Towards human retinal cones spatial distribution modeling

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Sampling is the reduction of a continuous signal into a discrete one, or the selection of a subset from a discrete set of signals. In the human retina, the mosaic of the cone photoreceptor cells samples the retinal optical projection of the scene, achieving the first neural coding of the spectral information from the light that enters the eye. To solve the sampling problem, the human retina has adopted an arrangement of photoreceptors that is neither perfectly regular nor perfectly random. Local analysis of foveal mosaics shows that cones are arranged in hexagonal or triangular clusters but extending this analysis to larger areas shows characteristics such as parallel curving and circular rows of cones associated with rotated local clusters. This aim of this study is to identify an algorithm capable of generating sampling arrays with the same range of densities in the retina and use specific metrics to compare the spatial and spectral properties of the cones' distribution.

We examined the human cone sampling by calculating the Nearest Neighbor (NN) regularity index of the population of cones in images of human retina. For testing, we used pure uniform sampling, Green noise and Pink noise samplers, a jittered sampler, a Poisson-Disk sampler and a Blue noise sampler. As reference we adopted the approach called *Blue Noise Through Optimal Transport* (BNOT), developed by de Goes et al. [1], because it allows to achieve the best Blue Noise distribution known today. The cone mosaics used for this work are from previously published images of patches of real human retinas. The *x* and *y* coordinates of the cells inner segments were manually plotted, a k-d tree structure has been used to find the nearest neighbor for each point, the Euclidean distance was calculated for each pair found this way and all the results are classified in histograms. Each distribution of nearest neighbors can be described by a normal Gaussian distribution: the regularity index is a quantitative method used for assessing spatial regularity of photoreceptor distributions and is expressed by the ratio of the mean μ by the standard deviation σ. This index is reported to be 1.9 for a full random sampling and the more regular the arrangement, the higher the value, usually in the range of 3-8 for retinal mosaics. In contrast with previous claims, our calculated indexes range from 8 to 12. The indexes for data generated with Green noise and Pink noise are assimilable to those of a full random sampling, in fact they are even lower, averaging 1.3 and 1.4 respectively; meanwhile, for the BNOT data, the indexes values are much higher, more than the double of the highest values for retinal RIs. Given the fact that fully regular hexagonal or square patterns are proven to have poor sampling properties and therefore not suitable for simulating cones distribution, while having infinite RI, in the scope of this work a higher RI indicates that BNOT is better at generating point processes than the other analyzed point processes.

Our results show that blue noise sampling can describe features of a human retinal cone distribution with a certain degree of similarity to the available data and can be efficiently used for modeling local patches of retina. Given the nature of blue noise algorithms, it should be possible to develop an adaptive sampling model that spans the whole retina. We hope this work can be useful to understand how spatial distribution affects the sampling of a retinal image, or the mechanisms underlying the development of this singular distribution of neuron cells and the implications it has on human vision.

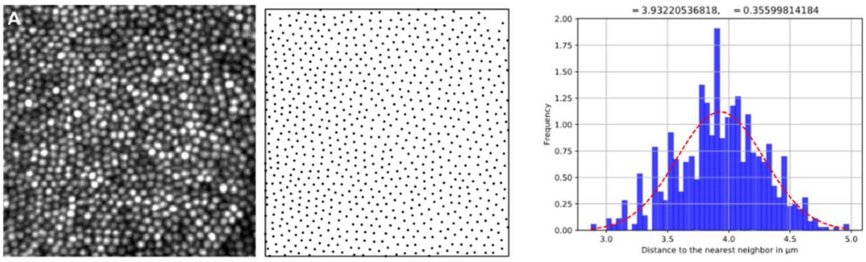

Figure 1: From left to right: The picture of the patch of retina from Scoles et al. [2], the point samples extracted from the cones' location, NN analysis with mean and standard deviation.

References:

1. De Goes, F., Breeden, K., Ostromoukhov, V., Desbrun, M.: Blue noise through optimal transport. ACM Trans. Graph. 31(6),171:1–171:11 (2012)
2. Scoles, D., Sulai, Y.N., Langlo, C.S., Fishman, G.A., Curcio, C.A., Carroll, J., Dubra, A.: In vivo imaging of human cone photoreceptor inner segments. Investigative ophthalmology & visual science 55(7), 4244–4251 (2014)