Portable HPC Toolbox for Simulation and Inversion of Waves

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Simulation & Inversion

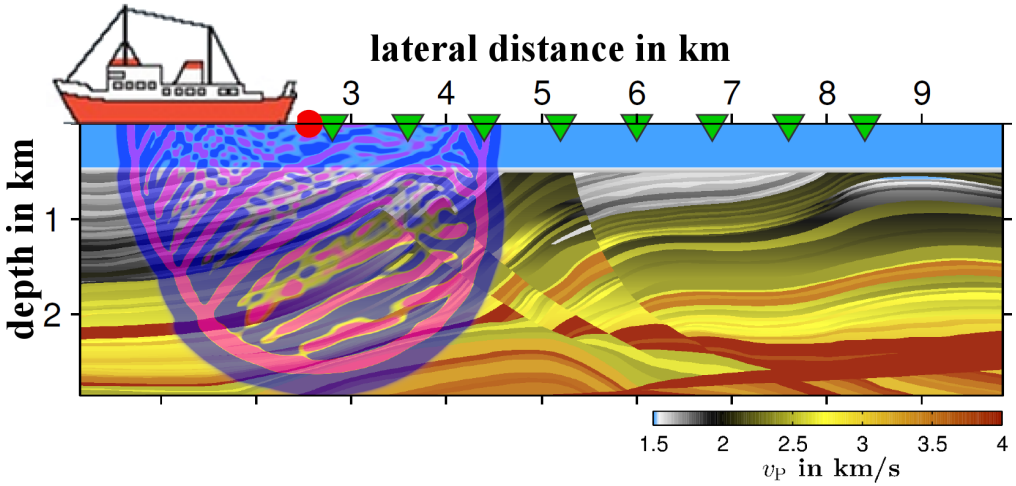
HPC Library LAMA

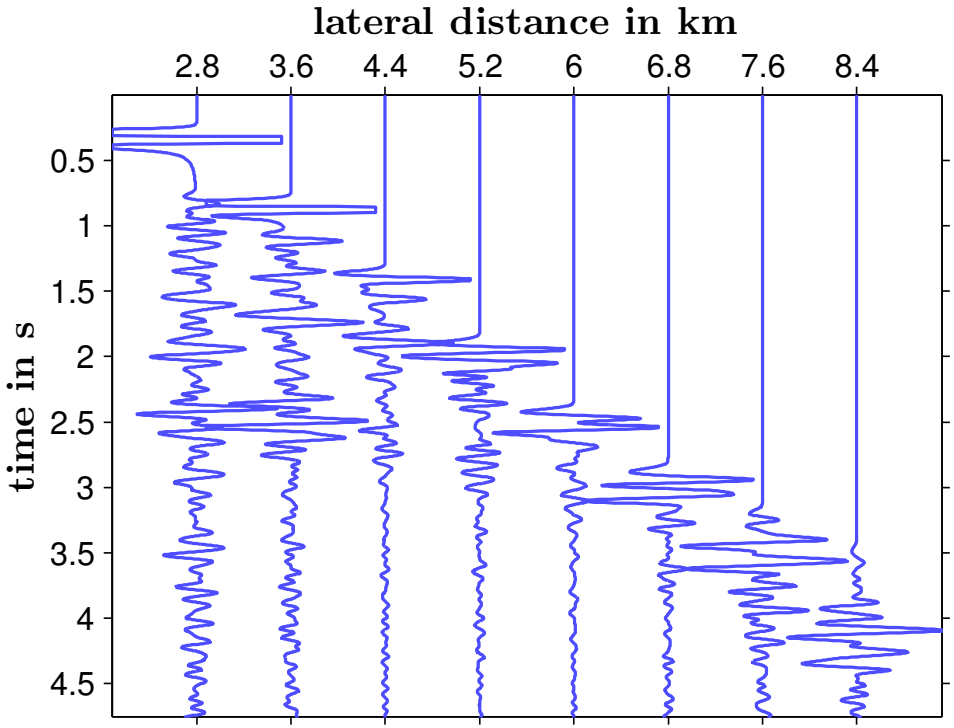
Load Balancing

Applications

Agenda

- Simulation and Inversion of Seismic Waves
- HPC Toolbox
  - FD Method
  - Discontinuous Grid
  - Partitioning
- Benchmark CPU/GPU
- Conclusion
- Outlook: Application of FWI



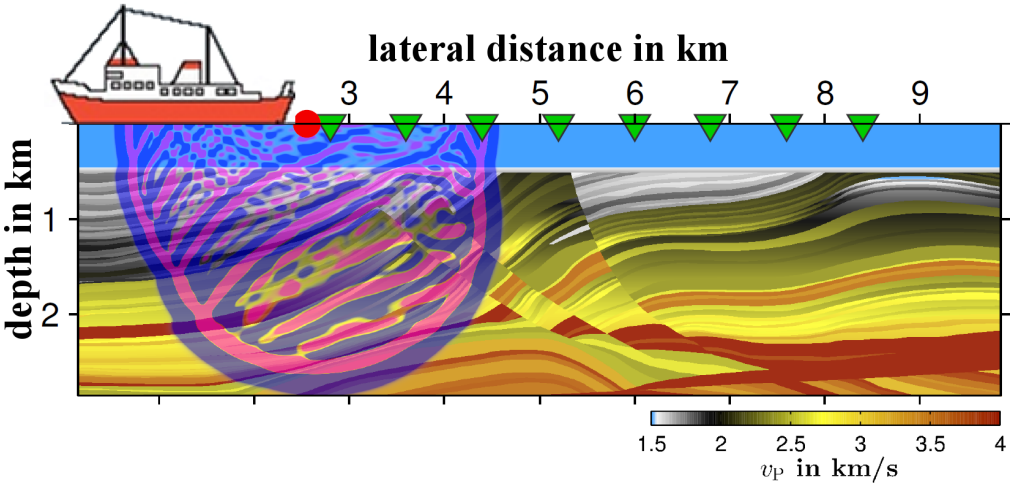


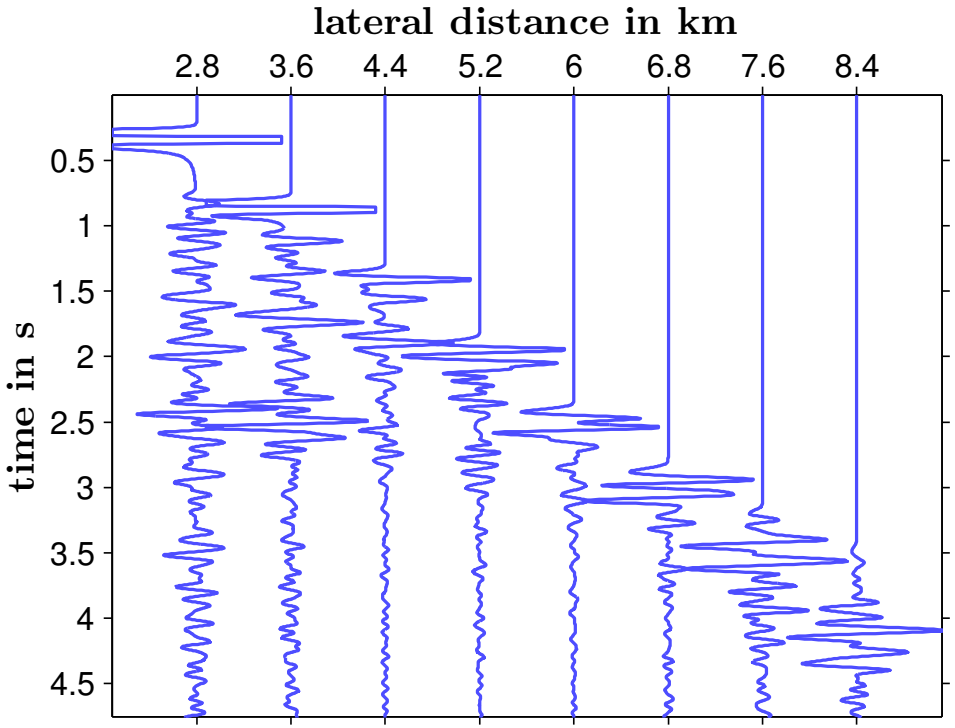
Simulation of Seismic Waves

Modelparameter:

- medium velocities v_p / v_s
- density
- attenuation

Wave equation (PDE) solved with finite difference method.





Full-Waveform Inversion

- inverse problem of seismic wave propagation
- find a model which explains seismic data
- full information of the recorded seismogram

C++ HPC Toolbox

HPC Tools

1. matrix-vector finite-difference solver (2D/3D acoustic / elastic / viscoelastic)
2. HPC library LAMA (mpi / OpenMP)
3. applications on heterogeneous architectures (CPU / GPU / Accelerator)
4. load balancing / graph partitioning (Geographer / ParMETIS)

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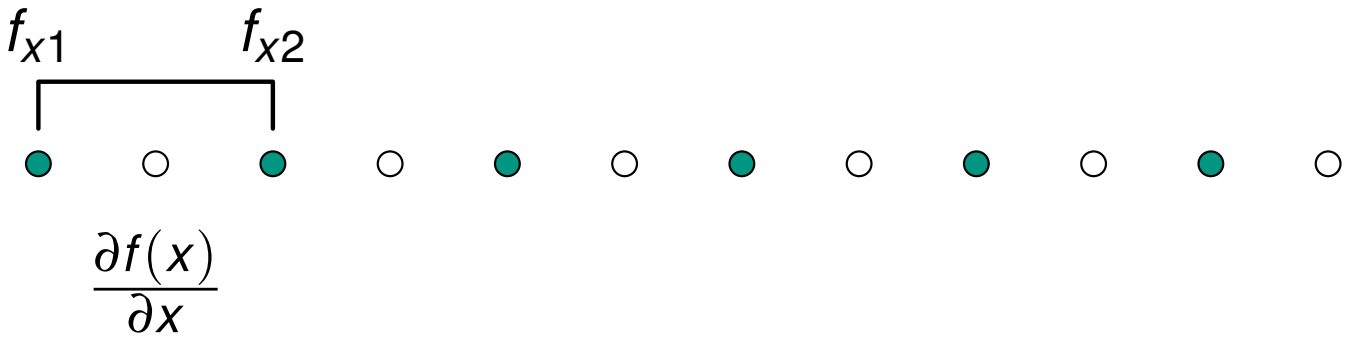
Focus in this talk

- matrix-vector formalism in FD-solver
- discontinuous grid
- partitioning

FD method

Conventional 1D FD operator for 2nd order derivatives on a staggered grid:

$$\left.\frac{\partial f(x)}{\partial x}\right|_{\frac{x_1+x_2}{2}} = \frac{f_{x_2} - f_{x_1}}{\Delta x}$$



Matrix-Vector Formalism

The operator for every grid point can be expressed as a matrix-vector product:

$$\begin{pmatrix} \frac{\partial f(x)}{\partial x}\Big|_{\frac{x_1+x_2}{2}} \\ \frac{\partial f(x)}{\partial x}\Big|_{\frac{x_2+x_3}{2}} \\ \dots \end{pmatrix} = \frac{1}{\Delta x} \cdot \begin{pmatrix} -1 & 1 & 0 & \dots \\ 0 & -1 & 1 & \dots \\ \dots & \dots & \dots & \dots \end{pmatrix} \cdot \begin{pmatrix} f_{x_1} \\ f_{x_2} \\ f_{x_3} \\ \dots \end{pmatrix}$$

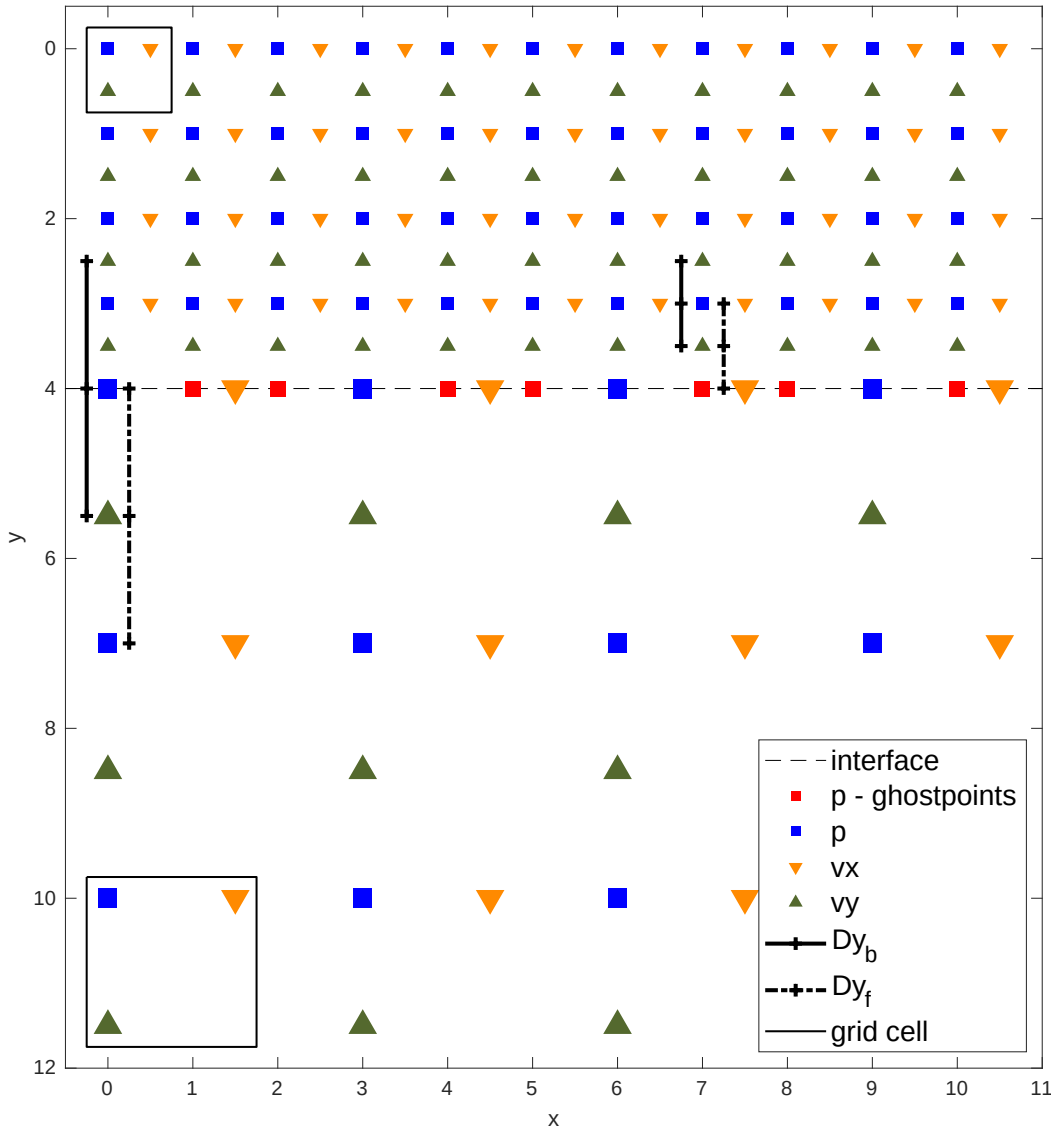
$$\frac{\partial \vec{f}}{\partial x} = \frac{1}{\Delta x} \cdot \underline{D} \cdot \vec{f}$$

- derivative matrix $\underline{D}$ has a strong sparsity rate
- FD coefficients in $\underline{D}$ can be adjusted for higher spatial order ($n = 2, 4, 6 \dots$)
- matrix with n non-zero elements per row

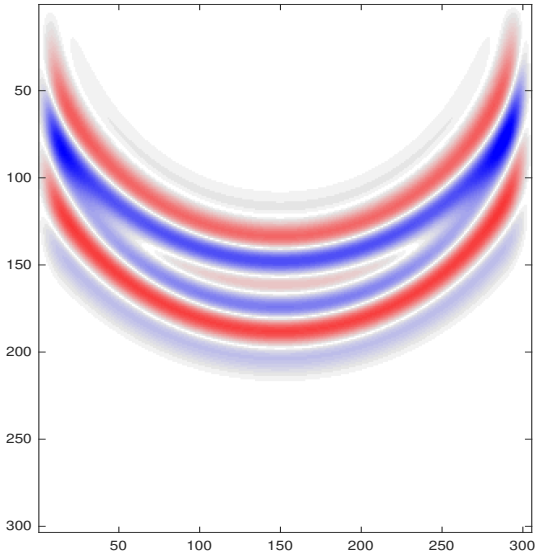
Discontinuous Grid

2D Acoustic example:

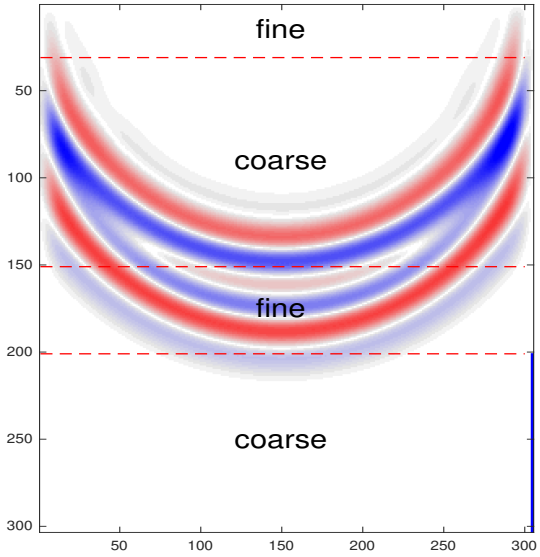
- connected regular grids
- 1D / 2D interpolation at the interfaces
- grid spacing factor: 3



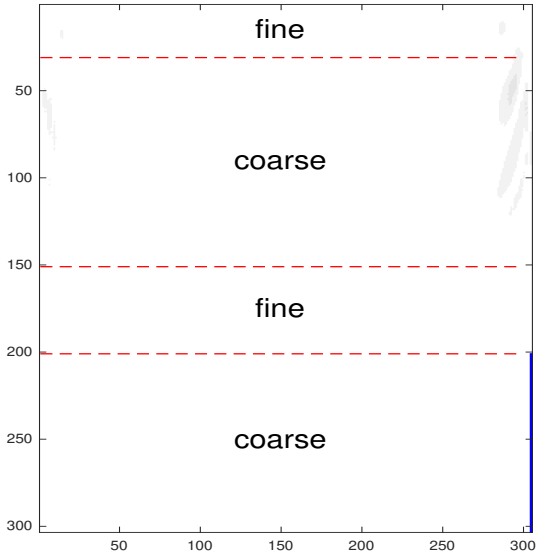
Discontinuous Grid



regular grid



discontinuous grid



difference x 2

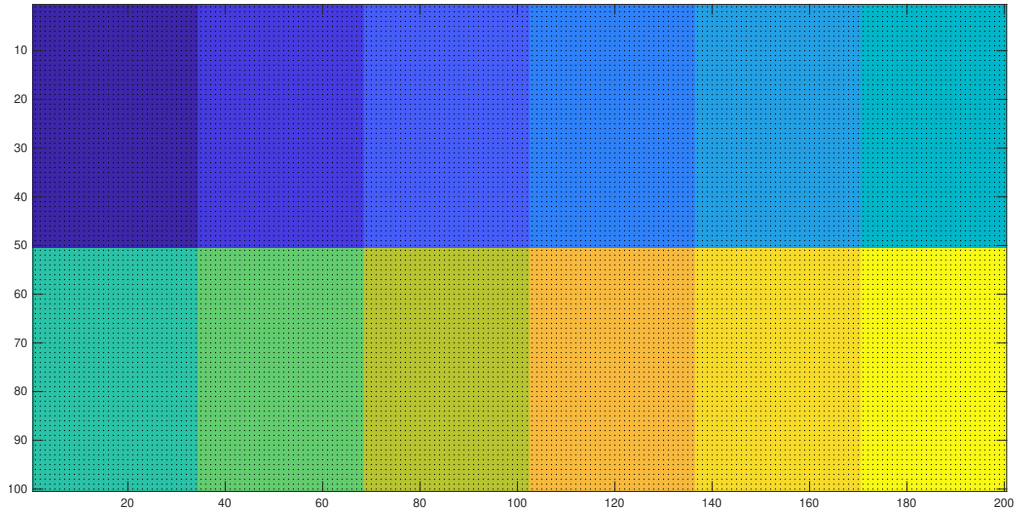
Setup

- homogeneous model
- 4 grid layers

Partitioning - Regular Grid

Grid partition

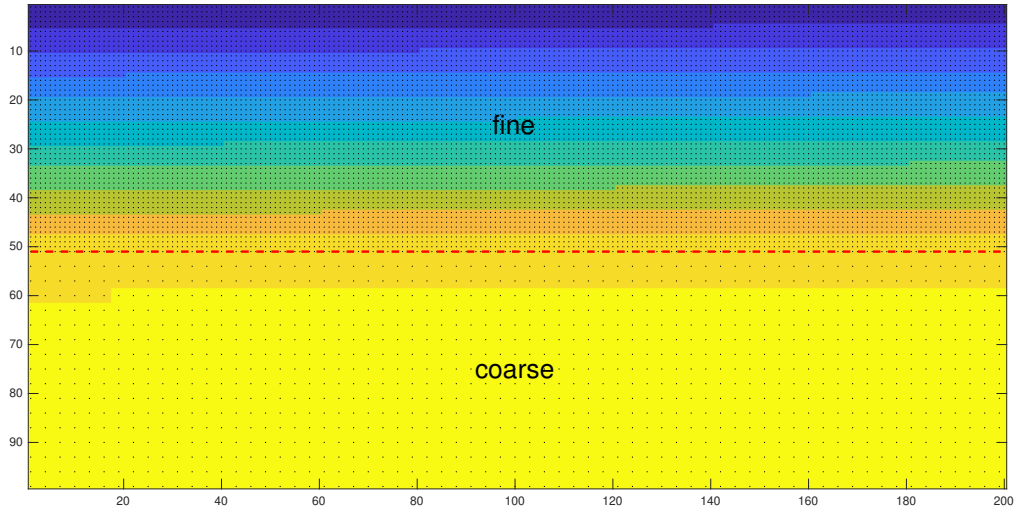
- regular process grid: NPx * NPy



Partitioning - Discontinuous Grid

Block partition

- equal sized blocks of model vector



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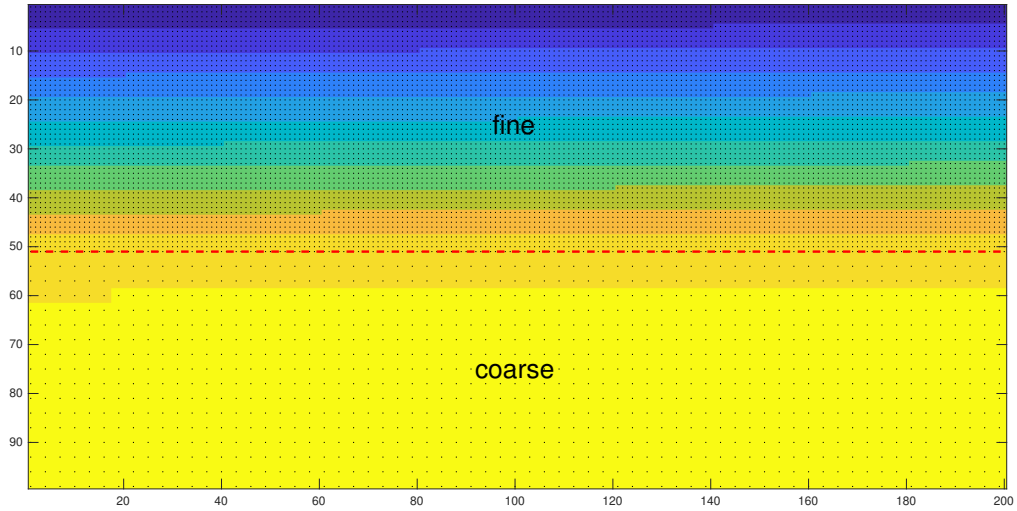
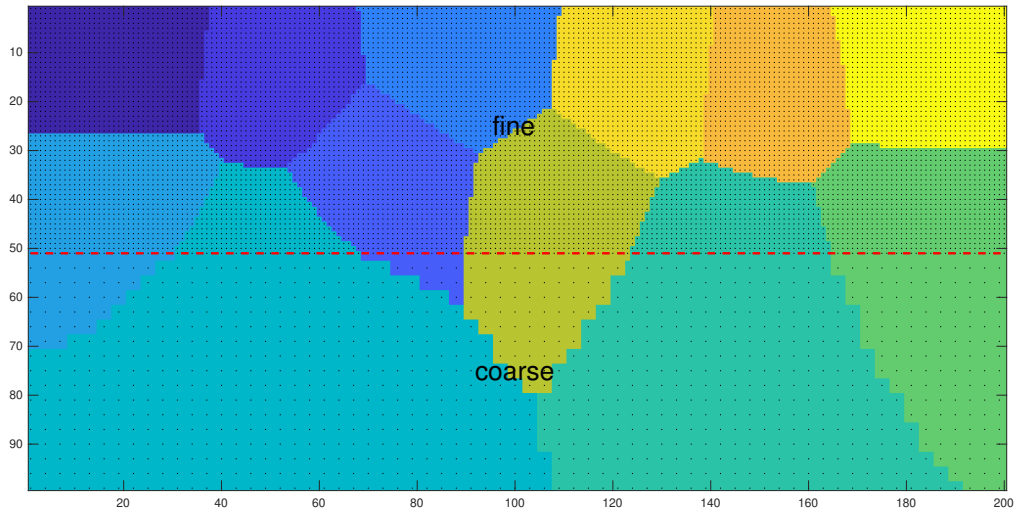
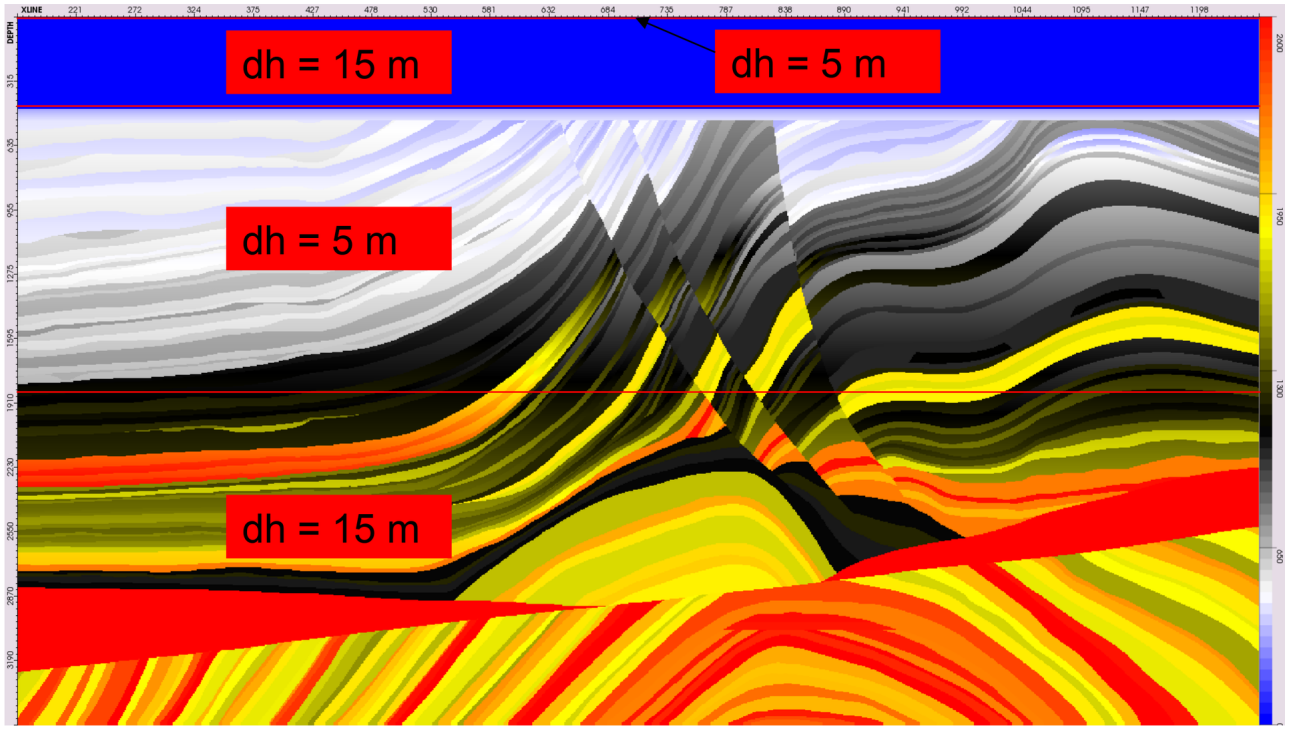


Graph partition (Geographer)

- start partition: block partition
- algorithm: k-means
- weights (imbalance)
  - absorbing boundary
  - variable FD-order
  - interpolation ...



3D Elastic Benchmark



FD-Order=2
FD-Order=6

FD-Order=12

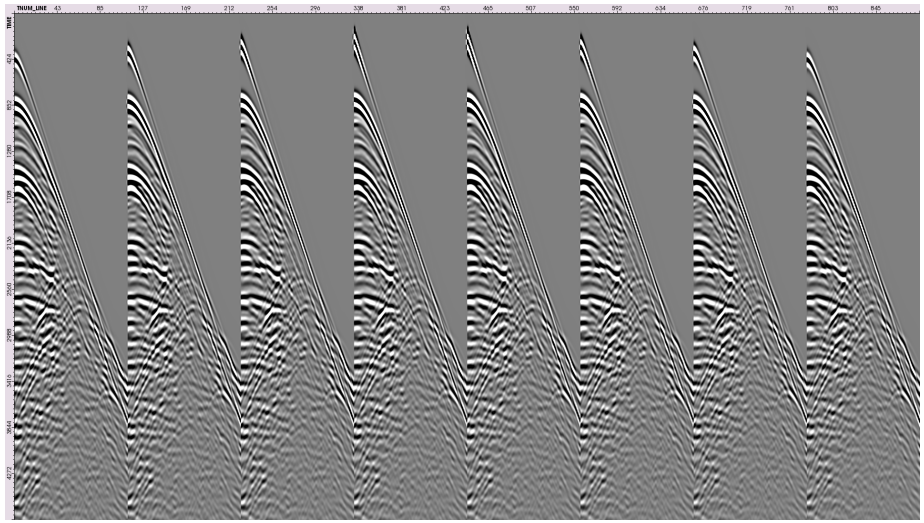
FD-Order=10

Setup

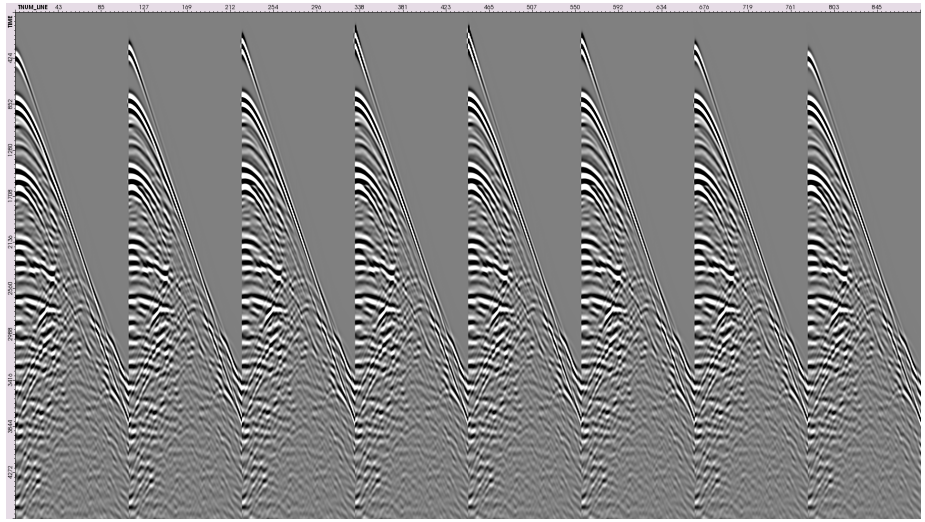
- FDorder regular/discontinuous: 12th order / 2nd-12th order
- timesteps regular/discontinuous: 11.1×10^3 / 8.6×10^3 (78%)
- model size regular/discontinuous: 155.7×10^6 / 66.8×10^6 GP (43%)

Benchmark Results

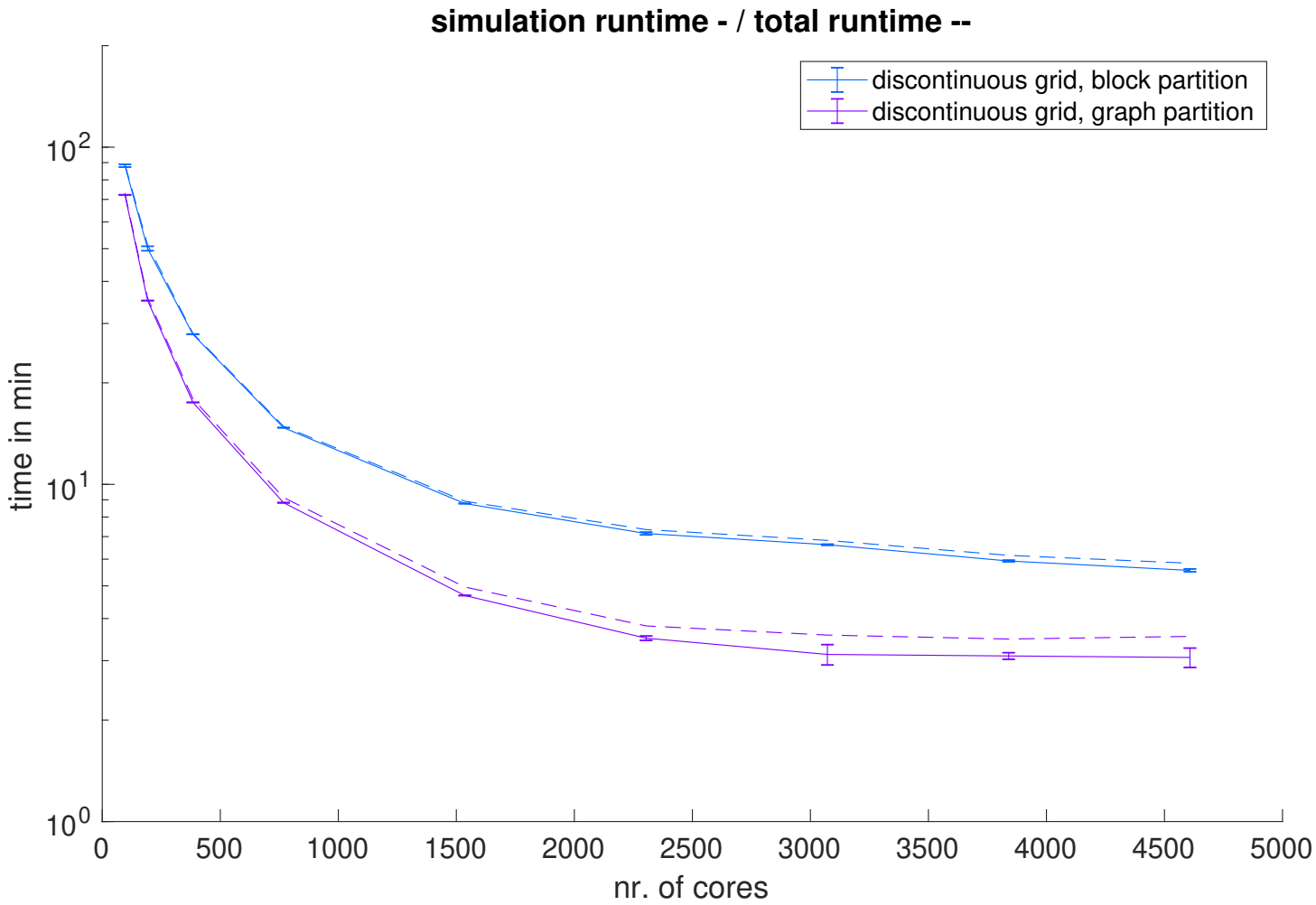
Regular Grid



Discontinuous Grid



3D Benchmark CPU - Strong Scaling



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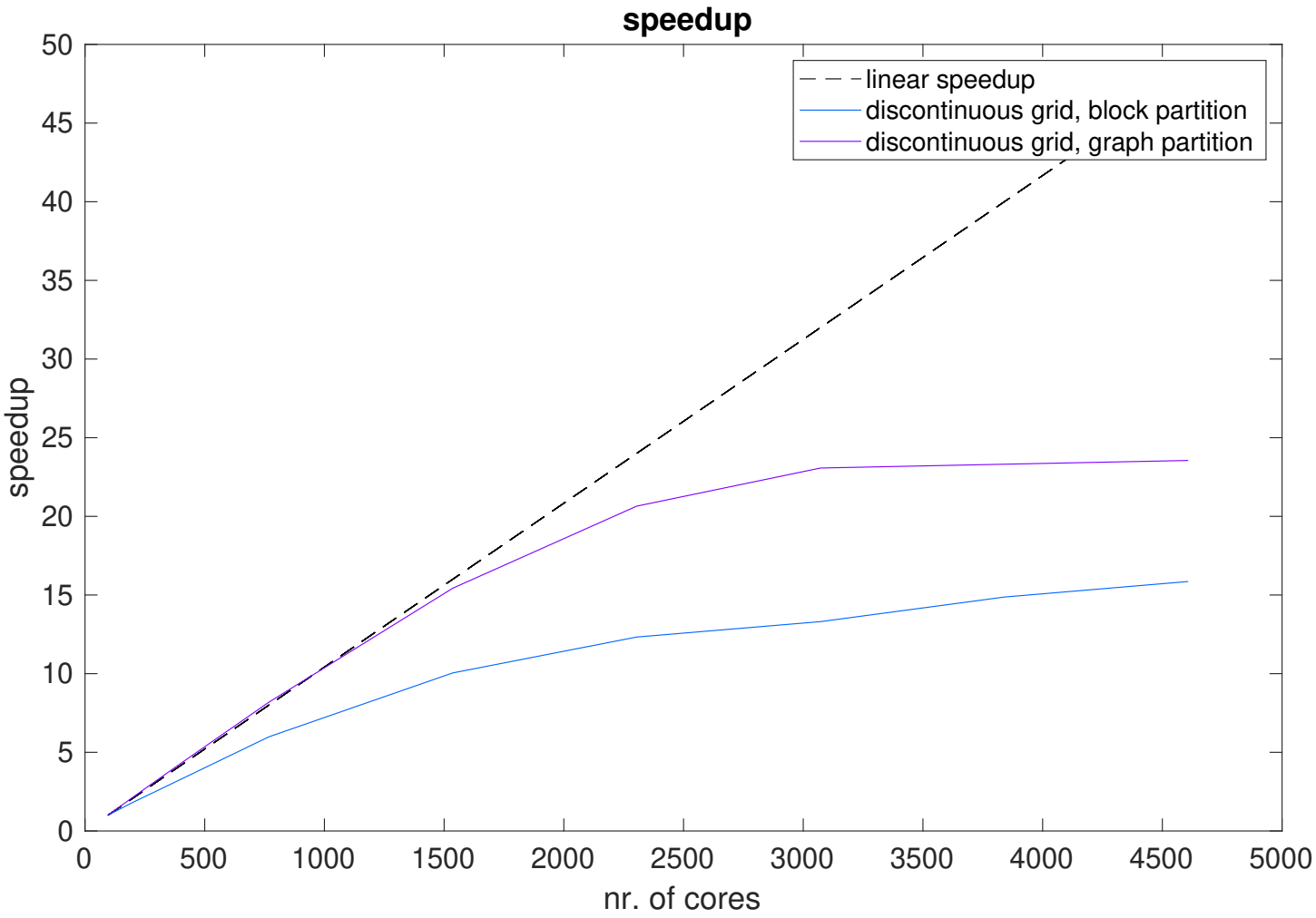
CPU: Dual Intel Xeon Platinum (2x24 cores)

3D Benchmark CPU - Strong Scaling



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Speedup relative to 2 Nodes (96 cores)

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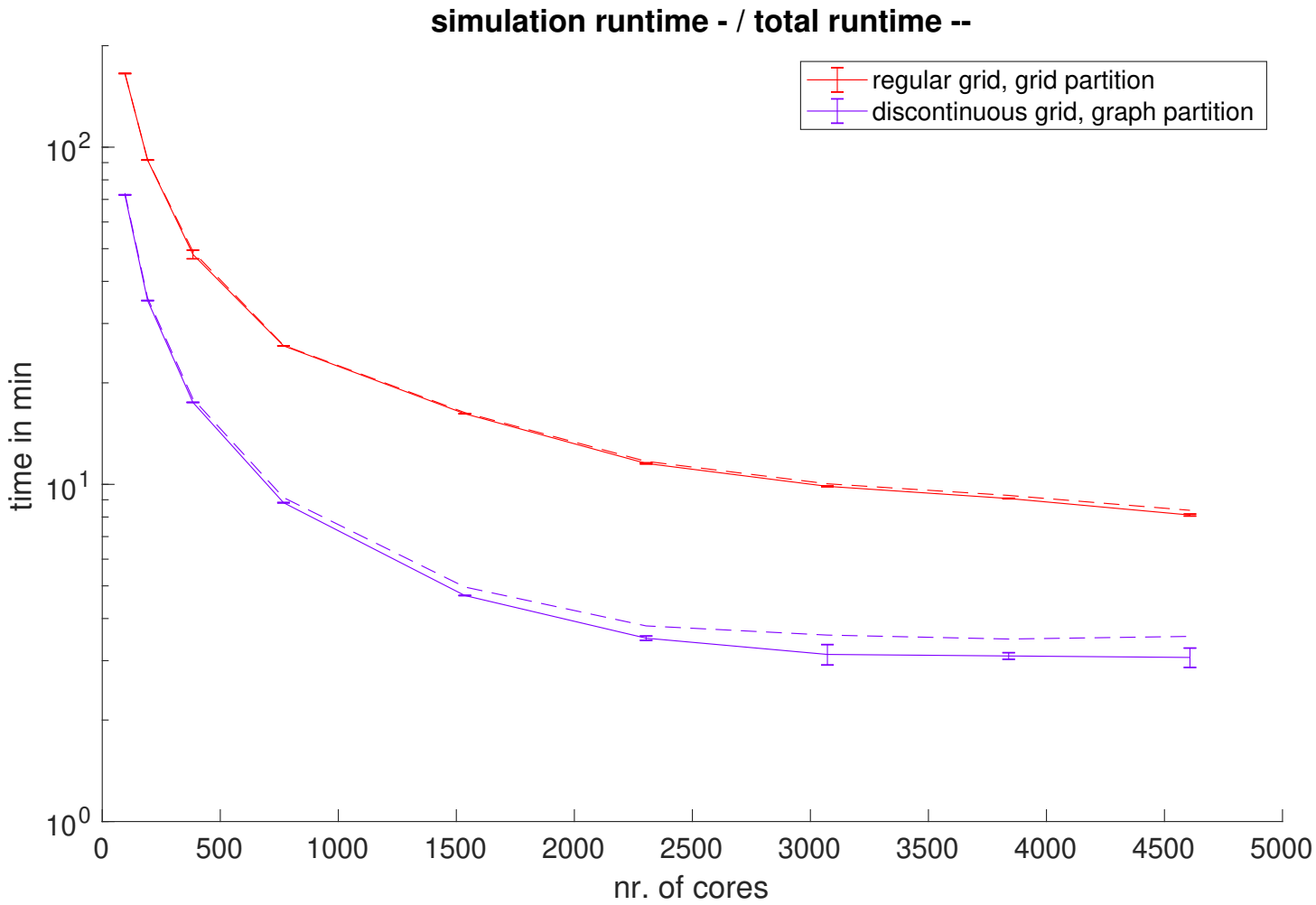
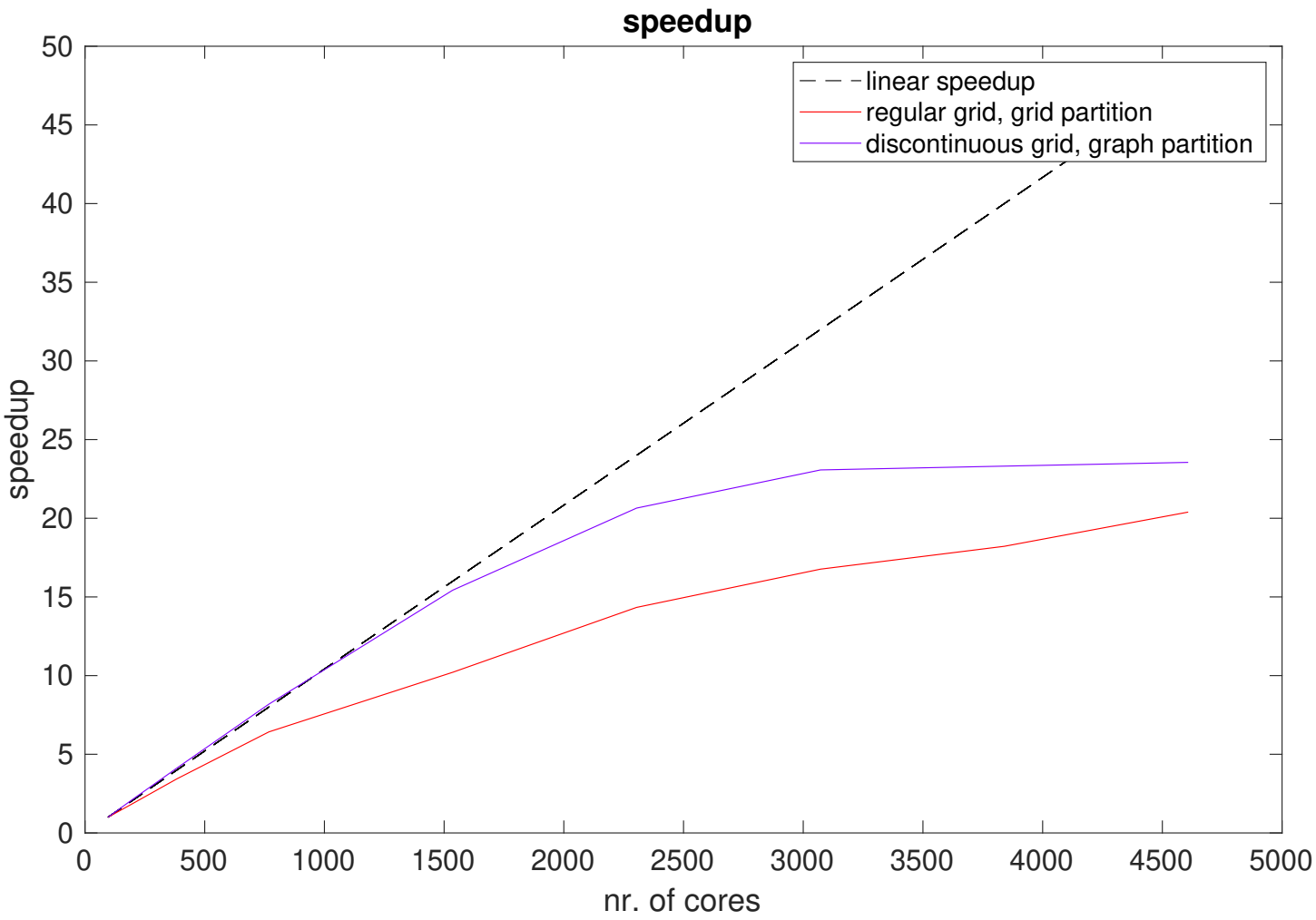


Speedup discontinuous grid:
2.5 - 3.3

3D Benchmark CPU - Strong Scaling



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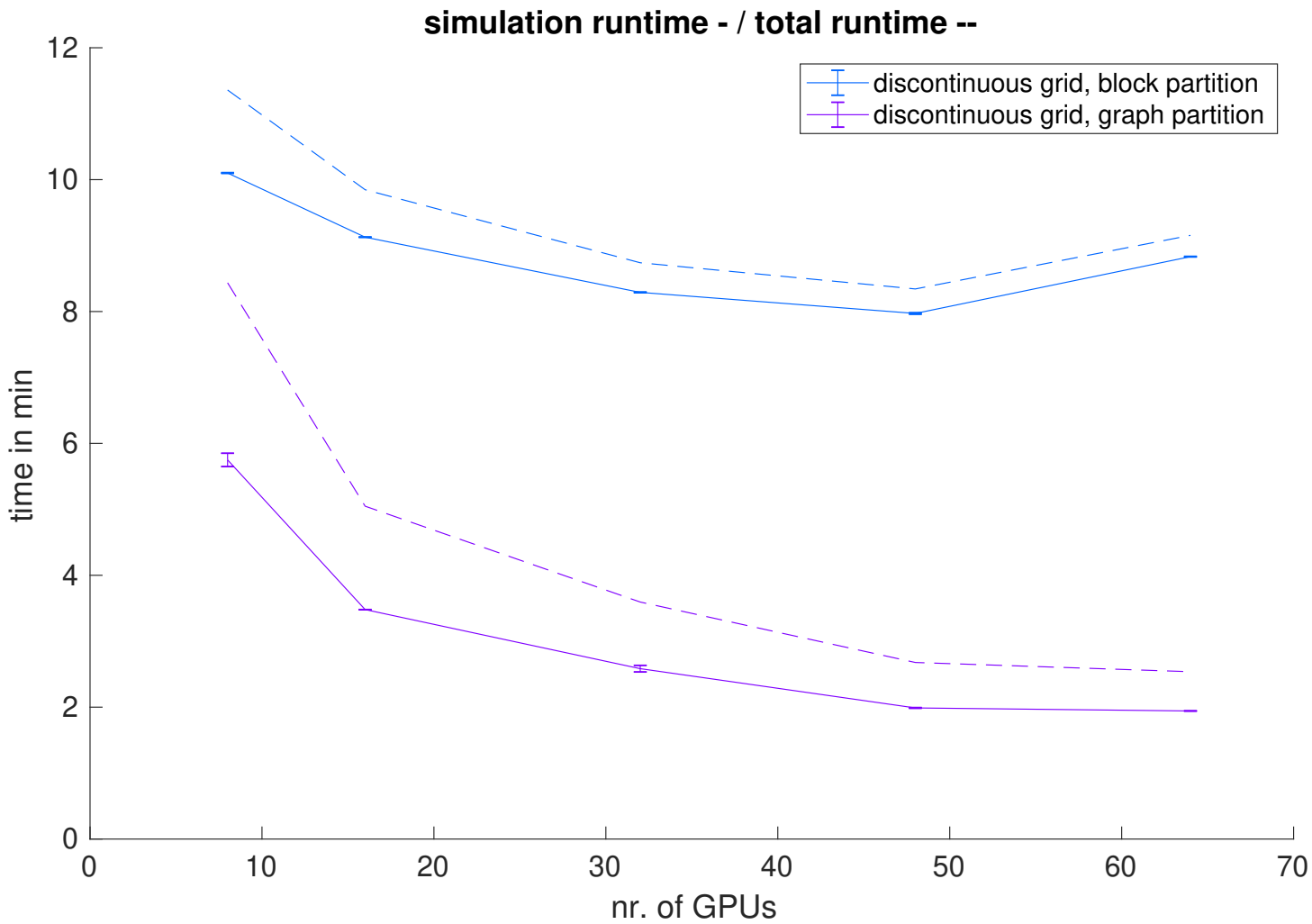
3D Benchmark GPU - Strong Scaling



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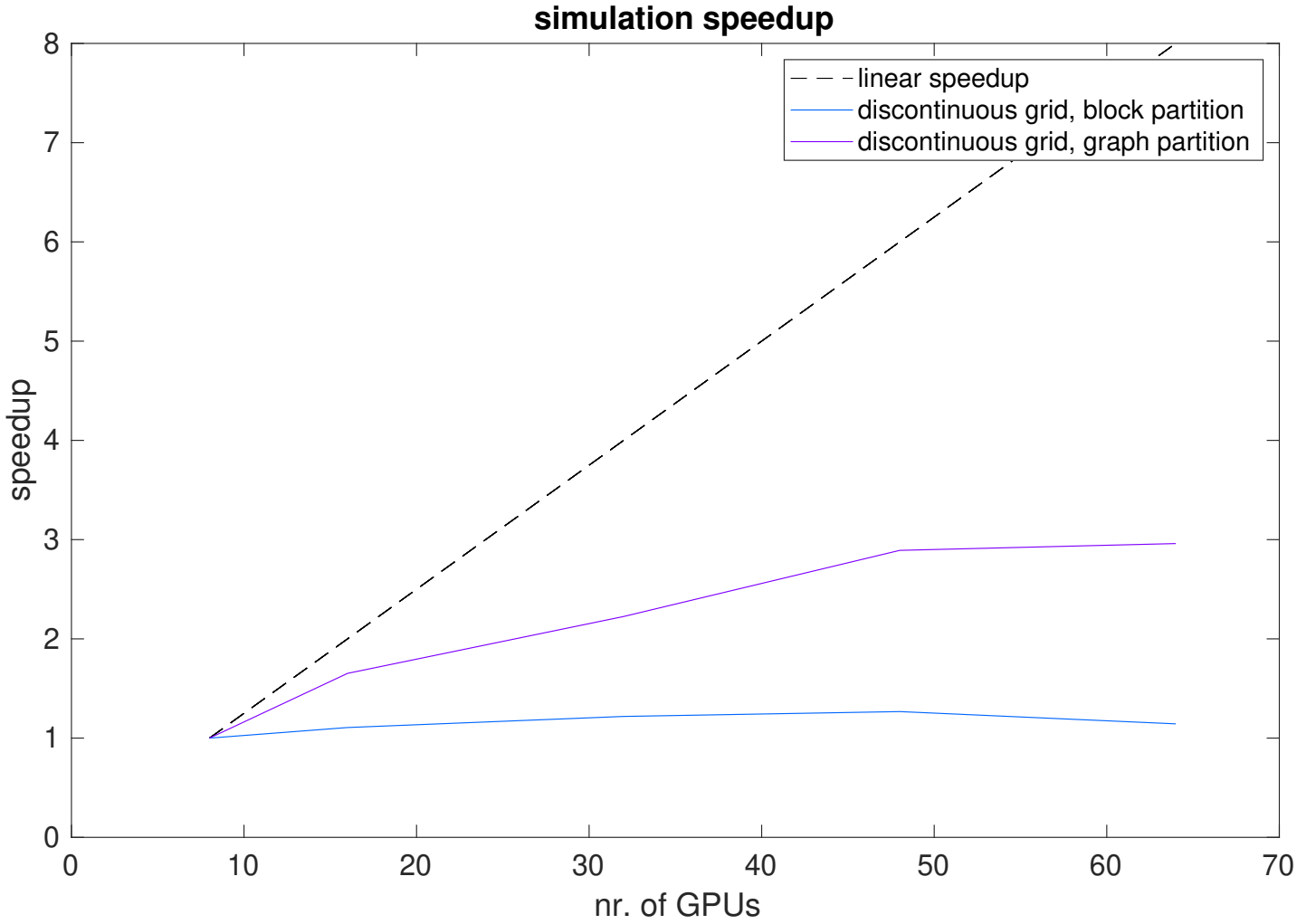
GPU: Nvidia V100 GPU

3D Benchmark GPU - Strong Scaling



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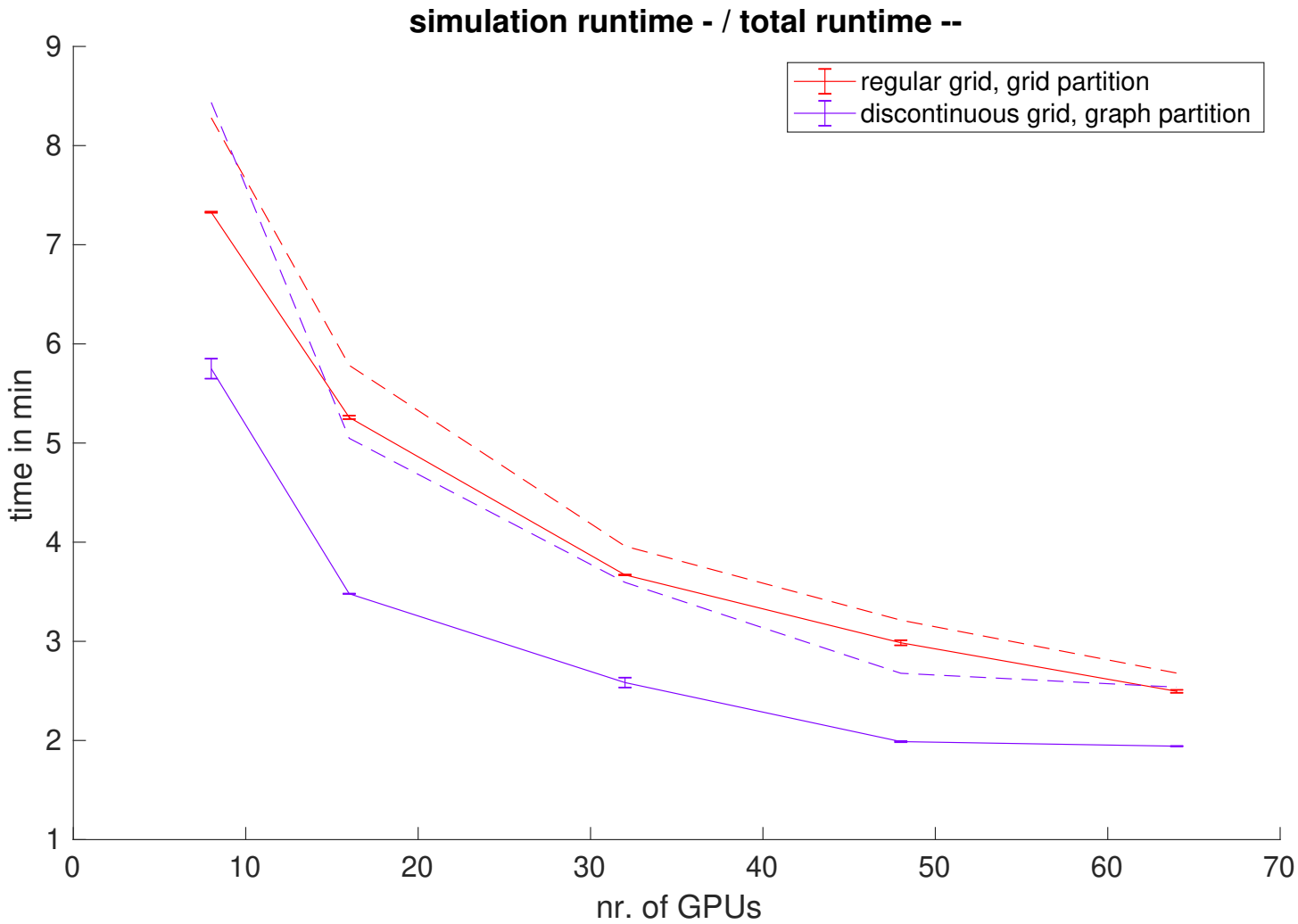
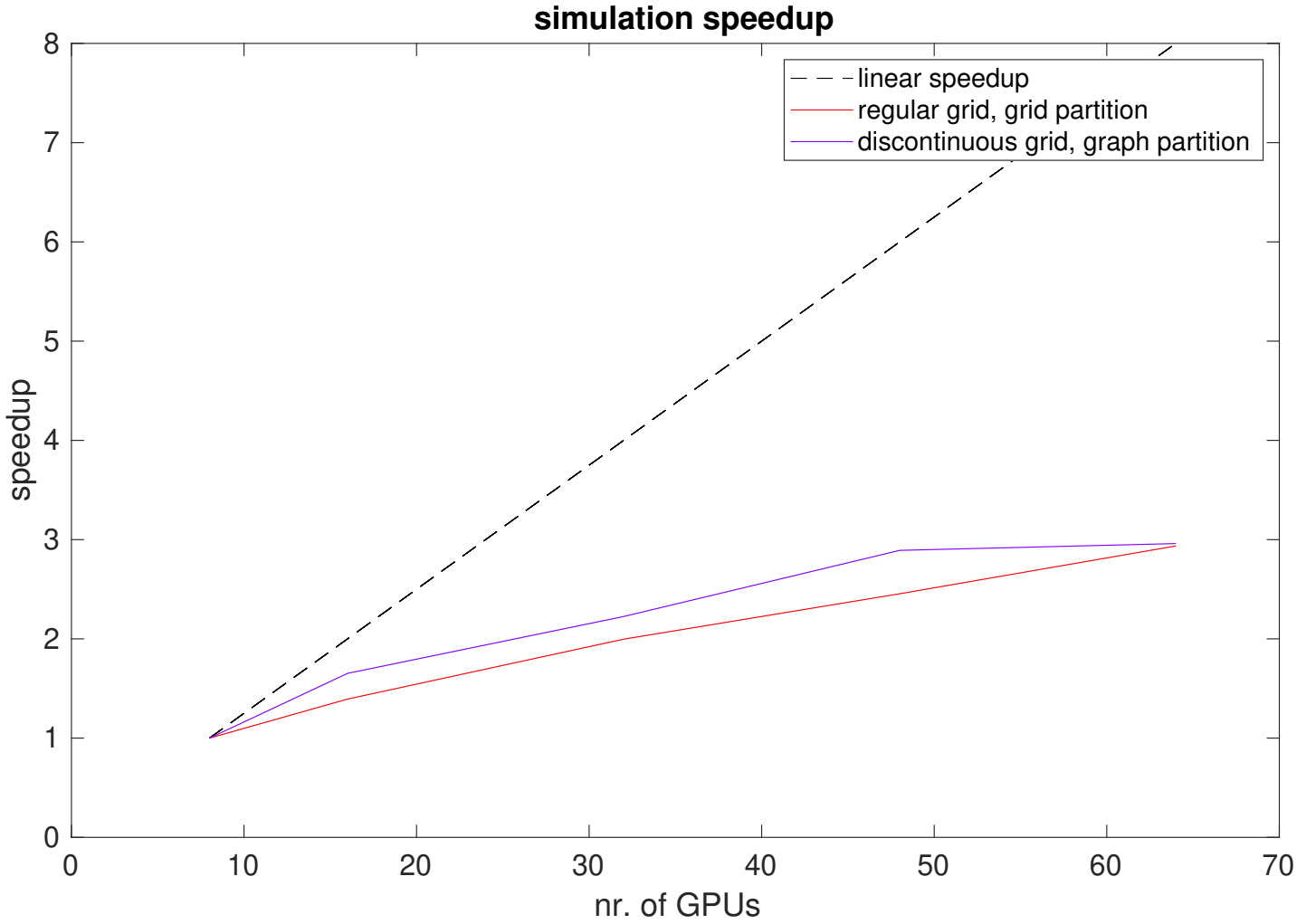
Speedup relative to 2 Nodes (8 GPUs)

3D Benchmark GPU - Strong Scaling



Speedup discontinuous grid:
1.3 - 1.5

3D Benchmark GPU - Strong Scaling



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Speedup relative to 2 Nodes (8 GPUs)

Conclusion

- HPC ToolBox
  - 2D/3D acoustic / elastic /viscoelastic forward solver
  - discontinuous grid
  - graph partitioning
  - task parallelisation for heterogeneous architectures

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Outlook:

- Full Waveform Inversion application on 3D "real" dataset

Outlook: seismic fieldwork

- Target: Ettlinger Line: trench built during the war of spanish succesion (18th century)

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Thank you for your attention

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