Performance of OpenMP loop transformations for the acoustic wave stencil on GPUs

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OpenMP and heterogeneous architectures

- The support for heterogeneous architectures was introduced in OpenMP 4.0 and OpenMP 4.5.
- OpenMP 5.1 introduced unroll and tiling loop transformations. Code offloading for these transformations is supported in Clang 13.
- Despite being around for decades, the availability of these transformations for portability across compilers is new. And we exercise it.

The application kernel

Kernel of seismic applications such as full-waveform inversion (FWI) and reverse-time migration (RTM), the propagation of acoustic waves can be modeled as a second-order partial differential equation (PDE) that follows:

\[ \frac{\partial^2 p(x, y, z, t)}{\partial t^2} - \nabla^2 p(x, y, z, t) = f(x, y, z, t) \] (1)

where \( v_p \) is the velocity, \( p(x, y, z, t) \) is the pressure field, and \( f(x, y, z, t) \) is the source. This PDE is solved by reverse-time propagation. Full-waveform inversion (FWI) and reverse-time migration (RTM), the Kernel of seismic applications such as in full-waveform inversion and time migration, the performance of these applications is highly sensitive to the choice of block size.

Setup of Experiments

- Experiments on three GPU architectures (see Table 1):
  - Discretized 2nd time order, space orders of 2, 8, and 16;
  - Grid sizes: 256, 512, and 1024 points with 400, 800, and 1600 time steps;
  - Float precision FP32, and FP64;
- Four strategies: collapse, unroll, tile, and tile+unroll. For tiling, best block shapes were obtained via auto-tuning.

Performance gains ranged from 1.13x to 2.93x. In most scenarios, the best performance was achieved by combining unroll and tiling.

The performance of tiling is highly sensitive to the choice of block size.