COVER ILLUSTRATION

Flatlanders

In the classic book, *Flatland*, written by Edwin A Abbott in 1884, the life of a square in a two dimensional world called Flatland was portrayed. The protagonist square explores perception by discussing what the world would look like if it were one dimensional or three dimensional. Eventually, the poor square is jailed for discussing a three dimensional world. In many ways, this extraordinary book broke the boundaries of the time by challenging what we knew, and still struggle to understand, about the boundaries of perception and the potential for dimensional worlds beyond our current understanding. This odd, and short, text has been repopularised by Clifford Pickover in his book *Surfing Through Hyperspace*. Pickover brings the conception of higher dimensions and higher dimensional consciousness to life. It is unlikely, though, that he will be visited by the local constabulary since such considerations are not such strange concepts to our society. Physicists and mathematicians deal with these concepts on a daily basis. But, how are dimensions perceived visually?

Proper interpretation of a three dimensional world with a two dimensional retina, such as ours, requires sophisticated neural processing and perhaps binocularity. Such neural processing must make certain assumptions with available data, although these manoeuvres are usually performed seamlessly. No animal possesses a three dimensional retina, although some fish have tiered retinas that could be considered as more than two dimensional in certain situations. Other animals, such as jumping spiders and carnivorous sea snails, have a linear curved retina consisting only of a band of photoreceptors no wider than 6–7 photoreceptors. This is, in essence, a one dimensional retina consisting of a line of photoreceptors. Nevertheless, the jumping spiders, at least, have surprisingly good vision and must have some form of three dimensional processing as they are most successful at prey capture. These creatures swing their retinas through an arc using the principle of scanning for acquisition of the image.

At least one remarkable creature, *Copilia quadrata*, illustrated on this month's cover (top), has an non-dimensional retina—a point retina consisting of 6–7 receptors! *C quadrata* is a copepod,

a class of the phylum Crustacea possessing a clutch of interesting eyes as illustrated by the *BJO* cover of August 2003. In this class, evolution has stumbled across rather extraordinary mechanisms for prey capture and mating that are often unique, and *C quadrata* is one such example.

Copepods are an enormously abundant class found in numerous aquatic habitats; they represent the base of the food chain and are extremely diverse. Although *C quadrata* is epipelagic, it has relatively deep and broad vertical 24 hour distribution, being found as deep as 200 metres, but it can also be found at the water's surface. This organism is transparent except for the orange pigment of the photoreceptors. The specimen illustrated on the cover may have recently eaten, resulting in pigment within the creature although it is otherwise transparent.

As with the jumping spider, *C quadrata* must scan back and forth, much like the cathode ray tube that provides an image for a television screen. Although the creature has what appear to be two eyes located anteriorly on the carapace, and resembles other invertebrates, the similarity with other creatures ends there. These larger external lenses are part of the carapace and do not move. Scanning takes place internally. The secondary lens, seen best on the sagittal image in the top picture on the cover, is positioned immediately distal to the diminutive point retina and proximal to the larger lens on the carapace.

Light initially contacts the external and larger lens with the parabolic posterior surface seen well in the sagittal photograph (a closely related species, *Corycaeus*, which has similar optics is seen in the bottom picture on the cover). The image is cast upon the secondary lens, which then brings the point to focus on the receptors, much like a telescope with an eyepiece and objective lens. The eyes scan horizontally (perpendicular to the anterior-posterior axis of the animal) within an angle of 10–15° as measured from the distal or first lens. Essentially, this is a linear scan and only in one dimension. To add to the curious nature of this visual system, the eyes move in opposite directions; although they do move simultaneously, they move in opposite directions at a rate of between 0.5–10 Hz! This is accomplished by a single muscle, with the retinas being yoked together, assuring rapid movements medially and slow movements temporally. Hence, these eyes obey Hering's law, although not in it original conception. Consequently, stereopsis is unlikely (Gregory RL, Origins of eyes—with speculations on scanning eyes. In: Cronly-Dillon JR, Gregory RL, eds. *Vision and Visual Dysfunction* 1991;**2**:52–9)

Without scanning, the point retina has a field of approximately 3° and could have a linear field of no more than a 45°, in the best of circumstances, but probably has much less. Despite the odd ocular movements, this system is one dimensional (although arguably two dimensional if one considers time, but there is no stereopsis and no sophisticated neural processing), so how is the second (or third dimension) measured? Or, is this the creature that Abbott considered when he wrote *Flatland*? Perhaps, as Gregory suggests (reference above), the second (or third) dimension is provided by the prey itself.

Copilia is a ferocious predator and feeds on vertically migrating plankton detected as these planktonic species move through the horizontal scan line. If the plankton moved horizontally, they would never enter the perceptive world of *C quadrata*. Hence, the prey may produce the next dimension with its movements. A simple but very elegant system to be packed into an animal measuring no more than 1 mm in width and 5–6 mm in length, including the tail. This amazing creature is no bigger than the head of a large pin and yet can teach profound lessons of perception. Just like *Flatland*.

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