Materials science

Snappy data storage

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A device has been developed that consists of mechanical bits, analogous to the magnetic bits used in computer hard drives. Information encoded in the bits programs the mechanical properties of the device. See p.386

Digital memory systems are an integral part of computers — for example, hard drives are used to write and read data that are stored magnetically. On page 386, Chen *et al.*[1] report a device in which mechanically encoded information can be written, stored permanently and retrieved at will. Moreover, the encoded information determines the mechanical properties of the device. Just as hard drives revolutionized computer systems, devices such as this could open the door to the next generation of soft robots and engineering materials, or to any application in which it would be useful to program the mechanical properties of a device remotely.

The building block of a hard drive is a magnetic bit, which has a value of 1 when it is magnetized in one direction and 0 when it is magnetized in the other. The value of a bit can be switched by an external electromechanical head to write new information. Conversely, the value of the bit can be retrieved by the same head to read the information. Such a system allows for non-volatile storage of information: even if the device has been switched off for several years, the information will be preserved.

The device developed by Chen *et al.* works on a similar principle, except for two key differences. First, the bits are not magnetic, but mechanical, and are made out of a shell that can undergo a snapping instability. In these instabilities, the curvature of a shell abruptly changes and the shell snaps from one stable state to another (Fig. 1a, b). Such instabilities are avoided at all costs in the design of large engineering structures such as silos, aircraft and rockets[2]. By contrast, they constitute the functional mechanisms of various soft structures[2], ranging from toys[3] to soft robotic devices[4], advanced materials[5,6] and even to the snapping leaves of venus flytraps[7]. Chen and colleagues designed their mechanical bits so that the two configurations of the shell are stable and the snapping can be controlled remotely by an external magnetic field, thus enabling reading and writing.

> **“The authors’ device is a noteworthy addition to the metamaterial toolbox.”**

The second difference between Chen and colleagues’ device and hard drives is that the states of the mechanical bits alter the overall mechanical properties of the device — in which the bits are arranged in a 6 × 6 two-dimensional array (Fig. 1c). Flexible elements in the bits, other than the shell, are designed so that the two states have starkly contrasting mechanical properties under pressure. The set of states encoded by the array therefore determines how hard it is to compress the device, and how much energy it can store.

Chen and colleagues’ device is an example of a metamaterial — a material that consists of engineered subunits, and which has properties not found in naturally occurring materials. Over the past few years, metamaterials have proved to be invaluable model systems for probing the frontiers of modern physics — for example, in the study of magnetic materials known as spin ices[8] and of exotic ‘topological’ phases of matter[9]. They are also potential game-changers for a wide range of high-tech applications[10], from prosthetics to aerospace applications.

But until now, the use of metamaterials to store and retrieve non-volatile memory has been an elusive goal. Previously reported work had shown that mechanical bits can be used to control mechanical properties[7], or that the state of mechanical bits can be switched remotely using magnetic fields[11], but no study had demonstrated both of these features in the same metamaterial. Chen and colleagues’ device is therefore a noteworthy addition to the metamaterial toolbox, potentially pointing the way to a variety of engineering applications that require on-the-fly control of stiffness and energy density — from the soles of orthopaedic shoes, to shock and vibration absorbers. The authors’ findings might also

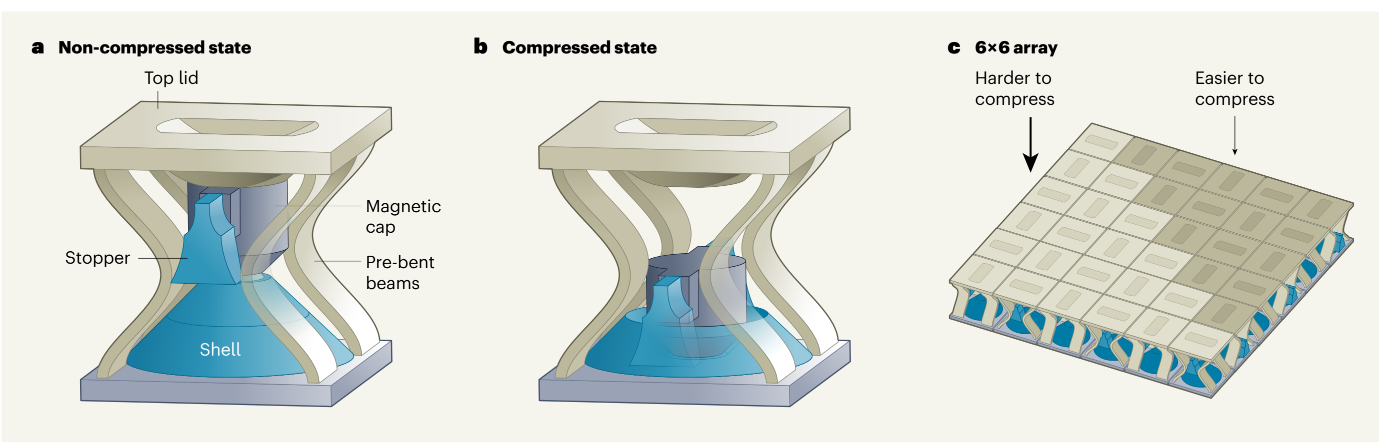

Figure 1 | A programmable metamaterial. a, **b**, Chen *et al.*[1] report the design of mechanical bits, devices in which a shell ‘snaps’ between two stable states of opposite curvature in response to an external magnetic field — analogous to the magnetic bits used in computer memory. A magnetic cap in the mechanical bits drives the snapping process. Four pre-bent beams and two stoppers (one of which is visible here) ensure a stark contrast in the compressibility of the bits in the two states: in the non-compressed state, the stoppers touch the beams, preventing further bending of the beams and stiffening the structure. **c**, The authors constructed a metamaterial consisting of a 6 × 6 array of the bits. The pattern of states encoded by the array can be programmed by an electromagnetic head (not shown), and determines the overall compressibility of the metamaterial: here, one section of the material is easier to compress than the other.

open up fresh avenues of research for the design of active metamaterials[12] (in which energy taken up by subunits translates into emergent, large-scale behaviour) that have a low-energy footprint.

Several limitations to Chen and co-workers' system present challenges and opportunities for future work. The mechanical bits have a complex geometry and need to be made from soft materials that exhibit ferromagnetism – the 'conventional' type of magnetism found in iron magnets. Moreover, the system contains only 36 bits and is about 20 cm × 20 cm × 3 cm in size. For practical applications, it would need to be miniaturized, transformed into a 3D system and fabricated on a large scale, but the paths towards these goals remain unclear. The current work also focuses on controlling the two most basic properties of materials: stiffness and energy density. Future work could explore ways of controlling myriad other effects, including wave propagation[9], energy dissipation and more-complex forms of deformation, such as changes of texture[8] or twisting motion[13].

The earliest computers were mechanical. Is it therefore a bad idea to go against historical trends by bringing features of computers, such as memory, back into mechanical systems? Not at all. In computers, the values of the individual bits remain local and are never coupled to a macroscopic property. By contrast, in Chen and colleagues' device, the values of the bits directly control emergent physical properties. This early example of remotely programmable matter opens the way for materials to process data, compute and learn.

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