True-amplitude CRS-based Kirchhoff time migration for AVO analysis

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Overview

Motivation
   Principle
   Effect of migration aperture on amplitudes

Common-Reflection-Surface stack

Adapted workflow
   Extraction of CRS attributes
   Velocity model determination
   Determination of migration attributes

Synthetic data example

Conclusions

Acknowledgments
Kirchhoff migration
Kirchhoff migration
Kirchhoff migration: stationary point
Kirchhoff migration: conventional aperture
Kirchhoff migration: minimum aperture
Optimum aperture = minimum aperture

- centered around stationary point
- size: projected Fresnel zone
Kirchhoff migration: minimum aperture

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Apertures & amplitudes

Problems with user-given apertures:

- too small: underestimated amplitudes and/or loss of steep events
- too large: undesired noise and/or other events contribute to stack

True-amplitude migration requires sufficiently large apertures.
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→ risk of operator aliasing

→ anti-alias filters tend to falsify amplitudes
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Common-Reflection-Surface stack

- alternative to standard NMO/DMO/stack approach
  - second-order approximation of reflection events in offset and midpoint direction
  - spatial stacking operator
    - much more prestack traces used
    - enhanced signal/noise ratio
  - fully automated coherence-based application
  - output:
    - zero-offset section/volume
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General workflow

Common Reflection Surface (CRS) stack

Kinematic wavefield (CRS) attributes

Event–consistent picking

Event–consistent smoothing

Determination of stationary point
Determination of projected Fresnel zone
Determination of CRP trajectory

Time migration velocity model

Minimum aperture time migration
Workflow: extraction of attributes

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Workflow: extraction of attributes

CRS stack provides kinematic wavefield attributes for each sample

▸ meaningful only along reflection events
▸ subject to outliers
▸ subject to unphysical fluctuations

▸ attribute-based event-consistent smoothing
  ◀ smooth input for determination of PFZ and stationary point
▸ attribute-based event-consistent picking
  ◀ input for velocity model determination
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- CRS attributes provide approximation of *diffraction* response
  - time migration operator
    - estimation of time migration velocity
    - estimation of operator apex
  - interpolation of velocity model

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Velocity model determination

True diffraction response
True reflection response
Approx. diffraction response
Approx. reflection response
True apex
Approx. apex

Distance [km]
Time [s]

2 4 6
P0
Velocity model determination
Velocity model determination

-3.5 -3 -2.5 -2 -1.5 -1 -0.5
2100  2200  2300  2400  2500  2600  2700  2800
t [s]
v [m/s]
picked stacking velocities
+ calculated migration velocities *
Velocity model determination

- CRS attributes provide approximation of *diffraction* response
  - time migration operator
    - estimation of time migration velocity
    - estimation of operator apex
- interpolation of velocity model
  - weighted polynomial interpolation
  - currently no physical constraints
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\( v_{\text{MIG}}: \text{interpolated} \)

\( x \) [m]

\( t \) [s]

\( v \) [m/s]
Workflow: migration attributes

Common Reflection Surface (CRS) stack ➔

Kinematic wavefield (CRS) attributes ➔

Event–consistent picking ➔

Event–consistent smoothing ➔

Determination of stationary point ➔

Determination of projected Fresnel zone ➔

Determination of CRP trajectory ➔

Time migration velocity model ➔

Minimum aperture time migration
PFZ & stationary point

Stationary point for ZO:

- migration operator $\tau_D$ is tangent to event $\tau_R$
- dip of reflection event related to emergence angle $\alpha$
PFZ & stationary point

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- dip of reflection event related to emergence angle $\alpha$
- dip of migration operator can be calculated analytically

$\Rightarrow$ minimum dip difference below given threshold determines stationary point

Projected Fresnel zone for ZO:

$\Rightarrow$ directly available from CRS attributes

\[
\frac{W_F}{2} = |x_m - x_0| = \frac{1}{\cos \alpha} \sqrt{\frac{v_0 \tau}{2 \left( \frac{1}{R_N} - \frac{1}{R_{NIP}} \right)}}
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PFZ & stationary point

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extrapolation of stationary point to finite offset
Widening of PFZ size with offset

reflector depth $z=1000$ m

reflector dip=0 deg
reflector dip=10 deg
reflector dip=20 deg

reflector depth $z=4000$ m

reflector dip=0 deg
reflector dip=10 deg
reflector dip=20 deg
Original model ($v_P$)
Zero-offset seismogram
Migration velocity model
Image gather
PreSTM stacked section (conventional)
PreSTM stacked section (CRS-based)
CRS-based stationary points
CRS-based ZO projected Fresnel zone

Time [s]
Distance [km]
PFZ width [m]
AVO (first target reflector)
AVO (second target reflector)

![Graph showing AVO (Amplitude Versus Offset) for second target reflector with different cases: CRS-based PSTM, no noise, CRS-based PSTM, noise, and conv. PSTM, noise. The x-axis represents depth in meters (h), and the y-axis represents amplitude. The graph compares the response at various depths for each case.](image-url)
AVO (third target reflector)

[Graph showing AVO data for different models: CRS-based PSTM with no noise, CRS-based PSTM with noise, and conventional PSTM with noise. The graph plots amplitude on the y-axis and depth in meters on the x-axis.]
ZO amplitudes (first target reflector)
Conclusions

CRS-based minimum aperture time migration concept allows

- simple, highly automated velocity model building
- stationary point & minimum aperture from CRS attributes
  - clearer images
  - more reliable amplitudes
- reduction of migration artifacts
  - no operator aliasing
  - less summing of unwanted contributions from other events
  - less summing of noise
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Related presentations

Workshop WS-2 “Velocity analysis for depth imaging”, Monday afternoon:

13:30 Common-Reflection-Surface stack – a generalized stacking velocity analysis tool

Session “Seismic Imaging”, Wednesday morning:

09:20 Smoothing and automated picking of kinematic wavefield attributes

09:45 CRS-stack-based seismic imaging for land data and complex near-surface conditions

11:25 Common-Reflection-Surface stack for OBS and VSP geometries and multi-component seismic reflection data