Many fundamental cellular processes require exquisitely orchestrated large-scale reorganization of structural filaments. One mechanism of reorganization is via internal forces generated by motor proteins. The transmission of these forces is mediated by a highly non-linear network of fiber-like filaments. To understand the role of buckling and failure in such networks, we examine a model nonlinear elastic network subjected to an internal force dipole. Such networks exhibit non-monotonic elastic deformation in response to the applied force. We observe a transition from linear and non-linear extensility to global contractile behavior. We demonstrate this emergence of contractile behavior is associated with a large-scale transformation of the underlying lattice structure. These results recapitulate observations of active microtubule/actin gels which transition from extensile flows to global contraction [J. Berezney et. al., arXiv 2110.00166]. This work underscores the importance of cytoskeletal networks and metamaterials whose failure modes and nonlinear mechanics can be engineered to generate complex and adaptive large-scale phenomena.

**ABSTRACT**

Self-organized buckling patterns underlie transition from macroscopic extension to contraction in active nonlinear elastic networks

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**THEORETICAL MODEL**

\[ H = \frac{1}{2} \sum_{\text{bond}(ij)} F_{\text{bond}}(ij)^2 + \sum_{\text{angle}(ijk)} \frac{\kappa}{2} \sin^2 \frac{\theta_{ijk}}{2} + \sum_{\text{force}(i)} F_i \cdot r_i \]

\[ \sigma_{ij}(x, y) = G_{ij}(x, y) f \]

\[ \frac{\partial \sigma_{ij}}{\partial t} = -f_i^{\text{eff}} \]

**SELF-ORGANIZED BUCKLING PATTERNS**

Fig. 1: Schematic of non-linear spring network.

Fig. 2: (Ronceray et. al., PNAS, 2016) Far-field dipole response shows contractile behavior for local extensile dipole.

Fig. 3: Rectification observed in our simulation where far-field stress is measured using the following formula.

**SPATIAL STRESS PATTERN**

Spatial pattern of the three independent components and trace of stress tensor in a linear-spring network (no buckling).

A linear network is characterized by isotropic elastic modulus described completely by two Lamé parameters. 

\[ \lambda = G = \frac{\sqrt{\mu}}{8} \]

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