Detecting the Detector: Significant Examples

Colin Bruce Jack

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ColinBJ@gmail.com

ABSTRACT

This paper adds supplementary information to my previous papers on Detecting The Detector[1,2] and should be read in conjunction with them. It lists potentially widespread categories of use of a detector-detecting sense, including some which may be ecologically or scientifically important. Candidates described are:

- The *Histioteuthidae* family, common name cockeyed squid
- Chameleons
- Members of the tarantula family which have convergently evolved a blue coloration of specific wavelength
- Fish and other marine animals which use counterillumination generally assumed to be for concealment, yet actually emit light from a pattern of discrete spots, which is not optimum for concealment but could be optimum for retroreflector-detection
- Some of the very wide range of animals which have light-detecting opsins distributed over their body surface. Especially in conjunction with the ability to vary the intensity or other properties of light reflected or emitted from the local body surface, this could enable omnidirectional detection of animals hiding in shadow: large-eyed predators at medium range, or small-eyed prey at close range.

Also potentially relevant to the widespread importance of a retroreflector-detecting sense is the existence of animals with pupils which do not have circular symmetry. This may be evidence of an ‘arms race’: how you do evolve an effective eye which minimizes its own detectability by retroreflection?

1. Cockeyed squid

All members of the *Histioteuthidae* family have two markedly different eyes: a larger one generally oriented upward, and a smaller one generally oriented downward.

The reason for the asymmetry is generally assumed to be optimisation for the different tasks of spotting dark objects against a bright background, and bright objects against a dark background. However an eye optimised to detect retroreflectors would also be expected to be different from one optimised for ordinary vision.

Two specific examples appear particularly promising:

Histioteuthis reversa, also known as the *reverse jewel squid* or *elongate jewel squid*, has a small eye surrounded by a ring of 17 large and one small photophores, and a large eye ringed by 10-14 small photophores with an additional 7 large photophores set in front of it.[3] The latter arrangement is almost comically similar to a simple design a student might construct from standard optoelectronic components to detect retroreflectors, using LEDs in place of photophores.

The surface of the large eye of ***Histioteuthis heteropsis***, also known as the *strawberry squid*, fluoresces a blue-green colour under external illumination.[4] This is exactly the type of emission – a specific wavelength emitted not merely closely adjacent to the eye, but actually from its forward surface – which would enable extremely efficient retroreflector-detection.

2. Chameleons

Chameleons have striking vision-related features apparently unrelated to their general colour-changing abilities. They have a unique eyelid which covers the eye right up to the edge of the circular pupil, whatever direction the eye is oriented. The colour of this eyelid can be changed quite rapidly. These properties are exactly what is required to detect retroreflection, including discriminating retroreflected light in a field of view brightly illuminated by other sources.

The two eyes can also be oriented independently of one another, which would enable efficient scanning for the presence of retroreflectors.

Chameleons are both conspecific and interspecific cannibals, so arms races within this group involving relative detectability are likely.

3. Tarantulas

A recently discovered puzzle is that many members of the tarantula family have evolved a blue coloration of wavelength close to 450 nm.[5] Yet the precise mechanisms to produce the colour vary, and have evolved independently and perhaps relatively recently.

A possible explanation: the tarantula has an obvious need to detect large-eyed predators such as birds and nocturnal mammals. However reflecting or fluorescing light, necessary for retroreflector detection, can give the tarantula's presence away. Over time, ecological and environmental changes may plausibly have altered the wavelengths which large-eyed predators are least sensitive to, and/or pay least attention to, worldwide in a similar way. Animals which must sometimes look at the sky might well evolve insensitivity for, or to actively filter out, the blue wavelength currently most scattered by the atmosphere. Even in very recent times, anthropogenic 'global dimming' and 'global browning' have altered the brightness and predominant colour of diffuse light from the sky worldwide.

There would be a strong evolutionary incentive for tarantulas to perform retroreflector detection by emitting whichever wavelength predators are currently least sensitive to, explaining rapid and potentially convergent evolution of different species as observed.

4. Counterillumination

Many fishes, and other species such as certain squid, emit light in a downwards direction which seems calibrated to mask the dark silhouette which an animal looking upwards from beneath them would otherwise observe against a background of diffused daylight or moonlight.

However the light is often emitted from a relatively small number of pointlike sources. This may be because of the practical difficulty of cultivating and controlling the luminescent microorganisms which many animals use for this purpose. However such patterns must be highly conspicuous at close range, puzzling if their sole or main purpose is camouflage.

Pointlike sources are however optimal for detecting retroreflection, if the angle between the detecting animal's light source and light detector is small as seen from the detection direction. Even with photophores located some distance from its eyes, an animal can pivot so that, as seen from a particular direction, the angle between its eye and one of its photophores is small. If photophores are arranged in a line collinear with the eye, the animal can even orient itself so that multiple photophores are anglewise close to the eye. Bristlemouths have photophores aligned in such lines.[6] It would be extraordinary to find that the most numerous animal on earth uses retroreflector-detection, and that this ability contributes to its success.

At least some of the animals currently assumed to be emitting light from their lower surface solely for the purpose of matched counterillumination camouflage may be primarily using the light to perform retroreflector detection, the matched counterillumination aspect being merely the way they make the light they must emit for retroreflector detection as inconspicuous as possible.

5. Body surface opsins

Many animals have opsins distributed copiously over their body surface, e.g. in human skin in melanocytes and keratinocytes. This seems like overkill if their light-detecting purpose is merely to avoid sunburn by altering the animal's behaviour and/or controlling the production and distribution of melatonin and other substances which confer UV protection. An extraordinary speculation would be that it gives some or many animals a secondary visual mechanism, allowing them to keep watch in all directions. For example detecting an approaching animal whose shadow falls on them.

Especially in conjunction with the ability to change the amount or property of light emitted or reflected from the adjacent skin area, this could also confer omnidirectional retroreflector-detecting capability. Skin opsins have recently been found in cephalopods.[7] While the sense would obviously be limited in resolution, the ability to detect large-eyed predators stalking them from deep shadow (e.g. in the case of small marine animals, detecting cuttlefish lurking in their burrows); or small eyed prey hiding behind and/or in the shadow of the detecting animal itself (e.g. in the case of bristlemouths, detecting copepods immediately beneath them) could be very useful.

Whimsically, present day humans or our ancestral line may conceivably have possessed such a sense, explaining the intuitive feeling some people have that they can detect whether they are being watched, and the intuition children have that being able to see someone, and being visible to them, are two sides of the same coin.

6. Pupil shape and eye detectability

Any focusing eye operating at low f-number acts as a good retroreflector because a high proportion of light either reflected or scattered from the plane of the retina is returned through the lens. Due to the reversibilty of ray optics, such light is refocused to travel precisely toward the point it came from.

If there is a reflective tapetum behind the retina, as is the case with many animals, and if the pupil aperture is symmetrical about its central point, whether circular or slit-shaped, then the eye acts as a good retroreflector even at high f-numbers: almost all light which is not absorbed in its transits through the retina is reflected back through the pupil to be redirected toward the source. However if the pupil is not symmetrical about its central point, and the tapetum on its own acts as a simple mirror rather than a retroreflector, this is not the case: indeed if the transparent pupil area occupies less than half the area of the minimum circle containing it, none of the light reflected by the tapetum need have a direct escape path.

(The tapetum is often described in the literature as itself retroreflecting, but does not necessarily have this property: a focusing eye as a whole system can act as a good retroreflector whether light which has reached the retina is backscattered as from a Lambertian source, simply reflected, or retroreflected. This may well have led to mischaracterisation of the properties of the tapetum considered on its own.)

A need to suppress retroreflection could explain the W-shaped pupil of the cuttlefish, the crescent pupil of the stingray, the string-of-pinholes pupil of the gecko, and the keyhole-shaped pupils of some snakes.

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