Designator Retinex, Milano Retinex and the locality issue

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Abstract

Several different implementations of the Retinex model have derived from the original Land and McCann paper. This paper aims at presenting two of them: the Land Designator and Milano Retinex. Land Designator is an alternative calculation described in his 1983 and 86 papers. Later, Jobson used it as the basis of the NASA Retinex. Milano Retinex is a family of slightly different Retinex implementations, here described together with the principal members of this family.

Introduction

Retinex model comes from the Land and McCann's work to model the appearances in complex scenes.

Their initial model was built from the study of modeling lightness sensations in Land's "Black and White Mondrian" experiment (Fig. 1)[1]. Here an achromatic Mondrian is placed under a gradient of illumination, darker at the top and more intense at the bottom. The gradient of illumination was carefully placed to control the light coming from the two different papers at the tips of the two arrows (Fig. 1). The upper paper patch had a high reflectance in dim illumination, while the dark reflectance paper in the bottom had higher illumination. The gradient in illumination was smooth, and was difficult to notice. The change in illumination was as large as the change in reflectances. The top high-reflectance paper in dim light had the same luminance as the low-reflectance paper in bright light.

Land' s experiment asked observer about the appearance of these two identical stimuli. The observers reported the sensation near-white at the top and the sensation near-black at the bottom. The challenge was to describe a computational algorithm that could predict different observer responses to identical input stimuli. The results of those studies concluded that human vision is neither a pure local, nor a pure global process.

The early Retinex implementation of this vision local/global behavior used paths to control the degree of spatial interaction. Retinex computation explained the relative visual sensations with the product of luminance ratios (from Fig. 1) computed along a path, shown in Fig. 2 [1]. In this case the path goes from the upper patch of Fig. 1 to the bottom one. This idea of paths will be the base of the Milano Retinex family presented later.

As a part of a series of papers and talks dedicated to the 50th anniversary of Retinex idea, this short paper limits its scope to the Land's Designator and to the Milano Retinex family.

Retinex Designator

In 1980 Edwin Land retired as President of Polaroid, in 1983 retired as Polaroid's Chairman of the Board and founded the Roland Institute of Science.

In his 1983 paper [2], Land described his "Designator" model. He wanted to make a hypothetical model based on a connection between a Retinex computation and the biology of human vision. He differentiated between a "static" and a "dynamic" version of Retinex. Both "Designators" are in line with the original Retinex formulation, except that the reset mechanism is not present. Retinex behavior without reset is profoundly different [3 Chapter 32].

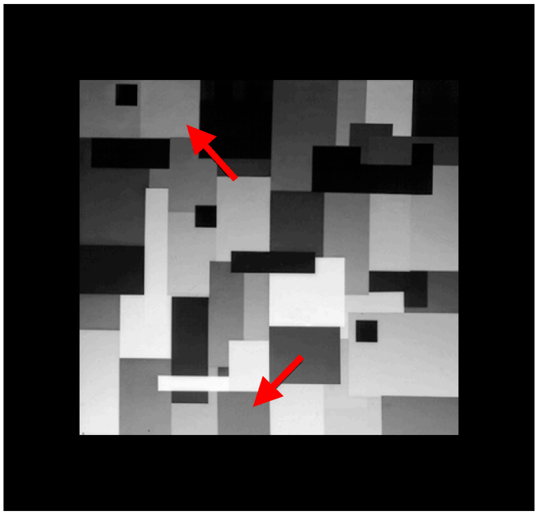
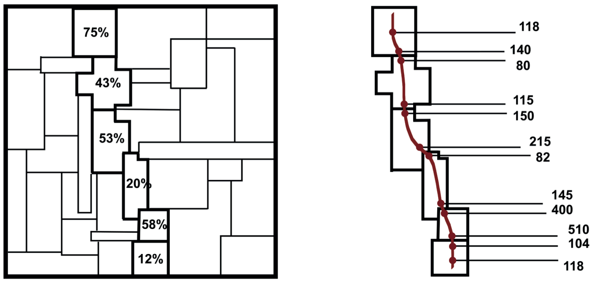


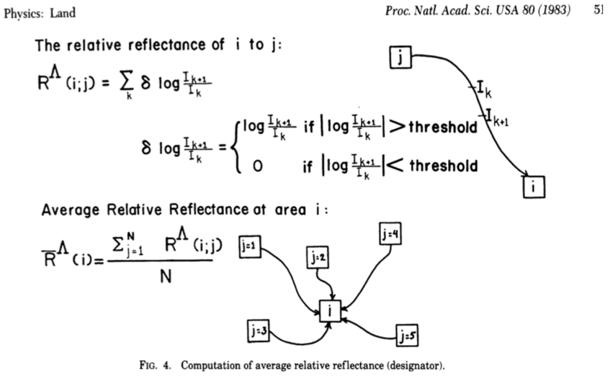
Figure 1. Black and white Mondrian (from [1])



$$\frac{43}{75} * \frac{53}{43} * \frac{20}{53} * \frac{58}{20} * \frac{12}{58} = \frac{1}{6.25} \qquad \frac{80}{140} * \frac{150}{115} * \frac{82}{215} * \frac{400}{145} * \frac{104}{510} = \frac{1}{6.25}$$

Figure 2. Retinex processing over the black and white Mondrian (from [1])

The static version is visible in Fig. 3, while the dynamic version is described in this way: "In the dynamic version, at brief intervals, one retinal cell or another in the family of cells containing the same kind of pigment will emit a signal which will proceed radially outward. This signal will be proportional to the logarithm of the intensity of the radiation falling on that retinal element. From it will be subtracted the logarithm of the intensity of the radiation falling on an adjacent retinal element. To this result will be added the output of the next adjacent cell minus the output of its neighbor, and so on. […] The signal will proceed in this way, with freedom to branch within the rule of implied directionality inherent in the concept of a signal radiating from a single source. From time to time one cell or another may be the initiator of a signal. At any given time, not more than a few hundred cells need to be radiating" [2].



Physics: Land Proc. Natl. Acad. Sci. USA 80 (1983) 51

The relative reflectance of i to j:

$$R^{\Lambda}(i;j) = \sum_k \delta \log \frac{I_{k+1}}{I_k}$$

$$\delta \log \frac{I_{k+1}}{I_k} = \begin{cases} \log \frac{I_{k+1}}{I_k} & \text{if } \left|\log \frac{I_{k+1}}{I_k}\right| > \text{threshold} \\ 0 & \text{if } \left|\log \frac{I_{k+1}}{I_k}\right| < \text{threshold} \end{cases}$$

Average Relative Reflectance at area i:

$$\overline{R}^{\Lambda}(i) = \frac{\Sigma_{j=1}^{N} \; R^{\Lambda}(i;j)}{N}$$

FIG. 4. Computation of average relative reflectance (designator).

Figure 3. Retinex static version without reset (from [2])

From this biologically inspired description originated the term Designator: "Let us consider the red-and-white pictures in terms of lightness numbers which, for convenience, let me call designators." [2].

Land used the average of all luminances as the denominator in his Designator algorithm. Since he did not use the nonlinear reset, that meant that the output value equaled the ratio of a papers luminance to the average luminance, often called a "Gray World" calculation [4].

To underline the importance of the local behavior he states: "The average is taken over areas from the entire visual field and not just those nearby; experiments indicate there may be nearly as much contribution from distant areas as nearby ones." [2].

After the presentation of the two versions Land states: "It is too soon to say what computational mechanisms will finally be most appropriate for the cellular anatomy. " [2].

I would like to conclude the description of the contribution of this paper with a beautiful phrase that describes every Retinex implementation: "A summary rule for Retinex theory is that color is always a consequence, never a cause." [2].

The 1986 Land paper

In this paper [5], Land is more detailed; he presents a method to calculate the Designator as the ratio of a central area to an extended surround. The *Gray World* mechanism is confirmed and implemented with a local-average computation.

About locality, he says: "A search for an operative compromise between an average taken over the whole field and an average taken over the contiguous areas gave promising results.".

The spatial specification of input comes only from the figures reported in Fig. 4. For a more detailed review see [3], chapter 32.7.1.

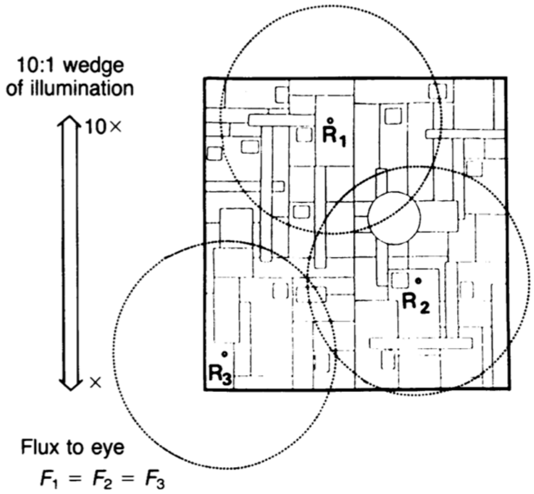


Figure 4. Land's illustration of of the Designator (from [5]). Here he presents his idea of spatial locality.

The NASA Retinex

Land simplification stimulated Jobson, Rahman, and Woodell from NASA, who in 1997 implemented the Designator with a convolution filter [6].

In NASA Retinex the image is filtered via a convolution, a very simple and efficient way to process the image; this explain the big diffusion of the method.

Here the shape of the filter is fixed; it does not depend on the image content. This explains the differences of filtering according to the frequency content of the input, and the tendency to desaturating colors, due to its *Gray world* normalization principle. Authors aimed at compensating this effect introducing a multi-level processing and a Color Restoration (CR) module. A series of numerous works followed, proposing modifications in the attempt of improving the method (see [3] Chapter 32.7.2).

Milano Retinex

The Milano Retinex family (see Fig. 5) started in 1993 [7] with the work from my graduation thesis.

The difference between these versions and the original Retinex is presented if Fig. 6 on an example path: the original Retinex with the red arrows, while Milano Retinex with the green arrow.

The red arrow indicates that the ratio-product-reset-average process takes place at each pixel. The calculated value of the average is stored at that pixel to be used the next time that a path passes that pixel. The reset process occurs many times along the path, particularly at the beginning of the calculation. Every ratio-product-reset of contributes to the output (Fig. 6 top).

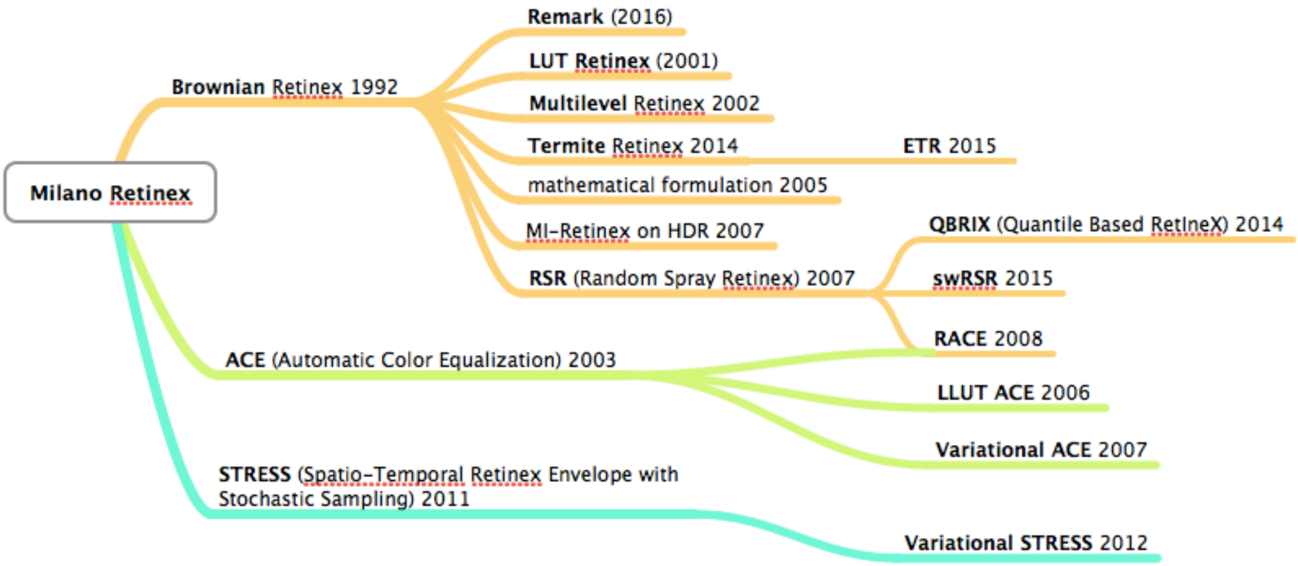


Figure 5. The Milano Retinex family

The Milano Retinex stores the ratio-product information along the entire path from a starting pixel to the pixel of interest. Performing as well the ratio-product-reset at each step, the output (green arrow) is the ratio of the pixel of interest to the maximum luminance pixel found along the path (Fig. 6 bottom).

A detailed comparison between the two approaches has not been done yet, and will be the subject of future works. However, on a quick analysis of their implementation, Milano Retinex shows clearly its redundancy, making the entire path computation just for a single contribution to the final pixel.

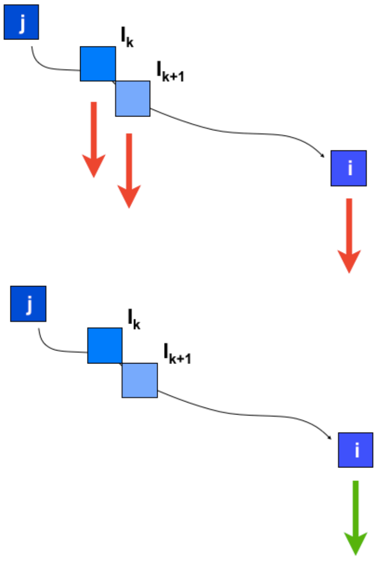


Figure 6. The difference between the Original Retinex (upper right) and Milano Retinex (bottom right)

The advantage of this redundancy is that the path is easier to formalize [8]. On a more general level, path role can be seen as the search for the local channel maxima, necessary for the normalization of the last pixel in the chain.

The Milano Retinex family

The structure of the Milano Retinex family is visible in Fig. 5. Here we want to present a descriptive overview of its members, not a technical presentation; for the technical details we ask readers to refer to the cited works. Here we aim at focusing mainly on the characteristics that differentiate each algorithm, to have a bird's eye view of the genesis and approaches beyond each one of them.

The first algorithm of the family is the Brownian Retinex [7, 9], where Brownian paths, generated with the mid-point displacement technique, explore the image. The choice of Brownian paths was made to avoid directional bias that generates unwanted shadows and at the same time to realize an easy way to sample over a wide area. Locality is demanded to the figure of sampling with its parameter. To experiment a spatial locality more in line with HVS and to save on computational time, a multilevel version has been devised in 2002 [10]. Initial interest was on color constancy [11, 12] and color normalization [13].

A noticeable quantum leap in computational costs arrived in 2007 with Random Spray Retinex (RSR) [14]. RSR substituted the Brownian paths with a random sampling made with a spray of points around the pixel to compute. This simplification defines more clearly the role of sampling for the locality and has originated other probabilistic formulations.

Approximate probabilistic models of the spray sampling based on quantiles are the base of QBRIX [15], with its global and local versions, and probabilistic models of sampling realized with random walks represented as Reward Markov Process are the base of Remark [16].

A variant of RSR is STRESS, for Spatio-temporal Retinex-inspired Envelope with Stochastic Sampling [17]. The idea of STRESS is to use sprays not only for "searching" the local white, but also for the local "black" and then stretch the pixel values accordingly. STRESS is implemented in GIMP (GNU Image Manipulation Program – www.gimp.org) from the version 2.8.

The idea of paths is preserved in Termite Retinex (TR) [18]. In this implementation, the creation of paths is not completely random, they are realized by a swarm of agents, called "termites", that consider contrast as a positive variable to influence the path generation. Moreover, termites traveling along a path leave a trace called "poison", this helps next termite to avoid pre-visited points in the generation of the next path.

This is the first work that implements a path generation dependent on the image content. The idea is that some areas are more relevant than others in the formation of the final visual sensation. The same approach is exploited by swRSR and ETR.

In swRSR (spatially weighted RSR) [19], the spray sampling is weighted by a figure of distance. In ETR (Energy-driven path search for Termite Retinex) [20], path generation is realized solving partial difference equations (PDE) on image gradients. This latter approach has not to be confused with the many implementations of Retinex with PDE: here PDE are used only to generate paths.

While researching on different Retinex implementations, we wanted to test a new model where locality was not realized with random sampling. With this goal in mind, in 2002 we have devised a variant of Retinex called ACE for Automatic Color Equalization [21, 22, 23, 24]. ACE substituted the random search with a complete scan of all the pixels in the image, realizing the locality with a distance function and the dependency from image content with a contrast amplification function.

The main problem of considering all the pixels in the computation of each single pixel is the overall computational cost. To speed-up the computation time some accelerated implementation have been devised so far [25, 26, 27], together with a PDE version [28].

From the mix of ACE and RSR originated RACE [29], where the two approaches are mixed thanks to a spray-based implementation of ACE.

Conclusions

The *Retinex at 50* special joint session at Electronic Imaging 2016 aims at being a tribute to Land and McCann Retinex, and a way to gather together scholars working on the model.

This paper has presented a brief overview about only two Retinex "families". I want to recall that this is not a technical survey. The goal is simply to present a piece of the history of this interesting and complex model with the hope to stimulate a bit of interest in the readers and to contribute to the overall picture coming from the whole session.

Acknowledgment

I would like to take this chance to thank all the colleagues and friends with whom I shared the long "path" of Milano Retinex: Daniele Marini, Carlo Gatta, Edoardo Provenzi, Massimo Fierro, Luca De Carli, Davide Gadia, Cristian Bonanomi, Ivar Farup, Øyvind Kolås, Gabriele Simone, Gabriele Gianini, Michela Lecca and all the students that have helped us.

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