed(t) = \omega(t) - \bar{\omega}(t) \tag{8}$$

$$\sigma(t) = \left| \frac{E'(t)}{2\pi E(t)} \right| \; [7] \tag{9}$$

$$q(t) = \frac{-\pi\omega(t)E(t)}{E'(t)} \tag{10}$$

4.3. Significance of Seismic Attributes

Instantaneous amplitude: Indicate major lithology changes, unconformities, gas and fluid accumulation.

First and second derivative of envelop: Indicate effects of absorption, sharpness of events, correlation tool.

Instantaneous phase: Event continuity, structural and stratigraphic configuration.

Instantaneous frequency: Frequency signature of events, effects of absorption and fracturing, depositional thicknesses.

Q factor: Direct estimate of absorption effects, fracture, gas zone and possible permeability.

5. Seismic Attributes Extraction

According to various attributes computing equations provided above, using C language achieve seismic attributes extraction. Original seismic section is shown as figure 3.

5.1. Extraction of Seismic Attributes Using C Language

The graphics of extracted various seismic attributes are shown in figure 4 to 8.

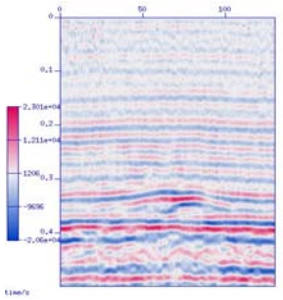

Fig.3.Original Seismic Section.

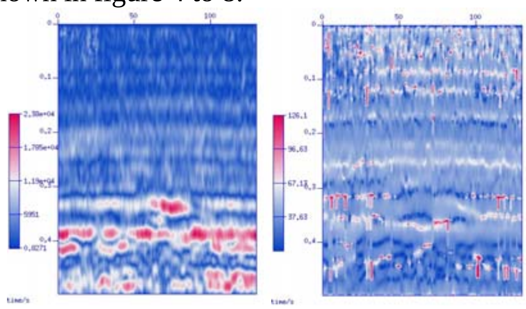

Fig.4. Left is instantaneous amplitude, right is instantaneous frequency.

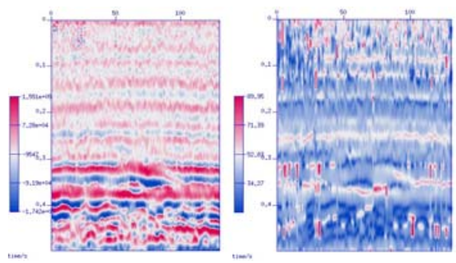

Fig.5.Left is first derivative of envelop, right is frequency weighted envelop.

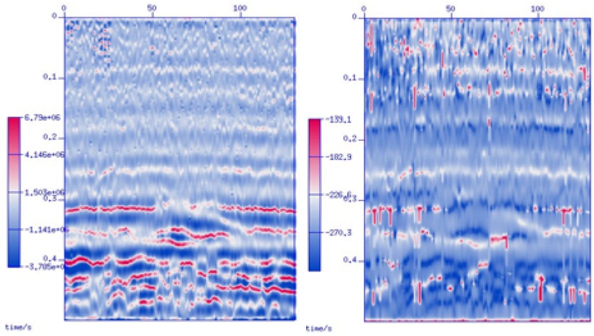

Fig.6.Left is second derivative of envelop , right is thin bed.

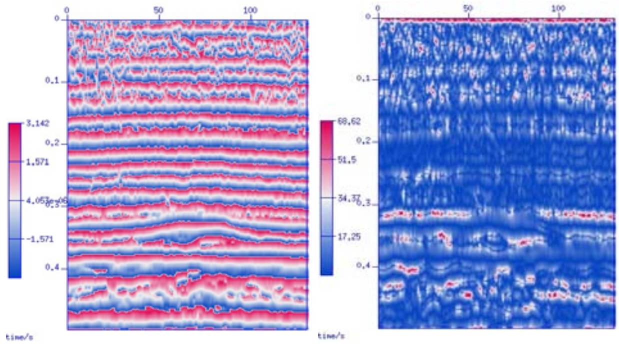

Fig.7.Left is instantaneous phase, right is instantaneous bandwidth.

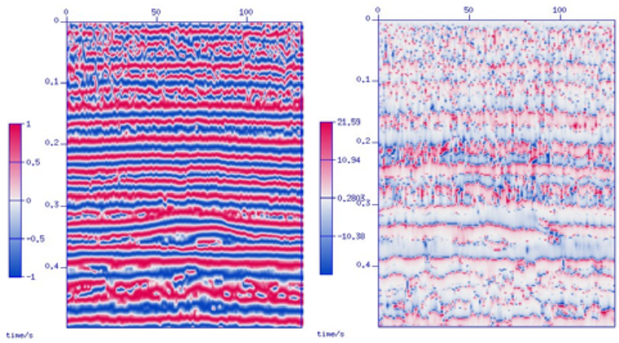

Fig.8.Left is cosine of instantaneous phase , right is Q factor.

5.2. Extraction Based on CUDA

Based on CUDA platform, using CUDA C language for extracting seismic attributes, then compare the results with that of C language. The main idea is to make each thread responsible for calculating one seismic trace, and realize parallel computing among different seismic traces.

6. the Results and Analysis

The GPU Experiments is NVIDIA Tesla C1060. It has 240 stream processors, 1.3 GHz domain frequency, 4GB memory, its single precision floating-point computing reaches 933Gflops per second.

By comparing the results using CUDA C language and C language, I found that there is no difference between them. This means that the experiment is successful in extracting seismic attributes using GPU.

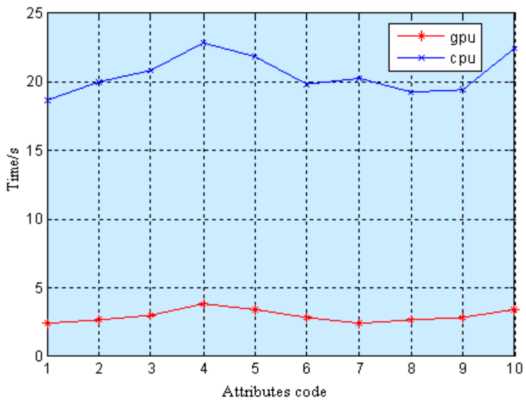

Fig.9.The CPU and GPU runtime for computing each attribute.

For each attribute, the CPU runtime and GPU runtime is calculated, and the results are shown in figure 9. From the figure we can clearly see the GPU computing time is far less than the CPU's. In general, using GPU to compute can make the process about 6 times faster. Experiments show: GPU hardware can significantly accelerate seismic attributes extraction, and this shows a bright future of GPU computing [8].

7. Acknowledgment

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