Why don’t we see color at night?

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1 Introduction

- Cones are used for day vision and rods are used for night vision
- Cones typically come in several classes with different spectral tuning (supportive of color vision)
- With rare exceptions,[1] rods in a single retina contain only one type of photopigment (not supportive of color vision)
- Why is it usually advantageous not to see in color at night?

(a) Nocturnal hawkmoth (b) Helmet gecko

Figure 1. *Exceptions to the rule*. Some animals retain color vision at low light levels.

2 Approach

- We formulate a simple statistical model of the visual world and of how visual stimuli lead to photoreceptor responses.
- Given the statistics of the visual world, we can use Bayes’ Law to estimate the stimulus from the array of photoreceptor responses. The estimator is tailored to the photoreceptor arrangement and noise properties.
- For any choice of arrangement and noise properties, we compute the expected estimation error obtained with the optimal estimator.
- We explore which arrangements minimize expected estimation error under daytime and nighttime lighting conditions.

3 Model

- We represent the visual world and photoreceptor arrangement along one spatial dimension.
- Model world:
  - There are just two colors in the world, represented here as red and green.
  - Neighboring pixels are similar in intensity (corr coef = 0.9). This high correlation is typical of natural images.
  - The red/green components at each pixel are also similar (corr coef = 0.8). This high correlation is typical of real photoreceptor classes.
  - The stimulus intensity distribution in the red and green color bands has the same mean and variance.
- Model eye:
  - There is at most one photoreceptor at each position.
  - Each photoreceptor is *either* red- or green-sensitive.
  - The image is blurred before photoreceptor sampling, and photoreceptor responses are noisy.

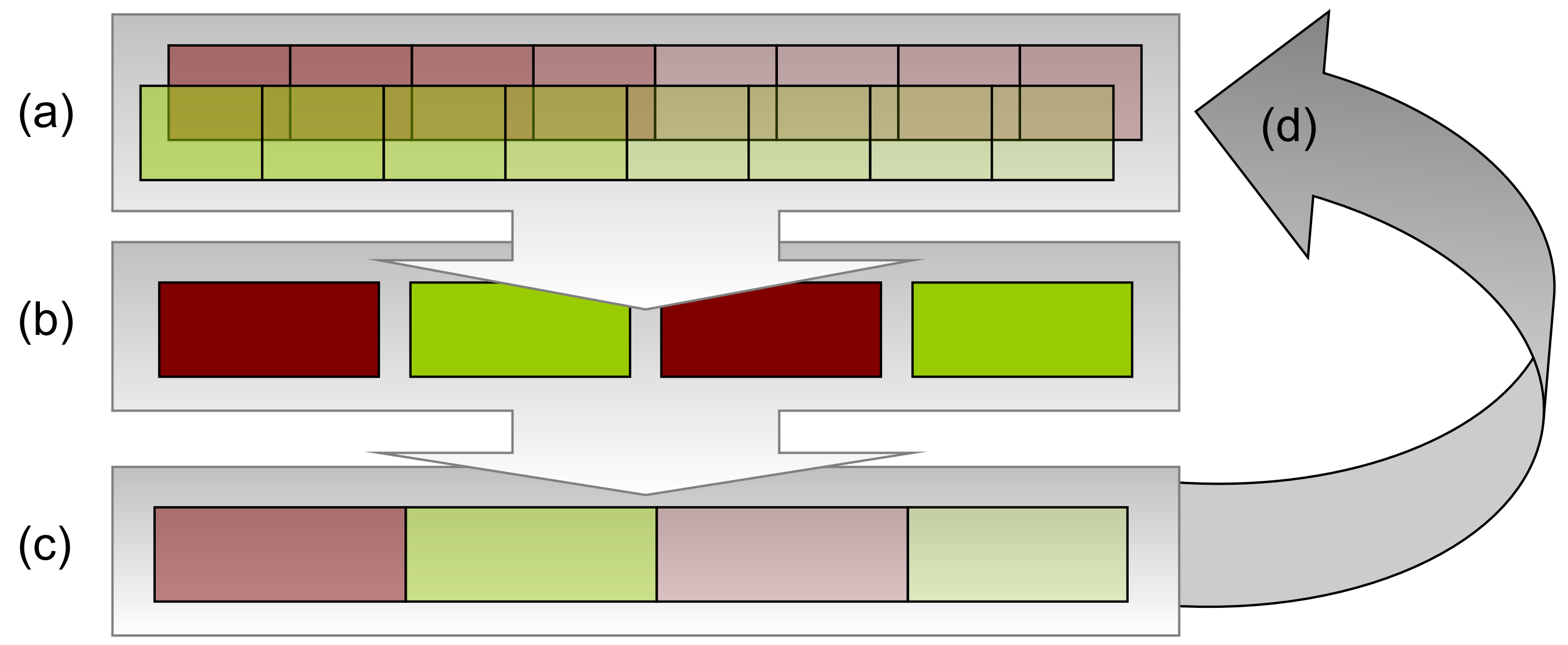

Figure 2. *Model structure*. (a) Visual world. Red and green components are separated for illustrative purposes. (b) Visual system. Here an alternating arrangement of four red- and green-sensitive photoreceptors is shown. (c) The photoreceptors respond to the image. (d) The responses are used to predict the stimulus (using Bayes’ Law).[2] The estimate is compared to the stimulus and the sum-of-squares prediction error is computed. For each arrangment, we use the expected prediction error over many draws from the visual world as our performance measure.

4 Results and Conclusions

- We varied SNR to simulate daytime and nighttime lighting conditions.
- When photoreceptors are equally noisy, an alternating photoreceptor arrangement minimized expected error under all lighting conditions (blue curve).
- When measurement error differs across photoreceptor classes,[3] we found that:
  - When SNR is large (daytime conditions), an alternating arrangement is optimal.
  - As SNR drops (nighttime conditions), the best arrangement contains only the less-noisy cone class.
- We conclude that when intrinsic noise differs across photoreceptor classes, color day vision and monochromatic night vision is the optimal retinal design.

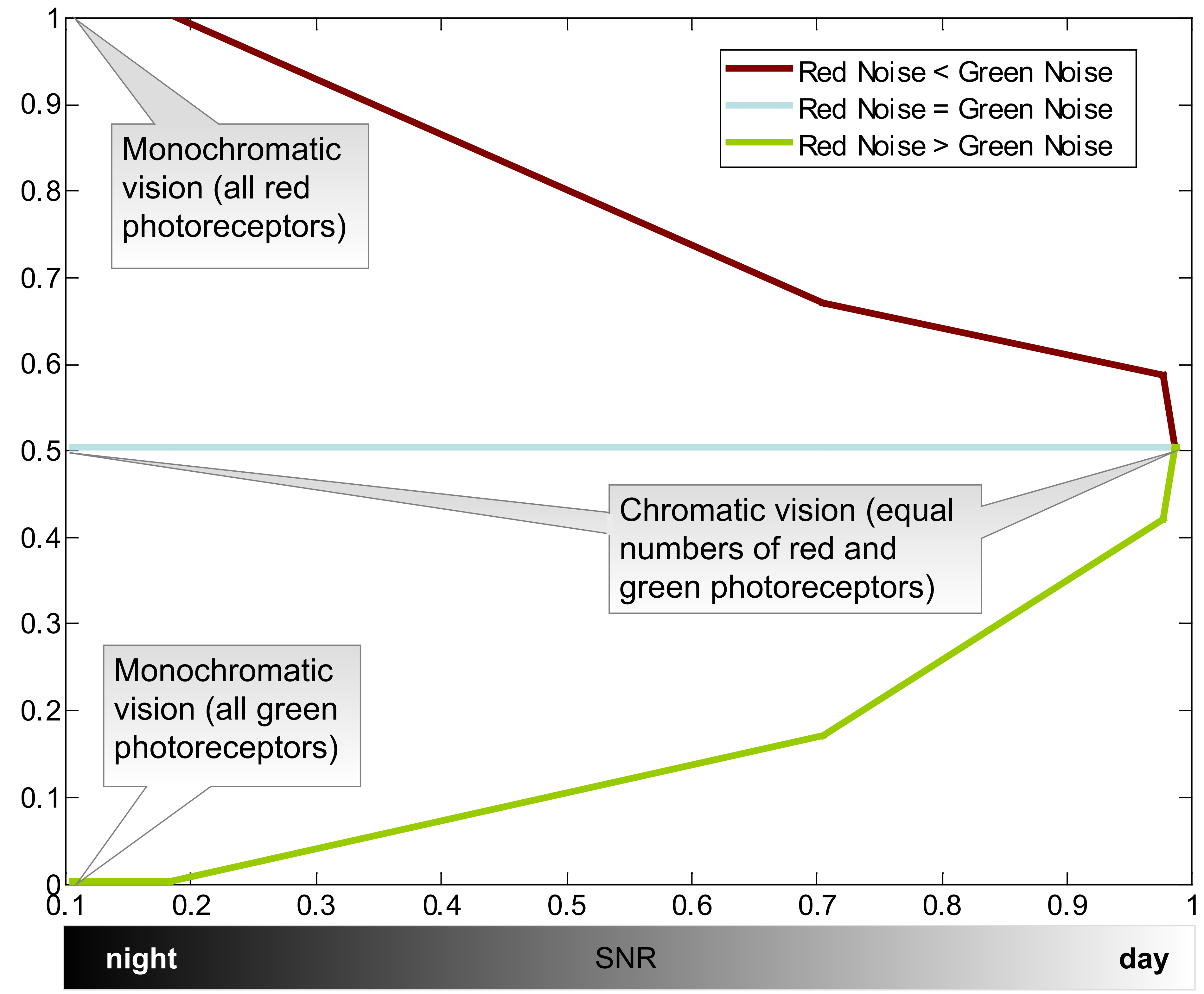

Figure 3. *Summary of findings*. Optimal photoreceptor arrangement red/green proportion is plotted as a function of signal-to-noise ratio (SNR).

References

1. Kelber, A., and Roth, L.S. (2006). Nocturnal colour vision - not as rare as we might think. J. Exp. Biol., 209, 781-788.

2. Brainard, D.H. (1994). Bayesian method for reconstructing color images from trichromatic samples. Proceedings of the IS&T 47th Annual Meeting, Rochester, NY, 375-380.

3. Rieke, F. and Baylor, D. A. (2000). Origin and functional impact of dark noise in retinal cones. Neuron, 26, 181-186.