1 On concentrated photoreceptors

Consider the question of why we must move our eyes across a line of text in order to read it. Generally, an entire line, paragraph, or even page fits comfortably inside our visual field, yet we laboriously move our eyes around in order to collect enough information to recognize the individual visual symbols of language. This behavior can be explained by the high concentration of cone photoreceptors in the center of our visual field (see Figure 1.1). The central 5^o of visual angle (about two thumbnails wide at arm's length) surprisingly account for roughly half of the cortical representation of the visual input in the brain, and thus it is only in this small area that highly selective character recognition is possible. In fact, uneven visual acuity is a pattern preserved across many branches of life from insects [4] to fish [2, 1] to birds [8] to mammals [7] (see Figure 1.2). Interestingly, it confers a fitness advantage independently of the size of the brain of the animal. To understand why this is at a basic level, suppose we have two regions in the retina A and B that map corresponding parts of the visual world w_A and w_B which on average contain information content a and b[1], and that they will receive computational resource allocation (e.g. photoreceptor density) x and y respectively, according to the genetics of the animal. Generally, we tend to find in animals that $x \propto a$ and $y \propto b$ (proportional allocation). That is, retinae have photorecptors concentrated where events and targets are most likely to project, at the center of binocular vision for humans or along a visual streak for animals in open terrain. An intuitive energy function which is maximized for proportional allocation subject to a constrained resource $x + y = 1, x > 0$, and $y > 0$ is:

$$F(x, y) = a \cdot tanh(kx) + b \cdot tanh(ky) \tag{1}$$

where $k > 0$ is a parameter controlling how fast the resource allocation results in information saturation to levels a and b. Figure 1.3 illustrates how k parameterizes the fitness landscape between that which gives rise to proportional allocation and that which gives rise to uniform allocation, which may model the environment of the deep-sea fish *Chauliodus* which possesses a uniform retina [5].

What computer vision scientists can learn from this fact of nature is that an algorithm allocating equal compute cycles to all parts of the visual input is suboptimal, independently of how great the available compuational power is. It it thus useful to establish priors on where events or objects are likely to occur, and this has been demonstrated empirically [6].

References

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[1] for instance a perfect recontruction allows the animal to distinguish between 2^a and 2^b important possibilities

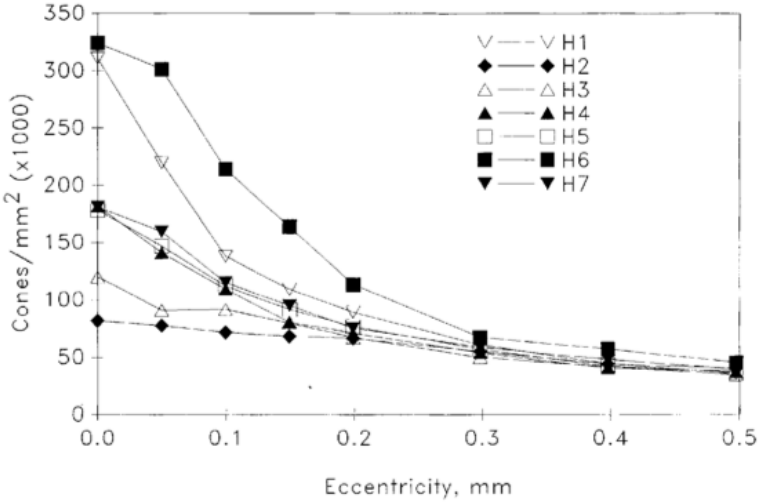

Figure 1: The peaked cone photoreceptor density in the human retina is shown as a function of distance from the fovea, taken from Curcio et al. [3]. Different lines correspond to different individuals.

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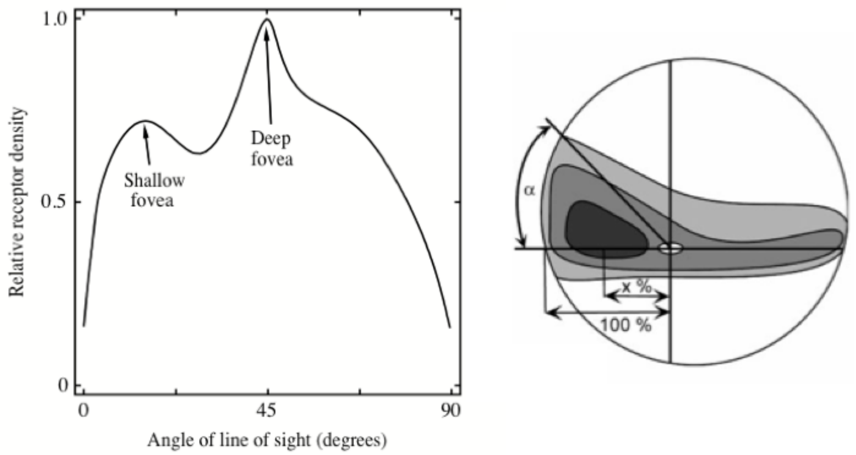
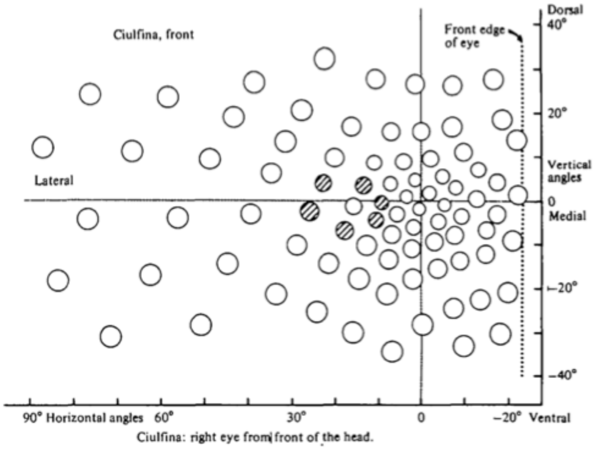


(a) falcon

(b) antelope



(c) mantis

Figure 2: The non-uniformity of photoreceptor densities observed across a wide range of animal species. (a) From Tucker et al. [8], photoreceptor density in an idealized falcon as a function of visual angle. (b) from Schiviz et al. [7], middle-wavelength cone photoreceptor densities in hartebeest (an African grassland antelope), (c) from Horridge et al. [4], ommatidia distribution in a species of mantis in the forward-looking part of the compound eye, as a function of visual angle.

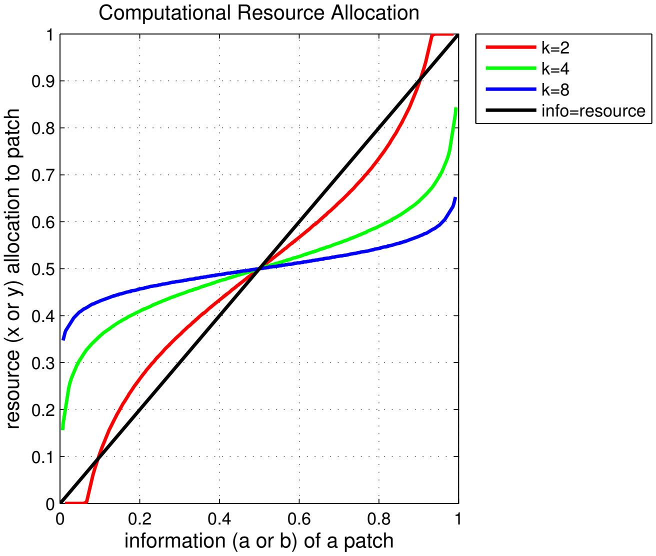


Figure 3: Under the fitness reward scheme given in Eq. 1.1, we show the optimal value (that which maximizes F) of x given a. Here, $a + b = 1$ and $x + y = 1$. This is a model of how the photoreceptor density in a retinal patch should grow with its average information content. In environments where there is slow incremental benefit (e.g. $k = 2$), the optimal allocation matches the information content tightly, but in an environment where the information content of a patch quickly saturates, the resource allocation is more uniform ($k = 8$).