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Conference At-a-Glance

Monday, November 7
Registration open 8:00 – 9:00 AM and 4:30 – 5:30 PM
• Color, Vision, and Basic Colorimetry,* see page 2
• ICC DevCon 2016,* see page 22

Tuesday, November 8
Registration open 7:00 AM – 4:00 PM
• Short Course Program,* see page 3
• Welcome Reception

Wednesday, November 9
Registration open 8:30 AM – 4:00 PM
• Opening Keynote: “Full Color Computational Imaging with Diffractive Optics,” Wolfgang Heidrich, see page 14
• Exhibition
• Technical Sessions
  • Colorful Viewing
  • Beyond the Rainbow
  • Colorful Matter
• Conference Reception

Thursday, November 10
Registration open 8:30 – 14:00
• Keynote: “The Evolution of Primate Color Vision,” Gerald H. Jacobs, see page 15
• IS&T Honors and Awards Presentations
• Exhibition
• Technical Sessions
  • Do You See What I See?
  • Interactive Paper Previews I
  • Illuminating Color
  • Interactive Paper Previews II
• Interactive Paper Session
• Evening Talk: “The Confluence of Art and Technology: 3D Printing at LAIKA’s Award-Winning Animation Studio,” Brian McLean and Rob Ducey, see page 17

Friday, November 11
Registration open 7:30 AM – 1:30 PM
• Color & Imaging Workshops, see page 19
• Keynote: “Google Street View: Unique Challenges of Collecting Imagery at Global Scale,” Luc Vincent and Rom Clement, see page 18
• Technical Session
  • Wrangling Color
• Best Paper Award Presentations

Conference Venue: San Diego, CA

With more than 70 miles of Pacific Ocean coastline and a Mediterranean climate, California’s second largest city offers a relaxed atmosphere. Known for its world-famous Zoo, lovely Balboa Park, the beautiful beaches of Coronado Island, and the USS Midway, San Diego is steeped in history related to Mexico and the Spanish settlement of the region.

The historic Westgate Hotel—located in the heart of downtown, a few blocks from the Gaslamp Quarter—hosts CIC24 (see page 23 for hotel reservation details). In November, temperatures range from 54-69°F/12-21°C with the possibility of minimal rain. For those who like to swim, ocean temperatures at that time of year average 68°F/18°C.

*Separate registration fee required.
CONGRESS
MONDAY NOVEMBER 7, 2016

M1: Color, Vision, and Basic Colorimetry
8:30 AM – 5:30 PM (8 hours)
Instructor: Geoff Woolfe, Canon Information Systems Research Australia Pty. Ltd. (CISRA)

This course provides a comprehensive overview of the fundamentals of vision and color science. It introduces students to the anatomy and physiology of the human visual system and enables students to understand the mechanisms of color vision and its relationship to the science of colorimetry. Cone and rod vision are discussed in terms of visual receptive fields, their spectral and temporal response, contrast sensitivity, and adaptation mechanisms.

The course also covers the basic elements of color, including light sources, material properties, and the observer. It introduces key foundations of colorimetry including standard illuminants and color matching functions of standard observers. This leads to an explanation of basic colorimetry beginning with the XYZ color space and eventually leading to explanations of chromaticity spaces and perceptually uniform color spaces such as CIELAB and CIELUV.

Benefits: Attendees will be able to understand:
• Detailed anatomic structure and physiological function of the human visual system.
• How adaptation mechanisms in the human visual system affect our perception of color and tone.
• The relationship between colorimetric systems and properties of light, materials, and observers.
• The concepts of metamerism, illuminant metamerism, and observer metamerism.
• How to compute colorimetric values and convert between commonly used color spaces.

Intended Audience: scientists and engineers involved in the development and optimization of color imaging systems.

Geoff Woolfe is president of IS&T and the senior general manager of the Image and Video Research Centre at Canon Information Systems Research Australia. Prior to this, he was principal research scientist in the Xerox Innovation Group and senior principal research scientist at the Kodak Research Laboratories. Woolfe received his BSc (Honors) and PhD in physical chemistry from the University of Melbourne (Australia) and MS in imaging science from the Rochester Institute of Technology (USA). He was awarded the Mees Award, Kodak’s highest honor for scientific achievement, is a member of the Honor Society of Phi Kappa Phi, and has previously served on the steering committee of the International Color Consortium. He is the author of more than 30 scientific papers and more than 50 US and international patents and patent applications in the fields of color and imaging science.

Short Course Fees
Separate registration is required.

<table>
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<th>after 10/9</th>
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IS&T reserves the right to cancel classes in the event of insufficient advance registration. Please register early.
This course builds on the framework of basic CIE colorimetry to provide students with a broad understanding of color appearance phenomena and color appearance modelling. Students are introduced to the color appearance metrics of lightness, brightness, colorfulness, saturation, chroma, and hue. Several important color appearance phenomena, related to changes in the state of adaptation of the human visual system are introduced. The course then leads on to a detailed study of the color appearance models more widely used in commercial and academic research.

Benefits: Attendees will be able to understand:
- How changes in the state of visual adaptation affect the perceived appearance of colors.
- A number of important color appearance phenomena and how an understanding of these phenomena can affect the design of imaging systems.
- The most important models used to predict color appearance phenomena and how the parameters used in these models relate to real world viewing environments.

Intended Audience: color engineers and research scientists involved with color reproduction, imaging device developers, and computer software developers. Knowledge of fundamental colorimetry is assumed.

See bio under course M1, page 2

After defining the basic terms surrounding the instruments and quantities used in spectral measurements in the color field, this course covers the operation and construction of spectrophotometers and spectroradiometers by discussing the function of each of the various subsystems present in the devices. Instrument standardization and the application of CIE geometries for reflectance and transmittance are covered. To evaluate instruments, the concepts of precision and accuracy of measurement devices is introduced along with practical suggestions for the analysis of instrument performance. The overall goal is to fully understand the procedures and concepts that lead to proper spectral measurements, the basis for colorimetric calculations.

Benefits: Attendees will be able to:
- Identify the components of spectrophotometers and spectroradiometers, as well as the functions of each.
- Define the standardization process of spectrophotometers and understand the implications of standardization upon the measurement process.
- Interpret measurement requirements and select appropriate measurement parameters and geometries for various applications.
- Understand the point of “hand-off” from spectral measurements to colorimetric calculations.

Intended Audience: color engineers and technologists responsible for making and interpret-
ing color measurements of any type. A technical background is not required, although an understanding of basic scientific principles is very helpful.

David R. Wyble is president and founder of Avian Rochester, LLC. Since 2011, Avian Rochester has been delivering color standards, traditional and custom measurements, and consulting services to the color industry. Prior to founding Avian Rochester, Wyble was a color scientist within the Munsell Color Science Laboratory at the Rochester Institute of Technology, and before that a member of Research & Technology Staff at Xerox Corp. He holds a BS in computer science and MS and PhD in color science from RIT and Chiba University, respectively.

**T1C: Introduction to Color Management for VFX: From Human Vision to Color Pipelines**
8:00 – 10:00 (2 hours)
Instructor: Marie Fétiveau, RodeoFX

Color sciences can sometimes look mysterious. But when the knowledge gaps are filled and the dots connected, there is no mystery, everything make sense altogether. This course is about filling those gaps to get a good working comprehension of how we handle colors in VFX and furthermore why we handle them that way. So, for example, if you are confused when someone talks about gamuts, if you want to know the difference between a 1D LUT or a 3D LUT (and why it’s actually important to know that difference), or you want to understand why ACES is essential, this course is a good place to be.

**Benefits:** Attendees will be able to:
- Learn about human vision basics.
- Understand colorimetry and colorspace, from trichromatic theory to standard colorspace, including reference colorspace.
- Learn calibrations basics.
- Understand color transform tools for VFX: LUTs, matrixes, CDL.
- Appreciate color management for the VFX: color pipelines, OCIO, ACES.

**Intended Audience:** anyone from novice to expert is welcome, but someone already an expert in VFX color management might not learn much. There are no prerequisites.

Marie Fétiveau graduated with an MEng in image multimedia audiovisual and communication (major) and an MS in computer science (Fundamental Computer Sciences and Applications major and Imaging and Cinema minor). She then worked for eight years at Mikros Image where she developed and managed open-source and proprietary projects for digital cinema, color pipeline, and image processing. During those years, Fétiveau developed a strong interest in ACES and, more generally, in visual perception coherency. In 2014, she joined RodeoFX as a Color/IO/MP Pipeline TD and was appointed Lead Pipeline TD a year later. She pursues her interests on challenging projects.

**T1D: Fundamentals of Psychophysics**
8:00 – 10:00 (2 hours)
Instructor: James A. Ferwerda, Rochester Institute of Technology

Psychophysical methods from experimental psychology can be used to quantify the relationships between the physical properties of the world and the qualities people perceive. The results of psychophysical experiments can be used to create models of human perception that can guide the development of effective color imaging algorithms and enabling interfaces. This course provides an
MONDAY SHORT COURSE

M1-Color, Vision, and Basic Colorimetry: 8:30 AM – 5:30 PM

<table>
<thead>
<tr>
<th>Time</th>
<th>Color &amp; Vision</th>
<th>Psychophys. &amp; Images</th>
</tr>
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<tbody>
<tr>
<td>8:00 – 10:00 AM</td>
<td>T1A: Advanced Colorimetry and Color Appearance</td>
<td>T1D: Fundamentals of Psychophysics</td>
</tr>
<tr>
<td>10:15 AM – 12:15 PM</td>
<td>T1A continues</td>
<td>T2D: Variational Color Image Enhancement Inspired by Human Vision</td>
</tr>
<tr>
<td>1:30 – 3:30 PM</td>
<td>T13A: Cone Fundamentals, Color Matching . . .</td>
<td>T3D: Color Image Quality Assessment</td>
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<td>3:45 – 5:45 PM</td>
<td>T4A: Normal and Defective Colour Vision Across the Lifespan</td>
<td>T4D: Colour Difference Perception for Images</td>
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</tbody>
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TUESDAY SHORT COURSES

8:00 – 10:00 AM | T1B: Fundamentals of Spectral Measurements for Color Science | T2B: Characterizing Surface Appearance |
| 10:15 AM – 12:15 PM | T2C: Color Optimization for Displays | T3B: Scanning of 3D Objects |
| 1:30 – 3:30 PM | T3C: Color Grading Motion Pictures for HDR Displays | T4B: Color and Appearance in 3D Printing |
| 3:45 – 5:45 PM | T4C: The Art of Making Better Pixels — HDR Display Concepts and Technologies |

Introduction to the theory and practice of psychophysics and teaches attendees how to develop experiments that can be used to advance color imaging research and applications. Hands-on examples will be used throughout so that attendees understand how to design and run their own experiments, analyze the results, and develop perceptually-based algorithms and applications.

Benefits: Attendees will be able to:
- Identify the major techniques for measuring perceptual thresholds and scales.
- Design perception experiments using these techniques.
- Analyze the data from these experiments to derive perceptual metrics.
- Apply these metrics to practical problems in color imaging.

Intended Audience: students and professionals who want to be able to interpret the results of perception psychology experiments and develop their own perception studies. The course assumes a basic level understanding of issues in color and imaging science and engineering and statistics. No specific knowledge of perception psychology is required. All relevant concepts are introduced in the class.

James A. Ferwerda is an associate professor and the Xerox Chair in the Chester F. Carlson Center for Imaging Science at the Rochester Institute of Technology. He received a BA in psychology, MS in computer graphics, and a PhD in experimental psychology, all from Cornell University. The focus of his research is on building computational models of human vision from psychophysical experiments and developing advanced imaging systems based on these models.

20% SAVINGS

Take 3 or more courses and get 20% off your total short course registration fee!
See registration form for details.
Surface appearance is of critical importance in a wide variety of fields including design, manufacturing, forensics, medicine, and cultural heritage preservation. In this tutorial, I introduce a framework for characterizing surface appearance that includes the visual attributes of color, gloss, translucency, and texture. I then review efforts that have been made to measure these attributes, and describe the psychophysical methods that are used to relate the physical properties of surfaces to their visual appearances. Finally, I discuss the potential for using computer-graphics techniques to simulate the appearances of complex surfaces and describe how new digital imaging technologies are being used to advance the measurement, modeling, visualization, and communication of surface appearance.

Benefits: Attendees will be able to:
- Identify the factors that contribute to the appearances of complex surfaces.
- Understand the physical bases of surface appearance and how these bases are measured.
- Learn about the psychophysical methods used to relate the physical and perceptual aspects of surface appearance.
- Distinguish the different systems used to describe and communicate surface appearance.
- Comprehend how computer-graphics and digital imaging techniques are rapidly advancing the state-of-the-art in surface appearance characterization.

Intended Audience: students and professionals who want to understand the physics and psychophysics of surface appearance. The course assumes a basic level understanding of issues in color/imaging science and engineering. All specialized concepts are introduced in the class.

Benefits: Attendees will be able to:
- Identify the critical color parameters for displays and their impact on display quality for smart phones, tablets, notebooks, desktops, LCD TV, and projectors.
- Understand color performances and limitations for various LCD modes like (IPS, MVA, FFS) and performance of the LED backlighting and quantum dot gamut enhancement.
- Select the optimal color model for a display and highlight its dependency on display technology.
- Understand the translation of the color model into the display ICC profile and how it is used by the color management module.
- Follow a live calibration and characterization of an LCD screen and of the projector used in the class using tools varying from visual calibrator to instrument based ones.
Apply the knowledge from the course to practical problems of color optimization for displays.

**Intended Audience:** engineers, scientists, managers, pre-press professionals, and those confronting display related color issues.

Gabriel Marcu is senior scientist at Apple Inc. His achievements are in color reproduction on displays and desktop printing (characterization/calibration, halftoning, gamut mapping, ICC profiling, HDR imaging, RAW color conversion). He holds more than 60 issued patents in these areas. Marcu is responsible for color calibration and characterization of Apple display portable and desktop products. He has taught seminars and courses on color topics at various IS&T, SPIE, and SID conferences or IWI Europe. He was co-chair of the 2006 SPIE/IS&T Electronic Imaging Symposium and CIC11; he is co-chair of the EI Color Imaging Conference: Displaying, Hardcopy, Processing, and Applications. Marcu is an IS&T and SPIE Fellow.

**T2D: Variational Color Image Enhancement Inspired by Human Vision**
10:15 – 12:15 (2 hours)
Instructor: Edoardo Provenzi, University Paris Descartes

In the last twenty years, variational principles in image processing and computer vision flourished. They allowed a deeper comprehension of important image features and provided more efficient solutions to many practical problems. This holds true also for color image processing. The first part of this short course provides a brief qualitative introduction to variational techniques, which is then applied to re-interpret the well-known histogram equalization method. During the second part, you are shown how to modify the variational framework of histogram equalization to take into account some basic properties of the human visual system. Results on natural images are presented and discussed.

**Benefits:** Attendees will be able to:
- Identify a variational technique.
- Describe histogram equalization in terms of minimization of energy functionals.
- Summarize the most important phenomenological properties of the human visual system.
- Combine visual features with variational principles in order to get efficient color enhancement algorithms.
- Compare different color enhancement techniques within the variational framework.

**Intended Audience:** intended for two audience groups. First, color/imaging scientists and engineers who would like to acquire information about some recent developments of color enhancement inspired by human vision, and second, Master and PhD students or post-docs who wish to approach the rapidly expanding domain of variational techniques. Variational principles amount to the definition of a suitable integral function called “energy” and the computation of its minima. In order to understand this, a general knowledge about differential calculus of functions is strongly recommended.

Edoardo Provenzi is an associate professor at the University Paris Descartes, France since 2014. He obtained a master in theoretical physics (2000) from the University of Milan, Italy, and a PhD in applied mathematics (2004) from the University of Genoa, Italy. Since 2004, he has been studying color vision and processing. His main research field is in the application of variational principles to formalize color enhancement techniques.

**20% SAVINGS**
Take 3 or more courses and get 20% off your total short course registration fee!
See registration form for details.
The trichromacy of human color vision depends on the spectral sensitivities of the long-, middle-, and short-wavelength-sensitive (L, M, and S) cones. These functions are also known as the “fundamental” color matching functions (CMFs) or cone fundamentals. They are the physiological determinants of human color matching, and thus all other CMFs should be linear transformations of them. The cone fundamentals of Stockman & Sharpe (2000) have been adopted by CIE TC 1-36 as the “physiologically-relevant” international standard for colorimetry. This course covers the physiological underpinnings of those cone fundamentals, their derivation and their relationship to other color matching functions, and luminous efficiency functions. As well as being important as mean or standard functions, the functions can also be modified to account for individual differences.

Benefits: Attendees will be able to:
• Understand the basics of phototransduction and how it relates to univariance and to cone spectral sensitivities.
• Learn about the determination of cone spectral sensitivities in normal and color deficient observers.
• Appreciate the relationship of cone spectral sensitivities to RGB color matching functions.
• Observe the relationship of cone spectral sensitivities to luminous efficiency functions and the determination of luminous efficiency.
• Appreciate the relationship of cone spectral sensitivities to XYZ color matching functions and the derivation of the CIE TC 1-36 XYZ CMFs.
• Learn how molecular genetics affect cone spectral sensitivity.
• Origins of individual differences in cone spectral sensitivity.
• Adjust standard cone spectral sensitivities to take into account individual differences.
• Measure individual differences.

Intended Audience: scientists and engineers with an interest in the basics of color vision and colorimetry and the application of the new CIE TC 1-36 “physiologically-relevant” international standard.

Andrew Stockman has been the Steers Chair of Investigative Eye Research at University College London (UCL) Institute of Ophthalmology since 2001. His broad research area is visual psychophysics; his specializations include color vision, rod vision, visual adaptation, temporal sensitivity, and clinical psychophysics. He is best known for his work on human spectral sensitivities. The Stockman & Sharpe cone spectral sensitivities and the related luminous efficiency function have been adopted by the Commission Internationale de l’Éclairage (CIE) as an international standard for color definition and color measurement. He is the principal author of the Colour & Vision Research Laboratories database website (www.cvrl.org), a widely-used color resource for both science and industry.

T3B: Scanning of 3D Objects
1:30 – 3:30 pm (2 hours)
Instructor: Holly Rushmeier, Yale University

This course provides an overview of techniques used to capture 3D shape and appearance. The principles of active methods, which use controlled projected light, are outlined. Active methods include the use of both visible and infrared patterns. They make use of either triangulation, photometric stereo, or time-of-flight to estimate shape. Passive methods use ambient light and employ shape from motion algorithms from computer vision. Passive methods have become more popular as
the quality of cameras has increased and algorithms have been refined. Appearance data may be obtained coincident with shape data or may be estimated from photographs in a separate process. Examples of using captured models in computer graphics, biology, and cultural heritage are given.

Benefits: Attendees will be able to:
• Understand the different methods for 3D scanning in terms of cost, ease of use, and reliability.
• Understand the applicability of different scanning techniques as a function of object size and material.
• Appreciate the level of human interaction required to process 3D data into a useful 3D model.

Intended Audience: students or practitioners who are interested in obtaining 3D models as input to design or as documentation. A bachelor’s degree in science or engineering is required.

Holly Rushmeier is a professor of computer science at Yale. She received a PhD (1988) in mechanical engineering from Cornell. Since receiving her PhD she has held positions at Georgia Tech, NIST, and IBM Tj Watson Research. Her current research focuses on scanning and modeling of shape and appearance properties, and on applications in the digital humanities and cultural heritage. She is a EuroGraphics Fellow and received the 2013 ACM SIGGRAPH Computer Graphics Achievement Award.

T3C: Color Grading Motion Pictures for HDR Displays
1:30 – 3:30 pm (2 hours)
Instructors: Stefan Luka, Walt Disney Feature Animation, and Peter Postma, FilmLight

High dynamic range (HDR) projectors and displays pose new challenges to film makers mastering for these new formats while continuing to support existing TVs and cinema projectors. This course provides an overview of current HDR technology used in cinema and television, focusing on the creative and technical challenges of mastering both new and archival content for HDR displays. Topics covered include a summary of creative options made available by HDR displays, current processes for color correction and mastering both animated and live action content, and areas that could benefit from better tools and additional research. Case studies from recent television and major motion pictures will be used to show how creative color choices are established and adjusted through the film making process and realized for HDR and non-HDR delivery formats.

Benefits: Attendees will be able to:
• List current HDR delivery and display formats and the strength and weaknesses of each.
• Describe the basic concepts, tools, and transforms used in HDR motion picture production color pipelines.
• Appreciate creative challenges when mastering for both standard and HDR displays.
• Understand common approaches to creative HDR color grading.

Intended Audience: motion picture professionals, engineers, software developers, and imaging researchers who wish to gain a more complete technical understanding of HDR mastering. A basic understanding of colorimetry and image processing is expected.

Stefan Luka is a senior software engineer and color scientist at Walt Disney Feature Animation, where he oversees the production and mastering color pipelines. His work in the motion picture industry has also included film restoration, digital cinema systems, and display development. He received a BS in engineering and applied science from Caltech and a MS in color science from RIT.

Peter Postma is product manager at FilmLight, developing tools incorporated into the Truelight...
color management and Baselight color grading systems used in motion picture productions large and small. Previously, he worked as a systems engineer at Kodak helping pioneer digital intermediate technology. He studied film and animation at RIT.

T3D: Color Image Quality Assessment
1:30 – 3:30 pm (2 hours)
Instructors: Jan Allebach, Purdue University, and Marius Pedersen, Norwegian University of Science and Technology

Image quality assessment is a topic of growing interest that has also been the subject of much recent research. In this short course, we examine the current thinking about color image quality from several different vantage points. First, we examine models that are inspired by the spatiochromatic properties of the human visual system, or by thinking about the visually relevant structural characteristics of images. These spatiochromatic approaches typically lead to a processed image that reflects visual significance of image errors on a pixel-by-pixel basis. They can account for a number of important aspects of human vision, including masking. Such pixel error maps may be converted to a single number that summarizes overall image quality by various approaches to spatial summation, including the accounting for visual saliency.

In this course, we describe some of these approaches, including those that are based on training with machine learning methods. Furthermore, we discuss methods for conducting psychophysical experiments to evaluate these specific aspects of image quality and how these results are used to evaluate the performance of objective image quality metrics. We introduce the most common performance measures and show examples of the performance of state-of-the-art image quality metrics. At last we focus to identify a set of key image quality attributes, such as tone reproduction, sharpness, contrast, graininess, color fidelity, and artifacts, and to compute these as a set of distinct metrics for evaluating image quality. We show the use of spider plots to illustrate how they separately and cumulatively affect overall image quality. Finally, we illustrate the use of these image quality concepts for the evaluation of printer workflows.

Benefits: Attendees will be able to:
• Understand the basic spatiochromatic characteristics of the human visual system.
• Understand methods for conducting psychophysical experiments to subjectively assess image quality.
• Be familiar with the major image quality metrics in use today and how to evaluate their performance.
• Understand methods for pooling the results of spatial image quality maps to yield a single-number assessment of overall image quality.
• Understand what the major image quality attributes are, what they measure, and how they are computed.
• Know how to generate and interpret spider-plots that provide an integrated view of how a given image performs across a set of image quality attributes.
• Gain insight into the application of the concepts introduced in this course to the solution of real-world problems in imaging systems development.

Intended Audience: scientists, engineers, analysts, and managers involved in the design, engineering, manufacturing, marketing, or evaluation of imaging and printing products, algorithms, or systems. Participants should be familiar with the function and basic properties of imaging systems. A rudimentary knowledge of color science, linear systems, and image processing will be helpful, but is not essential.

Jan P. Allebach is Hewlett-Packard Distinguished Professor of electrical and computer engineering at Purdue University. He holds courtesy appoint-
ments in computer and psychological sciences. Technologies developed in his laboratory have been licensed to major vendors of printers and can be found in products that have sold 100s of millions of units world-wide. Allebach is a Fellow of IS&T, IEEE, the National Academy of Inventors, and SPIE. He was named 2004 Electronic Imaging Scientist of the Year and is an Honorary Member of IS&T, the highest award bestowed by the Society. He is the recipient of the IEEE Daniel E. Noble Award, was elected to membership in the National Academy of Engineering, and is the recipient of the 2016 Edwin H. Land Medal given jointly by OSA and IS&T. From Purdue University, he is the recipient of ten different awards for teaching, mentorship, and research. He currently serves as a Distinguished Lecturer for the IEEE Signal Processing Society.

Marius Pedersen is associate professor in the Norwegian Colour and Visual Computing Laboratory at the Norwegian University of Science and Technology (NTNU), Norway. His work is centered on image quality assessment and he has more than 50 publications in this field. He received his Bsc in computer engineering (2006) and MSc in media technology (2007) from Gjøvik University College, Norway. He received his PhD in color imaging (2011) from the University of Oslo, Norway, with a dissertation on image quality metrics for the evaluation of printing workflows under the supervision of Pr. Hardeberg, Pr. Albregtsen, and Dr. Bonnier, sponsored by Océ. He is currently the head of the Norwegian Colour and Visual Computing Laboratory at NTNU.

3:45 – 5:45 PM

T4A: Normal and Defective Colour Vision Across the Lifespan
3:45 – 5:45 pm (2 hours)
Instructor: Caterina Ripamonti, Cambridge Research Systems Ltd. and University College London

The course aims to provide a general introduction to normal and defective color vision and to describe the principles of some existing software and tools that can be used to simulate how images may be perceived by observers with normal or defective color vision across the lifespan. The first part of the course provides the physiological fundamentals to understanding how color vision operates and focuses on the causes underlying individual differences in the perception of color across the lifespan. In particular, we examine the changes in color vision that take place as a consequence of the early development or aging of the visual system. This is followed by an analysis of the differences between color vision in normal trichromats and observers affected by inherited or acquired color deficiencies. The differences between normal trichromats and affected observers are considered in terms of spatial, temporal, and color resolution as well as their light and dark adaptation processes. The second part concentrates on simulating how vision changes during the lifespan. This is followed by the presentation of some image processing techniques used to simulate the differences between normal and affected observers in perceiving colored images.

Benefits: Attendees will be able to:
• Understand how normal color vision operates.
• Learn about the causes underlying individual differences in perceiving color.
• Appreciate the difference between normal and affected color vision.
• Simulate how vision changes during the lifespan.

20% SAVINGS
Take 3 or more courses and get 20% off your total short course registration fee!
See registration form for details.
Intended Audience: color engineers, scientists and designers. Those who wish to understand color vision of normal trichromats as well as observers with defective color vision. Those interested in understanding the principles of how to correct and improve the visual discrimination of images by affected observers or normal trichromats of different ages.

Caterina Ripamonti is a research scientist at Cambridge Research Systems Ltd. and an Honorary Senior Research Fellow at UCL Institute of Ophthalmology and Moorfields Eye Hospital (UK). She is the author of numerous papers on human color vision, spatial and temporal properties of normal and defective vision, and applied aspects of color science related to human factors. She is also the co-author of the book Computational Colour Science using MATLAB.

T4B: Color and Appearance in 3D Printing
3:45 – 5:45 pm (2 hours)
Instructor: Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD

Novel 3D printers can combine multiple colorful materials in a single object enabling the reproduction of an object’s color, texture, gloss, and translucency in addition to its shape. This short course provides an overview of the relevant 3D printing technologies and focuses on the color and appearance reproduction pipeline.

Benefits: Attendees will be able to:
• Understand the basic concepts of 3D printing as they relate to color and appearance.
• Understand the differences between the existing color-capable 3D printing technologies.
• Describe ways to represent color and other appearance properties attached to 3D shapes.
• Learn the main principles of the 3D color reproduction pipeline.
• Have a basic understanding of 3D surface halftoning.

Intended audience: attendees wishing to become more familiar with the opportunities and challenges of the emerging field of graphical 3D printing, which may include color and imaging specialists, 3D printer designers, and software developers.

Philipp Urban is head of the Competence Center 3D Printing Technology at the Fraunhofer IGD in Darmstadt, Germany, where he works on the appearance reproduction of objects using multmaterial 3D printers. During his career he has been a visiting scientist at the Munsell Color Science Laboratory at RIT and head of the color research group at TU Darmstadt. He holds an MS in mathematics from University of Hamburg and a PhD from Hamburg University of Technology.

T4C: The Art of Making Better Pixels: High Dynamic Range Display Concepts and Technologies
3:45 – 5:45 pm (2 hours)
Instructor: Timo Kunkel, Dolby Laboratories

The field of High Dynamic Range imaging or HDR was coined more than 20 years ago. During this time, various building blocks have been designed that are suitable to form perceptually compelling as well as technologically efficient HDR display systems, especially in the context of comprehensive HDR imaging pipelines. Now, with the advent of mainstream HDR technologies, it is important to identify several key perceptual and technological concepts to avoid pitfalls that can impact image fidelity when processing, transmitting, and displaying HDR imagery. This course is intended as an introduction into high dynamic range display system and its related imaging pipelines.

Benefits: Attendees will be able to:
• Understand how the human visual system perceives the physical world around us and how HDR display technologies cater to this.
• Understand how much display luminance and contrast do we benefit from expanding the dynamic range.
• Appreciate how we should display the ‘real’ physical world and how we convey artistic intent.
• Understand the interaction between HDR and Wide Color Gamut Imaging.
• Identify the difference of vivid and dynamic TV modes vs. true HDR and wide gamut display.
• Evaluate the impact of 2D dual modulation technologies in comparison to other display types such as OLED.
• Identify the importance of a display’s white and black levels, its tone curve, and quantization steps as well as its color gamut volume.
• Differentiate the considerations for creating compelling content that lives up to the capabilities of HDR displays.

Intended Audience: it is aimed at anyone working in image display related fields such as display design, content creation, image transport and broadcast, and vision science. No direct previous knowledge is required but a basic understanding of traditional display and imaging concepts is beneficial.

Timo Kunkel is a senior researcher for Dolby Laboratories. His main areas of research are HDR and wide color gamut imaging, advanced display systems, virtual reality technologies, and psychophysics. Over the last 15 years he also worked as an architecture and landscape photographer focusing on computational photography approaches. He received his PhD in computer science from the University of Bristol, UK and MSc in physical geography, remote sensing, and environment modeling from the University of Freiburg, Germany.

T4D: Colour Difference Perception for Images
3:45 – 5:45 pm (2 hours)
Instructor: Ronnier Luo, Zhejiang University, University of Leeds, and National Taiwan University of Science and Technology

This course is divided into two parts: color difference evaluation for color patches and images, respectively. The former covers the fundamental in understanding color difference assessments such as visual assessment methods, reference viewing condition, and evaluation and development of color difference formulae using visual results. The latter introduces the way and theory to extend the formulae based on patches for evaluating images such as conventional formula with add-on spatial filters, color appearance model based formula and image appearance model. Furthermore, the experiments conducted associated with CIE Technical Committee 8-02 Colour Difference Evaluation for Images are introduced. The visual results were used to evaluate the performance of various types of formulae.

Benefits: Attendees will be able to:
• Learn the techniques for visually assessing color difference.
• Understand different types of color difference formulae.
• Evaluate the performances of color difference formulae.
• Apply color difference formula for the imaging industry.

Intended Audience: color engineers and research scientists involved with color reproduction, imaging device developers, computer software developers. Knowledge of the fundamental colorimetry is assumed.

Ming Ronnier Luo is a global expert professor in the Department of Optical Engineering, Zhejiang University, China; professor of colour and imaging science at the School of Design, University of Leeds, UK, and the Director of Colour and Imaging and Illumination Centre (CIC) at the National Taiwan University of Science and Technology. He is also the Vice President of CIE. He has more than 480 publications in color and imaging science, recently in illumination engineering. He is a Fellow of IS&T and the Society of Dyers and Colourists.
**OPENING KEYNOTE**

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

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.

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**Wednesday November 9, 2016**

**9:00 – 10:00 AM**

**WELCOME AND OPENING KEYNOTE**

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

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**10:00 AM – 12:40 PM**

**COLORFUL VIEWING**

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

**JIST-First QUALITAS: Image Quality Assessment for Stereoscopic Images**, Cristian Bonanomi, Christine Fernández-Maloigne, Jamie Moreno, and Alessandro Rizzi; Università degli Studi di Milano (Italy), University of Poitiers (France), and National Polytechnic Institute (Mexico)

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

**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)

**JIST-First 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)

**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)

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**2:00 – 3:40 PM**

**BEYOND THE RAINBOW**

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

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

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

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

This year CIC is again including author demonstrations in the program. This event supplements technical talks and allows attendees the opportunity to view the hardware, software, test charts, test images, etc. discussed during presentations. These demonstrations will occur during the conference coffee breaks. Speakers interested in participating should contact Donna Smith at dsmith@imaging.org.

Demultiplexing Visible and Near-Infrared Information in Single-Sensor Multispectral Imaging, Zahra Sadeghipoor,¹ Jean-Baptiste Thomas,² and Sabine Susstrunk¹; ¹EPFL (Switzerland) and ²Bourgogne University (France)

4:20 – 5:20 PM
COLORFUL MATTER
CIC 24 Best Paper Award Winner Modelling Incomplete Chromatic Adaptation and Colour Contrast Using Memory Colour,
Qiyan Zhai,¹ M. Ronnier Luo,¹,² Peter Hanselaer,² and Kevin A.G. SmeP²; ¹Zhejiang University (China), ²KU Leuven (Belgium), and ³University of Leeds (UK)
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 Cui³; ¹Zhejiang University (China), ²University of Leeds (UK), and ³Wenzhou University (China)
Visual Perception of 3D Printed Translucent Objects, Bui Minh Vu,¹ Philipp Urban,² Tejas Madan Tanksale,² and Shigeki Nakachi¹; ¹Toyonashi University of Technology (Japan) and ²Fraunhofer Institute for Computer Graphics Research IGD (Germany)

6:30 – 9:30 PM
CONFERENCE RECEPTION
Join colleagues under the stars as we gather around the hotel’s rooftop pool for conversation, libations, and food

Thursday November 10, 2016

9:00 – 10:00 AM
THURSDAY KEYNOTE AND IS&T AWARDS
The Evolution of Primate Color Vision,
Gerald H. Jacobs, University of California, Santa Barbara (USA)

10:00 AM – 12:40 PM
DO YOU SEE WHAT I SEE?
Colour Vision during the Developing Age,
Caterina Ripamonti, Sarah Kalwarowsky, and Marko Nardini, Cambridge Research Systems, Ltd. (UK)
JIST-First 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)

THURSDAY KEYNOTE
The Evolution of Primate Color Vision
Gerald H. Jacobs, University of California, Santa Barbara

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

A Revisit of the MacAdam Colour Discrimination Ellipses, Maria Georgoula,1 Guihua Cui,2 and Ronnier Luo1,3; 1University of Leeds (UK), 2Wenzhou University, and 3Zhejiang University (China)

JIST-First Effects of Color Pairs on Warmth Perception in Interiors, Begüm Ulusoy and Nilgün Olguntürk, Bilkent University (Turkey)

12:20 – 12:40 PM
TWO-MINUTE INTERACTIVE PAPER PREVIEWS I

Improvement of Appearance from Motion by Using Omni-Directional Camera, Ryota Domon,1 Shoji Yamamoto,2 Hiroshi Kintou,3 and Norimichi Tsumura1; 1Chiba University, 2Tokyo Metropolitan College of Industrial Technology, and 3Nikon Corporation (Japan)

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

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

Artist Paint Spectral Database, Roy S. Berns, Rochester Institute of Technology (USA)

Viewpoint Entropy for Material Appearance, Yuto Hirasawa,1 Shoji Yamamoto,2 Ryota Domon,1 Hiroshi Kintou,3 and Norimichi Tsumura1; 1Chiba University, 2Tokyo Metropolitan College of Industrial Technology, and 3Nikon Corporation (Japan)

Classification of Painting Techniques with Color Run-Length Matrices, Alexandre Bony and Christine Fernandez-Maloigne, University of Poitiers (France)

Exploiting Wide-Gamut Displays, Greg Ward, Hyunjin Yoo, Afsoon Soudi, and Tara Akhavan, Irys Tec, Inc. (USA)

Extended Linear Color Correction, Graham Finlayson1,2 and Garrett Johnson2; 1University of East Anglia (UK) and 2Apple Inc. (USA)

Color Image Enhancement Using Weighted Multi-Scale Correction Coefficients, Ji-Hoon Yoo, WangJun Kyung, Shibudas Kattakkalil Subhashdas, and Yeong-Ho Ha, Kyungpook National University (Korea)

Illuminant Chromaticity Estimation via Optimization of RGB Channel Standard Deviation, Shibudas Kattakkalil Subhashdas, Ji-Hoon Yoo, and Yeong-Ho Ha, Kyungpook National University (Korea)

2:00 – 3:20 PM
ILLUMINATING COLOR

Effects of Inter-Observer Variation on Color Rendering Metrics, Michael J. Murdoch and Mark D. Fairchild, Rochester Institute of Technology (USA)

Evaluation of the IES Method for Evaluating Light Source Color Rendition in Terms of Metamer Mismatching, Brian Funt, Ben Hull, and Xiandou Zhang, Simon Fraser University (Canada)

Extension of CIE Whiteness Metric under Different Illuminants Shining Ma,1 Jing Liang,1,2 Minchen Wei,3 and Ming R. Luo1,4; 1Zhejiang University (China), 2Dalian Polytechnic University (China), 3The Hong Kong Polytechnic University (Hong Kong), and 4University of Leeds (UK)

Three-Dimensional Test Target for Illuminant Analysis, Nathan Moroney, Ingeborg Tastl, and Melanie Gottwals, HP Labs (USA)

3:20 – 3:50 PM
TWO-MINUTE INTERACTIVE PAPER PREVIEWS II

A Revision of CIECAM02 and its CAT and UCS, C.J. Li1,3 Z. Li,1 Z. Wang,1 Y. Xu,1 M. R. Luo,2 G. Cui,3 M. Melgosa,4 and M. Pointer2; 1University of Science and Technology Liaoning (China), 2University of Leeds (UK), 3Wenzhou University (China), and 4University of Granada (Spain)

Robust Multispectral Data Hiding in RGB Image Using Digital Watermarking, Kazushige Banzawa, Kazuma Shinoda, and Madoka Hasegawa, Tsunomiyami University (Japan)
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)

Color Spaces Emerging from Deep Convolutional Networks, Ivet Rafegas and Maria Vanrell, Universitat Autònoma de Barcelona (Spain)

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)

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)

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)

Individual Corresponding Colors Data and Chromatic Adaptation Transformations, Shengyan Cai, Tianjin University of Science & Technology (China), and Mark D. Fairchild, Rochester Institute of Technology (USA)

Color Recommendation for Drawing based Image Retrieval on Mobile Devices, Zhan Xu, Guoping Qu, and Chao Zhang, University of Nottingham (China)

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)

New Spectral Data for Skin Colours, Mengmeng Wang, 1 Ming Ronnier Luo, 1, 3 Kaida Xiao, 2 Sophie Wurger, 2 and Yuzhao Wang 3; 1 University of Leeds (UK), 2 University of Liverpool (UK), and 3 Zhejiang University (China)

Optimization of Color Accuracy, Luminous Efficiency, and Color Gamut in Display Media Technology, Rodney L. Heckaman, GD Vision, Inc. (USA)

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EVENING TALK

The Confluence of Art and Technology: 3D Printing at LAIKA’s Award-Winning Animation Studio
Brian McLean and Rob Ducey, Laika Animation Studios

Known for its use of rapid prototyping for facial animation—for which it was recognized with a 2016 Scientific and Engineering Award from the Academy of Motion Picture Arts and Sciences (Oscars®)—in the Oscar®-nominated animated films The Boxtrolls, ParaNorman, and Coraline, LAIKA studios is versed in the challenges of color and 3D printing. Join Director of Rapid Prototype Brian McLean and Technical Director Rob Ducey as they discuss what they’ve learned since they began this technical adventure a decade ago.

Comparison of Parameters for Texture Characterization, Rafael Huertas, 1 Pooshpanjan R. Biswas, 1 Charlotte Fraza, 1 Alain Tremeau, 2 Ana Gebejes, 3 and Markku Hauta-Kasari 3; 1 University of Granada (Spain), 2 University Jean Monnet (France), and 3 University of Eastern Finland (Finland)

Designing Spectral Power Distribution of Illumination with Color Chart to Enhance Color Saturation, Masaru Tsuchida, Kaoru Hiramatsu, and Kunio Kashino, NTT Communication Science Laboratories (Japan)

3:50 – 5:20 PM

INTERACTIVE SESSION

8:15 – 9:15 PM

EVENING TALK

Sponsored by HP Inc.

The Confluence of Art and Technology: 3D Printing at LAIKA’s Award-Winning Animation Studio, Brian McLean and Rob Ducey, Laika Animation Studios (USA)
Friday November 11, 2016

COLOR AND IMAGING WORSHOPS
see page 19 for details; select workshop when registering for the conference

8:00 AM – 12:00 PM
Camera Color Characterization: Theory and Practice
Chair: Sabine Süssstrunk, École Polytechnique Fédérable de Lausanne (Switzerland)

8:30 AM – 12:00 PM
The Life of a Color (Sponsored by ISCC)
Chairs: David R. Wyble, Avian Rochester, LLC and John Conant, Aerodyne Research, Inc. (USA)

9:00 AM – 12:00 PM
Color Science for 3D Printing: From Mondrian to Miró
Chairs: Peter Morovic, HP Inc. (UK) and Ján Morovic, HP Inc. (Spain)

1:30 – 2:30 PM
CLOSING KEYNOTE AND CIC AWARDS
Sponsored by Google
Closing Keynote: Google Street View: Unique Challenges of Collecting Imagery at Global Scale, Luc Vincent and Rom Clement, Google Inc. (USA)

2:30 – 4:45 PM
WRANGLING COLOR
JIST-First Random CFAs are Better than Periodic Ones, David Alleysson and Prakhar Amba, Université Grenoble Alpes, and Jérôme Dias, Orme Signals & Images (France)
Scene Color Correction under Non-Uniform Spatial Illumination and Atmospheric Transmittance, Hiroaki Kotera, Kotera Imaging Laboratory (Japan)
Use of Simulated Reflectance Spectra in Camera Transform Creation, Michael J. Vrhel, Artifex Software (USA)
Color Homography Color Correction, Graham Finlayson and Han Gong, University of East Anglia, and Robert Fisher, University of Edinburgh (UK)
JIST-First 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)

EXHIBIT AT CIC24!
Interested in exhibiting or sponsoring an event at CIC? Exhibit space is limited; contact Donna Smith to learn more about exhibits and sponsorship opportunities at dsmith@imaging.org.

Become part of the CIC online community! Search LinkedIn for “color and imaging conference”

November 7 – 11, 2016 • San Diego, CA
CIC Workshops

A workshop is included with your conference registration. It is also possible to register for just the ISCC-sponsored workshop (W2). See registration form for details.

W1: Camera Color Characterization
8:00 – 12:00
Chair: 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 radiance 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)
• Target based versus spectral camera characterization (Eric Walowit, consultant)
• Target based versus in situ spectral training data (Dietmar Wueller, Image Engineering GmbH & Co. KG)
• Multidimensional color lookup tables (Michael Vrhel, Artifex Software, Inc.)
• Live demonstration of spectral camera characterization, camera transform generation, and matching from capture to display (in cooperation with all speakers)

W2: The Life of a Color (sponsored by ISCC)
8:30 – 12:00
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, CAUS)
How a brand color is originally selected? What are the associated strategic decisions to align the color with a product/brand’s attributes? How are colors properly placed, both geographically and in the right customer segments?

The Management of a Color (Max Derhak, Onyx Graphics)
Traditional color management has used only CIEXYZ colorimetry. New systems account for a complete color process: from light sources onto objects, and captured through color matching, including perceptual aspects of color.

The Manufacturing of a Color (Ann Laidlaw, ACL Color Consulting LLC)
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.

The Perception of a Color (Mark Fairchild, RIT)
Follow a photon from the sun, to an object, into the human eye. Those photons are traced to their ultimate fate in a cone photoreceptor. Finally, aspects of neuroscience are used to explore how the photons result in color appearance.

W3: Color Science for 3D Printing: From Mondrian to Miró
9:00 AM – 12:00 PM
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 psychophysical 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.

Color 3D Printing and its Challenges (Ján Morovic and Peter Morovic, HP Inc.)
Even though 3D color printing technologies build up objects layer-by-layer, and these layers are two-dimensional, it would be a mistake to think of 3D simply as stacked 2D printing. From color formation, where local material combinations in an object are the basis, via metrology challenges following from complex surface geometry and phenomena like translucency, to the intricacies even of having reliable psychophysical methods for the evaluation of color appearance, color in 3D is anything but a simple extension of its 2D counterpart. These, and other, aspects of 3D printing pose challenges for delivering predictable and consistent color properties and call for new scientific and engineering work. At the same time, there is existing knowledge in adjacent fields that can accelerate the process of understanding and controlling color in 3D printing, which we would like to facilitate in this workshop.

Color Measurements for 3D Printing (Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD)
I start the talk by showing that measurements made by spectrophotometers used in the graphic arts industry are systematically biased towards lower reflectance for many resin materials used in multimaterial 3D printing. Then, I present a gonio-imager particularly dedicated to sample the Bidirectional Reflectance Distribution Functions (BRDF) of such materials or material compositions arranged in a color-characterization chart. The setup comprises an almost colorimetric RGB camera and a spectrally tunable light source allowing it to perform bidirectional reflectance measurements or to act as a bidirectional colorimeter. At the end of the talk, I
introduce a modular, fully-automatic color 3D scanning pipeline developed at our institute. It is capable of capturing bidirectional color information in addition to shape by combining photogrammetry and structured light scanning.

Material Appearance Measurement: The Road to Reality (Marc Ellens, X-Rite, Inc.)

Material appearance is more than color; it isolates the characteristics of the material that an observer uses to identify, categorize, and ultimately use the material for its intended purpose. The wide range of materials has often posed a challenge for virtualization as many characteristics of material representation need to be hand-crafted. Measured material appearance provides a direct construction of these appearance characteristics, shortening product lifecycles, and delivering more physically accurate and realistic visualizations. We address such questions as: what is material appearance? what characteristics of geometry contribute to the appearance? how can it be captured with today’s and tomorrow’s technology? what methods we can use to communicate this appearance? and, what are the challenges as we move forward?

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

With dramatically developed 3D color printing technique, the accurate color management and reproduction for 3D printed objects becomes more and more important, although it is still a huge challenge for color and imaging science. Conventional color image reproduction techniques based on CIE Colorimetry have been developed for more than 20 years and perform very well in transforming color images from one digital media to another under various viewing conditions. However, CIE standard observer and psychophysical data for color appearance modelling and color difference evaluation were all obtained for flat color samples. It is not straightforward or accurate to apply conventional color image reproduction technique for 3D printed objects. Moreover, it is great difficulty to evaluate color reproduction for 3D printed objects objectively using current technology. In this presentation, a brief summary of color reproduction for 3D printed objects is given. The limitation of CIE colorimetry for color reproduction of 3D printed object is discussed.

Tangible Imaging Systems: Bringing Virtual Surfaces into the Real World (James A. Ferwerda, RIT)

Surfaces are everywhere, and it's through the interaction of light with surfaces, that we visually perceive the properties of the world. We often create images of surfaces to document their visual properties, and it's clear that images can serve quite well as visual representations of surfaces. However, the visual information we get from an image of a surface is not the same that provided by the surface itself. In particular, we get a lot of information about surface properties by interacting with surfaces, either through direct manipulation, or through observation from different viewpoints, and conventional images don't support either of these behaviors. For this reason we have been working to develop tangible imaging systems, that harness the power of digital modeling, computer graphics, and sensor technologies to produce new kinds of images that look and behave much more like the surfaces they represent.

In this talk, I describe our efforts to develop a tangible imaging system we call ImpastoR that supports the photometrically-accurate and visually-realistic simulation of surfaces with complex color, gloss, and textural properties in real-world lighting environments, and allows users to interact with and manipulate these virtual surfaces as naturally as if they were real ones. I discuss the poten-
tial uses of tangible imaging systems in a range of scientific, cultural, and commercial applications.

**Color Assessment of Teeth and Skin Using Digital Imaging (Stephen Westland, University of Leeds)**

Quantification of the colorimetric and color appearance properties of teeth and skin in vivo present serious technical challenges. Unlike many man-made materials (including many plastics, textiles, and painted surfaces) teeth and skin are three-dimensional structures that present a surface that is often not flat. In addition, the features to be measured may be small relative to the apertures of many commercially available spectrophotometers and difficult to access with bulky equipment. Color assessment using digital images potentially provides an alternative route to conventional color measurement but in practice presents several different technical challenges. This presentation explores the difficulties in using digital cameras to assess color and color appearance of teeth and skin. Several practical case studies are presented to demonstrate ways in which digital imaging can be used in this context.

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**ICC DevCon 2016**

**International Color Consortium Developers Conference 2016**

**Monday, November 7, 2016 • Westgate Hotel, in conjunction with CIC24**

ICC DevCon 2016 focuses on presenting real world solutions and applications using iccMAX. Several real world scenarios can now be directly addressed by iccMAX based approaches that could not be easily accomplished with previous color management solutions. Attendees gain a better understanding of both the background as well as the practical application of their iccMAX based solutions.

Your opportunity to learn from experienced users in the imaging, printing, and publishing color community.

**Program**


- Introduction to iccMAX from the Business Perspective (William Li, Kodak)
- Color Tuning of a Painting by a Multispectral Lighting System—An iccMAX-based Approach (Pei-Li Sun and Wei-Chun Hung, NTUST, Taiwan)
- A Spectral Workflow for Encoding and Analyzing Artwork with iccMAX (Ben Bodner and Roy Berns, RIT)
- Modeling Colour Vision Deficiency with ICC Profiles (Phil Green, NTNU in Gjøvik)
- Correction of Display Viewing Angle with iccMAX (James Vogh, X-Rite)
- Implementing Observer Metamerism Correction on Wide Color Gamut Display using iccMAX Framework (Chris Bai, BenQ)
- WORKSHOP Hands-on with RefIccMAX (Max Derhak, Onyx Graphics)
- Reception and Table Exhibit

**Fees**

- $300 IS&T/ICC members / $200 each additional registration from the same company
- $400 non-members / $300 each additional registration from the same company

Early bird special: Register by October 9, 2016 with your CIC registration and get $50 off. Register for ICC DevCon when you register for CIC, see page 24.
Hotel and Travel Information

The Westgate Hotel
1055 Second Avenue, San Diego, CA 92101 • +1 619 238 1818

Rate: Deluxe King $189/night plus 12.5% tax. Note that room includes a refrigerator, complementary bottled water, and internet. Check in/out: 3:00 pm/noon

Rate availability: The discounted rate is available 3 days prior to the conference thru the night of the 11th, based on availability. Full payment for the first night and tax is due by the reservation deadline. Reservations made by the deadline will be confirmed when full payment for the first night is received.

Reservation Deadline: October 15, 2016 *Note: We suggest you make your reservations as soon as possible as there is a large conference coming into the city at the end of our meeting week and the rooms we are holding will revert to them after the Oct. 15 deadline.

Reservations: http://bit.ly/1QqQaDi or via phone: +1 800 522 1564 / Reference: CIC24

Cancellation Policy: Deposit is refundable if individual gives cancellation notice at least 10 days before arrival.

Parking: The hotel has valet parking, with in/out privileges, for $36/day.

Transportation Information

Airport: San Diego International Airport (SAN) is 3.1 miles from the hotel. For more information, visit www.san.org

Getting to/from Hotel/Airport
Via Taxi: Charge is approximately $15 to the hotel, depending on time of day and traffic.

Via San Diego Bus: The San Diego Bus system makes stops in both Terminal 1 and 2 of the airport. Take Route 923 to Downtown from the airport to Broadway & 3rd Avenue. It is approximately a one minute walk to the hotel. One-way fare is $2.25. For more information, visit www.sdmts.com/schedules-real-time.

Via Rental Car: There are 15 rental car agencies with the San Diego International Airport Rental Car Center, which is accessible via free shuttle. We advise renting cars online prior to arrival.

Getting around San Diego: Taxies, buses, and the San Diego Trolley are all available for transportation around the city. There is a trolley stop across the street from the hotel. One-way fare is $2.50. There are multiple bus stops located around the hotel. One-way fare is $2.25. For more information regarding the bus and trolley, visit www.sdmts.com/schedules-real-time.
CIC24 Conference Registration

Go to www.imaging.org/ist/conferences/CIC to register online.

Name
Title/Position
Company
Mailing Address

Telephone   Fax   Email

Conference registration includes admission to all technical sessions, CIC workshops, coffee breaks, Welcome and Conference Receptions, and conference abstract book and proceedings on flash drive. Separate registration fees are required for short courses.

1. Technical Program Registrations [CHECK ONE]

Please check ALL that apply. I am a:

☐ speaker    ☐ session chair    ☐ committee member
☐ IS&T member    ☐ only taking short courses    ☐ short course instructor

Please note: To better serve your needs, IS&T is offering conference registration options that include membership with either JIST or JEI at the same rate as a non-member fee.

<table>
<thead>
<tr>
<th></th>
<th>REGULAR thro Oct 9</th>
<th>after Oct 9</th>
<th>STUDENT thro Oct 9</th>
<th>after Oct 9</th>
</tr>
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<tbody>
<tr>
<td>Conference registration: current IS&amp;T/ISJ Member</td>
<td>$745</td>
<td>$845</td>
<td>$150</td>
<td>$250</td>
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<tr>
<td>Conf. registration (+ new or renewing membership + JIST)*</td>
<td>$845</td>
<td>$945</td>
<td>$175</td>
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<tr>
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<td>$945</td>
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<td>$275</td>
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<td>Conference non-member registration</td>
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<td>$945</td>
<td>$375</td>
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<tr>
<td>One-day: ☐ Wed ☐ Thurs ☐ Fri</td>
<td>$445</td>
<td>$495</td>
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<tr>
<td>ISCC-sponsored Workshop W2: The Life of Color ONLY**</td>
<td>$175</td>
<td>$225</td>
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<tr>
<td>ISCC Business Meeting and Lunch***</td>
<td>$10</td>
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<tr>
<td>ICC Dev/Con IS&amp;T/ICC Member****</td>
<td>$250</td>
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<tr>
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<td>$350</td>
<td>$400</td>
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2. CIC Workshop Selection (free with registration; select ONE)

☐ W1: Camera Color Characterization
☐ W2: The Life of a Color (sponsored by ISCC)
☐ W3: Color Science for 3D Printing: From Mondrian to Miró
☐ I do not plan to attend a workshop

* Membership benefits include access to the IS&T Digital Library, an online subscription to the Journal of Imaging Science and Technology (JIST) or Journal of Electronic Imaging (JEI), The Reporter newsletter, conference fee discounts, and access to the member directory, among other things. Membership takes effect by 11/15/16 and expires 12/31/17. This offer may be used for renewals.

** Conference registrants may take Workshop W2 for free as part of their conference registration. This option is for those coming only for the workshop.

*** The Inter-Society Color Consortium (ISCC) Business Meeting and Lunch follows the W2 workshop, from noon to 1:30 pm.

**** If more than one member of your company is registering for ICC DevCon 2016, we suggest you register via the DevCon website as there are discounts for additional people coming from the same company.
3. Short Course Registration (be sure to multiply number of classes by per course fee and place on total line)

Please note: Course notes for most classes are provided electronically prior to the conference for printing or viewing on your computer. Instructors without e-notes will provide hardcopies in class.

<table>
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<tr>
<th></th>
<th>thru Oct 9</th>
<th>after Oct 9</th>
<th>TOTAL</th>
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<tr>
<td>__ M1: Color, Vision, and Basic Colorimetry Member</td>
<td>$450</td>
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<tr>
<td>__ M1: Color, Vision, and Basic Colorimetry Non-member</td>
<td>$495</td>
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<tr>
<td>__ Student M1: Color, Vision, and Basic Colorimetry</td>
<td>$180</td>
<td>$230</td>
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<tr>
<td>__ T1A: Adv. Colorimetry and Color Appearance Member</td>
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<td>$300</td>
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<tr>
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<td>$300</td>
<td>$350</td>
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<tr>
<td>__ T1A: Adv. Colorimetry and Color Appearance Student</td>
<td>$90</td>
<td>$140</td>
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</tr>
<tr>
<td>__ 2-hour Non-member (per class; select below)</td>
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<td>$245</td>
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<tr>
<td>__ 2-hour Student (per class; select below)</td>
<td>$60</td>
<td>$110</td>
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</table>

Check all that apply

T1B T1C T1D
T2B T2C T2D
T3A T3B T3C T3D
T4A T4B T4C T4D

OR

Take ANY three or more classes and receive 20% off the total price

(enter three or more courses, fill in member or non-member fee next to each, add, and multiply by .80 to get your price, representing 20% savings; add additional lines if needed; students may not take advantage of this offer)

T or M____ $ _____ + T____ $ _____ + T____ $ _____ = $_____ x .80 =$_____ 

4. Extras

<p>| | | | |</p>
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<tbody>
<tr>
<td>__ Extra copy of conference proceedings</td>
<td>$135</td>
<td>$_____</td>
<td></td>
</tr>
<tr>
<td>__ Guest ticket for Welcome Reception</td>
<td>$35</td>
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<td></td>
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<tr>
<td>__ Guest ticket for Conference Reception</td>
<td>$65</td>
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</table>

Name/Affiliation of Guest for badge: ____________________________

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total from previous page $_____ 

Wire transfer fee ($25 if applicable) $_____ 

GRAND TOTAL $_____ 

Payment Method: [ ] AmEx [ ] MasterCard [ ] VISA [ ] Discover [ ] Wire Transfer [ ] Check 

Card#: ___________________________ Exp. Date: ____________

Name as it appears on card: __________________________________________

Authorization Signature: __________________________________________

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Return this form with signed credit card authorization to IS&T, 7003 Kilworth Lane, Springfield, VA 22151 or fax to 703/642-9094. Contact registration@imaging.org for wire transfer information; $25 must be added to the total for wire transfer payments to cover bank costs.

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Please note: To cover bank charges and processing fees, there is a cancellation fee of $75 until November 1, 2016. After that date, the cancellation fee is 50% of the total plus $75. No refunds will be given after November 25, 2016. All requests for refund must be made in writing.