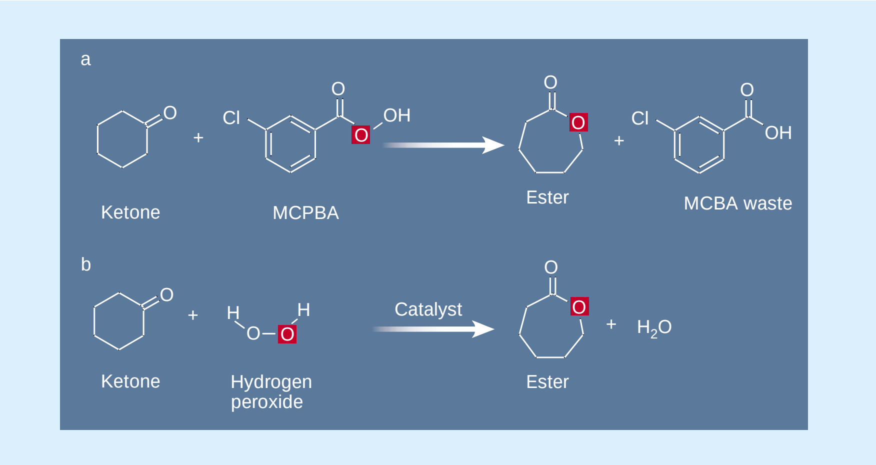

Figure 1 **The Baeyer–Villiger oxidation of ketones.** a, **The conventional oxidation using a common organic oxidant (MCPBA, an organic peroxy acid). The reduced form of the oxidant (MCBA, an organic acid), is the waste product of this reaction.** b, **The same reaction, but using the zeolite catalyst of Corma *et al.*[3] and hydrogen peroxide as the oxidant. Only a small amount of water is produced as waste.**

procedure[3]. The tin centre is responsible for the activation of the ketone substrate and increases its reactivity in being oxidized by hydrogen peroxide. The new catalysts have exceptional selectivity. In the oxidation of complex ketones containing other, potentially oxidizable, functional groups, they oxidize only the ketone group — that is, they perform Baeyer–Villiger oxidation. The catalysts are insoluble in water and in all organic solvents, and the reaction occurs at the interface between the solid catalyst and the liquid solution. At the end of the reaction, the catalyst can be removed and reused.

The catalysts devised by Corma *et al.* have been shown to work under laboratory conditions only, and moving from the production of just a few milligrams of ester to an industrial scale will not necessarily be straightforward. The catalysts will have to be synthesized in large quantities, their activity and lifetime will have to be improved, and their capacity to withstand industrial reaction conditions assessed. But they have genuine potential to be of great benefit in 'real world' applications.

Zeolitic materials have already successfully catalysed other oxidation reactions involving hydrogen peroxide as the oxidant. For instance, the Italian company EniChem is using titanium silicalites[9] to produce bulk chemicals such as propylene oxide, caprolactam and phenols. Titanium silicalites are a different class of zeolite, and are perhaps the most innovative oxidation catalysts to have emerged over the past 20 years. Given that background, one can be relatively optimistic about the prospects for the process developed by Corma *et al.* — it may prove to be a powerful tool in matching economic interests with sensible use of the environment. ■

Giorgio Strukul is in the Department of Chemistry, University of Venice, Dorsoduro 2137, 30123 Venezia, Italy.
e-mail: strukul@unive.it

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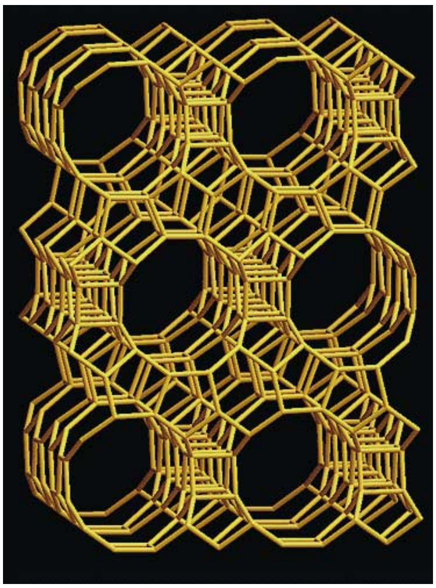

Figure 2 **A β-type zeolite of the form used by Corma *et al.*[3]. This view of the silicon- and aluminium-oxide framework shows the array of internal channels in which catalysis takes place. In synthesizing the new catalysts, tin is substituted for some of the silicon or aluminium atoms facing the channel, and so is incorporated into the framework. Tin centres are responsible for the catalytic activity of these materials. (Reproduced from ref. 10.)**

Neurobiology

Feeling bumps and holes

J. Randall Flanagan and Susan J. Lederman

We use our hands as well as our eyes to perceive physical objects. New insight into how our hands feel a surface may have implications for developing virtual-reality tools such as training devices for surgeons.

We can use our hands not only to manipulate the physical world, but also to perceive it. Using our hands to perceive the shape of an object often involves running the fingertips over the object's surface. During such 'active touch', we obtain both geometric and force cues about the object's shape: geometric cues are related to the path taken by the fingertips, and force cues to the contact forces exerted by the object on the fingertips. These cues are highly correlated, and it is difficult to determine the contribution of each to perception. On page 445 of this issue[1], however, Robles-De-La-Torre and Hayward describe an ingenious experiment in which they used a robotic device to uncouple force from geometric information. In a task involving the detection of bumps and holes, they show that force cues — not geometric cues — determine perceived shape. The result has implications for virtual-reality applications, and may lead to new insights into how our perceptions of shape are built up from sensory signals obtained during active touch.

The use of one's hands to perceive the physical world is known as 'haptic perception'. As a perceptual organ, the hand has several advantages over the eye: the hand can effectively 'see' around corners and can directly detect object properties such as hardness, temperature and weight. During active touch, the perceptual and motor functions of the hand are tightly linked, and people tailor their hand movements to the information they wish to extract[2]. Whereas 'local' information about the object, at the fingertip's point of contact, can be extracted simply by touching the surface[3,4], more global features can be determined either by

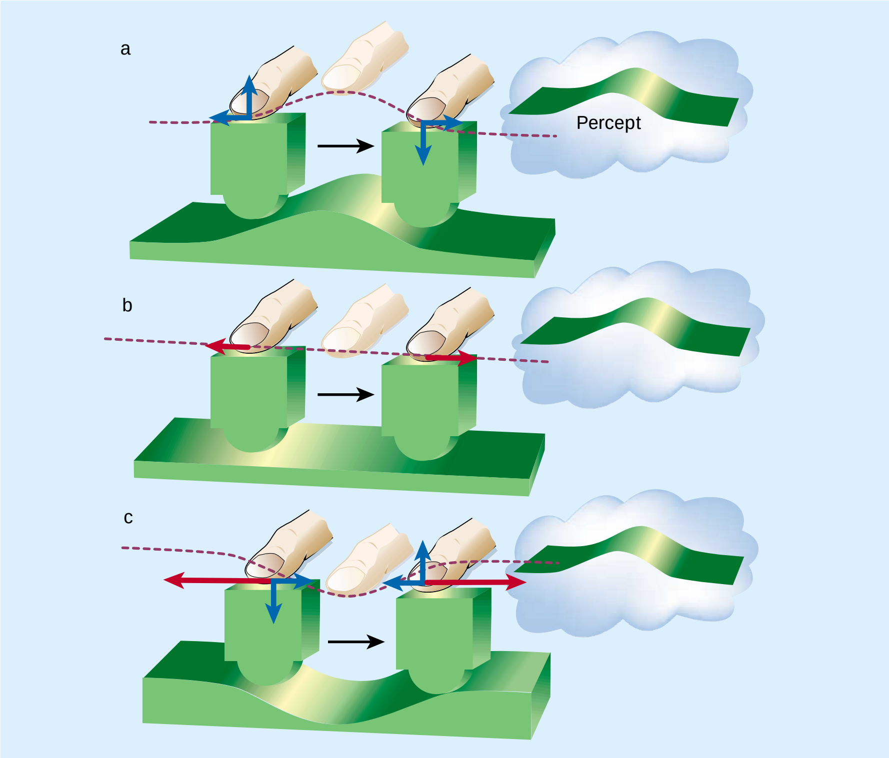

Figure 1 **How force and geometric cues contribute to the perception of shape by touching. Robles-De-La-Torre and Hayward[1] asked people to use a fingertip to slide an object over a surface (which they could not see), and to indicate whether they perceived a bump or a hole. In all cases shown, subjects perceived a bump.** a, **The object traverses a real bump, which gives rise to the physical forces shown by blue arrows. Horizontal forces resist and then assist lateral motion as the object goes over the bump. Vertical forces cause the object and fingertip to rise and fall (dotted line; geometric cues).** b, **The object slides across a flat physical surface but horizontal virtual forces (red arrows) consistent with a physical bump are applied to the object through a robotic device. Although the fingertip does not move up and down, subjects perceive a bump.** c, **A virtual bump, twice the magnitude of that in** b**, is combined with a physical hole. The result is a stimulus that has the horizontal force properties of a bump but the vertical geometric properties of a hole. Although the fingertip falls and then rises with the object, subjects still perceive a bump.**

enclosing the object in the hand or by moving the fingertips over the contours of the surface[5] and integrating sensory inputs over time. Haptic information may also be obtained 'remotely' — using a tool — in a range of contexts, from neurosurgery to carpentry[6,7].

To study the role of force and geometric cues in haptic perception of shape, Robles-De-La-Torre and Hayward[1] asked people to slide an object, held beneath the index finger, across a horizontal surface and to indicate whether they perceived a bump or a hole. The surface could contain a real or a virtual bump or hole; the authors created the virtual bumps and holes by using a robotic device to manipulate the horizontal forces on the object and fingertip. When the object traverses a real bump, horizontal forces first resist and then assist the sideways motion of the object (Fig. 1a). At the same time, vertical forces drive the object and finger up and then down. The opposite occurs when a real hole is traversed. In these experiments, the virtual bumps and holes gave rise to the same horizontal forces as real bumps and holes, but without the concomitant vertical motion of object and fingertip (Fig. 1b). Subjects perceived the virtual features as bumps and holes even though the fingertip did not move vertically.

In a second experiment, the authors directly pitted force cues against geometric ones. When subjects experienced horizontal forces corresponding to a bump while tracing a real hole, they perceived a bump (Fig. 1c). Similarly, they perceived a hole when the horizontal forces corresponded to a hole, even when the finger moved up and down over a bump. The implication is that horizontal forces provide the critical information needed to perceive shape by touch, and that these force cues dominate the geometric cues related to the path of the fingertip as it moves across a surface.

Practically, this work will impinge on the development of haptic interfaces used in virtual-reality applications. The results suggest that relatively inexpensive, planar 'force-feedback' devices could be used to create realistic perceptions of three-dimensional shape in a manner shown previously for virtual textures[8]. Ultimately, such devices may prove to be valuable in designing haptic communication systems such as virtual systems for surgical training[9].

More broadly, the methodology has implications for fundamental neuroscience. Processing of sensory stimuli in primates, including humans, is extremely complex and involves numerous sensory-receptor systems and many different cortical and subcortical brain regions. The ability to uncouple force and geometric cues[1], together with functional magnetic resonance imaging of brain activity and neurophysiological analyses of neural processes, may help neuroscientists to unravel the neural circuits that underlie haptic shape perception.

There are, of course, some aspects of Robles-De-La-Torre and Hayward's results that are worth exploring further. Work on visually guided movement has shown that distinct neural pathways process visual information for action and for perception[10,11]. Moreover, there have been several demonstrations that the motor system is not fooled by perceptual illusions[12,13]. So one question is whether the perceptual effects observed by Robles-de-la-Torre and Hayward translate into effects on action. For example, the shape of an object is one factor that affects how forces from the fingertips are controlled for stable grasping[14,15]; it is not known whether virtual shape information obtained from force cues will also influence the control of grasping.

In addition, in the authors' experiments[1], the shape of a surface was sensed remotely, using a tool. We must be cautious in extrapolating their conclusions to tasks that involve direct touch, in which further sensory information is available. For example, during direct touch, the angle between the fingertip and the surface changes with the slope of the surface, and this may provide cues about shape[16].

Nonetheless, the results reveal the importance of force cues in haptic perception of shapes. The next step will be to find out whether, and how, the contributions of force and geometric cues change with surface parameters such as the height and width of bumps and holes. ■

J. Randall Flanagan and Susan J. Lederman are in the Department of Psychology, Queen's University, Kingston, Ontario K7L 3N6, Canada.
e-mail: flanagan@psyc.queensu.ca

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Condensed-matter physics

In search of soft solutions

Douglas Durian and Haim Diamant

Physicists are turning their attention to delicate forms of matter, some of which appear mundane, but all of which are hard to understand. Fortunately, different materials share similar properties and problems.

Most forms of condensed matter are soft, but their physics is hard. Pick any apparently homogeneous material around you and wonder at the connection between its structure and behaviour: the magazine in your hands, the keyboard under your fingers, the flesh of your fingertips themselves, the contact lenses on your eyes, the cushion on your chair, the ink in your pen — the list is endless. These substances are composed of macromolecules and aggregates, with interactions that are too complex and too weak to form crystals spontaneously. Small external forces, slight perturbations in temperature, pressure or concentration, can all be enough to induce significant structural changes. Disorder, dynamics and deformation are the rule. Hence the phrase 'soft condensed matter'.

The full diversity of this field was on display at the largest conference* ever hosted by the Center for Nonlinear Studies. Over 300 researchers gathered to discuss advances in understanding polymers, liquid crystals, biomolecules, surfactant solutions, membranes and vesicles, foams and emulsions, colloidal suspensions and granular materials. Each of these topics constitutes a rich field of research in its own right, but together they have evolved into an intellectually coherent branch of physics with a growing scope and promising future. Hans Frauenfelder, the director of the Center for Nonlinear Studies, underscored this in his welcome speech: "I believe soft matter, which goes all the way from glasses to living systems, will be the main area of work for years to come." Indeed, at the conference it was clear that interest in glassy and biology-related systems is growing especially rapidly. More broadly, it emerged that many ideas cross over between topics, from the old to the new.

A well-established area of soft-matter research that continues to pose puzzles is the self-assembly of surfactants in solution — an essential process in many natural phenomena, from the cleaning action of soap to the formation of biological cell membranes. Surfactants are molecules with hydrophilic head groups and hydrophobic tails. In aqueous solution, surfactants must solve a tricky problem: how to arrange themselves in such a way that their heads are exposed to water while their tails are shielded. Depending on various factors, possible structures include spherical micelles, flat lamellae and long, cylindrical 'worm-like' micelles.

There are long-standing questions about the flow properties of surfactant solutions. When solutions of worm-like micelles undergo a non-uniform (shear) flow, their viscosity increases markedly, but no one knows why. The original idea, that the stressed micelles lengthen and entangle into a gel, can now be ruled out. One new proposal is that individual micelles can close up to form rings, and the size of these rings depends on the rate of shear. So at higher rates, rings are more likely to loop through one another, increasing the resistance to flow. Another idea is that short-range attractions cause long micelles to organize under stress into networks of bundles.

Whether or not bundling of worm-like micelles causes their increased viscosity, the hierarchical self-assembly of monomers into long filaments, bundles and higher levels of organization is ubiquitous in nature and is being widely studied. An important example is actin, whose self-assembled filaments serve as structural elements in muscular tissues and the cellular cytoskeleton. Depending on actin concentration and the presence of crosslinking proteins, the filaments form bundles or networks (see Fig. 1a), thereby strongly affecting the overall flow and elastic properties of the solution. Actin filaments can self-assemble even in a confined two-dimensional geometry when they associate with membranes. Another, less beneficial example is the self-assembly of misfolded proteins into filaments, ribbons and fibrils. The uncontrolled formation of these

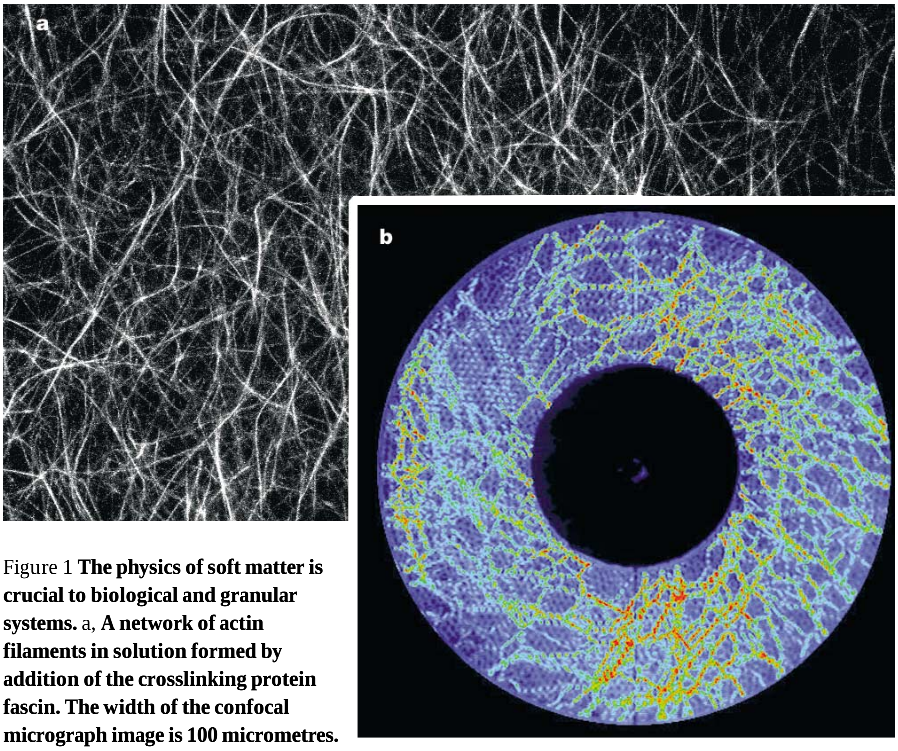

Figure 1 **The physics of soft matter is crucial to biological and granular systems.** a, **A network of actin filaments in solution formed by addition of the crosslinking protein fascin. The width of the confocal micrograph image is 100 micrometres. (Picture courtesy of Yiider Tseng and Denis Wirtz.)** b, **The force pattern in a two-dimensional array of small plastic disks subjected to shear in a ring-shaped container. The stresses cause birefringence in the material, and in this photoelastic image red and blue regions correspond to strong and weak local forces, respectively. The outer diameter of the ring is 38.2 cm. (Picture courtesy of Robert P. Behringer.)**

Principles of Soft Matter, 21st Annual International Conference of the Center for Nonlinear Studies, Los Alamos National Laboratory, Santa Fe, New Mexico, USA, 21–25 May 2001. http://cnls.lanl.gov/Conferences/POSM