

Simplifying Unstructured Grids for Oceanographic Visualizations



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Oceanbox

- Tromso-based
- Interactive oceanographic simulations
- Oceanography as a Service
- Web-Based Geographic Information System (Web GIS)
- Digital twin of the coastal ocean



The Problem

- Large data sets
 - High resolution (millions of spatial points)
 - Multi-dimensional
 - Payloads of 20Mb+
 - Unresponsive web application
 - Increased bandwidth costs

The Solution: Lossy Compression

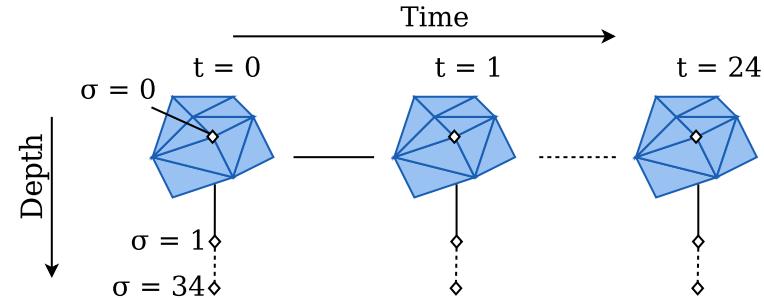
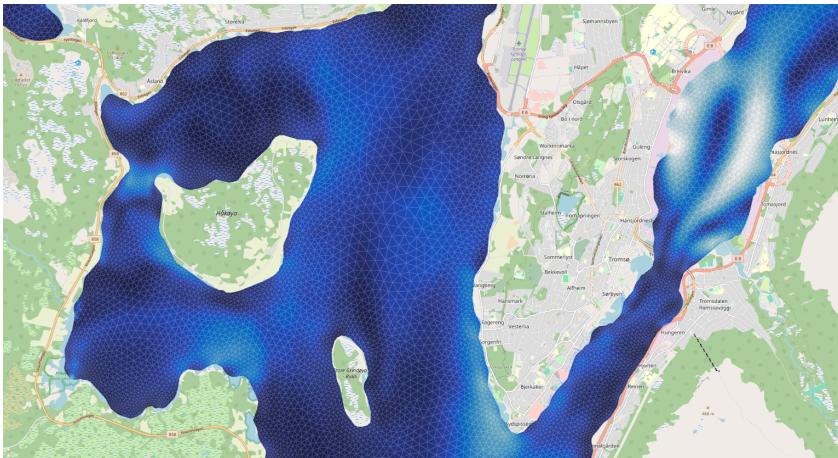
- Traditional approaches tricky
 - Accuracy of coordinates are important
 - Tiling/Multi-resolution not trivial with *unstructured grids*
 - Inflated data size should be smaller on the client

The Solution: Lossy Compression

Hybrid approach:

- Grid simplification
 - Remove vertices/nodes
 - Maintain visualization quality
 - **Angle bounded edge collapse**
- Floating-point compression
 - Compress one-dimensional vectors
 - Retain enough precision for visualization
 - The ZFP compressor

FVCOM grids



- Unstructured grid
 - ▶ Variable resolution
- Multiple dimensions
 - ▶ Coordinates, depth, time

Related Work

Rasterization-based approaches

- Good compression rates (90%)
- Requires *structured* grid layout

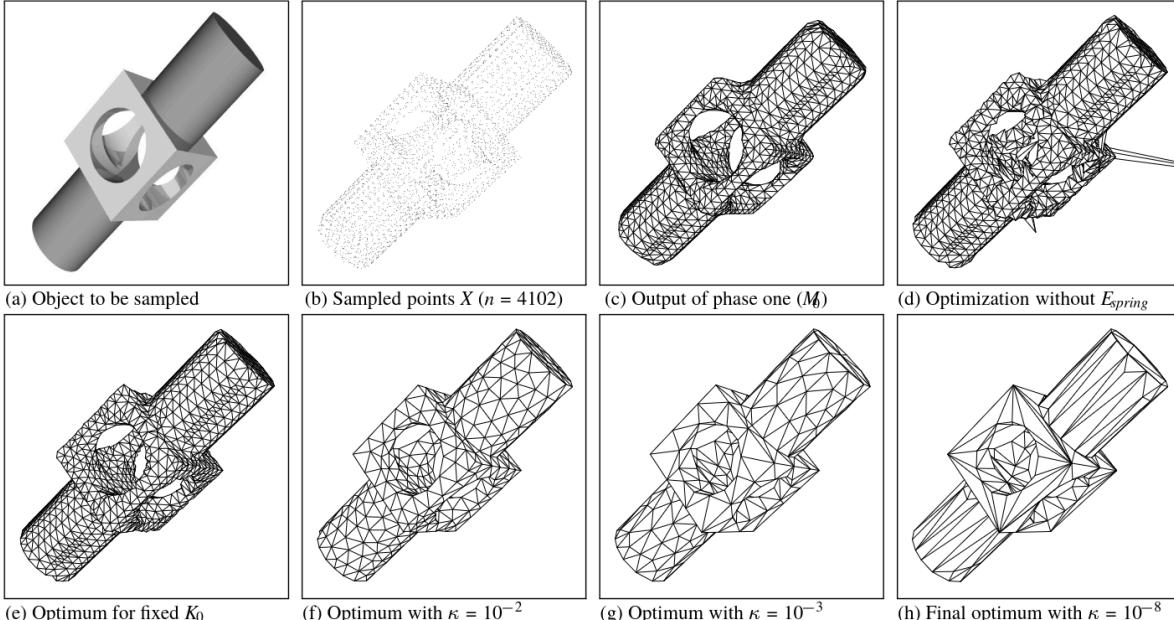
Tiling approaches

- Load only what you need
- Varying resolution
- Also requires structured grids

Mesh simplification

- More suited for unstructured grids
- Popular in literature: *3D mesh decimation*
- Not necessarily directly applicable...

Related Work: Mesh Simplification



- Approximate a surface
- Preserve topology
- Good reduction¹

However

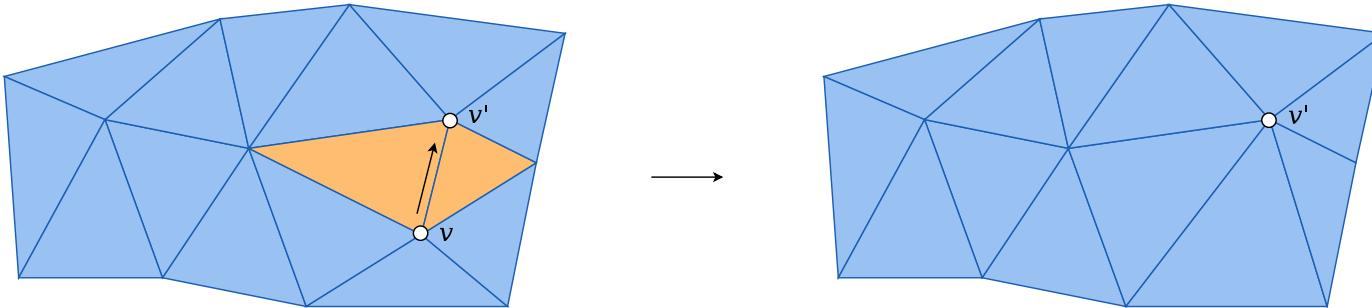
- Not ideal for 2D grids
- Need even resolution

¹Figure from Hoppe et al. “Mesh Optimization”, ACM, 1993, pp. 19-26

In the Capstone: Angle Bounded Half-edge Collapse

Adaptation from previous work.¹

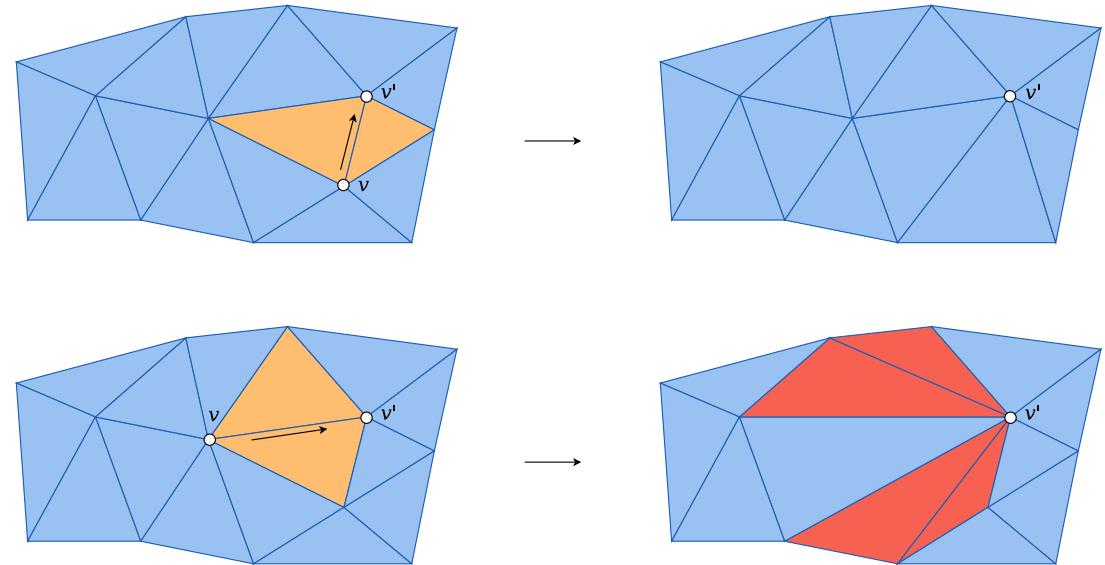
Half-edge collapse with a minimum angle criterion to inner angles



¹Hinderink et al. “Angle-Bounded 2D Mesh Simplification.” *Computer Aided Geometric Design*, vol 95, May 2022, p. 102085

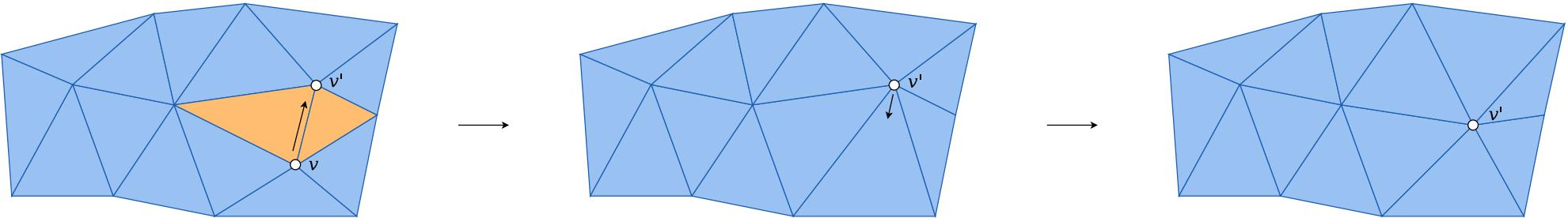
In the Capstone: Angle Bounded Half-edge Collapse

- We collapse v into v' by collapsing the half-edge
 $v \rightarrow v'$
- We define a strict angle bound θ
- We ensure inner angles θ_n respect $\theta_n > \theta$



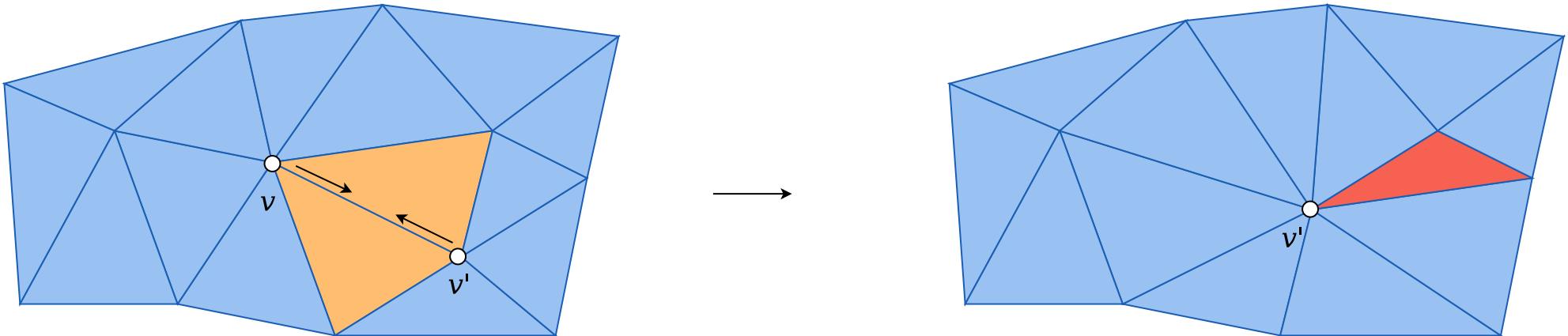
Improvement: Angle Bounded Edge Collapse

- Can be seen as a direct advancement of the half-edge collapse
- Simply use the average position of v and v'

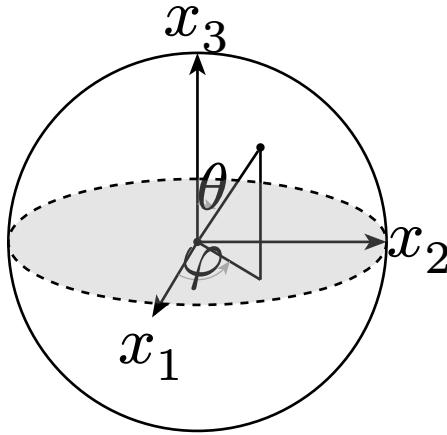


Improvement: Angle Bounded Edge Collapse

- Still enforce the same angle bound θ
- More collapses possible, quality better preserved



Merger Vertex Optimization



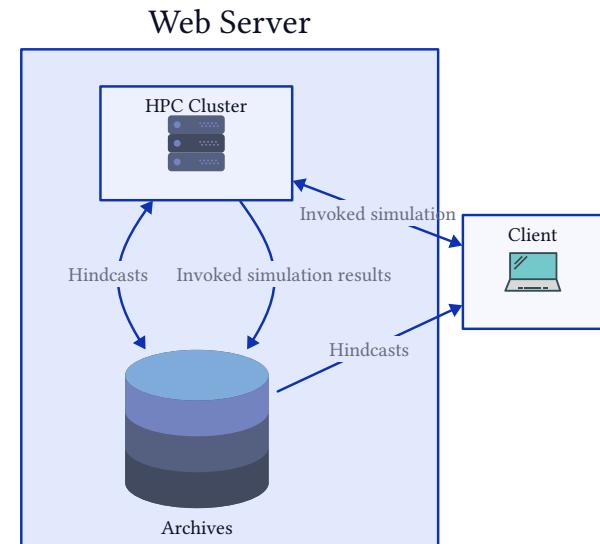
Architecture Overview

We concentrate on the data flow of *Archives*.

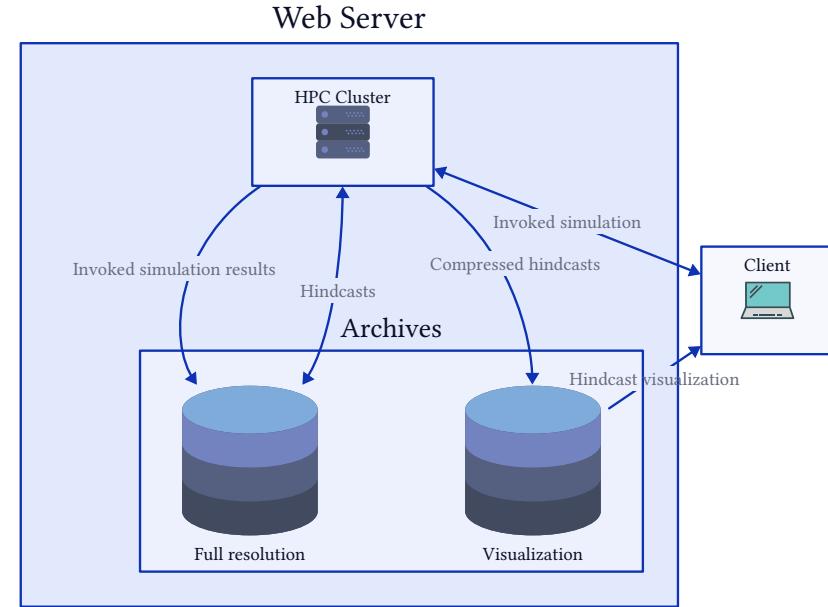
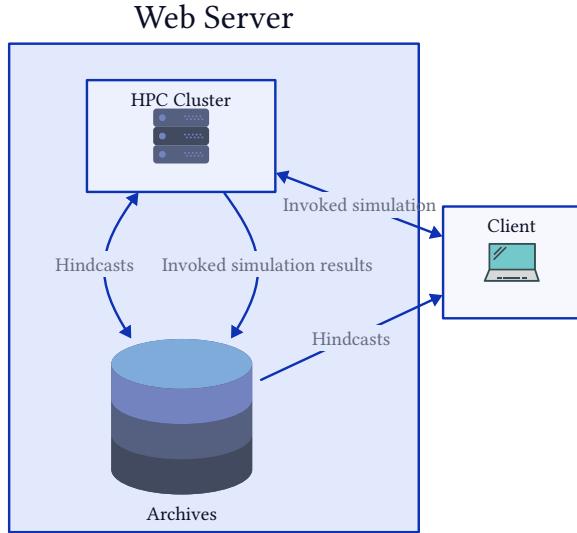
- *Hindcast simulations*
- *User invoked simulations*

Hindcasts are periodically produced, and are the basis of visualizations.

These are the archives we aim to compress/reduce.



Simplifying Unstructured Grids for Oceanographic Visualizations



Implementation Details

Two-fold design:

Grid Simplification

- Once per grid geometry
 - Can be slow
- Boundary nodes preserved

Archive Application

- Picking out values from full res -> compressed
- Vertices a proper subset of original vertices
- Also truncate depth dimension

Evaluation

Visualization similarity

- Inspection of raster images

Compression/Speedup

- Compression ratio of payloads
- Transfer speed

Geometric Error

- Angle distribution
- Triangulation inspection

For the Master:

- Pixel-by-pixel comparison
- Client execution time
- Hausdorff distance

Evaluation

Grids

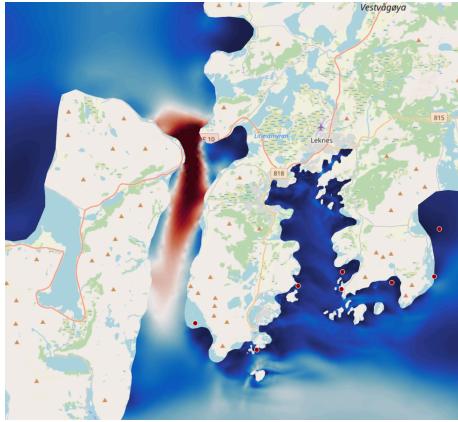
- Buksnes Waste (test)
- PO5 (prod)
- PO6 (prod)

Comparison

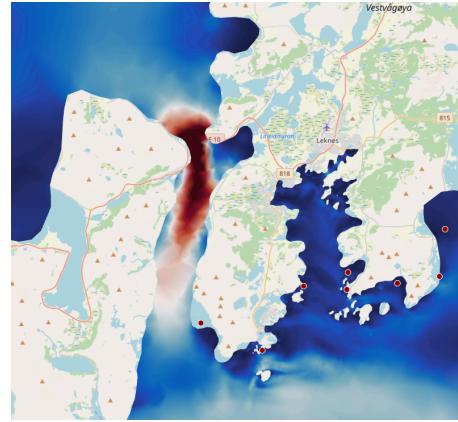
1. Original grid
2. Randomly reduced¹
3. Angle bound, $\theta = 28^\circ$
4. Angle bound, $\theta = 30^\circ$

¹Triangulated with Delaunay

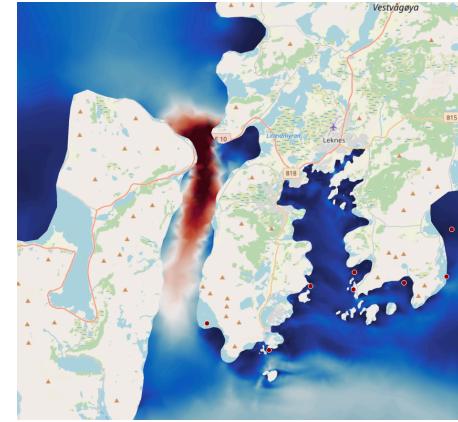
Visualization Similarity: Speed, Buksnes Waste



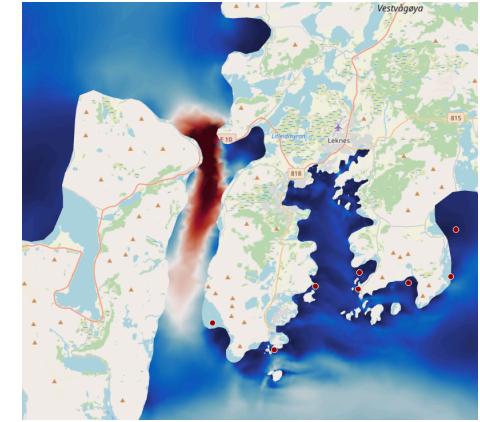
Original grid



Random reduction

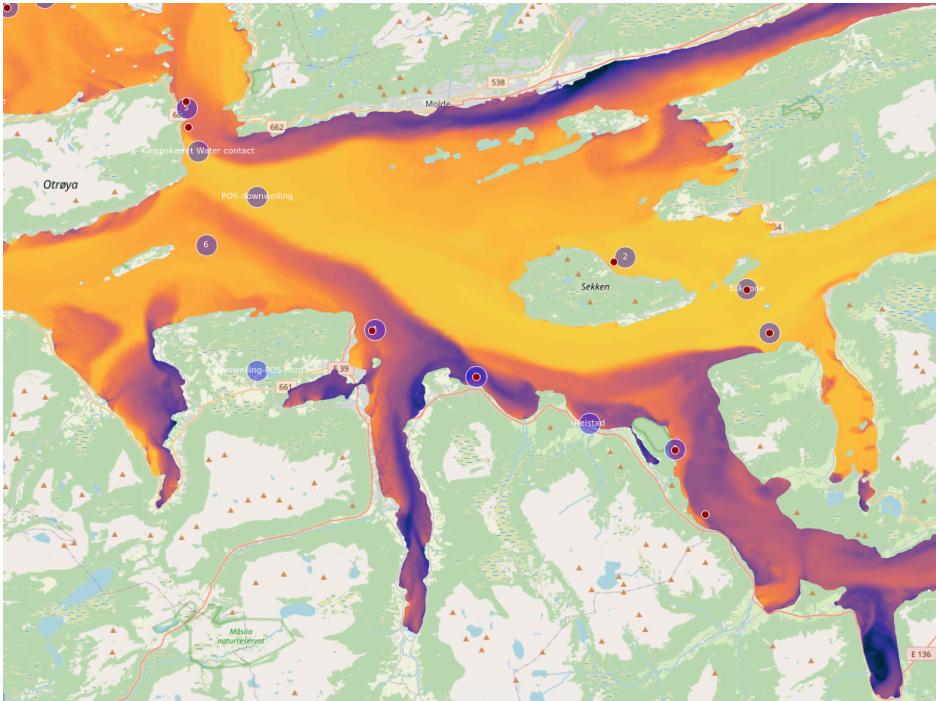


Angle bound, 28°

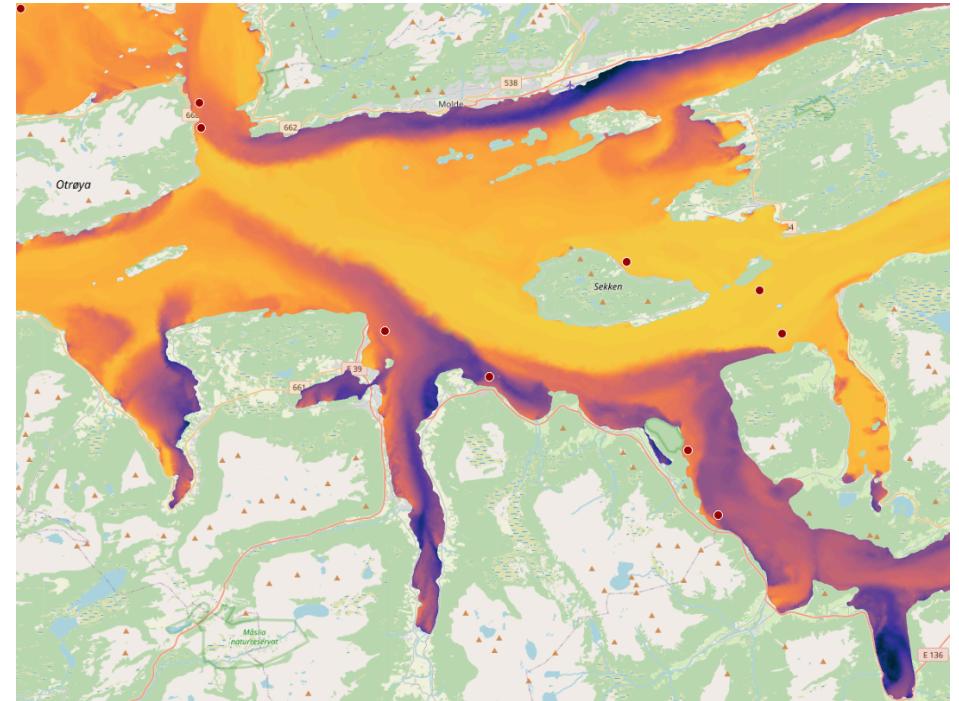


Angle bound, 30°

Visualization Similarity: Temperature, PO5

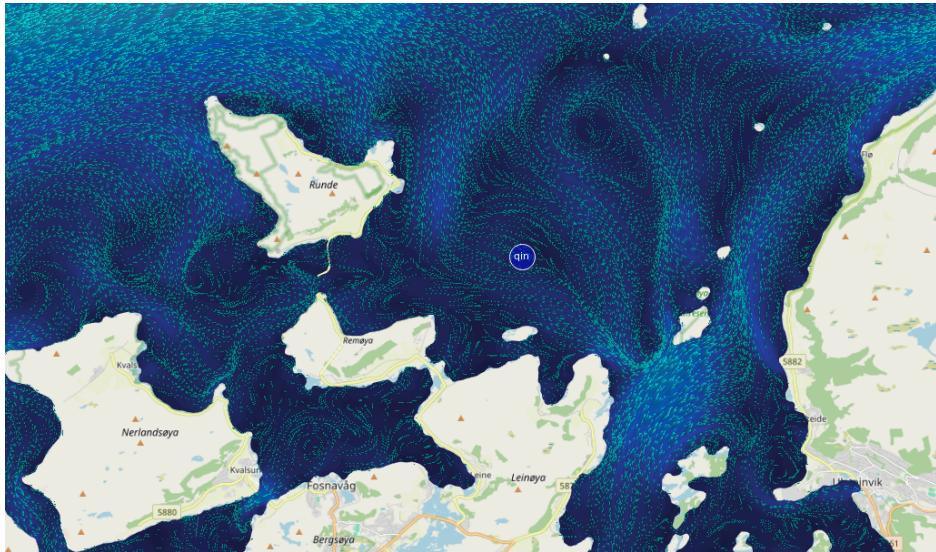


Original grid

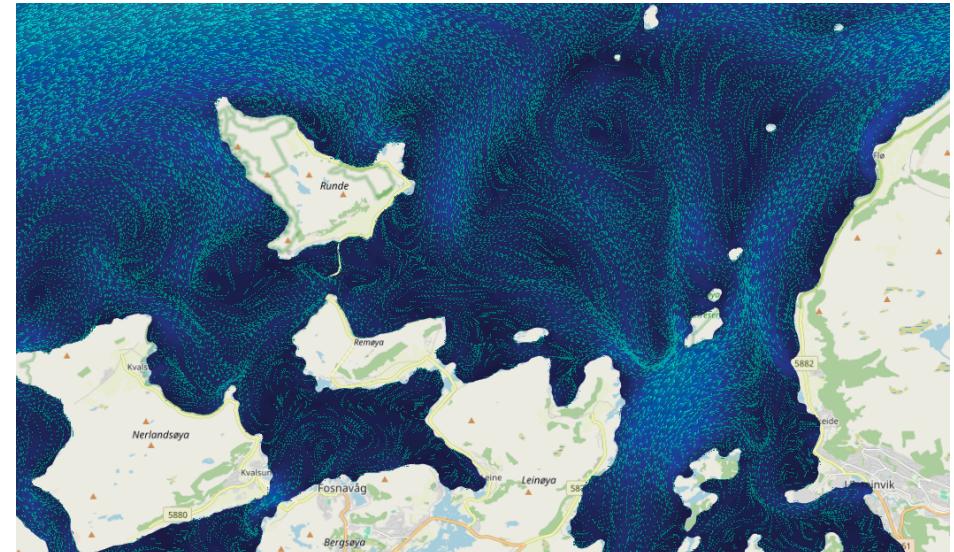


Angle bound, 28°

Visualization Similarity: Streams, PO5

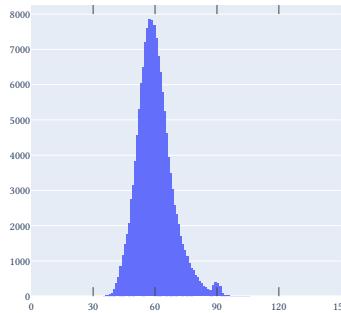


Original grid

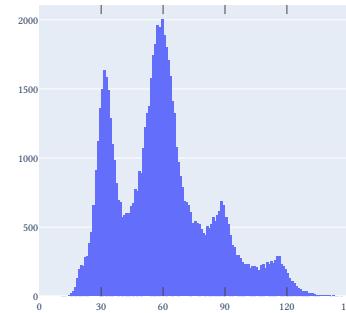


Angle bound, 28°

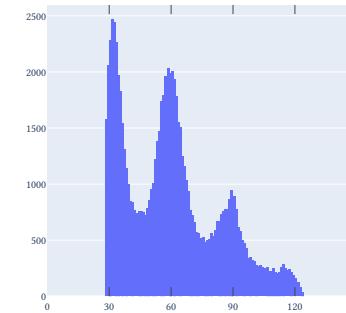
Geometric Similarity: Angle Distribution



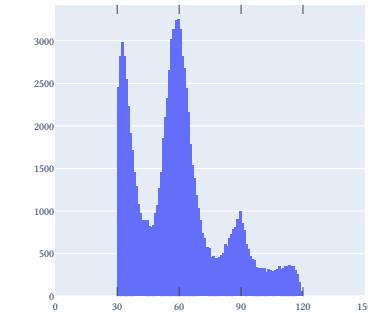
Original grid



Random reduction



Angle bound, 28°



Angle bound, 30°

Geometric Similarity: Triangulation



Original grid



Random reduction



Angle bound, 28°



Angle bound, 30°

Compression Ratio

DATA SET	SIZE / COMPRESSION RATIO				
	Nodes	Elements	Geometry	Nodal variable	On disk
Buksnes Waste	25 136	48 332	762 KiB	98 KiB	475 686 KiB
Random	1.87	1.93	1.91	1.88	29.27
SHAVER 28°	1.71	1.76	1.74	1.72	26.62
SHAVER 30°	1.43	1.45	1.45	1.44	22.05
PO5	459 242	869 324	13 669 KiB	1 793 KiB	8 473 272 KiB
SHAVER 28°	1.67	1.74	1.71	1.67	26.03
PO6	1 691 194	3 251 577	51 317 KiB	6 606 KiB	32 002 309 KiB
SHAVER 28°	1.64	1.69	1.67	1.64	25.58

Compression Ratio

- External factors
 - Lossless compression
- Nodal variable closer to theoretic

DATA SET	SIZE	
	Geometry	Nodal variable
Buksnes Waste	363 KiB	126 KiB
Random	71.2%	98.4%
SHAVER 28°	93.1%	98.8%
SHAVER 30°	93.8%	99.3%
PO5	7 250 KiB	2 300 KiB
SHAVER 28°	93.0%	100.6%
PO6	26 200 KiB	8 460 KiB
SHAVER 28°	91.6%	100%

Speedup

DATA SET	SPEED / SPEEDUP	
	Geometry	Nodal variable
Buksnes Waste	140 ms	22 ms
Random	3.68	2.44
SHAVER 28°	3.5	1.57
SHAVER 30°	2.92	1.47
PO5	2 700 ms	340 ms
SHAVER 28°	1.99	1.29
PO6	10 000 ms	950 ms
SHAVER 28°	1.85	0.84

- Unexpected results
 - ▶ Geometry vs Nodal variable
 - ▶ Buksnes vs PO5/PO6

Theory: Discrepancies in NetCDF *Chunk Size*

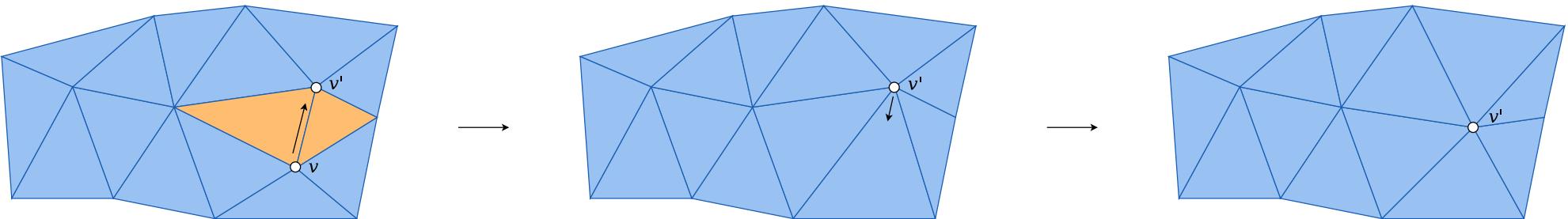
Summary

- Compression by Grid Simplification
- Angle bound half-edge collapse
- Varying results
 - Jagged visualizations
 - Only 1.7x compression



Future Work

- Angle bound *edge collapse*
- Investigate other methods
 - ▶ Spring constant
- “Conventional” lossy compression for variables



Questions