Event-directed Spectrum Extrapolation for Upsampling Seismic Traces

GEOCANADA 2010

Presented by : Zhengsheng Yao

Outline

- Introduction / motivation
- Methods review
- Spectrum extrapolation method
- Event-directed method
- Examples
- Conclusions

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Introduction / Motivation

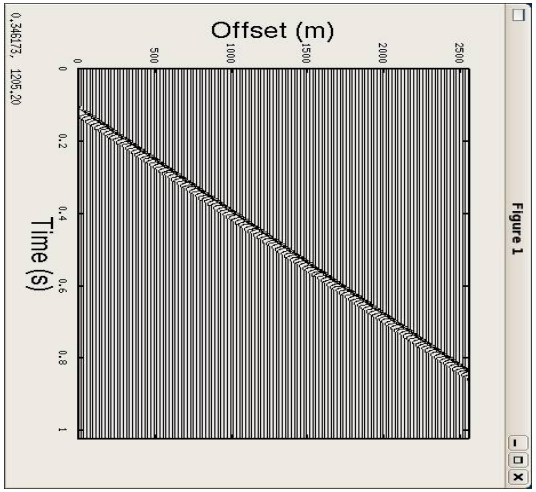
- High resolution seismic data processing requires high quality seismic data therefore trace interpolation becomes necessary.
- Methods available have limitations therefore developing advanced algorithms is of interest.
- A refinement of the current algorithms will be of benefit to our seismic community.

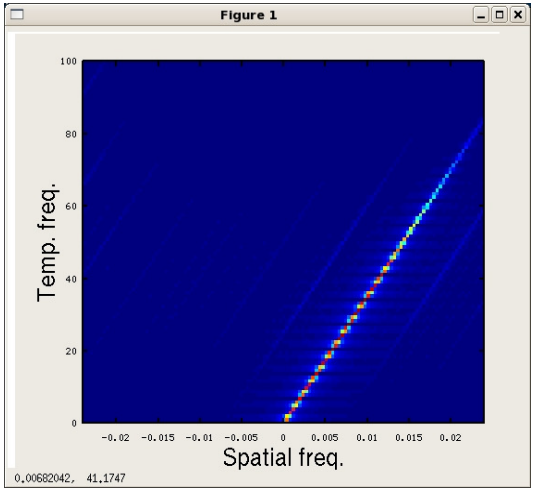
  i.e. ***Event-directed interpolation method***

Methods Review

Interpolation Principal: Interpolation has to follow seismic event direction to keep it's coherency / consistency.

Realization: Preserve the pattern of energy distribution.





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Methods Review

Time Domain

- Time slice interpolation via linear, cubic, polynomial, etc…
- Radon transform, traces correlation, etc..

Limitations

- Relatively simple pattern

Methods Review

F- K Domain

- F-K spectrum interpolation
- Fourier Reconstruction (Anti-leak) Method

Limitations

- Aliasing
- Amplitude handing

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Methods Review

Frequency Domain

- FX prediction filter method - Implicitly follows energy distribution

Limitations

- Handling of large gaps, prediction lag
- Handling of amplitudes, energy distribution varies with frequency

Methods Review

Spectrum Extrapolation Method

- Extension of Fourier reconstruction method

Advantage

- Filling large gaps
- Ease of use for high dimensions

Spectrum Extrapolation Method

Using Interpolation to fill missing traces

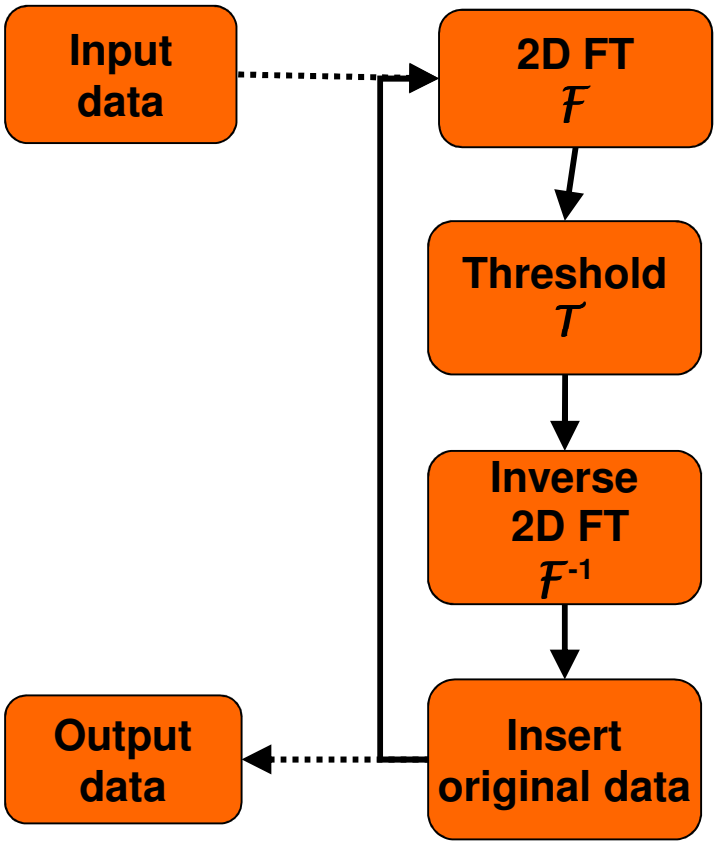
Gap filling - a group of traces missing
Upsampling - regular interval of traces missing

Realization: Formulate the problem as a underdetermined inverse problem. Spectrum density/power spectrum from desired traces is employed as priori information or constraint to force interpolation to follow the desired energy distribution pattern.

Assumption / condition of application: Missing traces do not change the pattern of the spectrum density/power spectrum.

Spectrum Extrapolation Method

POCS method



Adapted from Abma and Kabir (2006)

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Spectrum Extrapolation Method

Minimum Weighted Norm - An extension of the POCS method

(*Cabrera and Parks,1991)*

- Instead of using a band limited spectrum density as a constraint (excludes frequencies) to solve the problem iteratively, it uses the spectrum density as a priori weight function to solve a least squares problem, which leads to a faster convergence.

Spectrum Extrapolation Method

Observation:

- Both POCS and MWN can converge to a relatively similar result and if the band limited spectrum is used as the constraint, it turns out that both methods are equivalent (Ferreira,1996)

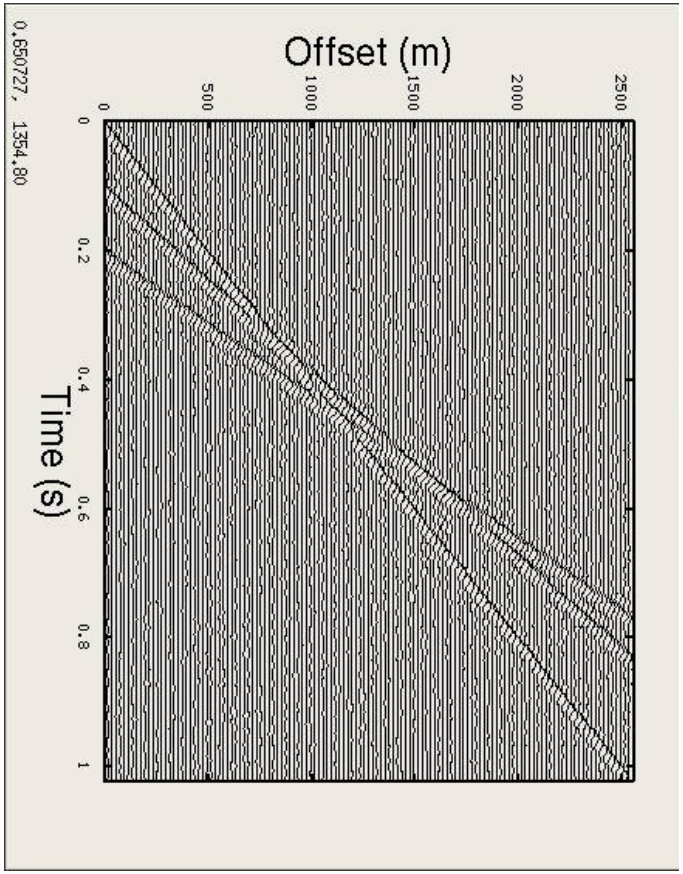
Hint:

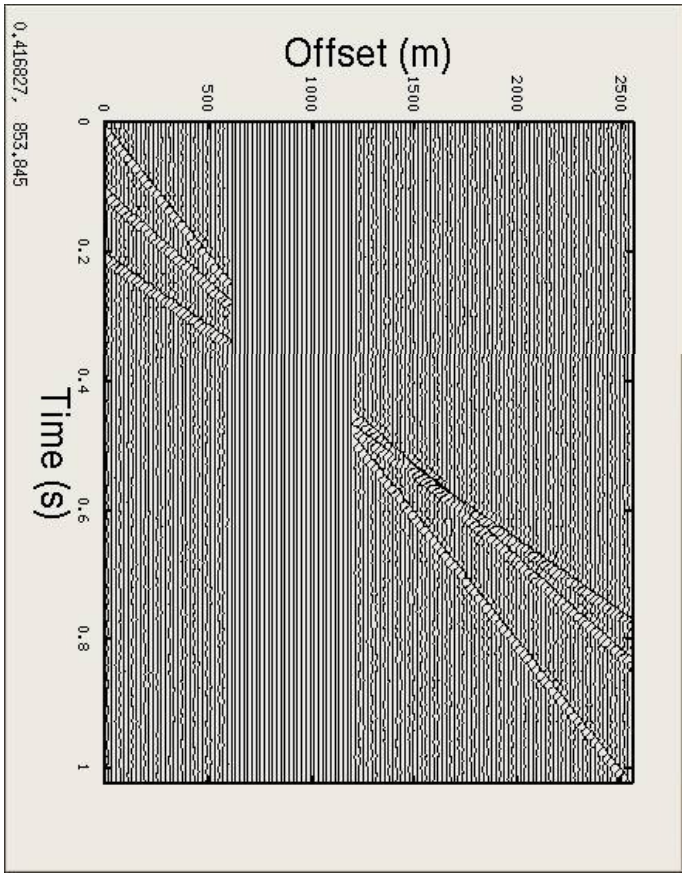
- Correctly estimating the desired power spectrum pattern is crucial

Question: How do we obtain the pattern of the desired spectrum?

Spectrum Extrapolation Method

Example - Seismic data with gaps (gap filling case)





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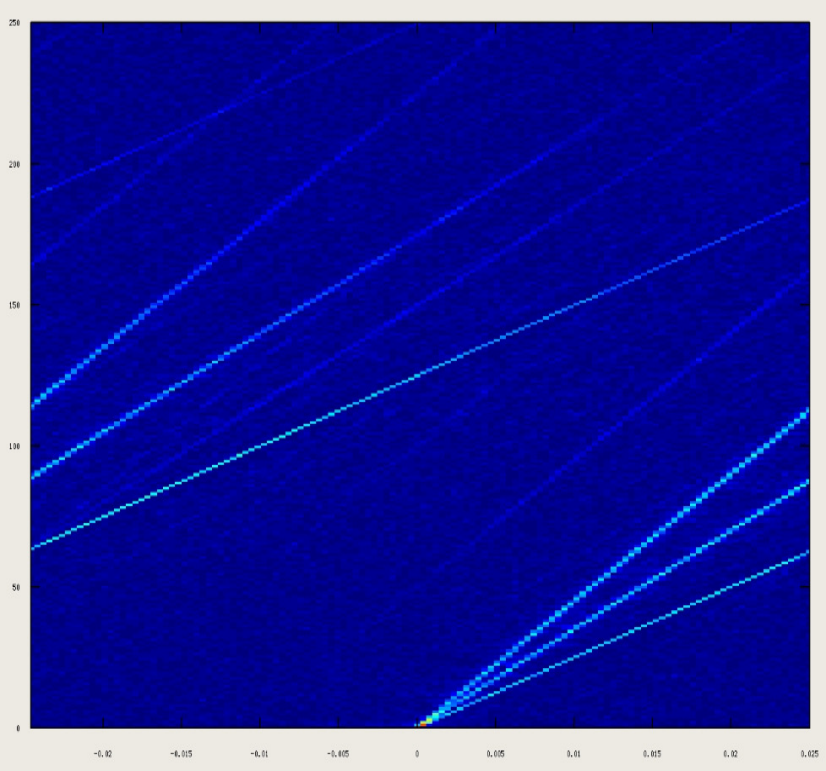
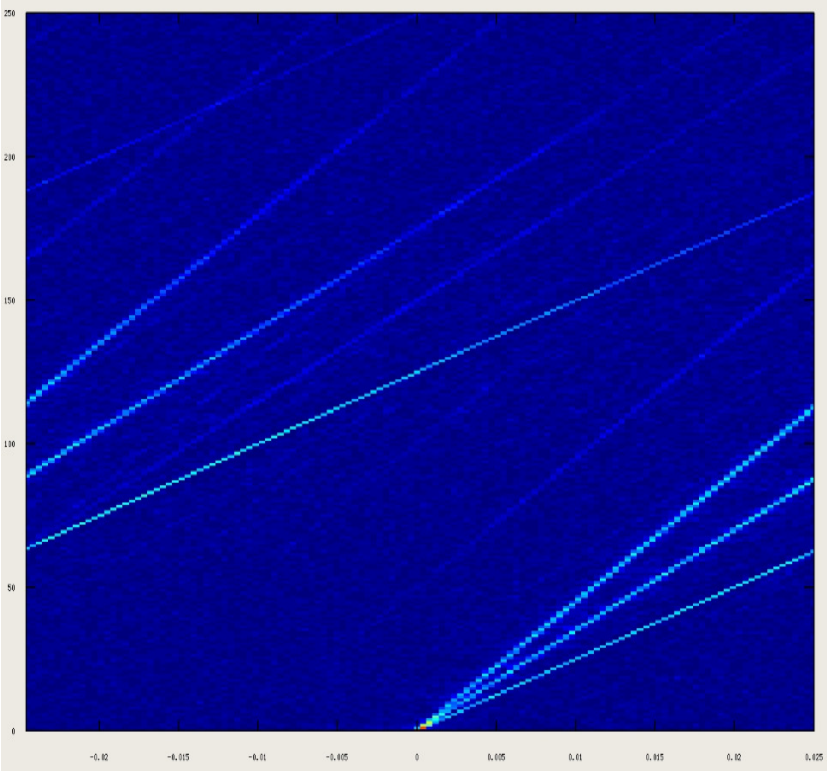
Spectrum Extrapolation Method

Example - fk spectrum corresponding to previous figure





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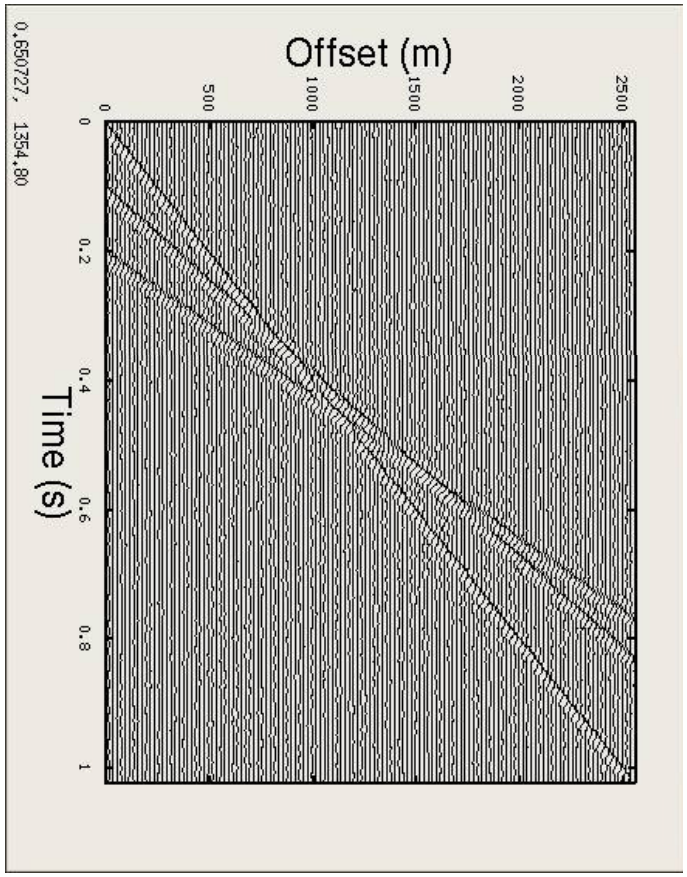
Spectrum Extrapolation Method

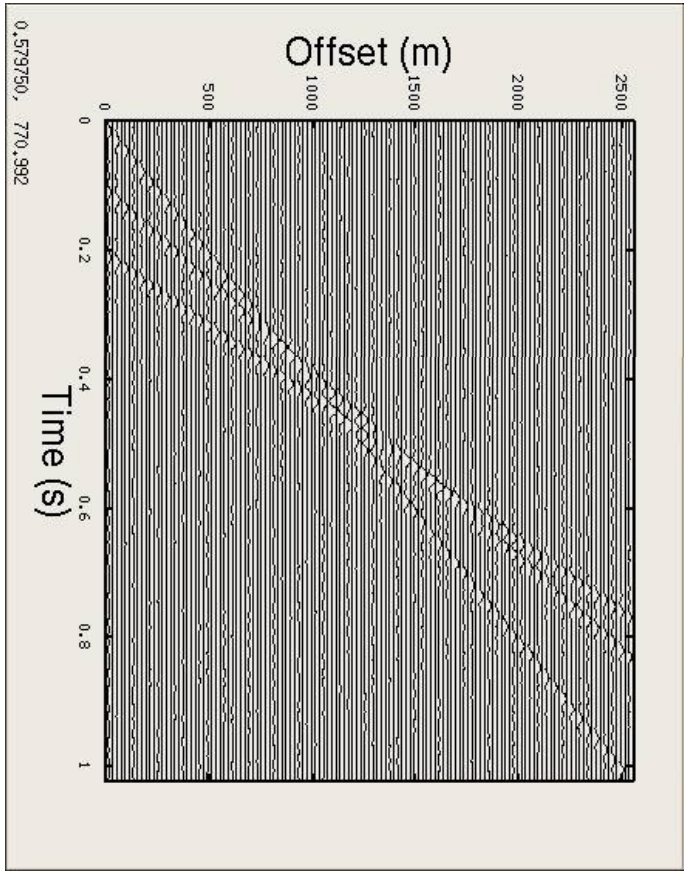
Observation

- Removal of small group of traces does not lose the original pattern of its spectrum
- Spectrum extrapolation method works well for missing data reconstruction

Spectrum Extrapolation Method

Example - Seismic data with regular decimated traces





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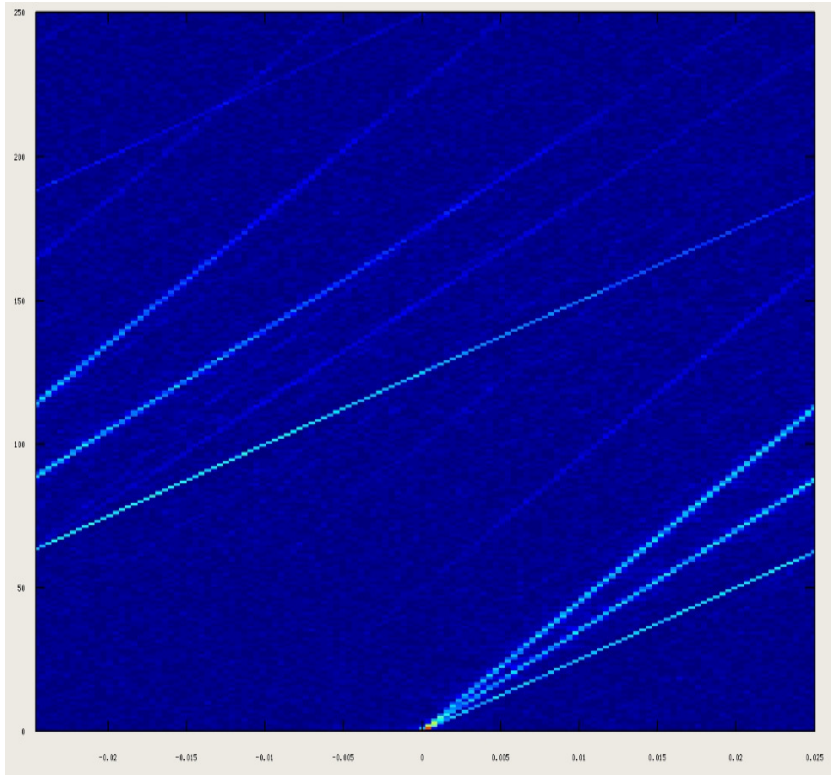
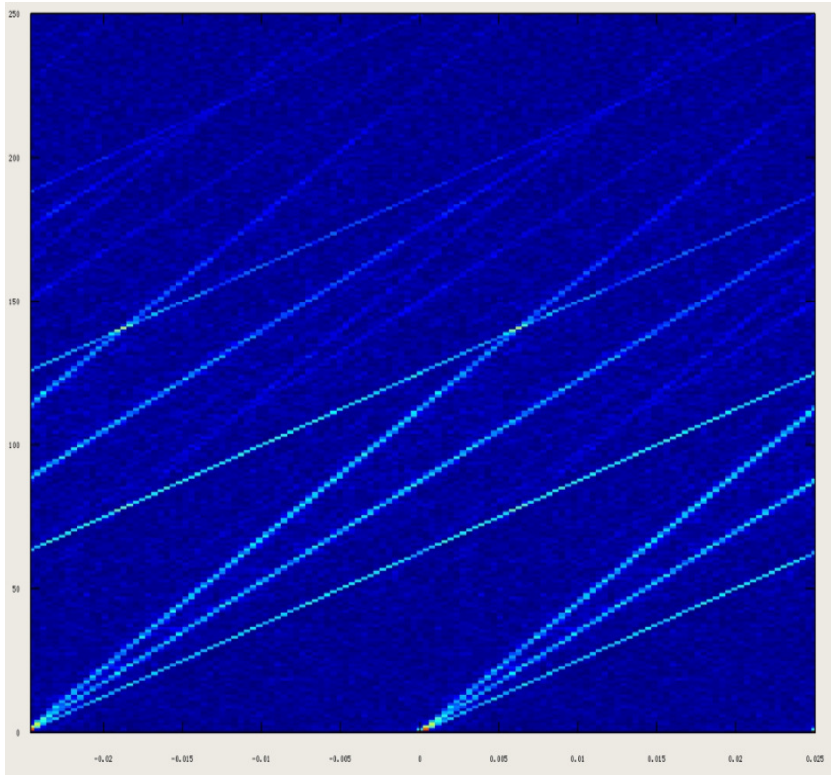
Spectrum Extrapolation Method

Example - fk spectrum corresponding to previous figure





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Spectrum Extrapolation Method

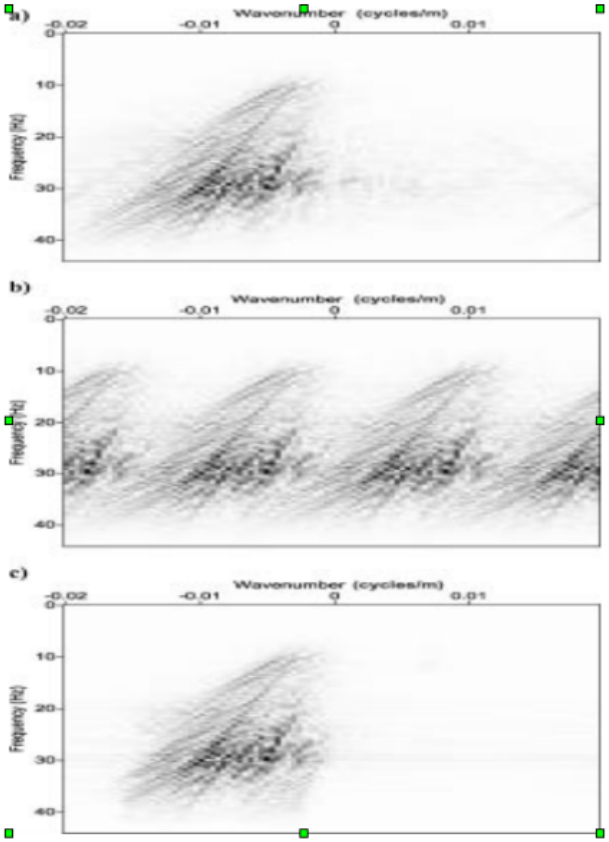
Observation

- Pattern of the power spectrum is duplicated due to the decrease in the effective Nyquist interval

Question: How to isolate the duplicated spectrum?

Solution 1: If the pattern of the desired power spectrum is known *priori*, then a simple mask technique can be used.

Spectrum Extrapolation Method



Adapted from Liu (2007)

Weakness

- Duplicated spectrum are not well separated (desired spectrum also aliased).
- Prior knowledge of the desired power spectrum is not available.

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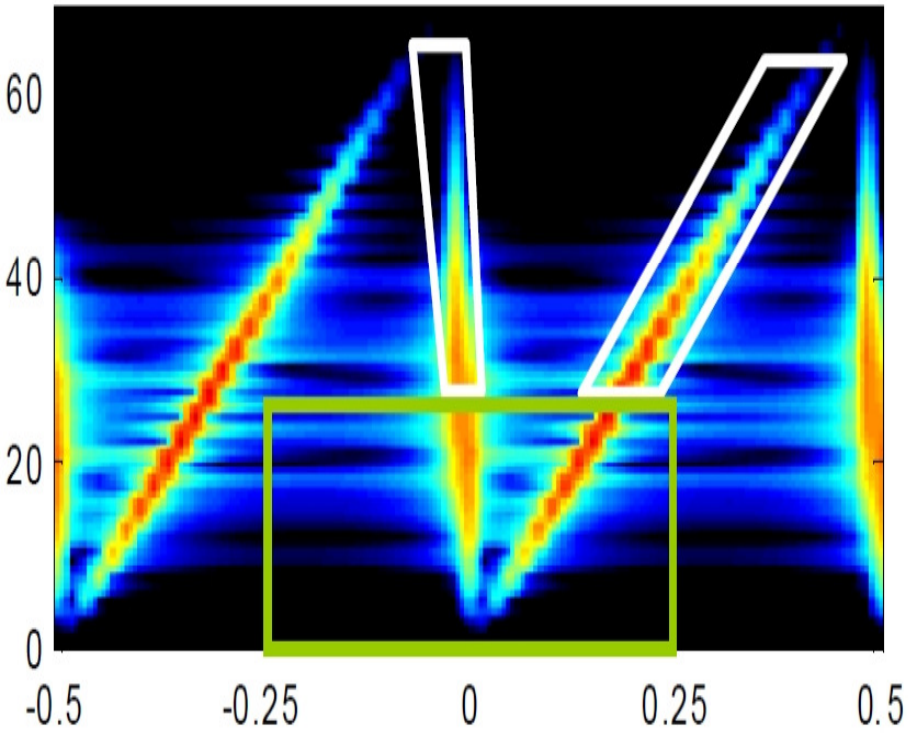
Spectrum Extrapolation Method

Solution 2: Low frequency spectrum extrapolation method

Zwartjes, P.M. and Sacchi, M.D. (2007) Schonewille, etal. (2009)



Weakness

- When desired power spectrum is aliased extrapolation itself is also an interpolation.

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Spectrum Extrapolation Method

Solution 3: MSAR Prediction Filter

(Naghizadeh, M. and M. D. Sacchi, 2007)

- Low frequency filter designed with proper space interval is used for higher frequency signal.
- Frequency reduced by factor of n and spatial interval increased by factor of n.

- If the interpolation with a prediction filter is computed in the time domain then the same interval for time sample is also required.

There is a relationship between the time sample interval and frequency!!!!

Event-directed Method

Fourier reconstruction:

$$d(x_h, f) = \sum_{j=1}^{q} D(k_j, f) e^{-ik_j x_h}$$

Naghizadeh, M. and M. D. Sacchi, 2009

Radon reconstruction:

$$d(x_h, f) = \sum_{j=1}^{q} R(p_j, \omega) e^{-i\omega p_j x}$$

- P is an invariant parameter and is independent of frequency.
- If P is known then all the components of K can be constructed.

Event-directed Method

Methodology

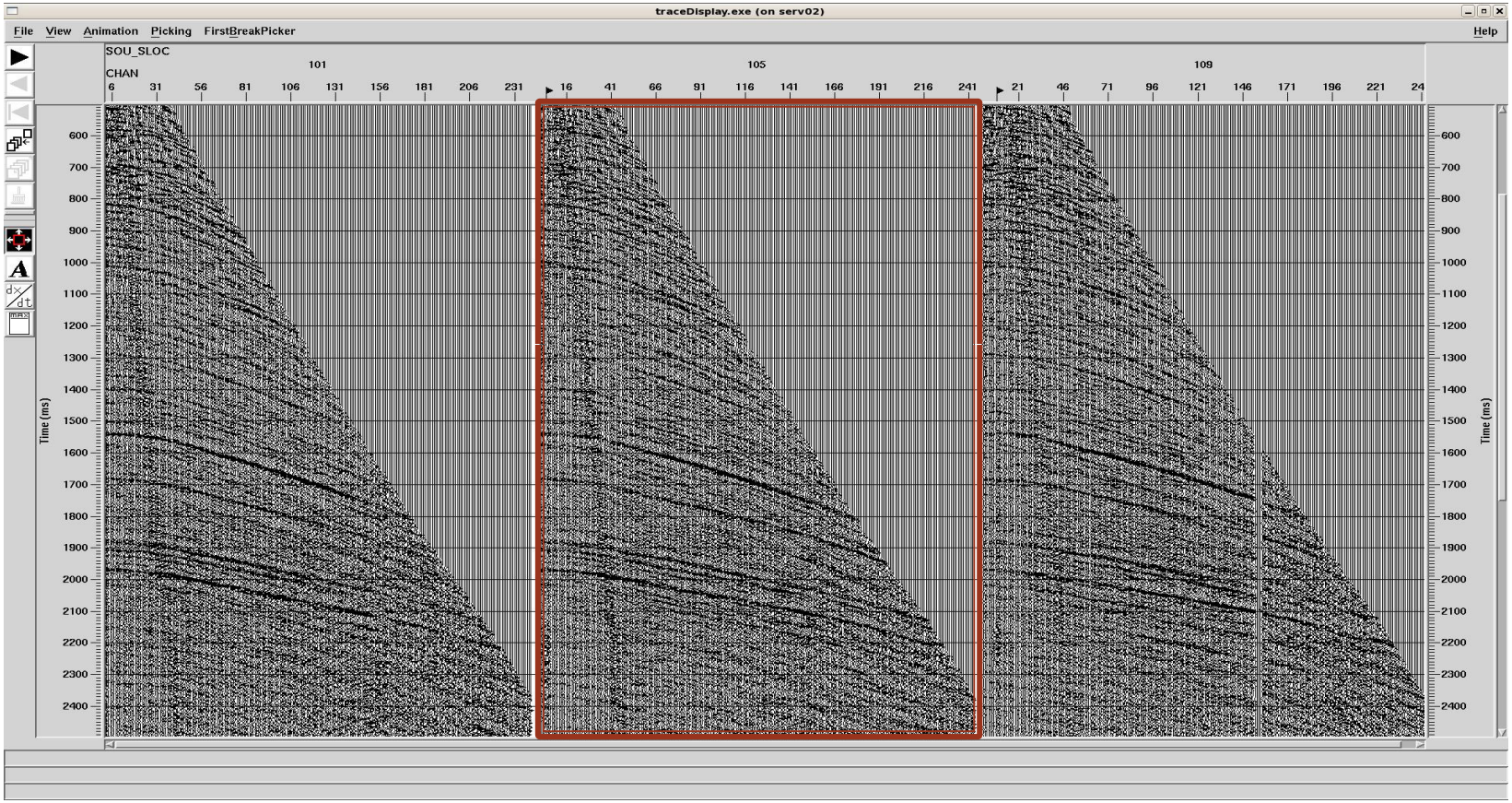
- Use the low frequency data that is not aliased to define P
- The P parameter is in turn used to build all k components with a proper Nyquist interval
- Use the reconstructed k to build a weighting function
- Perform MWN algorithm

Advantages

- Frequency band has been used to estimate P which results in parameter stability
- No need to update the weighting function

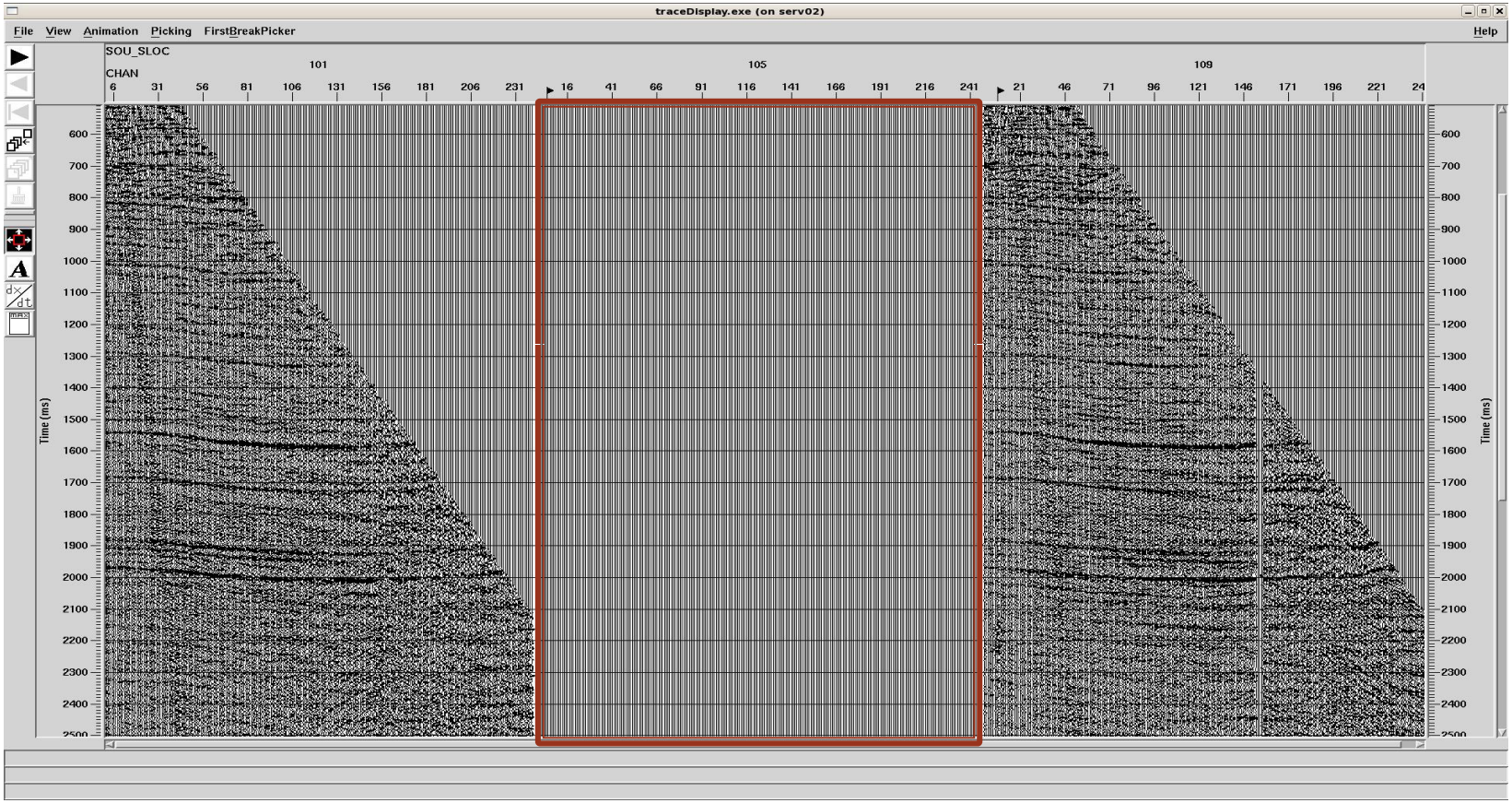
Event-directed Method

Data Example - Input



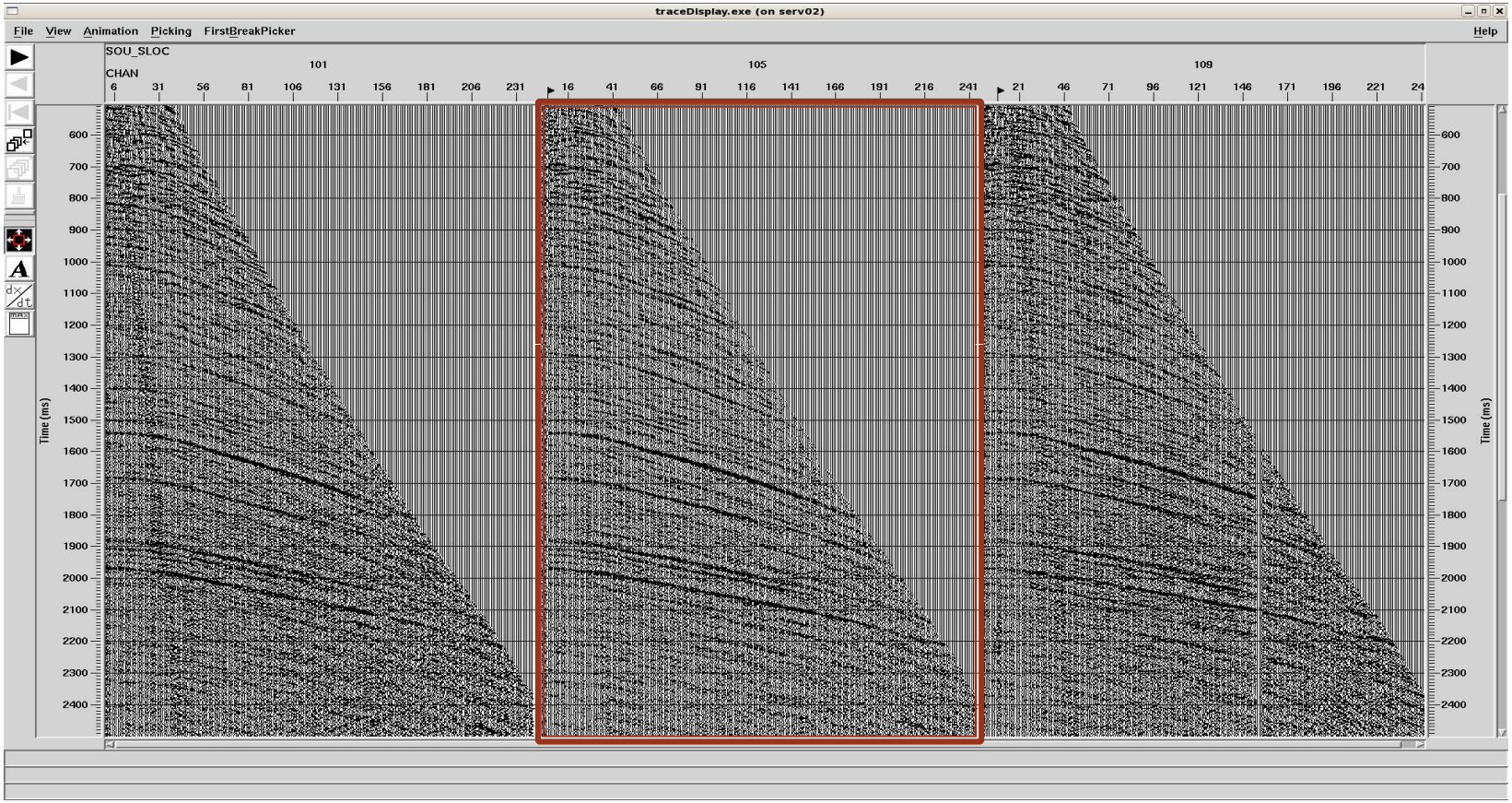
Event-directed Method

Data Example - Decimated

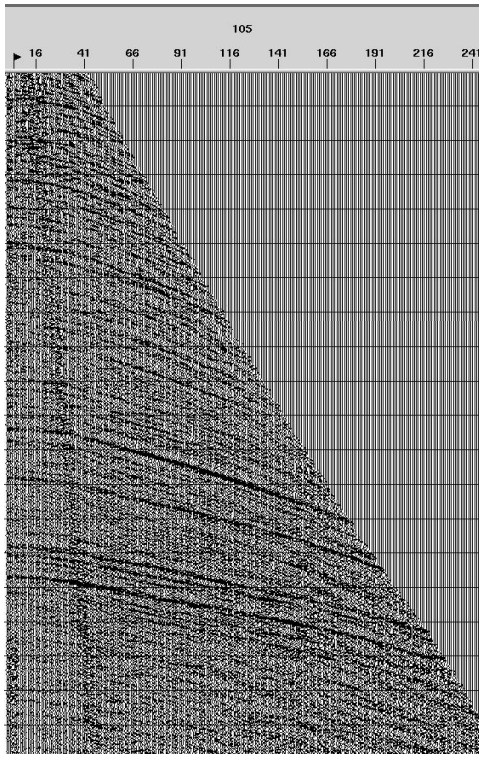


Event-directed Method

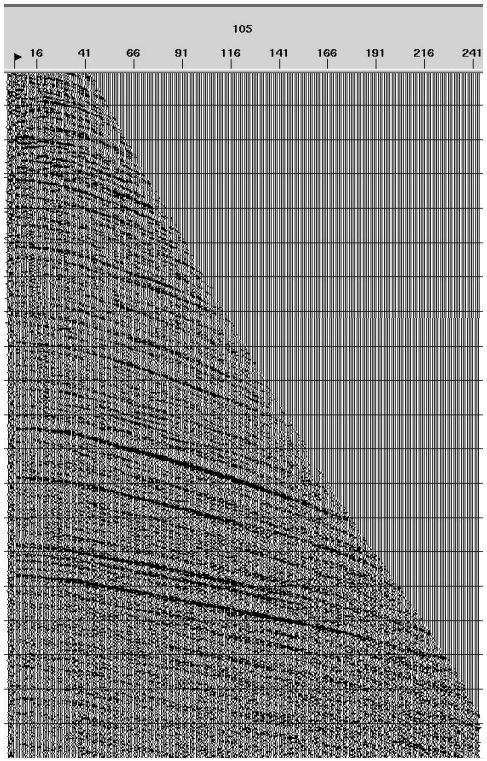
Data Example - Interpolated



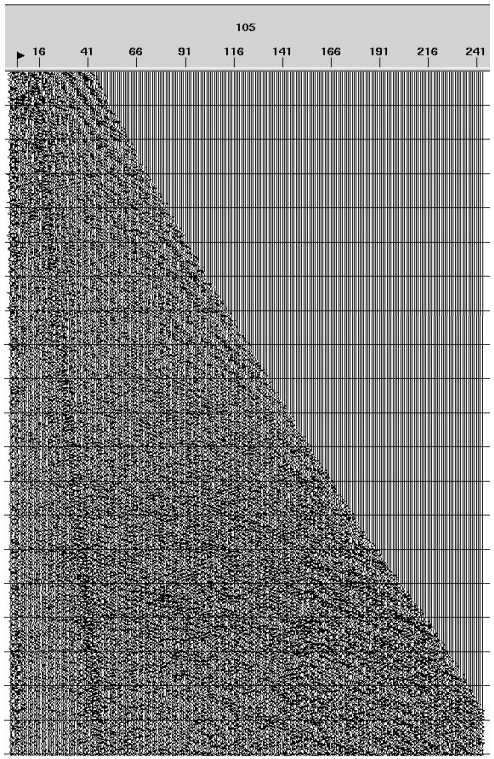
Event-directed Method



Original



Interpolated



Difference

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Conclusion

- In the spectrum extrapolation method, the desired spectrum estimation plays a crucial role that helps to constrain the interpolation along seismic events.
- The event-directed method provides an alternative and practical method to estimate the desired spectrum.
- Examples from both synthetic and real data demonstrates its capability of handling Upsampling interpolation.

Acknowledgement

- M. D. Sacchi for valuable discussions.
- Elvis Floreani and Gerry Schlosser for their input and collaboration.
- Absolute Imaging Inc. for giving me the resources and support for this project.

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