Animal Optics

I expect a number of you have been engaged about optics due to it being a visual field – you can see it with your own eyes. Simply, visible light from displays, the laser pointer, pictures you take with your camera, and so forth engage us. Of course this is not readily true if you are dealing in the wavelength ranges outside the visible, but you can feel the heat from IR, see the tan or feel the sunburn due to UV, see X-ray images at the doctor, and so forth. In the end, we all rely on our visual system to make it through the day – from driving, walking, watching a lecture, and going to the movies (well…). It has been found that over 50% of our cortex, which is the surface of the brain, is dedicated to processing the information from our eyes,[1] which is likely true for other animals with developed visual systems. Over the years I have noted my curiosity about how we see and how this extends to other animals.

Through the years I have learned or heard many things about animal visual systems. Here is a smattering of some of those:

- Most birds have four receptors in their eyes, while we have three. With this fourth receptor birds have vision that extends significantly into the ultraviolet (330 nm), while the visible range of wavelengths is defined by the human visual system (down to 380 nm).[2] The lens of the human eye does not allow the UV to be transmitted, but birds have a different material makeup in their lens which allows the transmission of UV.[3] Simply, birds see something completely different than what we see.
- A number of animals have eyes on the side of their heads, such as the horse. This gives the horse a much better field of view (340° between both eyes, but only the central overlap region of around 60° is binocular)[4] compared to us (around 214° between both eyes, and the central overlap region of around 120° is binocular).[5] Because the horse has such a large lens, the muscles that deform the lens to accommodate focus cannot do as much compared to our eyes. Thus, horses have a hard time focusing on near objects. This in conjunction with the lack of a large region of binocular vision, explains aspects of the horse's behavior. The lack of binocular vision means the horse must use additional cues to figure out depth. For example, it moves its head up and down to adjust the angular region of its binocular vision. Thus, it lowers its head to see near objects (e.g., something on the ground or the apple that you are offering) with its binocular vision, and it raises its head to see far objects (e.g., predator or obstacle it is jumping).
- Many animals have different shaped pupils, such as the cat, which has a vertical slit. Research from 2006 showed that it is to correct chromatic aberration in their eyes, especially in low light level conditions, such as while hunting at night. During these conditions cats have a relatively large pupil compared to the eye focal length (F/#). This results in poor depth of field, and chromatic aberrations can seriously degrade image formation. A solution to this problem is to have multi-focal optics, such that different points in the pupil have different focal lengths. Domestic cats have this, such that the different pupil zones focus different wavelength ranges. Thus, the image that is formed by the slit pupil will have the multiple wavelength ranges in focus through the separate focal elements of the cat's eyes.[6]

There are a multitude of additional examples out there. If you continue to explore the fascinating aspects of animal vision, you may take journeys into other areas. Two examples are how do birds, insects, and other animals have such amazing colors and do polar bears have fiber optic hairs? For the former, take a look at bird feathers – they come in such a large range of colors. At first blush most think of colors coming from pigmentation, such as fabric dyes in our clothing. This holds partially true for bird feathers. Pigments made from carotenoids give yellow, orange, and red colors to the feather. Pophyrins are rarer in feathers but cause green and red colors, and also phenomena in the UV (remember most birds can see into the UV). These pigments in conjunction with melanin give yellows to black and green to black, respectively. What about blue? It is not a natural pigment in bird feathers. Try telling that to the Mexican jay you can find in Madera Canyon to the south of Tucson.[7] Its color comes from the structure of its feather. Thus, blue-coloring in feathers arises from optical phenomena such as thin films, photonic crystals, and/or grating phenomena. Bird feathers are amazing optical devices! One of my students (Georgia Piatt) studied this for her Master's thesis, *From Cell to Barbule the Optics of Iridescent Bird Feathers*.[8] In particular she looked at the rock dove (pigeon) and the Wahnes's Parotia (i.e., one of the birds of paradise, see Fig. 1).[9] As you change your view angle and/or illumination angle of the bird, you will see color that varies. For these two birds it is done through a thin film effect of alternating layers of melanin and keratin, which have different indices of refraction. These multiple layers lead to constructive and destructive interface as a function of wavelength and angle. Figure 2 shows the layers, which for this bird of paradise is many distinct layers, and by modeling in software it shows the colors that you expect dependent on the angles of illumination and observation.[8]

Figure 1. Wahnes's parotia: male in black with the colorful breast arising from thin film effects and the female in brown. [9] The male does a very intricate dance to attract the female.[10, 11]

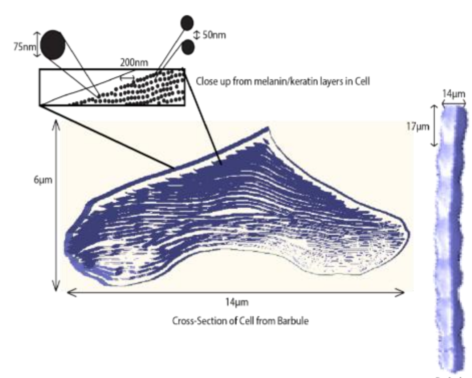

Figure 2. Structure of the barbule of the Wahnes's parotia as shown in Fig. 1. The lines or curves delineate change in the material between keratin and melanin.[8]

In regards to fiber-optic, polar bear fur, I had heard during my undergraduate days that polar bears had fiber optic hair, such that light that entered the hair tip would propagate down its length till it was absorbed in their skin. Simply, this is false![12]

There are so many things you can learn about optics by observing animals. Interestingly, as we do our research, it behooves us to look at what nature has done. Many scientists are trying to replicate what nature has done. For example, an analogy to the multi-focal element of the cat eye is the multi-focal diffractive replacement lens for the human eye that Prof. Schwiegerling has developed.[13]

Optics is awesome!

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1 https://www.rochester.edu/pr/Review/V74N4/0402_brainscience.html

2 https://doi.org/10.1016/S0065-3454(08)60105-9

3 Douglas, R. H., & Marshall, N. J. A review of vertebrate and invertebrate ocular filters, in *Adaptive mechanisms in the ecology of vision* (pp. 95-162). Springer Netherlands, 1999.

4 https://www.merckvetmanual.com/horse-owners/eye-disorders-of-horses/eye-structure-and-function-in-horses

5 https://en.wikipedia.org/wiki/Visual_field

6 https://doi.org/10.1016/j.cub.2006.02.046

7 https://en.wikipedia.org/wiki/Mexican_jay

8 Georgia Piatt, *From Cell to Barbule the Optics of Iridescent Bird Feathers* (Optical Sciences, M.S., awarded) 2018.

9 https://en.wikipedia.org/wiki/Wahnes%27s_parotia

10 https://www.youtube.com/watch?v=3hVh-Jea3_I

11 https://www.youtube.com/watch?v=iTmHtxJpEWE

12 https://www.rp-photonics.com/spotlight_2007_01_09.html

13 https://www.optics.arizona.edu/news-events/events/tla-presentation-maker-user-how-one-opsci-researcher-made-it-happen-0