Multiscale approaches for material science in a nutshell

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The description of the rich thermomechanical behavior of soft matter has been an outstanding challenge for many decades, from both theoretical and technological points of view. The advent of new experimental techniques has allowed for a deep understanding of the phenomena underlying the response of soft matter to stimuli, down to the molecular scale. This research effort has resulted in modeling the macroscopic response by a complex mechanism of energy exchanges among the different scales involved. Achieving this understanding, especially when it comes to the high performance of biological materials which is not always matched by artificial materials, has led to the emergence of new materials, with clever designs, possibly hierarchical. High thermomechanical performances have then been attained, especially in the field of bioinspired materials, even when the base materials exhibit a standard mechanical response.

From a theoretical point of view, the need for new theories showing how low-scale material and topological properties result in a homogenized, macroscopic material response was a driving force for a *reformulation of the classical theories of continuum mechanics*, with emphasis on microstructure and on multiscale approaches. Based on this description and on the classical multiscale approaches of rubber-like elasticity, a new successful impetus emerged for a synergic investigation between equilibrium and non-equilibrium statistical mechanics and kinetic theories at the lower scales, and the mathematical theory of non-linear elasticity.

1. Hierarchical biological materials and bioinspired examples
2. Classical single molecules models based on Statistical Mechanics approach
3. Discrete models with non-convex energies: mechanics and temperature effects. Some explicit examples.
4. A classical network model for rubberlike elasticity: extended affinity hypothesis
5. Some examples of multiscale modeling: protein based materials