Citation for John McCann: AIC Deane B. Judd Award 2021 recipient

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Color is the intersection of the physics of light, the psychophysics of appearance, and the art and technology of reproduction. John has a unique career; he is one of the few that deeply experimented in all these fields. This makes John one of the most influential persons in the field of color. These pages aim at summarizing his vast and fruitful work in which I had the honor and the opportunity to share a certain part. That made me a privileged observer. Many of the anedoctes reported come from direct experience, the others comes from a long series of personal communications with John.

John's Interest in Color

John has always been interested in the science of color. At Lowell High School he did an unsupervised science fair project on chromatography. As a freshman at Harvard he participated in Eugene Rochow's Freshman Seminar. As an independent project, he synthesized by different reactions cis- and trans-isomers of cuprous chloride($CuCl_2$). The two compounds with the same chemical composition have different colors: pale blue, and pink. The idea of creating research projects for Freshmen at Harvard and MIT was sponsored by Edwin Land, the founder and chief of Polaroid. As a participant John learned of an opportunity for part-time work at Polaroid.

John's senior thesis in Biology, in John Dowling's laboratory, measured the pupil response to afterimages. He repeated Alpern and Campbell's experiments showing that the pupil response follows the state of retinal adaptation. The work was presented at the 4th Colloquium of the Pupil, Baltimore, 1964. John received a B.A. degree in Biology from Harvard College in 1964.

Retinex models of spatial vision

In the 1960's John assisted Edwin Land in his Mondrian experiments, and he made a major contribution to the Land and McCann (1971) computation model of Lightness. Land wrote:

> "Our machine (computational model) should have a way of comparing areas that are distant from one another … when we were contemplating an array of black, white, and grey papers and puzzling about the next step, John McCann invented … a way of looking at the reflectance relationships between widely separated areas … the product of the ratios across distant edges is the same as the ratio we would get if we placed the two remote areas next to each other. … we can establish a series of sequential products which yields the relative reflectance of any area relative to the first area without knowing or involving the illumination." (Land, 1974: 36)

John began a career-long study of calculating Appearances using scenes with 20 by 24 pixels in a computer with hand-wound core memory in 1968. (McCann, 2021:LM Retinex)

Rod /Lcone Color

Also, in the 1960's John began his studies of rod and Lcone color in the production of color sensation. He integrated Edwin Land's Two Color photography with John Dowling's receptor dark-adaptation experiments. At Polaroid, John used dark-adaptation thresholds to study multicolor appearances with fully dark-adapted eyes in very low-color-temperature illumination. John and Jeanne Benton used dark adaptation threshold to find absolute L-, M-, S-cone thresholds. Using radiances well below M- and S-cone absolute thresholds they observed multicolor scenes from rod and L-cone supra-threshold stimuli. (McCann, 2021:rod-Lcone) At the AIC Interim Meeting Stockholm, McCann, (2008) presented new appearance matches of rod /Lcone colors.

Quantitative Color Constancy

Traditionally, color constancy is a null experiment that considers two spots of light. In the 1970's John began to ask observers to match all areas in Color Mondrians. McCann, McKee and Taylor (1976) used 17 papers in 5 different illuminations. Observers matched all the papers in all the illuminants. The authors measured all the scene segments, using Paul Brown's 1964 spectral sensitivities of L-, M-, S-cones. Cone quanta catches of all segments were the input to John's spatial models. Observer matches measured ground truth for the model. The LM Retinex model calculated the appearances of all Mondrian areas to evaluate the entire scene in all illuminants. Illuminants cause subtle departures from perfect constancy that constancy models should predict.

The analysis of all his color constancy matching data showed little correlation between cone quanta catches and matching appearances. The calculation of Scaled Integrated Reflectance did correlate with observer matches. The analysis of all papers in all illumination showed very small departures from perfect color constancy (associated with the overlap of cone spectral sensitivities). LM Retinex model predicted observer matches. (McCann, 2021:LandColorMondrian)

Visibility of Gradients

While Land's Color Mondrians showed near perfect Color Constancy, Land's Black and White Mondrians are a much greater challenge for computational models of vision. The multiplication of edges across the field of view approximates the appearances, but any calculation of appearance has to have a way of handling the radiance gradients between edges. Land and McCann (1971), in their LM Retinex Lightness Model used two operations that minimized the effects of gradients: threshold, and reset (normalization to local maxima). John studied the detection threshold of gradients. The results surprised him. He made a square photographic print with a luminance gradient between two parallel edges, on a uniform background. Observers had a 1 in 4 choice to identify the gradient's orientation (light to dark). Observers reported the orientation of a particular near-threshold gradient correctly 60% of the time. Repeating the same measurement with the observer twice as far away from the print doubled the rate of change of luminance on the retina. The surprise was that the observer reported the same 60% correct. Below the peak (3 cpd) of the contrast sensitivity curve, gradient detection threshold and contrast sensitivity of sine-wave gratings have abnormal responses. Below 3 cpd sine-wave detection threshold correlates with the number of cycles of sine wave, notspatial frequency. Low-spatial-frequency gradients respond to the spatial content of the rest of the scene. (McCann, 2021:EdgesGradients)

Digital Image Processing

In 1975 John and Jon Frankle set up Polaroid's first digital imaging laboratory. It had a PDP computer with a large (for 1975) disc memory, and an I²S digital image storage with array processing hardware. Back then, digital memory chips were limited to 8k of storage, and were very expensive. The hardware used 768 of these 8k chips to store a single 512 X 512 by 24 bit image. Along with Karen Houston, John used the system to study Color Constancy. With Jon Frankle, John developed, and patented efficient LM Retinex computation algorithms for HDR natural scenes.

The I²S digital images were displayed on a CRT monitor. John and Karen Houston calibrated the system, performed color constancy experiments on it, and presented the results at his first AIC meeting in 1980 (Harry Helson Memorial Symposium on Chromatic Adaptation, Williamsburg). Alan Robertson's (2007 Judd Medalist), Meeting Report said of McCann's talk: "An intriguing aspect of the work is the use of an advanced digital-image processor with a 512 X 512 pixel array. This apparatus permits the study of natural images viewed under different illuminants. The results can readily be analyzed in accordance with the Retinex processing model."(Robertson, 1980) These experiments (McCann and Houston, 1983) were the first Natural Scene vision experiments, and maybe the first vision experiments performed on digital display devices.

Frankle and McCann (1983) developed a system that captured natural scenes, calculated appearances, and wrote the computed image on film. This system converted >1000:1 High Dynamic Range (HDR) scenes to the 30:1 range in prints. These Retinex models mimicked what a painter would do to reproduce a scene. John's work began with photography, progressed to papers in controlled illumination, to computational electronic imaging. He developed and patented efficient algorithms for making spatial comparisons among all pixels in an image. The essential component of its computational efficiency was the use of multi-resolution spatial comparisons. Using this 1975 digital hardware Frankle and McCann (1983) calculated apparent lightnesses of a 512x512 color separation in 53 seconds. This spatial process made the photograph "John at Yosemite" (Figure 8C in McCann's Judd Award paper). It was the first digital example that mimicked what painters do in creating renditions of HDR scenes. It captured the scene's >1000:1 range; digital transformed it using L-M Retinex, and rendered the appearance image on print film. (McCann & Rizzi, 2012: 293-337)

Calculating the actual light on the retina

Stiehl, McCann & Savoy (1983) used Munsell's bisection procedure to make an HDR nine-step gray scale equal increment lightness target, using transparent filters on a 3,400nit lightbox. Stiehl calculated the retinal illuminances of the 9 equal lightness steps after intraocular scatter using the glare research of Vos (1991 Judd Medalist). Stiehl found a logarithmic relationship between retinal illuminance and the equal lightness steps. While CIE L* lightness is the cube root of relative luminance from the scene, the receptor's logarithmic response to luminance is proportional to lightness. Their work highlights the importance of scatter-corrected retinal illuminance in any quantitative model of lightness, and in all evaluations of uniform color spaces.

Color Constancy without Chromatic Adaptation

In Color Mondrians Land adjusted the illumination on a particular paper so that the light at the observer's eyes was identical to that of a different color paper in the Mondrian. Obviously, changing the uniform illumination changes the average L,M,S quanta catches (state of adaptation). The question is whether that change in adaptation state can affect the appearances of Mondrian areas viewed as an entire Natural Scene. Daw (1963) showed that afterimages, generated by light adaptation, are suppressed by scene edges that are different from the stabilized retinal afterimage. Nigel Daw formed a color afterimage. He then viewed the afterimage (maintaining the fixation point) on a black and white image of the same scene. The complementary color afterimage was clearly visible. He changed his fixation point, and the afterimage disappeared. The afterimage is suppressed when the edges in the real scene do not match the edges in the retinal afterimage. Daw then, moved his fixation back to the original fixation point; the afterimage reappeared. Based on Daw's experiments, Land's Mondrians were made of irregular rectangles to suppress the chromatic adaptation of afterimages.

John's experiments added an additional step to cancel the changes in adaptation stimulus. He changed the Mondrian's reflectance patterns to change the Mondrian's adaptation state back to their original values. In short, Land changed illumination, that changed the scene's average L, M, S cone catches (state of adaptation); McCann changed Mondrian reflectances to cancel adaptation changes by restoring the original average L, M, S quanta catches. McCann's modified Mondrian's removed the chromatic adaptation component from the experiment. Observers made the same color matches with, or without, these changes in the state of chromatic adaptation. Despite many attempts to measure the effects of chromatic adaptation in complex and natural scenes, John never found substantial changes. John reported the first part of this long series of experiments in the AIC 1987,"Wyszecki-Stiles Memorial Symposium on Color Vision Models", Florence, Italy , and the second part at the AIC 1997, 8th Congress Kyoto, Japan. (McCann, 2021:ConstancyWithoutAdaptation)

Color Technology

In the 1980's, imaging revolution began with Akio Morita's introduction of Sony's Mavica prototype digital camera. All imaging companies began the process of converting from silver halide films to digital imaging. John's *Vision Research Laboratory* made and developed:

- With Jim Burkhardt and Jay Thornton, made a real-time 3-D LUT transformation hardware for MacDonald Detweiler digital color film recorders;
- Integrated color management in a digital driver-license system;
- Polaroid's 20x24, and Museum 40x80 inch film cameras;
- With Jay Thornton, used 3-D LUTs transform to make, color-corrected *Replicas* of Museum paintings. This calibrated process removed films' fixed nonlinear tone scale response.

Polaroid Research Labs to McCann Imaging

In 1995 John retired from Polaroid as a Senior Laboratory Manager. He joined that lab first as a R&D lab tech, and had worked there for 35 years. During that period he was the administrator of Ansel Adams and John Sextant Consultants, Steve Benton's White Light Holography Lab, Bill Wray's Audio Research, Polaroid Replicas, Special Corporate Projects, and The Polaroid Research Machine Shop.

His wife Mary and John became McCann Imaging in 1994 consulting on Microscopy Imaging and Color Imaging. John consulted with Hewlett Packard. This work began in 1996, and it led HP's "Digital Flash" (alternatively called also "Adaptive lighting") cameras using L-M Retinex range compression in 2002. As well, his work at HP included studies of uniform color spaces, and 3-D LUT's to convert L*a*b*(with serious non-uniformities) to Munsell rendition space (MLab). The idea was to use all available L*a*b* instrumentation, but achieve perfect Munsell uniformity at all 3-D LUT nodes. (McCann, 1999) Also, at HP, McCann and Hubel (2003) patented an edge comparison Gamut Mapping algorithm based on Frankle and McCann (1983). John consulted for Konica, Apple, Gemological Institute, and Boston Scientific.

Optical Veiling Glare sets the limits of HDR Imaging

In 2006 John heard a student's paper claiming that the student's HDR photographs had captured 7 log10 units of accurate scene radiances. Having worked 35 years for a camera manufacture, John doubted that claim, and invited the student to have lunch to discuss optical veiling glare. John agreed about the scene's range, but asked the student if he had measured the actual light on the sensor. The student had not. Right after, John and I began a 15 year collaboration of thinking, measuring, experimenting with glare and the actual light on sensors: film, electronic and visual. This collaboration led to two books (McCann & Rizzi, 2012; McCann, Vonikakis, & Rizzi, dozens of papers (McCann, 2012:GlareLimitsHDR), and many tutorials.

Glare a plays a major role in both in the acquisition and in the display of HDR scenes. Multiple exposure algorithms assume that lenses have zero optical glare. If that were true then Multiple Exposures can increase the range of scene radiance. However, glare is real, and sets the same HDR limit in every exposure (after calibrated removal of tone-scale nonlinearities).

Given accurate scene radiances (not possible using cameras), we can calculate the light on the human retina (McCann & Rizzi, 2012: 145-171; McCann, Vonikakis, 2018). Retinal luminance shows vision's responses to light varies with the content of every scene.

3-D Color Constancy

At the 2009 AIC 11th Congress in Sydney, John reported work associated with the CREATE FP6 EU Project. This talk featured Carinna Parraman's watercolor paintings of a pair of 3-D Mondrians. One was an HDR scene, and other was an LDR scene. The HDR scene had painted wooden blocks in highly directional illumination. Its shadows had sharp edges. The LDR scene had identical painted wooden blocks in almost uniform illumination. (McCann's Judd Address-Figure 7c and 7d). Carinna's paintings are remarkable. They record the Appearances of the two scenes that have identical painted surfaces, but viewed in different HDR and LDR illuminations in the same room at the same time. The act of painting a matching scene segment on a flat piece of paper in uniform illumination, surrounded by the entire matching scene is the best measurement of Color Appearance! Iteratively, Carinna matched all scene segments in both 3-D Mondrians. She adjusted all the segments until they matched. (McCann, Parraman, & Rizzi, 2009) The second remarkable step was that Carinna used a Spectrolino® reflectance meter to measure full spectral plots, and CIE X, Y, Z values of all 104 block facets in LDR and HDR. All 208 individual matches are in a standard color space for analysis.

Perfect color constancy for reflective objects occurs when observers select the same reflectance spectra in standard and test surface in different illuminations. Using flat Mondrians in uniform illumination, McCann, McKee and Taylor (1976) reported nearly perfect correlation of Scaled Integrated Reflectances. Carinna's LDR painting reflectances showed good correction between standard and test areas, with some moderate departures from constancy. Her HDR painting reflectances showed many substantial departures from constancy. The HDR 3-D Mondrian, with its sharp edges in illumination, had poor color constancy. Even though this HDR Mondrian is the best approximation to real Natural Scenes, it had the least Color Constancy.

At the same time, test participants were invited to view and analyze the HDR and LDR Mondrians. They were given maps of block facets painted with the same paint. They were asked to make Magnitude Estimates of Color Appearances. This data also showed that HDR illumination with edges seriously eroded color constancy. (McCann, Parraman, & Rizzi, 2016)

2013 AIC Capstone Lecture

John gave the Capstone Lecture at the 2013 AIC 12th Congress Newcastle, UK. His talk, "Colour: Intersection of Art and Science", closed the meeting by summarizing the interconnections of the many different AIC fields of interest: Light/Matter interactions in Physics; Color-Opponency in Psychophysics; Color separation photography and printing; Appearances' dependence on edges in scenes; and Neurophysiology of the visual pathway.

Color Appearances before and after Cataracts Surgery

At the 11th AIC Congress Sydney, Prof. Mitsuo Ikeda's (2003 Judd Medalist) presented his studies on the color effects of his cataracts. In 2019, John and his wife Mary followed Ikeda example. They reported their experiments measuring their cataract changes in Color Appearances of Natural Scenes. Just prior to cataract surgery, the Farnsworth Munsell 100 Hue test results characterized them both as Tritanopic with serious loss of discrimination at 488 and 589 nm dominant wavelength chips. Both had taken the 100 Hue Test since the 1970's with close to zero scores until they developed operable cataracts. After surgery they returned to normal color vision scores in the 100 Hue Test.

With one implant and one cataract eye, they observed different Color Appearances in the two eyes. They tested many color filters to see if a filter over the implant eye could make appearance match in both eyes. They tested many scenes and found that the same filter (CC40Y) made the two eyes match. They performed this experiment as soon as their bandages were removed, and repeated it until the second operation. At first light the operated eye had substantial edema that affected optical clarity. Nevertheless, the CC40Y filter made the eyes have the best color match in all post-operation scenes. After the second implant, both eyes matched at first light. No long-term natural scenes adaptation was observed in after cataract removal. (McCann, 2021:CataractColor)

John's Color and Imaging Legacy

John's earliest work began with building computational appearance models by multiplying edge ratios to calculate appearances in natural HDR scenes. Land and McCann laid the framework for modeling human vision, and making cameras that mimic vision's scene processing. Their L-M Retinex model was a starting point for many other Retinex models, the many from my lab called Milano Retinex (McCann & Rizzi, 2012: 293-337). The Land and McCann (1971) paper is seminal to many papers regarded as the foundation of image processing: in spatial filtering (Stockham, 1972), in early computational frameworks of vision and AI models, (Marr, 1974; Horn, 1974), in models of neural processing (Grossberg and Todorović, 1988).

Fourteen years later in 1981, Morita stimulated the Digital revolution in photography that took 20 years to reach maturity. In the early 2000's HDR became a hot topic in digital image processing. All successful general solutions for HDR rendering optimize the scene's edge ratios.

All of John's work has the same pattern of research. It begins with a curious observation of an unanticipated result. It is followed by a novel experimental design to measure observer's responses to that curious visual stimulus. That design measures the appearance of the scene segment of interest, and many other scene segments in the field of view.

I like to underline a very important characteristics about John research attitude. John is meticulous about radiance calibration. John never uses estimates of display radiance made from digit values in computer memory. He always measures actual telephotometer radiances directly from scenes and display screens. Rarely does John describe observer preferences in image processing. He compares calculated results a with precisely defined ground truth. He embraced all aspects of human color research, and the entire digital imaging revolution. The idea connecting color, and natural HDR imaging is that appearance is controlled by spatial, multi-resolution processes.

Like all successful enthusiasts, John continues his study of color vision, photography, and fine art.

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