DFM Generator v2.2: a new method for simulating the growth of natural fracture networks

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Summary

Dynamic Fracture Model Generator (DFM Generator) is a new code to build geologically realistic models of natural fracture networks in geological formations, by simulating the processes of fracture nucleation, growth and interaction, based on geomechanical principles and the geological history of the formation. It implements the algorithm described in Welch et al. (2020), which was developed to generate more accurate, better constrained models of large fracture networks across large (km-scale) geological structures such as folds, major faults or salt diapirs.

Statement of Need

Natural fracture networks in geological formations can control various physical properties and processes such as mechanical strength, elastic stiffness, seismic response, and subsurface fluid flow. The fracture networks may be related to larger geological structures such as folds, major faults and salt diapirs. An ability to model such networks is therefore important in applications such as geological hazard prediction, monitoring pollutant dispersion and CO_2 sequestration.
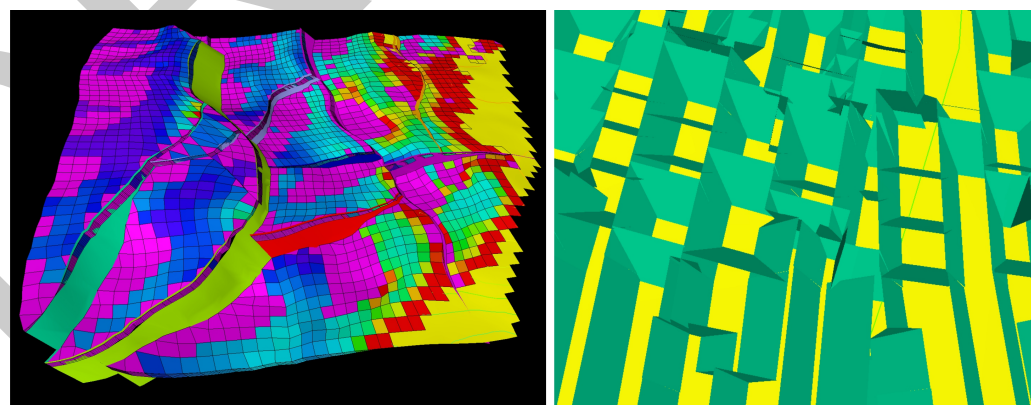

Figure 1: Figure 1: Comparison of an implicit fracture model (left) and an explicit DFN model (right). In the implicit fracture model, fracture density (defined as total fracture area per unit volume) is a continuum property in a grid of discrete cells. In the explicit DFN, individual fractures are represented as geometric objects. While the fracture density can be calculated from the DFN, it also contains other valuable information such as mean fracture length, fracture orientation and connectivity.

Fracture models may be of two types (Figure 1):

21 ▪ Implicit models, where the fracture network is represented by laterally variable continuum
22 properties such as fracture density.

23 ▪ Explicit Discrete Fracture Network (DFN) models, where individual fractures are repre-
24 sented as geometric objects.

25 It is not usually possible to map fractures in the subsurface directly, as they are below the
26 resolution of geophysical imaging techniques. The traditional solution to this problem has
27 been to build stochastic fracture models, in which fractures are placed at random locations
28 and given arbitrary sizes, the only constraint being to match observed fracture densities and
29 orientations from boreholes. However this method takes no account of the geology or the
30 geomechanical processes of fracture formation, and thus often results in inaccurate, poorly
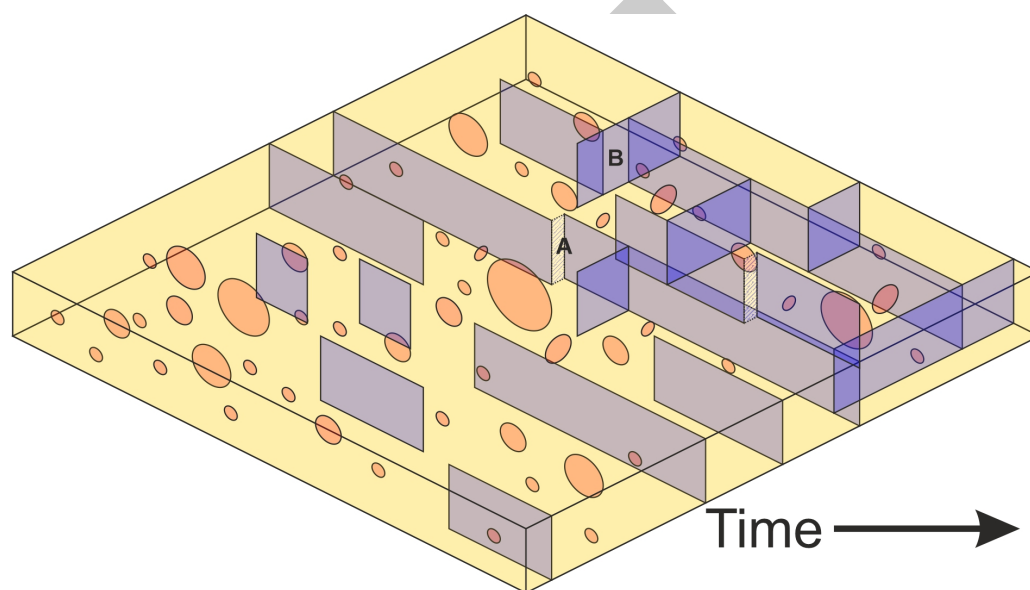31 constrained and geologically unrealistic models.

Figure 2: Figure 2: Schematic illustration showing the growth of a layer-bound fracture network. Initially, small circular microfractures develop within the layer (shown in red). These grow until they reach the top and bottom of the layer, whereupon they become layer-bound macrofractures, propagating laterally (shown in blue). These continue to grow until they terminate, either because they propagate into the stress shadow of a parallel microfracture (A) or because they intersect a perpendicular or oblique microfracture (B). Reproduced with kind permission from Fig. 2.2 of Welch et al. (2020).

32 To solve these problems, Welch et al. (2019) and Welch et al. (2020) developed a new
33 algorithm for building realistic models of layer-bound fracture networks by simulating the
34 nucleation, growth and interaction of fractures dynamically, based on geomechanical principles
35 and an understanding of the geological history of the structure. This algorithm combines linear
36 elastic fracture mechanics theory (Griffith, 1921; Sack, 1946; Sneddon, 1946) with subcritical
37 fracture propagation theory (Atkinson, 1984; Swanson, 1984) to calculate the rate of growth
38 of either circular or layer-bound fractures, in response to an applied strain (Figure 2). Unlike
39 conventional numerical modelling techniques, the new algorithm can efficiently model large
40 fracture networks across major geological structures. It can build explicit DFNs containing
41 hundreds of thousands of fractures in a reasonable runtime, but it can also build implicit
42 fracture models directly, with no limit to the number of fractures.

43 Building a fracture model dynamically in this way has advantages over conventional stochastic
44 techniques in terms of accuracy, insights gained, ease of use and uncertainty analysis. The
45 resulting model will more accurately reflect the underlying geology, and will predict properties,
46 such as fracture size distribution and permeability anisotropy, that must be supplied as input

properties in stochastic models. Furthermore, deterministic models are much quicker and easier to build than stochastic models. It is also easy to generate multiple realisations, representing different stages of fracture development, that can be used in uncertainty analysis.

Validation and application

DFM Generator has been validated by running simulations of actual fractured layers in outcrops and in the subsurface, and comparing the results with observed fracture patterns (Welch et al., 2019, 2020).

The main research applications are:

- To study the influence of various mechanical and physical parameters on the evolution and geometry of natural fracture networks.
- To generate fracture models for studying subsurface processes, such as in situ stress, rock failure and fluid flow.

Code availability

The code is provided with two interfaces:

- A standalone interface with text file input and output, that can be compiled in standard C Sharp for running simple models.
- A plug-in interface for the Petrel geomodelling package from Schlumberger, for running more complex models of real geological structures.

Both source and compiled code is available to download, along with documentation and user manuals, at https://github.com/JointFlow/DFMGenerator. The current release is v2.2.2.

Acknowledgements

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