Asynchronous OpenCL/MPI Discontinuous Galerkin Solver for Conservation laws

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We consider the following general form of hyperbolic conservation laws for an unknown vector $W(x,t) \in \mathbb{R}^m$ that depends on a space variable $x = (x^1 \ldots x^d)$, $d = 2$ or $3$, and time $t$ according to

$$\partial_t W + \sum_{k=1}^{k=d} \partial_k F^k(W) = S,$$

with the usual notations $\partial_t = \partial / \partial t$ and $\partial_k = \partial / \partial x^k$. In equation (1), functions $F^k(W)$ and $S$ characterize the physical model and we classically define the flux of the system by $F^k(W) n_k$ for space vector $n = (n_1 \ldots n_d) \in \mathbb{R}^d$. This very general mathematical framework can be applied to electromagnetism, fluid mechanics, multiphase flows, magneto-hydro-dynamics, Vlasov plasmas, etc.

We consider a mesh of the computational domain $\Omega$. In each mesh cell $L$, we approximate the field by a linear combination of basis functions $\psi^L_i$,

$$W(x,t) = W^L_i(t) \psi^L_i(x), \quad x \in L,$$

and apply the Discontinuous Galerkin (DG) approximation,

$$\forall L, \forall i \int_L \partial_t W \psi^L_i - \int_L F(W,W,\nabla \psi^L_i) + \int_{\partial L} F(W_L,W_R,n_{LR}) \psi^L_i = 0,$$

where $R$ is the neighbour cells along $\partial L$, $n_{LR}$ the unit normal vector on $\partial L$ oriented from $L$ to $R$, and $F(W_L,W_R,n)$ is the numerical flux, which satisfies $F(W,W,n) = F^k(W)n_k$. The DG methods is well-suited for parallel computing on GPU (Graphic Processing Units): it requires a large amount of uniform and simple computations, relies on explicit time-integration, and can be formulated to present a regular and local data access pattern.

In this work, we explain how we have implemented a general DG method for multi-GPU computations with the OpenCL and MPI libraries in order to achieve high efficiency. We also explain how the basis is essentially built on Gauss-Legendre or Gauss-Lobatto points by tensor products of one-dimensional Lagrange polynomials. We thus have nice interpolation property and obtain a nodal basis [2].

Our choice of basis functions allows for several standard optimizations such as local memory prefetching, exploitation of the sparse nature of the tensor basis [1], etc. The implementation relies on a splitting of the DG mesh into sub-domains and sub-zones. We rely on the OpenCL asynchronous task graph in order to overlap OpenCL computations, memory transfers and MPI communications.

Références


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