Biomimetics

Nature's template

Copying natural designs is one of the most delightful ways to develop technology. Andrew Parker unveils the stunning realm of optical biomimetics and explores how natural processes can be reproduced or even hijacked

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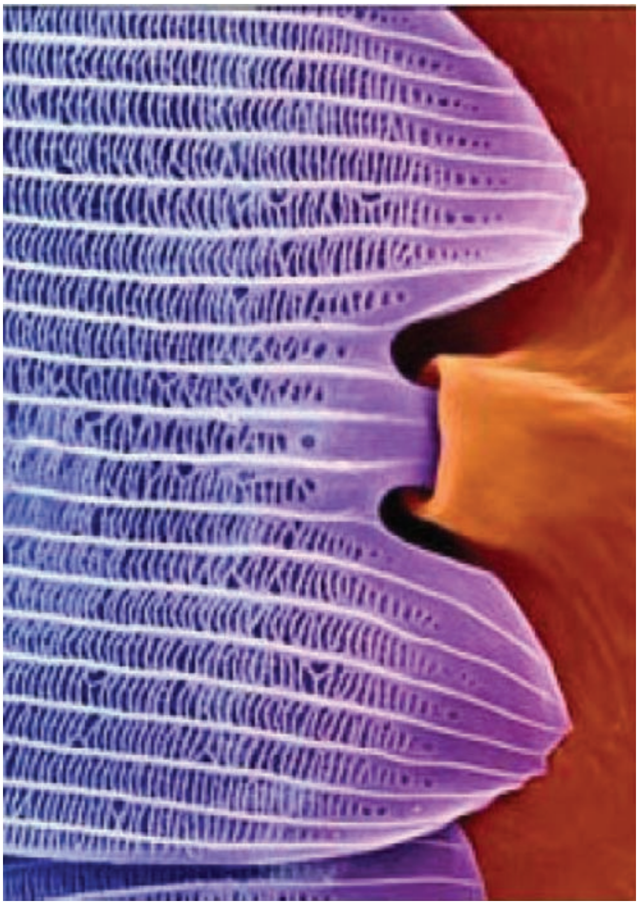

Occasionally Nature inspires completely new biomimetic inventions: from George de Mestral's 1941 discovery of Velcro, when he noted how burdock seeds stuck to his clothing, to today's superglues based on the Van der Waals' forces in the forests of tiny hair-like setae on a gecko's foot. More often, natural structures provide flawless examples of concepts already half-explored: the self-cleaning surface of the lotus leaf; the drag-reducing aerodynamics of a shark's skin.

Dazzling optical effects, in particular, are often due to nanostructures understood by physicists but not noted in Nature until the last few decades. Anti-reflective surfaces on moths' eyes that help them see in low-light conditions; iridescent scales on butterfly wings (right) and other insect scales that attract, camouflage, or startle – all are examples of nature's own metamaterials.

It's no longer surprising – though always a pleasure – to see that millions of years of evolution has anticipated the latest physics and chemistry. And nanoscientists have happily plundered these spoils by mimicking natural structures to manufacture impressive and useful devices.

But in the nano-sized realm, copying sometimes isn't good enough. Lithography can't always accurately mimic Nature's elaborate architecture, or if it can, commercial-scale manufacture is too expensive. Scientists are now realising that Nature needn't just inspire new designs: cells can actually be hijacked to grow natural structures for us.

To begin with, we have borrowed Nature's ready-made templates. Viruses have been harvested as building blocks to create iridescent films, while diatoms – single-celled algae – have been chemically converted into lace-like structures of nanocomposite materials.

But we still don't understand how cells grow their finely-branched designs in the first place. Intriguingly, the same kinds of nanostructures are found in many unrelated species – suggesting that all cells may use similar moulds, scaffolds, or templates. The ultimate goal of biomimetics may be to copy not Nature's designs, but its biomachinery – supplying the recipe to help optical nanostructures grow themselves.

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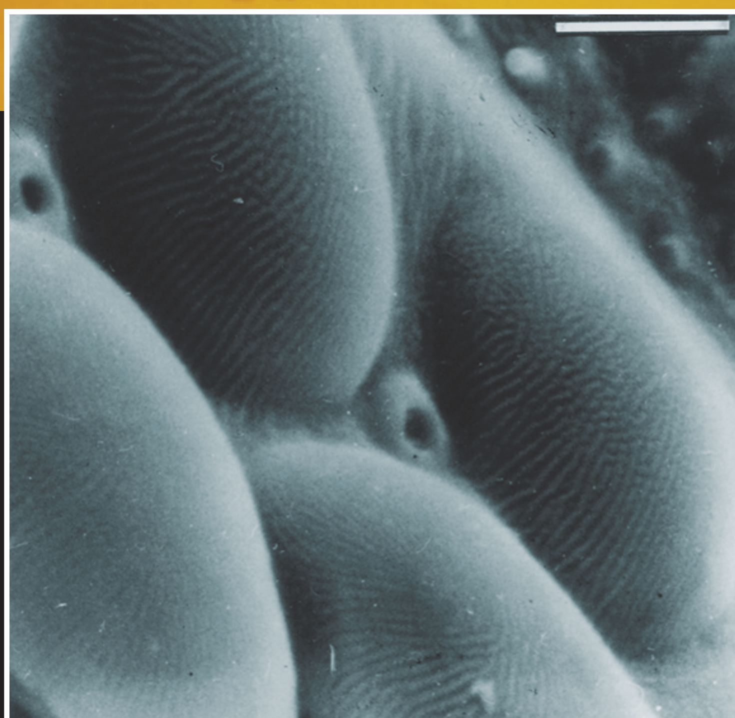

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Anti-reflective surfaces of fly and moth eyes are formed from directional ridges which maximise the absorption of light. Moth eye structures have already been harnessed for large-scale commercialisation, using lithographic techniques to print the surface pattern onto windows. The surface structures can be reproduced much more accurately using electron beam etching and have been used more recently in smaller, solid plastics and lenses.

The electron micrograph (below, right) shows a grating discovered on the cornea of a 45 million-year-old fly preserved in amber (above). This is able to capture light arriving at the surface from different angles. Consequently it has been used on the surfaces of solar panels, providing a 10 per cent increase in energy capture by reducing the reflected portion of sunlight.

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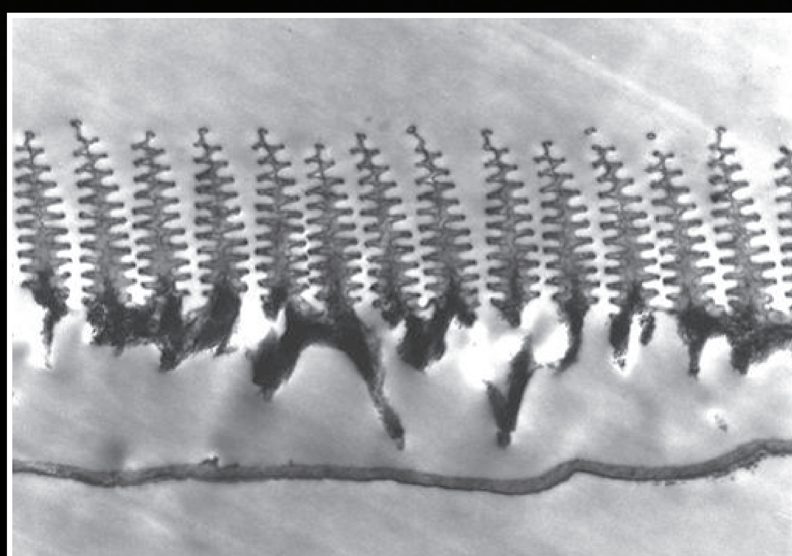
Iridescence is a well-recognised and beautiful phenomenon common to many insects and birds.

In Nature butterflies boast the greatest range of complex, optical architecture to produce iridescent effects on scales on their wings. *Morpho* butterflies – a group of brilliant blue butterflies found in Central and South America (inset above) – have wing scales containing tiny christmas tree-like structures, as shown in the electron micrograph (below, right). Each nanoscale tree is the perfect thickness and distance from the next branch and has the ideal refractive index to constructively interfere with blue light. As light shines down upon the structure, each branch reflects all of the blue light waves in the same phase in a single direction. This produces the cumulative, brilliant blue effect. All other wavelengths of light are reflected out of phase and cancel out (destructive interference).

Recently accurate reproductions of the *Morpho* structures have been made using ion beam chemical vapour deposition. These can be used in the production of colour filters for display units. The wing scales have also been used directly as templates to replicate the structures.



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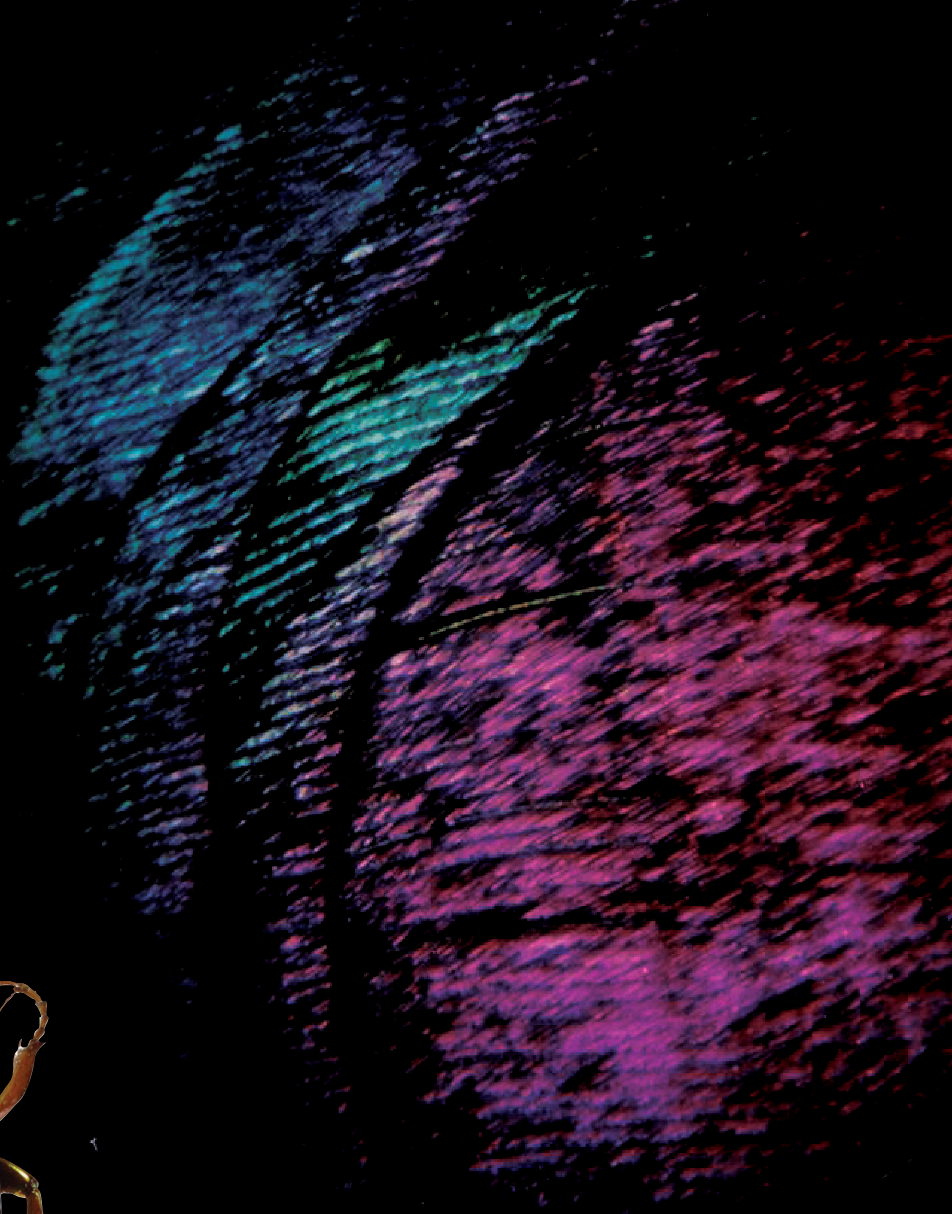
Photonic crystals (below, right) are nanoengineered structures that also produce iridescence. They have an ordered sub-wavelength structure that can control the propagation of light, only allowing certain wavelengths to pass through the crystal. Researchers have recently succeeded in copying crystal films from the beetle cuticle (below, left) and aim to exploit this device in in the cosmetics, paint, printing and clothing industries. Hummingbird feather barbs (above, right) provide an example of similarly sculpted three-dimensional architectures – with iridescence often caused by variations in porosity. Such devices have been mimicked using aqueous-based layering techniques.



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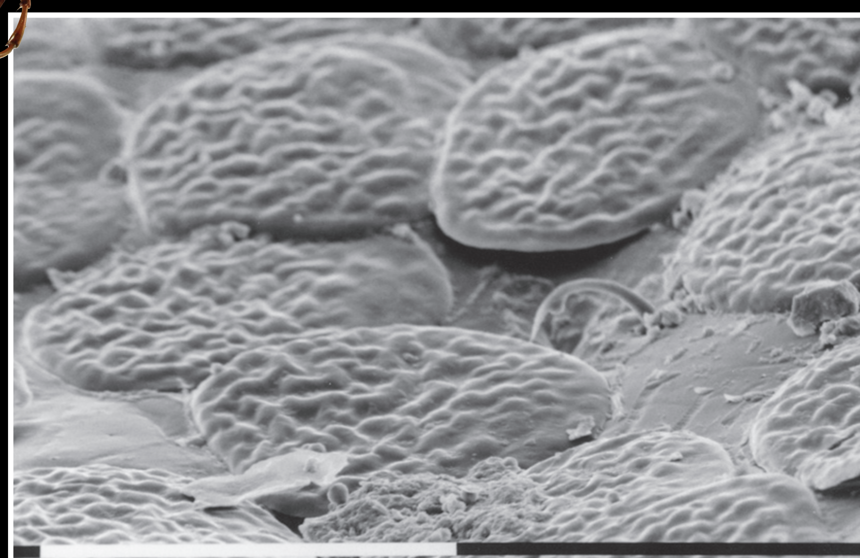

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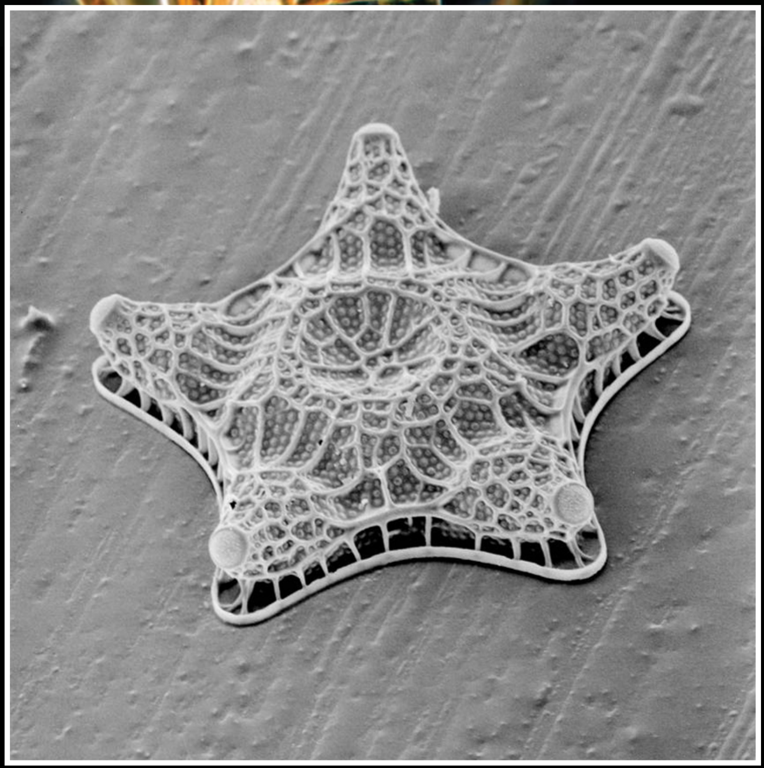
Nature is not only a useful template – it is an efficient manufacturer, whose techniques can be hijacked.

Butterfly scales have been grown in cell culture using cells removed from the chrysalis.

More recently, single-celled organisms have been used with work particularly focusing on diatoms – photosynthetic (algal) microorganisms (below, right). The cell wall (or frustule) of the diatom is made of pectin, a polysaccharide impregnated with silica. Pores in the frustule give the interior of the cell access to the external environment – enabling intracellular machinery to influence the formation of the frustule and dictate its final pattern. Silica particles are precipitated within specialised vesicles in the organism's membrane. These accumulate into blocks, which are deposited in an ordered pattern.

Using a medium containing nickel, the pore size of diatoms can be altered – changing the optical properties of the diatom to suit requirements, without the need for genetic manipulation. The photosynthetic process that deposits the silica onto the frustule can also be hijacked and silica replaced with another material.

Each individual diatom can give rise to colonies (above) of 100 million descendants in one month – achieving a high degree of complexity and hierarchical structure under mild physiological conditions. The ultimate goal is to replicate the nanomachinery within the diatom to produce self-assembling optical nanostructures.



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