Elastic Mechanical Cellular Automata

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Abstract

Cellular automata are computational frameworks known for their ability to model complex behaviors through simple, discrete rules. These systems consist of unit-cells, each in an 'on' or 'off' state, with states evolving each input cycle based on local interactions with neighboring cells. Elementary Cellular Automata (ECA), a subclass of one-dimensional arrays, are particularly notable for their simplicity and diverse behavior. Translating these rules into mechanical systems presents a novel approach to physical computation. However, developing a scalable and adaptable mechanical framework for accurately implementing ECA rules, such as rule 110, remains a challenge. Here, we present a general framework for realizing elastic mechanical metamaterials representing ECAs using a unified unit-cell design. Each unit-cell uses a bi-threshold logic gate, achieved through a tri-stable mechanism that governs its 'on' and 'off' states, while nonlinear springs handle the interactions between cells, transmitting forces based on the unit-cell's state and its neighbors. By adjusting the stiffness of these springs, different computational rules from ECA can be executed. Our framework provides design instructions for the ECA rules, and enables scalability by simply adding more unit-cells to increase computational capacity. The ability to dynamically modify spring stiffness in situ offers further flexibility, allowing for real-time changes in computation. By harnessing elastic mechanical structures, these mechanical ECAs open new possibilities for embedding computation into materials, paving the way for innovations in self-regulating rule-based systems.

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