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***Review Article** (Open Access)*

THE WAY ANIMALS PERCEIVE THEIR WORLD SINCE THE EVOLUTION OF VISION: A REVIEW ON VISUAL PERCEPTION

Nilarun Manna, Sumit Banerjee and Anulipi Aich*
Department of Zoology, Bhairab Ganguly College, Belgharia,
Kolkata 700056, West Bengal, India
**Author for Correspondence: aanulipi@gmail.com*

ABSTRACT
Our visual world, is it the same for all other animals? No, surprisingly it is not. All the animals with vision have numerous ways to see their respective worlds. All of them have different equipments, mostly eyes, for sensing light in their environment. Although various animals evolved different optical structures, the fundamental components for all are photoreceptors, which contain 2 types of proteins opsin and chromophore. About 555 million years ago in the Ediacaran period, possibly the first eye fossil was found with structures like modern insects in a trilobite, *Olenellus fowleri*. In vertebrates, the visual information that is received by the retina is meticulously analysed. Several invertebrates have excellent light sensitivity with the ability to discern a broad colour spectrum and polarised light. Majority of world's living animals are marine, and they have evolved a myriad of special characters which help them to see in the darkness of the sea floor. In this review we will explore all how all the animals have adapted their perception and vision according to their environment, excluding humans of course as there are several studies conducted on human eyesight in the medical field, whereas we are exploring the animal kingdom from prokaryotes to higher vertebrates.

***Keywords:** Visual Perception, Evolution of eye, visual adaptation, Compound eye, Single Lens eye, Echolocation*

INTRODUCTION

Visual Perception, such a hefty term and must be tough to comprehend. There are around 8.7 million species in the world (Mora *et al.*, 2011) of which very few phyla have evolved a visual system. Let us find out together by diving into the animal kingdom and explore the insane ways they see this colourful world around us. Perception comes from the Latin word "Perceptio" which means to gather or receive (Schacter, 2011). It is the interpretation of what is sensed by an individual in its environment which involves signals that go through the nervous system, which in turn result from physical or chemical stimulation of the sensory system. In the book 'Seduction of the Minotaur', Anaïs Nin said, "We see things not as they are but as we are". Visual perception is the brain's processing of the visual stimulus received from the sensory system, involving interpretation and mental manipulation of the sensory information as required to act respectively (Knudsen, 2020). Different animals have several ways of acting upon their visual data depending upon how their visual system has evolved. The complexity, arrangement & specific adaptation of their eyes finalise how they see their environment; which is also termed as "umwelt" (Kull, 2010). Before we look at how various animals view the world, lets quickly investigate how eyes evolved and adapted in various life forms because, as said by the Biologist Theodosius Dobzhansky in The American Biology Teacher Magazine, "Nothing in biology makes sense except in the light of evolution."

EVOLUTION OF OPTICAL ORGANS

Primitive optical structures

The formation of any kind of eye in an animal follows the same developmental patterns and genetic machinery suggesting that the ancestor of eyed animals had some form of light sensing ability. The most primitive visual organ was eyespots which are opsins or photosensitive proteins that sense only the presence of light enough for photoperiodism and circadian functions. In *Euglena* sp., the eyespot or stigma consists of a red pigment and photosensitive crystals allowing the organism to detect & move toward light (Fig.1). Some jellyfish, sea stars, flatworms, and ribbon worms have pigment spot ocelli which have randomly distributed pigment (red or black) and no other structures (McGraw-Hill, 2007).

The functional unit of the eye are the photoreceptors containing opsins. The principal functions of the eye are to detect presence and direction of light, shading, in the form of dark pigment, for sensing the direction of light and generate impulses to help the organism respond accordingly. Opsins are borne on a layer of microvilli in Protostomes and cilia in Deuterostomes to maximise the surface area of exposure (Autrum, 1979). However, the clamworm or ragworm larva, *Platynereis dumerilii*, has both microvillar photoreceptor and ciliary photoreceptor deep in the brain which can detect light and make out only water and fine, floating particles (Fig.2). At their earliest, these eyes were two celled. Larvae of mussels, sea cucumbers and flatworms also use such eyes to show phototropic movements (Arendt *et al.*, 2004; Jékely, 2012).

In some animals, an ocelloid (Latin. oculus, meaning eye and the suffix '–oid' meaning "like." Hence, ocelloid means eye like) is found which is a subcellular analog to camera-type eyes in, found in athecate dinoflagellates, more complex than eyespots (Fig.3), (Gavelis *et al.*, 2015). It consists of a translucent, roundish hyalosome acting like a refractive lens, surrounded by a layer of mitochondria serving as the cornea, constrictive rings like the iris and a heavily pigmented melanosome (Hayakawa *et al.*, 2015). It is believed that ocelloid helped detecting prey.

The simplest multicellular organisms with photosensitive patches are Hydras which curl into a ball when exposed to bright light (Fig.4). Their vision is based on opsins, which change shape when light strikes them, and ion channels, which respond to the shapeshifting by generating an electrical signal. These permit them to sense the direction and intensity of light not to discriminate an object from its surroundings. A simple eye or pigment pit is a type of eye composed of a single lens and a simple retina.

Pit eyes started out as an eyepatch in ancient molluscs which concaved into a cup allowing limited amount of light to hit the receptors depending upon its angle. Planaria eyes can differentiate direction and intensity of light due to their cup-shaped and heavily pigmented retinocytes which shield the photoreceptors from light exposure from all directions except for a single opening (Fig.5). Deeper the cup, better is the ability of perception (Schoenemann *et al.*, 2009).

Many animals of Class Gastropoda also have ocelli (singular. Ocellus. Latin oculus = eye and means "little eye") at the tip or base of their tentacles which can retract into the stalk itself in response to danger (Zieger *et al.*, 2008). Ocelli can detect lower illumination and have a faster response time. Cnidarians and starfishes also possess ocelli. Dorsal ocelli are found on the dorsal or frontal surface of the head of many insect orders, mostly flying insects, which coexist with the compound eyes. Two ocelli are directed to the left and right of the head and one a central or median ocellus in front (absent in terrestrial insects). The refractive power of the lens is not enough to form an image on the photoreceptor layer and hence help to just detect light (Wilson, 1978). In flying insects, they help to maintain flight stability due to the under focused image, wide field view and high light-collecting ability adapted to measure changes in brightness during flight (Fig.6).

Simple optical structures

Arachnids possess several pairs of simple eyes instead of compound eyes, each adapted for a specific task or tasks (Fig.7), (Foelix, 2011). The principal and secondary eyes in spiders are arranged in four, or occasionally fewer, pairs. Only the principal eyes have moveable retinas. The secondary eyes have a reflector at the back of the eyes. The photosensitive part of the receptor is next to this, so they get direct and reflected light. In hunting or jumping spiders a forward-facing pair possesses the best resolution and telescopic component to see the small prey at a large distance (Peaslee *et al.*, 1989).

Further improvement was made by narrowing the opening of the pit so that light enters through a small aperture, like a pin-hole camera, helping the retina to resolve images. Pin-hole camera eyes, lacking a lens and cornea, are found in the *Nautilus* sp. providing poor resolution dim imaging, but are still a major improvement from the pit eyes (Fig.8), (Schwab, 2018). Unlike humans with 3 kinds of photoreceptors, Crustaceans have 12 thus they can see linear, circular, polar, and hyperspectral colours.

The penultimately lens evolved which initiated as a transparent protective layer of skin that grew over the opening, transforming into an optical instrument to focus light on retina improving the resolution of viewed object. In Class Cubozoa, 24 eyes arranged in four clusters; 16 photosensitive pits but one pair in each has a lens, retina, iris, and cornea. Some jellyfish like *Cladonema* sp. have developed eyes but no brain (Fig.9). However, in camera-type eyes, transparent cells split into two layers, with liquid in between serving as a circulatory fluid, mechanical protection and increasing optical power and image resolution (Melissa M. Coates, 2004; Coates *et al.,* 2001).

Ultimately, a transparent layer and an opaque layer may split forward from the lens into a cornea and iris further forming aqueous humour (Ali *et al.,* 1985). The choroid increases vascularity aiding in circulation and allowing larger eye sizes. The iris's sphincter muscles control the amount of light entering the eyes and the ciliary muscles holding the lens alter its shape to aid in precise image formation on the retina. This type of camera-like eyes is now functionally identical to the eye of most modern cephalopods and vertebrates (Fig.10), (Nilsson & Pelger, 1994).

Many animals have eyes which developed from a completely different path, branching out from the pigment spot (Nilsson, 1983, 2009, 2017). Scallops have multiple, tiny mirror-type eyes along their mantles which use a concave, parabolic guanine crystals to focus and retro-reflect light on a double-layered retina, the outer responding most strongly to light and the inner to abrupt darkness, providing exceptional contrast and ability to detect changing light patterns and motion (Fig.11), (Land *et al.*, 1992).

Complex optical structures

In Insects and some members of Phylum Annelida and Class Bivalvia, compound eyes are derived from duplication of ocelloids (Fig.12), (Land *et al.*, 1992). This kind of eye is composed of thousands of independent visual units called ommatidia (singular. Ommatidium), which can form images in the same way as a camera eye in vertebrates, in a poor resolution, but excellent for detection of quick movement (Fig.13). Compound eyes are better at detecting edges and can form images. In some, the eyes have a pseudopupil which appears as a black spot, moving across the eye as the head is rotated. It occurs when the ommatidia that one observes is along the optical axes of viewing, absorb the incident light, while those to one side reflect it (Zeil *et al.*, 1996). With Compound eyes, animals perceive the surroundings as a blurry jigsaw puzzle with each piece shaped like a hexagon (Fig.14). Chitons have a dispersed network of tiny eyes over the surface of their shells which may act together as a compound eye (Fig.15). Compound eyes are of two types, namely, apposition eye, which form multiple inverted images and superposition eye, which form a single erect image. Apposition eye can either be typical or each lens may form an image which is combined in the brain where it is called Schizochroal compound eye or neural superposition eye whereas Superposition eyes are of 3 types, refracting, reflecting, and parabolic (Fig.16, 17), (Buschbeck, 2005). Nocturnal insects possess refracting superposition eye which has a gap between the lens and the rhabdom (receptive part) and no side wall. Each lens takes light at an angle to its axis and reflects it to the same angle on the other side resulting in an image at half the radius of the eye. In parabolic superposition eye the parabolic surfaces of the inside of each facet focus light from a reflector to a sensor array. Long-bodied decapods have reflecting superposition eyes, which also have a transparent gap but use corner mirrors instead of lenses. Flying or preying insects have flattened and larger facets of ommatidia forming a fovea which gives acute vision as it receives light from a spot.

In Phylum Onychophora, one or two layers of the shell's cuticula continues to form cornea depending on recency of ecdysis (Fig.18). Along with the lens and two humours, the cornea aids in focusing of light behind the retina and protects the eyeball from contamination and parasites (Schoenemann *et al.*, 2009).

Stemmata (singular stemma) are a type of simple eyes found in various holometabolous larvae (insects which show complete metamorphosis), adults of several hexapods and most myriapods, which evolved by the reduction of a compound eye (Fig.19). These eyes are composed of a single biconvex, crystalline lens in front of a single cluster of photoreceptors called retinula. These eyes can acutely form a rough image and are extremely sensitive to polarized light aiding in night vision (Meyer-Rochow, 1947).

A parietal, pineal or third eye is the photoreceptive part of epithalamus, associated with the pineal gland, present at the top of the head in some vertebrates (Fig.20). It helps to regulate circadian rhythm and thermoregulation. Lampreys have two parietal eyes which may have allowed them to sense threats from above (Romer, 1977). Nauplius larvae of Crustaceans have parietal eye containing a lens and senses the direction of light but cannot resolve details. Brine shrimps retain this for life.

In short, visual organs started out as photoreceptors which developed onto pigmented eye spots. From these, the evolution took two paths, one towards compound eyes and the other towards camera type eyes. In various arthropods, pigment spots evolve into ocelloids and then compound eyes, which further diversified into apposition, refracting superposition and reflecting superposition eyes successively. For others, this pigment spot turned into a pigment cup and as the cups opening got narrower, they evolved into pin-hole camera eyes. The opening of these type of eyes gradually enclosed and lens formed, resulting in the most primitive type of camera type eyes which further evolved into the ones we are so familiar with (Fig.21).

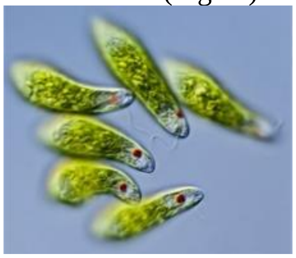

Fig 1: *Euglena* sp. with red eyespots (Bailey, 2023)

Fig 2: *Platynereis dumerilii* (Mack, 2023)

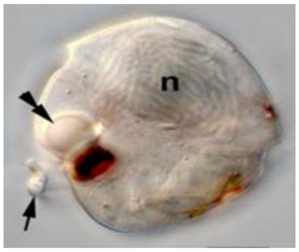

Fig 3: Dinoflagellate with ocelloid (Hoppenrath et al, 2009)

Fig 4: *Hydra* sp. (iNaturalist, 2024)

Fig 5: *Planaria* sp. with visible pit eyes (Perkins, 2011)

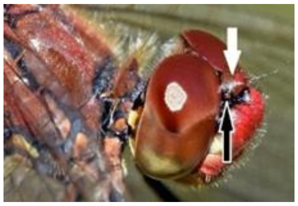

Fig 6: Dragonfly with visible Ocelli (Ray Cannon, 2020)

Fig 7: Eyes of a Jumping Spider (Clein, 2019)

g 8: *Nautilus* sp. With n-hole camera eyes Vikipedia, 2015)

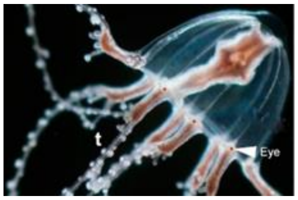

Fig 9: *Cladonema* sp. with eyes (National Geographic, 2010)

Fig 10: Octopus (Cephalopod) eyes (iStock, 2017)

Fig 11: Scallop's blue coloured mirror eyes (Palmer et al, 2017)

Fig 12: Eyes of some arthropods with visible pseudopupils (Reddit , 2012)

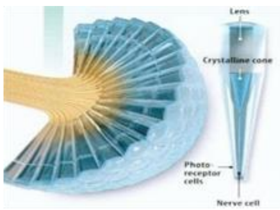

Fig 13: Basic Compound eye structure (Pixelrz, 2024)

Fig 14: Vision through Compound eyes (Williams & Dyer, 2012)

Fig 15: Chiton and its eyes (National Geographic, 2011)

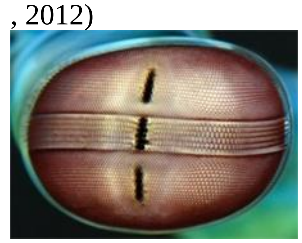

Fig 16: Apposition eye of Mantis Shrimp (U.S. National Science Foundation, 2019)

Fig 17: Superposition eye of a fly (iStock, 2017)

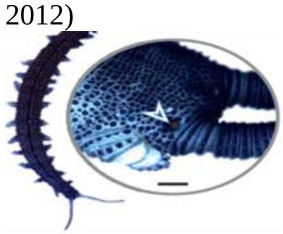

Fig 18: Eye of a velvet worm (Beckmann et al, 2015)

Fig 19: Stemmata of Centipede (Deviant Art, 2013)

Fig 20: Parietal eye Of Iguana (Jones, 2020)

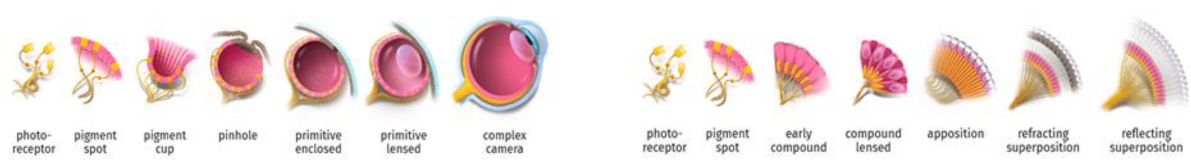

Fig 21: Evolution of Eyes (Belan, 2022)

SPECIAL ADAPTATIONS OF OPTICAL ORGANS IN ANIMALS

As said by Charles Darwin in his book, 'On the Origin of Species', "It is not the most intellectual of the species that survive; but the species that is able to adapt and adjust to the changing environment in which it finds itself.". We discussed the basic ways the eyes evolved in various animal groups but some show little or complete variation in some structures to aid in perceiving the environment they live in. In this section we shall look at ingenious and insane ways animal eyes adapted into. Predators have eyes on the front of their heads for better depth perception to focus on prey. Prey animals' eyes tend to be on the side of the head giving a wide field of view to detect predators from any direction. Someone said, "Eyes in front, I hunt. Eyes on side, I hide." (Fig.22). Ambush predators have vertical, slit-like pupils to judge distances of prey by focusing on the object viewed and defocusing the horizontal background whereas prey animals possess horizontal pupils which produces a much wider or panoramic field of view (Banks *et al.*, 2015).

Invertebrate Adaptations

Almost all animals have round, horizontal or vertical pupils but like everything in science, there also is a weird exception. Cuttlefish, have eyes analogous to vertebrates, like any other cephalopod, but cuttlefish pupil is W-shaped which helps it to balance a vertically uneven field of light, that is to perceive depth, which is common in the watery depths they inhabit (Fig.23). They cannot see colour but can perceive polarised light which enhances contrast. They change focus by shifting the position of the entire lens with respect to the retina, instead of reshaping the lens, like a camera. Also, they are devoid of a blind spot as the optic nerve is present behind the retina (Schaeffel *et al.*, 1999). Cockeyed squid remains in an oblique position in its habitat with a larger, yellow, bulging left eye and a smaller right eye (Fig.24). The larger eye scans the water above the squid for prey's shadow visible against the light and the smaller eye searches depths below to detect bioluminescence against the darkness around (Thomas *et al.*, 2017). Many species of the Cockatoo Squid are bioluminescent organisms and possess light organs on the undersides of their large or telescopic & stalked eyes to cancel their shadows (Fig.25). The Largest Eye in animal Kingdom, Colossal Squid, measuring over twenty-seven centimetres in diameter, the size of a football (Fig.26). The California purple sea urchin is covered with photoreceptors on its surface hence, the entire organism is sensitive to light, that is, it can perceive in all directions, so it uses its spines to block out some of the light to help focus the light for better vision (Fig.27), (Ullrich-Lüter *et al.*, 2011).

Pisces Adaptations

The deep sea is a hotspot of strange enigmas and anomalies. For instance, almost all deep-water or mesopelagic up to bathypelagic fishes have large, upward pointing eyes. Telescope fish have tubular, large, forward-pointing, telescoping eyes with large lens highly adapted to detect shape of their prey against the remaining light from above hence they orient themselves vertically in the water column (Fig.28), (Froese, 2012). Flashlight fishes have white coloured organs containing bioluminescent bacteria underneath their eyes which allow them to forage, evade predators and communicate. Black lids slide up to cover or uncover these organs when needed (Fig.29), (James *et al.*, 1975). Barreleye fishes have large, telescoping eyes, which protrude from the head gazing upwards or forwards, enclosed in a large transparent dome of soft tissue (Fig.30). It also contains a green pigment in its eyes may filter out sunlight coming directly from the sea surface, helping them to spot animals directly overhead (Robison *et al.*, 2008). Many fishes of the bathypelagic zones or those which live in complete darkness such as blind cave fish have completely lost their eyes and rely on their lateral line or chemoreceptors instead (Fig.31). The Stoplight loosejaw produces red bioluminescence so it can hunt as most deep-sea fishes are blind to red light (Fig.32), (Kenaley, 2007). At the sea floor, flatfish, which show negative buoyancy to rest on the seafloor, have typically symmetric, elongated shape in larval stages which float on the surface as plankton. As they reach adulthood, one of the eyes migrates across the top of the head to the other side of the body, loses its swim bladder and spines, and sinks to the bottom blind side down (Fig.33), (Chapleau *et al.*, 1998). Four eyed fish can see above and below the water surface simultaneously (Fig.34). It has eyes that are split horizontally, each with its own pupil and retina as it floats at the surface to feed or avoid flying predators (Albensi, 1998). The barred sand burrower fish, also called the marine Chameleon, has a convex cornea with an embedded flat lens (Fig.35). The cornea which is 1/7th of the eyes thickness, can focus allowing the fish to have depth perception without moving its head (Schwab *et al.*, 2005). Larvae of Zebrafish process the images they perceive with respect to their environment (Fig.36). Above the larva, the vision is achromatic as there is no need of colour vision towards the sky due to absence of colours.

Below and across the horizontal orientation, the larva has tetrachromatic vision, perceiving colour like bees and birds. In front, the larva perceives more of the UV spectrum to aid in prey capture. Hence, zebrafish larva is said to have an asymmetric retina (Zimmermann, 2018).

Amphibian & Reptilian Adaptations

Chameleons have the strangest eyes on the planet, which can move independently of each other, resulting in almost 360° vision (Fig.37). It can also switch between monocular vision, when both eyes are used separately and binocular vision, when both eyes are used to look at the same scene. Uniquely, a negative or concave lens, a positive or convex cornea and corneal accommodation for monocular depth perception. A negative lens increases image size, and a positive cornea allows accurate focusing by accommodation (Ott *et al.,* 1995 & 1998). Crocodile eyes have a layer of reflective, mirrored crystals behind retina (Fig.38). During the day, a pigment in these crystals acts like a pair of sunglasses but at night, the pigment cells retract, allowing the crystals to reflect light back onto the retina, amplifying the strength of the image. They are active throughout the day and thus, their eyes are adapted for dim or night vision better (Karl *et al.,* 2018). Sea Turtle eyes have individual photoreceptors containing red oil droplets help them see on the dark sea floor by obstructing shorter wavelengths picking up longer wavelengths (Fig.39). Snakes, some skinks, some lizards and almost all geckos have brille, a layer of transparent, immovable disc shaped skin or scale, instead of eyelids, so, some of them lick their eyes to clean and moisturize them (Fig.40), (Bellairs *et al.,* 1947). Snakes which are diurnal have UV filtering visual pigments or lenses to increase sharpness and contrast which is not seen in nocturnal species which are transmissive (Simões et al. & Caspermeyer, 2016). Diurnal snakes typically have round pupils and moderate-sized eyes whereas nocturnal snakes have large eyes, many with slit-like pupils (Fig.41). Boas, Pythons and Pit Vipers can 'see' in the dark using infrared radiation from the animal's body in front of them with the help of protein channels located in their pit organs (Fig.42). This allows them to detect the animal's heat signature and form a thermal image of the same. Similar thermal imaging system is also seen in *Drosophila* and Vampire bats as well (Fig.43), (Gracheva *et al.,* 2016).

Avian & Reptilian Adaptations

All birds and some reptiles have eyes similar in structure to the vertebrate eye except they possess a special comb like vascularized and pigmented, non-sensory structure, the pecten, originating from the choroid projecting into the vitreous humour from the blind spot (Fig.44). It helps to reduce the number of blood vessels in the retina and leading to high sharpness and UV protection (Kiama *et al.,* 2001). Many birds are sensitive to the visible spectrum and UV, that is, they are tetrachromic (Fig.45), (Wilkie *et al.,* 1998). Birds have high contrast sensitivity (Ghim *et al.,* 2006); sensitivity to flickering and slow movements such as stars and constellations aiding in migration (Jones *et al.,* 2007); when an object is partially blocked, humans unconsciously tend to make up for it and complete the shapes which is absent in birds (Sekuler *et al.,* 1996) and can also perceive magnetic fields by moving their head to detect its orientation. The right eye of a migratory bird contains photoreceptive proteins called cryptochromes that interact with the Earth's magnetic field located in their field of view providing directional information and bionic vision helping them to hunt (Heyers *et al.,* 2007). Diurnal birds of preys like eagles are equipped with the best eyes in the animal kingdom with is exceptionally sharp because each eye has two foveae compared to one in humans (Fig.46). The cones in the fovea are ridiculously small and tightly grouped, allowing them to see minute details from extreme distances. Nocturnal birds like Owls have larger, tubular eyes with large numbers of tightly packed retinal rods, no cones, and a few coloured oil droplets to reduce light intensity (Fig.47). Retina contains a retroreflective, collagenous layer called tapetum lucidum which reflects visible light back through the retina, increasing the light available to the photoreceptors, contributing to the superior night vision of some animals (Gunter *et al.,* 1951). Surface feeding birds, like Sea Gulls, have red oil droplets in the cones to improve contrast and sharpness (Fig.48). Birds that must look through an air-water interface have more deeply coloured carotenoid pigments in the oil droplets to help them locate shoals of fish (Lythgoe, 1979). Birds that fish by stealth, like herons, observe the prey in an angle to cancel out the lateral shift (Fig.49). Birds that pursue fish under water, like loons, have less red oil drops, instead have a flexible lens, and use the nictitating membrane as an additional lens to allow greater optical accommodation (Fig.50), (Gill, 1995). Birds which spend most of their life wandering close to the ocean surface, like albatross have a Giganto Cellularis, a long, narrow, gangliocyte rich area on retina, helping detect prey near the surface as a bird fly low over it (Fig.51), (Hayes *et al.,* 1991). Penguin eyes have flat cornea and strong lens adapted to diving (Fig.52). Hooded merganser eyes can bulge part of the lens through the iris when submerged (Fig.53). Curvature of the cornea determines whether a bird has better day or night vision (Graham, 1991). An ostrich's eye is the larger than its brain, largest among all land animals, measuring five centimetres across (Fig.54).

Mammalian Adaptations

Even among mammals, mostly dichromatic, a wide variety of eye adaptations are easily detectable. Horse eyes are anterio-posteriorly flattened and have dichromatic vision hence they cannot distinguish red, like vision in red-green colour-blindness in humans (Fig.58), (Carroll *et al.,* 2001). Mostly, domesticated horses are myopic whereas wild horses are hyperopic and have poor accommodation ability. Also, in binocular vision, they have a central, vertical blind spot whereas in monocular vision, they have two blind spots, in front and right behind the head (Fig.57), (Giffin *et al.,* 1998). Reindeer eyes, specifically the tapetum lucidum, undergo a colour change in the winter season from golden in summers to prussian in winter (Fig.55, 56). In the prolonged Arctic winter, the pupils of reindeer dilate for extended periods of time which obstructs the small fluid draining vessels of the eyes, increasing internal eye pressure. This pressure affects the type of light reflected by the tapetum as the collagen gets squeezed out and get tightly packed (Jeffery *et al.,* 2013). Canines, felines and rodents have similar colour vision with red-green colour blindness thus can only distinguish yellow, blue, and indigo, perceiving red and green as two similar yellowish hues. Additionally, dogs have poorer eyesight compared to humans which is compensated only by its sense of smell; dogs have vision that is like myopic people while cats have vision like hyperopic people. But they can perceive movements faster than humans and see better at night due to tapetum lucidum. On top of the colour weakness, dogs have poor eyesight, which blurs the details of objects whereas cats have more rods hence have better night vision (Fig.58, 59, 60, 61), (Neitz *et al.,* 1989; Jacobs Gerald H. 2009). Primates evolved trichromatic vision whereas most of the mammals are dichromatic (Kawamura, 2016). Tarsiers have the largest eyes of any primate with respect to its body size, about the size of its brain (Fig.62). Catarrhines (baboons, macaques, langurs, orangutans, gorillas, chimpanzees, bonobos etc) and howler monkeys have separate cones to distinguish red and green. In Platyrrhines (marmosets, spider monkeys, woolly monkeys, squirrel monkeys etc) red and green are genetically determined (X-linked), males are always dichromatic, whereas females may be either dichromatic or trichromatic (Napier & Groves, 2024).

ECHOLOCATION AS A MEANS TO "SEE"

Many animals live in the darkest corners of the Earth; hence, some organisms have evolved echolocation or biosonar. Echolocating bats, toothed and baleen whales, burrowing mammals like shrews, tenrecs, solenodons and soft furred tree mice (Siemers *et al.,* 2007; Gould, 1965; Eisenberg & Gould, 1966; He *et al.,* 2021) and cave dwelling birds like cave swiftlets and the oilbirds emit calls and listen to the echoes of those calls that return from various objects near them creating a map of their surroundings when sight is not an option. This is not the conventional "seeing" but like snakes with pit organs which make a thermal image, these animals form a "mental blueprint" of their environment using sound. Echolocating bats use biosonar to navigate and forage. They can determine an object's distance, size, shape, density, and the direction of movement if it is dynamic (Fig.64), (Lima *et al.,* 2013). Echolocation is advantageous when searching for small prey, whereas vision is advantageous when avoiding obstacles (Boonman *et al.,* 2013). Biosonar is used by toothed whales (dolphins, porpoises, river dolphins, killer whales, and sperm whales)

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which can hear ultrasonic frequencies and baleen whales (right, bowhead, pygmy right, and grey whales and rorquals) which can hear infrasonic frequencies (Fig.65), (Viglino, 2021). Soft furred tree mice and shrews emit low amplitude, multi-harmonic and frequency modulated sounds devoid of echolocation clicks with reverberations used for simple, close range spatial orientation to investigate their habitat (Fig.66), (Siemers *et al.*, 2007). Oilbirds and cave swiftlet emit calls to fly and navigate through trees and caves (Fig.67), (Cavendish, 2000). These animals use biosonar due to their dark, turbid, or absorptive habitat and acoustically favourable environment (Hughes, 1999).

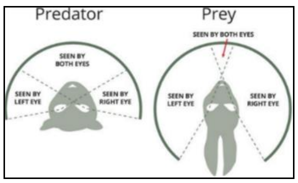

Fig 22: Visual field of predator Vs prey (Robert, 2020)

Fig 23: Eye of Cuttlefish (Hanquet, 2012)

Fig 24: Yellow eye of a Cock-eyed squid (Eloise Hamann, ewritessite, 2017)

Fig 25: Eyes of Cockatoo squid (Schlining, 2017)

Fig 26: Eye of a Colossal squid (iStock, 2018)

Fig 27: California Sea Urchin (Fackler, 2009)

Fig 28: Telescope fish (Reddit, 2014)

Fig 29: Flashlight fish (Tumblr, 2019)

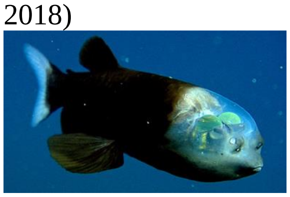

Fig 30: Barreleye fish (Schlining, 2017)

Fig 31: Blind cave fish (Kemeny, 2022)

Fig 32: Stoplight loosejaw (Wikipedia, 2020)

Fig 33: Flatfish (Ferrebeekeeper, 2015)

Fig 34: Four-eyed fish (Wambugu, 2019)

Fig 35: Barred sand burrower fish (Maxime et al, 2018)

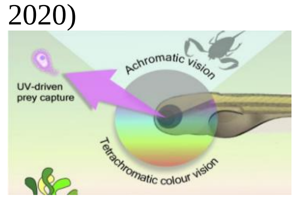

Fig 36: Differential vision in zebrafish larva (Bray, 2021)

Fig 37: Chameleon eyes (Heuclin, 2012)

Fig 38: Crocodile eye (Fineartamerica, 2022)

Fig 39: Sea Turtle eye (Rath, 2014)

Fig 40: Brille on a snake eye (Wikipedia, 2007)

Fig 41: Typical Diurnal Vs some Nocturnal snakes' eye (Wikipedia, 2006)

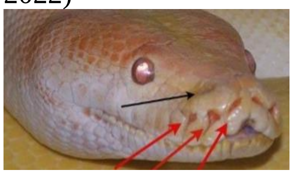

Fig 42: Boa with its pit organs (marked in Red, Millichamp , 2022)

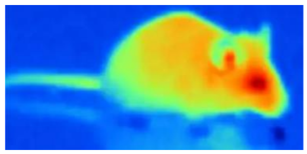

Fig 43: Infrared or thermal image as seen by a snake (Carroll, 2012)

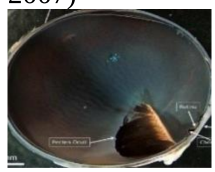

Fig 44: Dissected eye with pecten (marked) (Wisely et al, 2017)

Fig 45: Colour Vision in Humans Vs Birds (Reddit, 2022)

Fig 46: Eye on an Eagle (Erickson, 2007)

Fig 47: Eye of an Owl (iStock, 2017)

Fig 48: Eye of a Sea Gull (Shutterstock, 2017)

Fig 49: Eye of a Heron (Willoughby, 2016)

Fig 50: Eye of a loon (Cumming, 2012)

Fig 51: Eye of an Albatross (Tobias Hayashi, 2022)

Fig 52: Eye of a Penguin (Edwards, 2011)

Fig 53: Hooded merganser (Thompson, 2019)

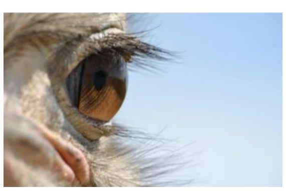

Fig 54: Eye of an Ostrich (Esterhuizen, 2020)

Fig 55: Tapetum Lucidum of a Cat ("Glowing" cat eyes, 2024)

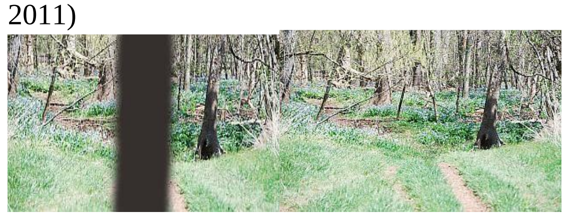

Fig 57: Horse Vs Human Vision showing Blindspot (Johnson, 2008)

Fig 56: Reindeer Eyes across the seasons (Kalish, 2023)

Fig 58: Human Vs Horse Colour Vision (Paul and Stevens, 2020)

Fig 59: Human Vs Dog Colour Vision (Meyers, 2021)

Fig 60: Human Vs Cat Colour Vision (Spector, 2013)

Fig 61: Squirrel eye (Stackexchange, 2018)

Fig 62: Tarsier eyes (Tarsier Facts, 2016)

Fig 63: Bonobo eye (Coghlan, 2014)

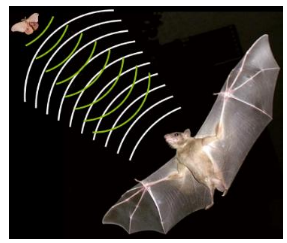

Fig 64: Echolocation in Bats (Rendall, 2013)

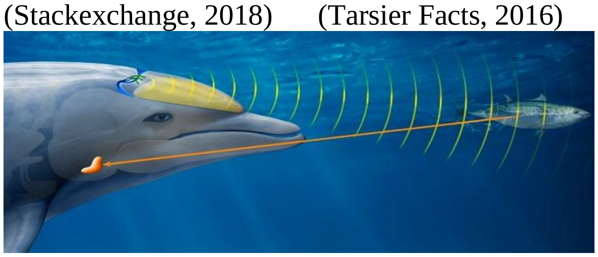

Fig 65: Echolocation in Whales and Dolphins (Sarfati, 2019)

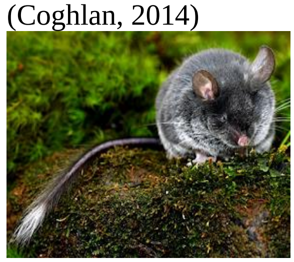

Fig 66: Soft furred tree mice (Liu and Xiaofeng, 2021)

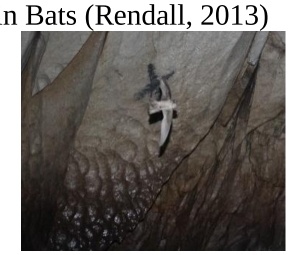

Fig 67: Cave Swiftlet (Wikipedia, 2020)

CONCLUSION

As curious beings, us humans wonder how the world will look like through the eyes of other animals. We may not be able to view directly through the eyes of other creatures, still, we can appreciate the diverse beauty of vision. Although we are unable to read the minds of animals or communicate with them, we can use scientific research to quench the thirst of knowledge. Almost all animals have some type of light sensing abilities, even in darkest of habitats such as the deep ocean. Hence, we reviewed assorted studies, analysing how animals focus, see colour, see other organisms, sense or perceive nearby objects and so on. Eyes of different animals have evolved to fit their respective survival required according to their niche, hence what might be good for one animal, might not be useful for another. How an animal looks at its habitat can help us understand their behavioural patterns such as circadian rhythms. The human trichromatic eye sees a wonderfully colourful world but cannot detect other light spectrums or images at a great distance, on the contrary, other animals get a glimpse into the world unseen by us. Sometimes it becomes beyond imagination of a human being about what an animal can see through us. Let us ensure we preserve their wild homes, just as they are meant to be seen.

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