AMG preconditioning using a Stencil-CSR matrix format on GPUs

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We present a hybrid sparse matrix format for exploiting the structure typical of discretized partial differential equations (PDEs) with piecewise-constant coefficients. This hybrid format combines a "stencil" representation for blocks of matrix rows corresponding to regions with constant coefficients (which become "stencil-structured regions" in the new format) with the general-purpose Compressed Sparse Rows (CSR) representation for the domain boundary and inter-region frontiers.

This hybrid format is suited for multigrid preconditioners harnessing GPU acceleration. Indeed, the stencil representation enables spatial blocking, provides a speed-up over a pure CSR format on the GPU, and requires significantly less memory usage. Moreover, highly regular multigrid coarsening patterns can be used inside stencil-structured regions. The coarser grid matrix can then be computed directly in the new format, reducing the algebraic multigrid (AMG) preconditioner set-up cost in comparison with a pure CSR approach.

An implementation of this AMG method is compared with AmgX, a CSR-based GPU-accelerated solver from NVIDIA. Results suggest that for large enough problems (more than 1 million unknowns) with adequate structure, exploiting the hybrid stencil-CSR format allows for significantly better performance, in terms of both run time to solution and memory usage.

References:

[1] S. Boukhris, A. Napov and Y. Notay. Algebraic multigrid using a stencil-CSR hybrid format on GPUs. Technical report GANMN 22-01. 2022. Available at https://www.agmg.eu/YvanNotay/PDF/ganmn2201.pdf

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