An equation-free, nested, concurrent multiscale approach without scale-separation

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Nested multiscale approaches based on computational homogenisation rely on the appropriate coupling between macroscale finite elements (FEs) and microscale representative volume elements (RVEs). This involves applying the average macroscale deformation appropriately to the microscale RVEs, for instance by using periodic boundary conditions. It also involves extracting the average microscale stress and sending it back to the macroscale FEs. For linear macroscale FEs the formulation and implementation are not particularly complex, but they become involved if higher-order macroscale FEs are used. The reason is that then not only the macroscale deformation and the average microscale stress must not be transferred between the scales, but also their spatial gradients. Another disadvantage is that scale-separation must hold, which makes the approach computationally expensive if used concurrently (i.e. by using the microscale model in a part of the domain, whilst coarse-graining the remainder).

In this talk, a new multiscale approach is presented that does not rely on macro-to-micro and macro-to-micro relations. This makes its implementation relatively straightforward. It also makes the implementation and formulation as straightforward for linear macroscale FEs as for higher-order macroscale FEs (we show examples for cubic macroscale FEs which are never been used for multiscale approaches based on computational homogenisation to the best of our knowledge). Scale-separation is also not required to hold. This has the advantage that a gradual transition of macroscale FEs towards regions in which the microscale model is fully resolved can be obtained, entailing a reduction of the computational costs compared to approaches based on homogenisation.

These two important advantages are not for free, as their price is paid by additional computational costs in coarse-grained regions, relative to approaches based on computational homogenisation. First, the number of degrees of freedom (DOFs) is considerably higher, because many microscale DOFs appear in the macroscale computation. Second, the number of RVEs that must be considered per macroscale FE is larger than for traditional multiscale approaches based on computational homogenisation. Consequently, the approach is particularly useful if, (i) scale-separation does not hold (in a part of the domain or in the entire domain), (ii) the microscale model needs to be fully resolved in a part of the domain (which is strongly related to point (i)), and/or (iii) if higher-order macroscale FEs are required.

The presentation starts with an explanation of the approach by considering a string of 20 springs and finishes with a network of more than 80M beams and 233M DOFs.