An optimization based approach to large scale flow simulation in fractured media

Sandra Pieraccini*, joint work with S. Berrone* and S. Scialò*

The simulation of flows in fractured media is a challenging issue relevant in several critical applications (Oil&Gas enhanced production, geothermal applications...). We consider in this context the Discrete Fracture Network (DFN) models. DFNs are given by a (possibly large) number of planar polygons in the 3D space, stochastically distributed, resembling the fractures in the underground. The quantity of interest is the flow potential, called hydraulic head. The flow on each fracture is ruled by the Darcy law, and flux exchange among fractures occurs through fracture intersections. Suitable matching conditions are therefore imposed at fracture intersections in order to ensure continuity of the hydraulic head and flux balance. These matching conditions strongly couple the local equations defined on the fractures. Common issues to be tackled are the complexity of the domain and the huge computational cost. Indeed, very large scale problems are encountered, when performing simulations at basin scale, since the number of fractures involved may realistically count even 10^6 fractures. Furthermore, one of the major complexities related to standard approaches is the construction of good quality computing grids on the fractures for the underlying space discretization. Indeed, if some mesh conformity is required along traces intersection, the meshing process may result in a excessively fine, poor quality mesh, or it may even result infeasible.

In recent work, we proposed a novel approach for flow simulations on arbitrary DFNs based on a PDE-constrained optimization reformulation of the problem. The proposed approach aims at allowing the use of non-conforming grids, thus facilitating the meshing process. The exact fulfillment of the matching conditions at fracture intersections is replaced by the minimization of a properly defined functional. The minimization process is constrained by the local state equations. After a suitable space discretization, the overall problem is reformulated as a quadratic programming problem with linear equality constraints. Within such reformulation, we are able to mesh each fracture independently of the other fractures, thus totally circumventing any problem in the mesh generation. Furthermore, the method is naturally conceived in a fracture-oriented way, and decoupled computations on the fractures are envisaged.

Due to the very large scales encountered, iterative solvers and related preconditioning issues are a must, and parallel computing is in order. Focusing on the linear algebra issues related to the method, we will discuss robustness and efficiency of the approach on realistic DFNs, with a large heterogeneity in fracture dimensions, distance, and angles formed by fracture intersections. Scalability performances of a tailored parallel implementation will be also discussed.

*Politecnico di Torino, Corso Duca Degli Abruzzi, 24, 10129 Torino, Italy