Structure-preserving Smoothing for Seismic Amplitude Data by Anisotropic Diffusion using GPGPU

Joner Duarte
jduartejr@tecgraf.puc-rio.br
Outline

● Introduction
  ○ Why is noise attenuation important?
  ○ Objective
  ○ Related Works

● Structure-preserving Smoothing Method

● Parallel Approach

● Results

● Conclusion
Introduction

Why is noise attenuation important?

Original seismic data – crossline 905 of F3 block

Zoom area from the input data and the corresponding filtered image.

Volume of the Netherlands offshore F3 block downloaded from the Opendtect website.
Introduction

Why is noise attenuation important?

Preserve relevant structural features is fundamental.
Introduction

Why is noise attenuation important?

Seismic attributes have been used to accelerate interpretations, and their results are directly related to the quality of the seismic data.
Introduction

Why is noise attenuation important?

Curvature attributes are widely used to improve seismic interpretation process. The results of curvature attribute can be directly improved by our iterative noise attenuation process.
Introduction

Objective

Remove noise preserving relevant details such as structural and stratigraphic discontinuities in interactive time.
Related Works

- [1990] Perona and Malik, Scale-Space and Edge Detection Using Anisotropic Diffusion
- [2002] Hocker and Fehmers, Fast structural interpretation with structure-oriented filtering
- [2009] Dave Hale, Structure-oriented smoothing and semblance
Overview

- Pampanelli P., *Seismic amplitude smoothing by anisotropic diffusion preserving structural features*, 2015
- Use the instantaneous phase as horizon indicator attribute
- Two steps
  - Compute the constraints
  - Assemble and solve the system of equations
- Iterable
Structure-preserving Smoothing Method

- **Compute Hilbert Transform**
  \[ Y(t) \]

- **Compute Seismic Complex Trace**
  \[ Z(t) = X(t) + iY(t) \]

**STEP 1: Computing Seismic Attributes**

**STEP 2: Applying The Anisotropic Diffusion Filter**

Input Volume

Do you wish iterate again?

Filtered Volume
Structure-preserving Smoothing Method

Input Volume

STEP 1: Computing Seismic Attributes

STEP 2: Applying The Anisotropic Diffusion Filter

Filtered Volume

Do you wish iterate again?

• Compute Horizon Indicator Attribute\(^1\)

\[
\vec{\nabla} \Phi = \left( \frac{\delta \Phi}{\delta x}, \frac{\delta \Phi}{\delta y} \right)
\]

\[
\frac{\delta \Phi}{\delta x} = \frac{1}{X^2 + Y^2} \left( X \frac{\delta Y}{\delta x} - Y \frac{\delta X}{\delta x} \right)
\]

\[
\frac{\delta \Phi}{\delta y} = \frac{1}{X^2 + Y^2} \left( X \frac{\delta Y}{\delta y} - Y \frac{\delta X}{\delta y} \right)
\]

where \( \Phi \) is the instantaneous phase attribute

1 – Silva, P.M. et al., Horizon indicator attributes and applications. SEG Technical Program Expanded Abstracts 2012.
Structure-preserving Smoothing Method

- Compute Horizon Indicator Attribute¹

\[ \overrightarrow{\nabla \Phi} = \begin{pmatrix} \frac{\delta \Phi}{\delta x'} \\ \frac{\delta \Phi}{\delta y} \end{pmatrix} \]

Do you wish to iterate again?

STEP 1: Computing Seismic Attributes

STEP 2: Applying The Anisotropic Diffusion Filter

Input Volume

Filtered Volume

instantaneous phase gradient

\[ \overrightarrow{\nabla \Phi} \]

\[ \overrightarrow{\nabla \Phi} \perp \]

horizon
Structure-preserving Smoothing Method

• Compute Fault Attribute\(^1\)

\[ F_{\text{max}} = \text{MAX}(|\nabla \vec{X} \cdot \nabla \Phi^\perp|, |\nabla \vec{Y} \cdot \nabla \Phi^\perp|) \]

where \( \nabla \vec{X} \) represents the normalized vector of the amplitude gradient and \( F_{\text{max}} \in [-1, 1] \)

---

Structure-preserving Smoothing Method

• Diffusion Tensor
\[ D = \frac{\nabla \phi}{\nabla \phi} \times \left( \frac{\nabla \phi}{\nabla \phi} \right)^T \]

• Fault Preserving Factor
\[ \varepsilon = F_{max}^2 \]

STEP 1: Computing Seismic Attributes

STEP 2: Applying The Anisotropic Diffusion Filter

Input Volume

Filtered Volume

Do you wish iterate again?
Structure-preserving Smoothing Method

- The Anisotropic Diffusion Filter
  - Solving the linear system $Ax = b$ of size $m \times m$, where $m = w \times h$
  - Stencil 3x3

\[
\frac{\delta u}{\delta t} = \nabla \cdot (\epsilon D \nabla u)
\]

\[
u_{x,y}^{n+1} = u_{x,y}^n + \Delta t \nabla \cdot \left( \epsilon_{x,y}^n D_{x,y}^n \nabla u_{x,y}^{n+1} \right)
\]
Parallel Approach

Compute Seismic Attributes (STEP 1)

**CPU**
- FFTW3
- OpenMP
- 1 loop for each trace (Hilbert Transform)
- 1 loop with 1 inner loop

**GPU**
- CUFFT
- 2 kernels (Hilbert Transform)
- 1 kernel to compute attributes
  - 1 thread per sample

Memory used in this step

- Input seismic section
- Hilbert Transform
- \( Y(t) \) Imaginary part of complex trace
- Horizon Attribute
- Instantaneous phase gradient
- Fault Attribute (\( \varepsilon \))
- \( dxx \)
- \( dxy \)
- \( dyy \)
- Diffusion tensor
Parallel Approach

Assemble and Solve the System of Equations (STEP 2)

– System solver
  • 50~70% of total time of one iteration
  • Libraries for solving sparse linear systems
  • Sparse matrix format: CSR (Compressed Sparse Row)

Memory used in this step

\[ \sim 31 \times \text{input image size} \]

\[ A \times x = b \]

- \( A \): Input section size (19x)
- \( x \): Filtered image (1x)
- \( b \): Input image (1x)
- NUMERICAL METHOD: Input section size (10x)

= 31x Input section size
Parallel Approach

Numerical Methods

- Conjugate gradient (CG)
  - Symmetric linear systems
  - Symmetric and positive-definite matrix
    \[ Ax = b \implies A^T Ax = A^T b \]

- Biconjugate gradient stabilized (BiCGStab)

- Generalized minimal residual (GMRES)

Stop criteria
- Error tolerance: $10^{-4}$
- Limit of 100 iterations
- No preconditioner used
Parallel Approach

Libraries

- Intel MKL 11.3
- CUSP 0.5.1
- ViennaCL 1.7.0
- There are other libraries that we may try in the future (MUMPS, cuSOLVER, PARALUTION, etc)
Results

HP Z820 Workstation
- 64 GB RAM
- Intel(R) Xeon(R) E5-2620
- 6 cores (12 threads)

Inline 240 of the volume of the Netherlands offshore F3 block¹
- 951 x 462

Tesla k40
- 12 GB
- 2880 processors

Linear system size: 439362 x 439362

¹Volume of the Netherlands offshore F3 block downloaded from the Opendtect website
Results

Inline 240 of the volume of the Netherlands offshore F3 block
Results

Inline 240 of the volume of the Netherlands offshore F3 block

Original slice 1 iteration 3 iterations 5 iterations 10 iterations
## Results

<table>
<thead>
<tr>
<th>Number of iterations</th>
<th>CG</th>
<th>GPU Speedup using CG</th>
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<tbody>
<tr>
<td></td>
<td>MKL (ms)</td>
<td>CUSP (ms)</td>
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<tr>
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<tr>
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The GPU speedup using CG for different GPU iterations.
# Results

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![GPU Speedup using BiCGStab](image.png)
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GPU Speedup using GMRES

![Graph showing GPU speedup using GMRES]
Results

Filtering time with 1 iteration

Filtering time with 10 iterations

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Conclusions

- Method that attenuates noise preserving structural features

- Improves interpretation efficiency and also can enhance the results of other seismic attributes

- Fast enough to be interactive
Conclusions

- It can be used on demand during the interpretation process and also be integrated with tools like Cintiq tablet

- CUSP library proved to be very fast for our problem with a high level interface that makes it very simple to use
Acknowledgements

Questions???