Programming Mechanical Metamaterials: Topological states of matter as a design principle

Abstract: Mechanical metamaterials have novel elastic and acoustic properties--negative Poisson's ratios and compressibilities, phononic bandgaps, bistability and acoustic lensing--which derive from their structure. Properties may be made robust by linking them to the system's topological state, in which the global structure determines and protects a particular mechanical response, equivalent to the behavior of electronic systems such as topological insulators. Topologically nontrivial states may be achieved in virtually any marginally rigid (isostatic) structure and at any scale: hinged frames, jammed packings, 3D-printed structures, origami/kirigami, self-assembled lattices and oscillator networks.

The immediate effect of topologically polarizing such a system is to create protected floppy edge modes. The ultimate goal is to manufacture systems with arbitrary programmed mechanical responses that are robust against disorder and fluctuations. I will describe two recent advances: (1) Creating materials with bulk topological modes and (2) Exploiting global mechanical instabilities to alter the topological state. In the first case, I describe lattices (the equivalent of Weyl semimetals) that possess topologically-protected bulk zero modes, leading to a sinusoidal elastic instability at incommensurate wavelength. In the second case, I consider systems with global elastic instabilities and show that the nature of such an instability determines much of the lattice's mechanical and acoustic properties, such as the structure of its edge modes. Finally, I show that extending this instability into the nonlinear regime can alter the topological polarization, hence tuning the edge stiffness by many orders of magnitude.

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