PROCEEDINGS
IS&T/SPIE
Electronic Imaging
Science and Technology

Color Imaging XIV: Displaying, Processing, Hardcopy, and Applications

Reiner Eschbach
Gabriel G. Marcu
Shoji Tominaga
Alessandro Rizzi
Editors

20–22 January 2009
San Jose, California, United States

Sponsored and Published by
IS&T—The Society for Imaging Science and Technology
SPIE

Volume 7241

Proceedings of SPIE, 0277-786X, v. 7241

The papers included in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. The papers published in these proceedings reflect the work and thoughts of the authors and are published herein as submitted. The publishers are not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from this book:
Author(s), "Title of Paper," in *Color Imaging XIV: Displaying, Processing, Hardcopy, and Applications*, edited by Reiner Eschbach, Gabriel G. Marcu, Shoji Tominaga, Alessandro Rizzi, Proceedings of SPIE-IS&T Electronic Imaging, SPIE Vol. 7241, Article CID Number (2009).

ISSN 0277-786X
ISBN 9780819474919

Copublished by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org
and
IS&T—The Society for Imaging Science and Technology
7003 Kilworth Lane, Springfield, Virginia, 22151 USA
Telephone +1 703 642 9090 (Eastern Time) · Fax +1 703 642 9094
imaging.org

Printed in the United States of America.

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B … 0Z, followed by 10-1Z, 20-2Z, etc.

The CID number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

Contents

Conference Committee

Symposium Chair

Nitin Sampat, Rochester Institute of Technology (United States)

Symposium Cochair

Jan P. Allebach, Purdue University (United States)

Conference Chairs

Reiner Eschbach, Xerox Corporation (United States)
Gabriel G. Marcu, Apple Computer, Inc. (United States)
Shoji Tominaga, Chiba University (Japan)
Alessandro Rizzi, Università degli Studi di Milano (Italy)

Program Committee

Jan P. Allebach, Purdue University (United States)
Scott J. Daly, Sharp Laboratories of America, Inc. (United States)
Phil J. Green, London College of Communication (United Kingdom)
Roger-David Hersch, École Polytechnique Fédérale de Lausanne (Switzerland)
Choon-Woo Kim, Inha University (Korea, Republic of)
Michael A. Kriss, Consultant (United States)
Fritz Lebowsky, STMicroelectronics (France)
Nathan Moroney, Hewlett-Packard Company (United States)
Chris Tuijn, Agfa-Gevaert Group (Belgium)

Session Chairs

1 Color Studies
Reiner Eschbach, Xerox Corporation (United States)

2 Retinex-based Methods
Alessandro Rizzi, Università degli Studi di Milano (Italy)

3 Displays I
Gabriel G. Marcu, Apple Computer, Inc. (United States)

4 Displays II
Choon-Woo Kim, Inha University (Korea, Republic of)

5 Vision
Reiner Eschbach, Xerox Corporation (United States)

6 Dark Side of Color
Alessandro Rizzi, Università degli Studi di Milano (Italy)

7 High Dynamic Range Imaging
Shoji Tominaga, Chiba University (Japan)

8 Spectral Imaging
Michael A. Kriss, Consultant (United States)

9 Image Enhancement
Chris Tujin, Agfa-Gevaert Group (Belgium)

10 Image Processing
Michael A. Kriss, Consultant (United States)

11 Printing I
Reiner Eschbach, Xerox Corporation (United States)

12 Printing II
Gabriel G. Marcu, Apple Computer, Inc. (United States)

Abstracts from Session "The dark side of color"

Alessandro Rizzi*[a], Reiner Eschbach[b], Stephen Hoskins[c], Garrett M. Johnson[d], John McCann[e], Nathan Moroney[f], Sabine Süsstrunk[g], Stephen Westland[h]

[a] DTI – Università degli Studi di Milano, Italy
[b] Xerox Corp., USA
[c] University of the West of England, UK
[d] Apple, USA
[e] McCann Imaging, USA
[f] HPLabs, USA
[g] EPFL, CH
[h] University of Derby, UK

As part of the "Color Imaging XIV: Displaying, Hardcopy, Processing, and Applications" conference, a novel special session entitled, "Dark Side of Color" has been presented at Electronic Imaging 2009. This session aims at introducing innovative thinking, and discussion from experts working in a wide range of disciplines related with color, to foster ideas and stimulate about open issues and common misunderstanding in color science and technology. It is composed by a limited number of invited short presentations that are presented as summaries in this paper together with an overall description of the session point of view.

What is the dark side of color ?

Color is a very complex phenomenon that cannot be explained with only physics principles. The human vision system is what transforms the physical stimuli into the colors we see.

Color related topics are sometime taught and communicated without presenting their inner complexity, their limits and the simplifications that sometime are at their base. A-critically following pre-defined "recipes" can lead to the risk of loosing the overall framework and consequently a complete understanding of the chosen technique.

Classic colorimetric methods, specifically designed to deal with color in aperture mode (isolated, out of visual context), have become dominant in digital color science and technology. Their use has been extended to deal with a great variety of situations in which color is considered inside a visual context, thus outside its initial scope. Color science is facing this transitional evolution in order to deal with color in context and appearance, but without substantial changes in their original foundation.

There is a need for widening the scientific debate and discuss about paradigms. This can be achieved by, for example, new questions, different attention for details; information in the margins that so far are often discounted or overlooked. These aspects are what we consider to be the "dark side of color".

The invited speakers of this section have been asked to stimulate ideas and discussions on the needs and the characteristics of possible alternative approaches and/or point of view. This session aims at suggesting paradigm shifts, lateral thinking and bottom up experimentation by re-addressing the current state of the evolving situation in color in sciences, arts and technologies.

Following these principles, every speaker has choosen a topic of his/her preference and presents open issues and problems in a short 10-minute presentation. The presentation abstracts are reported in the following sections to give the reader a glance on the discussed topics.

We would like to stress that basically no answers are expected to arise from the presentations of this session, but more likely questions and perspective shifts.

1. THE SPEAKERS

Here are the abstracts of the speakers that will participate at this first session of the Dark Side of Color. They are listed in alphabetical order.

1.1 "Well asked questions" Reiner Eschbach

We apologize with the readers, but for technical reasons this abstract was not available at the moment of printing this book.

1.2 "Pictorial information as transcribed by the artist or designer" Stephen Hoskins

Current technologies are designed to capture a pictorial image by reflectance of light upon the sensor, in order to create the potential to render a colour image pixel by pixel, which can then be re-rendered repeatedly without losing colour information or fidelity. Whilst this may be the method that is used when taking a photograph. It may not be what the user is thinking they are doing when they capture a digital image. pixels only render colour, an image is only represented by coloured pixels there is little or no other information, should there be? As an example Artists and designers make a series of choices before rendering a pictorial image, whether through paint, print or photography. Those choices can be influenced by many factors often bearing no relation to accurate rendition of the colour viewed. They are however closely related to the accurate rendition of the pictorial image that the artist has chosen to represent. This talk will try and articulate some of the approaches that an artist makes, with visual examples for each approach and then try to demonstrate how those decisions will affect the outcome of the image the artist then creates.

1.3 "Consider the Size: And Other Display Features" Garrett M. Johnson

Modern display technologies are being developed at a breathtaking pace. We now have the ability to watch movies on our mobile phones, or display pictures taken with these phones on our home theaters. In addition to changes in image size, these displays offer a wide range in contrast, resolution, dynamic range and color gamuts. As the number of viewing devices increases so to does the variety of viewing conditions. Color or image appearance models, while also making great strides, have not yet come close to being able to predict the changes in appearance that these modern displays may cause. As a result, we often find content creators needing to manually adjust the appearance of images based upon the desired output device. Many times these same creators are viewing images on one type (or size) of device and mentally adjusting them for a different type.

Consider this paper a call to arms, or perhaps a plea, for increased study on the effects of display size and technology on color appearance. Do our traditional viewing condition descriptors still hold valid for a tiny or giant screen? What happens when the surround and background blend into one? Is the increased contrast and sharpness of a mobile display perceptual or a function of the display itself? What happens when we view our mobile display outside or in a train tunnel? These are just a subset of many of the questions that still remain for color and image appearance.

1.4 "Adaptation! … What Adaptation?" John McCann

In almost ever conversation with vision scientist one hears the statement " the eye adapts…". Always, this statement is true. The problem is that there are so many ways that the visual system "adapts' that the words have no meaning. The visual system exhibits chemical dark-adaptation, neural light-adaptation, diurnal melatonin-adaptation, pupil adaptation, chromatic adaptation, von Kries adaptation, Blakemore spatial-frequency adaptation, McCulloch colored-stripe adaptation and many more kinds of adaptation. All neurons adapt. There are more than 10^6 retinal receptors that adapt, and potentially 10^{10} cortical neurons that adapt. What do we mean when we say “the eye adapts”?

1.5 “The Opposite of Green is Purple?” Nathan Moroney

The conventional understanding of opponent colors has red and green as one axis and yellow and blue on a second axis. This perceptual opponency is a result of the trichromatic nature of human color vision in combination with subsequent processing in the visual system. This red-green and yellow-blue opponency is fundamental to many different color spaces. CIELAB, CIELUV, CIECAM02, IPT, YCC and more all incorporate this concept of chromatic opponency. In most cases the yellow and blue opponent axes are reasonable. However for the red-green axis it is more like a purple-green axis due to a consistent, significant bending of the red-green axis.
Is dark purple the opposite of green? This paper summarizes the result of analyzing a wide range of color spaces based on their actual opponency. The consistent limitation of a shared matrix formulation for opponency is discussed and finally a simple, invertible color space is considered. The angular differences between quadrants and computed antonyms is shown to be significantly more consistent using this hypothetical alternative color space.

1.6 “Now...what color was that again?” Sabine Süsstrunk

Classic colorimetry is based on color matching. We assume that people judge (and compare) colors under the same viewing conditions, and that these "colors" consists of relatively large uniform patches. If the viewing conditions are not similar, color appearance models are applied, but these again were developed based on uniform patch psychophysics. It is, however, well known that the spatial organization of a scene and temporal characteristics of a video have a large effect on perceived color appearance. While once in a while a new study is published, we as a community have not achieved real progress in systematically investigating and modeling this spatio-chromatic interactions. I will give a short introduction on some of the more promising research, and will outline where I believe more research is needed.

1.7 “Stepford – the city for Colour Engineering” Stephen Westland

The Stepford Wives is a 1972 novel by Ira Levin in which the protagonist becomes convinced that the wives of Stepford are actually look-alike androids. Attendees at recent color-engineering conferences could draw similar conclusions about international research projects in the area of color imaging in that research seems to be becoming less and less varied and more incremental in progress. The convergence of color research is in part due to the remarkable success of the 1931 CIE system and the various systems and processes that have been developed based upon 1931 (or 1964) CIE colorimetry. Although the CIE system was developed from color-matching experiments for the purpose of color specification, subsequent developments such as CIELAB and CIECAM02 allow for the prediction of colour appearance whilst the lack of non-uniformity in CIELAB has been corrected by metrics such as the CMC color-difference equation to allow the reliable prediction of colour difference. Despite the success of colour-difference equations for use in textile, plastic and paint industries the application of color-difference metrics to what are commonly referred to as complex images (images of natural or man-made scenes) has been less successful. Given certain constraints the notion of calculating pixel-by-pixel color differences has been effective; for example, when the two images have a pixel-by-pixel correspondence, S-CIELAB can predict differences between images. However, it is difficult to imagine that the pixel-by-pixel calculation of color differences will be able to reliably predict differences between images in the more general case. Similarly, color-appearance models are now sophisticated and allow the prediction of some complex color appearance phenomena. However, recent findings that the spatial pattern of color backgrounds can affect color appearance would seem to demand more than could be reasonably expected from the current crop of color-appearance models. In this presentation some potential limitations of color-difference equations and color-appearance models will be introduced and shown to stem from fundamental common assumptions; these key assumptions will be challenged.