Bearing all

One of the greatest wishes of conservationists is to raise public awareness about their species of interest. Best of all, where possible, is to let the public have access to view wildlife close up and in real time. But for many species this is just not possible: their environment is too inaccessible and human encounters would be too disruptive. So a new webcam located in the Alaskan wilderness at a site known to attract grizzly bears bent on a bit of salmon fishing has proved a huge hit with the public this summer.

The 114,000-acre McNeil River State Game Sanctuary in a roadless area about 250 miles southwest of Anchorage is one of the best places in the world to see brown bears, especially for the few weeks in the summer when they turn out to fish for salmon.

The 'bearcam' is turned on from 5 am until 11pm and during the afternoon a member of staff at the nearby Pratt Museum in Homer controls the solar-powered camera to get the best views.

The idea came from park managers wanting to let more people enjoy the spectacle. Only 250 people a year are allowed into the sanctuary to view the bears and these are selected by lottery leading to disappointment for thousands.

The resulting bearcam has been a huge success. "It's wonderful," wrote one journalist reviewing the site this month. "There are about eight grizzlies, sitting on rocks in the river, or in the river itself, looking down. It looks cold in the water. A salmon jumps, a bear takes a swipe, misses, licks his lips. And I'm watching this live in London. How excellent is that?" (www.ngm.com/wildcamgrizzlies)

Worldview: Brown bears can now be watched via an Alaskan webcam boosting global public awareness of these animals. (Photo: Daniel Cox/Photolibrary.)

Quick guide

Structural colour in Lepidoptera

Pete Vukusic

What are Lepidoptera?
Butterflies, moths and skippers form the order of insects known as Lepidoptera. Estimated to include more than 150,000 species, they are widely studied and have long been known to have highly complex morphologies, fascinating lifecycles and remarkable ecologies.

Their broad wings are invariably covered with arrays of minute scales. Each scale is a thin, flattened, cuticular evagination from an individual cell in its wing's epithelium. Whether patterned or unadorned, and with few exceptions, it is these scales that are the pointillistic sources of all colour on lepidopteran wings. Their development offers a spectacularly diverse range of possible wing appearances, both in pattern and in colour.

What is structural colour?
The colour of each lepidopteran scale is created either by pigments, such as melanins, flavonoids, pterins, and so on, or by a periodic ultra-structure formed from the scale's cuticle. In some cases, there are both pigmentary and non-pigmentary contributions to an individual scale's appearance.

The non-pigmentary source of colour, referred to as structural colour, is a very important component in the appearance of many different animal systems — examples are found in many other orders of insects, as well as in birds and aquatic animals. Some flora also make use of it. In Lepidoptera, the ecological selection pressures and the processes responsible for cuticle formation have led to a remarkable diversity of scale designs for producing structural colour.

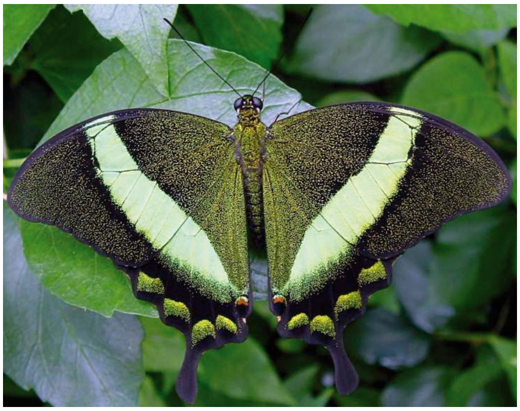

Figure 1. The *Papilio palinurus* butterfly, pictured here, simultaneously produces two structural colours (yellow and blue) from a single form of wing-scale ultra-structure. These pointillistic colour centres combine to produce the stimulus of green to our eyes.

Structural colour utilizes the wave-nature of light. As a wave, light can experience wave superposition; that is, groups of waves may add together to reinforce or diminish their combined effect. For this to happen effectively and therefore to produce a distinct colour effect, there must be a definite structural order in the system; importantly, the physical dimension of this order, the period, must be on a par with the wavelength of light. This phenomenon is often referred to as interference and is identical to the mechanism that produces the iridescent colours in soap bubbles; other names for it include Bragg diffraction or coherent scattering.

Why is it advantageous to be structurally coloured? Structural colour offers several key functionalities that are not accessible using pigmentation. The first, in broad terms, is that it provides the facility for a system, such as a butterfly wing, to control explicitly the way that light reflects from it, propagates within it or is transmitted through it.

Clearly, as these aspects control visual appearance, from camouflaging to ultra-long distance signalling, and even to thermoregulation, it is a vitally important feature. As such, it has been a key variable in the evolution of very many different species. Such control over light extends not only to pretty much all aspects of the narrowness or breadth of its spectral purity, but also to the intensity of the colour, its perceived angle-dependence and also the angle over which it is visible. Strong linear or circular polarisation may also be incorporated into the colour signal if the appropriate scale structures are present.

How are these sorts of morphological structures formed? The processes that determine the characteristic morphology of each butterfly or moth's colour pattern begin long before metamorphosis, while the creature is still a larva and its wings still undifferentiated internal imaginal disks. As the wing develops, its outer surface forms slender projections from widely spaced scale cells. The projections flatten, elongate and then develop series of periodic or aperiodic ultra-structures. These ultimately underpin the scale's function and appearance. A growing scale cell lays down a thin malleable outer layer of cuticle, firstly around itself (as the secretion and assembly of cuticle takes place extracellularly), then on the structures forming the inner layers of cuticle. When the cell finally dies back into the epithelium of the wing, the newly formed scale dries and hardens to leave the finished functional product.

With some scale types, namely those that feature a form of two-dimensional periodicity within the specialised ridging on the scale's dorsal surface, drying-related elastic buckling is proposed as the mechanism by which the requisite periodic precision is attained. In other forms of scale, those which comprise a fully three-dimensional photonic crystal, the scale cell forms a three-dimensional network of smooth endoplasmic reticulum which it appears to use to control the three-dimensional structure and spacing of secreted cuticle.

What are some good examples of structural colour in Lepidoptera? Let us start with *Morpho* butterflies since these are among the most well known and conspicuously coloured species. The intensely bright iridescent blue wings of some species of the *Morpho* family facilitate very long-range signalling (they can be seen from a quarter of a mile away). A highly periodic, one-dimensional multilayer, with alternating cuticle and air layers, is arranged in the discrete arrays formed by each scale's specialised ridging. These create a reflection of up to 80% of incident blue light and offer the wing an extremely broad angular visibility. Other *Morpho* species use a superficial layer of scales, on top of the blue reflecting ones, to diffract the reflected blue light out into even broader angles, increasing angular visibility still further.

A similar sort of structure, with modified multilayer dimensions, is used to create a highly reflective signal from the wings of some ultra-violet iridescent *Colias* butterflies, such as *C. eurytheme* males. To our eyes, however, as we are unable to discern these shorter wavelengths, their wings appear yellow, because of the presence of pterin pigment granules packed between the structurally coloured ridges.

Several of the gloss swallowtail butterflies, *Papilio palinurus* is one example (Figure 1), exhibit wonderfully soft green-coloured banding across their wings. The green is entirely structural in origin. High magnification inspection, however, reveals curved multilayers beneath the surface of hundreds of 5 micron diameter concavities on each of the wings' green scales, which simultaneously reflect yellow from their centres and blue annuli from around their sides. Together they form juxtaposed pointillistic colour centres which, to our eyes, create the stimulus of the colour green (the same principle is used in many neo-impressionist paintings).

One further special feature of this structurally coloured system, and possibly the reason it evolved, is that only the blue colour component is significantly linearly polarised; linear polarisation is sometimes used for intra-specific signalling in Lepidoptera, so this system seems ideally designed to be cryptically green to, say, predator visual systems that do not see differences in the polarisation of light, while broadcasting linearly polarised blue signals to conspecifics.

A separate small family of swallowtails, the *Nireus* group that is indigenous to the Afrotropics, concurrently employs a fluorescent pigment and not one, but two forms of specialised photonic structure: a multilayer and a two-dimensional photonic crystal slab. These carefully control the emission direction of the fluorescent light and make the butterfly a much brighter object than it would be without them. This is the first known example in which fluorescent pigment and colour-producing or colour-controlling nanostructures are so closely tied together.

There are a vast number of other examples. Lepidopteran structural colour systems, and those in other orders too, truly exhibit a remarkable ability to control the flow of light and colour in so many ways and for so many purposes.

Why is this subject worth investigating? Textbooks tell us that a colour pattern is a slice in time; a frozen moment in the dynamic processes of development and evolution. Genetic information is translated into the manipulation of cell systems and cuticle assembly to give final patterns and appearances.

To understand these processes in Lepidoptera, we examine the biological components that underpin their wing colours and patterns. We seek to know how changes in genes and development can control colour and pattern; how larval food plant quality affects male sexual quality indicators; how the forms and relative weighting of inter-specific and intra-specific selection pressures affect wing colour intensity, hue, polarisation and angular visibility.

A study of the biology of the wing colours and patterns of Lepidoptera is a study of evolution itself. Now, within this field, it is increasingly clear that structural colour, and the many ways in which it is produced, is a fundamental component.

From the perspective of technological photonics, these lepidopteran systems are amazingly elaborate. They feature self-assembled highly complex biological engineering for photonic purposes (amongst others) that, given the limited range of constituent materials, exhibit an ingenuity of design that easily surpasses all but a few of our best technological efforts. Technology is keenly interested in the ideas and design principles that such natural photonic systems, such as those in certain Lepidoptera, are able to offer.

Who knows how much photonics research time may be saved, or how many technological design solutions may be realised, simply by looking to nature's wing for inspiration?

Where can I find out more?

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Primer

The nature of *Drosophila melanogaster*

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'The time has come,' the Walrus said,
'To talk of many things:
Of shoes - and ships - and sealing-wax -
Of cabbages - and kings -
And why the sea is boiling hot -
And whether pigs have wings.'

Lewis Carroll, Through the Looking-Glass

Many biologists have dreamed of a research organism that can be studied from many, if not all, perspectives. The fruit fly, *Drosophila melanogaster*, may be just such an organism. Its genetics have been studied since the early 1900s, starting in Thomas Hunt Morgan's fly rooms at Columbia and Caltech. Since then, numerous studies have used fruit flies to uncover important aspects of evolutionary processes such as selection, migration and genetic drift. Concurrent studies using the fruit fly have unraveled fundamental processes of cell biology, neurobiology and development. Despite this impressive array of accomplishments, very little is known about *D. melanogaster*'s natural history and ecology in the wild.

A better understanding of this species' natural history can help direct research questions posed in the laboratory and the field. For example, such questions come to mind as: Does *D. melanogaster* overwinter and if so where? Is dispersal important to its natural history, and if so, when and how far do animals disperse? Do flies exhibit aggressive behaviour, sleep, group sex or homosexual courtship in nature? Is learning important in nature and if so how long do flies remember? Do flies