Parallel Three-Dimensional Constrained Delaunay Meshing

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ABSTRACT

The ability to generate meshes in parallel is critical for the scalability of the entire finite element solution and adaptation pipeline. There is a range of parallel meshing algorithms that can be classified by the degree of coupling between the sub-problems. Here coupling refers to the amount of communication and synchronization needed to enforce compatibility between adjacent sub-meshes processed concurrently by multiple threads or processes. Tightly coupled parallel meshing algorithms require a large amount of communication overheads, but allow for low decomposition costs and complexity. On the other hand, loosely coupled algorithms benefit from low, and often asynchronous, communication, but the proper domain decomposition and interface refinement are challenging problems.

Delaunay refinement is an appropriate sequential method for use in a parallel meshing algorithm because it allows for mathematical guarantees on the termination and on the properties of the resulting meshes. These guarantees together with a matching design and analysis of a parallel algorithm lead to a robust implementation that can be run reliably on expensive massively parallel platforms. The constrained Delaunay algorithm presented here is a weakly coupled approach consisting of three main steps: (1) construction of sub-domain interfaces, (2) concurrent initial meshing of the interiors of the sub-domains, (3) concurrent refinement of the sub-domains, which includes communication along the interfaces, to achieve the required mesh quality. The first step is out of the scope of this work, as we rely on an external domain decomposition solution [1]. The second step is quickly performed without communication by a sequential meshing algorithm, e.g., Tetgen [2]. Most of the computation and communication is performed in the third step.

Our previous work on two-dimensional parallel constrained Delaunay meshing [3] does not directly generalize to three dimensions because asynchronous vertex insertion on three-dimensional interface surfaces does not generally converge to a globally conforming mesh. We present our three-dimensional algorithm and its experimental evaluation. We show that our distributed communication protocol allows for guaranteeing the consistency of interfaces, and for overlapping computation with communication. We mathematically prove the properties of our protocol such as the termination, and the bounds on the number of messages. Our future work includes the integration of this algorithm with a more tightly coupled parallel meshing algorithm in order to leverage the modern hierarchical supercomputing platforms due to their variability in communication and data access costs at the hardware levels.

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