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CIC24 Technical Papers Program: Schedule and Contents

WEDNESDAY NOVEMBER 9, 2016

Opening Keynote

Session Chair: Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)

9:05 – 10:00

Keynote sponsored by Canon USA, Inc.

Canon

9:05 **Full Color Computational Imaging with Diffractive Optics,** *Wolfgang Heidrich, King Abdullah University of Science and Technology (KAUST) (Saudi Arabia)* **1**

Co-designing optics and computational methods provides access to new regions in the optical design space, promising improved imaging performance and increased flexibility. Computational imaging with diffractive optics in particular shows great promise for lighter, more compact, flexible, and powerful imaging systems. In this talk I will outline some recent advances that promise to make diffractive optics competitive for full-color imaging with small and lightweight form factors.

Colorful Viewing

Session Chair: Xuemei Zhang, Apple, Inc. (USA)

10:00 – 12:40

10:00 **Large-Gamut Color and Spectral Display Using Sub-Wavelength Gratings,** *Peter Morovic,[1] Ján Morovic,[1] Francesco Aieta,[2] Marco Fiorentino,[3] Charles Santori,[4] and David Fatal[2]; [1]HP Inc. (Spain), [2]LEIA 3D, [3]Hewlett-Packard Laboratories, and [4]Verily (USA)* **2**

As content creation, editing, approval, prototyping, manufacturing and consumption become ever more distributed, the ability to display a broad variety of colors becomes increasingly more important. Displays that use RGB filters or even backlights cannot span all spectra or even just colors that occur in nature. To improve the accuracy of spectral and color reproduction, there have been attempts to include additional color primaries in displays. Existing solutions, however, impact cost, scalability, or spatial resolution and are predominantly applicable to projections system. We propose an approach based on combining diffraction gratings extractors (Fattal et al., 2013) and the HANS imaging pipeline (Morovic et al., 2011) initially developed for printing. This combination offers access to a very large color and spectral gamut with power the same backlights as commercially used today.

10:20 **JIST-First Paper** **QUALITAS: Image Quality Assessment for Stereoscopic Images,** *Christine Fernandez–Maloigne and Jamie Moreno, University of Poitiers (France); and Alessandro Rizzi and Cristian Bonanomi, Università degli Studi di Milano (Italy)* **7**

In this article, the authors present a method for assessing image quality in stereoscopic images: QUALITAS. The proposed method is inspired by some features of the human visual system, such as contrast sensitivity, response to visual disparity and perception of distance. Individual qualities of the stereo-pair are not simply averaged. QUALITAS introduces Contrast Band-Pass Filtering on a wavelet domain in both views; in this way it weights left and right images perceptually depending on viewing conditions. The authors have tested the method on the LIVE 3D stereoscopic image database and compared the results with a wide set of image quality metrics from current research.

10:40 – 11:20 — Coffee Break

11:20 **Visibility of Spatiotemporal Noise in Digital Video,** *Tamara Seybold, Betina L. Koelln, Aynur Pasha, and Harald Brendel, Arnold & Richter Cine Technik (Germany)* **20**

Motivated by the visual appearance of spatially denoised video sequences, we study the visibility of dynamic (temporal) noise. We investigate the visibility of noise for different spatial frequency bands. We conduct a subjective test with 22 observers. Included are two types of test patterns in the test: static (spatial) noise patterns and dynamic (spatiotemporal) noise. Eight spatial frequency bands are used for each pattern type. We obtain two main results: First, the contrast sensitivity of spatially low-frequency noise is significantly higher with temporal variation. Second, the noise visibility also depends on the content of the image or video. As the noise is masked by the content of the image, it becomes less perceivable. As higher frame rate might be used in future, a second test was performed comparing 24fps and 48 fps. Results show that the noise visibility is very similar. The significant increase of visibility with the temporal variation of spatially low-frequency noise should be respected in the design of future video processing methods.

11:40 **Temporal Drift Correction of Residues for Perceptually based Video Compression,** *Mark Q. Shaw, HP Inc., and Jan P. Allebach and Edward J. Delp, Purdue University (USA)* **27**

In this paper we investigate a method for correcting a encoding artifact due to the periodic nature of video coding. This paper builds upon earlier work by incorporating temporal drift correction feedback in the encoder to prevent visible artifacts seen when an I-frame reset occurs. The method has been implemented in the H.264 JM 18.0 reference encoder, and has been shown to significantly improve the perceived quality of the video quality when compared to the encoded video without temporal drift correction.

12:00 **JIST-First Paper** **Orientation Modulation for Data Hiding in Chrominance Channels of Direct Binary Search Halftone Prints,** *Vlado Kitanovski and Marius Pedersen, Norwegian University of Science and Technology (Norway)* **32**

In this article, we propose a joint halftoning and data hiding technique for color images. To ensure high quality of the printed image, the color direct binary search (CDBS) iterative halftoning algorithm is used. The proposed approach uses the commonly available cyan, magenta and yellow colorants to hide data in the chrominance channels. Orientation modulation is used for data embedding during the iterative CDBS halftoning stage. The detector is using PCA-learned components to extract the embedded data from the scanned image. Experimental results show that this proposed CDBS-based data hiding method offers both higher data hiding capacity and higher robustness to the print-and-scan channel when compared to the state-of-the-art grayscale counterpart method. The relatively high correct detection rate make this approach suitable for applications which require exact extraction of embedded data in prints.

12:20 **PARAWACS: Color Halftoning with a Single Selector Matrix,** *Peter Morovic and Ján Morovic, HP Inc. (Spain), and Jay Gondek, Matthew Gaubatz, and Robert Ulichney, HP Inc. (USA)* **41**

Halftoning is one of the key stages of any printing image processing pipeline. With colorant-channel approaches, a key challenge for matrix-based halftoning is the co-optimization of the matrices used for the individual colorants, which becomes increasingly complex and over-constrained as the number of the colorants increases. Both choices of screen angles (in clustered-dot cases) or structures and control over how the individual matrices relate to each other and result in over- versus side-by-side printing of the colorants impose restrictions that are challenging to reconcile. The solution presented in this paper relies on the benefits of a HANS pipeline, where local Neugebauer Primary use is specified at each pixel and where halftoning can be performed using a single matrix, regardless of the number of colorants used. The provably complete plane-dependence of the resulting halftones and an application to security printing will be presented among the solution's benefits.

12:40 – 14:00 — Lunch Break

Beyond the Rainbow

Session Chair: Mark Shaw, HP Inc. (USA)

14:00 – 15:40

14:00 **Efficient Multispectral Reflectance Function Capture for Image-based Relighting,** *Chloe LeGendre, Xueming Yu, and Paul Debevec, USC Institute for Creative Technologies (USA)* **47**

Image-based relighting (IBRL) renders the appearance of a subject in a novel lighting environment as a linear combination of the images of its reflectance field, the appearance of the subject lit by each incident lighting direction. Traditionally, a tristimulus color camera records the reflectance field as the subject is sequentially illuminated by broad-spectrum white light sources from each direction. Using a multispectral LED sphere and either a tristimulus (RGB) or monochrome camera, we photograph a still life scene to acquire its multispectral reflectance field—its appearance for every lighting direction for multiple incident illumination spectra. For the tristimulus camera, we demonstrate improved color rendition for IBRL when using the multispectral reflectance field, producing a closer match to the scene's actual appearance in a real-world illumination environment. For the monochrome camera, we also show close visual matches. We additionally propose an efficient method for acquiring such multispectral reflectance fields, augmenting the traditional broad-spectrum lighting basis capture with only a few additional images equal to the desired number of spectral channels. In these additional images, we illumi-

nate the subject by a complete sphere of each available narrow-band LED light source, in our case: red, amber, green, cyan, and blue. From the full-sphere illumination images, we promote the white-light reflectance functions for every direction to multispectral, effectively hallucinating the appearance of the subject under each LED spectrum for each lighting direction. We also use polarization imaging to separate the diffuse and specular components of the reflectance functions, spectrally promoting these components according to different models. We validate that the approximated multispectral reflectance functions closely match those generated by a fully multispectral omnidirectional lighting basis, suggesting a rapid multispectral reflectance field capture method which could be applied for live subjects.

14:20 **Spectral Image Analysis of Florescent Objects with Mutual Illumination,** *Shoji Tominaga, Keiji Kato, Keita Hirai, and Takahiko Horiuchi, Chiba University (Japan)* **59**

This paper proposes a method to analyze the observed images of fluorescent images influenced by mutual illumination and estimate the spectral components. We suppose a general case where the entire surfaces of fluorescent objects have mutual illumination effects. First we model mutual illumination between the two objects. It is shown that the spectral composition is summarized with four components of (1) diffuse reflection, (2) diffuse-diffuse interreflection, (3) fluorescent self-luminescence, and (4) interreflection by mutual fluorescent illumination. Each component has two unknown factors of the spectral functions depending on wavelength and the weighting factors depending on pixel location. Second, an iterative algorithm is developed to solve this nonlinear estimation problem. Moreover, aiming a general solution which is independent of the initial conditions, we adopt a stabilization index to enforce the spectral smoothness and the spatial smoothness. Finally, the feasibility of the proposed method is shown using the spectral images of two adjacent fluorescent objects captured by a spectral imaging system in the visible range.

14:40 **Evaluating Robustness of the Method to Estimate Five Components from Skin Spectral Image,** *Rina Akaho, Misa Hirose, Munenori Fukunishi, and Norimichi Tsumura, Chiba University (Japan)* **65**

In this research, we evaluate robustness for noise and change of epidermis thickness in the method to estimate five components that are melanin, oxy-hemoglobin, deoxy-hemoglobin, shading and surface reflectance from spectral reflectance of skin at 5 wavelengths. We also estimated the five components from measured image of age spot and circles under eyes using the method. As a result of evaluation, we found that the noise of image is required to be 0.1% or less to accurately estimate five components and the thickness of epidermis affects the estimated value. However, we could acquire the distribution of major causative for age spot and circle under eyes by applying the method to measured spectral images.

15:00 **Non-Contact Video based Estimation of Pulse Transit Time Using Quantitation Method of Hemoglobin Level,** *Munenori Fukunishi,[1] Taku Yonezawa,[1] Genki Okada,[1] Kouki Kurita,[1] Shoji Yamamoto,[2] and Norimichi Tsumura[1]; [1]Chiba University and [2]Tokyo Metropolitan College of Industrial Technology (Japan)* **71**

Blood pressure is usually measured with a contact device called a sphygmomanometer cuff. Recently blood pressure can be easily measured with portable devices such as smart watches that take advantage of the progress of mobile technology. Even with the use of mobile devices, contact measurement is still required, which is one of the biggest limitations for monitoring.

In this paper, we propose non-contact video based estimation method of pulse transit time (PTT) based on the quantitation method of hemoglobin level. The correlation between PTT measured by the proposed method and the blood pressure measurement with sphygmomanometer cuff was between -0.5792 to -0.7801, which confirms the effectiveness of the proposed method.

15:20 **Demultiplexing Visible and Near-Infrared Information in Single-Sensor Multispectral Imaging,** *Zahra Sadeghipoor,[1] Jean-Baptiste Thomas,[2] and Sabine Süsstrunk[1]; [1]EPFL (Switzerland) and [2]Bourgogne University (France)* **76**

In this paper, we study a single-sensor imaging system that uses a multispectral filter array to spectrally sample the scene. Our system captures information in both visible and near-infrared bands of the electromagnetic spectrum. Due to manufacturing limitations, the visible filters in this system also transmit the NIR radiation. Similarly, visible light is transmitted by the NIR filter, leading to inaccurate mixed spectral measurements. We present an algorithm that resolves this issue by separating NIR and visible information. Our method achieves this goal by exploiting the correlation of multispectral images in both spatial and spectral domains. Simulation results show that the mean square error of the data corrected by our method is less than 1/20 of the error in sensor spectral measurements.

15:40 – 16:20 — Coffee Break / Exhibit Open

Colorful Matter

Session Chair: Ján Morovic, HP Inc. (Spain)
16:20 – 17:20

Recipient of the CIC24 Best Paper Award

16:20 **Modelling Incomplete Chromatic Adaptation and Colour Contrast Using Memory Colour,** *Qiyan Zhai,[1] M. Ronnier Luo,[1,3] Peter Hanselaer,[2] and Kevin A.G. Smet[2]; [1]Zhejiang University (China), [2]KU Leuven (Belgium), and [3]University of Leeds (UK)* **82**

The chromatic adaptation and colour contrast cause the colour appearance shift according to the adapting illuminant and background, respectively. It is difficult to distinguish between these effects because they all have an impact on the colour appearance of object. An experiment was conducted using memory colour matching approach in real scene at a high luminance level of various sources on the blackbody locus and some saturated colours. The results were used to develop two kinds of models for the incomplete adaptation factor (D) in CAT02. The necessity of a target dependent correction was discussed.

16:40 **Investigating Performance of Uniform Color Spaces for High Dynamic Range and Wide Gamut Color Difference Applications,** *Muhammad Safdar,[1] M. Ronnier Luo,[1,2] and Guihua Cui[3]; [1]Zhejiang University (China), [2]University of Leeds (UK), and [3]Wenzhou University (China)* **88**

This study investigated that which of the available color spaces performs best in different aspects when encoding high dynamic range and wide gamut color difference signals. Six different color spaces including CIELAB, CIELUV, CAM16-UCS, ICtCp, ICaCb, and zICaCb (current modification of ICaCb), were investigated for their performance in terms of local and global uniformity, hue linearity, encoding of Rec.2020 signals, convergence of iso-hue lines at single point (locus), distance between locus and origin, and computational cost. A new metric was developed for hue linearity test.

Comprehensive testing was performed using the most reliable datasets and some modifications were proposed in the recently developed color space named ICaCb. Results showed that the current zICaCb outperformed other spaces tested for most of the measures and gave similar performance for other measures.

17:00 **Visual Perception of 3D Printed Translucent Objects,** *Bui Minh Vu,[1] Philipp Urban,[2] Tejas Madan Tanksale,[2] and Shigeki Nakauchi[1]; [1]Toyohashi University of Technology (Japan) and [2]Fraunhofer Institute for Computer Graphics Research IGD (Germany)* **94**

In order to reproduce translucent objects by 3D printers employing fully transparent (or clear) material, modeling the human visual perception of translucency is crucial. In this preliminary study, a set of 256 texture-less samples was created by mixing white and clear materials using multi-jet 3D printing. The samples differ in both lateral light transport properties and transmittance. Two psychophysical experiments were conducted to reveal the relationship between transmittance and a perceptually uniform scale for translucency. The results show that Stevens' power law describes well this relationship within the optically thin range of samples. Furthermore, the sensitivity to lateral light transport is small compared to transmittance for the texture-less sample set.

18:30 – 21:30
Conference Reception. Westgate Pool Deck

THURSDAY NOVEMBER 10, 2016

Thursday Keynote and IS&T Awards

Session Chair: Marius Pedersen, Norwegian University of Science and Technology (Norway)
9:00 – 10:00

9:00 **The Evolution of Primate Color Vision,** *Gerald H. Jacobs, University of California Santa Barbara (USA)* **100**

Human color vision represents only one of a number of alternative ways in which animals exploit spectral differences in their visual environments in support of behavioral choice. In recent years, comparative examinations of color vision in a wide variety of different species, coupled with even more broad-scale studies of the genes that specify photopigment proteins (opsins), have provided insights into the multiple pathways followed during the evolution of color vision. Among other things, these advances show how our own color capacity and that of our close primate relatives likely arose.

Do You See What I See?

Session Chair: Edoardo Provenzi, Université Paris Descartes (France)
10:00 – 12:40

10:00 **Colour Vision during the Developing Age,** *Caterina Ripamonti, Cambridge Research Systems, Ltd; Sarah Kalwarowsky, Birbeck University; and Marko Nardini, Durham University (UK)* **101**

It has been previously shown that chromatic discrimination across the life span is characterised by a bell-shape function that has its maximum at 20-30 years; after this age the ability to discriminate colours decreases due to age-related ocular and neuronal changes. However, it is unclear why the discrimination should also be poorer during the paediatric age range.

In this study we tested psychophysically if the elevated discrimination thresholds of a paediatric population reflect a real anatomical and/or functional visual development; or if they are biased by the difficulty in performing the discrimination task, and the attentional resources required to execute the test. We compared paediatric performance at two chromatic discrimination tests: the Universal Colour Discrimination Test (UCDT), and the Farnsworth-Munsell 100 Hue Test (FM100HT). The UCDT used a simple 2-alternative-forced-choice task to measure the minimum saturation required to discriminate the chromatic target from its achromatic background. Saturation thresholds were measured near the protan, deutan, and tritan confusion lines. Each threshold took about 2 minutes and was repeated twice for a measure of reliability. The FM100HT required the observer to sort a large number of caps according to their hue, and on average it took about 20 minutes to complete the test. The two tests were run on the same day and in random order.

We tested a population of 56 paediatric observers: 18 aged 5- 6 years, 20 aged 9-10 years and 18 aged 13-14 years; all had normal colour vision, as assessed by either the Ishihara or the HRR plates. Our control group consisted of 18 adult observers aged 18-23 years; all had normal colour vision.

Expectedly, we found that the mean total error scores measured with the FM100HT dramatically varied with age. Surprisingly, chromatic discrimination thresholds measured with the UCDT were approximately constant across age for all confusion axes. In fact, apart from a few outliers, all paediatric observers showed chromatic discrimination thresholds that fell within the normal trichromatic range.

In conclusion, we found that chromatic discrimination in our paediatric population can be as good as chromatic discrimination in young adults, when assessed with a sensitive and fast colour discrimination test based on a simple task, like the UCDT.

10:20 **JIST-First Paper** **Using a Behavioral Match-to-Sample Method to Evaluate Color Vision Deficiency Simulation Methods,** *Joschua Thomas Simon-Leidtke and Ivar Farup, Norwegian University of Science and Technology (Norway)* **106**

Color vision deficiency (CVD) simulation methods are used both to simulate color vision of color-deficient people and as input for image enhancement methods for the color-deficient. However, a standardized method to compare simulation methods has not yet been defined. We propose a behavioral methodology to evaluate, compare and rank different simulation methods. By using accuracy and response time data from a match-to-sample experiment, we can assess behavioral performance of simulation methods. We show firstly that the match-to-sample paradigm is well suited to show performance differences between observer groups; secondly, that the simulation methods do indeed simulate the desired CVD to some degree; and thirdly, we show that the proposed methodology can be used to rank different simulation methods. Our results indicate that the simulation method proposed by Brettel et al. depicts deutan CVD more accurately than the simulation method proposed by Kotera.

10:40 – 11:20 — Coffee Break / Exhibit Open

11:20 **Individual Differences in Color Matching and Adaptation: Theory and Practice,** *Mark D. Fairchild, Rochester Institute of Technology (USA)* **115**

Individual differences in color matching functions are well known and have recently been well modeled and quantified. The phenomenon even carries a unique name, observer metamerism. However, to date, no research has explored the effects of observer metamerism (or other individual differences

in physiological mechanisms) on chromatic adaptation and color appearance. This paper presents a computational study of the effects of observer metamerism on predicted corresponding colors, the result of chromatic adaptation. The ranges of predicted corresponding colors are computed, analyzed and explored. The differences in predicted chromatic adaptation (using a von Kries model) are very significant and could have practical importance. Additionally, a computation of the required precision in psychophysical experiments on chromatic adaptation indicates that the precision required to adequately model individual differences (well less than one CIELAB unit) is an order of magnitude better than that of previously published research on which models such as CIECAM02 are built.

11:40 **A Revisit of the MacAdam Colour Discrimination Ellipses,** *Maria Georgoula,[1] Guihua Cui,[2] and Ronnier Luo[1,3]; [1]University of Leeds (UK), [2]Wenzhou University, and [3]Zhejiang University (China)* **121**

MacAdam colour discrimination data have been the fundamental basis for the definition of just noticeable colour difference. Lighting stimuli and products are compared in regard to these ellipses data. The current study examines the validity of the MacAdam ellipses and investigates the best tool to evaluate colour difference of light stimuli. Pairs of chromaticity colour difference were processed with the aim to be simulated as light sources on a display and over 23000 assessments were accumulated by a group of 20 observers. Experiments were based on the ratio method and all pairs were examined against two different backgrounds; a black background and a grey background with the same specifications as the one employed in the MacAdam experiment. Different colour difference metrics and colour spaces were investigated in terms of ellipse fitting and colour difference performance.

12:00 **JIST-First Paper** **Effects of Color Pairs on Warmth Perception in Interiors,** *Begüm Ulusoy and Nilgün Olguntürk, Bilkent University (Turkey)* **126**

Warmth perception is a physical, emotional, semantic, and sensorial bond between people and their environments. Although the effects of single colors have been explored, there has been no research on how paired colors affect warmth perception in interiors. Therefore, the main aim of this study is to investigate these effects of colors and color pairs. Each model was assessed by 32 participants, totaling 96 different participants assessed the color models (Red, White, Green, and their pairs) under controlled conditions, both on a seven-point semantic differential scale and through open-ended questions. The results show that both single colors and paired colors affect warmth perception in interiors. White, Green, and Red are warmer than each other, respectively. Red appears to increase and White appears to decrease the warmth perception of their pairs in interiors. Another important finding of the study is that there is no effect of color location in paired colors.

Interactive Preview I

Session Chairs: Adrià Forés Herranz, Apple Inc. (USA), and Kristyn Falkenstern, Digimarc Corporation (USA)
12:20 – 12:40

Improvement of Appearance from Motion by Using Omni-Directional Camera, *Ryota Domon,[1] Shoji Yamamoto,[2] Hiroshi Kintou,[3] and Norimichi Tsumura[1]; [1]Chiba University, [2]Tokyo Metropolitan College of Industrial Technology, and [3]Nikon Corporation (Japan)* **136**

We present a rapid measurement method for material appearance based on surface reflectance properties of three-dimensional object. Conventional methods have some problems relating to the size, cost, and difficulty of operation. Appearance from Motion method proposed by Dong et al. is appropriate to conquer above problem. Their method challenged to estimate the surface reflectance under unknown lighting. However, a use of multiple unknown parameters causes the loss of convergence, and sometimes preys on the accuracy and computational cost. Therefore, we improved the algorithm of Appearance from Motion method to use the omni-directional camera for incident lighting component. We demonstrate valuable results for accuracy of reproduction and reduction of computational cost by using the omni-directional camera.

Perceptually Equivalent Luminance Level of Large-Screen TVs, *Taeseong Han, Sungjin Kim, and Dongwoo Kang, LG Display Co., Ltd. (Korea)* **142**

Recently, large-screen televisions over 55-inch have been widely popularized. Display manufacturers need to know which luminance has great preference, familiarity, less fatigue and low power consumption for large-screen TVs. Most of earlier studies had focused on the proper luminance of TVs by considering a screen illuminance, visual angle and average picture level. On the other hand, it has been assumed that an amount of light and an average luminance on field of view of displays influence on a proper luminance. It has been focused on the perceptually equivalent luminance in large-screen TVs compared with current 55-inch TVs as mainstream. A physical measurement about amount of light and a subjective evaluation to examine the relationship of the perceptually equivalent luminance between a 55-inch display and large-screen displays have been conducted. The evaluation results show that average luminance on field of view is a major factor to influence the perceptually equivalent luminance. And it obtained the perceptually equivalent luminance of large-screen TVs is relatively low.

Emotion Monitoring Using Remote Measurement for Physiological Signals by Camera, *Genki Okada, Taku Yonezawa, Kouki Kurita, and Norimichi Tsumura, Chiba University (Japan)* **147**

In this paper, we propose the method of emotion monitoring using physiological signals such as RR intervals and blood volumes obtained by analyzing hemoglobin concentration from facial color images. The emotion monitoring has a great potential in areas such as market research, safety measure, medical, and robot systems. Recently, the most popular method of emotion monitoring is by using physiological signals. However, the previous studies are not practical due to using special instruments such as electrodes or laser speckle flowgraphy to obtain physiological signals. Therefore, the proposed method uses simple RGB camera. Using 27 kind of features calculated from the physiological signals from the camera, we classified five different emotional states (amusement, anger, disgust, sadness and surprise). As a result, we could classify emotions with 94% accuracy by selecting features.

Viewpoint Entropy for Material Appearance, *Yuto Hirasawa,[1] Shoji Yamamoto,[2] Ryota Domon,[1] Hiroshi Kintou,[3] and Norimichi Tsumura[1]; [1]Chiba University, [2]Toyko Metropolitan College of Industrial Technology, and [3]Nikon Corporation (Japan)* **152**

In this paper, we proposed an evaluation model to quantify the viewing condition that enhances the material appearance of object without dependence on shape of object. The proposed model is based on viewpoint entropy which is used to find appropriate eye position. In order to establish this model, we first clarify the surface that have important infor-

mation related to material appearance by measuring the gaze point with eye tracking equipment. Next, we added experimental results as a weight coefficient of material appearance into the conventional viewpoint entropy. We verified that our model is applicable to metal and ceramic objects by comparing the results between subjective evaluation and computational evaluation using the proposed model.

Classification of Painting Techniques with Color Run-Length Matrices, *Alexandre Bony and Christine Fernandez-Maloigne, XLIM Laboratory, CNRS and University of Poitiers (France)* **157**
In human and computer vision, the analysis of color and texture is primordial for object recognition and image classification. The analysis of color textures mainly contributes to the automatic classification in industrial images, satellite images, bio-medical images, or patrimonial images. The aim of this paper is to propose a new color statistical measure for texture analysis, based on color Run-Length Matrices (cRLM), associated to Principal Component Analysis (ACP) for paintings classification. The effectiveness of our approach is assessed by results of perfect classification in a same group of the attributes space of all the paintings of an artist. These results suggest that color Run-Length Matrices are a suitable basis for color texture analysis in numerous applications based upon color textured regions classification.

Exploiting Wide-Gamut Displays, *Greg Ward, Hyunjin Yoo, Afsoon Soudi, and Tara Akhavan, Irystec, Inc. (USA)* **163**
We present a hybrid color mapping (HCM) designed to preserve a selected region in chromaticity space while exploiting the larger gamut of the intended target display. Our method is based on the hypothesis that outside a certain set of critical colors, people are less particular and prefer a more saturated appearance if available. This hypothesis was borne out in the subject study we conducted. While other practitioners have implemented similar gamut-mapping techniques, our definition of preserved colors is more flexible and not based purely on saturation level. We employ an exponent or "acceleration factor" in our mapping to better preserve neighboring colors for a more natural appearance. Our method further avoids contrast and luminance changes, works between arbitrary gamuts, and is a fully invertible one-to-one mapping between color volumes.

Extended Linear Color Correction, *Graham Finlayson[1,2], and Garrett Johnson[2], [1]University of East Anglia (UK) and [2]Apple Inc. (USA)* **168**
Color correction is often posed as a linear regression problem either from camera RGB to XYZ – where the aim is use a camera for color measurement – or to a display color space such as sRGB for image reproduction. While linear regression is simple and also ensures exposure independence, the mapping found through regressing RGB to XYZ is not optimal in terms of perceived color.

In this paper, we begin by observing that the best linear transform for mapping RGB to XYZ to minimize a color difference metric, such as CIE LAB, is not separable. In particular we show that the best fitted Y channel should be different depending on whether L*, a* or b* error is minimized. Consequently, we develop an extended linear regression framework for CIE LAB where we solve for Y – we map RGB onto Y – three times – once for L*, once for a* and once for b*. As in conventional regression we solve for X and Z only once.

Experiments demonstrate that compared to our new extended linear regression method the mean, 95% quantile and CIE LAB error afforded by simple linear least-squares is respectively 30%, 50% and 70% larger. Extended linear regression delivers leading color correction performance with fewer parameters than competing methods.

Color Constancy Algorithm Using Weighted Multi-Scale Correction Coefficients, *Ji-Hoon Yoo,[1] Wang-Jun Kyung,[2] Shibudas Kattakkalil Subhashdas,[1] and Yeong-Ho Ha[1]; [1]Kyungpook National University and [2]Aurora (Korea)* **174**
The degraded images can be improved by image quality enhancement techniques considering color, contrast, and various other parameters related to images. Based on color constancy, the previous image enhancement algorithms, such as white patch assumption (WPA) and gray world assumption (GWA) algorithms, have several limitations. The color correction of resulting image has an antagonistic effect if the local region of an input image is biased by an individual color. Also, the correction result is degraded when the image does not have any white patches. Furthermore, the resulting image has low saturation, which degrades the correction result if images have monotonic color. To improve on these limitations, this paper proposed a color image enhancement algorithm based on the weighted multi-scale compensation coefficients using GWA algorithm. The multi-scale Gaussian filter is used for computing average values of local and global degraded color and calculating correction coefficients for size, pixel, and channel of multi-scale filtered images independently based on the brightness of the image. Then, the weights are determined for weight-sum of multi-scale correction coefficients by analyzing local color distribution of the image. Finally, the degraded color is improved by utilizing correction coefficients, which are integrated in original image, and degraded color saturation is improved using the proposed weights. The experimental results have shown that, compared with previous algorithms, the proposed algorithm improved color and contrast of various degraded image and produced better correction results.

Illuminant Chromaticity Estimation via Optimization of RGB Channel Standard Deviation, *Shibudas Kattakkalil Subhashdas, Ji-HoonYoo, and Yeong-Ho Ha, Kyungpook National University (Korea)* **180**
Illuminant estimation is the primary sftep to solve the color constancy problem. There are various statistical-based, learning-based and combinational-based color constancy algorithms already exist. However, the statistical-based algorithms can only perform well on images that satisfy certain assumptions, learning-based methods are complex methods that require proper preprocessing and training data, and combinational-based methods depend on either pre-determined or dynamically varying weights, which are difficult to determine and prone to error. Therefore, this paper presents a new optimization based illuminant estimation method which is free from complex preprocessing and can estimate the illuminant under different environmental conditions. A strong color cast always has an odd standard deviation value in one of the RGB channels. Based on this observation, a cost function called the degree of color cast(DCC) is formulated to determine the quality of illuminant colorcalibrated images. Here, a swarm intelligence based particle swarm optimizer(PSO) is used to find the optimum illuminant using the degree of illuminant tinge. The proposed method is evaluated using real-world datasets and the experimental results validate the effectiveness of the proposed method.

12:40 – 14:00 — Lunch Break

Illuminating Color

Session Chair: Abhijit Sarkar, Microsoft Corporation (USA)
14:00 – 15:20

14:00 **Effects of Inter-Observer Variation on Color Rendering Metrics,** *Michael J. Murdoch and Mark D. Fairchild, Rochester Institute of Technology (USA)* **187**
Metrics for describing the color rendering characteristics of light sources are based on CIE standard observers. However, the range of natural variation in color sensitivity over people with normal color vision means any individual may see something different than the standard observer. Modeling results quantify the effects of these inter-observer differences on color rendering metrics CIE 13.3 (CRI) and IES TM-30-15. Inter-observer differences are smallest at high color fidelity values and generally larger for light source spectra with steep transitions and narrow peaks.

14:20 **Evaluation of the IES Method for Evaluating Light Source Color Rendition in Terms of Metamer Mismatching,** *Brian Funt and Ben Hull, Simon Fraser University (Canada), and Xiandou Zhang, Hangzhou Dianzi University (China)* **192**
The Illumination Engineering Society's Rf color rendering index [IES TM-30-15, 201] is compared to the MMCRI [Metamer Mismatching as a Measure of the Color Rendering of Lights, Mirzaei & Funt, Proc. AIC 2015]. IES Rf is based on color differences using a special set of 99 surface reflectances; while, in contrast, MMCRI is based on all theoretically possible reflectances. The two indices evaluate many lights similarly, but the MMCRI ranks some lights—especially those having strong peaks and wavelength regions of minimal power—lower than does Rf. Is this difference in rating simply due to the fact that MMCRI uses all theoretically possible reflectances including step functions? A 'practical' version of MMCRI based on a set of 41 million real, measured spectral reflectances, rather than all theoretically possible reflectances, turns out to concur with the original MMCRI and shows that the disagreement between Rf and MMCRI is more fundamental. Overall, the present study suggests that Rf may overrate the color rendering properties of some lights; and, at the very least, indicate the type of lights upon which future psychophysical testing should concentrate.

14:40 **Extension of CIE Whiteness Metric under Different Illuminants,** *Shining Ma,[1] Jing Liang,[1,2] Minchen Wei,[3] and Ming R. Luo[1,4]; [1]Zhejiang University (China), [2]Dalian Polytechnic University (China), [3]The Hong Kong Polytechnic University (Hong Kong), and [4]University of Leeds (UK)* **198**
An experiment was conducted to extend the CIE whiteness metric under white sources having different CCTs. Three versions based on CIE whiteness index were derived and they all gave similar degree of accuracy in predicting experimental data. The one with CAT02 performed quite well and is simple to use by applying the original CIE whiteness index under D65. The tint limits were also verified and a limit of ±5T is proposed.

15:00 **Three-Dimensional Test Target for Illuminant Analysis,** *Nathan Moroney, Ingeborg Tastl, and Melanie Gottwals, HP Inc. Laboratories (USA)* **203**
Test targets, such as color charts, are often used for characterizing image capture systems. This paper describes a test target that uses three-dimensional sinusoids of varying orientation to analyze the illumination for a given scene. Specifically the magnitude of the contrast of the imaged sinusoids is used to estimate the angular orientation of the illuminant. A target consisting of sixteen sinusoids sampled every 11.25 degrees is shown to estimate the angular location of the illuminant to within 6.6 degrees in a laboratory setting. Furthermore this accuracy is achieved even with the introduction of a diffuser into the scene. This target is also used to differentiate two illuminants of differing chromaticity. In addition the target is used to differentiate the relative diffuseness of various locations on the bottom of a light booth. Finally the virtual target is also useful for understanding the illumination of 3D visualization software. The design and production of the target is described in more detail as are additional applications and use cases. The introduction of known three dimensional structure into test targets is a promising area for the design of targets for evaluation of image capture systems.

Interactive Previews II

Session Chairs: Adrià Forés Herranz, Apple Inc. (USA), and Kristyn Falkenstern, Digimarc Corporation (USA)
3:20 – 3:50

A Revision of CIECAM02 and its CAT and UCS, *Changjun Li,[1,3] Zhiqiang Li,[1] Zhifeng Wang,[1] Yang Xu,[1] Ming Ronnier Luo,[2] Guihua Cui,[3] Manuel Melgosa,[4] and Michael Pointer[2]; [1]University of Science and Technology Liaoning (China), [2]University of Leeds (UK), [3]Wenzhou University (China), and [4]University of Granada (Spain)* **208**
Various attempts have been made to overcome the mathematical problems of CIECAM02. All focused on modifications keeping the original structure of CIECAM02, and resulted in some loss of accuracy in predicting experimental visual results. The current paper proposes to merge the separate adaptation to the chromaticity and luminance of the illuminant by using a new space rather than the two different spaces proposed in the original CIECAM02. The new space, defined by a new matrix M16, is a cone-like space. From the new structure and space a new colour appearance model, named CAM16, has been derived. At the same time, a new chromatic adaptation transform, named CAT16, and a new uniform colour space, named CAM16-UCS, have been also developed. Performance tests showed that CAM16 and its associated CAT16 and CAM16-UCS not only solved all the mathematical problems reported for CIECAM02, but also performed as well as or even better than the original CIECAM02 model and its associated chromatic adaptation transform CAT02 and color space CAM02-UCS. These performance tests included predictions of experimental data currently available as visual colour appearance datasets, corresponding colour datasets and colour difference datasets. Furthermore, CAM16 is simpler than CIECAM02.

Robust Multispectral Data Hiding in RGB Image Using Digital Watermarking, *Kazushige Banzawa, Kazuma Shinoda, and Madoka Hasegawa, Utsunomiya University (Japan)* **213**
In this paper, we propose a method of embedding the spectral information into an RGB image by robust watermarking. The difference between an original image and a multispectral image estimated from the RGB image by Wiener estimation is referred to as the residual. The estimated spectral residual data are compressed by JPEG2000 and embedded into the wavelet coefficients of chrominance channel. When a multispectral image is reconstructed from an RGB image, our proposed method can improve the quality of the reconstructed multispectral image in comparison with a multispectral image estimated by Wiener estimation because the residual data can be extracted from the watermarked RGB image. Additionally, if the watermarked RGB image is compressed with a lossy compression

method, the proposed method can obtain the high-quality reconstructed multispectral image because this method uses robust watermarking. The experimental results show that there is almost no significant difference in the RGB image.

Functional Illumination Supporting the Visual Detection of Plaques, *Taisei Kondo,[1] Juan L. Nieves,[2] Eva M. Valero,[2] Hiroshi Higashi,[1] and Shigeki Nakauchi[1]; [1]Toyohashi University of Technology (Japan) and [2]University of Granada (Spain)* **219**
Some people often suffer from periodontal diseases and poor oral environments can be the cause of such diseases. The maintenance of oral health is a crucial issue for general health. One of the measures to maintain oral health is by brushing teeth to remove plaque. However, it is difficult to remove plaque perfectly because the color of plaque is similar to the color of the teeth making it difficult to find remaining plaque by simple visual inspection. In this study, we propose a functional illumination that helps detecting plaque on teeth. The functional illumination was optimized to enhance the color difference between the plaque and the teeth in a CIELAB color space. We designed the spectrum of the illumination by NLP (Non Linear Programming) in such a way that the color difference between the teeth and the plaque is maximized. The optimized illumination has a peak at 420 nm because the largest difference is observed in the reflectance between the teeth and the plaque in this wavelength. The color difference increased with the functional illumination by a factor of 3 with respect to a normal white light source. Additionally, we implemented the real functional illumination by a combination of LEDs and it was able to enhance color discrimination. For different participants, the functional illumination could also enhance color discrimination.

Color Spaces Emerging from Deep Convolutional Networks, *Ivet Rafegas and Maria Vanrell, Universitat Autònoma de Barceolona (Spain)* **225**
Defining color spaces that provide a good encoding of spatio-chromatic properties of color surfaces is an open problem in color science. Related to this, in computer vision the fusion of color with local image features has been studied and evaluated. In human vision research, the cells which are selective to specific color hues along the visual pathway are also a focus of attention. In line with these research aims, in this paper we study how color is encoded in a deep Convolutional Neural Network (CNN) that has been trained on more than one million natural images for object recognition. These convolutional nets achieve impressive performance in computer vision, and rival the representations in human brain. In this paper we explore how color is represented in a CNN architecture that can give some intuition about efficient spatio-chromatic representations. In convolutional layers the activation of a neuron is related to a spatial filter, that combines spatio-chromatic representations. We use an inverted version of it to explore the properties. Using a series of unsupervised methods we classify different type of neurons depending on the color axes they define and we propose an index of color-selectivity of a neuron. We estimate the main color axes that emerge from this trained net and we prove that color-selectivity of neurons decreases from early to deeper layers.

The Effectiveness of Colour Appearance Attributes for Enhancing Image Preference and Naturalness, *Yuteng Zhu,[1] M. Ronnier Luo,[1,2] Sebastian Fischer,[3] Peter Bodrogi,[3] and Tran Quoc Khanh[3]; [1]Zhejiang University (China), [2]University of Leeds (UK), and [3]Technische Universität Darmstadt (Germany)* **231**
Investigation of image quality on preference and naturalness using 1-dimensional and 2-dimensional colour attributes was performed. Each colour attribute varied in two directions, and each direction had two levels, i.e. large and small. In the present study, paired comparison was employed for image preference and categorical judgement for image naturalness assessment. The aim was to evaluate the performance and effectiveness of 1-dimensional and 2-dimensional colour attributes on image quality. Furthermore, cultural difference, the relationship between image preference and naturalness, the difference between memory colours in colour patches and digital images were examined. The experimental results revealed that the effectiveness of colour attributes on image quality vary with image content.

The Necessity of a Whiteness Scale for FWA-Enhanced Whites, *Minchen Wei,[1] Shining Ma,[2] and Ming R. Luo[2,3]; [1]The Hong Kong Polytechnic University (Hong Kong), [2]Zhejiang University (China), and [3]University of Leeds (UK)* **237**
Two scales (i.e., Cho's whiteness scale and Berns' depth scale) were investigated to see whether they can accurately predict the whiteness of surface colors (e.g., textile and paper), both scales were found to be highly correlated to the NCS samples in past studies. The results indicated that the whiteness of samples without FWA-enhancement was highly correlated to both scales, but neither of them can predict the whiteness of FWA-enhanced white samples. These FWA-enhanced samples did not follow the concept that higher lightness and lower chroma produce whiter appearance. The study suggests the necessity to have a unique model to characterize the whiteness of FWA-enhanced whites, especially given the wide use of FWAs around human beings.

An iccMAX Material Profile Example: Converting Spectral Images of Artwork to Paint-Concentration Images, *Ben Bodner and Roy S. Berns, Rochester Institute of Technology (USA)* **242**
The ICC is introducing a new standard, iccMAX, that allows for customized connection spaces. The step-by-step process of implementing a complex linear algorithm in an iccMAX material profile is presented. This provides a reference for creating iccMAX profiles that use the programmable calculator functionality. The algorithm converts spectral reflectance to paint concentrations that produce a spectral match. Several tools are discussed that produce iccMAX profiles for a spectral workflow being developed at the Studio for Scientific Imaging and Archiving of Cultural Heritage at RIT.

Individual Corresponding Colors Data and Chromatic Adaptation Transforms, *Shengyan Cai, Tianjin University of Science & Technology (China), and Mark D. Fairchild, Rochester Institute of Technology (USA)* **248**
It has been well established, through the study of observer metamerism, that color matching functions vary across individual observers. Chromatic adaptation transforms, however, have not been similarly studied to examine carefully for individual differences. Existing chromatic adaptation transformations, such as CAT02 that is embedded within CIECAM02, are fitted to population data on corresponding colors that tell us little about individual differences and have inherently large uncertainty. It is often stated that fitted von Kries type models fit within the population of observers (e.g. within the inter-observer variability) rather than accurately fitting the mean of the data (e.g. within the standard error of the mean of a population or an individual). That suggests two questions examined in this work: Do such models actually predict the mean results? And can individual data on chromatic adaptation be described with 3x3 von Kries type models. These questions are approached by collecting corresponding colors data with very high accuracy and precision allowing the analysis and examination necessary to begin creating the next generation of accurate chromatic adaptation transforms.

Color Recommendation for Drawing based Image Retrieval on Mobile Devices, *Zhan Xu, Chao Zhang, and Guoping Qiu, University of Nottingham (China)* **254**
Color selection plays an important role in drawing based image retrieval. Frequently, users are overloaded by color options to select while drawing the query. In this paper, a color recommendation method dedicated to drawing-to-retrieve image search is proposed and implemented in our draw-to-retrieve application, which aims at assisting users in choosing colors in order to improve image retrieval efficiency in terms of drawing time and retrieval accuracy. Then, this method is tested in a preliminary experiment designed to explore how the image retrieval efficiency is affected when different colors are provided the palette. In order to illustrate an application of proposed approach, images of natural scenes are used as an example. 23 participants took part in the experiment to perform draw-to-target tasks of 36 images using three different color palettes. There are mainly three results concluded from the experiment: firstly, the image retrieval efficiency drops as the difficulty of target image increases; in addition, providing useful colors in the palette can lead to an more efficient retrieval; finally, the retrieval has better performance using our color recommendation approach than commonly used 20-color palette and a subjective evaluation of the participants is also included.

ICC Profile Color Table Compression, *Chuohao Tang,[1] Weibao Wang,[1] Sean Collison,[2] Mark Shaw,[2] Jay Gondek,[2] Amy Reibman,[1] and Jan P. Allebach[1]; [1]Purdue University and [2]HP Inc. (USA)* **260**
ICC profiles are widely used to provide transformations between different color spaces in different devices. The color lookup tables (CLUTs) in the profiles will increase the file sizes when embedded in color documents. In this paper, we discuss a compression method that decreases the storage cost of the CLUTs. A compressed color table includes quantized DCT coefficients for the color table, the additional nodes with large color difference, and the coefficients bit assignment table. This method supports lossy table compression to minimize the network traffic and delay, and also achieves relatively small maximum color difference.

New Spectral Data for Skin Colours, *Mengmeng Wang,[1] Ming Ronnier Luo,[1,3] Kaida Xiao,[1] Sophie Wurger,[2] Yuzhao Wang,[3, 4] and Minchen Wei[4]; [1]University of Leeds (UK), [2]University of Liverpool (UK), [3]Zhejiang University (China), and [4]Hong Kong Polytechnic University (Hong Kong)* **266**
Two experiments were conducted for collecting skin database at the Universities of Liverpool and Leeds (UK) and Zhejiang University (China). Overall, 235 subjects from 4 different skin groups (Caucasians, Chinese, South Asian, and Dark) were recruited. Each was measured using 4 types of colour measuring methods (tele-spectroradiometer, spectrophotometer, digital camera, and visual assessment) including 6 instruments and 2 sets of colour charts. The results from the former two types are summarised here. The results were analysed in terms of skin colour distribution, repeatability, and inter-instrumental agreement between 4 skin groups in CIELAB coordinates and spectral domain.

Texture Characterization by Grey-Level Co-Occurrence Matrix from a Perceptual Approach, *Ana Gebejes,[1] Rafael Huertas,[2] Alain Tremeau,[3] Ivana Tomic,[4] Pooshpanjan R. Biswas,[2], Charlotte Fraza,[2] and Markku Hauta-Kasari[1]; [1]University of Eastern Finland (Finland), [2]University of Granada (Spain), [3]University Jean Monnet (France), and [4]University of Novi Sad (Serbia)* **271**
Texture, along with color, is one of the most important characteristics of a material defining its appearance. While color had been studied for a long time and continues being an interesting topic, the analysis of texture has traditionally been postponed, mainly because of its difficulty, and remains a challenge. Depending on the application, different approaches to texture characterization have been proposed in the bibliography. In this work, texture is considered in the context of visual perception and the second order statistical measurements based on the Grey-Level Co-occurrence Matrix (GLCM) have been computed for a database of texture images (KTH-TIPS and KTH-TIPS2). In the literature, there is no available information about the number of features needed for texture characterization, although no less than five parameters are typically employed. In our previous work, the selection of the optimal texture features was studied through Principal Component Analysis (PCA), using only those that are statistically significant describing the studied textures. In this work, the texture features obtained were analyzed from a perceptual point of view.

Designing Spectral Power Distribution of Illumination with Color Chart to Enhance Color Saturation, *M. Tsuchida, K. Hiramatsu, and K. Kashino, NTT Communication Science Laboratories (Japan)* **278**
We propose a method to enhance color saturation while keeping the color appearance of white by controlling the spectral power distribution (SPD) of illumination. A color chart is used to design the SPD of illumination, which enables us to enhance several colors at the same time. In experiments, a sixteen-color LED lighting system was used as a light source. The intensity of each colored light can be modulated and is determined using three color patches of the X-Rite ColorChecker™. The color checker and multicolor wood-block prints were used to evaluate the results of color enhancement. The color distributions of these objects before and after changing the SPD of illumination were compared on a chromaticity diagram. Results show that the selected three colors are well enhanced while keeping metameric white and the color balance under daylight.

Interactive Paper Session / Exhibit Open

15:50 – 17:15

Evening Talk

Session Chair: Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)

20:15 – 21:15

20:15 **3D Color Printing in Stop Motion Animation,** *Brian McLean and Rob Ducey, Laika Animation Studios (USA)*

Evening Talk sponsored by HP Inc.

FRIDAY NOVEMBER 11, 2016

CIC Workshops

Session Chairs: Nicolas Bonnier, Apple Inc., and Maria Vanrell, Universitat Autònoma de Barcelona

times vary; see workshop description

8:00 – 12:00

W1: Camera Characterization

Organized by Dietmar Wueller, Image Engineering GmbH & Co. KG (Germany); Moderated by Sabine Süsstrunk, EPFL (Switzerland)

This workshop covers the process of camera characterization in theory and practice. Background and demonstrations are provided on all important aspects.

Many camera manufacturers utilize traditional test chart based color characterization methods because of reluctance to change running systems or incomplete appreciation of the benefits of modern characterization techniques.

This workshop identifies known issues in traditional approaches and demonstrates potential solutions using current technology including multispectral LED light sources, in situ measurements of spectral radiances of natural objects, and modern color transform methods including multidimensional color look up tables. This workshop provides all the information needed to implement advanced color correction in cameras and software.

Speakers for this workshop are:

The need for camera characterization and calibration and the impact of color correction on general image quality, *Kevin Matherson, Microsoft Corporation (USA)*

Target based versus spectral camera characterization, *Eric Walowit, consultant (USA)*

Target based versus in situ spectral training data, *Dietmar Wueller, Image Engineering GmbH & Co. KG (Germany)*

Multidimensional color lookup tables, *Michael Vrhel, Artifex Software, Inc. (USA)*

8:30 – 12:00

W2: ICC Life of Color Workshop (sponsored by ISCC)

Session Chairs: David R. Wyble, Avian Rochester, LLC, and John Conant, Aerodyne Research, Inc. (USA)

Within the context of the CIC technical program, "color" has a more limited scope, and does not typically include creative and production aspects. This workshop is designed to help expose attendees to those and other facets of color, all described as how a color is processed through various disciplines. This exposure can help technologists "connect the dots" by learning first hand how color and imaging research is applied. This workshop will serve as the technical content for the 2016 Annual Meeting for the Inter-Society Color Council (ISCC), but the content is appropriate for all conference attendees. The workshop will be followed by the ISCC Annual Business Meeting Lunch (additional fee). Four presentations begin with the creative design process and work through color communication, production, and finally perception.

The Design of a Color, *Leslie Harrington, Color Association of the United States (USA)* **283**

The color of a brand is walked through several phases from initial selection through the final analysis to understand how well it has met the brand needs. Several steps are described: the associated strategic decisions; how to align the color with a product/brand's attributes/voice; what are the customer segmentations and geographical positioning; and trend influences and competitive landscape.

Life of a Color—The Management of a Color, *Max Derhak, Onyx Graphics, Inc. and International Color Consortium (ICC) (USA)* **284**

Color management is the process by which colors are described, communicated, transformed and reproduced using a device independent color representation. Traditional color management has used only CIEXYZ colorimetry based on a single observer (the 1931 Standard 2° observer) and single illuminant (D50). A new color management system is described (iccMAX) that accounts for a complete color process from light sources onto objects captured through color matching, and provides the means to add perceptual aspects of color.

The Manufacturing of a Color, *Ann Laidlaw, ACL Color Consulting LLC (USA)* **289**

The path of a color is described from the creative process through development, approval, and manufacturing. The use of robust standards and consistent procedures is crucial to managing accurate color with on-time deliveries, especially when products are fabricated from multiple materials

From Photon to Brain: The Perception of Color, *Mark Fairchild, Rochester Institute of Technology (USA)* **291**

In the natural daylight environment, colors are most often perceived due to a sensor process that is initiated by a photon that was effectively (and sometimes literally) emitted by the sun some 90 million miles ((150 million km) away. These photons reach us about 8 minutes after leaving the sun, but what are the chances we actually detect one of them? This paper (and the accompanying presentation) begin with a photon departing the sun and as the question, what are the chances we detect it? The system examined includes light leaving the sun, penetrating the atmosphere, striking a piece of grass, being reflected to an eye, and then being absorbed by one of the retinal photoreceptors. Sensory and perceptual phenomena occurring after the photon is converted to other forms of energy in the brain are also briefly discussed.

9:30 – 12:00

W3: Color Science for 3D Printing: From Mondrian to Miro

Session Chairs: Peter Morovic and Ján Morovic, HP Inc. (Spain)

This workshop looks at the state-of-the-art of color science in 3D, as well as presents the upcoming challenges of 3D printing in color. While there is a rich and well established body of work in the Mondrian world (2D) that allows us to predict, model, and measure the colors of surfaces, their appearance in a given environment, the perceptual differences between surfaces under a variety of conditions, perform reliable psychophysic and psycho-visual experiments etc., a Miró world (3D) has additional complexity and additional degrees of freedom that need to be considered for a thorough understanding of how we perceive colors of objects that have different shapes, depths, textures, and surface finishes—and that vary significantly with illumination geometry etc. A straight-forward application of 2D methods often fails to deliver since, after all, these were derived for a flat

world where many of these effects can be discounted. The field of color science in 3D is still relatively young and is a treasure trove of open problems that require rigorous work and creative solutions. This workshop is both an overview of the state-of-the-art, as well as an invitation for the community to tackle them.

Speakers for this workshop are:

Color Assessment of Teeth and Skin Using Digital Imaging, *Marc Ellens, X-Rite, Inc. (USA)*

Color 3D Printing and its Challenges, *Stephen Westland, University of Leeds (UK)*

Tangible Imaging Systems: Bringing Virtual Surfaces into the Real World, *James A. Ferwerda, Rochester Institute of Technology (USA)*

Interactive Material Appearance Simulation and Portable Material Appearance Description, *Andrew Page, NVIDIA Corporation (USA)*
Engineers have received the benefits of shortened development times and improved products through the use of simulation for many years now. Product design decisions are now able to receive the benefits from digital simulation through the use of physically accurate, interactive light simulations which correctly show the material and light appearance. 3D printing will only accelerate the need for virtual prototyping since each piece can be unique; the production run may only ever be one unit. This presentation will show how NVIDA's Material Description Language (MDL) and Iray interactive renderer can make it easy to see how your designs will look, whether you're using additive or more traditional manufacturing techniques.

Color Measurements for 3D Printing, *Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)*

Overview of Color Image Reproduction for 3D Printing Using CIE Colorimetry, *Kaida Xiao, University of Liverpool (UK)*

12:00 – 13:30 — Lunch Break

Closing Keynote and Best Paper Award

Session Chair: Michael J. Murdoch, Rochester Institute of Technology (USA)
13:30 – 14:20

Keynote sponsored by Google Inc.

13:30 **Google Street View: Unique Challenges of Collecting Imagery at Global Scale,** *Luc Vincent and Rom Clement, Google Inc. (USA)*

Wrangling Color

Session Chair: Tamara Seybold, Arnold & Richter Cine Technik (Germany)
14:30 – 16:45

14:30 **JIST-First Paper** **Random Color Filter Arrays are Better than Regular Ones,** *Prakhar Amba, David Alleysson, and Jérôme Dias, Université Grenoble Alpes (France)* **294**
Most of digital cameras today use a color filter array (CFA) and a single sensor to acquire color information of the scene. In this article, we ask which arrangement of colors in the mosaic of the CFA provides the best encoding of the scene. As a solution of the inverse problem of demosaicing, we consider a linear minimum mean squared error model. We used redundancy given by the neighborhood on the sampled image to ensure the stability of the solution. For some CFAs, LMMSE with neighborhood provides equivalent reconstruction results and less variability among the image content compared to edge-directed demosaicing on the Bayer. LMMSE allows comparing CFAs of regular pattern with random ones. We show that mosaics with random arrangement of colors and quasi equal proportion of RGB provide best reconstruction performance.

14:50 **Scene Color Correction under Non-Uniform Spatial Illumination and Atmospheric Transmittance,** *Hiroaki Kotera, Kotera Imaging Laboratory (Japan)* **300**
Our daily scene visibility is degraded due to both spatial non-uniformities in A) illumination and B) atmospheric transmittance. Since the illumination extremely drops in the shade of tree or house and the atmospheric transmittance is disturbed by floating particles in the air, we never see the grand truth scenes even if under clear sky. This paper challenges to recover the scene color visibilities by removing the spatial non-uniformities of A) and B). Firstly, a modified BLF-SSR (Bi-Lateral Filter Single-Scale Retinex) is introduced to enhance the shadow visibility. A sharp bilateral filter is used for creating the edge-preserving surround to make a "halo-less" SSR like as MSR (Multi-Scale Retinex).

Secondly, an improved de-hazing algorithm is proposed to estimate the scene transmittance based on dark channel prior hypothesis. The proposed single image de-hazing algorithm works to remove the disturbances caused by atmospheric layer and to see the haze-free objects through the air pollution. The model works not only for heavy air pollution but also for thin ha scenes often encounters in daily life.

The proposed dehazing model shows "veiling factor α" is a key parameter for improving the usual scene's color appearance. The veiling factor is set to $\alpha \cong 0.9$ for heavy PM 2.5 pollution scene, while it should be set relatively lower values such as $\alpha \cong 0.7 \sim 0.2$ for the daily thin hazy scene. Once estimated scene transmittance is used to preset the veiling factor automatically.

The paper introduces typical cases where Retinex and De-hazing work collaborative and complementary in comparison with state-of-the art other models.

15:10 – 15:40 — Coffee Break

15:40 **Use of Simulated Reflectance Spectra in Camera Transform Creation,** *Michael J. Vrhel, Artifex Software (USA)* **306**
Spectral simulation methods can be useful in the creation of mappings from recorded values to colorimetric values for cameras and scanners. In this work, a spectral data set is expanded using simulated spectra created from a real data set. The expanded data set is used to create a multi-dimension-

al look-up-table (MLUT). The performance of the MLUT is compared to the performance of an MLUT created without the simulated spectral data. Results suggest that the use of simulated spectra in creating an MLUT could help to reduce maximum errors.

16:00 **Color Homography Color Correction,** *Graham Finlayson and Han Gong, University of East Anglia, and Robert Fisher, University of Edinburgh (UK)* **310**
Homographies – a mathematical formalism for relating image points across different camera viewpoints – are at the foundations of geometric methods in computer vision and are used in geometric camera calibration, image registration, and stereo vision and other tasks. In this paper, we show the surprising result that colors across a change in viewing condition (changing light color, shading and camera) are also related by a homography. We propose a new color correction method based on color homography. Experiments demonstrate that solving the color homography problem leads to more accurate calibration.

16:20 **Strengths and Limitations of a Uniform 3D-LUT Approach for Digital Camera Characterization,** *Sebastian Fischer, Paul Myland, Matthias Szarafanowicz, Peter Bodrogi, and Tran Quoc Khanh, Technische Universität Darmstadt (Germany)* **315**
Digital color imaging technology has become omnipresent in today's modern life. Digital image capturing and reproduction devices such as smartphones, digital still and video cameras, dis-plays, printers, and color scanners can be found in every home, offering extremely high functionality and flexibility. In order to guarantee qualitatively good results regarding the whole image processing pipeline and to achieve high user acceptance, opti-mized color conversion and correction algorithms play a crucial role. In this context, a new implementation method of uniform three-dimensional lookup tables (3D-LUTs) based on a standard-ized pre-measured spectral reflectance database will be presented and applied for the color correction of digital camera systems. The strengths and limitations of such an implementation will be discussed and a performance comparison with the standard 3[1]3 matrix color correction will be conducted. It can be found that the proposed 3D-LUT approach outperforms the matrix method in terms of CIEDE2000 color differences and color reproduction properties, but still has its limitations when it comes to achromatic colors and the representation of color gradients.

16:40 **Closing Remarks**

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