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DISCRETE MECHANICAL MODELS AND UPSCALING TECHNIQUES FOR DISCRETE MATERIALS

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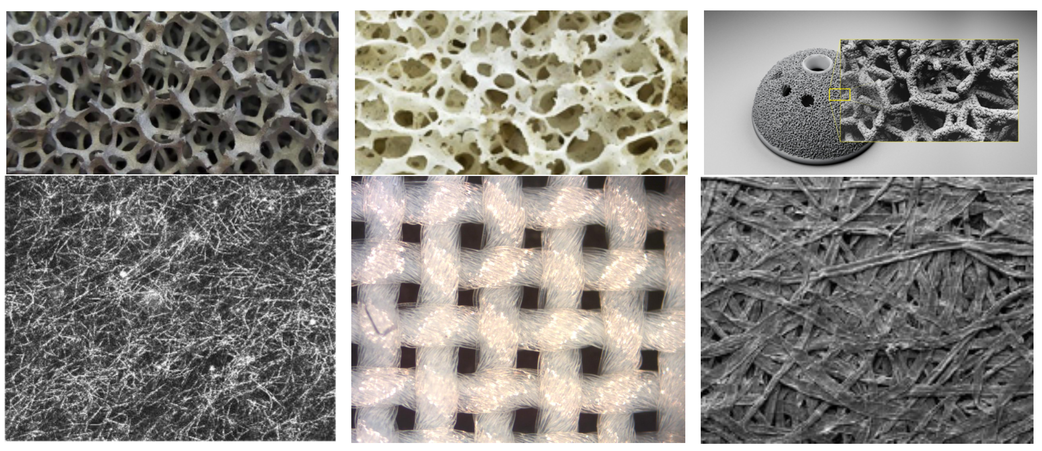
DISCRETE MATERIALS

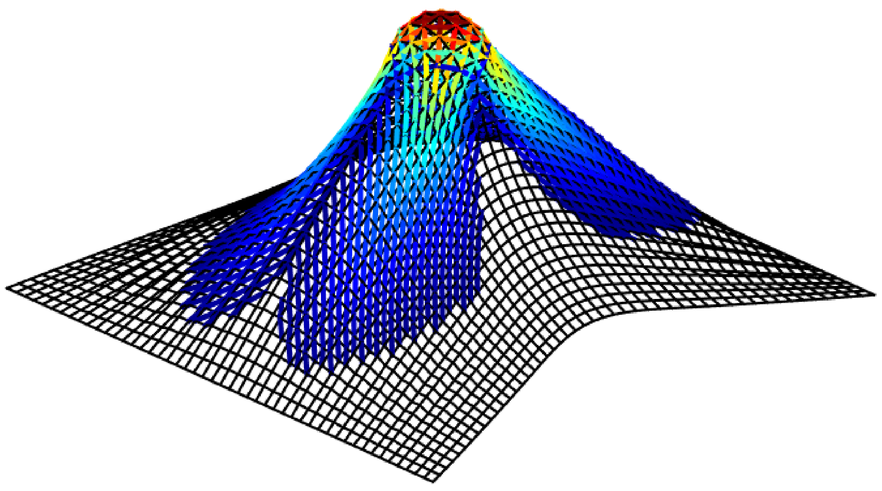
Numerous natural and man-made materials are essentially discrete structures at the mesoscale or microscale (see Fig. 1). Discrete mechanical models can be formulated to capture typical mechanical phenomena arising from this discreteness. Failure in these materials, which often starts with the fracture of an individual bond, can be predicted based on the small-scale mechanics with these models. For failure, but also for non-local mechanics, no phenomenological descriptions are required in these models. This makes them more predictive than constitutive material models for this type of materials.

FIGURE 1



Some discrete materials. Clockwise, starting top-left: metal foam, bone, printed metal structure, collagen, woven fabric, paper material.

FIGURE 2



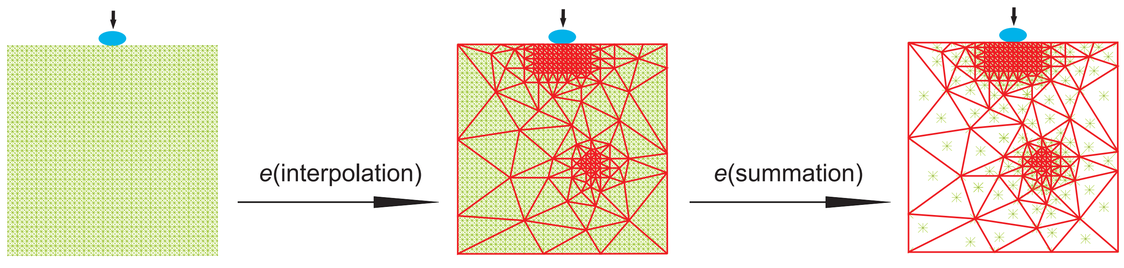
The strains of the diagonal springs that contribute, as predicted by a discrete mechanical model for a woven fabric exposed to punching.

COMPUTATIONAL COSTS

These models however also come with an important disadvantage. The computational costs are prohibitively expensive for simulations of physically relevant applications. The typical length scale in most computations of applications is on the order of centimeters to meters after all, whereas the typical length scale of the discreteness in these materials ranges from micrometers to millimeters. Consequently, these computations are characterized by:

- large numbers of degrees of freedom, and
- equally large numbers of integration points that need to be visited to construct the governing equations.

FIGURE 3



The two reduction steps of the QC method: interpolation and reduced-integration/ summation/sampling. The crux is how to apply both steps such that the resulting error remains acceptable.

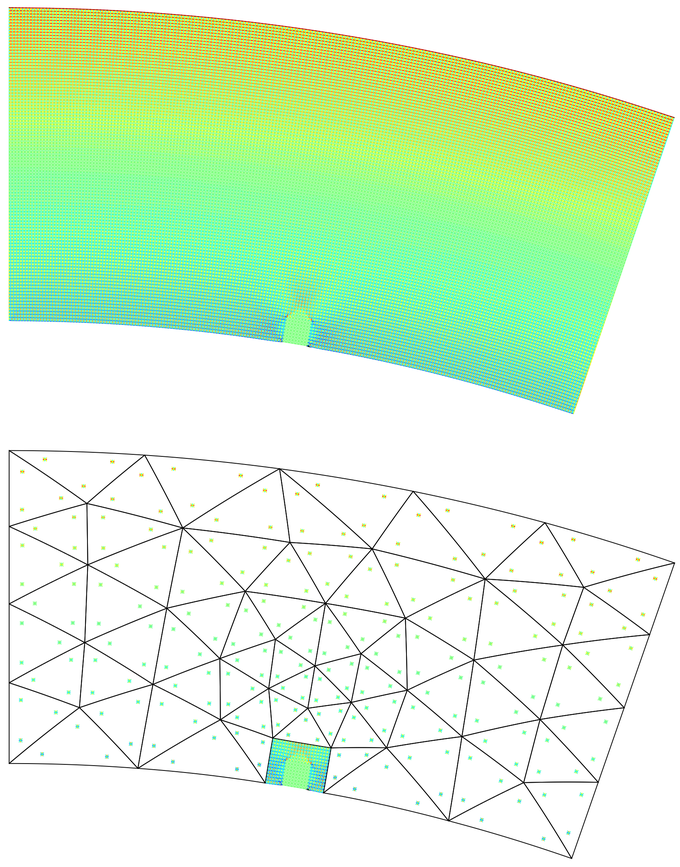
UPSCALING TECHNIQUES

These two causes of excessive computational costs can be resolved by two reduction steps:

- interpolating the original degrees of freedom (avoiding large numbers of degrees of freedom), and
- sampling only a few of the original integration points (avoiding large numbers of integration points).

Several numerical techniques in computational mechanics can be distinguished that directly, or indirectly, achieve these two reduction steps. Computational homogenisation schemes (e.g. FE^2 frameworks) effectively achieves this. Reduced order modelling schemes (e.g. based on proper-orthogonal-decomposition) with reduced integration schemes achieve this (i.e. hyperreduction). The main approach employed here however is the quasicontinuum (QC) method (see Fig. 3 & 4) (Tadmor, Phillips, and Ortiz, 1996). It was originally aimed at conservative atomistics (springs), but we have generalised it so it can be used for beam and spring models that include dissipation (e.g. plasticity, fibre-to-fibre failure and frictional fibre-to-fibre sliding) (Beex, Peerlings, and Geers, 2011; Beex, Peerlings, and Geers, 2014a; Beex, Peerlings, and Geers, 2014b; Beex, Peerlings, and Geers, 2014c; Beex, Kerfriden, et al., 2014d; Beex, Rokos, et al., 2015). If you want to know more, do not hesitate to talk to me!

FIGURE 4



The strains predicted by a direct numerical simulation of an elastoplastic lattice (top) and those predicted by an associated QC computation (bottom).

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