

Numerical tools for multiscale wave propagation in geophysics

[Extended Abstract]

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1. INTRODUCTION

Current methods of elastic tomography in geophysical media are mainly based on the arrival times of the first waves, which correspond to a particular homogenization regime. The late coda, that corresponds to a diffusion-like regime, and cannot be processed with classical deterministic approaches, is mostly disregarded. Our long-run objective is to complement the classical tomography methods with statistical information gathered from the coda and the higher frequency content of the recorded signals. Such an objective requires the construction of numerical tools that can efficiently adapt to the required scale of study. While scalable wave propagation solvers are available for running on today's largest computers [5], the numerical bottlenecks now arise elsewhere, such as with meshing or visualization. We describe in this paper two such issues and propose solutions. In particular, we present (i) a scalable meshing algorithm that automatically considers topographical details up to a parametrizable level and efficiently constructs parallel hexahedral meshes, and (ii) a scalable random field generator that efficiently constructs elastic parameter fields with chosen statistics.

2. SCALABLE PARALLEL MESHER FOR GEOPHYSICAL APPLICATIONS

Meshing is particularly hard considering high-resolution wave propagation problems using conformal hexahedra in realistic Earth geometries. Here, high resolution means meshes containing several billions of elements [1, 2]. Recently some groups have broken the barrier of running analyses on very large meshes using octrees, exhausting all available resources on the biggest machines in USA and Europe. In this work, we present an automatic parallel procedure to create 3-D unstructured conformal hexahedral meshes based on the 3-octree data structure proposed in [7].

A 3-octree is a data structure where a cell is divided into 27 new cells [7]. The procedure to create the hexahedral mesh employs the bottom-up scheme where the finest cells are build first. For our purposes, high-resolution cells are located closest to Earth surface (because wave velocities are lower on average there) and when we move away from the surface, the cells may have lower resolution, grading the mesh. However, the transition between a fine cell to a coarse cell must avoid hanging nodes (constraint of the Spectral Element Method). Figure 1 shows the template with 13 cells used in this work and is based on [3]. As the transition among cells faces occurs only vertically, only this template suffices.

The whole process is done in parallel. The domain is initially partitioned in a 2D grid among processors. Bottom-up construction is done independently on each processor. The transition layers are inserted every m meters (input data). A smooth scheme [6] is used to fit the octree mesh with the bathymetry surface generating from data extracted from NOAA (National Oceanic and Atmospheric Administration) bathymetry database. A weak scalability analysis performed on Occigen machine (at CINES, France) reveals that increasing the number of octree levels the computation/communication ratio is low, measured by TAU. Meshes

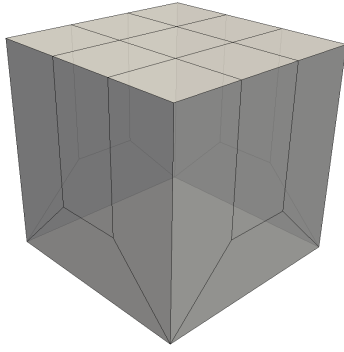


Figure 1: 13-cell template used to remove face hanging nodes

of billions of hexahedra are generated very fast (see poster for details).

3. SCALABLE PARALLEL RANDOM FIELD GENERATION

The generation of a realization of a random field can be performed in the space domain with a Cholesky factorization of the covariance matrix R . The computational cost scales as $\mathcal{O}(N^3)$ in the general case, but can be improved to sub- $\mathcal{O}(N^2)$ using a polynomial approximation of $R^{1/2}$ [4]. On the other hand, working in the spectral domain, the complexity of the generation schemes is $\mathcal{O}(N^2)$ and can be improved to $\mathcal{O}(N \log N)$ with the Fast Fourier Transform [8].

This scalability issue arises because the random field is assumed correlated over the entire domain. However, in most cases, the correlation length is much smaller than the global size of the domain. We therefore propose to generate a realization over the entire domain as a superposition of smaller independent realizations, gluing them together through transition volumes. The number of operations per processor then remains constant, even when $L \gg \ell_c$. Results and theory have shown that a transition volume of 5 to 10 ℓ_c is enough to make statistics homogeneous over the whole domain. A weak scalability analysis performed on Igloo machine (CentraleSupélec) shows that the computing cost reaches a plateau only dependent on ℓ_c , after an initial linear phase.

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