

Metamaterial Performs Computations in a New Way

A mechanical network of flexible links can be designed to solve a problem in matrix algebra.

By **David Ehrenstein**

A research team has developed a triangular mechanical network that can squeeze and wiggle in a multitude of preprogrammed ways [1]. The metamaterial design—realized in experiments with various materials, including Legos—may have applications from shock absorption to protein modeling. But the researchers also demonstrated that their structures can solve problems in matrix algebra. Performing computations in materials without converting

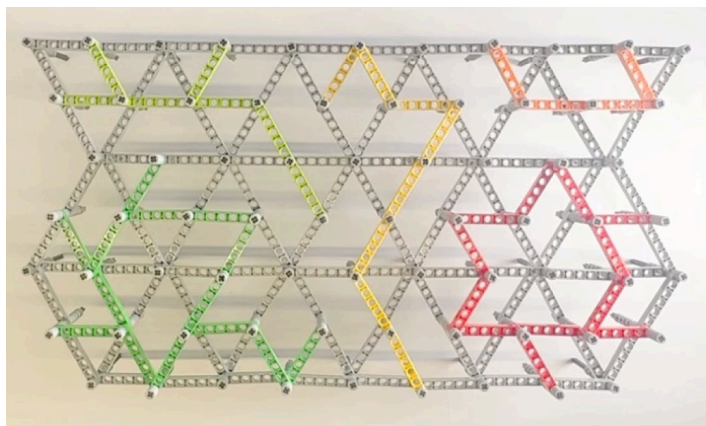
information to electrical signals could be useful when durability and energy efficiency are more important than computing power, for example, in components of some soft robots.

Recent work showed that a mechanical system can perform similar computations [2]. However, this previous demonstration was limited in the number of inputs and outputs that it could accommodate, says Yair Shokef of Tel Aviv University in Israel. It also had rather large components that made it difficult to adapt to different applications.

Shokef and his colleagues, who produced the latest demonstration, built their 2D networks from equilateral triangles. Each triangle consisted of rigid beams with hinge points at each vertex and at the center of each side, for a total of three so-called corner nodes and three edge nodes per triangle. Importantly, each triangle had one or two “bonds”—beams that connected edge nodes and that determined the ways in which the triangle could be distorted or flexed.

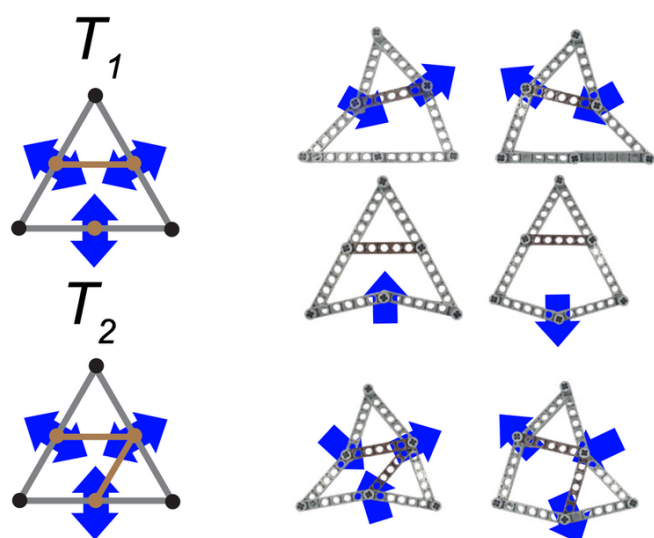
The targeted math problem was the product of a 2D vector and a 2×2 matrix. To perform this computation, the researchers 3D printed a hexagonal network from a rubbery polymer and used narrow diamond shapes for the rigid elements. The edge nodes of this network served as the inputs and outputs of the calculation.

To start a computation, the team displaced two adjacent edge nodes by distances whose values in millimeters corresponded to the x and y components of the input vector. These displacements then propagated through the network, which acted as the matrix by inducing shifts of internal elements according to the chosen bond structure and topology. The



Each triangle in the Lego network includes one or two internal “bonds” that connect two sides of the triangle, and they determine the ways in which the triangle can flex (see figure below). Some bond configurations are “floppy,” allowing a displacement to propagate through the network (light green, dark green, yellow, and orange). Other bond configurations are “frustrated” in that they resist displacement (red). Both of these configurations were used for matrix multiplication demonstrations. (Video is sped up by 2 times.)

Credit: W. Liu *et al.* [1]

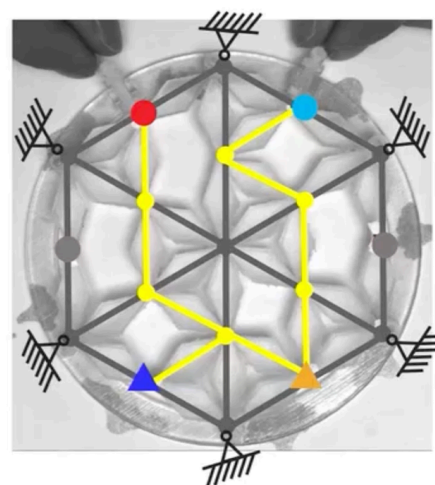


Acute stress. Each triangular building block in these networks has either one internal bond (T_1) or two internal bonds (T_2). These bonds determine how it flexes.

Credit: W. Liu *et al.* [1]

output of the calculation was measured at the opposite end of the hexagon, where the displacements of two edge nodes represented the components of the product vector.

The team showed that the technique can be generalized to larger numbers of inputs and outputs and to higher dimensional matrices. Shokef says that such additional capability would eventually allow the researchers to integrate computation into so-called adaptive materials. These materials “could perform the basic computations that are necessary to adjust themselves to certain cues from the outside and even to progressively learn to adapt to changing environmental perturbations,” he says. To get there, researchers will need to integrate the computing with material properties such as stiffness and shape morphing.



This mechanical computation network is made of elongated-diamond-shaped beams of a rubbery polymer, and each vertex of the hexagon is fixed in place. To compute the product of a matrix and a time-dependent vector, the researchers push and pull “input” nodes x (red) and y (light blue) for about ten seconds and simultaneously measure the resulting displacements at “output” nodes u (dark blue) and v (yellow). α represents the factor by which the displacement diminishes with each bond-to-bond connection.

Credit: W. Liu *et al.* [1]

David Ehrenstein is a Senior Editor for *Physics Magazine*.

REFERENCES

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2. T. Louvet *et al.*, “Reprogrammable, in-materia matrix-vector multiplication with floppy modes,” *Adv. Intell. Syst.* **7**, 2500062 (2025).