MAS.963 Special Topics: Computational Camera and Photography
Fall 2008

Animal Eyes, Part 1

Prof. Ramesh Raskar November 14, 2008
Notes by anonymous MIT student Lecture 11

Introduction

These notes describe part 1 of a lecture given by Quinn Smithwick on animal eyes, based on the book of the same name by M. F. Land [1]. Discussion of this material is relevant to the development of new camera technologies, as successful imaging device designs are often found to parallel constructs that are found in nature. By studying what occurs in nature we may be inspired to create new and better imaging devices.

These notes are supplementary to the slides, which are available on the course website. Therefore, these notes should be read as a companion to the slides which give insight into the class discussion provoked by the material and the material that was covered by not stated on the slides.

Each section below corresponds to the title of a slide in the Animal Eyes presentation, and details the extra information relevant to that slide. If no additional information was discussed for that slide, than no section is included.

Photoreceptor Proteins

It was noted here that the eye is one of the most biologically active areas of the body, due to the need to continuously replenish the retinal in the photoreceptors.

The bright spot effect that remains when a bright light is observed is known as washout. It is due to a depletion of the retinal in the photoreceptors in one region of the retina.

Two methods the eye uses to control noise are noted by Quinn. Unlike the neural signaling in other parts of the body, the neurons of the eye signal continuously until their output is suppressed by the retinal chain reaction when photons are received. The other method the eye uses is to require multiple incident photons before signaling. Quinn tells us that about 5 are required.

Polarization

Many types of insects have polarization sensitivity. The peacock shrimp has circular polarization sensitivity.

Some have hypothesized that the human eye has some polarization sensitivity. Quinn gives the visibility of the pattern in car rear-windshields, which is only visible under polarization, as possible circumstantial evidence. But this effect could also be caused by incident polarized light, as can occur with certain sky conditions.

In fact, many animals use the polarization of the sky for navigation. Quinn relates that at some time airlines gave out polarized films to let passengers observe this effect.

Parietal Eye

We note that humans have some light sensitive cells that bypass the optic nerve and vision regions of the brain to directly affect the autonomic nervous system.

Eye Spot

We wonder why the Euglena spirals towards light. The motion is some kind of search pattern, but how does it work?

Members of the class express frustration with the literature on these topics as typically unverified hypotheses are all that can be found in the way of explanation for form and behavior.

One device that is reminiscent of the eye spot with pigment cells is the single fiber spectrometer.

Multiple Eye Spots

The class wonders how something like a starfish, which has eye spots on each of its tentacles and no central nervous system, can move around without tearing itself apart.

Eye Pits

There is a lot of discussion about the snake, which has a thermal pit, as to whether it is possible for the snake to do thermal imaging with the pit on not. As Quinn shows on the slide, there is a group that has shown that it is theoretically possible to use a pit like the Snake's for imaging, but this does not mean that the snake is using it that way.

We also note that the thermal pit is in addition to normal vision (the snake also has eyes) and that it is believed that the pits first evolved for protection, such as aiding in the location of hiding places, and were only later co-opted for predation.

Ramesh speculates that snakes which are charmed by snake charmers are actually responding to the snake like shape of the instrument being played, rather than the sound. He wonders if we shouldn't use heat sources to charm them.

Compound vs. Simple Eye

We note that the Tombo camera is similar to the compound eye.

It is hard to have a high a high resolution compound eye because of diffraction of light. In other words, to increase the resolution a smaller columnater is required, which increases the diffraction blurring effects.

Pinhole Eye

We note that one non-obvious disadvantage of the pinhole eye is that parasites can crawl inside and infest it, since it is open to the environment. One solution for this is for animals to "fill it with goo," as Quinn says. This may be the first step towards a lens in the eye.

Spherical Lens

The class wonders why nature uses spherical lenses at all given the difficulties they create. It is easier to manufacture them when grinding is required. But what is the reason that they would grow that way? Possibly the surface tension of water tends to make things spherical.

It is possible to reduce the artifacts due to a spherical lens by using a curved sensor. The University of Illinois has come up with a flexible sensor design[2]. We note that a curved surface is not *required* to correct spherical aberration, it can be done with other types of optics, and that the decision is a trade-off between complexity of the sensor and complexity of the optics. We also note that the spherical aberration is only one type of aberration that affects lenses.

GRIN Lens

Ramesh notes that the earth's atmosphere can act like a GRIN lens.

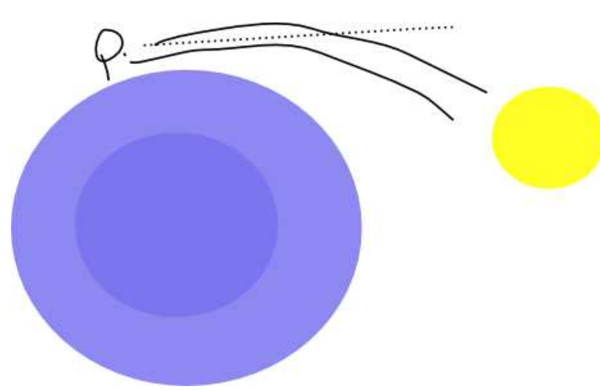

Figure 1: The earth's atmosphere can behave like a GRIN lens.

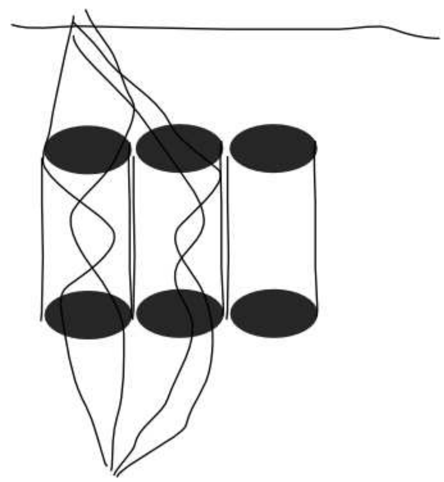

Figure 2: A photocopies uses GRIN to focus an image. Unintuitively, each GRIN lens column does not focus light for only the pixel below it.

Aside about cloaking

This discussion was inspired by the GRIN lens. We discussed the ability of some materials to make light bend corners, which is "easy" for sound and radar, but difficult for wavelengths in the visible spectrum. The material must have a negative index of refraction for this to occur. It is possible to simulate such a material with a metamaterial - a construction of other materials which have the net effect of a negative index of refraction.

Other examples of cloaking involve putting an object inside a glass sphere, and a large convex lens.

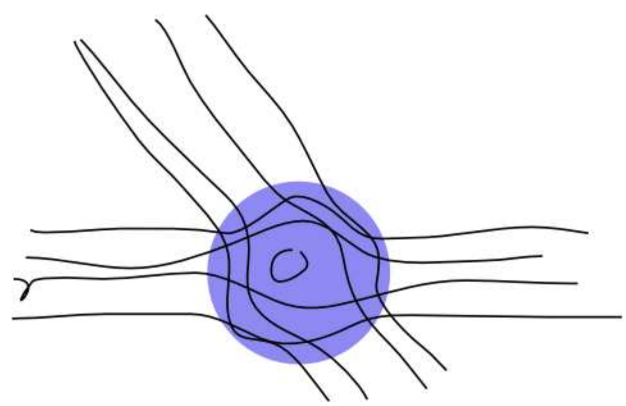

Figure 3: A spherical object cloaking the object inside.

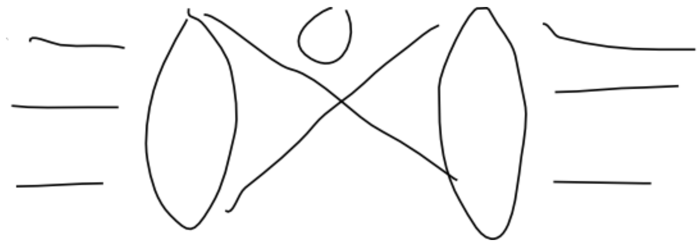

Figure 4: Two lenses cloaking an object between them. This is similar in principle to the sphere, but is view position dependant.

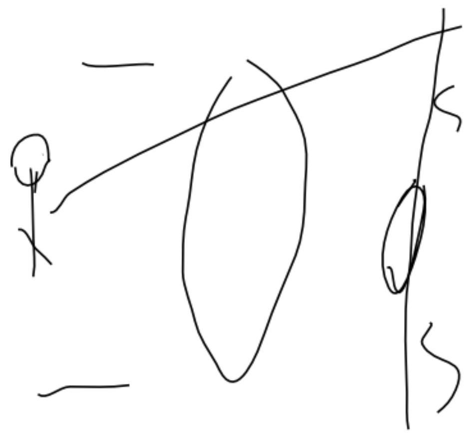

Figure 5: A single convex lens cloaks the object behind it. This is also view position dependant.

Chromatic Aberrations

Cats are an example of an animal that uses the GRIN method at the bottom of the slide to combine multiple chromatic aberrations into a single image. We were unable to come up with what types of advantages this might confer on an animal.

We note that some camera manufacturers (Canon) use a grating to undo the chromatic aberration in their lenses. Ramesh wonders if this blocks 50% of the light, but Prof. Hiura thinks that they use a phase grating.

Focusing

Jim notes that the human eye has a rotational degree of freedom for object tracking. He suggests we look in the mirror and tilt our heads from side to side to observe the effect.

Aside about the human eye's blind spot

The blind spot is caused by the area in which the optic nerve leaves the eye.

The prevailing design for electronic pixels has a similar configuration. The circuitry is placed on top of the photosensitive layer of the sensor and obstructs a small portion of it. As the pixel pitch decreases, the size of this readout circuitry does not decrease, meaning that a larger percentage of each pixel is blocked. For pixels ¡ 1 micron this begins to become a significant problem. Various work has been done to put the electronics on the back of the sensor. Although this is more light efficient it is less electrically efficient.

The evanescent wave, a wave that travels along the surface of an object, also begins to cause problems for small pixel pitch. It creates crosstalk between neighboring pixels.

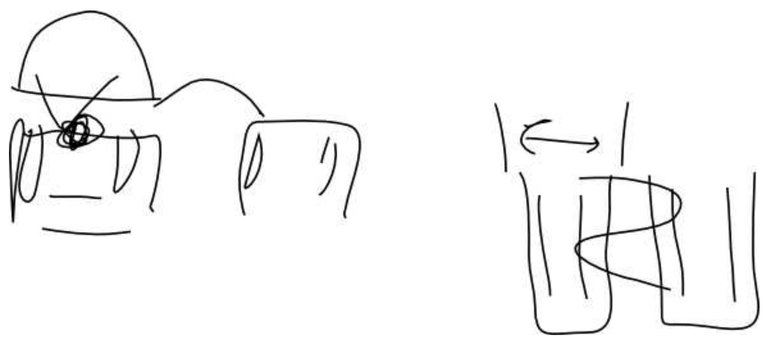

Figure 6: This diagram show the electronics covering the pixel grow proportionally as the pixel shrinks. The evanescent wave is depicted crossing two small pixels.

Cornea

Quinn mentions that horses have a very flat cornea, like a ramp. It was once speculated that they used this to obtain different focal lengths in different visual regions, but this is not the case.

Accommodation

Some animals have adjustable accommodation. Ducks, for example, have a spherical lens that pushes through the pupil to form a tight sphere which allows them to see underwater. The lens relaxes for a flatter cornea tuned to vision in the air.

Quinn has a flexible rubber dog that he squishes to demonstrate this effect.

Ramesh mentions Optotune which can change its focal length electronically by changing its index of refraction.

Iris/Pupil

Edgarton used polarizers to get a particularly fast shutter for photographic the beginning of nuclear bomb explosions. It is also advised to use a disposable mirror to reflect the light into the camera without exposing the camera to the shockwave. This technique is also used to photograph bullets.

Nocturnal Vision

Owls have cylindrical eyes. They cannot point them in different directions, which is why they are able (and required) to turn their heads so far around.

Some animals are able to bin their photoreceptors together to achieve lower spatial resolution night vision.

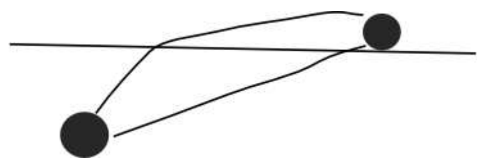

Figure 7: Some animal's eyes have multiple focal lengths in different regions of the eye to allow them to see objects above and below the water.

References

[1] Land, Michael F. and Nillson, Dan-Eric. *Animal Eyes*, Oxford University Press, 2002.

[2] Sun, Yugang and Rogers, John. *Structural forms of single crystal semiconductor nanoribbons for high-performance stretchable electronics*, Journal of Materials Chemestry, 2007, Vol. 17.