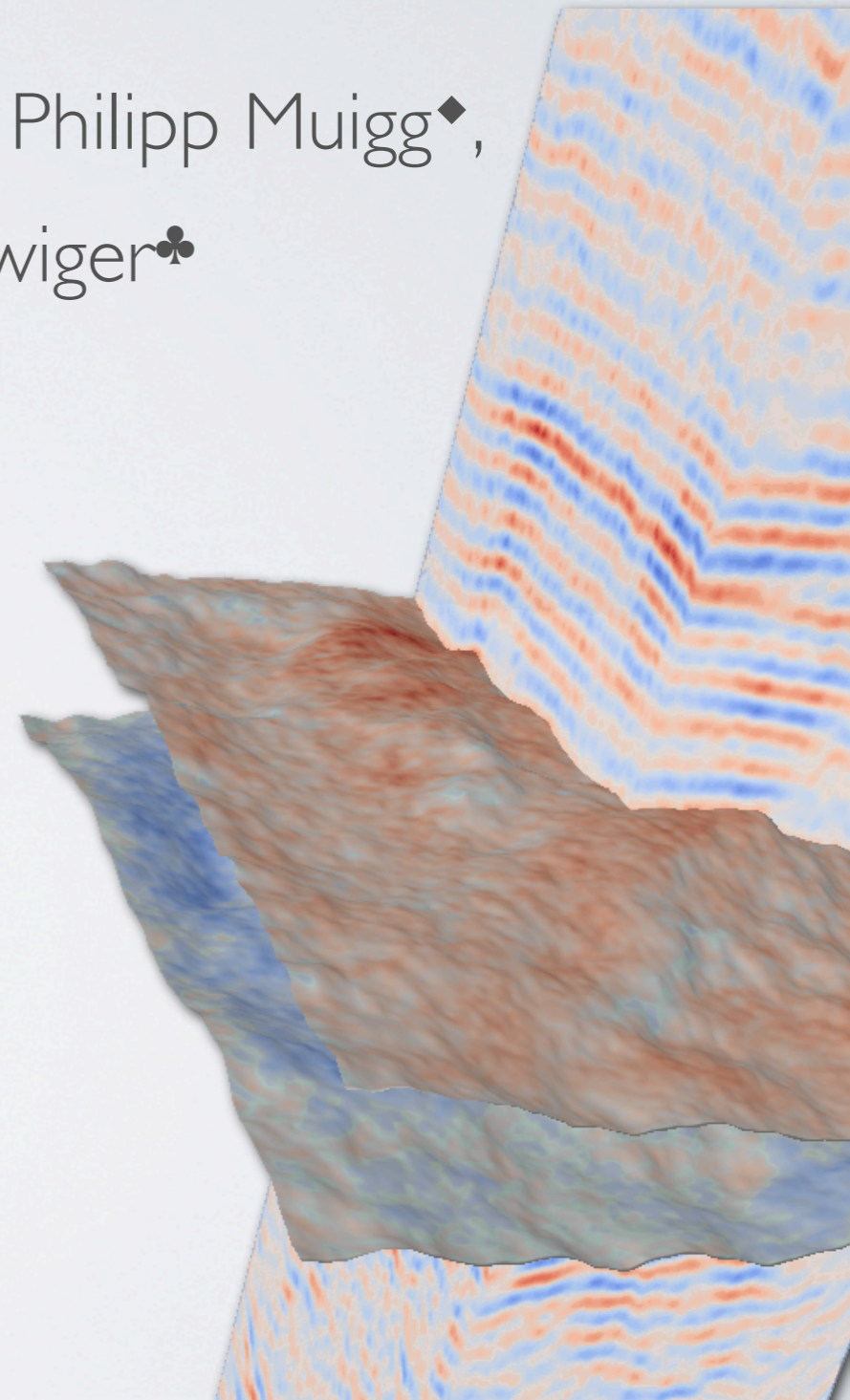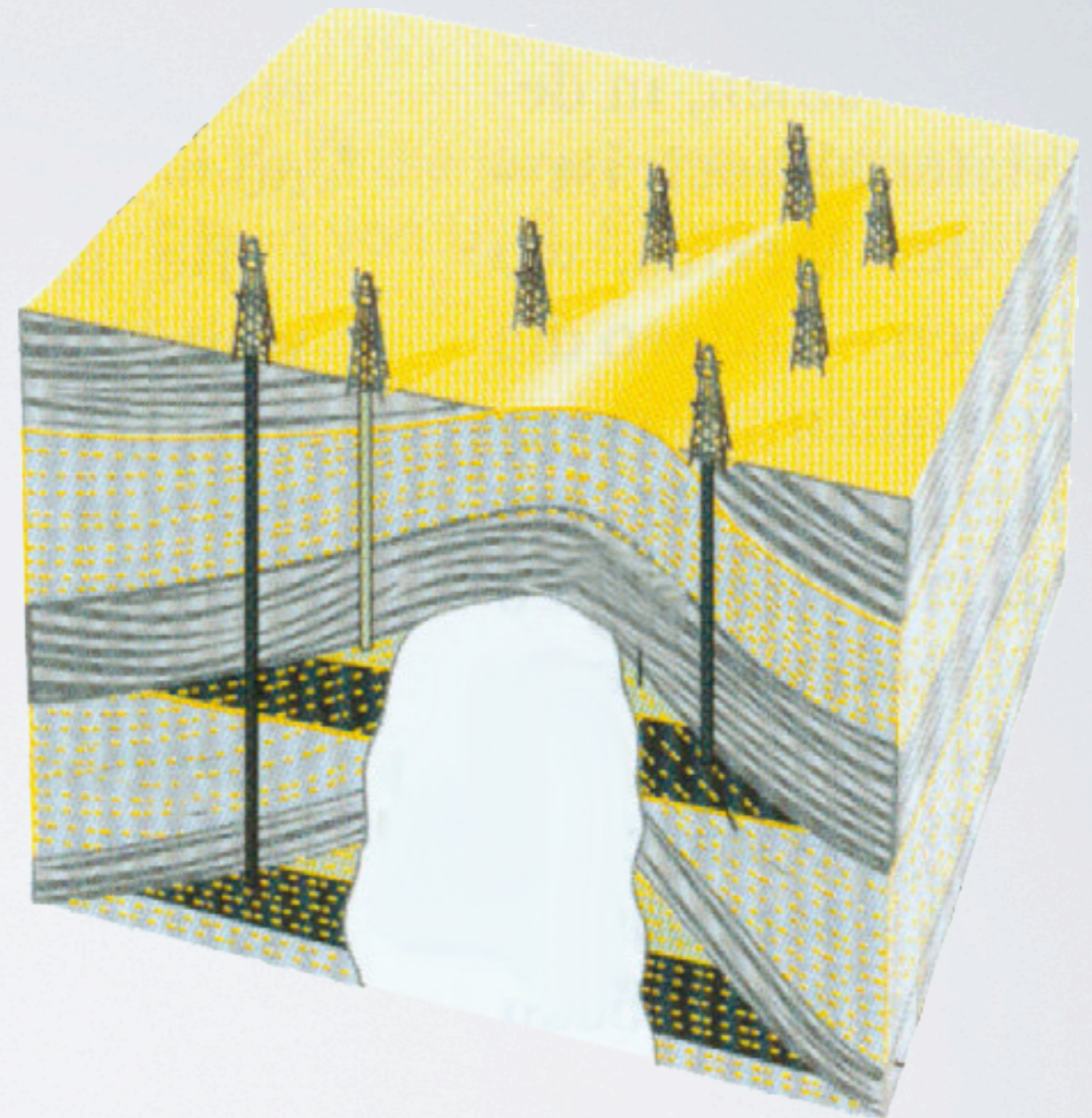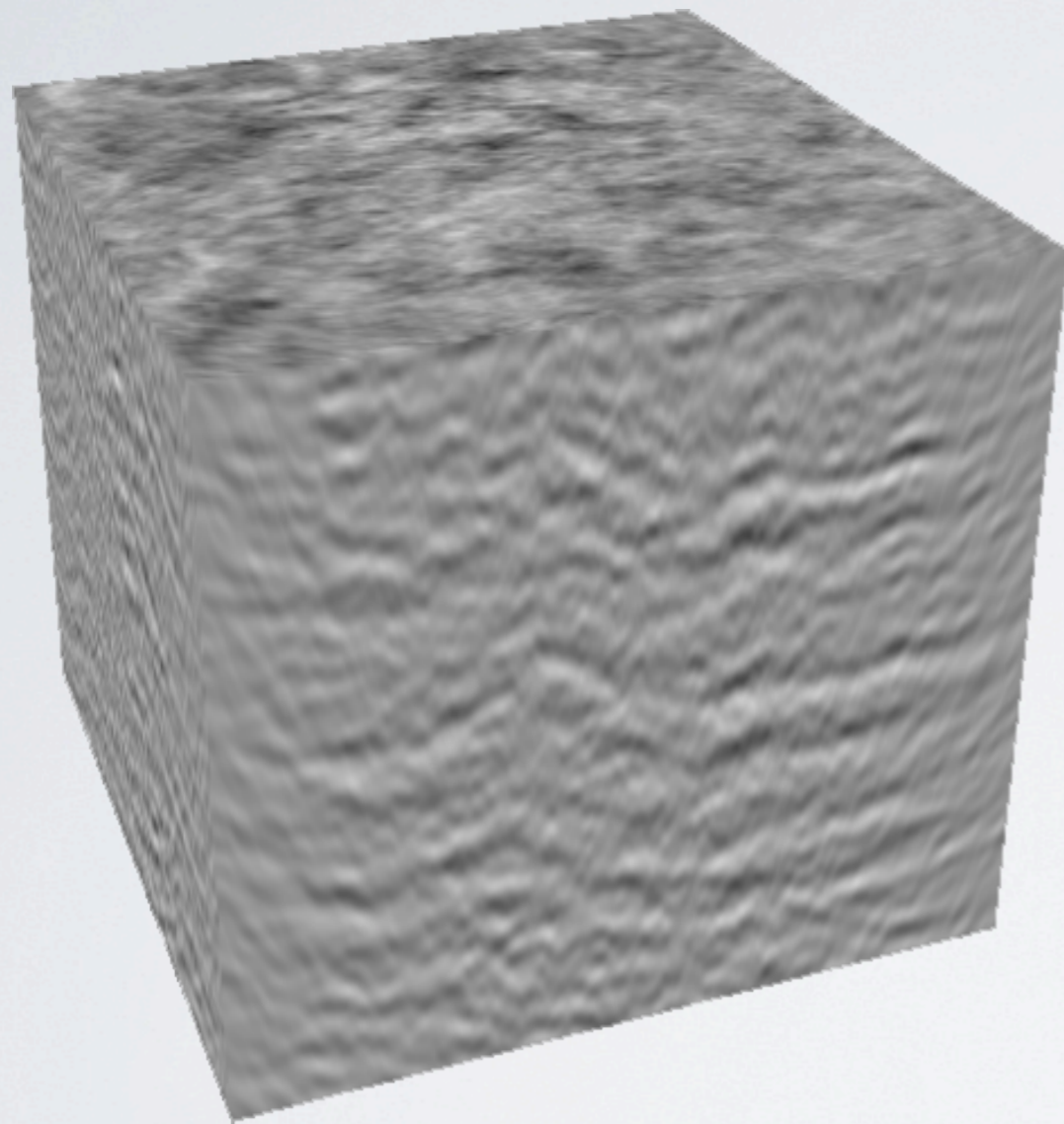# Interactive Seismic Interpretation with Piecewise Global Energy Minimization

Thomas Höllt♣, Johanna Beyer♣, Fritz Gschwantner•, Philipp Muigg♦,

Helmut Doleisch♦, Gabor Heinemann▪, Markus Hadwiger♣

♣ King Abdullah University of Science and Technology
• VRVis Research Center
♦ SimVis GmbH
▪ Heinemann Oil GmbH

Seismic Interpretation
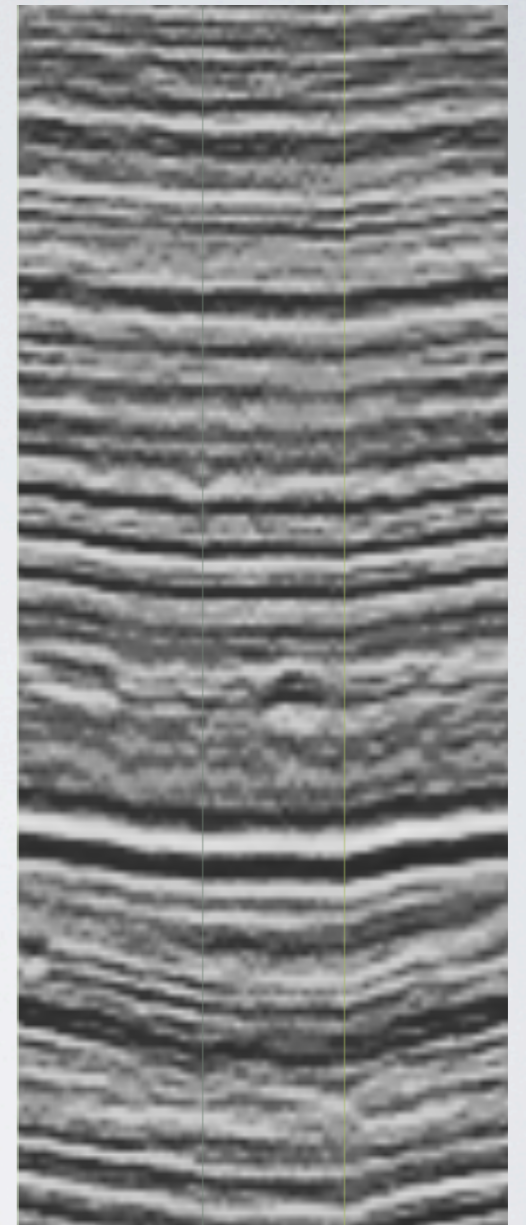

Grotzinger et al.
Understanding Earth

What is a Horizon?

- Boundary between two different subsurface layers

- These boundaries reflect seismic waves

- Amplitude of reflected waves is measured

- Strong amplitude depicts a boundary

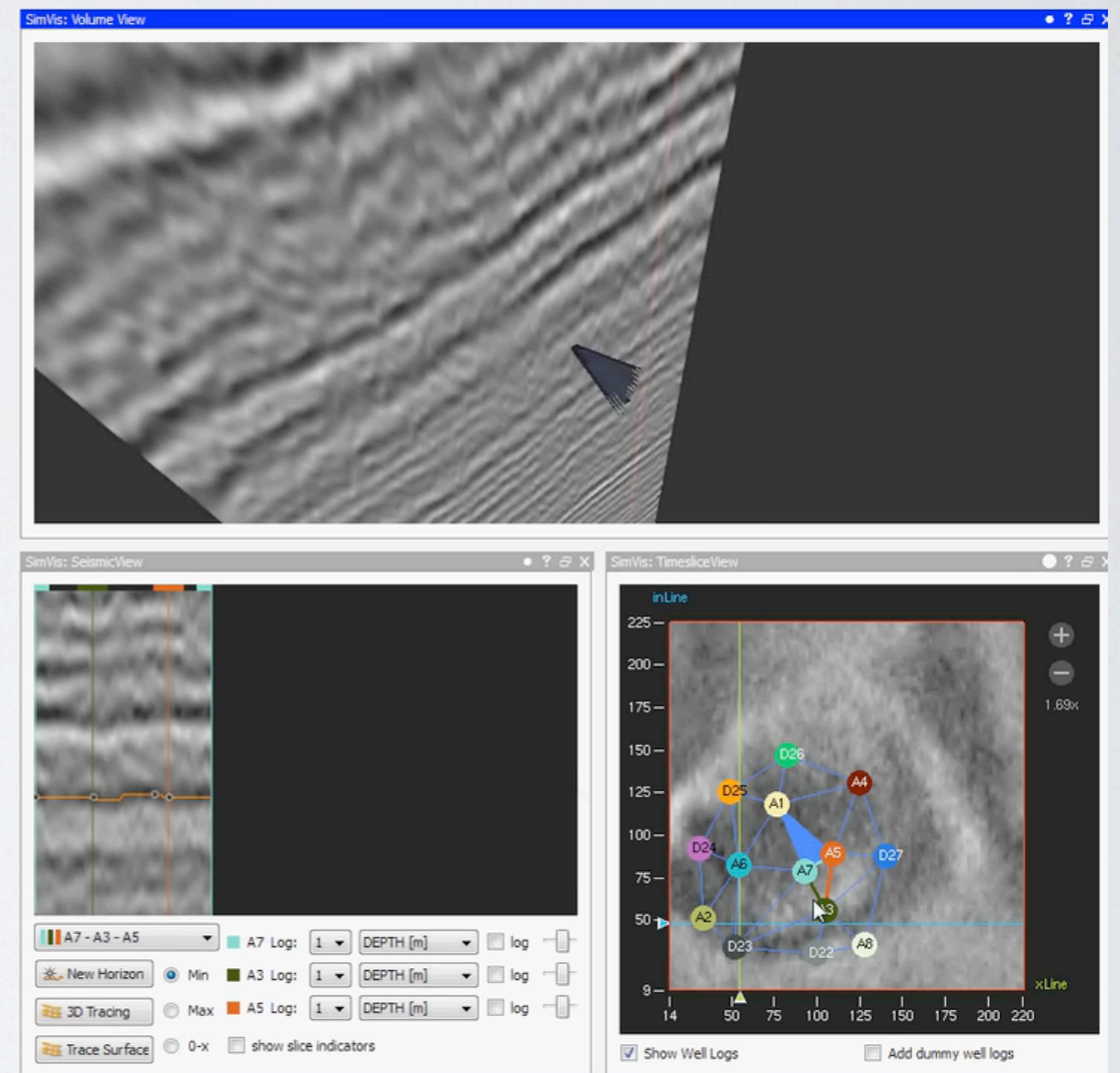- Horizons indicated by ridge-, valley-lines/surfaces

Workflow

- Interpretation based on well logs/positions

  - Triangulate well logs
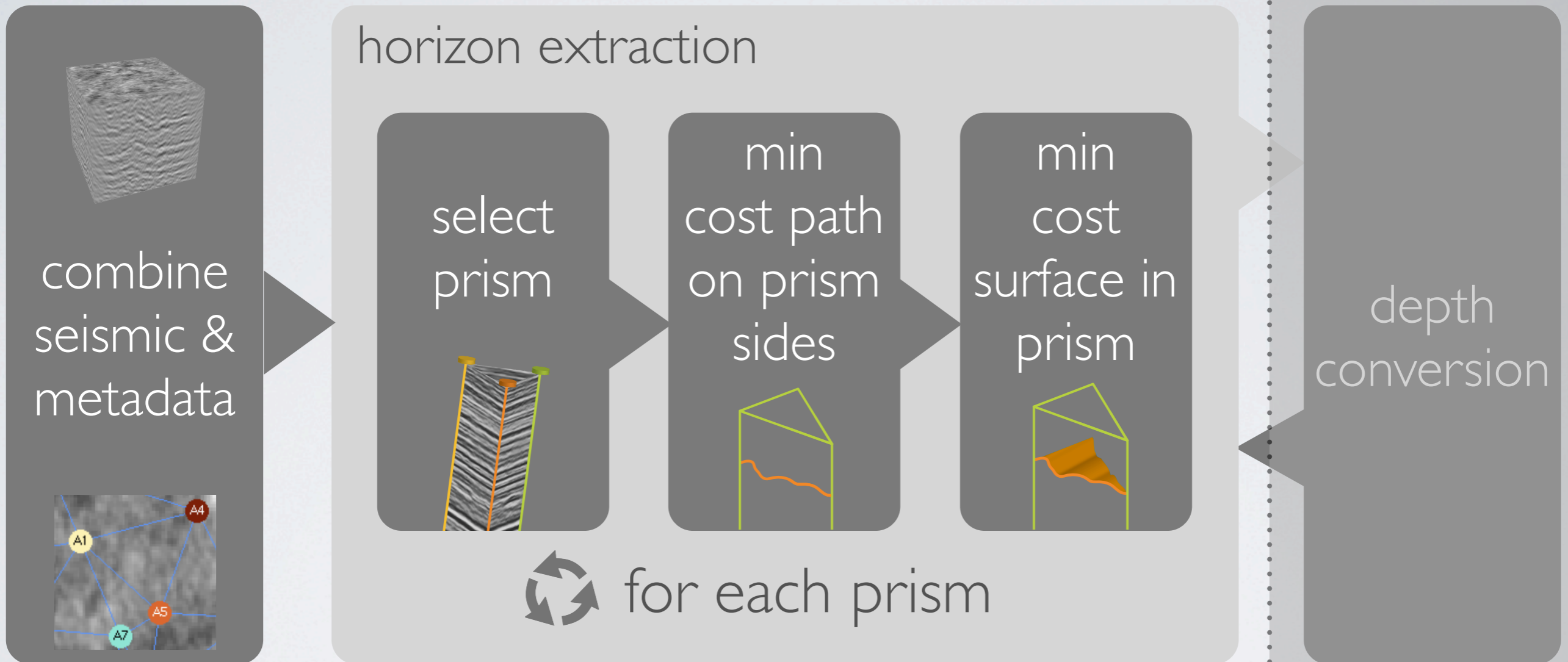
  - Work on triangles/prisms instead on slices

Workflow

- Interpretation based on well logs/positions

  - Triangulate well logs

 - Work on triangles/prisms instead on slices

Workflow

combine seismic & metadata

horizon extraction

select prism

min cost path on prism sides

min cost surface in prism

↻ for each prism

depth conversion

Horizons as Features

- In image segmentation:

  - segments are features

  - boundaries implicit

- Explicit boundary segmentation

  - Explicit boundary labeling

  - Boundary constraints

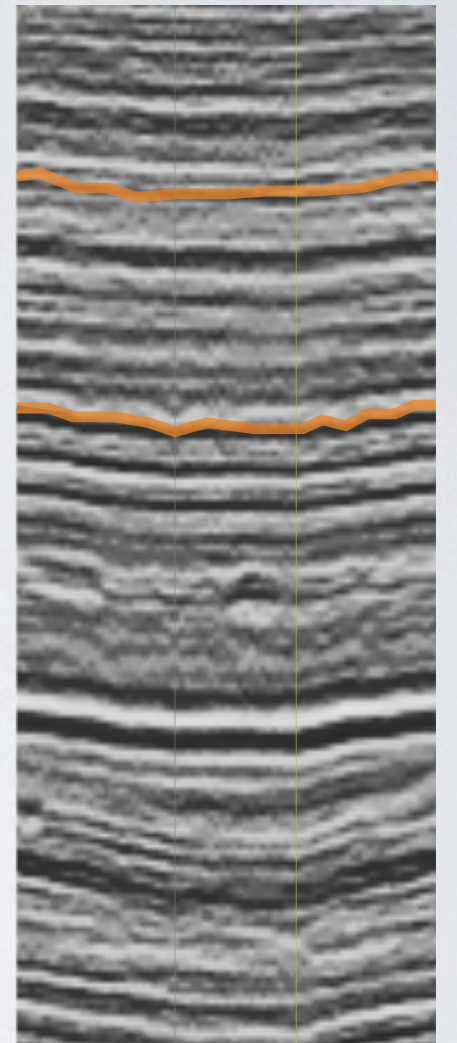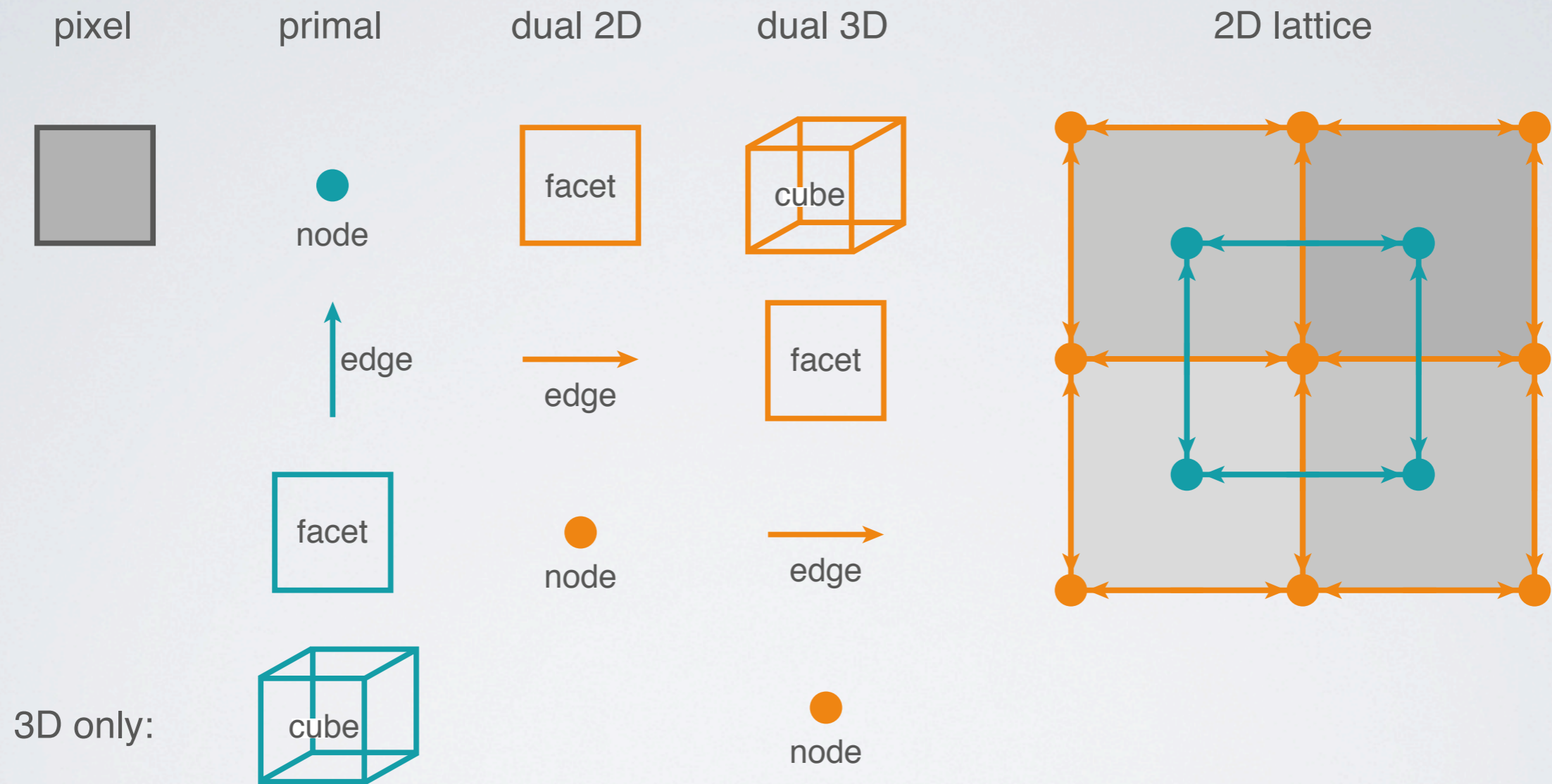 - Works on primal instead of dual graph
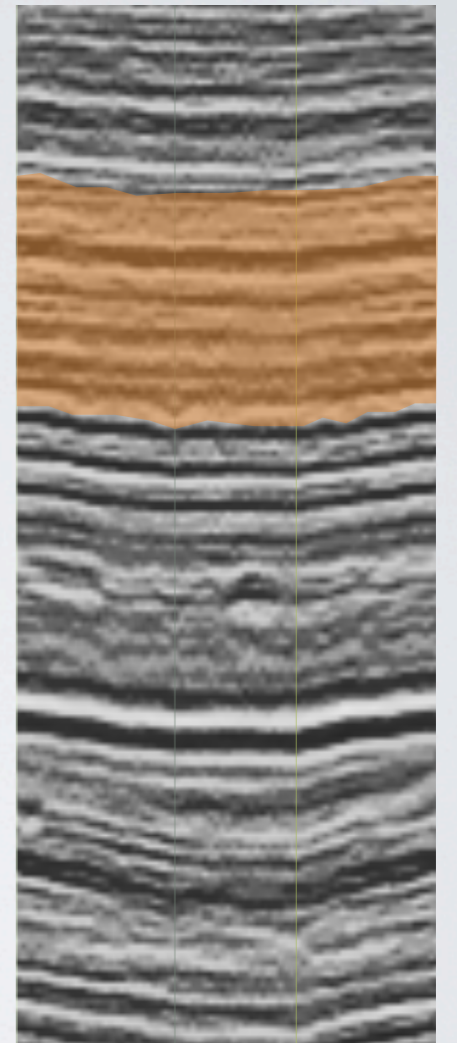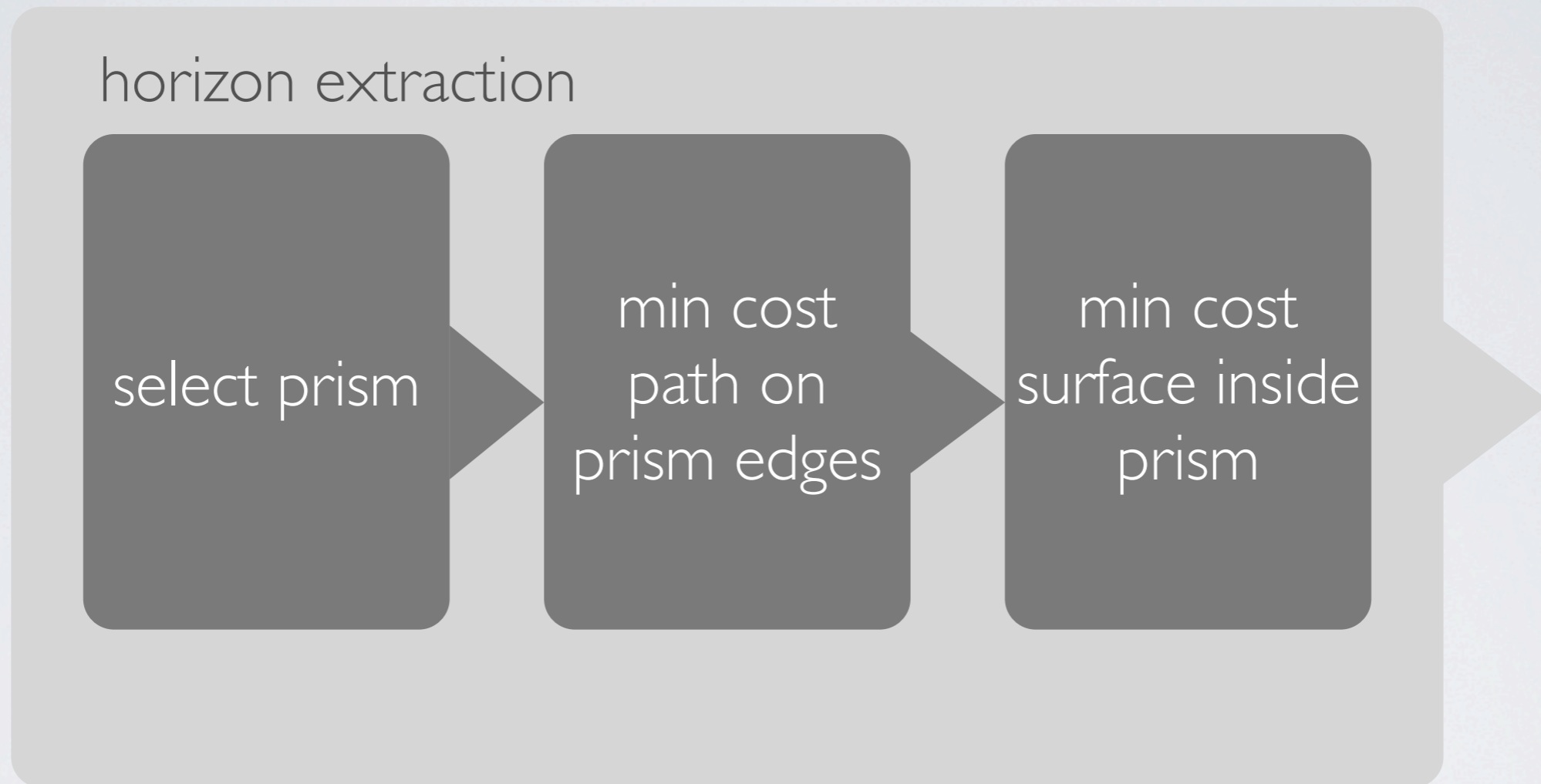
Horizons as Features

- In image segmentation:

  - segments are features

  - boundaries implicit

- Explicit boundary segmentation

  - Explicit boundary labeling

  - Boundary constraints

  - Works on primal instead of dual graph
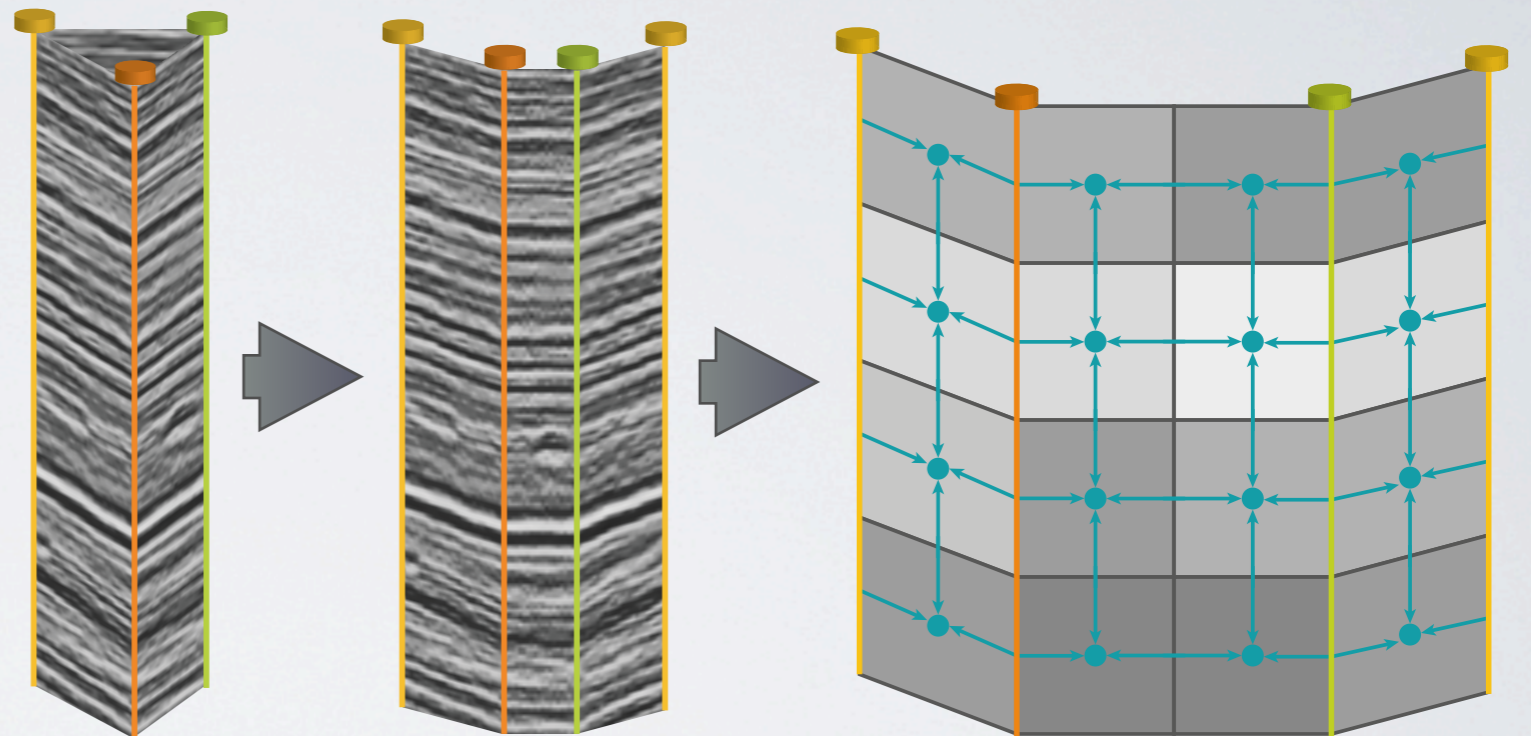
Image/Seismic to Graph

Horizon Extraction

horizon extraction

select prism → min cost path on prism edges → min cost surface inside prism

2D Min Cost Paths

min cost path on prism edges   (1st prism)

seed point

2D primal graph

compute minimum cost path

surface boundary
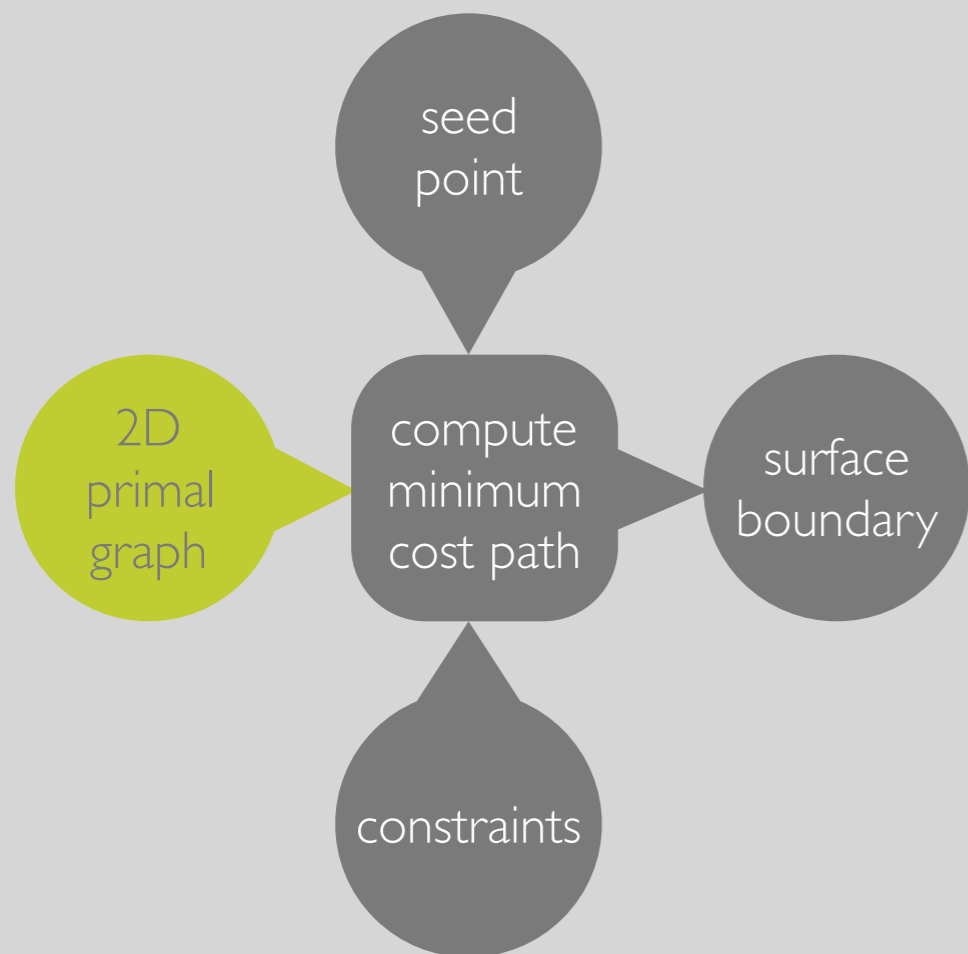
constraints

- Input: prism sides, rep. as primal graph

2D Min Cost Paths

min cost path on   (1st prism)
prism edges

seed
point

2D
primal
graph

compute
minimum
cost path
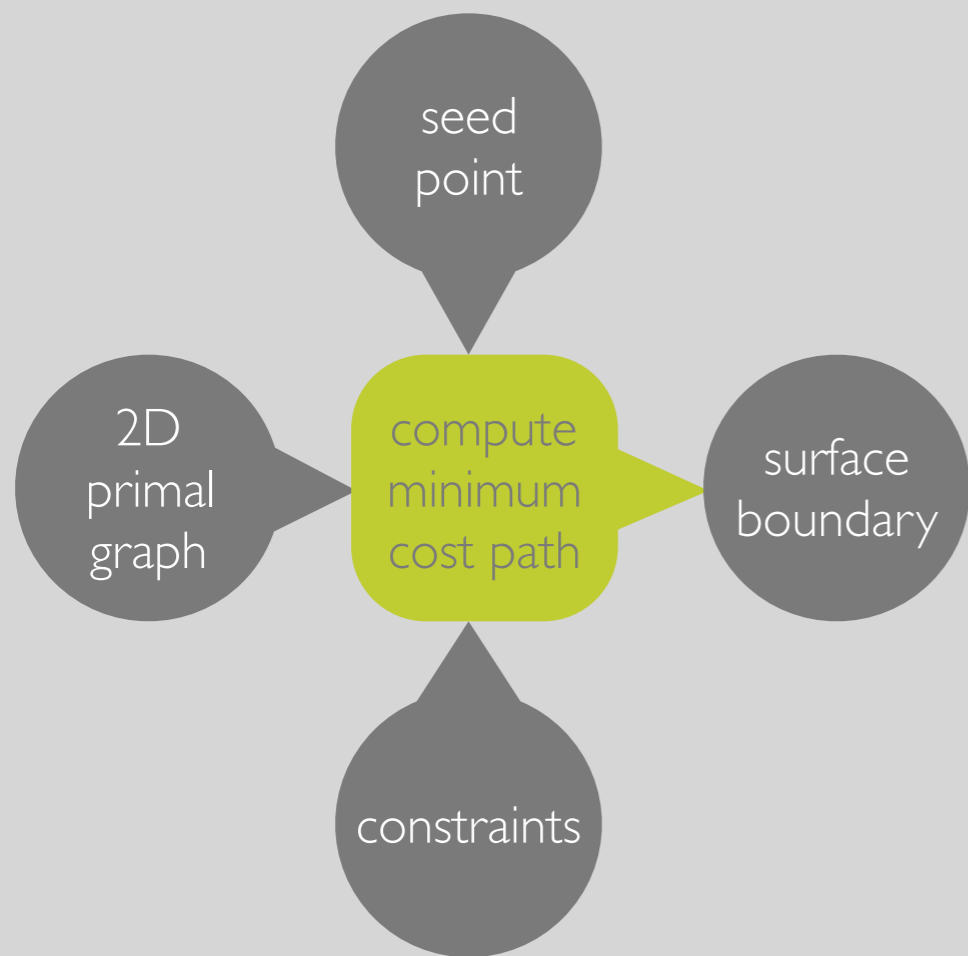
surface
boundary
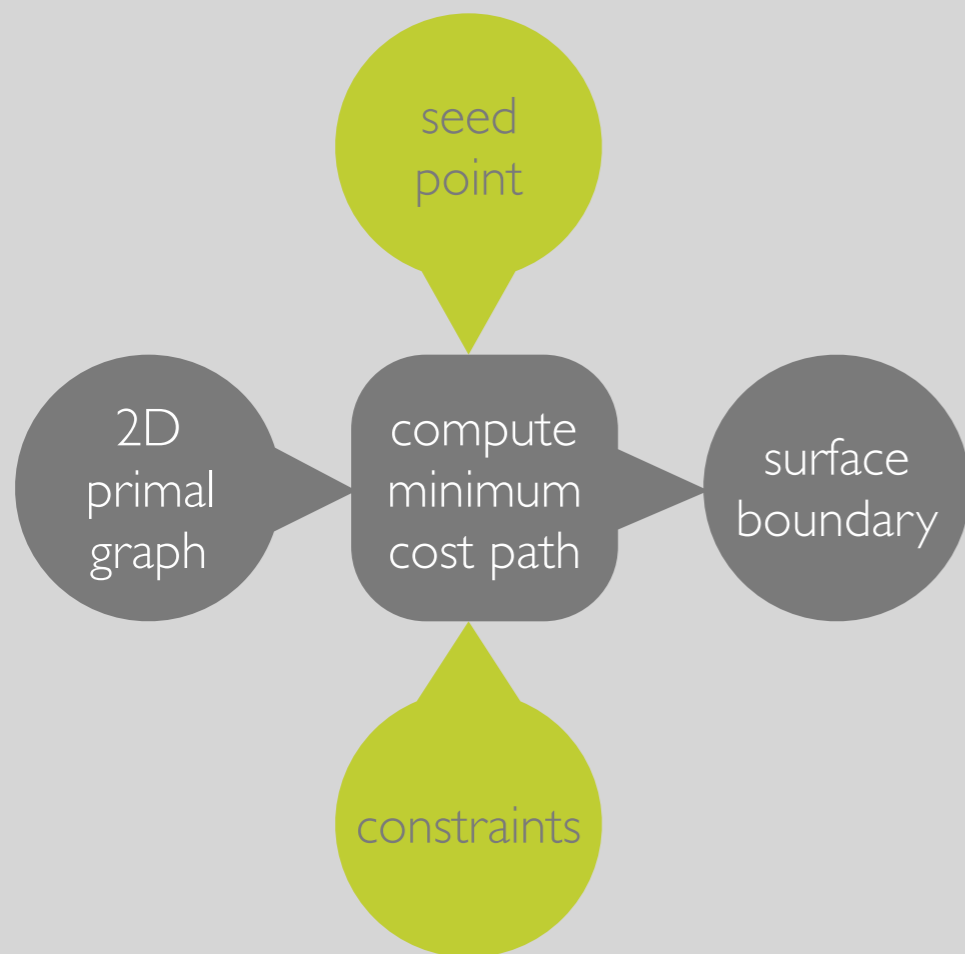
constraints

- Seed is start- and target-node

- Nodes can be added as constraints

- Path split up in segments connecting constraints

2D Min Cost Paths

min cost path on   (1st prism)
prism edges

seed
point

2D
primal
graph

compute
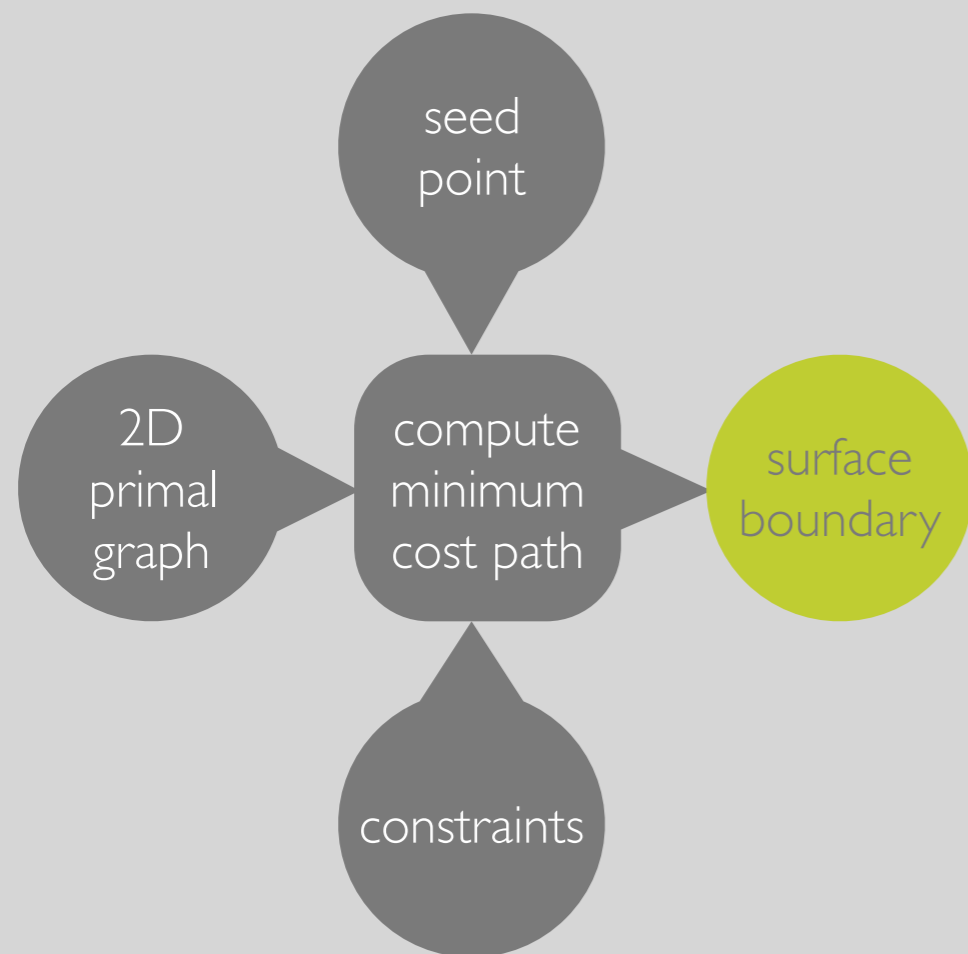minimum
cost path

surface
boundary

constraints

- Variant of Dijkstra's algorithm

- Cost of edges defined by adjacent nodes
  (dev. from target amplitude
   + dev. from average amplitude)

2D Min Cost Paths

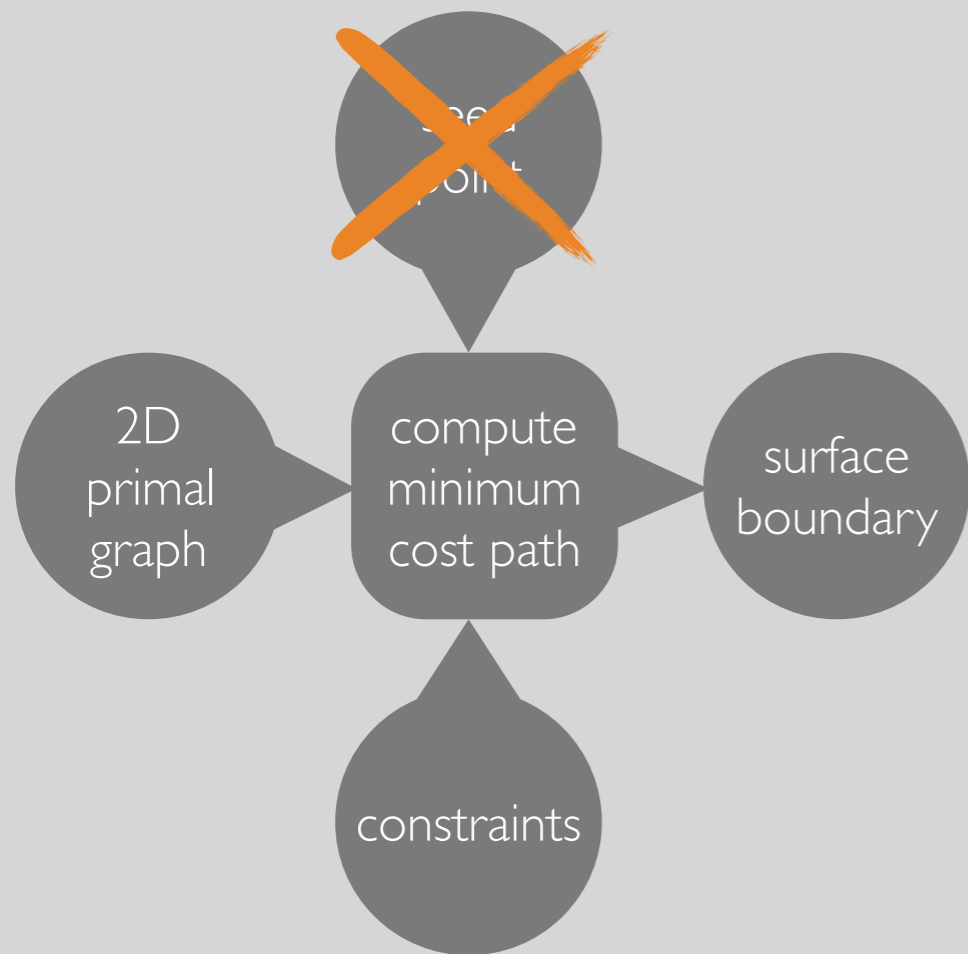min cost path on prism edges (1st prism)

seed point

2D primal graph → compute minimum cost path → surface boundary

constraints

- Set of pixels forming closed contour on the prisms sides

2D Min Cost Paths

min cost path on
prism edges

seed
point

2D
primal
graph → compute
minimum
cost path → surface
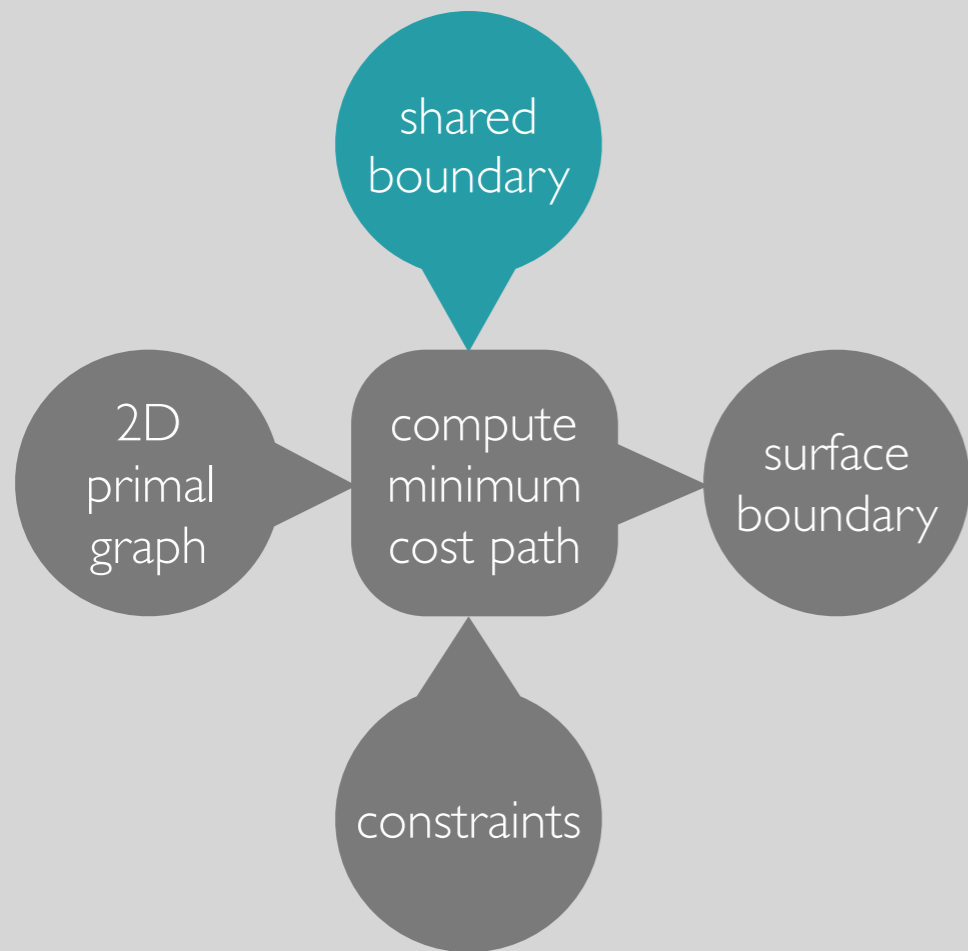boundary

constraints

- For adjacent prisms no new seed needed

- Traced paths are shared between prisms

  - Positions at well logs fixed for traced paths

  - Fixed positions function as seeds/constraints

2D Min Cost Paths

min cost path on
prism edges

shared
boundary

2D
primal
graph

compute
minimum
cost path

surface
boundary

constraints

- For adjacent prisms no new seed needed

- Traced paths are shared between prisms

  - Positions at well logs fixed for traced paths

  - Fixed positions function as seeds/constraints

Horizon Extraction II
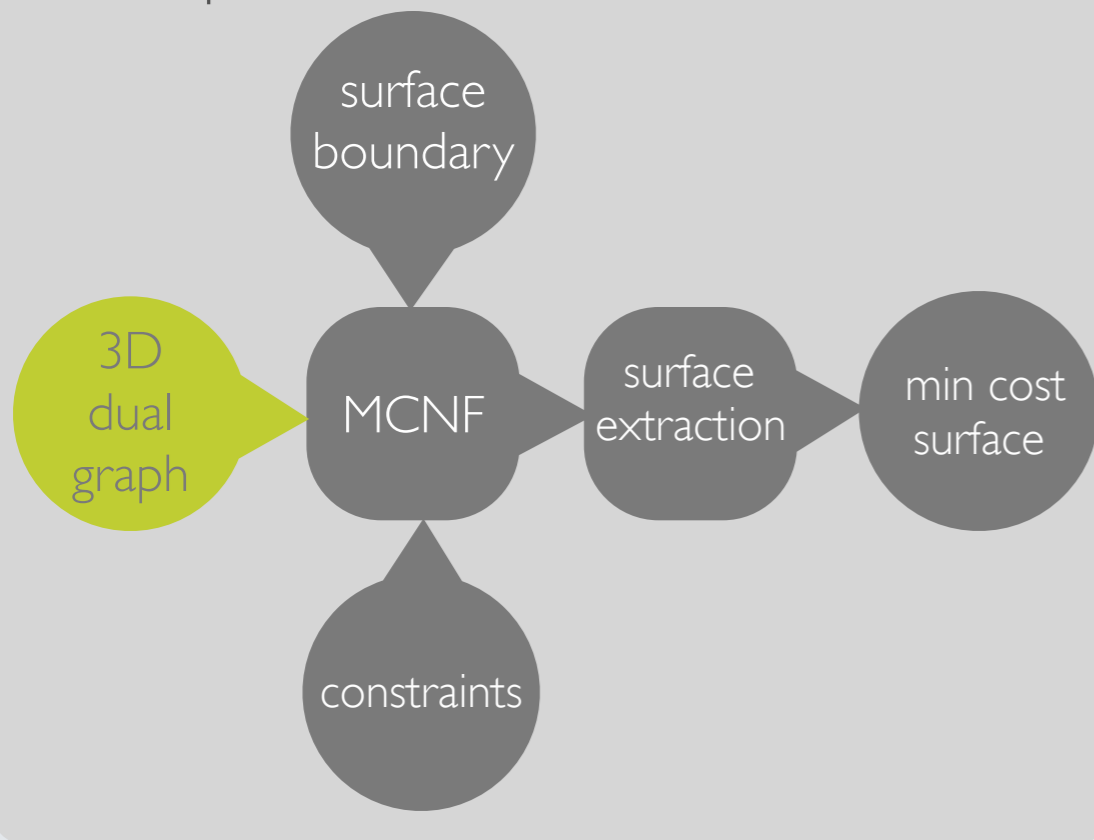
horizon extraction

select prism → min cost path on prism edges → min cost surface inside prism

3D Min Cost Surfaces

min cost surface
inside prism

surface
boundary

3D
dual
graph

MCNF

surface
extraction
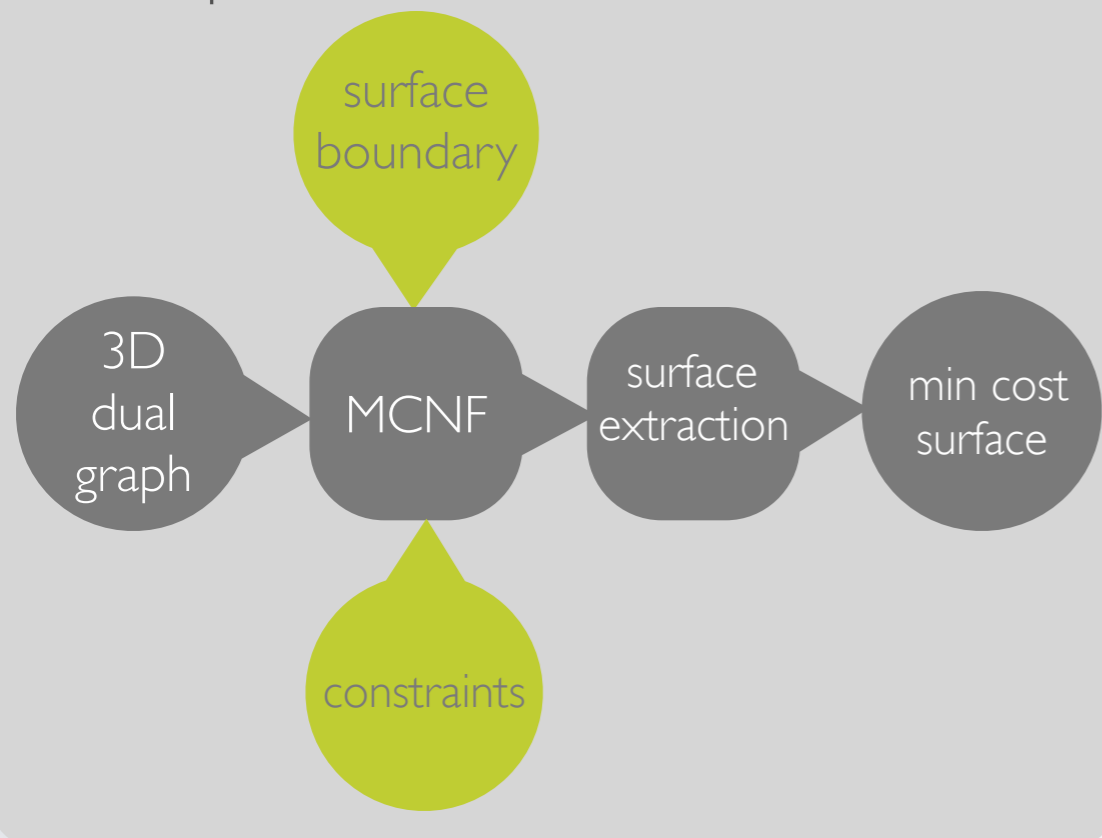
min cost
surface

constraints

- Dijkstra's algorithm not for surfaces

- Instead solve dual problem

  ➡ Minimum cost Circulation Network Flow (MCNF)

- Input is the dual graph

3D Min Cost Surfaces

min cost surface
inside prism

surface
boundary

3D
dual
graph → MCNF → surface
extraction → min cost
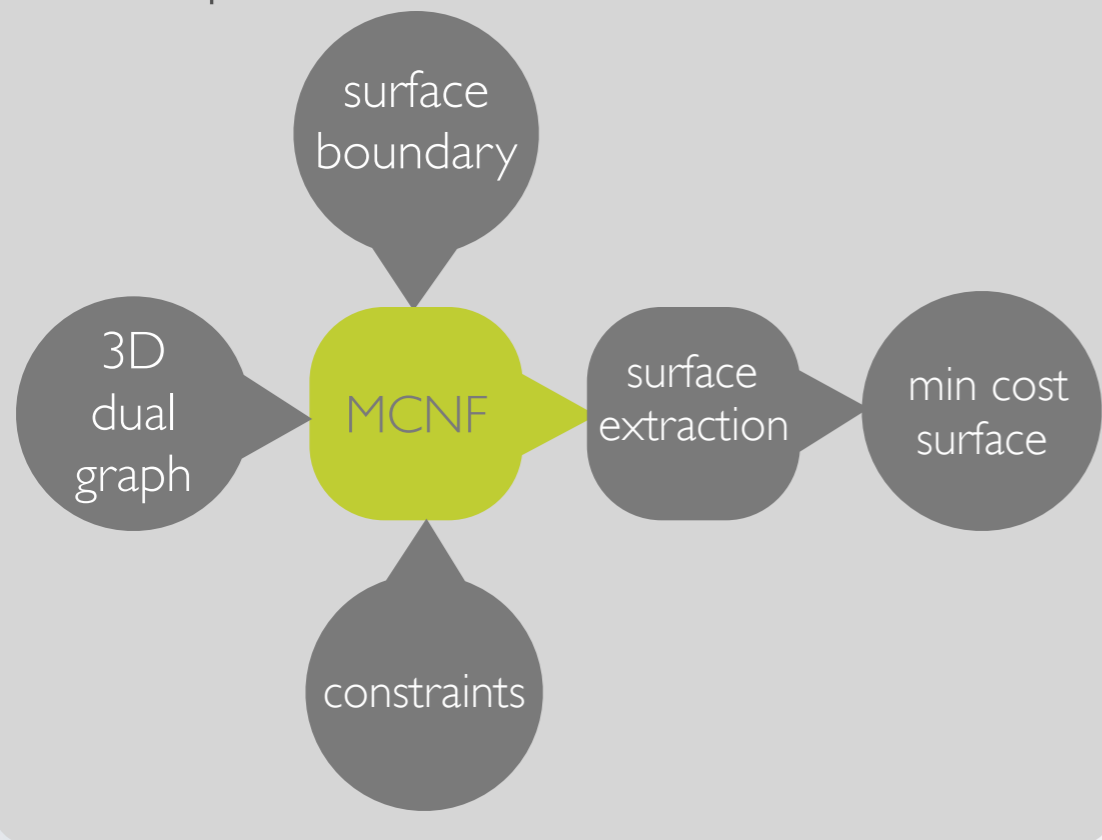surface

constraints

- Min cost path functions as outer surface boundary

- Facets can be added as constraints

  - Facet boundary is inner surface boundary

3D Min Cost Surfaces
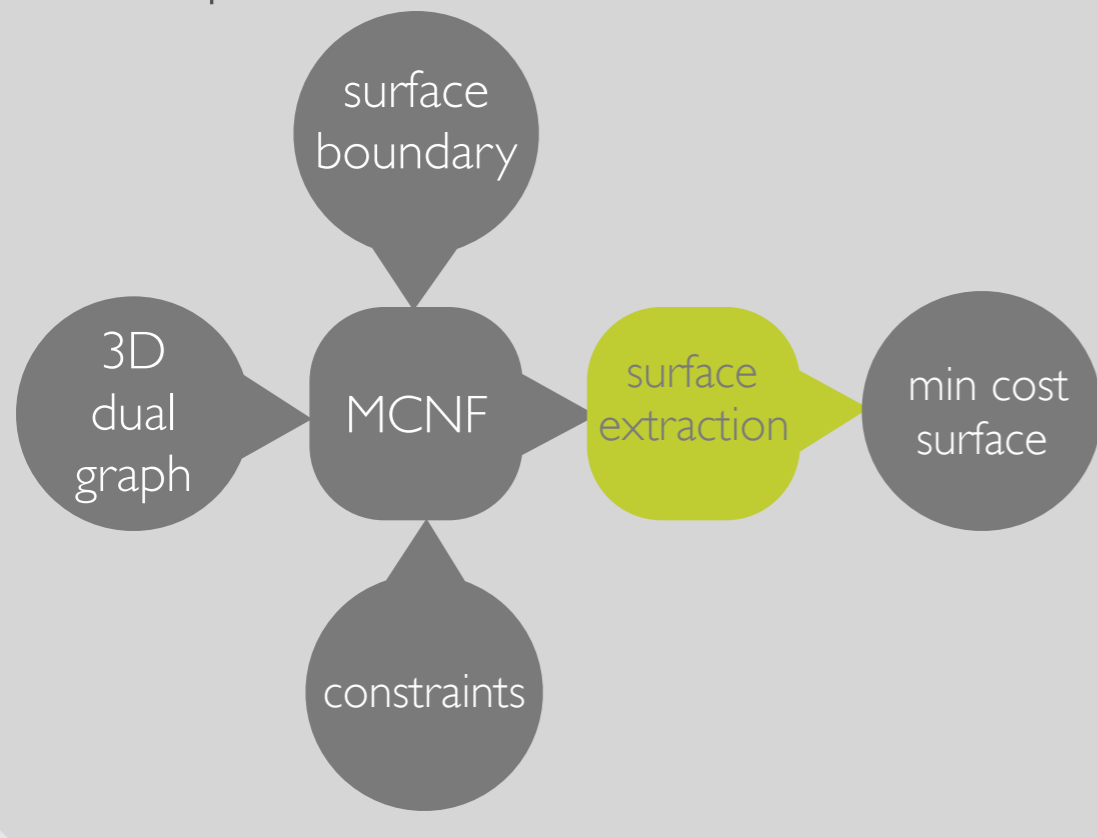
min cost surface
inside prism

- MCNF using lemon graph library

- Same cost function as min cost path

  - used for edge capacity in dual graph

3D Min Cost Surfaces
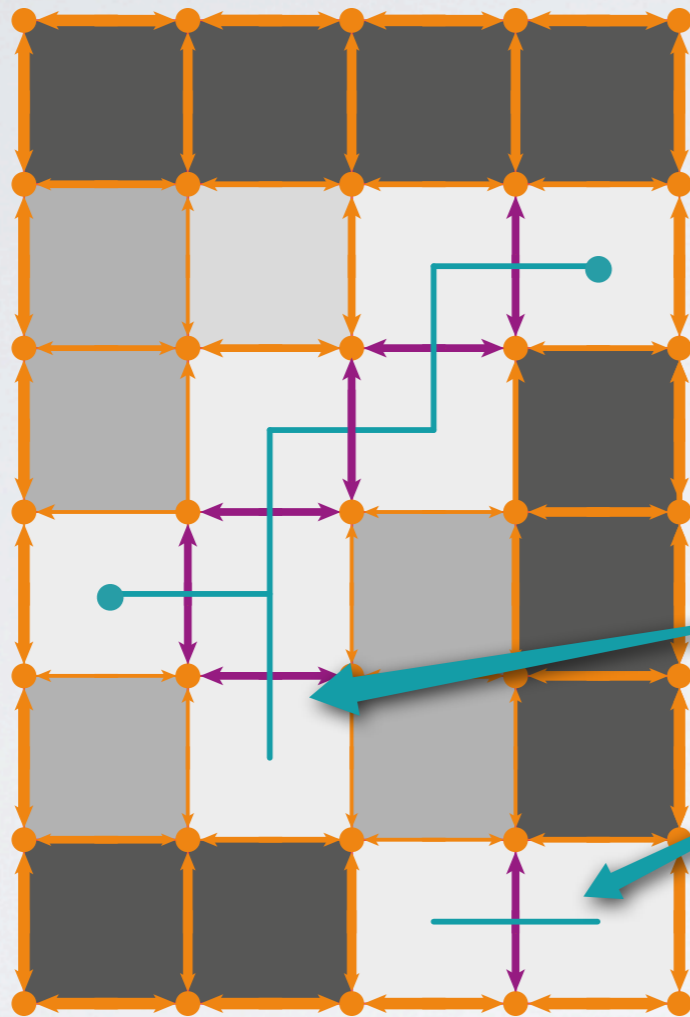
min cost surface
inside prism

- surface boundary
- 3D dual graph
- MCNF
- surface extraction
- min cost surface
- constraints

- MCNF returns set of facet candidates

  - Min cost surface is closed surface bounded by initial boundary

  - False candidates might be:

    - dead ends

    - disconnected from the surface

  - Removed by iteratively deleting candidates without neighbors an all sides

3D Min Cost Surfaces

dual edge (orange arrow)

saturated dual edge (purple arrow)

path in primal (teal line)

boundary nodes (teal dot)

- MCNF returns set of facet candidates

  - Min cost surface is closed surface bounded by initial boundary

  - False candidates might be:

    - dead ends

    - disconnected from the surface

  - Removed by iteratively deleting candidates without neighbors an all sides

3D Min Cost Surfaces

min cost surface
inside prism

surface
boundary

3D
dual
graph

MCNF

surface
extraction

min cost
surface

constraints
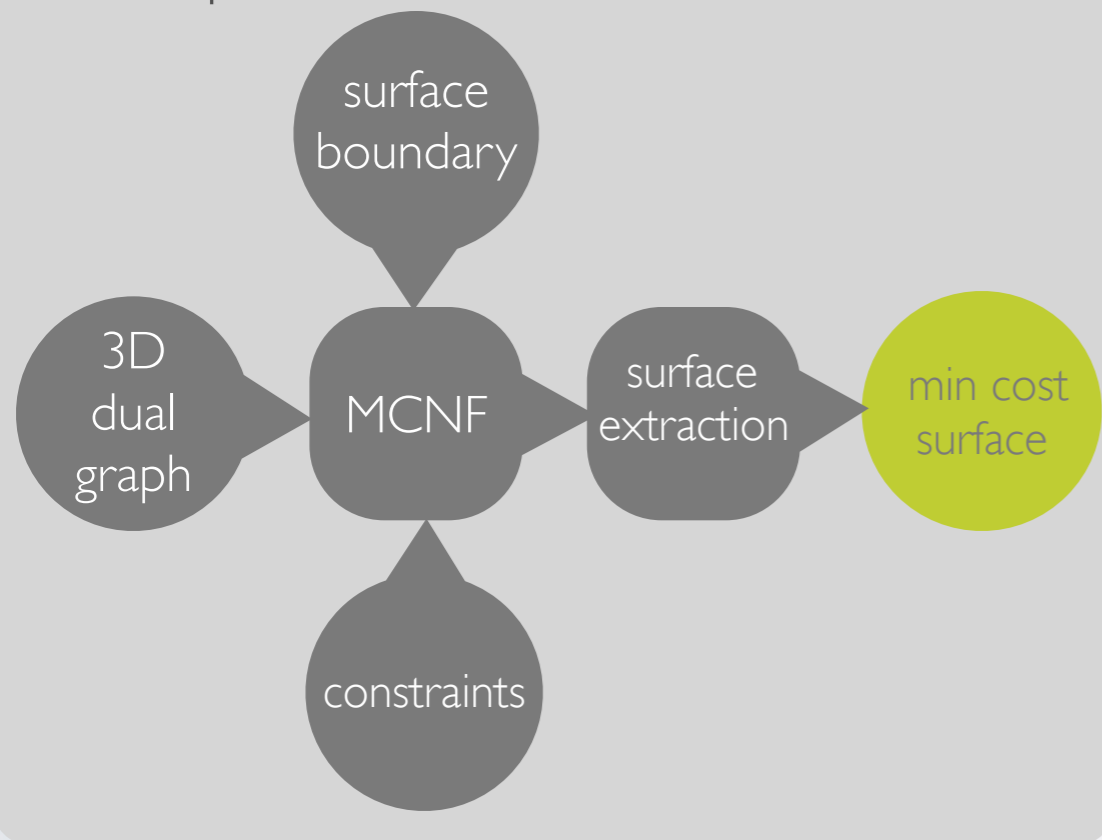
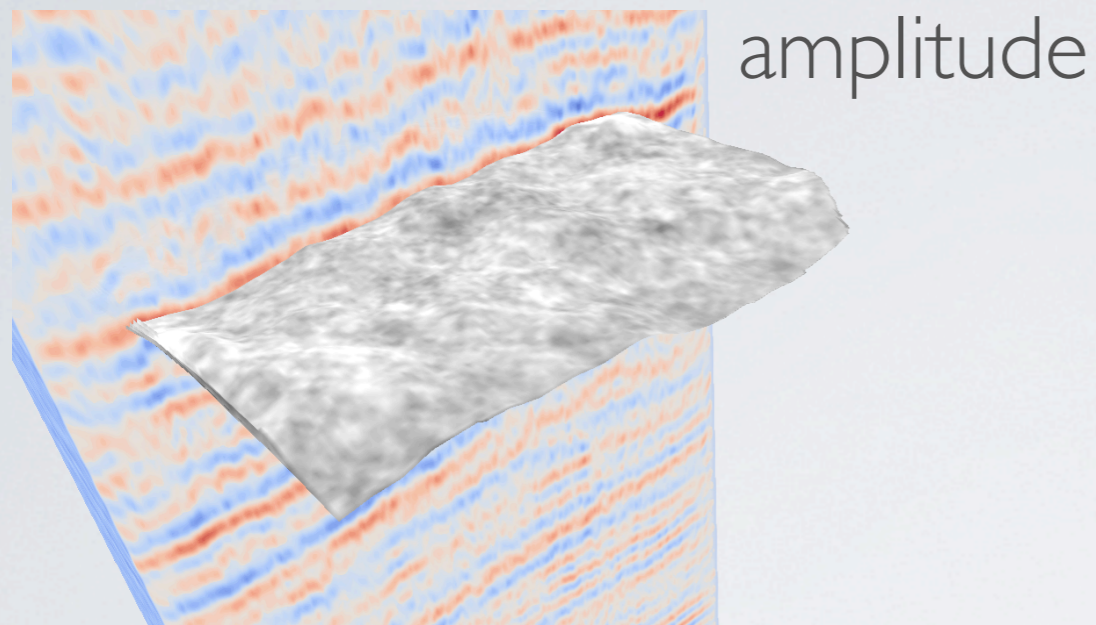- Set of facets forming closed surface inside prism
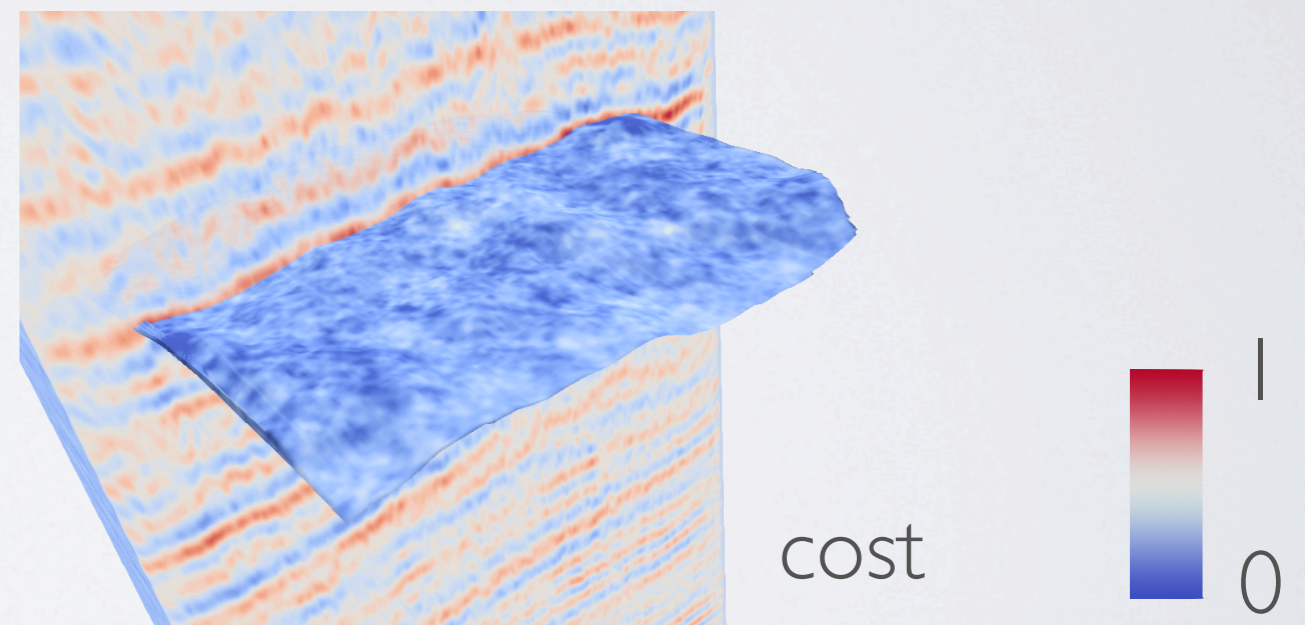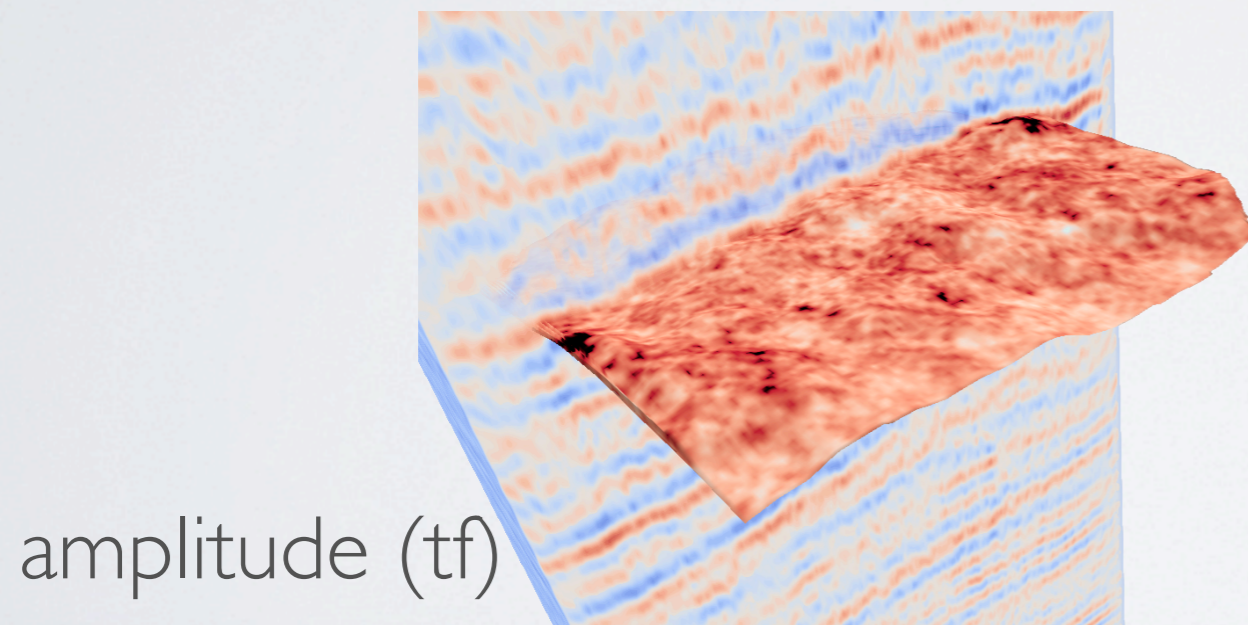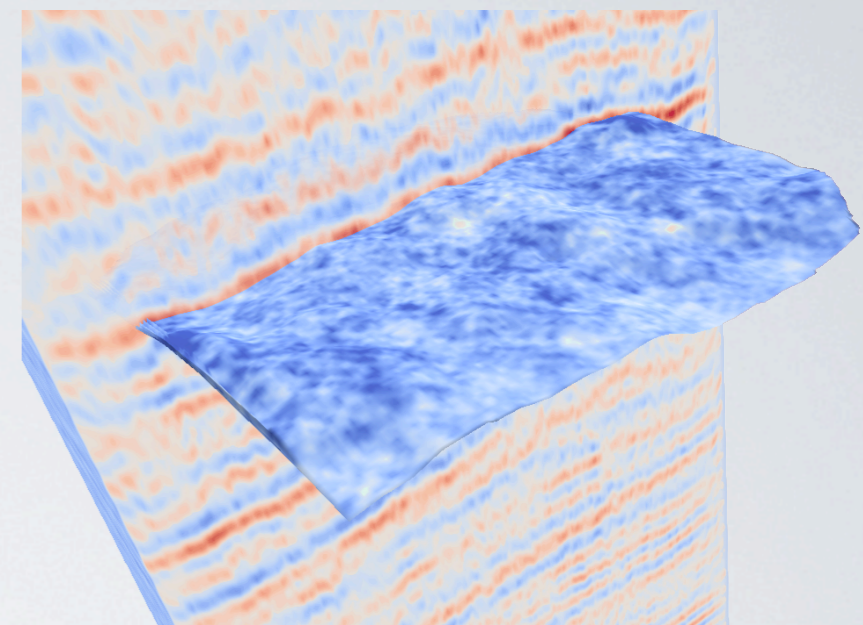
Horizon Visualization

- Horizons shown in all applicable views
  (volume view, slice views, interpretation view)

- In volume view as geometry alongside dvr

- Several properties plotted directly onto
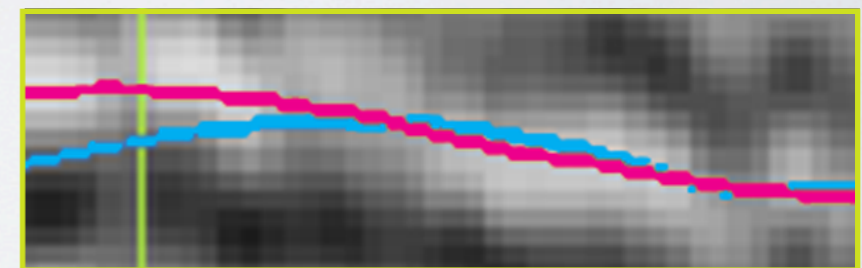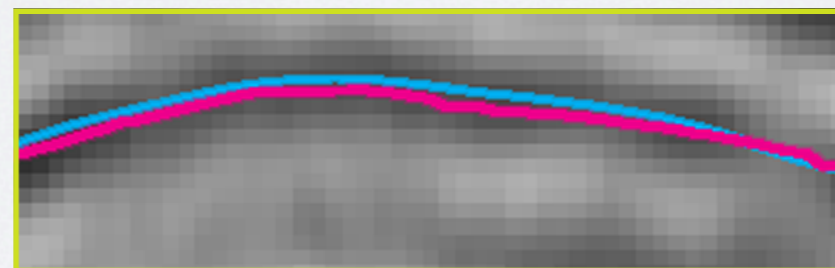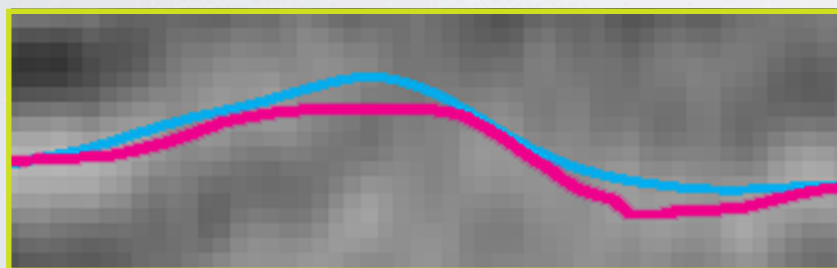 horizons (amplitude, deviation, cost…)
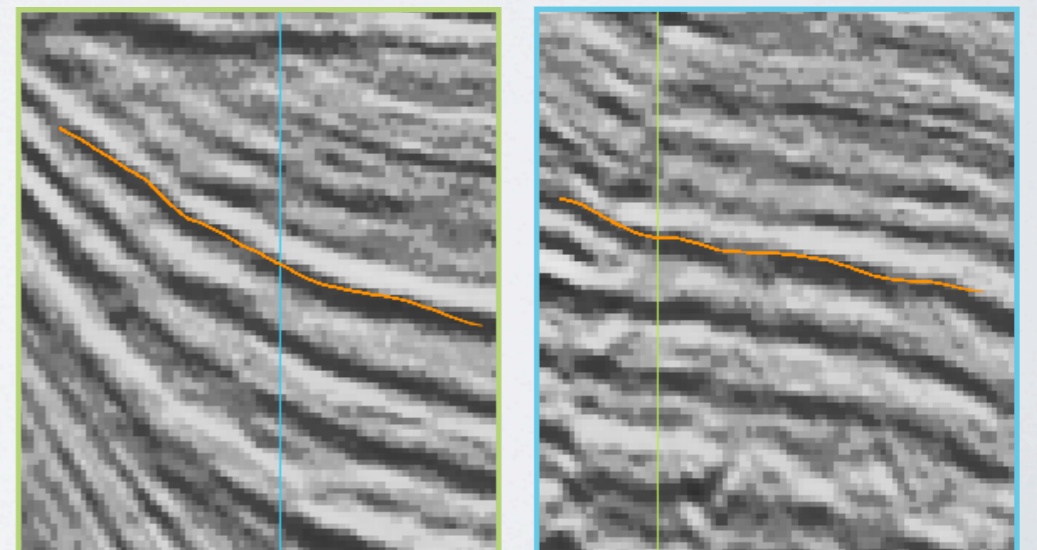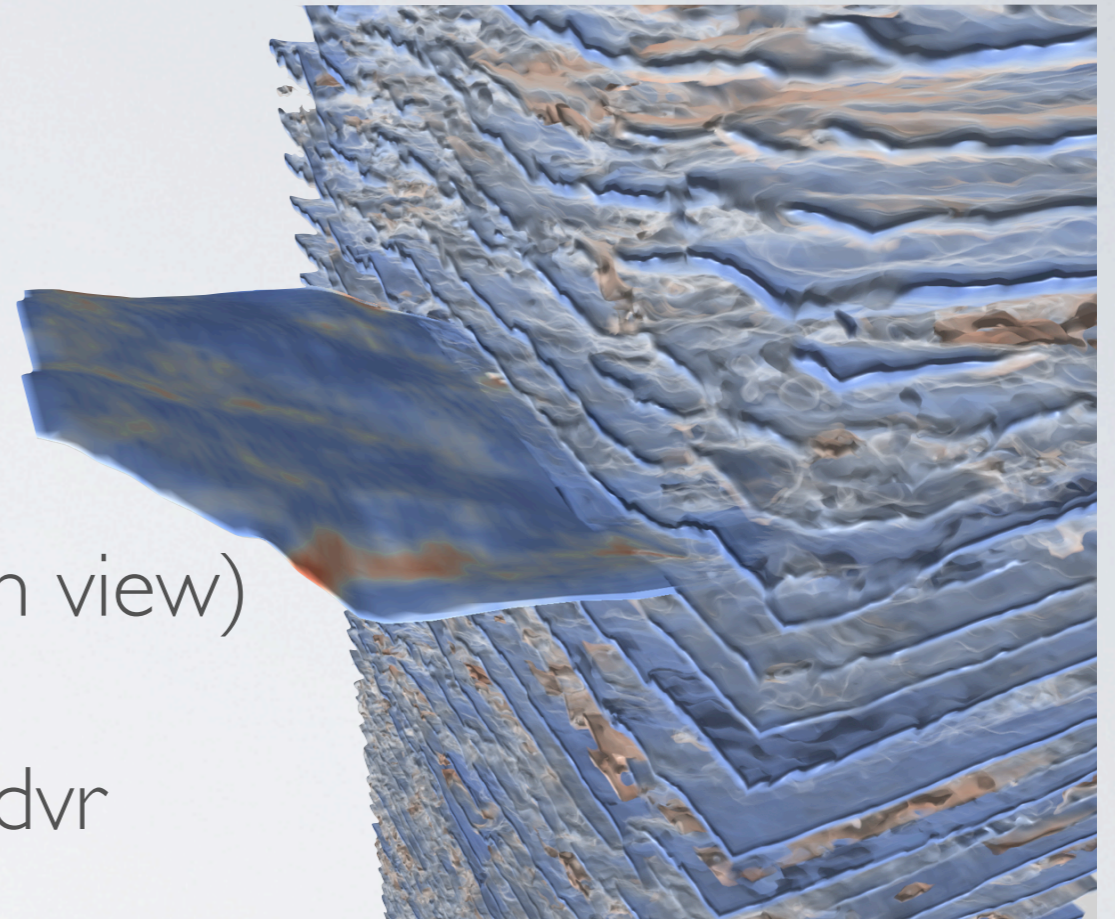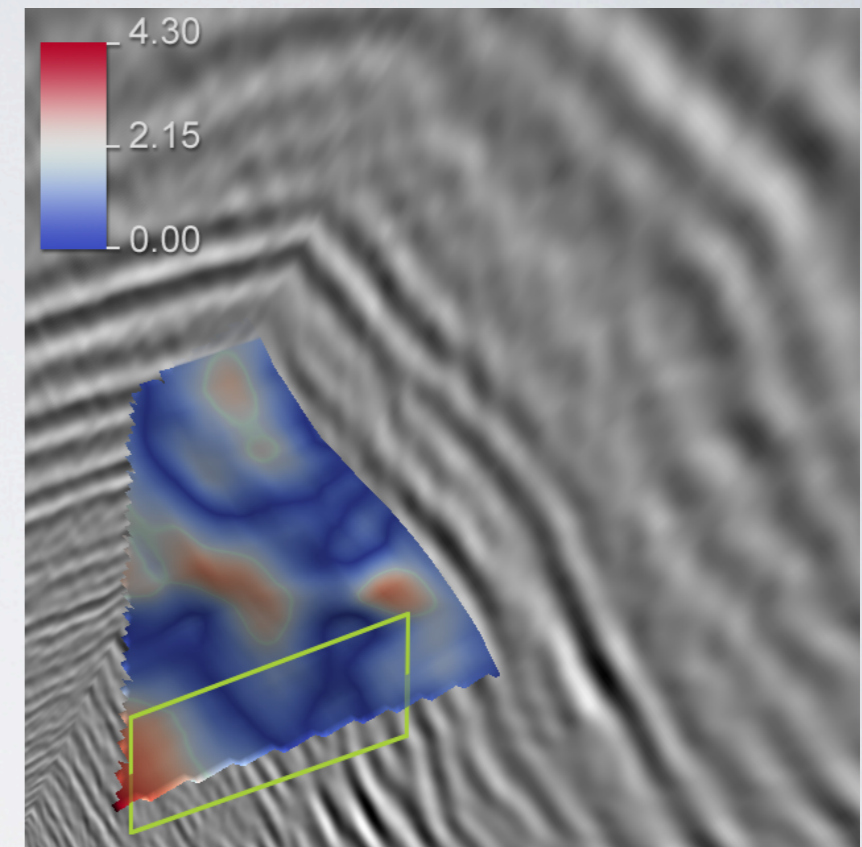
Horizon Visualization

amplitude

difference
to target
amplitude

amplitude (tf)

cost

1

0

Surface Quality
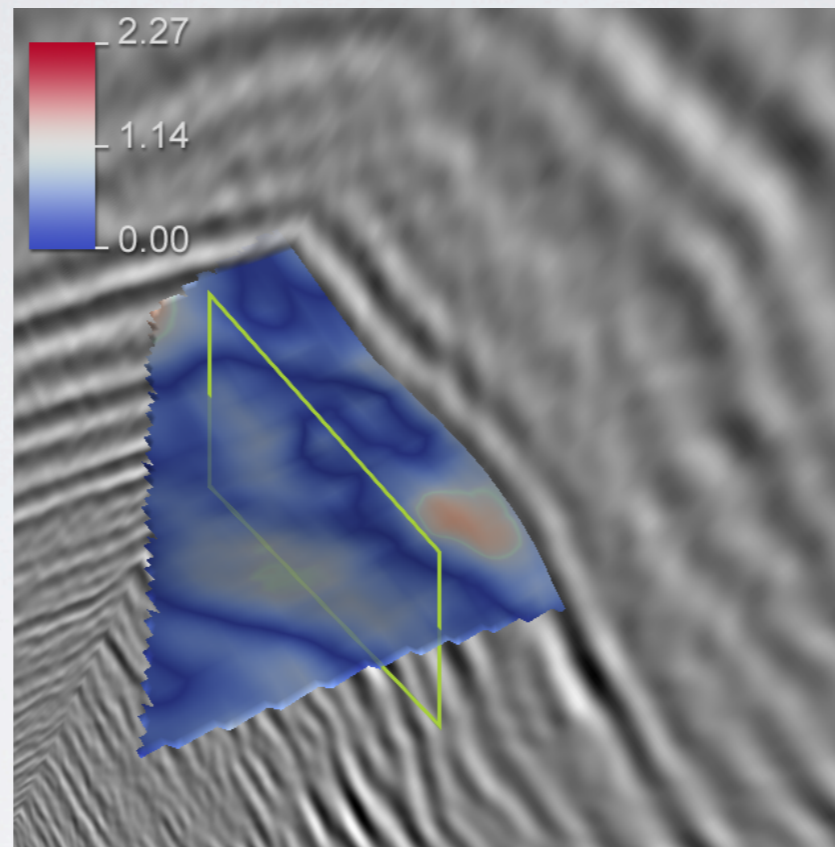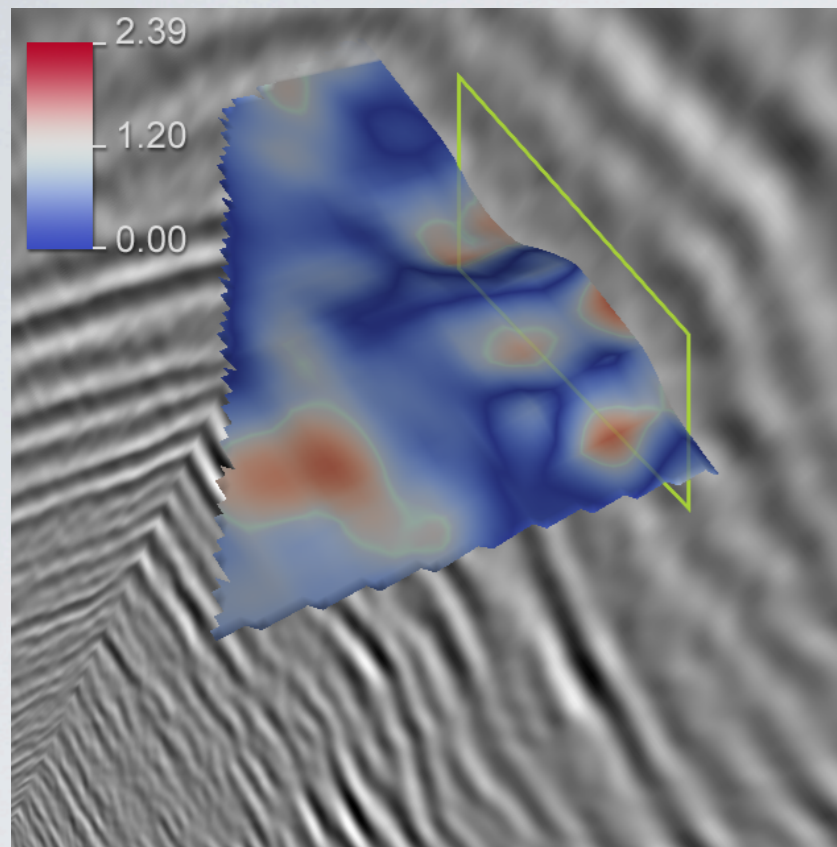
— our method   — manual interpretation

Results

horizon	constraints	edit time	tracing time	max distance
a	1+8	< 5min	61sec	2,39px
b	1+5	< 2min	53sec	2,27px
c	1+5	< 5min	74sec	4,3px
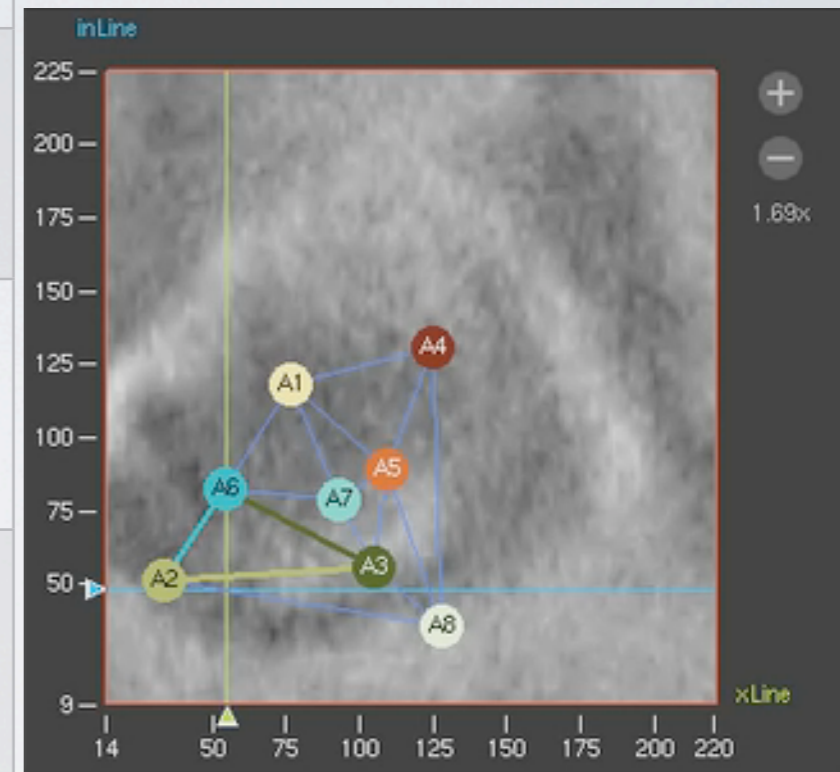
- 240x240x1509 volume
- ~⅕ area covered
- 8 logs
- 9 prisms
- ~20k triangles for surface

Conclusions & Future Work

- Prism based approach & decoupling of 2D interaction and 3D computation received well by collaborators

- Horizons in context of volume + superimposed properties
  ➡ instantaneous feedback on quality

- Performance, performance, performance!

  - Cuda implementation of surface computation

- Integrate live depth conversion

QUESTIONS?

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Interactive Seismic Interpretation with Piecewise Global Energy Minimization