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In this paper, we change the optimization so that the overall filter transmittance is bounded, i.e. we solve for the filter that (for a uniform white light) transmits (say) 50% of the light. Experiments demonstrate that these filters continue to solve the color correction problem (they make cameras much more colorimetric). Significantly, the optimal filters by restraining the average transmittance can deliver a further 10% improvement in terms of color accuracy compared to the prior art of bounding the low transmittance.

Most cameras still encode images in the small-gamut sRGB color space. Converting a small-gamut image to a wider-gamut is a challenging problem. Many devices and software use colorimetric strategies that map colors from the small gamut to their equivalent colors in the wider gamut. This colorimetric approach avoids visual changes in the image but leaves much of the target wide-gamut space unused. Noncolorimetric approaches stretch or expand the small-gamut colors to enhance image colors while risking color distortions. We take a unique approach to gamut expansion by treating it as a restoration problem. A key insight used in our approach is that cameras internally encode images in a wide-gamut color space (i.e., ProPhoto) before compressing and clipping the colors to sRGB’s smaller gamut. Based on this insight, we use a software-based camera ISP to generate a dataset of 5,000 image pairs of images encoded in both sRGB and ProPhoto. This dataset enables us to train a neural network to perform wide-gamut color restoration. Our deep-learning strategy achieves significant improvements over existing solutions and produces color-rich images with few to no visual artifacts.

In the Maximum Ignorance with Positivity (MIP) assumption we assume that all reflectances with per wavelength values between 0 and 1 are equally likely. A weakness in the MIP is that it fails to take into account the correlation of reflectance functions between wavelengths (many of the assumed reflectances are, in reality, not possible). In the Maximum Ignorance with Positivity (MIP) assumption we assume that all reflectances with per wavelength values between 0 and 1 are equally likely. A weakness in the MIP is that it fails to take into account the correlation of reflectance functions between wavelengths (many of the assumed reflectances are, in reality, not possible).
In this paper, we explore how the performance of Sparse Coding can be further advanced. We point out that in the original A+ framework, the sparse dictionary used for neighborhood separations are optimized for the spectral data but used in the projected RGB space. In turn, we demonstrate that if the local linear mapping is trained for each spectral neighborhood instead of RGB neighborhood and then, theoretical or if we could recover each spectrum based on where it locates in the spectral space, the Sparse Coding algorithm can actually perform much better than the leading DNN method. In effect, our result defines one potential (and very appealing) upper-bound performance of point-based SR.

In this paper, we describe a comprehensive method for estimating the surface-spectral reflectance from the image data of objects acquired under multiple light sources. This study uses the objects made of an inhomogeneous dielectric material with specular highlights. A spectral camera is used as an imaging system. The overall appearance of objects in a scene results from the chromatic factors such as reflectance and illuminant and the shading terms such as surface geometry and position. We first describe the method of estimating the illuminant spectra of multiple light sources based on detecting highlights appearing on object surfaces. The highlight candidates are detected first, and then some appropriate highlight areas are interactively selected among the candidates. Next, we estimate the spectral reflectance from a wide area selected from an object’s surface. The color signals observed from the selected area are described using the estimated illuminant spectra, the surface-spectral reflectance, and the shading terms. This estimation utilizes the fact that the definition domains of reflectance and shading terms are different in each other. We develop an iterative algorithm for estimating the reflectance and the shading terms in two steps repeatedly. Finally, the feasibility of the proposed method is confirmed in an experiment using everyday objects under the illumination environment with multiple light sources.

**Investigating the Upper-bound Performance of Sparse-coding-based Spectral Reconstruction from RGB Images**, Yi-Tun Lin and Graham D. Finlayson, University of East Anglia (UK) .......................................................... 19

In Spectral Reconstruction (SR), we recover hyperspectral images from their RGB counterparts. Most of the recent approaches are based on Deep Neural Networks (DNN), where millions of parameters are trained mainly to extract and utilize the contextual features in large image patches as part of the SR process. On the other hand, the leading Sparse Coding method ‘A+’ which is among the strongest point-based baselines against the DNNs—seeks to divide the RGB space into neighborhoods, where locally a simple linear regression (comprised by roughly 102 parameters) suffices for SR.

In this paper, we explore how the performance of Sparse Coding can be further advanced. We point out that in the original A+ framework, the sparse dictionary used for neighborhood separations are optimized for the spectral data but used in the projected RGB space. In turn, we demonstrate that if the local linear mapping is trained for each spectral neighborhood instead of RGB neighborhood and then, theoretically or if we could recover each spectrum based on where it locates in the spectral space, the Sparse Coding algorithm can actually perform much better than the leading DNN method. In effect, our result defines one potential (and very appealing) upper-bound performance of point-based SR.

**SPECTRA**

Session Chair: Michael Brown, York University (Canada).

2 Nov: 02:00 – 03:00 (TOKYO)

Break in program to accommodate time zones
Effects of Display and Ambient Illuminance on Visual Comfort for Reading on a Mobile Device, Yu Liu and Ming Ronnier Luo, Zhejiang University (China) 42
A psychophysical experiment was carried out to investigate visual comfort when reading on three OPPO Find X3s displays at three luminance levels (100, 250 and 500 cd/m²) at five illuminance levels (0, 10, 100, 500 and 1000 lx). Twenty young observers evaluated visual comfort using a 6-category points method. The results showed that observers felt most comfortable at the illuminance of 500 lx or display luminance of 500 cd/m². There was an interaction between ambient illuminance and display luminance. High ambient light and display brightness levels provide a more pleasant visual experience. In low ambient light, however, the lower the brightness level, the more comfortable it is to see. Regarding the influence of background colour on visual comfort, the observers felt more comfortable having a grey background than white or black colour. When at dim illuminance, the background colour would have a great influence on visual comfort for negative contrast conditions, but when at higher illuminance, different background lightness levels had a great impact on visual comfort for positive contrast conditions. The above findings are very similar to the display luminance levels of 100 and 250 cd/m².

JIST-first Preliminary Result on the Direct Assessment of Perceptible Simultaneous Luminance Dynamic Range, Fu Jiang and Mark D. Fairchild, Rochester Institute of Technology (US) 47
The human visual system is capable of adapting across a very wide dynamic range of luminance levels; values up to 14 log units have been reported. However, when the bright and dark areas of a scene are presented simultaneously to an observer, the bright stimulus produces significant glare in the visual system and prevents full adaptation to the dark areas, impairing the visual capability to discriminate details in the dark areas and limiting simultaneous dynamic range. Therefore, this simultaneous dynamic range will be much smaller, due to such impairment, than the successive dynamic range measurement across various levels of steady-state adaptation. Previous indirect derivations of simultaneous dynamic range have suggested between 2 and 3.5 log units. Most recently, Kunkel and Reinhard reported a value of 3.7 log units as an estimation of simultaneous dynamic range, but it was not measured directly. In this study, simultaneous dynamic range was measured directly through a psychophysical experiment. It was found that the simultaneous dynamic range is a bright-stimulus-luminance dependent value. A maximum simultaneous dynamic range was found to be approximately 3.3 log units. Based on the experimental data, a descriptive log-linear model and a nonlinear model were proposed to predict the simultaneous dynamic range as a function of stimulus size with bright-stimulus luminance-level dependent parameters. Furthermore, the effect of spatial frequency in the adapting pattern on the simultaneous dynamic range was explored. A log parabola function, representing a traditional Contrast Sensitivity Function (CSF), fitted the simultaneous dynamic range data well.
The point that any more enhancement will result in a drop in the image contrast. Observers were instructed to enhance the quality of the images to study we introduce the Subjective Enhanced Image Dataset (SEID) in which could possibly be linked to the fact that current image quality metrics are not able to accurately evaluate the quality of enhanced images. In this study we focus on introducing new image enhancement techniques. While these techniques show a good performance and are able to increase the quality of images, little attention has been paid to how and when over-enhancement occurs in the image. This possibly be linked to the fact that current image quality metrics are not able to accurately evaluate the quality of enhanced images. In this study we introduce the Subjective Enhanced Image Dataset (SEID) in which 15 observers are asked to enhance the quality of 30 reference images which are shown to them once at a low and another time at a high contrast. Observers were instructed to enhance the quality of the images to the point that any more enhancement will result in a drop in the image quality. Results show that there is an agreement between observers on when over-enhancement occurs and this point is closely similar no matter if the high contrast or the low contrast image is enhanced.


SESSION BREAK / POSTERS AVAILABLE FOR VIEWING
Join speakers and other attendees in the CIC29 Gather.town.
to information compression, specifically variational autoencoders (VAEs) with a bottleneck constraint. To this end, we propose a framework—colour conversion—that allows a fair comparison of colour spaces. We systematically investigated several ColourConvNets, i.e. VAEs with different input-output colour spaces, e.g. from RGB to CIE \( L*a*b* \) (in total five colour spaces were examined). Our evaluations demonstrate that, in comparison to the baseline network (whose input and output are RGB), ColourConvNets with a colour-opponent output space produce higher quality images. This is also evident quantitatively: (i) in pixel-wise low-level metrics such as colour difference (DE), peak signal-to-noise ratio (PSNR) and structural similarity index measure (SSIM); and (ii) in high-level visual tasks such as image classification (on ImageNet dataset) and scene segmentation (on COCO dataset) where the global content of reconstruction matters. These findings offer a promising line of investigation for other applications of VAEs. Furthermore, they provide empirical evidence on the benefits of colour opponent representation in a complex visual system and why it might have emerged in the human brain.

11:50 (New York) / 16:50 (Paris)
00:50 (Tokyo)

Modeling Chromatic Contrast Sensitivity across Different Background Colors and Luminance, Marcel Lucassen, Dragan Sekulovski, and Marc Lambrou, Signify Research (the Netherlands); and Giang Xu and Ming Rorrier Luo, Zhejiang University (China)

In this research we compare chromatic contrast sensitivity models for two separate datasets and for the pooled dataset. They were obtained from two studies employing a very similar experimental paradigm. The data represent threshold visibilities of chromatic Gabor patterns varying in spatial frequency, background chromaticity, direction of color modulation and luminance, at constant stimulus size. Using the extended data set, we re-confirm our previously reported finding that a model based on color-opponent contrast signals is an improvement over a cone contrast model. However, when linear background scaling in classic cone contrast is replaced by nonlinear background scaling, an improvement of almost similar size is obtained. The results of this study can be of interest for the development of vision models employing the processing of spatio-chromatic information.

NOISE
Session Chair: Jennifer Gille, independent (US)
2 NOV: 12:10 – 12:50 NY / 17:10 – 17:50 PARIS
3 NOV: 01:10 – 01:50 TOKYO

12:10 (New York) / 17:10 (Paris)
01:10 (Tokyo)

Influence of Procedural Noise on the Glossiness of 2.5D Printed Patches, Abigail Trujillo Vazquez1, Donatela Šaric2, Susanne Klein1, and Carinna Etchebehere1; 1HP Inc. (Spain) and 2HP Inc. (UK)

Perlin noise, a type of procedural noise, was used for the design of elevation files for 2.5D printing. This printing method uses elevation data from a height map to create physical relief by superimposing layers of ink. In this experiment, the grayscale values of noise functions were used as elevation values to build different surface structures in UV curable ink by 2.5D printing. Printed samples with varying levels of Perlin noise were created and their reflectance properties were studied by measuring the values of specular gloss. The roughness and specular gloss of the printed surfaces were effectively influenced when varying the persistence and octaves of the noise functions. The aim of implementing the procedural approach to a high-resolution printing method has been to explore the reflectance properties of custom noise functions when transferred to the physical realm. This might contribute to better understand the effect of surface structure on the appearance of materials. Potentially, this approach will enable the use of relief printing to produce structures with a more natural appearance and a desired glass value by using a low-cost computing process.

12:30 (New York) / 17:30 (Paris)
01:30 (Tokyo)

Real World Metamer Sets: Or How We Came to Love Noise, Peter Morovic1, HP Inc. (Spain) and Jan Morovic2, HP Inc. (UK)

It is well known that color formation acts as a noise-reducing lossy compression mechanism that results in ambiguity, known as metamersism. Surfaces that match under one set of conditions—an illuminant and observer or capture device—can mismatch under others. The phenomenon has been studied extensively in the past, leading to important results like metameter mismatch volumes, color correction, reflectance estimation and the computation of metamer sets—sets of all possible reflectances that could result in a given sensor response. However, most of these approaches have three limitations: first, they simplify the problem and make assumptions about what reflectances can look like (i.e., being smooth, natural, residing in a subspace based on some measured data); second, they deal with strict mathematical metamersism and overlook noise or precision, and third, only isolated responses are considered without taking the context of a response into account. In this paper we address these limitations by outlining an approach that allows for the robust computation of approximate unconstrained metamer sets and exact unconstrained parameter sets. The notion of spatial or relational parameter sets that take neighboring responses into account, and applications to illuminant estimation and color constancy are also briefly discussed.

3 Nov: 01:50 – 02:20 (Tokyo)
SESSION BREAK / POSTERS AVAILABLE FOR VIEWING
Join speakers and other attendees in the CIC29 Gather.town.

29th Color and Imaging Conference Final Program and Proceedings
In this paper, we describe a method to estimate BRDF measurements for different printed colours, using just the BRDF measurements of the substrate and the primary inks. A model is trained using the BRDF measurements of the unprinted substrate and the cyan, magenta, and yellow inks, where four different diffuse and specular measurements of each are used as predictors to find the reflectance factor at a different lighting and viewing angle. In this approach only four spectral measurements of each test colour are required to estimate BRDF. This reduces the number of measurements required to estimate BRDF of a printed surface and to estimate the spectral reflectances that describe its material surface characteristics.

**COLOR CONUNDRUMS I**

**Conundrum A:**
**What is HDR?**
Facilitator: Timo Kunkel, Dolby Laboratories, Inc.
HDR is widely talked about in a multitude of contexts. On the surface, it often seems straightforward to define what HDR is. However, when starting to dig deeper, it is not that simple anymore. Is HDR a special effect? a type of image processing or encoding? a graphics technique? a series of images at different exposures? a special camera? a special display? Let’s discuss what HDR means to you!

**Conundrum B:**
**Communication of Color**
Facilitator: Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD
Is color a separable property of objects? The physiological evidence of color channels in early vision would seem to support this view, however many color phenomena contradict this simple idea. What does this mean for how we measure, characterize, and ultimately communicate color?

**Conundrum C:**
**Color and Vision: Beyond the Rainbow**
Facilitator: James Ferwerda, Rochester Institute of Technology
How do processes other than those based on the spectral properties of light contribute to the perception of color? How do color illusions arise? How do simultaneous contrast, assimilation, induction colors, etc. work? What is the role of expectation? What can these phenomena tell us about color processing at all levels of the visual system?

**TWO-MINUTE INTERACTIVE PAPER PREVIEWS FOLLOWED BY INTERACTIVE PAPER POSTER SESSION A**

Session Chair: Minjung Kim, Facebook Reality Labs (US)

**Development of a Three-dimensional Color Rendition Space for Tunable Solid-state Light Sources, Dorukalp Durmus, Pennsylvania State University (US)**

The quality of building electric lighting systems can be assessed using color rendition metrics. However, color rendition metrics are limited in quantifying tunable solid-state light sources, since tunable lighting systems can generate a vast number of different white light spectra, providing flexibility in terms of color quality and energy efficiency. Previous research suggests that color rendition is multi-dimensional in nature, and it cannot be simplified to a single number. Color shifts under a test light source in comparison to a reference illuminant, changes in color gamut, and color discrimination are important dimensions of the quality of electric light sources, which are not captured by a single-numbered metric. To address the challenges in color rendition characterization of modern solid-state light sources, the development of a multi-dimensional color rendition space is proposed. The proposed continuous measure can quantify the change in color rendition ability of tunable solid-state light devices with caveats. Future work, discretization of the continuous color rendition space, will be carried out to address the shortcomings of a continuous three-dimensional space.

Selection of Optimal External Filter for Colorimetric Camera, Michael Vitel, Artifex Software, and H. Joel Russell, North Carolina State University (US)

A database of realizable filters is created and searched to obtain the best filter that, when placed in front of an existing camera, results in improved colorimetric capabilities for the system. The image data with the external filter is combined with image data without the filter to provide a sixband system. The colorimetric accuracy of the system is quantified using simulations that include a realistic signal-dependent noise model. Using a training data set, we selected the optimal filter based on four criteria: Vora Value, Figure of Merit, training average, $\Delta E$, and training maximum $\Delta E$. Each selected filter was used on testing data. The filters chosen using the training $\Delta E$ criteria consistently outperformed the theoretical criteria.
Effect of Digitally Generated Colored Filters on Farnsworth-Munsell 100 Hue Test by Red-green Color Vision-deficient Observers, Shunnuma Saito and Keiko Saito, Kagawa University (Japan).

In this study, the effects of four different digitally generated colored filters on the Farnsworth-Munsell 100 hue test (100-hue test) are analyzed by red-green color vision deficient (CVD) observers. We digitally simulate the colored filters based on the spectral transmittance of four colored filters, which have been used previously. Five red-green CVD observers are subjected to the 100-hue test on a monitor under nine filter conditions, which comprise one condition without filter and eight conditions with filters. The results suggest that a colored filter that transmits long wavelengths and absorbs medium wavelengths may improve the color discrimination performance of protans and deutans.

Highlighted Document Image Classification, Yafei Mao¹, Yufang Sun¹,
Peter Bauer², Todd Harris², Mark Shaw², Lixia Li², and Jan Allebach¹;
¹Purdue University and ²HP Inc. (US).

There are many existing document image classification researches, but most of them are not designed for use in constrained computer resources, like printers, or focused on documents with highlighter pen marks. To enable printers to better discriminate highlighted documents, we designed a set of features in CIE Lc(h*a*b*) space to use along with the support vector machine. The features include two gamut-based features and six low-level color features. By first identifying the highlight pixels, and then computing the distance from the highlight pixels to the boundary of the printer gamut, the gamut-based features can be obtained. The low-level color features are built upon the color distribution information of the image block. The best feature subset of the existing and new features is constructed by sequential forward floating selection (SFFS) feature selection. Leave-one-out cross-validation is performed on a dataset with 400 document images to evaluate the effectiveness of the classification model. The cross-validation results indicate significant improvements over the baseline highlighted document classification model.

A Digital Test Chart for Visual Assessment of Color Appearance Scales, Mark Fairchild, Rochester Institute of Technology (US).

A digital color appearance test chart, akin to a ColorChecker® Chart for human perception, was developed and evaluated both perceptually and computationally. The chart allows an observer to adjust the appearance of a limited number of color patches to allow a quick evaluation of perceived brightness, colorfulness, lightness, saturation, and hue on a display. The resulting data can then be used to compare observed results with the predictions of various color appearance models. Analyses in this paper highlight some known shortcomings of CIELAB, CIECAM02, and CAM16. Differences between CIECAM02 and CAM16 are also highlighted. This paper does not provide new psychophysical data for model testing; it simply describes a technique to generate such data and a computational comparison of models.

Time Course Chromatic Adaptation under Highly Saturated Illuminants, Hui Fan, Ming Ronnier Luo, and Yuechen Zhu, Zhejiang University (China).

The goal of this study was to investigate the time course characteristics of chromatic adaptation under highly saturated illuminants. A psychophysical experiment with neutral matching method was conducted on a mobile display at different luminance levels. Models of chromatic adaptation degree against duration of time were fitted using a proportional rate growth function. The upper limit and growth rate of adaptation degree were studied. It was found that higher adapting luminance and lower display luminance lead to higher degree and faster speed of chromatic adaptation. This study also proposed the time to achieve stable chromatic adaptation.

Models to Predict Naturalness and Image Quality for Images Containing Three Memory Colors: Sky, Grass, and Skin, Jason Ji, Dalin Tian, and Ming Ronnier Luo, Zhejiang University (China).

When evaluating the image quality, people mostly would like to concentrate on the color appearance of memory objects, representing the naturalness and reality of the image scene. Generally, an image with objects which have perfect memory colors reproduction will give natural and harmonious feelings. Many previous studies had proved the critical role of naturalness in image quality assessment, but it was still tough to scale the image naturalness precisely. In this study, natural images with blue sky, green grass, and skin colors were selected and partially rendered to develop the model of preference and naturalness of typical memory colors. A psychophysical experiment was conducted to collect the visual data of these images. Afterward, the psychophysical data were used to build the preference models and naturalness models, respectively. The models were then compared with previous studies. Results showed that the new models could accurately predict the preference and naturalness of target memory colors.

New Colour Appearance Scales under High Dynamic Range Conditions, Xi Li¹ and Ming Ronnier Luo¹,²;
¹Zhejiang University (China) and ²Leeds University (UK).

New colour appearance scales close to daily experience and image quality enhancement are highly desired including whiteness, blackness, vividness, and depth. This article describes a new experiment to accumulate the data under HDR (high dynamic range) conditions. The data were then used to test the performance of different colour appearance scales such as CIELAB and CAM16-UCS plus the recent extension by Berns’ Vab*, Dab*. The results showed those Berns’ scales gave a reasonable performance. However, it was found no scale is capable of predicting colour appearance data covering a wide dynamic range. New scales were developed based on the absolute scales of brightness and colourfulness of CAM16-UCS and gave accurate predictions to the data.

Dye Amount Estimation in a Papanicolaou-stained Specimen using Multispectral Imaging, Sauri Takeyama, Tomokazu Watanabe, and Masahiro Yamaguchi, Tokyo Institute of Technology; Takumi Ura and Fumikazu Kimura, Shinshu University, and Keiko Ishi, Okayama City Hospital (Japan).

Papanicolaou stain is mainly used in cytological diagnosis such as gynecological diseases. In the image analysis of stained histopathology specimens, color unmixing technique, which estimates the dye abundance map, is useful. In this paper, we apply the dye amount estimation method based on color unmixing to Papanicolaou-stained specimens. In the proposed method, we capture the Papanicolaou-stained samples using a multispectral microscope, and then we estimate the amount of dyes from the observation and practically measured the spectral characteristics of the stain. Besides, we construct an application depicting the amount of stain and the bar graph plot. In the experiments, we verify the feasibility of the proposed method and analyze a precancerous lesion of the uterine cervix using the proposed method.

A New Corresponding Color Dataset Covering a Wide Luminance Range under High Dynamic Range Viewing Condition, Xinye Shi, Yuechen Zhu, and Ming Ronnier Luo, Zhejiang University (China).

An experiment was carried out to investigate the change of color appearance for 13 surface stimuli viewed under a wide range of illuminance levels (15-32000 lux) using asymmetrical matching method. Addition to the above, in the visual field, observers viewed colours in a dark (10 lux) and a bright (200000 lux) illuminance level at the same time to simulate HDR viewing condition. The results were used to understand the relationship
between the color changes under HDR conditions, to generate a corresponding color dataset and to verify color appearance model, such as CIECAM16.

White Appearance for Optimal Text-background Lightness Combination Document Layout on a Tablet Display under Normal Light Levels, Hai-Poo Huang1, Hung-Chung Li2, Minchen Wei1, and Yu-Cheng Huang1; 1Chihlee University of Technology (Taiwan), 2Chang Gung University of Science and Technology (Taiwan), and 3The Hong Kong Polytechnic University (Hong Kong) 188

In the study, two psychophysical experiments are carried out to understand the visual comfort and white appearance of a tablet display. Twenty-four observers assess the visual comfort of document layouts, and eleven observers rate the whiteness percentage of the stimulus under normal light levels with a CCT of 6500 K. The result of the experiment for visual comfort indicates that a combination of black text with a light grey background presents the better visual comfort. On the other hand, the finding of the white appearance experiment shows that the observers rate the stimulus with CCT of 6515 K and a Duv of 0 as the whitest.

White Balance Preference under Multiple Light Sources, Anku and Susan P. Farnand, Rochester Institute of Technology (US) 193

White balance is one of the key processes in a camera pipeline. Accuracy can be challenging when a scene is illuminated by multiple color light sources. We designed and built a studio which consisted of a controllable multiple LED light sources that produced a range of correlated color temperatures (CCTs) with high color fidelity that were used to illuminate test scenes. A two Alternative Forced Choice (2AFC) experiment was performed to evaluate the white balance appearance preference for images containing a model in the foreground and target objects in the background indoor scene. The foreground and background were lit by different combinations of cool to warm sources. The observers were asked to pick the one that was most aesthetically appealing to them. The results show that when the background is warm, the skin tones dominated observers’ decisions and when the background is cool the preference shifts to scenes with same foreground and background CCT. The familiarity and unfamiliarity of objects in the background scene did not show a significant effect.

JIST-first Emphasis on Material Appearance by a Combination of Dehazing and Local Visual Contrast, Hiroaki Kotsuka, Koteru Imaging Laboratory (Japan) 197

Material appearance is a perceptual phenomenon that the brain interprets from the retinal image. Though, it is not easy to analyze what features of optical images are effectively related to the stimulus inside the visual cortex. For this reason, an intuitive or heuristic approach has been taken to simulate the material appearance. The simulation results are expected to drive innovation for not only traditional craft or plastic arts industry but also more realistic picture displays on 4K/8K HDTV and Virtual Reality or Computer Graphics. Optical surface property of material is modeled by BRDF (Bidirectional Reflectance Distribution Function). Specular S and Diffusion D components are responsible for the “glossiness” and “textured” and are used to emphasize the material appearance by simply adjusting the mixing ratio. This study introduces the following two key models to emphasize the material appearance of a given image without using such measuring means as BRDF and discusses how they work individually and cooperatively. (1) aσ-based Dehazing model to emphasize clarity, wetness, gloss. (2) β-based Contrast model to emphasize texture, roughness.

JIST-first New Encoder Learning for Captioning Heavy Rain Images via Semantic Visual Feature Matching, Chang-Hwan Son and Pung-Hwi Ye, Kunsan National University (Republic of Korea) 207

Image captioning generates text that describes scenes from input images. It has been developed for high-quality images taken in clear weather. However, in bad weather conditions, such as heavy rain, snow, and dense fog, poor visibility as a result of rain streaks, rain accumulation, and snowflakes causes a serious degradation of image quality. This hinders the extraction of useful visual features and results in deteriorated image captioning performance. To address practical issues, this study introduces a new encoder for captioning heavy rain images. The central idea is to transform output features extracted from heavy rain input images into semantic visual features associated with words and sentence context. To achieve this, a target encoder is initially trained in an encoder-decoder framework to associate visual features with semantic words. Subsequently, the objects in a heavy rain image are rendered visible by using an initial reconstruction subnetwork (IRS) based on a heavy rain model. The IRS is then combined with another semantic visual feature matching subnetwork (SVFMS) to match the output features of the IRS with the semantic visual features of the pretrained target encoder. The proposed encoder is based on the joint learning of the IRS and SVFMS. It is trained in an end-to-end manner, and then connected to the pretrained decoder for image captioning. It is experimentally demonstrated that the proposed encoder can generate semantic visual features associated with words even from heavy rain images, thereby increasing the accuracy of the generated captions.

JIST-first Development of a System to Measure the Optical Properties of Facial Skin using a 3D Camera and Projector, Kumiko Kikuchi1, Shojo Tominaga2,3, and Jon Y. Hardeberg2; 1Shiseido Co., Ltd. (Japan), 2Norwegian University of Science and Technology (Norway), and 3Nagano University (Japan) 219

We have developed a system to measure both the optical properties of facial skin and the three-dimensional shape of the face. To measure the three-dimensional facial shape, our system uses a light-field camera to provide a focused image and a depth image simultaneously. The light source produces a projector that produces a high-frequency binary illumination pattern to separate the subsurface scattering and surface reflections from the facial skin. Using a dichromatic reflection model, the surface reflection image of the skin can be separated further into a specular reflection component and a diffuse reflection component. Verification using physically controlled objects showed that the separation of the optical properties by the system correlated with the subsurface scattering, specular reflection, or diffuse reflection characteristics of each object. The method presented here opens new possibilities in cosmetology and skin pharmacology for measurement of the skin’s gloss and absorption kinetics and the pharmacodynamics of various external agents.

COLOR CONUNDRUMS II

2 NOV: 20:20 – 21:10 NY
3 NOV: 01:20 – 02:10 PARIS / 09:20 – 10:10 TOKYO

Join colleagues for an informal discussion about one of the color-related topics listed below. While each conundrum is led by a facilitator, the goal is for everyone to share their opinions and experiences. Choices during Color Conundrums II are:

Conundrum D: Color and Color Names Around the World and Through Time
Facilitator: Minjung Kim, Facebook Reality Labs
How are colors named across languages or classified in different places? Are there names for particular colors that don’t translate well between
What do you think is the most pressing or important color-related problem that needs to be solved now?

Conundrum F:
What color problem needs to be solved ASAP?
Facilitator: Dave Wyble, Avian Rochester, LLC
What do you think is the most pressing or important color-related problem that needs to be solved now?

DAY 3
WEDNESDAY 3 NOVEMBER / THURSDAY 4 NOVEMBER

WHITE AND COLOR
Session Chair: Kate Edwards, Datacolor (US)

08:30 (New York) / 13:30 (Paris) / 21:30 (Tokyo)
Welcome Remarks
Sessions Host: Peter Morovic, HP Inc. (Spain)
JIST-first Perception of White for Stimuli with Luminance beyond the Diffuse White, Yiqian Li and Minchen Wei, The Hong Kong Polytechnic University (Hong Kong)

The appearance of color stimuli with luminance levels beyond the diffuse white is gaining importance due to the popularity of high dynamic range (HDR) displays. Past work on color appearance of stimuli, color appearance models, and uniform color spaces, mainly focused on the stimuli with luminance levels below the diffuse white, which were produced using surface color samples or conventional standard dynamic range (SDR) displays. In this study, we focused on the perception of white appearance for stimuli with luminance beyond the diffuse white. Human observers adjusted the color appearance of a stimulus to the whitest under different adapting conditions, including a dark condition and 12 illuminated conditions. It was found that the chromaticities for producing white appearance under the dark condition were generally similar to those under the 6500 K conditions, regardless of the adapting luminance levels. In comparison to a recent study focusing on the stimuli with luminance below the diffuse white, the perception of white under the conditions with the adapting CCT levels of 2700, 3500, and 5000 K was significantly affected by the lightness level of the stimulus, which cannot be accurately characterized by CAM02-UCS. The results can be used for reproducing white appearance for highlights in HDR scenes. Further investigations on uniform color spaces for characterizing stimuli with luminance beyond the diffuse white are urgently needed for processing and displaying HDR images.

09:00 (New York) / 14:00 (Paris) / 22:00 (Tokyo)
The Impact of the Helmholtz-Kohlrausch Effect on the Appearance of Near-white Paper Colours, Gregory High and Phil Green, Norwegian University of Science and Technology (Norway) 

This paper investigates the impact of the Helmholtz-Kohlrausch effect on near-white substrate colours. As the luminance of the test colour (or its simulated reflectance in a soft-proof setup) approaches that of the adapting white point the viewing mode changes from ‘surface mode’ to ‘aperture mode’, and the appearance of the test colour becomes self-luminous. However, some substrates with optical brighteners fall close to this threshold between viewing modes, since the OBAs not only increase the perceived reflectance but also increase the HK effect, where it is very prominent in bluish colours. For graphic arts content shown on a display system, this essentially breaks the soft-proofing paradigm. The practical application of this work relates to cross-media colour reproduction, where the lightness appearance of some substrates is not adequately described by their colormetric values, and this may impact on choice of proofing strategies.

CIC29 BEST PAPER: G0 Revisited as Equally Bright Reference Boundary, Hao Xie and Mark Fairchild, Rochester Institute of Technology (US) 

Brilliance and zero grayness (denoted as G0) and are two terms coined by Ralph Evans. Nayatani, Heckaman and Fairchild have done series of work to incorporate them into comprehensive color appearance models. In this work, those concepts were reexamined to scale lightness/brightness across the chromaticity diagram. Specifically, observers, mostly with a color science background, were asked to adjust the luminance of a color patch to appear with no grayness, or equivalently just about/cease to glow. The hypothesis was that lightness can be equalized across those chromaticities and the Helmholtz-Kohlrausch effect is automatically incorporated. This hypothesis was verified in a follow-up experiment where another group of observers completed paired comparisons of the brightness between the collected G0 results. The G0 task was also repeated under another two levels of adaption backgrounds, based on which different absolute brightness results for a given chromaticity might be derived. In addition, high correlations between the G0 results (as a perceptual boundary between appearance modes) and different physical gamut boundaries including MacAdam’s optimal colors were found for possible computational proxies and ecologically meaningful implications.

09:40 (New York) / 14:40 (Paris) / 22:40 (Tokyo)
SESSION BREAK / POSTERS AVAILABLE FOR VIEWING
Join speakers and other attendees in the CIC29 Gather.town.

CLOSING KEYNOTE
Session Chair: Michael Mundich, Rochester Institute of Technology (US)
3 NOV: 10:00 – 11:00 NY / 15:00 – 16:00 PARIS / 23:00 – 00:00 TOKYO
Learning to Estimate Lighting from a Single Image, Jean-François Lalonde, Université Laval (Canada) [abstract only; no proceedings paper]

Combining virtual and real visual elements into a single, realistic image requires the accurate estimation of the lighting conditions of the real scene. Unfortunately, doing so typically requires specific capture devices or physical access to the scene. This talk presents approaches that alleviate these restrictions and instead automatically estimate lighting from a single image. In particular, recent works that frame lighting estimation as a learning problem for both the indoor and outdoor illumination scenarios are
presented. In both cases, large datasets of omnidirectional HDR images are leveraged for training the models. It will be shown that using our illumination estimates for applications like 3D object insertion can achieve photo-realistic results on a wide variety of challenging scenarios.

IS&T Award Presentations
Presenter: Susan Farrand, IS&T President
Jon Hardeberg, 2020 Fellow, for outstanding contributions to the field of multispectral imaging and digital imaging quality.

Norimichi Tsumura, 2020 Raymond C. Bowman Award for his many contributions teaching and helping others in imaging science, in particular for color and medical applications.

3 Nov: 11:00 – 11:30 (New York) / 16:00 – 16:30 (Paris)
4 Nov: 00:00 – 00:30 (Tokyo)
SESSION BREAK / POSTERS AVAILABLE FOR VIEWING
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TWO-MINUTE INTERACTIVE PAPER PREVIEWS FOLLOWED BY INTERACTIVE PAPER POSTER SESSION B
Session Chair: Malthe Astad, University of Liverpool (UK)
3 Nov: 11:30 – 13:00 NY / 16:30 – 18:00 PARIS
4 Nov: 00:30 – 02:00 TOKYO

Interactive (Poster) Paper authors provide a brief overview of their work, followed by talks with authors in the CIC29 Gather.town.

Use of Spectral Information for Red Scale Pest Control, Carlos E. García-Guerra1, Francisco J. Burgos-Fernández1, Eloi Canals1, Fernando Díaz-Doutón1, Abel Zaragoza2, Albert Virgili2, and Mentiñe Vilaseca2, 1Universitat Politècnica de Catalunya and 2COMERCIAL QUÍMICA MASSO, S.A. (Spain) 253
Decreasing the use of pesticides is one of the main goals of current agriculture, which requires fast, precise and continuous assessments of crop pests. Citrus pests cause a lot of damage worldwide and the techniques to evaluate them are mainly based on manual, time-consuming readings of insects stuck on traps spread over the crops. This is the case of red scale insects, whose control is notably challenging due to their small size and high reproduction rate. Hence, in this work, we carry out a spectral characterization of this insect in the visible range through spectrometric devices, microscopy and hyperspectral imaging technology to analyze the feasibility of using this information as a means of automatically identifying specimens belonging to this species in this era of precision agriculture. The results obtained show that spectral reflectance differences between red scales and other insects can be recorded at long (red) wavelengths and that red scales are morphologically different, i.e., smaller and more rounded. A reflectance ratio computed from spectral images taken at 774 nm and 410 nm is proposed as a new approach for automated discrimination of red scales from other insects.

Colourlab Image Database: Geometric Distortions, Marius Pedersen and Seyed Ali Amirshahi, Norwegian University of Science and Technology (Norway) 258
Over the years, a high number of different objective image quality metrics have been proposed. While some image quality metrics show a high correlation with subjective scores provided in different datasets, there still exists room for improvement. Different studies have pointed to evaluating the quality of images affected by geometrical distortions as a challenge for current image quality metrics. In this work, we introduce the Colourlab Image Database: Geometric Distortions (CID-GD) with 49 different reference images made specifically to evaluate image quality metrics. CID-GD is one of the first datasets which include three different types of geometrical distortions; seam carving, lens distortion, and image rotation. 35 state-of-the-art image quality metrics are tested on this dataset, showing that apart from a handful of these objective metrics, most are not able to show a high performance. The dataset is available at www.colourlab.no/cid.

Reflectance Estimation from Snapshot Multispectral Images Captured under Unknown Illumination, Vlado Kitonovski, Jean-Baptiste Thomas, and Jon Yingve Hardeberg, Norwegian University of Science and Technology (Norway) 264
Multispectral images contain more spectral information of the scene objects compared to color images. The captured information of the scene reflectance is affected by several capture conditions, of which the scene illuminant is dominant. In this work, we implemented an imaging pipeline for a spectral filter array camera, where the focus is the estimation of the scene reflectances when the scene illuminant is unknown. We simulate three scenarios for reflectance estimation from multispectral images, and we evaluate the estimation accuracy on real captured data. We evaluate two camera model-based reflectance estimation methods that use a Wiener filter, and two other linear regression models for reflectance estimation that do not require an image formation model of the camera. Regarding the model-based approaches, we propose to use an estimate for the illuminant’s spectral power distribution. The results show that our proposed approach stabilizes and marginally improves the estimation accuracy over the method that estimates the illuminant in the sensor space only. The results also provide a comparison of reflectance estimation using common approaches that are suited for different realistic scenarios.

Lippmann Photography: History and Modern Replications of the Elusive Structural Colour, Elizabete Kozlovska, Susanne Klein, and Frank Menger, University of the West of England (UK) 270
In 1908 physicist Gabriel Lippmann won the Nobel Prize for creating a true colour process using standing waves. This paper reviews the historic process of creating Lippmann plates and applies them to recreate the process with modern materials. The optics of the created samples are reviewed, comparing results to Lippmann’s own research and modern attempts by other researchers to recreate or improve the process.

Radiometric Spectral Fusion of VNIR and SWIR Hyperspectral Cameras, Federico Grillini, Jean-Baptiste Thomas, and Sony George, Norwegian University of Science and Technology (Norway) 276
When two hyperspectral cameras are sensitive to complementary portions of the electromagnetic spectrum it is fundamental that the calibration processes conducted independently lead to comparable radiance values, especially if the cameras show a shared spectral interval. However, in practice, a perfect matching is hard to obtain, and radiance values that are expected to be similar might differ significantly. In the present study we propose to introduce an ultralinear correcting factor in the radiometric calibration pipeline of two hyperspectral cameras, operating in the visible near infrared (VNIR) and short wave infrared (SWIR) intervals. The linearity properties of both cameras are preliminarily assessed, conducting acquisitions on five standardized targets, and highlighting noise at the sensors level and different illumination fields as the main causes of radiance mismatch. The correction step that we propose allows the retrieval of accurate and smoothly connected VNIR-SWIR reflectance factor curves.

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Optimising a Euclidean Colour Space Transform for Colour Order and Perceptual Uniformity, Luvin Munish Ragoo and Ivar Farup, Norwegian University of Science and Technology (Norway) ........................................ 282

In this paper, we attempt to optimise a colour space transform for colour order and perceptual uniformity to verify if a trade-off could be achieved between the two. The IPT colour space is used as basis for the optimisation. An optimisation model consisting of a modified XYZ-to-UMS matrix, a non-linearity factor, and two geometric transformation matrices is proposed. Two objective functions are constructed based on the optimisation model, where one would improve perceptual uniformity primarily and the other would improve colour order instead. Finally, the two objective functions are combined, in an attempt to optimise both simultaneously and see if a trade-off between the seemingly incompatible features can be achieved. The performance of the optimised IPT transform is then compared to the original IPT transform, in terms of relative improvements in perceptual uniformity and colour order. Finally, the results show that there is indeed an inverse relationship between the two objectives. However, by adjusting the bias of the optimisation, a balance could be achieved between the two, where both colour order and perceptual uniformity was improved with respect to the original IPT transform.

Joint Demosaicing of Colour and Polarisation from Filter Arrays, Alexandra Spote and Pierrejean Lapray, Université de Haute-Alsace (France); and Jean-Baptiste Thomas and Ivar Farup, Norwegian University of Science and Technology (Norway) .................................................. 288

This article considers the joint demosaicing of colour and polarisation image content captured with a Colour and Polarisation Filter Array imaging system. The Linear Minimum Mean Square Error algorithm is applied to this case, and its performance is compared to the state-of-the-art Edge-Aware Residual Interpolation algorithm. Results show that the LMMSE demosaicing method gives statistically higher scores on the largest tested database, in term of peak signal-to-noise ratio relatively to a CPFA-dedicated algorithm.

Image-based Goniometric Appearance Characterisation of Bronze Patinas, Yoko Aragaki1,2, Clotilde Bouss1, Angele Deucher2, and Jon Yrgve Hareideberg2, 1Centre of Research and Restoration of the Museums of France (France); 2Norwegian University of Science and Technology (Norway); and 3National Institute of Patrimony (France) ......................................................... 294

Patinas are a form of metal polychromy used to decorate metallic artworks. Due to the nature of the metallic surface, their colour and gloss is perceived differently when the illumination and viewing directions vary. Sparkle effect on surfaces is a physical phenomenon caused by micro-facets on the surface coating which are also perceived with changing viewing and illumination geometry.

In this paper, a method designed for the measurement of sparkle is applied to the goniometric characterisation of bronze patinas. Using a set of six different patinas, in three colours and two surface finishes, it is found that these surfaces exhibit different appearance when illuminated and viewed at different angles. Moreover, the roughness of the patinas is measured and as expected, as the roughness increases the specular reflectance peak decreases. The experiment is repeated at two different institutions with different sets of equipment to test its repeatability and robustness.

The sparkle is presented as a function of the angle of tilting, and it is characterised by its maximum value and full-width half-maximum. It is found that the maximum and the roughness have a negative exponential relationship whereas the full-width half-maximum and the roughness have a linear relationship.

An Analysis of Spectral Similarity Measures, Mirko Agarla, Simone Bianco, Luigi Celona, and Raimondo Schettini, University of Milano-Bicocca (Italy); and Mikhail Trabakou, Huawei Technologies Co. Ltd. (Russia) ................................................................. 300

In this paper we analyze the most used measures for the assessment of spectral similarity of reflectance and radiance signals. First of all we divide them in five groups on the basis of the type of errors they measure. We proceed analyzing their mathematical definition to identify unintended behaviors and types of errors they are blind to. Then exploiting the Munsell atlas we analyze the correlation between metrics in terms of both Pearson’s Linear Correlation Coefficient (PLCC) and Spearman’s Rank Order Correlation Coefficient (SROCC). Finally we analyze the behaviour of the selected metrics with respect to two different color properties: the Chroma and the Lightness computed in the CIE L* a* b* color space. The source code of the spectral measures considered is available at the following link: https://celuigi.github.io/spectral-similarity-metrics-comparison/.

Benchmarking Modern Gloss Correlators with Established ISO 2813 Standard and Visual Judgment of Gloss, Donatella Sari1,2, Andreas Kriauciuni2, Marco Mattuschka2, and Phil Green2, Fraunhofer Institute for Media Technologies (Germany); 1Norwegian University of Science and Technology (Norway); and 3Vizoo 3D (Germany) ......................................................... 306

Interaction between the diffuse colour and the gloss of its surface is common. In this work, the influence of different gloss levels is tested on the diffuse colour. Firstly, we investigated how the albedo colour correlates with the reflected specular part. Furthermore, we provided a visual experiment. The visual experiment is conducted in two parts. The results of the visual experiment show that changing the angle of illumination does not affect the final gloss perception. Furthermore, a fitting of the gloss perception is done to find a parameter that correlates with the visual perception of gloss. The results show that there is a quadratic correlation between the Canon scattering indexes and the perceptual gloss.

Extending the Unmixing Methods to Multispectral Images, Jizhen Cai1,2,3, Hermine Chatoux1, Clotilde Bouss1,2, and Alamin Mansouri1, University Bourgogne Franche-Comté; 1Centre de Recherche et de Restauration des Musées de France, and 3Centre National de la Recherche Scientifique (France) ......................................................... 311

In the past few decades, there has been intensive research concerning the Unmixing of hyperspectral images. Some methods such as NMF, VCA, and N-FINDR have become standards since they show robustness in dealing with the unmixing of hyperspectral images. However, the research concerning the unmixing of multispectral images is relatively scarce. Thus, we extend some unmixing methods to the multispectral images. In this paper, we have created two simulated multispectral datasets from two hyperspectral datasets whose ground truths are given. Then we apply the unmixing methods (VCA, NMF, N-FINDR) to these two datasets. By comparing and analyzing the results, we have been able to demonstrate some interesting result for the utilization of VCA, NMF, and N-FINDR with multispectral datasets. Besides, this also demonstrates the possibilities in extending these unmixing methods to the field of multispectral imaging.

Estimating Visual Difference between Reproduction Gamuts: Moving Our Pilot Study from the Lab to Online Delivery, Gregory High, Peter Nussbaum, and Phil Green, Norwegian University of Science and Technology (Norway) ......................................................... 317

Images reproduced for different output devices are known to be limited in the range of colours that can be reproduced. It is accepted that reproductions made with different print processes, and on different substrates, will not match, although the overall reproduction appearance can be optimized using an output rendering. However, the question remains: how different
are they visually? This paper reports on a pilot study that tests whether visual difference can be reduced to a single dimensional scale using magnitude estimation. Subject to recent Covid restrictions, the experiment was moved from the lab to an online delivery. We compare the two methods of delivery: in-person under controlled viewing conditions, and online via a web-based interface where viewing conditions are unknown.

**Long Range Diffusion with Control of the Directional Differences**, Ali Alsom and Hans Jakob Rivertz, Norwegian University of Science and Technology (Norway) 323

A fast, spatially adaptive filter for smoothing colour images while preserving edges is proposed. To preserve the edges, we use a constraint that prohibits the increasing of the gradients in the process of diffusion. This constraint is shown to be very effective in preserving details and flexible in cases where more smoothing is desired. In addition, a filter of exponentially increasing diameter is used to allow averaging non-adjacent pixels, including those separated by strong edges.

**Perceptual Navigation in Absorption-scattering Space**, Davit Giglashvili, Philipp Urban, Jean-Baptiste Thomas, Marius Pedersen, and Jan Yngve Hardeberg, Norwegian University of Science and Technology (Norway) and Fraunhofer Institute for Computer Graphics Research IGD (Germany) 328

Translucency optically results from subsurface light transport and plays a considerable role in how objects and materials appear. Absorption and scattering parameters characterize the distance a photon travels inside the medium before it gets absorbed or scattered, respectively. Stimuli produced by a material for a distinct viewing condition are perceptually non-uniform w.r.t. these coefficients. In this work, we use multi-grid optimization to embed a non-perceptual absorption-scattering space into a perceptually more uniform space for translucency and lightness. In this process, we rely on A (alpha) as a perceptual translucency metric. Small Euclidean distances in the new space are roughly proportional to lightness and apparent translucency differences measured with A. This makes picking A more practical and predictable, and is a first step toward a perceptual translucency space.

**Influence of Acquisition Parameters on Pigment Classification using Hyperspectral Imaging**, Dipendra J. Mandal, Sony George, and Marius Pedersen, Norwegian University of Science and Technology (Norway); and Clotilde Boust, Centre de Recherche et de Restauration des Musées de France (France) 334

Pigment classification of paintings is considered an important task in the field of cultural heritage. It helps to analyze the object and to know its historical value. This information is also essential for curators and conservators. Hyperspectral imaging technology has been used for pigment characterization for many years and has potential in its scientific analysis. Despite its advantages, there are several challenges linked with hyperspectral image acquisition. The quality of such acquired hyperspectral data can be influenced by different parameters such as focus, signal-to-noise ratio, illumination geometry, etc. Among several, we investigated the effect of four key parameters, namely focus distance, signal-to-noise ratio, integration time, and illumination geometry on pigment classification accuracy for a mockup using hyperspectral imaging in visible and near-infrared regions. The results obtained exemplify that the classification accuracy is influenced by the variation in these parameters. Focus distance and illumination angle have a significant effect on the classification accuracy compared to signal-to-noise ratio and integration time.

**The Influence of Wedge Angle, Feedstock Color, and Infill Density on the Color Difference of FDM Objects**, Ali Payami Gallin and Are Strandlie, and Philip John Green, Norwegian University of Science and Technology (Norway) 347

The surface appearance in additive manufacturing (AM) has attracted attention in recent years due to its importance in evaluating the quality of 3D printed structures. Fused Deposition Modeling (FDM), also known as Fused Filament Fabrication (FFF), holds an important share of the AM market because of its large economic potential in many industries. Nevertheless, the quality assurance procedure for FDM manufactured parts is usually complicated and expensive. The enhancement of the appearance at different illumination and viewing angles can be exploited in various applications, such as civil engineering, aeronautics, medical fields, and art. There are two steps in improving the microstructure and material appearance of printed objects, including pre-processing and post-processing. This study aims to elucidate the role of the pre-processing phase in the development of FDM parts through the assessment of color differences. For this purpose, a set of polymeric samples with different wedge (slope) angles were 3D printed using an FDM printer. The color difference between the elements is discussed and correlated with the pre-processing parameters. It is revealed that the wedge angle of the elements in the design, slicing process, and infill density could alter the color appearance of the printed parts in a predictable trend. This research suggests that low infill density and wedge angles in polylactide filaments can result in a more stable color appearance.
CHANGING APPEARANCE

Session Chair: Javier Vazquez Corral, Universitat Autònoma de Barcelona (Spain)
3 NOV: 19:00 – 20:10 NY
4 NOV: 00:00 – 01:10 PARIS / 08:00 – 09:10 TOKYO

19:00 (New York)
00:00 (Paris) / 08:00 (Tokyo)

Welcome Remarks
Sessions Host: Michael Murdock, Rochester Institute of Technology (US)
19:10 (New York)
01:10 (Paris) / 09:10 (Tokyo)

A Study on Memory Colours, Mingkai Cao and Ming Ronnier Luo,
Zhejiang University (China) .................................................. 362
Memory colour has generated a sustained interest in the colour world. Previous studies mainly focused on the reflection colour chips and colour samples on real scenes or displays. Less attention was paid to the specific attributes of memory colour. In this paper, the forced choice psychophysical experiment method was used to study the preference, the colourfulness and the naturalness memories of 29 familiar objects on mobile displays by Chinese observers. The experiment collected the memory colours data and the representative memory colour was specified by CIELAB L*, a*, b* value. The intra-observer and inter-observer variations were analyzed by mean colour difference from the mean values, which was compared with other similar studies. An ellipsoid model was established to represent results in terms of memory colour centre and colour range in CIELAB a*b* space. At the same time, the results of this experiment were compared with those of previous experiments.

19:30 (New York)
00:30 (Paris) / 08:30 (Tokyo)

Accumulation of Corresponding Colours under Extreme Chromatic Illuminations and Modification of CAM16, Yuechen Zhu and Ming Ronnier Luo1,2; 1Zhejiang University (China) and 2University of Leeds (UK) ................................................................. 368
The goal of this study was to investigate the chromatic adaptation under extreme chromatic lighting conditions using the magnitude estimation method. The locations of the lightings on CIE1976 u’v’ plane were close to the spectrum locus, so the colour purity was far beyond the previous studies, and the data could test the limitations of the existing models. Two psychophysical experiments were carried out, and 1,470 estimations of corresponding colours were accumulated. The results showed that CAT16 gave a good prediction performance for all the chromatic lightings except for blue lighting, and the degree of adaptation was relatively high, that is, D was close to 1. The prediction for blue lightings was modified, the results showed the performance of CAM16 could be improved by correcting the matrix instead of the D values.

19:50 (New York)
00:50 (Paris) / 08:50 (Tokyo)

The Threshold of Color Inconstancy, Che Shen and Mark Fairchild,
Rochester Institute of Technology (US) .................................. 374
Color inconstancy refers to significant changes in the perceived color of an object across two or more different lighting conditions, such as daylight and incandescent light. This research focuses on defining the threshold of color inconstancy between generated D65 and A illumination through a psychophysical experiment. Although modern color appearance models provide equations to calculate the degree of adaptation, a neutral grey match experiment was completed to produce more accurate D values for the experimental viewing conditions. Like setting an instrumental color tolerance experiment, a second, sorting, experiment was used to define the threshold of color inconstancy. This threshold is the color shift, expressed in color difference terms, required for observers to notice a color change across changes in illumination. In addition, the tolerance ellipsoid for each Munsell principal hue group was also established.

DEScribing APPEARANCE

Session Chair: Javier Vazquez Corral, Universitat Autònoma de Barcelona (Spain)
3 NOV: 20:30 – 21:10 NY
4 NOV: 01:30 – 02:10 PARIS / 09:30 – 10:10 TOKYO

20:30 (New York)
01:30 (Paris) / 09:30 (Tokyo)

Testing Colour Appearance Model based UCS using HDR, WCG, and COMBVD Datasets, Qiang Xu1, Muhammad Safdar2, and Ming Ronnier Luo1,3; 1Zhejiang University (China), 2Avient Corporation (Singapore), and 3University of Leeds (UK) ................................. 381
Two colour appearance models based UCSs, CAM16-UCS and ZCAM-QMh, were tested using HDR, WCG and COMBVD datasets. As a comparison, two widely used UCSs, CIELAB and ICTCP, were tested. Metrics of the STRESS and correlation coefficient between predicted colour differences and visual differences, together with local and global uniformity based on their chromatic discrimination ellipses, were applied to test models’ performance. The two UCSs give similar performance. The luminance parametric factor kL, and power factor γ, were introduced to optimize colour-difference models. Factors kL of 0.75 and 0.5, gave marked improvement to predict the HDR dataset. Factor kL of 0.3 gave significant improvement in the test of WCG dataset. In the test of COMBVD dataset, optimization provide very limited improvement.

20:50 (New York)
01:50 (Paris) / 09:50 (Tokyo)

Comparison of Remote and In-person Tutorials of Color Appearance Phenomena, Dorukalp Durmus, Pennsylvania State University (US) .................................................. 387
Accurately describing the effect of lighting on color appearance phenomenon is critical for color science education. While it is ideal to conduct in-person tutorials to demonstrate the color appearance fundamentals, laboratory tutorials have been limited due to COVID-19. The limitation of in-person gatherings and the increase popularity of remote teaching help evoke alternative methods to demonstrate color appearance phenomena. Here, a remote tutorial method is described, and results are compared to in-person tutorials. While the remote tutorial had weaker result in representing observers’ color experience compared to the in-person lab tutorial, remote demonstrations can be used to demonstrate and discuss the limitations of color imaging, and the difference between the human visual system and digital imaging systems.