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4.209 “Science & Art of Depiction”
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VISUAL EVOLUTION & ACCOMODATION:
THE HAWK AND THE AMOEBA

A degree of responsiveness towards environmental conditions may assure an organism's survival. One critical environmental factor is light. As old as the beginnings of evolution itself, some organisms, to this day, reflect some of the most primitive means of responding to light from its environment. Through these means they are able to 'understand' objects and events in their surroundings. Ultimately, this 'knowledge' helps to ensure the organism's survival.

According to Vicki Bruce the ability for an organism to be sensitive to a form of energy, such that some information about the environment may be provided, is called *perception*.

Light is one such form of energy and that which, for the sake of this essay, will be concentrated on.

In relation to Bruce's definition of perception we may begin to rethink our understanding of the organism's 'means' to perceive; we may rethink our definition of the word 'eye'.

In the evolution of the organism's perceptive capacities, we may begin with the single-celled animal. In such animals as the *amoeba* the absorption of light is harnessed by <u>light-sensitive molecules</u> contributing to its ability to move.

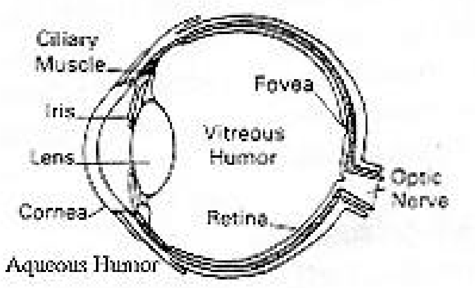
One step ahead, is the possession of <u>pigment molecules</u> specialized for light sensitivity. This may be elaborated in some protozoans where the pigment is concentrated into an <u>eyespot</u>. The concentration of *photoreceptor cells*, an enhancement of the pigment molecule, are also known as eyespots. In general, most animals sensitive to light, as well as some mollusks, possess photoreceptor cells.

The evolution of the 'eye' beyond the photoreceptor cell may be thought of in terms of directional sensitivity. While the directional sensitivity of animals with photoreceptor cells is limited to the arrangement of the pigment within the cells, the "eye-cup" or *ocellus*, a result of sinking a patch of receptor cells into the skin, is sensitive to light from a narrower angle in comparison. As such some level of spatial pattern in the optic array of light may be detected as the photoreceptors within the ocellus are sensitive to light in a narrow segment of the array. Subsequently, an animal with eye cups distributed over its body is able to detect even finer spatial patterns in the optic array.

Finally we arrive at the *single-chambered eye*, or what we most commonly associate our understanding of the 'eye' with. Vicki Bruce calls this 'the true eye'. In looking at an alternate source, the American Heritage College Dictionary defines the 'eye', among other definitions, as "the faculty of seeing; vision." May we ascribe the capacities of pigment molecules, the photoreceptor cell, or the ocellus to respond to light as the act of 'seeing'. What does it mean to see? In so far as to achieve an understanding of or to apprehend an external condition, it may be argued that a jellyfish, responding to a sudden reduction in light intensity when a predator passes overhead, is able to perceive but not 'see' or 'visualize'. This difference may be emphasized, as visualization, by definition, requires a visual apparatus or 'the true eye'. According to Steven Collins, the ability of the animal's spectral and spatial sensitivities in order to construct an *image* may be understood as 'vision'. More precisely, Bruce explains the notion of the formation of an image as the condition where "all light rays reaching the eye from one point in space are brought together at one point in the image, so that each receptor cell in the eye is struck by light coming from a different narrow segment of the optic array." What exactly does this mean?

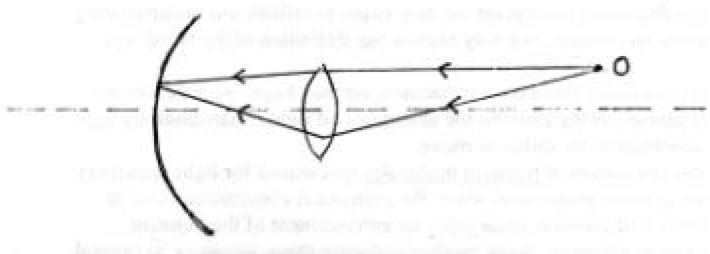
A basic outline of image formation in the single-chambered human eye may be provided. In our environment, to a greater or lesser degree, light is reflected off of every lit surface. This may be understood as light rays bouncing off of objects, being projected in various angles. When we 'see' objects, we are in essence capturing this light energy and converting it into nerve impulses that must be delivered to the brain for further integration into visual images. This conversion takes place on the eye's *focal plane* or *retina,* where our photo receptor cells are located.

Figure 1



Returning to Bruce's definition, in order to have a focused image, light coming from the same point in space or light reflected off of one point of an object, "O", must reach our retina at one point.

Figure 1a



In order for this to happen, the light rays of different angles, coming from the object, must be refracted so that they may converge. In the human eye, this is accomplished by its convex lens.

Figure 1

Figure 2a

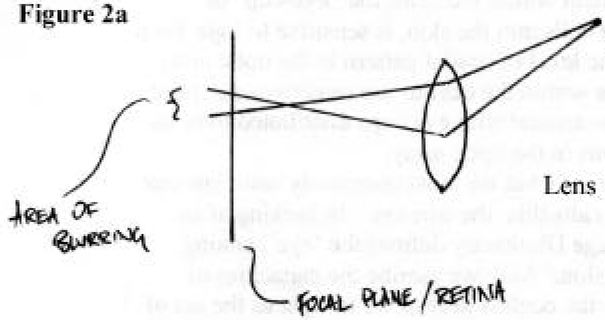
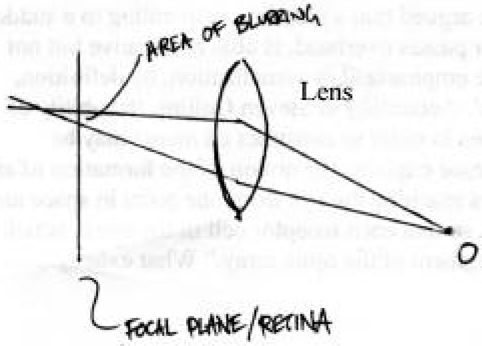


Figure 2b



A reason why images may appear unfocused or blurred is a result of the light rays converging at a point which is either in front of or behind the focal plane.

Figure 2a, 2b

According to Bruce, the ability to detect the spatial patterns from the optic array of light is known as *visual acuity*. While there are other processes, the most important consideration known to limit visual acuity is the efficiency with which the eye is able to map the spatial pattern of the optic array onto the retina.

While the lens is the chief means by which light is refracted, there are other structures lying in the path of the incoming light. **Figure 1** Besides the lens, the cornea, aqueous humor and vitreous body make up these media. These structures, in particular the cornea plays a key role in the visual acuity of the eye particularly in other organisms, if not in humans.

In regards to visual acuity, the special accommodative abilities of birds of prey make them an interesting species to examine. Looking back at the opposite end of the spectrum, just as it is an imperative in the amoeba, the hawk's responsiveness to its environment, with regard to its vision, assures its survival. When diving on its prey, the slightest miscalculation could mean continued hunger or the demise of the wrong individual.

To conclude this essay, the modes of accommodation of the eye of the fascinating diurnal birds of prey may be highlighted. Their level of visual acuity sets them apart from humans as well as other birds.

While humans are capable of *lenticular accommodation* through contraction of the ciliary muscle, the same muscles are responsible for the alteration in the curvature of the cornea in birds. Another prominent difference is the bird's large size of the eye. This permits 1. the formation of a large retinal image, 2. an increase in the depth of focus, 3. the presence of elaborate and diverse retinal areas and foveas. Apart from the flat shape of the eye characteristic for most birds,

Figure 3 diurnal species possess a globose shape permitting greater visual acuity.

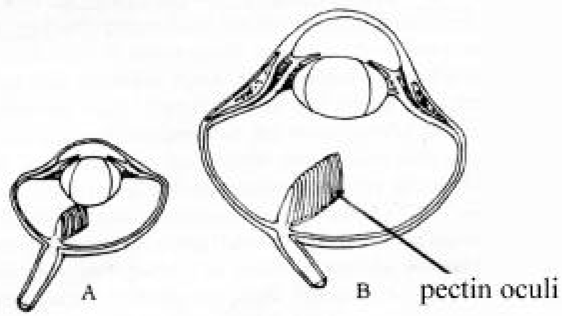


Figure 3 Shapes of avian eyes as revealed by the ventral half of left eyeball: (A) flat; (B) globose

Furthermore, the avian lens is soft and malleable and thus easily deformed, capable of considerable alterations in its curvature.

That which would convince one most to believe that the avian eye is more evolved than the human eye is the avian retina. First of all, it contains a fascinating array of photoreceptors. There are three types of visual elements –rods, single cones, double cones, as opposed to the two elements of the human eye. Moreover, within the single cones is a large oil droplet which promotes increased color discrimination.[1] Second of all, the avian retina contains three "areas of acute vision"[2]: the central area, the lateral area and the linear area which, opposed to the oval or circular shape of the first two, has the form of a long band or ribbon. Within both the central and lateral area are depressions or fovea[3] (opposed to the one central fovea in the human eye). Moreover, specific to diurnal birds of prey, the central fovea is a deep, well-excavated pit containing extremely thin cones. The lateral fovea provides direct forward vision for rapid descent towards these birds' prey while both the lateral and the central fovea combined achieve accurate perception of distance and speed. In 1920, Rochon-Duvigneaud theorized that in these bifoveate conditions both fovea actually function independently, constituting a sort of compass by giving separate points of distinct vision; an incredible apparatus for the estimation of distances.

[1] This is a result of increased color contrast by functioning, in combination with different visual pigments, to cut off the short wave branch of the pigment sensitivity curve and displacing the sensitivity maximum to longer wavelengths.

[2] These represent thickenings of the sensory retina involving thinner and longer visual cells that improve resolving power, combined with a existing increase in the number of bipolar and ganglion cells.

[3] Foveas are caused by a radial displacement of the more internal layers of the retinal area, resulting in a shallow saucer-shaped or deep funnel-shaped cavities. Visual cell density is greater in the fovea than elsewhere in an area.

Several functions have been attributed to the linear area including movement detection and spatial orientation by determining the normal position of the eye with respect to the horizontal plane. The presence of all three distinct retinal areas is a unique adaptation that permits the formation of three separate and distinct visual fields, two lateral monocular fields (one for each eye) and a central binocular field. This arrangement, again, characteristic of diurnal birds of prey, allows for a very high degree of visual acuity and stereoscopic vision.

A final major distinction of the avian eye is the presence of a bizarre supplemental nutritional device –the *pectin oculi*. **Figure 3** Projecting into the vitreous body, the pectin is believed to be a supplementary device enhancing the perception of movement. Supposedly, this is achieved via the shadow the pectin casts upon the retina influencing retinal responses and thus the sensitivity to movement in the optic array.

It is argued that in some species, the diurnal bird of prey possesses a resolving power at least eight times greater than that of man. While the evolution of greater complexity in eyes may lead one to believe so, it would be misguided to think of the eye of the hawk as superior over other organisms. It may certainly be argued, in so far as the evolution of the organism's perceptive capacities is concerned, that the hawk's eye is more advanced than the system of eye spots distributed over the mollusk's body. Yet, the degree to which an organism is capable of responding to its external environment is in accordance with its need for maintaining its day-to-day activities. The bird's sensory world is primarily visual resulting in the sophistication and complexity of which our limited visual experience provides little intuitive appreciation for. Organisms that are less visually dependent exhibit other features as their activities will vary.

The ultimate goal for every life form, survival, is dependent on numerous factors and achieved in various ways. After all, what good would it do for a human individual to possess the bony process above the eye that shields the hawk from the frenzied threshing of an insecurely held victim?

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