MSST'08 Tutorial: Data-Intensive Scalable Computing for Science

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Acknowledgements:
CMU: Randy Bryant, Garth Gibson, Bianca Schroeder (University of Toronto), Greg Ganger.
Intel: Steve Schlosser, David O'Hallaron.
Yahoo!: Milind Bhandarkar, Eric Baldeschwieler.

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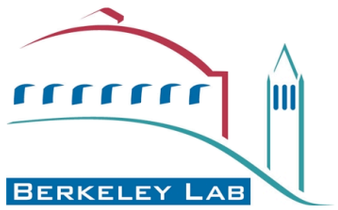

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Agenda

- Motivation
- Turning I/O intensive into CPU intensive workloads
- Failure trends in HPC
- DISC
- Hadoop Intro
- Generating Ground Models for Earthquake Simulations
- M45! Experiences

Methods for compressing large seismic wavefields

Turning I/O intensive data-analysis tasks into massively parallel compute-intensive ones.

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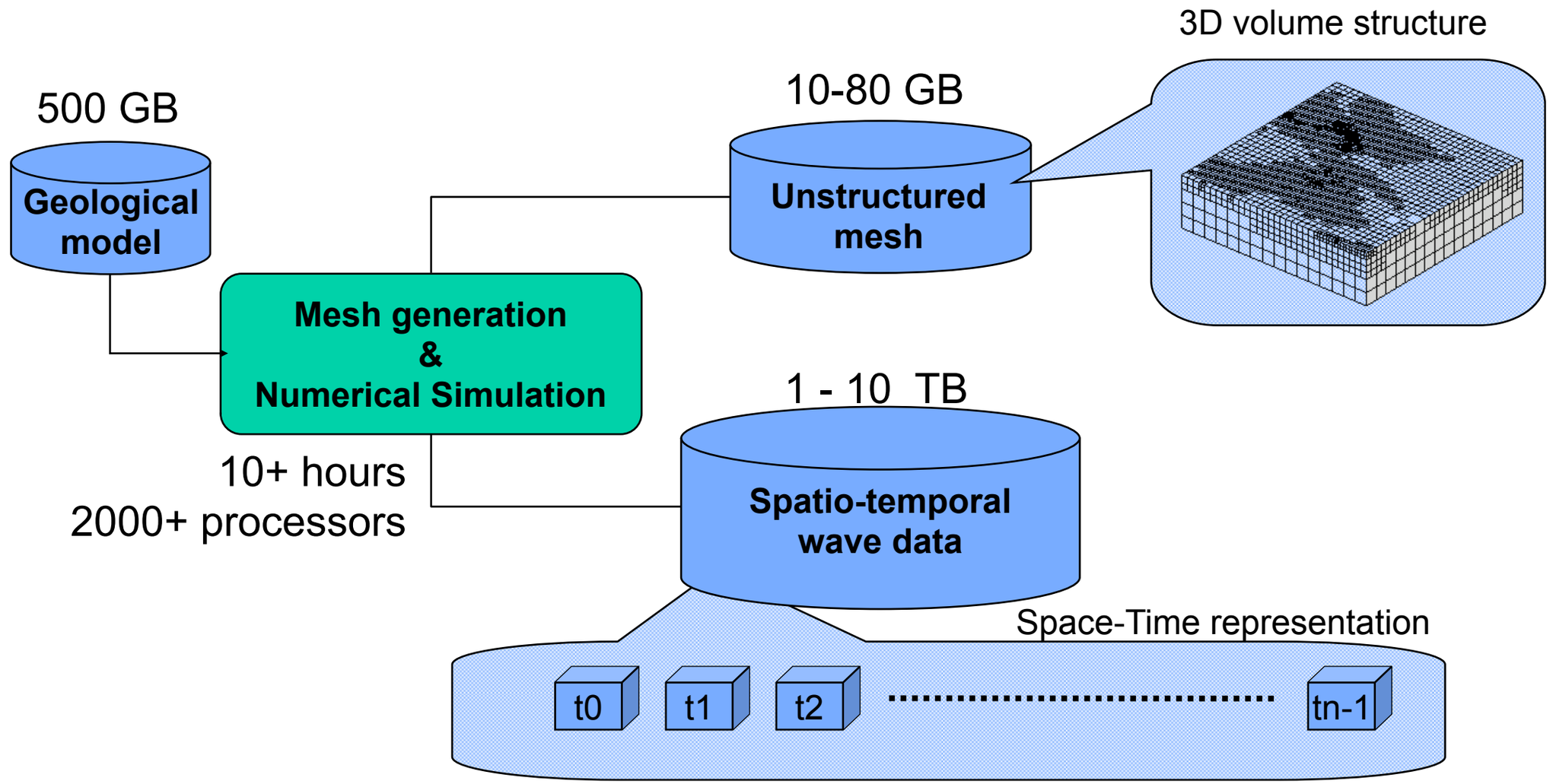
Motivation

- Data analytics increasingly difficult at scale
  - Difficult to program
  - Stress I/O and memory systems
  - Dealing with failures
- Search companies routinely process the web graph
- Interest in Data-Intensive Scalable Computing
- How can this be leveraged for science HPC?

Data-Intensive Processing in Seismic Simulation

- Setup: Generating ground models.
- Data-analytics in Quake 4D wavefields: Terabytes per each simulated scenario.



Data analysis challenges

- Resource constraints: I/O BW and memory.
- Complex data operations:
  - Selection, transposition, FFT, filtering…
- Difficult data sharing and management.
- Need for semi-interactive data analysis.
- Data is at risk: write-once / read-never!

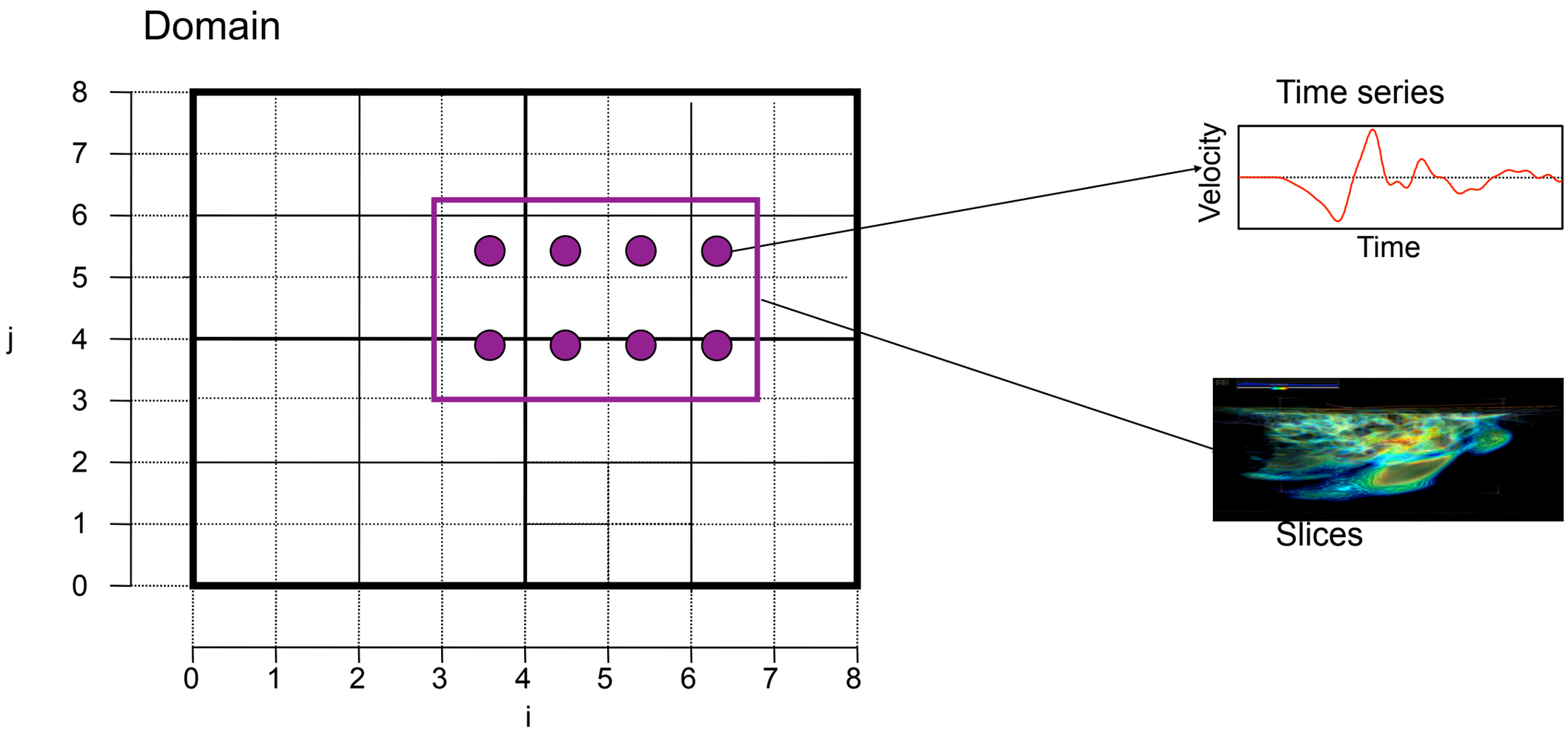
- Need better mechanisms for processing datasets.

Approach

- Field representation:
  spatially indexed compressed data structures
- Effectively, turn data-intensive into compute-intensive.

- Indexed compressed wavefield representations:
  - BEM compression.
  - Frequency-domain compression.
- Microsolver computational query-time model.

Data-analysis queries

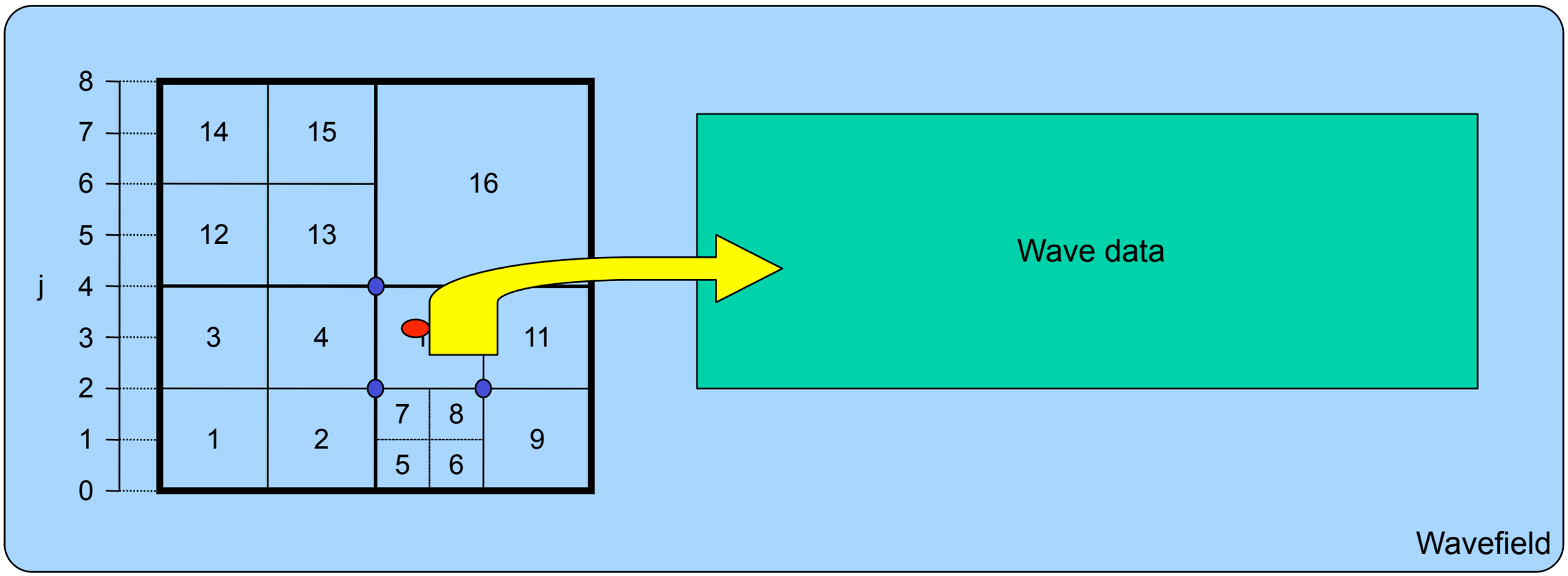


Region of interest (origin, extent, spacing, rotation)

Dimensionality: 0D, 1D, 2D, 3D.

Sampling queries

Querying wavefields



- Mesh: Spatial index, e.g., etrees.
- Find element containing query point.
- Use element corners to retrieve wave data

Compression approach

- Wavefields are floating point datasets

Floating point compression state of the art

- Floating point compression is a hard problem.
- High-entropy bit patterns.

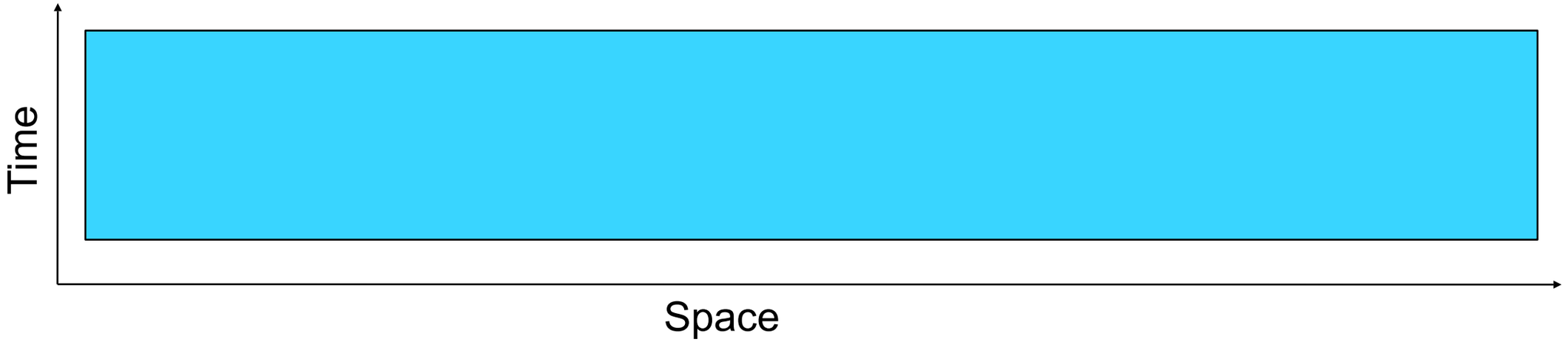
- NASA's image compression: Quantization.
- JPEG 2000: 3D FP images, DCT, DWT, BigInt.
- LLNL: Lorenzo predictor + FP encoding.
- Cornell's value prediction FP encoding.
- Floating point sound compression.

Compression approach

- Wavefields are floating point datasets
- Frequency domain representation
  - Wavefields are band-limited
- Requires a storage layout change
  - Out of core matrix Transposition
- Boundary Element Method Compression (BEMC)
  - Dimensionality-reduction
  - Works in the frequency-domain
  - Allows for incremental reconstruction

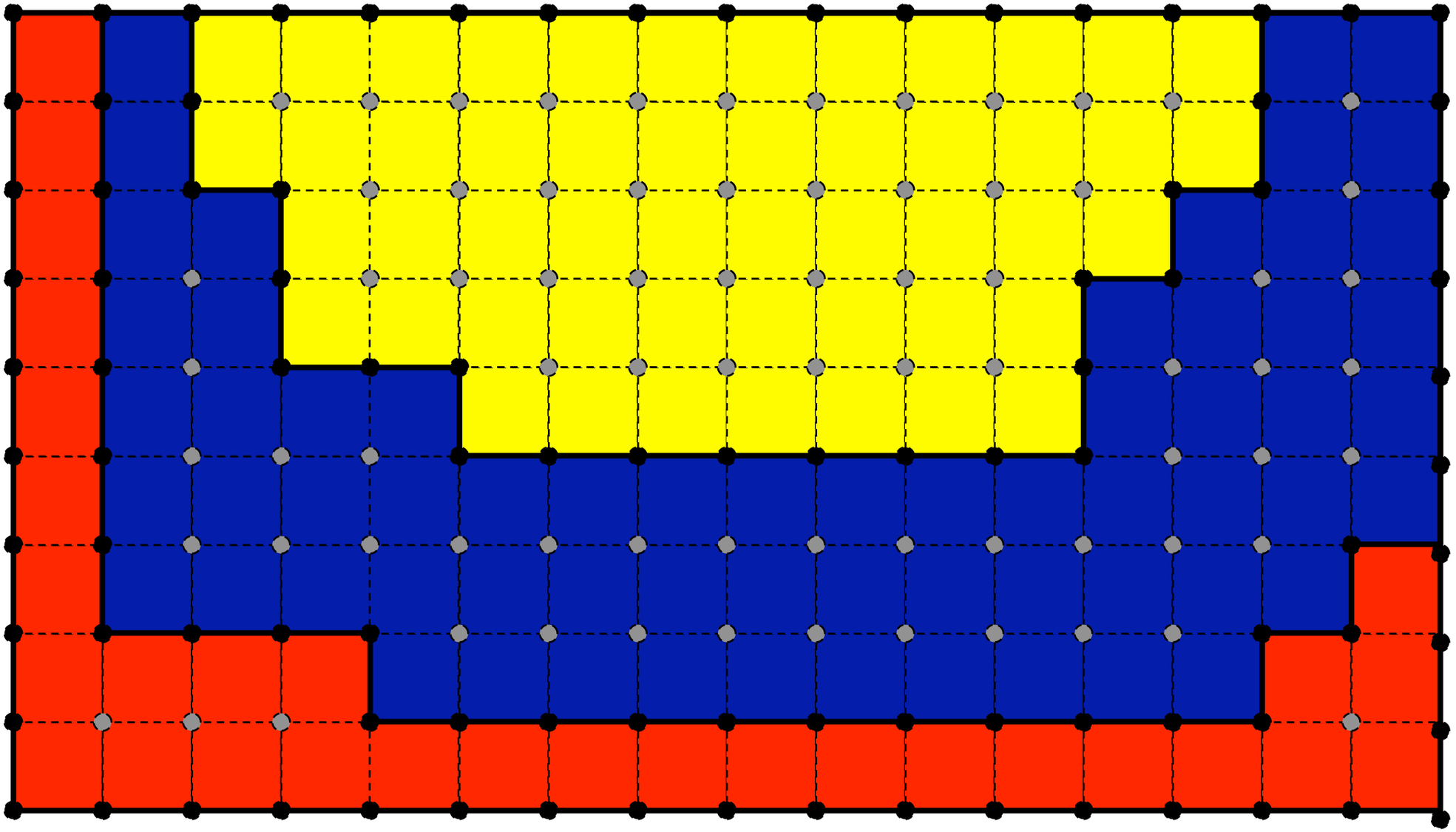
Wavefield storage layout

- Wavefields as matrices: Space x time.
- Large aspect ratios.
- Transposition



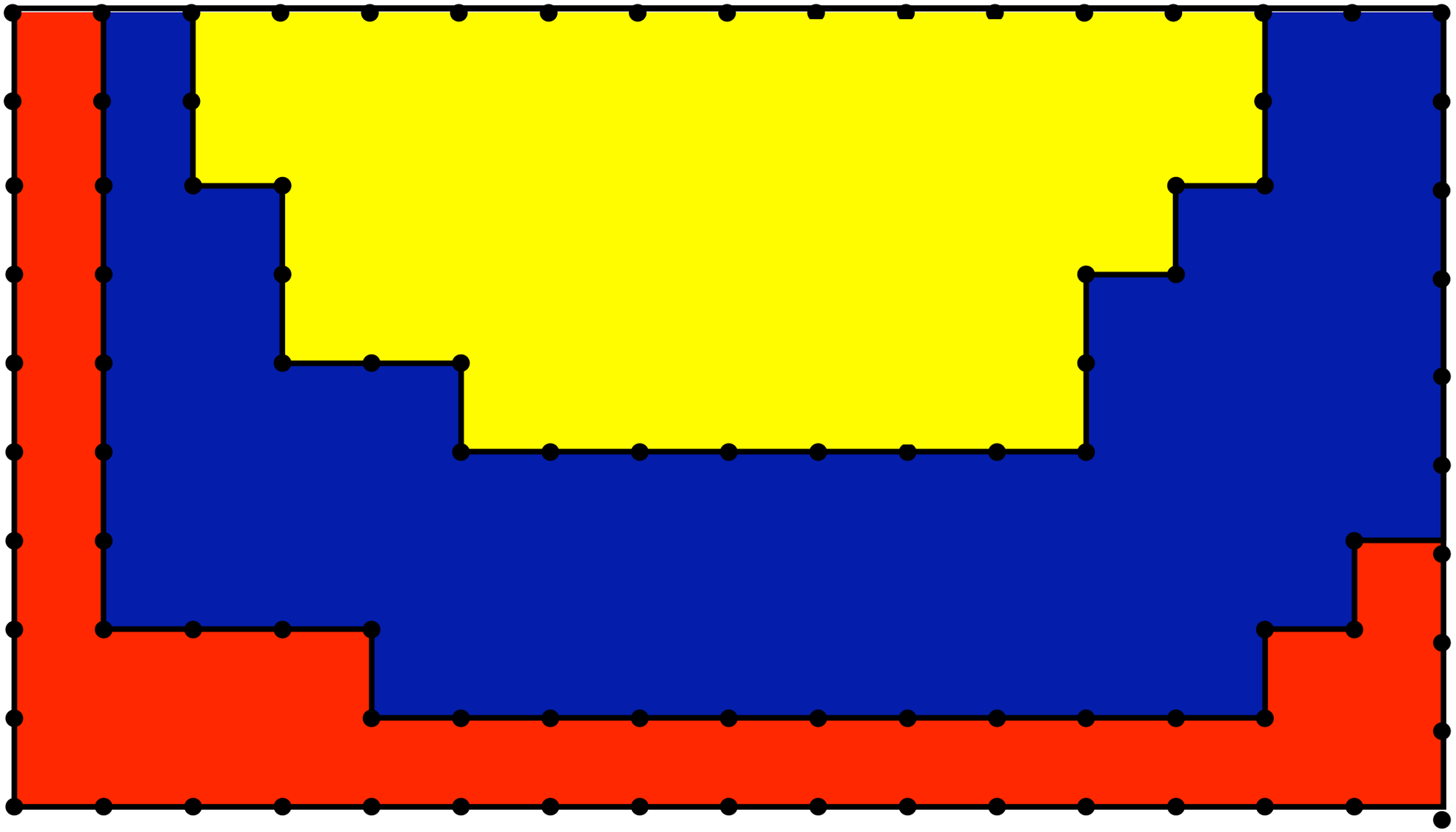
Column size	Row size	
	Small	Large
Small	In-core	Seq. Write
Large	Seq. Read	Split R/W

BEM compression



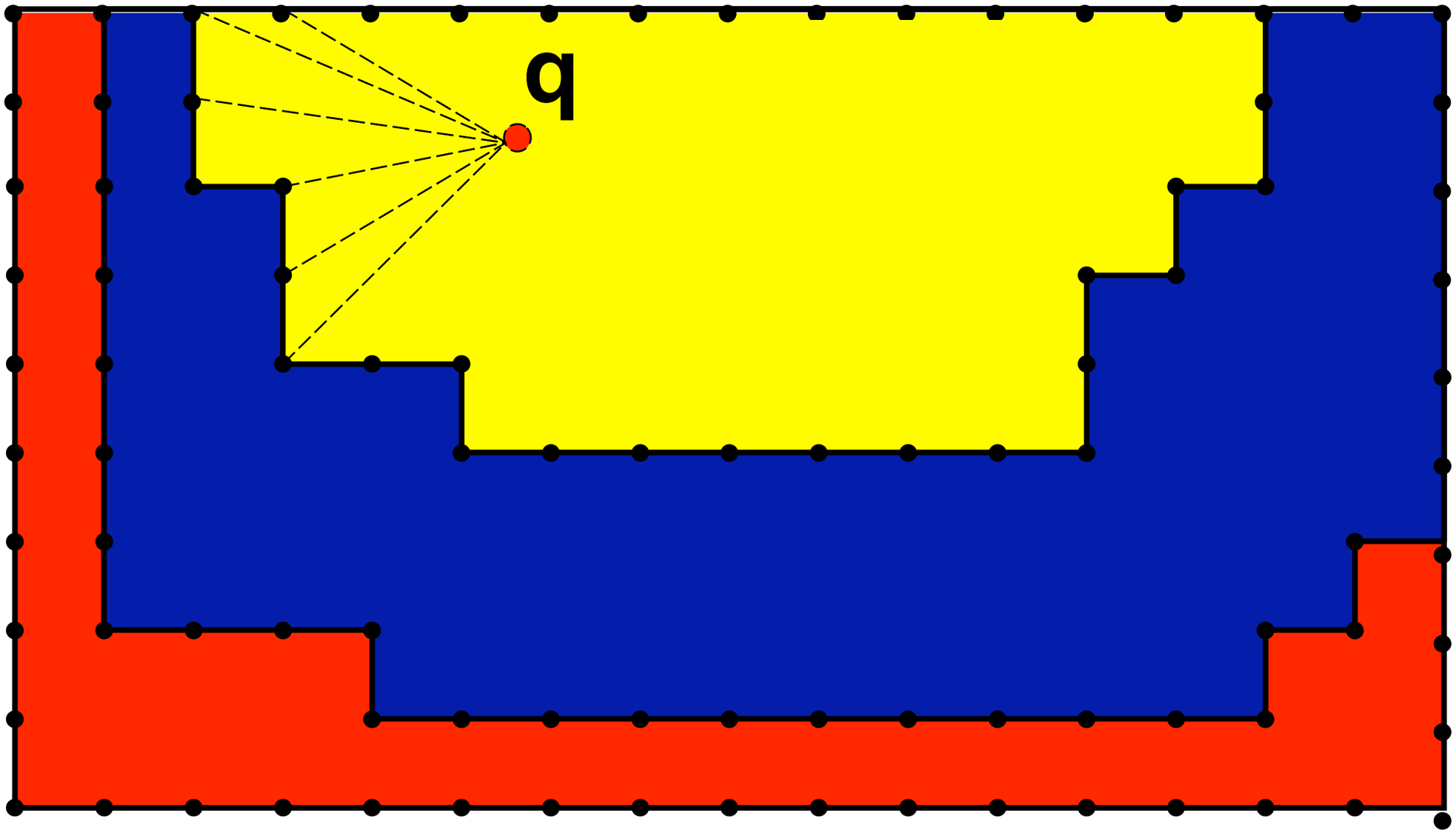
Wavefield domain representation.

BEM compression



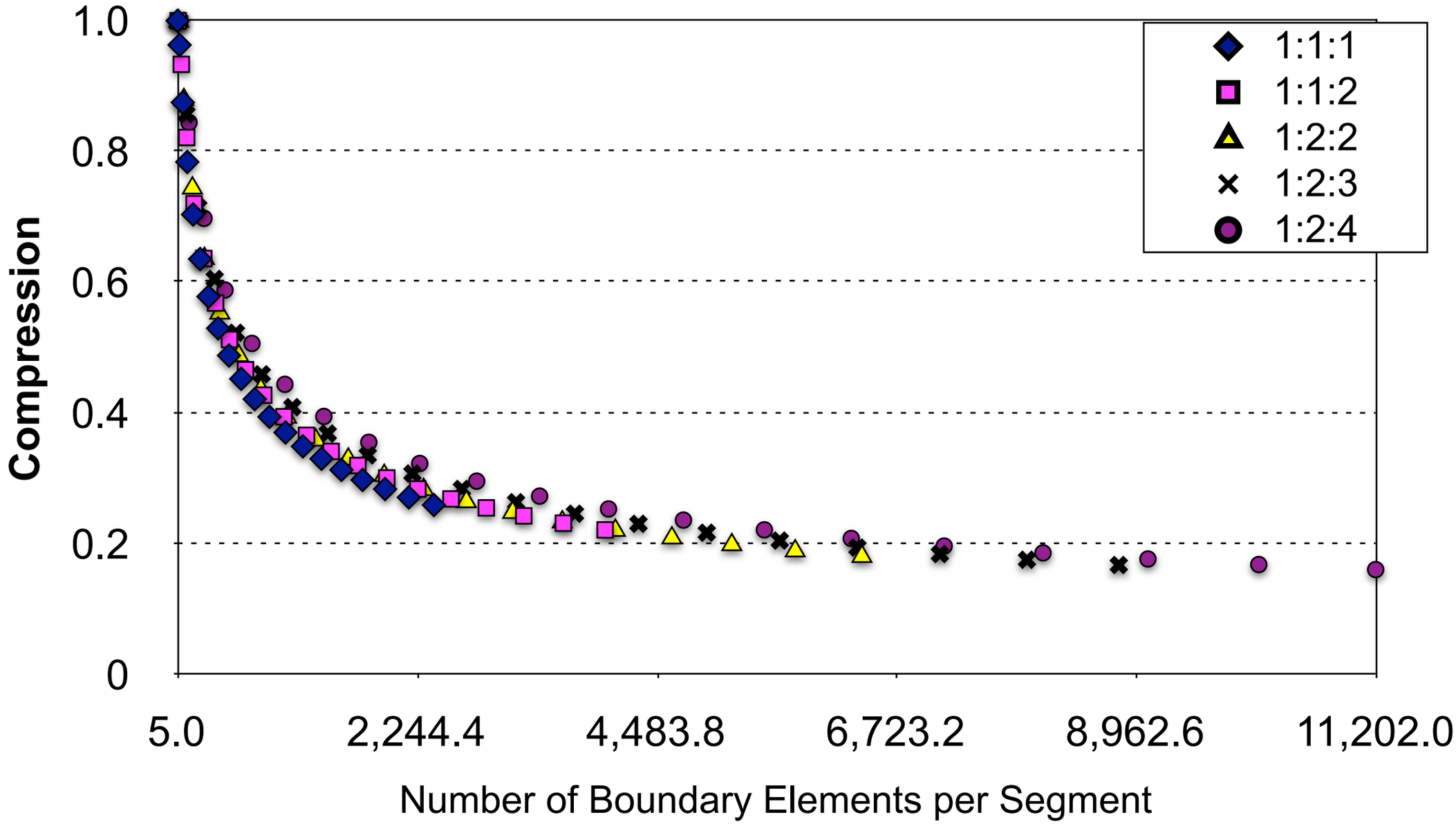
- Wavefield boundary representation.
- Only store values at the boundary.

BEM compression



- Wave data computation with query-time microsolver.
- Convolution u(ξ) * G(ξ,q).

Potential volume to boundary reduction



- Compression factors between 1.5X and 3X.

BEM compression steps

- Model segmentation: find homogeneous regions.
- Generate a boundary meshes.
- Extract wavefield data for boundary mesh nodes.

- Frequency domain representation.
- Transpose from space-time to time-space.
- Transform to the frequency domain.

Query-time BEM microsolver

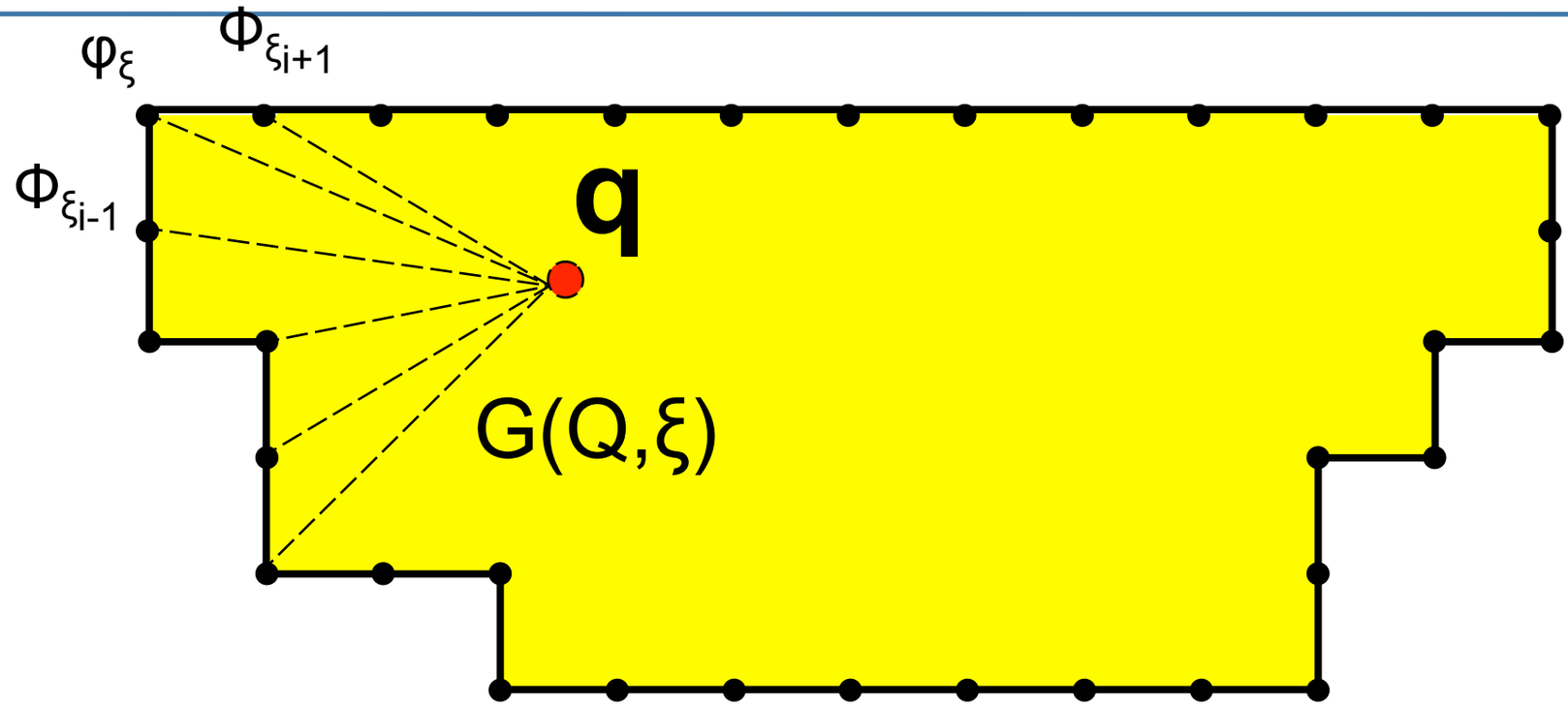
1. Spatial lookup: Find region containing q.
2. Compute phi values for boundary elements.
3. Compute q's data from phi values.

For all frequencies (ω).

Phi-computation: once per region.

$$ui(p,\omega) = \sum_{k=0}^{n-1} \int_{\xi_k} \phi_\omega(\xi) G_i(p,\xi,\omega) d\xi$$

BEM microsolver query computation



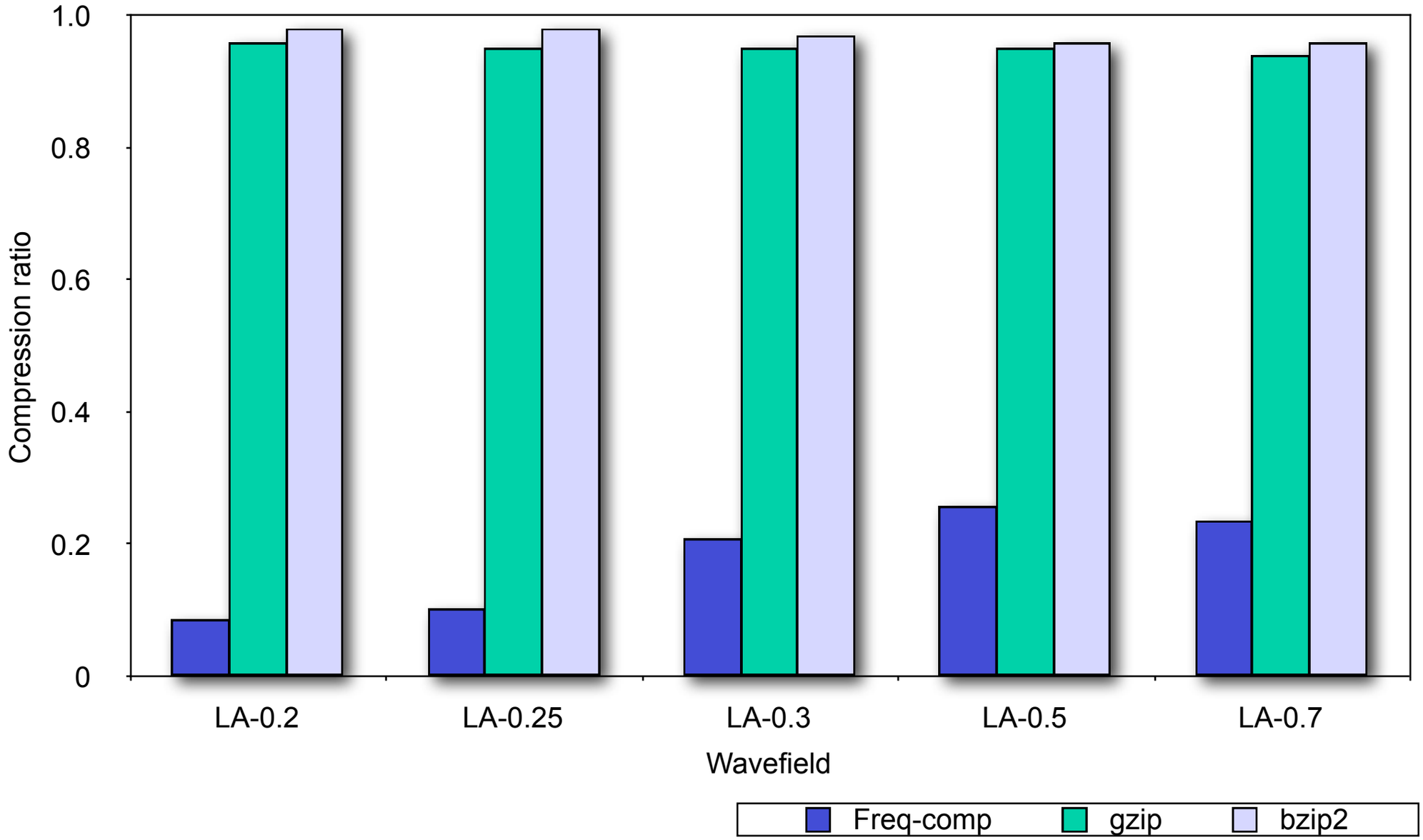
- Apply the integral equation again.
- Phi values are now known.
- Iterate over all BEs and add contribution.

Seismic wavefields

Wavefield	Mesh		Size (GB)
	elements	nodes	
LA-0.2 Hz	0.4 M	0.5 M	6.3
LA-0.3 Hz	1.6 M	1.8 M	25
LA-0.5 Hz	8 M	8.6 M	116
LA-0.7 Hz	18 M	19.4 M	260
LA-1.0 Hz	64.1 M	66.5 M	893

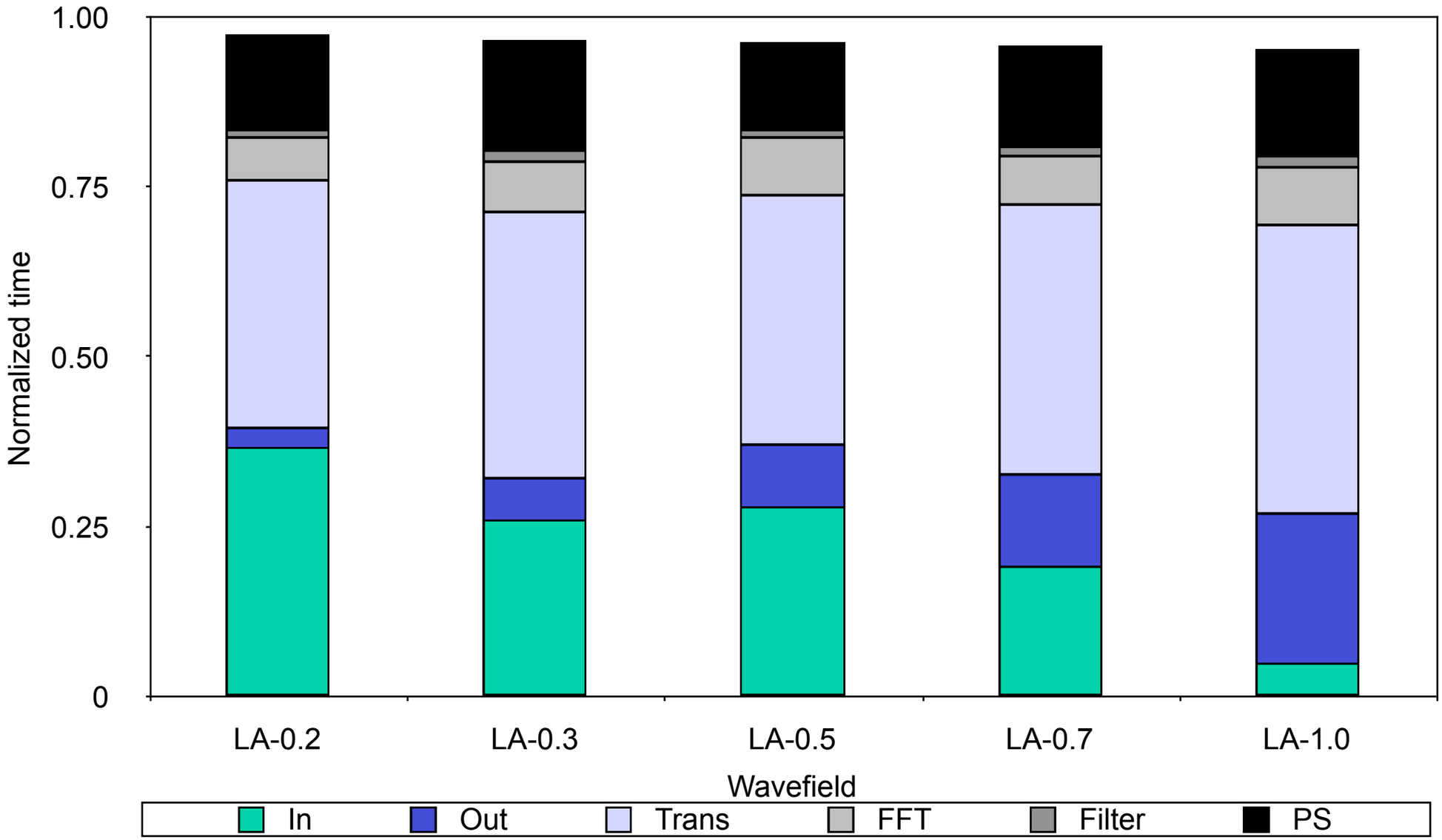
- Min Vs = 500m/s, PPWL = 10
- Pre-segmented LA-basin 0.2Hz model.
- Simulated time = 60s, dt = 0.01s.
- Output sampling rate = 10 Hz, 600 output steps.

Frequency-domain compression ratio



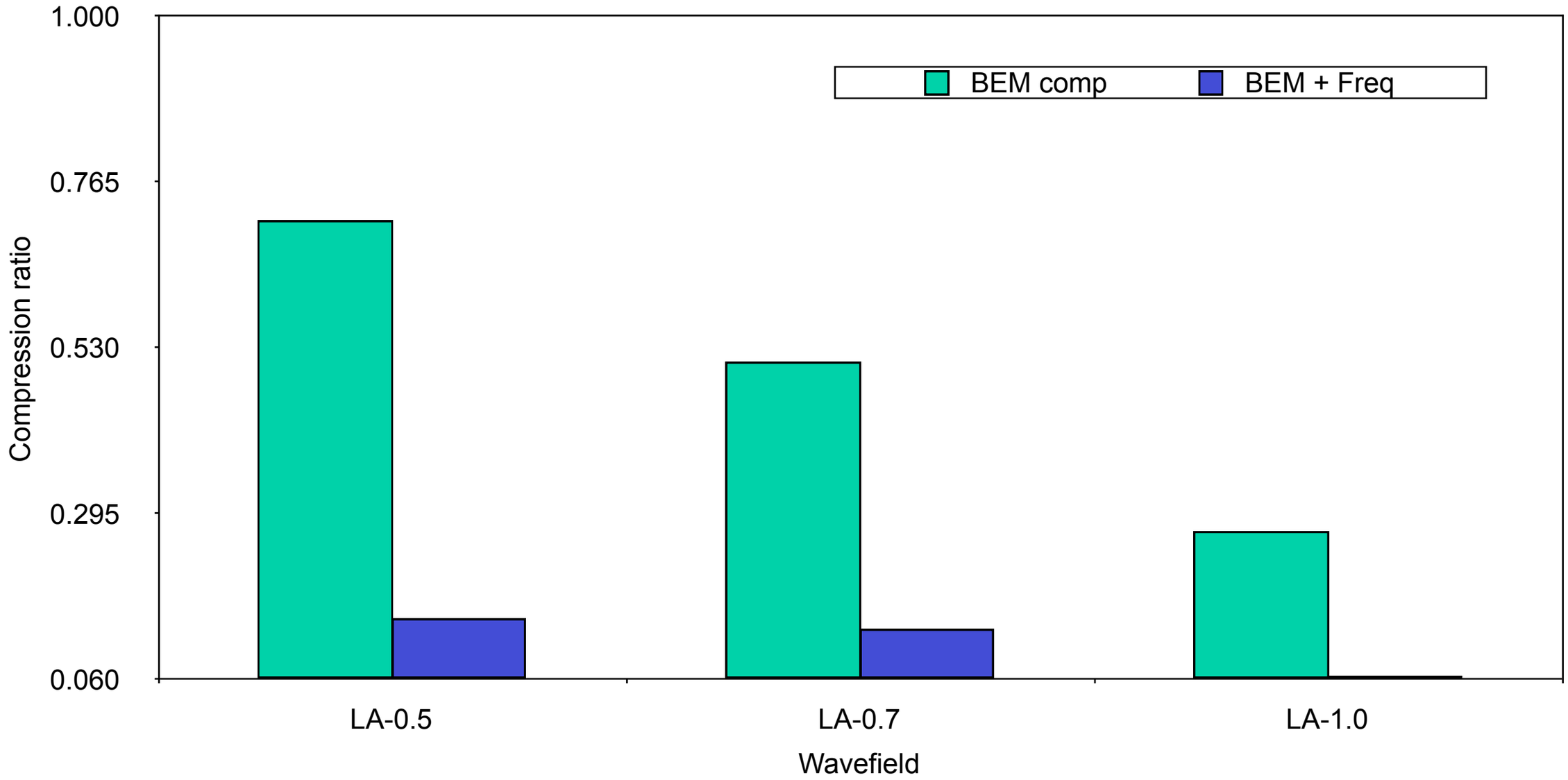
- Compression factor: 5X – 10X.

Frequency compression time



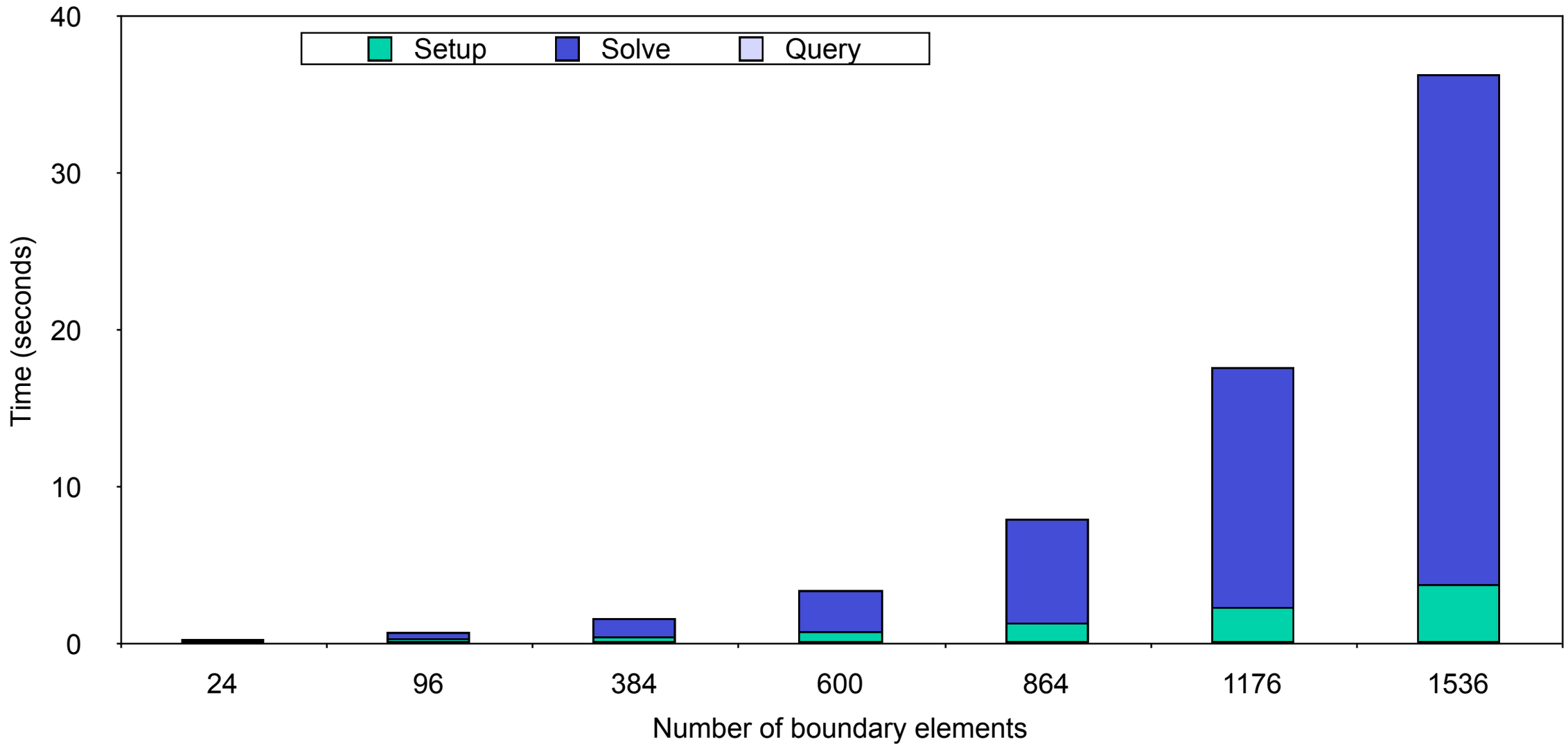
- Compression time < cp time.

BEM compression



- BEM compression factor: 1.4X - 3X.
- BEM + freq. compression factor: 7X – 10X.

BEM query time computation cost



- Query O(n), Setup O(n2), Solve O(n3)

Parallel BEM computation

- Partitioning across homogeneous regions.
- Partitioning phi computation across frequencies.
- Solving system of equations in parallel.
- Partitioning across query points.

Conclusions

- New computational wavefield database approach.
  - Spatially indexed compressed fields.
  - Microsolvers: query-time computation.
- Data-intensive to compute-intensive tasks.

- Indexed compressed wavefield representations:
  - Frequency-domain compression (4X – 5X).
  - BEM compression (5X – 10X) .
- SMT out-of-core efficient transposition (copy time).

Yes … but

- Requires application transformations: Hard!

- What other approaches can we take?

- What about dealing with failures?