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Toward An Unstructured Mesh Database

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Unstructured meshes are used in several application domains such as earth sciences (e.g., seismology), medicine, oceanography, climate modeling, GIS as approximate representations of physical objects. Meshes subdivide a domain into smaller geometric elements (called cells) which are glued together by incidence relationships. The subdivision of a domain allows computational manipulation of complicated physical structures. For instance, seismologists model earthquakes using elastic wave propagation solvers on hexahedral meshes. The hexahedral contains several hundred millions of grid points and millions of hexahedral cells. Each vertex node in the hexahedrals stores a multitude of data fields. To run simulation on such meshes, one needs to iterate over all the cells, iterate over incident cells to a given cell, retrieve coordinates of cells, assign data values to cells, etc.
Although meshes are used in many application domains, to the best of our knowledge there is no database vendor that support unstructured mesh features. Currently, the main tool for querying and manipulating unstructured meshes are mesh libraries, e.g., CGAL and GRAL. Mesh libraries are dedicated libraries which includes mesh algorithms and can be run on mesh representations. The libraries do not scale with dataset size, do not have declarative query language, and need deep C++ knowledge for query implementations. Furthermore, due to high coupling between the implementations and input file structure, the implementations are less reusable and costly to maintain.
A dedicated mesh database offers the following advantages: 1) declarative querying, 2) ease of maintenance, 3) hiding mesh storage structure from applications, and 4) transparent query optimization. To design a mesh database, the first challenge is to define a suitable generic data model for unstructured meshes. We proposed ImG-Complexes data model as a generic topological mesh data model which extends incidence graph model to multi-incidence relationships. We instrument ImG model with sets of optional and application-specific constraints which can be used to check validity of meshes for a specific class of object such as manifold, pseudo-manifold, and simplicial manifold. We conducted experiments to measure the performance of the graph database solution in processing mesh queries and compare it with GrAL mesh library and PostgreSQL database on synthetic and real mesh datasets. The experiments show that each system perform well on specific types of mesh queries, e.g., graph databases perform well on global path-intensive queries. In the future, we investigate database operations for the ImG model and design a mesh query language.