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CIC22 Technical Papers Program: Schedule and Contents

see IAPD Program beginning on page xvii; page numbers in program refer to the paginated proceedings book found on the enclosed usb stick; papers without page numbers do not have a corresponding paper.

WEDNESDAY NOVEMBER 5, 2014

Welcome and Joint Opening Keynote

Session Chairs: Jennifer Gille, Qualcomm Technologies, Inc., and Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

9:00 – 10:00 AM

Amphitheater

9:10 **Sensing Surfaces with GelSight*,** *Ted Adelson, Massachussetts Institute of Technology*

Keynote sponsored by Canon USA, Inc.

Canon

Digital Pathology, Color, and Imaging Joint Panel

Session Chair: Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

10:00 – 11:00 AM

Amphitheater

The Important Aspects in Digital Pathology Standardization*, *Yukako Yagi, Massachusetts General Hospital (USA)*

Clinical Implementation of Digital Pathology*, *John Gilbertson, Harvard Medical School and Massachusetts General Hospital (USA)*

Color Management in Digital Pathology, *W. Craig Revie[1], Mike Shires[2], Pete Jackson[2], David Brettle[3], Ravinder Cochrane[1], and Darren Treanor[2,3]; [1]FFEI Ltd., [2]University of Leeds, and [3]Leeds Teaching Hospitals NHS Trust (UK)* . . . . . .

In digital microscopes and whole slide imaging systems, images of slides are captured, transmitted and reproduced on a computer display. In order to allow pathologists to interpret these images accurately and efficiently it is important that colors from the slides are displayed in a consistent and reliable fashion.

The final color of the image presented to the viewing pathologist depends on several steps through the imaging pathway, including sample illumination, magnification, image capture, compression, storage, and reproduction on the computer display. There are many possible system designs and, within a single system, different setup options which can affect the final image leading to significant variation in image appearances.

This paper summarizes recent work by members of the International Color Consortium Medical Imaging Working Group to develop test materials and methods for the assessment of color calibration of digital microscope systems. This work includes sharing of ideas on device calibration, image processing and display.

The paper further discusses the challenges encountered in the development of a suitable color target that includes a set of patches with spectra similar to those encountered when viewing pathology slides with stained tissue samples. *[See Appendix 01 for short paper and figures.]*

Validation of Whole Slide Imaging*, *Liron Pantanowitz, University of Pittsburgh Medical Center (UPMC) Shadyside (USA)*

11:00 —11:40 AM Coffee Break

Joint Keynote

Session Chair: Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

11:40 AM – 12:35 PM

Amphitheater

11:40 **Microimaging: Seeing the Unseen in Living Patients,** *Guillermo J. Tearney, Massachusetts General Hospital, Harvard Medical School, and Wellman Center for Photomedicine (USA)*

Abstract: Today's gold standard for medical diagnosis is histology of excised biopsies or surgical specimens where tissue is taken out of the body, processed, sectioned, stained and looked at under a light microscope by a pathologist. There are many limitations of this technique, including the fact that it is inherently invasive, time consuming, costly, and dangerous for some organs. Furthermore, oftentimes the diseased tissue is not readily seen by visual inspection and as a result the tissue is sampled at a random location, which can be highly inaccurate. If we could instead conduct microscopy inside the body, then we could provide tools for screening, targeting biopsies, making primary disease diagnosis, and guiding intervention on the cellular basis. This promise has motivated the development of a new field, termed in vivo microscopy, the goal of which is to obtain microscopic images from living human patients. Two in vivo microscopy technologies, confocal microscopy and optical coherence tomography, are currently available and in clinical use. Upcoming developments, including whole organ microscopy, swallowable microscopy capsules, molecular imaging, and very high resolution microscopic devices are in the pipeline and will likely revolutionize how disease is diagnosed and how medicine is practiced in the future.

12:35 — 2:00 PM Lunch Break

Do You See What I See?

Session Chair: Alessandro Rizzi, Università Degli Studi di Milano

2:00 – 3:20 PM

Amphitheater

2:00 **Observer Variability in Color Image Matching on a LCD Monitor and a Laser Projector,** *Yuta Asano[1,2], Mark D. Fairchild[1], Laurent Blondé[2], and Patrick Morvan[2]; [1]Rochester Institute of Technology (USA) and [2]Technicolor (France)* **1**

Wide color gamut media are emerging in the market, and this trend has

*No abstract or paper available.

Week At-A-Glance

SHORT COURSE: MONDAY NOV. 3

8:30 am – 5:30 pm (8 hours)

M1: Color, Vision, and Basic Colorimetry

Instructor: Geoff Woolfe, CISRA

SHORT COURSES: TUESDAY NOV. 4

8:00 am – 12:00 noon (four hours)

T1A: Advanced Colorimetry and Color Appearance

Instructor: Geoff Woolfe, CISRA

T2A: Lightfield Imaging

Instructor: Todor Georgiev, Qualcomm Techn., Inc.

8:00 – 10:00 am (2 hours)

T3A: Color Gamut Mapping

Instructor: Phil Green, Gjøvik University College

T5A: Normal and Defective Color Vision across the Lifespan

Instructor: Caterina Ripamonti, Cambridge Research Systems Ltd. and UCL Institute of Ophthalmology

10:15 am – 12:15 pm (2 hours)

T1B: Color Calibration of Imaging Systems

Instructor: Phil Green, Gjøvik University College

T2B: Spectral Imaging Workflow

Instructor: Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD

T3B: Measuring and Modeling Individual Differences in Color Matching Functions

Instructor: Mark Fairchild, RIT

T4B: Digital Color Management for Television and Movies

Instructor: David Long, RIT

1:30 – 5:30 pm (four hours)

T1C: Optimal Design of Color Systems

Instructor: Geoff Woolfe, CISRA

1:30 – 3:30 pm (2 hours)

T2C: Color Optimization for Displays

Instructor: Gabriel Marcu, Apple Inc.

T3C: Fundamentals of Whole Slide Imaging (WSI) System

Instructor: Nicholas Charles Jones, Massachusetts General Hospital

T4C: LED Lighting Technology and Application

Instructor: Nadya Piskun, Philips Color Kinetics

T5C: High-Dynamic-Range Imaging: Capture, Rendition, and Applications

Instructors: Alessandro Rizzi, Università Degli Studi di Milano, and John McCann, McCann Imaging

3:45 – 5:45 pm (2 hours)

T3D: Color Rendition by Light Sources

Instructor: Wendy Davis, University of Sydney

T4D: Color Image Quality Assessment

Instructors: Jan Allebach, Purdue University, and Marius Pedersen, Gjøvik University College

Wednesday November 5th

	CIC	IADP
9:00	**Conference Opening and Joint Keynote** Sensing Surfaces with GelSight, Ted Adelson	
10:00	**Digital Pathology, Color, and Imaging Joint Panel:** **• The Important Aspects in Digital Pathology Standardization, Yukako Yagi** **• Clinical Implementation of Digital Pathology, John Gilbertson** **• Color Management in Digital Pathology, W. Craig Revie et al.** **• Validation of Whole Slide Imaging, Liron Pantanowitz**	
11:00	40 minute coffee break in exhibit area	
11:40	**Joint Keynote:** Microimaging: Seeing the Unseen in Living Patients, Guillermo J. Tearney	
12:35	Lunch break	
	Do You See What I See?	**3D Imaging, Visualization, and Analysis**
2:00	Observer Variability in Color Image Matching on a LCD Monitor and a Laser Projector, Yuta Asano et al.	Analysis of 3D Histology Imaging, Yukako Yagi
2:20	Improving the Perceptual Uniformity of a Gloss Space, Adria Fores et al.	Understanding 3-Dimensional World from 2-Dimentional Immuno-Fluorescent Adjacent Sections, Sho Fujisawa et al.
2:40	Modeling Observer Variability and Metamerism Failure in Electronic Color Displays, David L. Long and Mark D. Fairchild	Connection and Deformation of Pathological Images via a Macro Image for Comparing Different Modality Images of Brain Tumor, Takashi Ohnishi et al.
3:00	Prediction of Incomplete Chromatic Adaptation under Illuminant A from Images, Shoji Tominaga et al.	Spectrally Encoded Confocal Microscopy for Guiding Lumpectomy, Elena F. Brachtel et al.
3:20	40 minute coffee break in exhibit area	
	Picture Perfect	**Digital Pathology Systems and Evaluations**
4:00	An Image Difference Metric based on Simulation of Image Detail Visibility and Total Variation, Marius Pedersen	Point of Use QA in Digital Pathology Slides, David Brettle et al.
4:20	Considering Saliency in a Perception Inspired Gamut Reduction, Javier Vazquez Corral et al.	Development of a Prototype for Hepatocellular Carcinoma Classification Based on Morphological Features Automatically Measured in Whole Slide Images, Yoshiko Yamashita et al.
4:40	Colour Management of Prints with Variant Gloss, Teun Baar et al.	Enhancing Automatic Classification of Hepatocellular Carcinoma Images through Image Masking, Tissue Changes and Trabecular Features, Maulana Abdul Aziz et al.
5:00	**Interactive Paper Previews I;** see list beginning on page vi.	Comparative Study between Quantitative Digital Image Analysis and Fluorescence In-Situ Hybridization (FISH) of Breast Cancer Equivocal HER2 2+ Cases, E. Ayad et al.
	Conference Reception – 5:30 – 7:30 PM	

Thursday November 5th

	CIC	IADP
	CIC Keynote and Society Awards	**IADP Special Lectures 1: Digital Pathology Perspectives**
9:00	Plenoptic Cameras and Microscopes: Multimodal Capture, Todor Georgiev	An Editors Perspective on Digital Pathology, Stanley Cohen
9:20		Digital Teleconsultation: Clinical Perspectives, David Wilbur
9:40		Pathology Through Pixels: Image Analysis in Biotechnology, Robert Dunstan
	Beyond the Rainbow	**WSI User Interface**
10:10	Spectral Printing with a CMYKRGB Printer: A Closer Look, Steven Le Moan and Philipp Urban	Scalable Adaptive Graphics Environment (SAGE): A Novel Way to View and Manipulate Whole-Slide Images, Bruce Levy and Victor Mateevitsi
10:30	Nano-Media: A Novel Multi-Channel Color Image Display with Embedded Covert Information, Reza Qarehbaghi et al.	Using a Novel WSI Software Platform for an International Multi-Center Validation Study to Assess the Histological Growth Pattern of Liver Metastases, Yves Sucaet et al.
10:50	40 minute coffee break in exhibit area	
		Analysis Approaches in Digital Pathology
11:30	Rapid Simulation of Translucent Material with Contrast-Reversing Rendering, Ryota Domon et al.	Quantification Accuracy of Liver Fibrosis by in vivo Elastography and Digital Image Analysis of Liver Biopsy Histochemistry, Justinas Besusparis et al.
11:50	Principal Component Analysis for Skin Reflectance Reconstruction, Kaida Xiao et al.	Aggregation Dynamics of Particulate Blood Platelets, Suresh Ahuja
12:10	**Interactive Paper Previews II;** see list beginning on page xi.	Leukocyte Adhesion, the Endothelial and Vascular Dysfunctions, Suresh Ahuja
12:30	Lunch break	
	Bright Ideas	**Education and Telepathology**
2:00	Color-Printed Gloss: Relating Measurements to Perception, Sepideh Samadzadegan et al.	The Use of Virtual Microscopy and a Wiki in Pathology Education: Tracking Student Use, Involvement and Response, Zev Leifer
2:20	Gaussian Illuminants and Reflectances for Colour Signal Prediction, Hamidreza Mirzaei and Brian Funt	Ten Years of Experience Teaching Oral Pathology to Dental Students Using Whole Slide Imaging (WSI): What Have We Learned?, Janusz Szymas et al.
2:40	Pixel-Wise Illuminant Estimation for Mixed Illuminant Scenes based on Near-Infrared Camera Information, Joschua Thomas Simon-Liedtke et al.	Exploring Viewing Behavior Data from Whole Slide Images to Predict Correctness of Students' Answers during Practical Exams in Oral Pathology, Slawomir Wolkowski et al.
3:00	Light Profile Uniformity in Linear Lighting Applications, Michael J. Murdoch et al.	MGH Whole Slide Imaging Teleconsultation Practice in Dermatopathology, Nicholas C. Jones et al.
	Colorful Language	Digital Pathology Data Brokerage: A Standard Recommendation for Complex Digital Pathology Information Web-Services, Aristidis G Anagnostakis et al.
3:20	Adapting Color Difference for Design, Danielle Albers Szafir et al.	
3:40	A Similarity Measure for Large Color Differences, Nathan Moroney et al.	Image File Management to Support International Telepathology, Liron Pantanowitz et al.
4:00	**Interactive/Poster Paper Session and Exhibit time** See IADP list beginning on page xxvii. See CIC lists beginning on pages vi and xi.	
	day ends at 5:30 PM	

Friday November 7th

	CIC	IADP
	CIC Workshops	**Color Image Processing**
8:00	Choose 1 of 4; see page xiv – xv for details.	9:00 Whole Slide Image Analysis System for Quantification of Liver Fibrosis, Tokiya Abe et al. 9:20 Staining Correction in Digital Pathology with Dye Amount Look-up-table (LUT), Pinky A. Bautista and Yukako Yagi 9:40 A New 2D Histogram in HSV Space For Color Image Retrieval, K. Elasnaoui et al.
10:00	30–40 minute coffee break in exhibit area	
10:30	Workshops continue	**IADP Special Lectures 2: Digital Pathology and Imaging Applications** 10:40 Digital Pathology - How Far Are We From Automated Tissue - based Diagnosis?, Klaus Kayser et al. 11:00 Computational Cancer Pathology, Andrew H. Beck 11:20 The Role of Micro CT in the Imaging of Cancer, M. Griffin et al. 11:40 Discussion time. 12:00 Lunch
12:30	Lunch Break	
1:30	**IADP Closing and Joint Keynote:** Human Factors in Telepathology: the 21st Century Agenda, Ronald S. Weinstein	
	Putting Color to Work	**IADP Conference Ends** followed by MGH Tours
2:20	Imaging Color Target for Off-Axis Illumination Reflectance Microscopy, Jennifer D. T. Kruschwitz and Roy S. Berns	
2:40	An Engineering Model for Color Difference as a Function of Size, Maureen Stone et al.	
3:00	Compression of Reflectance Data Using an Evolved Spectral Correlation Profile, Peter Morovic et al.	
3:20	Image Sensor Modeling: Color Measurement at Low Light Levels, Mehdi Rezagholizadeh and James J. Clark	
3:40	30 minute coffee break	
4:10	**CIC Closing Keynote and Paper Award Presentations**	
	Color Research in Boston, John McCann	
	day ends at 5:15 PM	

been accelerated by ITU recommendation, Rec.2020 in 2012. Wide color gamut media possess spectrally narrow primaries, which would potentially increase the degree of observer metamerism. In this study, it was investigated if observer metamerism could be a serious issue under practical viewing conditions. Namely, real images were used as a matching stimulus instead of uniform colors. We carried out the color image matching experiment on two different media: an Apple Cinema HD LCD monitor and a Microvision laser projector. The results from 28 color-normal observers were analyzed. The obtained inter-observer variability was large enough that observer metamerism would be a serious issue where the laser projector is viewed together with conventional media. Each observer had a match point that was significantly different from those of other observers. It was found that effective field size changes (and an observers CMFs change) depending on image contents. Complex images require smaller field size whereas simple images require larger field size.

2:20 **Improving the Perceptual Uniformity of a Gloss Space,** *Adria Fores and Mark D. Fairchild, Rochester Institute of Technology, and Ingeborg Tastl, Hewlett-Packard Laboratories (USA)* **7**

The perceptual gloss space defined in Pellacini *et al.* Could be used for quality control applications to bring similar benefits as seen in color with the use of CIELAB. However, a distance metric to relate all the dimensions in the space does not exist, and the space was only validated with the materials used to define the space.

The current space's distance metric does not allow relating differences in lightness to the other dimensions: contrast gloss and distinctness of image gloss. The lightness perception uniformity of the space was first evaluated in a psychophysical study, where the observers' lightness discrimination was found to decrease as lightness increased. A function was derived to model the lightness perception observed and it was included into the distance metric of the space.

The space uniformity around sixteen positions in the gloss space was evaluated in a second psychophysical study to assess the overall space uniformity. The space was found to be perceptually non-uniform outside the samples used when the space was created. Also, an improved gloss difference equation that takes into account the non-uniformity of the space is presented, showing a statistical significant improvement over the current gloss difference equation of the space and reducing the STRESS value from 39.76 to 22.96.

2:40 **Modeling Observer Variability and Metamerism Failure in Electronic Color Displays (CIC/JIST Paper*),** *David L. Long and Mark D. Fairchild, Rochester Institute of Technology (USA)* **14**

The electronic display industry has begun a migration towards higher color gamut devices driven by LED, OLED, quantum dot and laser technologies capable of generating near monochromatic color stimuli in the traditional red, green, blue three-channel paradigm. The use of highly selective spectral stimuli, however, poses a risk to the consistency of visual experience amongst a group of disparate, but otherwise normal, color observers. Several models of spectral color vision have surfaced in recent research and are helping investigators to better understand the implications for color experience variability. The present research serves to summarize various color difference indices that may be useful in predicting the magnitude of observer response inconsistencies and applies them to simulations of current electronic displays as examples of potential concerns these new high-gamut technologies might raise. In particular, various laser-based displays are shown to perform with significantly increased observer variability versus traditional ITU-R Rec. 709 and SMPTE 431 RGB-primary displays utilized in the cinema industry. Further, observer metamerism can be reduced significantly with proper optimization of a multichannel projection system comprising seven explicitly designed primary spectra.

3:00 **Prediction of Incomplete Chromatic Adaptation under Illuminant A from Images (CIC/JIST Paper*),** *Shoji Tominaga, Takahiko Horiuchi, Shiori Nakajima, and Mariko Yano, Chiba University (Japan)* **28**

The authors propose a method of image rendering to predict the incomplete chromatic-adaptation effect for paintings. A simple model of incomplete chromatic adaptation is developed to predict the appearance of the paintings under the illumination of an incandescent light source and to produce the full color image on a display device. The authors extend the von Kries framework to incomplete chromatic adaptation. An index parameter representing the degree of incomplete chromatic adaptation is defined based on the color temperature of the black-body radiators. First,

* *CIC/JIST Papers appear in Vol. 58, Issue 3 of the* Journal of Imaging Science and Technology, *are presented at CIC, and are found within the CIC proceedings as a reprint from JIST.*

the optimum value of the index parameter is determined by visual experiments on memory matching using real paintings and color patches, so that the color image produced on the display is matched to the original appearance of objects in a real scene. This approach is shown to have better performance in comparison with the traditional CIECAM02. Next, an algorithm is presented to estimate the index parameter of the incomplete adaptation index based on the image data of colorimetric rendering for a target painting. It is found that the index parameter can be estimated using only three features extracted from the color image. The color images rendered with the estimated parameter are used to predict the incomplete chromatic-adaptation effect for the original painting under the incandescent light source. The feasibility of the proposed method is confirmed based on a series of experiments using a variety of paintings.

3:20 —4:00 PM Coffee Break

Picture Perfect

Session Chair: Paul Hubel, Apple Inc.
4:00 – 5:00 PM
Amphitheater

4:00 **An Image Difference Metric based on Simulation of Image Detail Visibility and Total Variation,** *Marius Pedersen, Gjøvik University College (Norway)* **37**
Many image quality and image difference metrics have been proposed over the last decades. An important factor when evaluating the image quality or image difference is the viewing distance. In this paper we propose a new image difference metric based on the simulation of detail visibility and total variation. The simulation of detail visibility by using shearlets takes into account the viewing conditions and the viewing distance, and calculation of the image difference is done by total variation. Evaluation has been carried out to verify the simulation of image detail visibility, and it is showing promising results. Evaluation of the new image difference metric is also promising.

4:20 **Considering Saliency in a Perception Inspired Gamut Reduction,** *Javier Vazquez-Corral, Syed Waqas Zamir, and Marcelo Bertalmío, Universitat Pompeu Fabra (Spain)* **43**
Gamut reduction transforms the colors of an input image within the range of a target device. A good gamut reduction algorithm will preserve the experience felt by the viewer of the original image. Saliency algorithms predict the image regions where an observer first focuses. Therefore, there exists a connection between both concepts since modifying the saliency of the image will modify the viewer's experience. However, very little attention has been given to relate saliency and gamut mapping. In this paper we propose to modify a recent gamut reduction algorithm proposed by Zamir *et al.* In order to better respect the saliency of the original image in the reproduced one. Our results show that the proposed approach presents a gamut-mapped image whose saliency map is closer to that of the original image with a minor loss in the accuracy of perceptual reproduction.

4:40 **Colour Management of Prints with Variant Gloss,** *Teun Baar[1,2], Maria V. Ortiz Segovia[1], and Hans Brettel[2]; [1]OCE Print Logic Technologies S.A. and [2]Institut Mines-Telécom Telécom ParisTech, CNRS LTCI (France)* **48**
Advanced printing techniques are currently used to incorporate special effects in printouts. There is an increasing interest in the reproduction of material appearances and art work, with the focus on reproducing aspects such as colour, surface texture and gloss variations. However, for material surfaces of which the level of glossiness varies, the colour is often affected due to the applied gloss effect. The effect of the (local) gloss level on the colour is not incorporated in the colour management, which results in a mismatch with respect to the intended colour. We propose a workflow to control the reproduction of colour for the case of using multiple gloss modes in a printing system. Although currently one single ICC profile is used to manage the colour of the printout, our workflow proposes using one ICC profile per gloss level that adapts the colour transformations locally based on the applied gloss level. Our results show an improved reproduction of the colour and smoother colour transitions between gloss levels of prints with variant gloss.

Interactive Previews I*

Session Chairs: Juan Lin, Ricoh Americas Corp., and Albrecht Lindner, Qualcomm Technologies, Inc.
5:00 – 5:30 PM
Amphitheater

Noise Characteristics of a Single Sensor Camera in Digital Color Image Processing, *Tamara Seybold, Arnold & Richter Cine Technik; and Özlem Cakmak, Christian Keimel, and Walter Stechele, Technische Universität München (Germany)* **53**
Denoising algorithms are usually tested on standard test images with artificial white Gaussian noise added. This noise model cannot be applied in the denoising of digital images taken with a single sensor camera because of the signal-dependence of the noise, the demosaicking and the color transformations. We study the noise characteristics with respect to the signal domain. Noise distribution and variance are measured in the raw data and approximated using a Gaussian distribution with a variance linearly dependent on the signal. We evaluate the influence of white balance, debayering and the signal domain and calculate the spatial correlation of the noise. In our experiments we both evaluate the influence of the noise characteristics on human perception and on the performance of denoising methods. Based on a subjective test with 18 participants we can show that the spatially correlated camera noise is more visible than the white Gaussian noise and decreases the visual quality of color image sequences significantly. To evaluate the impact of the noise characteristic on denoising, two state-of-the-art denoising methods are applied to our test data. When the noise is signal-dependent and spatially correlated through debayering the peak signal-to-noise ratio (PSNR) decreases by up to 8 dB. We conclude that it is very important to take into account the correct noise characteristics for increasing the visual quality of color image sequences in future research.

Unveiling PM 2.5 Pollution Layer for Viewing Clear Scenes, *Hiroaki Kotera, Kotera Imaging Laboratory (Japan)* **59**
Atmospheric pollution by PM2.5 is a serious problem now at Beijing, China and its neighboring countries. The de-hazing or de-fogging methods for degraded images have been a long-pending question at NASA Langley Research Center. Recently their basic Retinex model advanced into Visual Servo system. While the current main stream for unveiling the atmospheric pollution layer is based on scattering physics. Above all, a single image de-hazing model based on Dark Channel Prior hypothesis is

*These papers are previewed during this session and presented Thursday from 4:00 – 5:30 PM during the Interactive Paper Presentation Session.

beyond the conventional three, has demonstrated to be beneficial for a wide range of applications. Its ability of acquiring images beyond the visible range and applicability in many different application domains lead to the design and the development of a number of multispectral imaging technologies and systems. Given different systems to choose from, it is important to be able to compare them in a general and in many situations specific to a certain application of interest. In this paper, we evaluate several conventional and recently proposed multispectral imaging systems, both qualitatively and quantitatively. Both spectral and colorimetric accuracies are used as the criteria in the quantitative evaluation. The systems are evaluated and compared for two specific applications: imaging of natural scenes and paintings (cultural heritage), as well as for a general spectral imaging solution. This work provides a framework for the evaluation and comparison of different multispectral imaging systems, which we believe, would be very helpful in identifying the most appropriate technique or system for a given application.

Efficient POC-based Correspondence Detection Method for Multi-Channel Images, *M. Tsuchida[1], S. Sakai[2], K. Ito[2], K. Kashino[1], J. Yamato[1], and T. Aoki[2]; [1]NTT Corporation and [2]Tohoku University (Japan)* **113**
We propose a new POC (phase-only correlation)-based high-accuracy correspondence detection method for multi-channel images. There is the possibility of improving detection accuracy because conventional POC-based methods do not use color information. In the proposed method, a normalized cross spectrum (or cross-phase spectrum) and weight are calculated for each color channel in the Fourier domain. The weight is determined by the amplitude of the cross spectrum. The weighted normalized cross spectra of all color channels are combined and inverse Fourier transformation is conducted to obtain a POC function. An experimental evaluation of the matching accuracy between the conventional POC-based method and the proposed method shows that RMSE decreased approximately 25%. This paper also describes an application of the proposed method to a stereo image matching. The average detection ratio of correspondences between a stereo-pare image is improved 64% to 95%.

Automatic Color Reference Target Detection, *Luis E. García Capel and Jon Y. Hardeberg, Gjøvik University College (Norway)* **119**
The use of standard color reference targets at image acquisition allows to compensate for different camera characteristics, illumination conditions and exposure times, ensuring true colors in digital photo workflows. Reliable automatic detection of reference targets makes color correction faster, and this becomes critical in mass digitization processes. The existing automatic algorithms usually assume that there is little perspective distortion and/or that the scanning resolution is known, achieving very limited results for example when the relative size of the color target is unknown. In this paper we present a preprocessing step that aims at automatically detecting a region of interest (ROI) where the reference target is located. We compare the performance of one of the available automatic tools (CCFind) with and without this pre- processing step, and show a considerable improvement in the detection of color reference targets in a new

challenging dataset. In addition, a simple template matching approach is compared with the performance of CCFind. The results show that the selection of a smaller ROI complements well with the existing approaches and helps to improve detection.

Enhancement of Visibility by Adjusting Brightness based on App Image Categorization in Mobile Device, *Dae-Chul Kim[1], Bong-Seok Choi[1], Wang-Jun Kyung[1], Dong-Wook Kang[2], Kyung-Mo Kim[2], and Yeong-Ho Ha[1]; [1]Kyungpook National University and [2]Samsung Electronics Co. LTD (Korea)* **125**

The visibility of images displayed on mobile devices can vary significantly according to the lighting conditions. Generally, the brightness of a mobile device is adjusted to enhance visibility according to the intensity of illumination. However, different brightness settings can be more suitable to different types of content even under the same illumination. Accordingly, this paper presents a method to adjust a device's brightness according to the features of the displayed app images. We started by performing two subjective tests under various lighting conditions for selecting the features concerning visibility for several apps screenshots and for selecting a satisfactory range of device brightness for each of those. Then, we analyzed the relationship between the app image features and the satisfactory brightness levels. Subsequently, the images are categorized by using two features: the average brightness and the distribution ratio of advancing colors related to satisfactory brightness. The optimal device brightness for each category is then selected by the maximum frequency of satisfactory device brightness. Experimental results show that the categorized app images with optimal device brightness have high satisfaction ratio under various light conditions.

CONFERENCE RECEPTION
5:30 – 7:30
Foyer

THURSDAY NOVEMBER 6, 2014

Keynote and IS&T Awards

Session Chair: Jennifer Gille, Qualcomm Technologies, Inc.
9:00 – 10:10 AM
Amphitheater

9:10 **Plenoptic Cameras and Microscopes: Multimodal Capture*,**
Todor Georgiev, Qualcomm Technologies, Inc. (USA)

Keynote sponsored by Hewlett-Packard Company

Beyond the Rainbow

Session Chair: Aditya Sole, Gjøvik University College
10:10 AM – 12:10 PM
Amphitheater

10:10 **Spectral Printing with a CMYKRGB Printer: A Closer Look,**
Steven Le Moan, Technische Universität Darmstadt and Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany) **131**

With the advent of multi-channel technologies, printers offer more and more possibilities for spectral reproduction. In order to print a specific color sensation, there are now more degrees of freedom when it comes to combining inks (i.e. more metamerism). In this paper, we take the example of a CMYKRGB printer and propose to visualize the extent of its spectral variability (or degree of metamerism) through the analysis of so-called paramer-mismatch gamuts. We then evaluate the suitability of the recently proposed LabAB interim connection space in the design of look-up tables for spectral color management. We demonstrate in particular that the spectral variability of this printer is small enough to drastically reduce the number of necessary grid points needed to sample the connection space without loss of perceived quality.

*No abstract or paper available.

10:30 **Nano-Media: A Novel Multi-Channel Color Image Display with Embedded Covert Information,** *Reza Qarehbaghi, Hao Jiang, and Bozena Kaminska, Simon Fraser University (Canada)* **136**
In this paper, a novel color image display with concurrent data storage is presented. We use a Nano-Media concept that consists of a nano-fabric based on sub-wavelength pixelated structures and an intensity control layer (ICL) deposited on top of a fabric. The ICL is used to tune the brightness of individual RGB sub-pixels and to obtain the desired pattern, data or image. Using this technology, any information can be stored and displayed as optical machine and/or human readable. The experimental work is presented to show the Nano-Media used for the multispectral layers of information storage and display. The fabrication results are discussed together with the practical examples for various applications.

10:50 —11:30 AM Coffee Break

11:30 **Rapid Simulation of Translucent Material with Contrast-Reversing Rendering,** *Ryota Domon[1], Shoji Yamamoto[2], Kentaro Hikosaka[3], and Norimichi Tsumura[1]; [1]Chiba University, [2]Tokyo Metropolitan College of Industrial Technology, and [3]Nikon Corporation (Japan)* **141**
We present a rendering method to reproduce translucent appearances in real-time. Since the translucency is caused by complicated light behavior such as scattering and absorption, reproducing translucent material requires computationally expensive cost. Due to its computational cost, it is difficult to apply the digital mock-up with the computer graphics for the purpose of cost reduction and acceleration of developing products. In order to reproduce the translucent appearance rapidly, we focus on the contrast-reversing image processing. We embed this simple image processing method to the reflection model. Our proposed method can reproduce in real-time with almost the same appearance compared to commercial rendering software.

11:50 **Principal Component Analysis for Skin Reflectance Reconstruction,** *Kaida Xiao[1,2], Zhenghui Qin[1], Tushar Chauhan[2], Changjun Li[1], and Sophie Wuerger[2]; [1]University of Science and Technology Liaoning (China) and [2]University of Liverpool (UK)* **146**
Principal component analyses (PCA) were conducted for skin spectral reflectance of a new skin colour database. Results for skin colours from different ethnic groups were analysed and reflectance reconstruction based on first three components obtained by PCA were investigated. Significant differences in the derived principal components for the three ethnic groups were found. Furthermore, a new nonlinear optimization model based on all reflectance data was developed for generating the three basis functions for reflectance reconstruction. Comparison results for reflectance predictions show the basis functions obtained from the new optimisation model are better than those obtained from PCA.

Interactive Previews II*

Session Chairs: Juan Lin, Ricoh Americas Corp., and Albrecht Lindner, Qualcomm Technologies, Inc.
12:10 – 12:35 PM
Amphitheater

Methods to Assess the Relative Number of Discernible Colors for Displays, *Yuan Li, Stephen Westland, Qianqian Pan, and Vien Cheung, University of Leeds (UK)* **151**
The quantitative description of the size of a display gamut is crucial for designing the wide-gamut display of high saturation primaries. Three methods are proposed for the calculation of the number of discernible colors in a display gamut volume. The methods are demonstrated with a comparison of two mobile phone displays, one based on AMOLED technology and the other based on LCD technology. The AMOLED has 60-80% more discernible colors than the LCD display. Not only is the result relatively invariant to the computational method but it is also similar when the analysis is carried out in CIELAB space or CIECAM02 space.

Color Naming Transitions, *Maria J.S.P. Brasil, Physics Institute, UNICAMP (Brazil), and Stephen Westland and Qianqian Pan, University of Leeds (UK)* **155**
We explore the notion that variations in cone spectral sensitivities could cause variations in color-name boundaries between individuals. Fifteen observers made color matches to a test stimulus (580 nm) with three primary lights in a visual colorimeter. The same observers took part in two psychophysical experiments to determine the color-naming boundary between two focal colors (yellow and green). In one experiment observers used a slider bar to indicate the boundary; in the other they were presented with a color stimulus and asked to state whether it was yellow or green in a 2afc design. In the case of the 2afc experiment the results indicate some evidence to suggest a correlation in the position of the name boundary and the ratio of red and green lights used in visual color matches.

Perceptual Spatial Uniformity Assessment of Projection Displays with a Calibrated Camera, *Ping Zhao[1], Marius Pedersen[1], Jean-Baptiste Thomas[2], and Jon Yngve Hardeberg[1]; [1]Gjøvik University College (Norway) and [2]Université de Bourgogne (France)* **159**
Spatial uniformity is one of the most important image quality attributes in visual experience of displays. In conventional researches, spatial uniformity was mostly measured with a radiometer and its quality was assessed with non-reference image quality metrics. Cameras are cheaper than radiometers and they can provide accurate relative measurements if they are carefully calibrated. In this paper, we propose and implement a work-flow to use a calibrated camera as a relative acquisition device of intensity to measure the spatial uniformity of projection displays. The camera intensity transfer functions for every projected pixels are recovered, so we can produce multiple levels of linearized non-uniformity on the screen in the purpose of image quality assessment. The experiment results suggest that our work-flow works well. Besides, none of the frequently referred uniformity metrics correlate well with the perceptual results for all types of test images. The spatial non-uniformity is largely masked by the high frequency components in the displayed image content, and we should simulate the human visual system to ignore the non- uniformity that cannot be discriminated by human observers. The simulation can be implemented using models based on contrast sensitivity functions, contrast masking, etc.

*These papers are previewed during this session and presented Thursday from 4:00 – 5:30 PM during the Interactive Paper Presentation Session.

*No abstract or paper available.

Colour Separation of *n*-Colour Printing Process Using Inverse Printer Models, *Kiran Deshpande, London College of Communication (UK); Phil Green, Gjøvik University College (Norway); and Michael R. Pointer, University of Leeds (UK)* **194**
Although the *n*-colour printing process increases the colour gamut, it presents a challenge in generating colour separations. This paper evaluates different methods of implementing the inverse printer model to obtain the colour separation for *n*-colour printing processes. The constrained optimisation and the look-up table based inversion methods were evaluated. The colorant space was divided into sectors of 4-inks and the inverse printer models were applied to each sector. The results were found to be adequate with the mean CIEDE2000 values between the original colours and the model predicted colours below 1.5 for most of the models. The lookup table based inversion was computationally faster than the constrained optimisation approach. The 9-level lookup table model gave accurate prediction without costing the processing time. It can be used to replace spot coloured inks with the 7-colour printing process in packaging printing to achieve significant cost savings.

Performance of Various Color Difference Models in Challenging Regions of CIELAB Color Space, *Renzo Shamey, Renbo Cao, Weethima Sawatwarakul, and Juan Lin, North Carolina State University (USA)* . . **200**
To examine the performance of a select group of advanced color difference equations against visual color difference data, we report the development of a combined visual dataset consisting of samples in the CIE low and high chroma blue color centers (NCSU-B and NCSU-B2), a recent set of near black samples (NCSU-BK) and a new dataset around a gray center (L*=50.56, a*=-0.11, b*=0.03), hereafter called NCSU-Gr, using the gray scale method. The new gray dataset consisted of 21 matte painted samples, and the visual difference between each of the samples against the standard was assessed by 35 color normal observers under highly controlled viewing and illumination conditions and using the AATCC gray scales, in three separate sittings, and a total of 2205 assessments were obtained. The performance of two groups of color difference equations consisting of: 1) those based on CIELAB color space and 2) those based on more uniform color spaces/appearance model such as DIN, CIECAM02 and OSA, against the visual dataset was examined for the NCSU-Gr, and also for the combined dataset (NCSU-COM). The results show that CIEDE2000 (2:1:1) exhibits the best performance for the NCSU-Gr dataset in comparison to other equations examined. This confirms that the G term in the CIEDE2000 significantly improves its performance in the near neutral gray region. An examination of the performance of the models against the combined dataset, however, shows that the more uniform color space/appearance models produce better results than models based on CIELAB color space, with CAM02-SCD performing significantly better than other equations except CAM02-UCS.

Bright Ideas

Session Chair: Patrick Emmel, Clariant International Ltd.
2:00 – 3:20 PM
Amphitheater

2:00 **Color-Printed Gloss: Relating Measurements to Perception,** *Sepideh Samadzadegan and Jana Blahová, Technische Universität Darmstadt, and Philipp Urban, Fraunhofer-Institut für Graphische Datenverarbeitung IGD (Germany)* **207**
In order to assess the print quality, color and gloss are two important factors that should always be considered. In this paper, we investigate the impact of color on gloss using printed color samples varying between low and medium gloss levels. A psychophysical experiment was conducted to relate specular gloss measurements to perception. Results show that second order polynomials describe well this relationship independently of the underlying color. Following the same trend for all colors, the magnitude of perceived gloss decreases with increasing lightness.

2:20 **Gaussian Illuminants and Reflectances for Colour Signal Prediction,** *Hamidreza Mirzaei and Brian Funt, Simon Fraser University (Canada)* **212**
An alternative to the von Kries scaling underlying the chromatic adaptation transforms found in colour appearance models such as CIECAM02 is suggested for predicting what the colour signal (e.g., XYZ) reflected from a surface under a first illuminant is likely to become when lit instead by a second illuminant. The proposed method, G2M, employs metameric Gaussian-like functions to model the illuminant and reflectance spectra. The method's prediction is based on relighting the Gaussian-like reflectance spectrum with the second Gaussian-like illuminant. Tests show that the proposed G2M method significantly outperforms CIECAT02.

2:40 **Pixel-Wise Illuminant Estimation for Mixed Illuminant Scenes based on Near-Infrared Camera Information,** *Joschua Thomas Simon-Liedtke, Jon Yngve Hardeberg, and Per Ove Husøy, Gjøvik University College (Norway)* **217**
Computational color constancy or white balancing methods for digital cameras emulate the ability of the human visual system to adapt to different lighting situations and to maintain color constancy. Global white balancing algorithms have been shown to give remarkable results for scenes illuminated by one light source, but proven less adequate for multi-illumination scenes where multiple light sources are present. Using information from an additional near-infrared channel can be used to estimate the white point at every pixel in the image by comparing the pixels' NRGB values to a multi-dimensional lookup table with precomputed NRGB values. This estimated white point can then be used for white balancing via linearized Bradford transform. The lookup table requires measurement of multiple reflectance and illumination spectra that are representative for an office environment. The method performs better than conventional global white balancing methods.

3:00 **Light Profile Uniformity in Linear Lighting Applications,** *Michael J. Murdoch, Philips Research (the Netherlands); Susanne Seitinger, Eric Roth, and Peter Goldstein, Philips Color Kinetics (USA); and Ulrich Engelke, Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Australia)* **222**
LED lighting in a linear form factor can provide valuable accent lighting and vertical illumination in architectural cove and graze applications. Ideally, linear lights provide a smooth gradient of light onto a surface without disturbances along their length. However, socket shadows between discrete fixtures and multiple LEDs per fixture can lead to visible nonuniformities, often worse near the light source but mixed to uniformity further away. Perceived mixing distances in the illumination patterns of a variety of linear light sources were assessed visually, and objective metrics based on illumination measurements were developed. Accurate predictions of mixing distances are shown based on trends in CIE DE2000 color errors computed between the measured light pattern and analogous Gaussian-weighted local neighborhood regions. Effects of variations in parameters of DE threshold and neighborhood size and shape are discussed.

Colorful Language

Session Chair: Youngshin Kwak,
Ulsan National Institute of Science and Technology
3:20 – 4:00 PM
Amphitheater

3:20 **Adapting Color Difference for Design,** *Danielle Albers Szafir[1,2], Maureen Stone[1], and Michael Gleicher[1]; [1]University of Wisconsin-Madison and [2]Tableau Research (USA)* **228**

CIELAB is commonly used in design as it provides a simple method for approximating color difference. However, these approximations model color perception under laboratory conditions, with correctly calibrated displays and carefully constrained viewing environments that are not reflective of complexity of viewing conditions encountered in the real world. In this paper, we present a data-driven engineering model for parametric color difference that extends CIELAB to be more broadly applicable to real-world conditions. Our model can be tuned to a desired range of viewers and conditions using a simple modeling procedure, while minimally increasing the complexity of the model. We demonstrate our approach empirically by modeling color differences for the web by leveraging crowdsourced participants.

3:40 **A Similarity Measure for Large Color Differences,** *Nathan Moroney, Ingeborg Tastl, and Melanie Gottwals, Hewlett-Packard Laboratories (USA)* **234**

Hundreds of large color differences, of magnitude 20 ΔE_{00}, were generated and used in a visual sorting experiment. The process of generating these color differences and two specific experiments are described in detail. The results show that small color difference metrics, such as ΔE_{00}, do not consistently model the visually sorted differences for large differences. A new similarity measure, based on a cosine similarity between categorical vectors of colors, is described and used to more consistently model large color differences. This similarity metric can be used to better characterize large color errors during reproduction, for image processing operations such as segmentation or as a feature for content retrieval. The new measure can also be applied to visual phenomena, such as categorical perception, in which within category color differences are perceived as smaller than across category differences.

Interactive Paper Presentation Session

4:00 – 5:30 PM
Lobby and Foyers

FRIDAY NOVEMBER 7, 2014

CIC22 Workshops

Workshops run concurrently, with a coffee break from 10:00 – 10:30 AM in various rooms, posted onsite. Select one from the following. If papers are presented within a workshop, they are listed below that workshop.
8:00 AM – 12:30 PM, unless noted
10:00 —10:30 AM Coffee Break

W1: From Image Processing to Visual Neuroscience through the Retinex Theory of Color Workshop

Chairs: Marcelo Bertalmío, University Pompeu Fabra (Spain); Alessandro Rizzi, University of Milano (Italy); and John McCann, McCann Imaging (USA)

The Retinex theory of Edwin Land proposed a model of human color vision based on color perception experiments. The original Retinex algorithm, by Land and McCann, is capable of performing color correction and contrast enhancement of images, with some limitations regarding overexposed pictures and visual artifacts stemming from its implementation based on one dimensional paths. By replacing these paths by two dimensional kernels while maintaining all the basic tenets of the theory, another Retinex algorithm was obtained that does not produce artifacts and can be extended into a variational formulation allowing to handle naturally both over and underexposed images. Furthermore, this variational formulation linked Retinex with histogram equalization in image processing and with efficiency of representation and lightness induction in visual neuroscience.

This workshop provides attendees with a clear and novel look at the Retinex theory of color vision, seeing its contributions in a new light and showing the potential for applications to problems in image processing and computer graphics such as color constancy, contrast enhancement, haze removal, tone mapping of high dynamic range images, gamut reduction and extension for cinema, and color transfer.

W2: New Insights on Metamerism Workshop

Chair: Michal Mackiewicz, University of East Anglia (UK)
Note: This workshop begins at 9:00 AM

This workshop bring researchers who work in various parts of the relevant fields together so that the most recent insights can be shared and new ideas stimulated. The relevant disciplines include those that touch upon various aspects of metamerism from the general mathematics of color formation equation to metamerism issues related to certain specific applications. The idea here is to present the current research in the related research fields and the specific challenges in those fields. The collation of presentations on this specific topic in one workshop should provide new insights that benefit the related relevant disciplines.

From Metamerism to Metamer Mismatching and Beyond*, *Alexander D. Logvinenko, Glasgow Caledonian University (UK)*

Metamer Mismatch Volumes of Flat Grey, *Brian Funt and Hamidreza Mirzaei, Simon Fraser University (Canada); and Alexander D. Logvinenko, Glasgow Caledonian University (UK)* **240**

Metamer mismatching refers to the fact that two objects reflecting light causing identical colour signals (i.e., cone response or XYZ) under one illumination may reflect light causing non-identical colour signals under a

*No abstract or paper available.

second illumination. As a consequence of metamer mismatching, two objects appearing the same under the first illuminant can be expected to appear different under the second illuminant. Metamers of the flat grey reflectance (*i.e.,* 50% across the visible spectrum) are of particular interest since they show the potential seriousness of metamer mismatching. Metamer mismatching of flat grey is very significant for some lights and includes the possibility of 20 objects having the same colour signal as flat grey under red light dispersing into a whole hue circle under a neutral ("white") light. Flat grey under LED illumination is also shown to have a significant metamer mismatch volume when the light is changed to D65.

Metamerism in Printing: Bane or Boon*, *Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)*

Calculating Metamer Sets for Spectrally Tunable LED Illuminators*, *Michal Mackiewicz, University of East Anglia (UK)*

W3: Camera Color Characterization Workshop

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

This workshop covers the whole process of camera characterization in theory and practice; a talk is provided on all important aspects. The talks are followed by a practical demonstration of spectral characterization and implementation of the data (in cooperation with all speakers)

Many camera manufacturers stick to old test chart based color characterization methods because they reluctant to change a running system or have not fully understood what modern technology can do.

The goal of the workshop is to identify and demonstrate known issues in this process and provide potential solutions using latest technology like multispectral LED light sources in combination with in situ measured spectral radiances of natural objects and modern implementations of color look up tables so that participants get all the information they need to implement advanced color correction in their cameras and software.

Why Cameras Need to be Characterized and Calibrated*, *Kevin Matherson, Microsoft Corporation (USA)*

Target-based versus Spectral Camera Calibration*, *Eric Walowit (USA)*

Target-based versus In Situ Spectral Training Data*, *Dietmar Wueller, Image Engineering GmbH & Co. KG (Germany)*

Impact of Color Correction on General Image Quality*, *Paul Hubel, Apple Inc. (USA)*

CCM versus Color Lookup Tables*, *Michael Vrhel, Artifex Software, Inc. (USA)*

W4: Next Generation Color Printing Workshop

Chairs: Ludovic Gustafsson Coppel and Radovan Slavuj, Gjøvik University College (Norway)

Emerging techniques such as multi-channel and multi-layering (2.5D/3D) printing open new research areas and applications in printing. This workshop gives researchers in color science, appearance modelling and/or printing technology the opportunity to share ideas and discuss potential applications with representatives from leading printer manufacturers. The goal is to provide a forum for brainstorming the future of printing and identifying new research problems and potential industrial applications.

The workshop begins with a series of invited talks from established researchers from printing companies and academia who present their views on the future of printing. A panel discussion follows. lead by a group of postgraduate students and postdocs conducting research in the field of spectral-, multilayering-, and 2.5D-printing. Participants have the opportunity to ask questions and give a short presentation of their ongoing research or development. The workshop concludes with a demonstration session showing new printing applications, opening further discussion between participants who are encouraged to bring their own hands-on materials

Colour Printing 7.0: Next Generation Multi-Channel Printing, *Ludovic Gustafsson Coppel, Aditya Sole, and Jon-Yngve Hardeberg, Gjøvik University College (Norway)* **242**

Colour Printing 7.0: Next Generation Multi-Channel Printing (CP7.0) is a training and research project funded under the Marie Skłodowska-Curie Initial Training Networks (MCITN) call in EU's seventh framework programme (FP7) . The project is led by Gjøvik University College in collaboration with five full network partners and six associated partners from academia and industry. The project addresses a significant need for research, training and innovation in the printing industry. The main objectives of this project are to train a new generation of printing scientists who will be able to assume science and technology lead-ership in this established technological sector, and to do research in the colour printing field by fully exploring the possibilities of using more than the conventional CMYK inks. The research fo-cuses particularly on spectral reproduction (new spectral colour modelling, spectral gamut mapping, halftoning and image quality assessment) and on multilayering printing methods to control ink mixing, relief (2.5 D prints) and surface properties. This paper reviews the achievements of the project so far in conjunction with a topical workshop at the 22nd Colour and Imaging Conference on "Next generation colour printing."

What is the Colour of Your Eye?* *Reiner Eschbach, Xerox Corporation (USA)*

Next-gen Printer: Let's Make a Wish*, *Nicolas Bonnier, Canon Information Systems Research Australia Pty Ltd (Australia)*

Halftone-Palate Type of Both Soft-proofing and Hard-proofing Applications via Multispectral Approach for High-Fidelity Printing Systems*, *Mei-Chun Lo, Shih Hsin University (Taiwan)*

12:30 —1:30 PM Lunch Break

IADP Closing Joint Keynote

Session Chairs: Klaus Kayser, Humboldt University (Charite), Institute of Pathology, and Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

1:30 – 2:20 PM

Amphitheater

1:30 **Human Factors in Telepathology: The 21st Century Agenda*,** *Ronald S. Weinstein, Arizona Telemedicine Program (USA)*

*No abstract or paper available.

Putting Color to Work

Session Chair: Caterina Ripamonti, UCL, Institute of Ophthalmology
2:20 – 3:40 PM
Amphitheater

2:20 **Imaging Color Target for Off-Axis Illumination Reflectance Microscopy,** *Jennifer D. T. Kruschwitz and Roy S. Berns, Rochester Institute of Technology (USA)* **247**

A color target has been designed and fabricated for off-axis illumination reflectance microscopy that utilizes microlens arrays and color mirrors. The color mirrors are optical interference coatings that are similar to designs used for anti-counterfeiting effect pigments. This system of microlenses and color mirrors allows the user to image different colored specular highlights. An infinite number of spectral reflectance profiles can be created with these color targets and used not only colorimetrically, but also for multispectral imaging applications. The targets are not limited to the visible region; they can also be designed to work in the ultra-violet and infrared wavelength regions. This paper will describe how these targets work, the image capturing considerations (flat-fielding, white balance, etc.), and some experimental results.

2:40 **An Engineering Model for Color Difference as a Function of Size,** *Maureen Stone[1], Danielle Albers Szafir[1,2], and Vidya Setlur[1]; [1]Tableau Research and [2]University of Wisconsin-Madison (USA)* **253**

This work describes a first step towards the creation of an engineering model for the perception of color difference as a function of size. Our approach is to non-uniformly rescale CIELAB using data from crowd-sourced experiments, such as those run on Amazon Mechanical Turk. In such experiments, the inevitable variations in viewing conditions reflect the environment many applications must run in. Our goal is to create a useful model for design applications where it is important to make colors distinct, but for which a small set of highly distinct colors is inadequate.

3:00 **Compression of Reflectance Data Using an Evolved Spectral Correlation Profile,** *Peter Morovic and Ján Morovic, Hewlett-Packard Company (Spain); Michael H. Brill, Datacolor; and Eric Walowit (USA)* **259**

Since spectral data is significantly higher-dimensional than colorimetric data, the choice of operating in a spectral domain brings memory, storage and computational throughput hits with it. While spectral compression techniques exist, e.g., on the basis of Multivariate Analysis (mainly Principal Component Analysis and related methods), they result in representations of spectra that no longer have a direct physical meaning in that their individual values no longer directly express properties at a specific wavelength interval. As a result, such compressed spectral data is not suitable for direct application of physically meaningful computation and analysis. The framework presented here is an evolution and extension of the spectral correlation profile published before. It is a simple model, driven by a few adjustable parameters, that allows for the generation of nearly arbitrary, but physically realistic, spectra that can be computed efficiently, and are useful over a wide range of conditions. A practical application of its principles then includes a spectral compression approach that relies on discarding spectral wavelengths that are most redundant, given correlation to their neighbors. The goodness of representing realistic spectra is evaluated using the MIPE metric as applied to the SOCS and other databases as a reference. The end result is an efficient, yet physically meaningful, compressed spectral representation that benefits computation, transmission and storage of spectral content.

3:20 **Image Sensor Modeling: Color Measurement at Low Light Levels (CIC/JIST Paper),** *Mehdi Rezagholizadeh and James J. Clark, McGill University (Canada)* **265**

The investigation of low light imaging is of high importance in the field of color science from different perspectives. One of the most important challenges that arises at low light levels is the issue of noise or, more generally speaking, low signal-to-noise ratio (SNR). In the present work, effects of different image sensor noises, such as photon noise, dark current noise, read noise, and quantization error are investigated in low light color measurements. In this regard, a typical image sensor is modeled and employed for this study. A detailed model of noise is considered in the process of implementing the image sensor model to guarantee the precision of the results. Several experiments have been performed over the implemented framework and the results show the following: first, photon noise, read noise, and quantization error lead to uncertain measurements distributed around the noise free measurements and these noisy samples form an elliptical shape in the chromaticity diagram; second, even for an ideal image sensor, in very dark situations, stable measurement of color is impossible due to the physical limitation imposed by the fluctuations in photon emission rate; third, dark current noise reveals dynamic effects on color measurements by shifting their chromaticities towards the chromaticity of the camera black point; fourth, dark current dominates the other sensor noise types in the image sensor in terms of affecting measurements. Moreover, an SNR sensitivity analysis against the noise parameters is presented over different light intensities.

CIC22 Closing Keynote: Color in Boston

Session Chair: Jennifer Gille, Qualcomm Technologies, Inc.
4:00 – 5:15 PM
Amphitheater

4:00 **Color Research in Boston,** *John McCann, McCann Imaging* . **276**

In the 22 years of the Color Imaging Conference, this is the first time we meet in Boston. The history research on color by Bostonians begins with Benjamin Thompson's (Count Rumford's) study of complementary colors in 1793. The history includes the experiments of Oliver Wendell Homes, William James, Leonard Troland, Alfred Munsell, Smittie Stevens, George Wald, Paul Brown, John Dowling, Edwin Land, David Hubel, Torsten Wiesel, Bevil Conway, and many more. The talk will trace the many connections between physics, psychology, photography, and color that have roots in Boston.

5:00 **Presentation of the Paper Awards**

Best Student Paper Award sponsored by MERL

MITSUBISHI ELECTRIC
Mitsubishi Electric Research Laboratories

5:05 **Closing and plans for 2015 in Europe**

IADP Technical Papers Program: Schedule and Contents

see CIC22 Program beginning on page iii; those IADP papers with short papers and figures are noted below, and found in the appendix of the CIC22 proceedings book, found on the accompanying usb stick. The IADP program is also published in *Analytical Cellular Pathology*.

WEDNESDAY NOVEMBER 5, 2014

Welcome and Joint Opening Keynote

Session Chairs: Jennifer Gille, Qualcomm Technologies, Inc., and Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

9:00 – 10:00 AM

Amphitheater

9:10 **Sensing Surfaces with GelSight*,** *Ted Adelson, Massachussetts Institute of Technology*

Keynote sponsored by Canon USA, Inc.

Canon

Digital Pathology, Color, and Imaging Joint Panel

Session Chair: Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

10:00 – 11:00 AM

Amphitheater

The Important Aspects in Digital Pathology Standardization*, *Yukako Yagi, Massachusetts General Hospital and Harvard Medical School (USA)*

Clinical Implementation of Digital Pathology*, *John Gilbertson, Harvard Medical School and Massachusetts General Hospital (USA)*

Color Management in Digital Pathology, *W. Craig Revie[1], Mike Shires[2], Pete Jackson[2], David Brettle[3], Ravinder Cochrane[1], and Darren Treanor[2,3]; [1]FFEI Ltd., [2]University of Leeds, and [3]Leeds Teaching Hospitals NHS Trust (UK)*

In digital microscopes and whole slide imaging systems, images of slides are captured, transmitted and reproduced on a computer display. In order to allow pathologists to interpret these images accurately and efficiently it is important that colors from the slides are displayed in a consistent and reliable fashion.

The final color of the image presented to the viewing pathologist depends on several steps through the imaging pathway, including sample illumination, magnification, image capture, compression, storage, and reproduction on the computer display. There are many possible system designs and, within a single system, different setup options which can affect the final image leading to significant variation in image appearances.

This paper summarizes recent work by members of the International Color Consortium Medical Imaging Working Group to develop test materials and methods for the assessment of color calibration of digital microscope systems. This work includes sharing of ideas on device calibration, image processing and display.

The paper further discusses the challenges encountered in the development of a suitable color target that includes a set of patches with spectra similar to those encountered when viewing pathology slides with stained tissue samples. *[See Appendix 01 for short paper and figures.]*

Validation of Whole Slide Imaging*, *Liron Pantanowitz, University of Pittsburgh Medical Center (UPMC) Shadyside (USA)*

11:00 —11:40 AM Coffee Break

Joint Keynote

Session Chair: Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

11:40 AM – 12:35 PM

Amphitheater

11:40 **Microimaging: Seeing the Unseen in Living Patients,** *Guillermo J. Tearney, Massachusetts General Hospital, Harvard Medical School, and Wellman Center for Photomedicine (USA)*

Abstract: Today's gold standard for medical diagnosis is histology of excised biopsies or fsurgical specimens where tissue is taken out of the body, processed, sectioned, stained an looked at under a light microscope by a pathologist. There are many limitations of this technique, including the fact that it is inherently invasive, time consuming, costly, and dangerous for some organs. Furthermore, oftentimes the diseased tissue is not readily seen by visual inspection and as a result the tissue is sampled at a random location, which can be highly inaccurate. If we could instead conduct microscopy inside the body, then we could provide tools for screening, targeting biopsies, making primary disease diagnosis, and guiding intervention on the cellular basis. This promise has motivated the development of a new field, termed in vivo microscopy, the goal of which is to obtain microscopic images from living human patients. Two in vivo microscopy technologies, confocal microscopy and optical coherence tomography, are currently available and in clinical use. Upcoming developments, including whole organ microscopy, swallowable microscopy capsules, molecular imaging, and very high resolution microscopic devices are in the pipeline and will likely revolutionize how disease is diagnosed and how medicine is practiced in the future.

12:35 — 2:00 PM Lunch Break

3D Imaging, Visualization, and Analysis

Session Chairs: Stanley Cohen, Center for Biophysical Pathology, Rutgers-New Jersey Medical School, and Masahiro Yamaguchi, Tokyo Institute of Technology

2:00 – 3:20 PM

3rd floor, Rotunda

2:00 **Analysis of 3D Histology Imaging*,** *Yukako Yagi, MGH PICT Center, Massachusetts General Hospital (USA)*

*No abstract available

2:20 **Understanding 3-Dimensional World from 2-Dimentional Immuno-Fluorescent Adjacent Sections,** *Sho Fujisawa, Dmitry Yarilin, Ning Fan, Mesruh Turkekul, Ke Xu, Afsar Barlas, and Katia Manova-Todorova, Molecular Cytology Core Facility, Memorial Sloan-Kettering Cancer Center (USA)*

Background: In many fields of biological sciences including embryology and cancer research, understanding of 3-dimensional structures is crucial to uncovering normal and pathological phenomena. While the most optimal method would be to directly observe the complete object without any destruction, staining and imaging of thick sections and whole mount samples can be challenging. For decades, researchers have serially sectioned large tissues, stained each with chromogen-based immunohistological methods and painstakingly reconstructed the 3-dimensional volume. The limiting factor with immunohistological staining is the difficulty in detecting multiple antigens with different chromogens on the same tissue. At our Molecular Cytology Core Facility at Memorial Sloan-Kettering Cancer Center, we successfully and routinely perform immuno-fluorescent staining using automated staining machines and have combined IF staining and 3D reconstruction of serial sections. This method allows simultaneous detection of up to four different antigens on the same sections in a highly reproducible and specific manner. The resulting stack can be a stunning visualization of 3D structure and be quantitatively analyzed. *[See Appendix 02 for short paper and figures.]*

2:40 **Connection and Deformation of Pathological Images via a Macro Image for Comparing Different Modality Images of Brain Tumor,** *Takashi Ohnishi, Takuya Tanaka,Yuka Nakamura, Noriaki Hashimoto, and Hideaki Haneishi, Chiba University (Japan); Jennie Taylor, Massachusetts General Hospital (USA); Matija Snuderl, New York University Langone Medical Center (USA); and Yukako Yagi, Massachusetts General Hospital Pathology Imaging and Communication Technology (PICT) Center and Harvard Medical School (USA)*

Background: Magnetic Resonance Imaging (MRI) is a preferred modality for diagnosis of brain tumor. However, because infiltrated regions with tumor are often indistinct on the MR image, it is difficult to identify tumor regions exactly. For revealing the relationship between tissue information and MR signal of the tumor, pathological images and MR images at the same regions have to be analyzed. However, it is not easy to correspond pathological images to MR images because pathological images are divided and deformed through tissue specimen making. We propose a registration scheme of a set of pathological images and MR image by referring a macro image that is captured by an optical camera. In the first step, parted pathological images are pieced together and deformed with macro image. In the second step, connected pathological image is registered to MR image. This paper shows connection and deformation methods for the pathological image. [See *Appendix 03* for short paper and figures.]

3:00 **Spectrally Encoded Confocal Microscopy for Guiding Lumpectomy,** *Elena F. Brachtel, Barbara L. Smith, Guillermo J. Tearney, and Dongkyun Kang, Massachusetts General Hospital (USA)*

Background: Complete removal of breast cancer during a single breast-conserving lumpectomy procedure is often challenging due to the lack of adequate intraoperative tools to accurately determine the margin status. About one third of lumpectomy patients are found to have positive margins upon final histologic analysis, which usually is reported within a week after surgery. These patients are then required to undergo additional surgeries, which increases the patient morbidity, cosmetic challenges, and healthcare cost. Spectrally encoded confocal microscopy (SECM) is a high-speed confocal microscopy technique [1] that can visualize cellular and sub-cellular features of an unstained fresh tissue. SECM is 10-100 times faster than conventional confocal microscopes and has been demonstrated to image an entire endoscopic mucosal resection (EMR) esophageal tissue (10 mm by 10 mm) within 15 seconds [2]. The high imaging speed of SECM may make it possible to rapidly image the margins of entire lumpectomy specimens to comprehensively determine margin status without sampling error. Real-time feedback regarding the margin status could enable the surgeon to achieve more thorough tumor removal in a single surgery and will significantly reduce the need for additional surgeries. The aim of this preliminary study was to test SECM for visualizing breast cancers with various morphologic features. *[See Appendix 04 for short paper and figures.]*

3:20 — 4:00 PM Coffee Break

Digital Pathology Systems and Evaluations

Session Chairs: John Gilbertson and David Wilbur, Massachusetts General Hospital and Harvard Medical School

4:00 – 5:20 PM

3rd Floor, Rotunda

4:00 **Point of Use QA in Digital Pathology Slides,** *David Brettle and Darren Treanor, Leeds Teaching Hospitals NHS Trust; Craig Revie, FFEI; and Mike Shires, University of Leeds (UK)*

Background: In digital histopathology traditionally prepared and stained slides are scanned in a dedicated scanner to produce extremely high resolution images. The resultant image fidelity is affected by many variables including the staining processes, scanner design/setup and ultimately the image display. Little or no routine quality control is applied at any of these stages and as a result widely varying images can be produced for the same sample.

Method: It is proposed an intra slide test tool would allow each variable in the imaging chain to be quantified. This will allow routine quality control monitoring as well as the ability to normalize or correct the image. A Point Of Use QA (POUQA) test tool is proposed made of two key zones that can be applied to every slide:

Zone 1: Fixed color patches to allow accurate positioning of the resultant image in colour space. The patches can either be for a wide gamut of color space and/or more localized depending on the stain.

Zone 2: Comprised of a suitable substrate that will uptake the stain proportionally to the clinical sample. This will allow quantification of the variability in staining and provide a reference for slide fading.

Other zones can be added as required e.g for white balance or resolution measurement.

Results: This presentation will include initial stage proof of concept results of an intra-slide QA tool using H&E stain and demonstrate how slide variability can be normalized.

Conclusion: A digital pathology POUQA test tool has been developed that allows both color and stain assessment and introduces image assurance into potentially every digital pathology slide.

4:20 **Development of a Prototype for Hepatocellular Carcinoma Classification Based on Morphological Features Automatically Measured in Whole Slide Images,** *Yoshiko Yamashita[1,4], Tomoharu Kiyuna[1], Michiie Sakamoto[2], Akinori Hashiguchi[2], Masahiro Ishikawa[3], Yuri Murakami[4], and Masahiro Yamaguchi[4]; [1]NEC Corporation, [2]Keio University, [3]Saitama Medical University, and [4]Tokyo Institute of Technology (Japan)* . . . . . .

Introduction: The advent of new digital imaging technologies including high-throughput slide scanners is making a very compelling case as part of the clinical workflow. Tools developed for morphometric image analysis are accelerating the transition of pathology into a more quantitative science. The system for detection of regions suspected to be cancerous in gastric and colorectal tissue is already available. There is a real need for not only cancer detection but also quantification of histological features, because quantitative morphological characteristics can include important diagnostic and prognostic information. If an association between quantitative features and clinical findings is indicated, quantification of morphological features would be extremely useful to select the best treatment. Image measurement technology has the potential for investigative pathology also. We have developed a prototype system for both quantification of morphological features and automated identification of hepatocellular carcinoma (HCC) within whole slide images (WSI) of liver biopsy based on image recognition and measurement techniques. Our system displays quantified cell and tissue features as histogram, bar graph, and heat map on the screen. Displaying all features in such a unified visualization makes it easy to interpret quantitative feature. In this paper, we present a prototype designed specifically for morphological feature visualization in an easy-to-understand manner. *[See Appendix 05 for short paper and figures.]*

4:40 **Enhancing Automatic Classification of Hepatocellular Carcinoma Images through Image Masking, Tissue Changes and Trabecular Features,** *Maulana Abdul Aziz[1], Hiroshi Kanazawa[1], Yuri Murakami[1], Fumikazu Kimura[1], Masahiro Yamaguchi[1], Tomoharu Kiyuna[2], Yoshiko Yamashita[1,2], Akira Saito[2], Masahiro Ishikawa[3], Naoki Kobayashi[3], Tokiya Abe[4], and Akinori Hashiguchi[4]; [1]Tokyo Institute of Technology, [2]NEC Corporation, [3]Saitama Medical University, and [4]Keio University (Japan)* . . . . . .

Background: Hepatocellular carcinoma (HCC) is a malignant tumor with hepatocellular differentiation and one of the most common cancer in the world. This type of cancer is often diagnosed when the survival time is measured in months causing high death rates [1]. For the purpose to support histopathology diagnosis of HCC, we have developed an experimental system of "Feature measurement software for liver biopsy" [2]. The system provides pathologists the quantitative measurement of tissue morphology using a digital slide of hematoxylin-eosin (HE) stained liver tissue specimen, as well as the HCC detection based on those measurement results. In this study, we are focusing on the classification process of HCC images in the system. Previously, Kiyuna et al [3] had introduced an automatic classification of HCC images based on 13 types of nuclear and structural features, where each feature consists of 6 statistical distribu-

tions. In order to improve the classification performance, we have developed methods to segment the liver tissue and quantify additional tissue features such as trabecular morphology [4]. This paper reports the evaluation results on the impact of the segmentation and the additional features in the HCC detection performance. *[See Appendix 06 for short paper and figures.]*

5:00 **Comparative Study between Quantitative Digital Image Analysis and Fluorescence In-Situ Hybridization (FISH) of Breast Cancer Equivocal HER2 2+ Cases,** *E. Ayad, M. Mansy, D. Elwi, and M. Salem, Faculty of Medicine, Cairo University (Egypt); M. Salama, University of Utah and ARUP Reference Lab (USA); and K. Kayser, Humbold University (Charite), Institute of Pathology (Germany)*

Background: Optimization of workflow for breast cancer samples with equivocal HER2/neu score 2+ results in routine practice, remains to be a central focus of the ongoing efforts to assess HER2 status. According to the College of American Pathologists/American Society of Clinical Oncology guidelines equivocal HER2/neu score 2+ cases are subject for further testing, usually by FISH investigations. It still remains on open question, whether quantitative digital image analysis of HER2 immunohistochemically (IHC) stained slides can assist in further refining the HER2 score 2+.

Aim of this work: To assess utility of quantitative digital analysis of IHC stained slides and compare its performance to fluorescence insitu hybridization in cases of breast cancer with equivocal HER2 score 2+.

Materials and Methods: Sixty specimens from breast cancer patients with previously (interactively) diagnosed represented the study population. Her2 stained slides were scored. Cases with HER2/new score of 2++, were digitally scanned by iScan [Produced by BioImagene (Now Roche-Ventana)]. The IHC signals of HER2 were measured using an automated image analyzing system (MECES, www.Diagnomx.eu/meces). Contemporary new cuts were prepared for FISH examination.

Results: Three out of the fifteen cases with equivocal HER2 score 2+, turned out to be positive (3+) by quantitative digital analysis, and 12 were found to be negative in FISH too. Two of these three positive cases proved to be positive with FISH, and only one was negative.

Conclusions: Quantitative digital analysis is highly sensitive and relatively specific when compared to FISH in detecting HER2/neu overexpression. Therefore, it represents a potential reliable substitute for FISH in breast cancer cases which desire further refinement of equivocal IHC results.

CONFERENCE RECEPTION
5:30 – 7:30
Foyer

THURSDAY NOVEMBER 6, 2014

IADP Special Lectures 1: Digital Pathology Perspectives

Session Chairs: Arvydas Laurinavicius, Vilnius University, and Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

9:00 – 10:00 AM
3rd Floor, Rotunda

9:00 **An Editors Perspective on Digital Pathology,** *Stanley Cohen, Center for Biophysical Pathology, Rutgers NJMS (USA)*

There is currently a major disconnect in the publishing universe not only for retention, transmission, and analysis of digital images in pathology but also for new and emerging computationally intensive imaging methodologies. Many authors gravitate towards engineering journals, which are not usually read by pathologists or, for that matter, most biomedical investigators. Often, the pathobiological application shown is a proof-of-concept rather than a sophisticated investigative study. Papers that appear in pathology journals have the opposite problem; they are sketchy about the physical/engineering side of the work, and do not attract many readers from the engineering and physics community. Nature Methods partially bridges this gap, but it is more about the technology than the application of this technology for novel scientific discovery. For this reason, there is a need for a journal that can attract both kinds of authors (and readers) and serve as an integrative focus for work in these fields. Our evolving work towards this goal will be discussed.

9:20 **Digital Teleconsultation: Clinical Perspectives,** *David Wilbur, Massachusetts General Hospital (USA)*

Abstract: The emerging field of digital pathology has many applications including the ability to easily and quickly consult with colleagues at a distance. Teleconsultation can take a variety of forms and has a number of different applications. Immediate analysis of specimens, such as rapid cytology adequacy determination and frozen section interpretation are now employed using real time screen sharing and whole slide imaging technologies. Both have been shown to be accurate and have proven to be substantial productivity enhancers for pathologists. Secondary consultation practices have employed predominantly the whole slide imaging approach and have also been shown to be accurate. Uptake of teleconsultation for second opinions has been limited by the expense and therefore availability of scanning technology, but in the future, as whole slide imaging become more routine and cost-effective, this aspect of teleconsultation is certain to grow. This presentation will discuss the workflow and components necessary for the types of teleconsultation noted above. Available data in support of each application will be reviewed. Practical considerations for implementation and pitfalls will be discussed.

9:40 **Pathology Through Pixels: Image Analysis in Biotechnology*,** *Robert Dunstan, Biogen Idec (USA)*

*No abstract available

WSI User Interface

Session Chairs: Klaus Kayser, Humboldt University (Charite), Institute of Pathology, and Craig Revei, FFEI Limited

10:00 – 10:50 AM

3rd Floor, Rotunda

10:00 **Scalable Adaptive Graphics Environment (SAGE): A Novel Way to View and Manipulate Whole-Slide Images,** *Bruce Levy and Victor Mateevitsi, University of Illinois at Chicago (USA)*

Background: The Scalable Adaptive Graphics Environment (SAGE) was developed at the University of Illinois at Chicago's (UIC) Electronic Visualization Laboratory (EVL) to facilitate collaborative efforts that require the sharing of data-intensive information for analysis. SAGE is a cross-platform, community-driven, open-source visualization and collaboration tool that enables users to access, display and share a variety of data-intensive information, in a variety of resolutions and format, from multiple sources, on tiled display walls of arbitrary size. SAGE walls have had the capability to display digital-cinema animations, high resolution images, high-definition video-conferences, presentation slides, documents, spreadsheets and computer screens; however, there was no way to display and manipulate histologic whole-slide images (WSI). Our desire was to create a tool to permit the importation, display and manipulation of WSI in the SAGE environment.

Methods: The Pathology Department and the EVL at UIC, through a grant from the University's Center for Clinical and Translational Science set out to develop a prototype of a SAGE tool for the use of WSI in this collaborative environment and then to create a series of scenarios for its use involving patient care, medical education and research. The goal was to create a tool that would allow the user to manipulate the WSI in ways similar to common WSI viewers.

Results: We were able to develop a usable prototype of a SAGE tool for the use of WSI. Our initial prototype can import only the NDPI file format utilized by Hamamatsu, which we chose as our primary scanner is a Nanozoomer. Once the WSI is imported, the tool allows the manipulation of the WSI (panning and zooming) from a computer through SAGE Pointer. A very simple annotation tool has been created as a prototype. We can open multiple WSI images simultaneously on out six by three screen tiled display (the equivalent of a 250 inch monitor). Demonstration scenarios have been created for its use in patient care, medical education and research. The very high resolution of this tiled display allows for detailed examination of the WSIs.

Conclusions: SAGE is an ideal environment to display WSI for patient care, education and research. We have demonstrated its use in patient care, education and research. While our tool is merely a prototype at this time and only basic functionality, we hope to expand the tool in the future. We will expand the WSI file formats that can be imported to make the tool vendor neutral. We will increase the versatility of the annotation tools. We will create a mechanism for manipulating the WSI directly on the screen through the touch interface. We will explore the collaborative advantages of this tool through sending them between SAGE walls.

10:20 **Using a Novel WSI Software Platform for an International Multi-Center Validation Study to Assess the Histological Growth Pattern of Liver Metastases,** *Yves Sucaet and Wim Waelput, Pathomation (Belgium) and Peter Vermeulen and Gert Van den Eynden, CORE, University of Antwerp, Antwerp, Belgium, on behalf of the Liver Metastasis Research Consortium (Belgium)* . . . . . .

Background: The histological growth pattern (HGP) of solid tumor metastases to liver is an easy-to-assess and integrative histopathological parameter of tumor–stromal interactions (1). With preliminary data suggesting that the HGP of colorectal cancer liver metastases has prognostic value (2), we hypothesize that it also might predict response to therapy (1,3). To enhance pathological assessments, we organized an international multi-center validation study within the Liver Metastasis Research Consortium. *[See Appendix 07 for short paper and figures.]*

10:40 —11:30 AM Coffee Break

Analysis Approaches in Digital Pathology

Session Chairs: Stanley Cohen, Center for Biophysical Pathology, Rutgers-New Jersey Medical School, and Klaus Kayser, Humboldt Univeristy (Charite), Institute of Pathology

11:30 AM – 12:30 PM
3rd Floor, Rotunda

11:30 **Quantification Accuracy of Liver Fibrosis by in vivo Elastography and Digital Image Analysis of Liver Biopsy Histochemistry,** *Justinas Besusparis[1], Skirmante Jokubauskiene[1], Benoit Plancoulaine[2], Paulette Herlin[2], Aida Laurinaviciene[1], Arida Buivydiene[3,4], and Arvydas Laurinavicius[1]; [1]Department of Pathology, Forensic Medicine and Pharmacology, Faculty of Medicine, Vilnius University (Lithuania), [2]Path-Image/Bio TiCla, University of Caen (France), [3]Centre of Hepatology, Gastroenterology and Dietetics, Vilnius University Hospital Santariskiu Clinics, (Lithuania), and [4]Clinic of Gastroenterology, Nephrourology and Surgery, Medical Faculty, Vilnius University (Lithuania)*

Background: Chronic hepatitis C is a rapidly spreading infection and continues to be leading cause of chronic liver disease. Liver fibrosis staging is essential in management on these patients. The accurate assessment of hepatic fibrosis plays an important role for determining treatment, screening strategies and prognosis. The aim of this study was to evaluate accuracy of non-invasive transient elastography and three digital image analysis tools, for measuring the extent of fibrosis in human liver biopsies, based on the biopsy fibrosis reference data obtained by stereological point counting method.

Methods: Liver biopsy cores from 68 patients diagnosed with viral hepatitis C were used in this study. Total liver fibrosis was evaluated by transient elastography, digital image analysis on Masson s trichrome (MAS) and Picro Sirius Red (PCR) stained tissue specimens, using Leica/Aperio Colocalization, Genie image analysis software and a home made principal component analysis algorithm (PCA). Stereology grid count (20 out of 68 digital slides) and pathologist's visual score using METAVIR grading system were performed. Stereological estimation of the volume fraction of fibrosis was taken as a reference. All methods were compared, using correlation, linear regression analysis and ANOVA test.

Results: The volume fractions of fibrosis obtained by PCR Colocalization (9.38-+8.77) were closest to the reference value of PCR estimated by Stereology (12.6-+11.55) while other methods indicated underestimation. The PCR stereology values correlated strongly with the values obtained using the Colocalization ($r = 0.95$, $p < 0.001$) and Genie ($r = 0.98$, $p < 0.001$) software. Single linear regression analysis demonstrated some advantage of the PCR Genie analysis over the PCR Colocalization,transient elastography and PCA. In log-transformed measurements for r-square 0.96 the slope was 0.925 for PCR Genie, versus r-square 0.91 with a slope of 0.986 for PCR Colocalization, r-square 0.76 with a slope of 0.42 for PCA and r-square 0.35 with a slope of 0.917 for elastography. ANOVA revealed statistically significant differences of PCR Colocalization and PCR Genie results between METAVIR II, III, IV groups, including pairwise comparisons, except I versus II groups.

Conclusion: Digital analysis methods applied to Picro Sirius Red histochemical staining of biopsy material revealed almost perfect correlation with criterion standart obtained by stereology point counting and outperformed Masson's trichrome staining and transient elastography. PCR Genie algorithm could be the method of choice with a slight underestimation bias, which is considered acceptable for both clinical and research purposes.

11:50 **Aggregation Dynamics of Particulate Blood Platelets,** *Suresh Ahuja, Xerox Corporation (USA)*

Abstract: Blood is a multiphase fluid composed of erythrocytes, red blood cells, erythrocytes (RBC), white blood cells, leukocytes and thrombocytes, platelets suspended in plasma. Red blood cells are known to form aggregates in the form of rouleaux. Formation of rouleaux is affected by the intrinsic properties of RBCs such as the elastic behavior of the RBC membrane which contributes to the resistance of RBCs to aggregate. Hydrodynamic interactions between the thrombus shape, RBCs and platelets can result in certain azimuth positions where the drop in velocity occurs at the proximity of both the upstream and downstream edge of the thrombus that is accompanied by a rapid velocity increase in the narrowed region. The RBCs alter the flow profiles significantly from the typical low Reynolds (Re) number flow, and also enhance the deposition of free flowing platelets onto the thrombus. There are at least two competing models, based either on bridging or on depletion. Thrombosis, the pathological process of the hemostatic system to form unwanted blood clots, can impair blood flow to vital organs and ultimately result in stroke or myocardial infarction. Platelets are the principal components of the hemostatic plug formed to arrest bleeding after an injury to the vascular wall. Their adhesion to the site of damage and to the previously adsorbed platelets is a critical stage in the formation of both hemostatic plugs and pathological thrombi.

There is a continual platelet drift from the RBC-rich region of the vessel towards the wall by a succession of turning and crossing events. This is a consequence of the deformation of the RBC caused by the platelet upon collision. Margination of the platelets toward the vascular wall is critically dependent on their interaction with the red blood cells. Margination of the platelets can be due to the volume exclusion process whereby the platelets are pushed towards the wall by a lateral motion of the RBC towards the center of the vessel. The lateral migration of the RBC in a shear flow arises due to its deformability. The deformability of RBC is determined by the geometry, elasticity and viscosity of its membrane Another cause of margination is due to shearing flow, where the continuous collision between the RBC and platelets results in the RBC migration that causes a concentration gradient forcing a net

flux of platelets being pushed (migrate) towards the vessel wall. In hemostasis, platelets are placed closer to the injured vessel wall and the injured site

Aggregation of platelets is accelerated by shear rate during blood flow. The adhesion of platelets to each other and to Red Blood cells depend on collisions of elastic platelets to soft RBC in a hydrodynamic flow with Johnson-Kendall-Roberts (JKR) models In this way the cohesive impulse, required for the hard-sphere model, is calculated together with other parameters, namely the collision duration and the coefficient of restitution. Aggregate morphology, elastic modulus and surface energy are critical in determining adhesion to straight and tortuous capillary walls and to Red Blood Cells for required optimizing coagulation. Model predictions are compared with experimental results.

12:10 **Leukocyte Adhesion, the Endothelial and Vascular Dysfunctions,**
Suresh Ahuja, Xerox Corporation (USA)

Abstract: The leukocytes or White Blood Cells membrane has numerous folds microvilli, which provide an excess area about 100%, which probably allows cell deformation without a change in surface area and volume. Whereas erythrocytes consist of a viscoelastic membrane with cytoplasm of relatively low and constant viscosity, all leukocytes exhibit viscoelastic properties depend on internal structures. Leukocytes stiffness rigidity is largely determined by the cytoskeleton of actins and actins-binding protein and its degree of cross linking. Together with the fact that white blood cells have a larger volume than red cells this leads to a situation that the resistance imposed by a single white cell in capillaries is much larger than that of a single red cell. Fortunately, we have much fewer leukocytes than erythrocytes in the circulation. The viscous coefficient is several orders of magnitude higher than that of erythrocytes, and this is manifest in ability of leukocytes to cause intermittent cessation of capillary flow. Leukocytes stiffness rigidity is largely determined by the cytoskeleton of actins and actins-binding protein and its degree of cross linking. As large number of leukocytes move at a wide range of speeds, collisions occur. These collisions result in abrupt changes in the motion and appearance of leukocytes. The formation of adhesive bonds depends on local velocity and shear forces to the captured cells. The rheological changes allow enable the defence against foreign organisms to be controlled, but also contribute to the microcirculatory failure. During local or systematic ischemia, microcirculatory obstruction is facilitated by the reduced leukocyte deformability and increased adhesion. Migration of leukocytes in blood flow and collision with vessel wall depends on the direct hemodynamic interaction of leukocytes with erythrocytes results in pushing leukocytes against the endothelium. A collision model between leukocyte and erythrocyte is presented which results in leukocyte being adhered to endothelium as shear stress and surface energy increases.

12:30 — 2:00 PM Lunch Break

Education and Telepathology

Session Chairs: Klaus Kayser of Humboldt University (Charite), Institute of Pathology, and Liron Pantanowitz, University of Pittsburgh Medical Center Shadyside

2:00 – 4:00 PM

3rd Floor, Rotunda

2:00 **The Use of Virtual Microscopy and a Wiki in Pathology Education: Tracking Student Use, Involvement, and Response,** *Zev Leifer, New York College of Podiatric Medicine (USA)*

Background: The Pathology Laboratory course at the New York College of Podiatric Medicine involves the use of Virtual Microscopy. As with traditional microscopes, the students can scan the whole slide, section by section, and zoom in or out for further detailed study. Using the advantages of Digital Pathology, the students can, in addition, access the slide collections from other medical schools and put up normal histology (control) slides side-by-side with the patholgy. They cut and paste and preserve the ROI that they find. They edit and annotate (circle, underline, label, add arrows, etc). The creation of a wiki, its application and the student response to it is yet another level of pre-professional training to the above.

Method: A wiki was created (pathlab2014.wikifoundry.com)for the Class of 2014. The students saved, edited and uploaded their slides. In the wiki format, other students could comment, further edit, even delete the slides.

Results: 216 images were uploaded. These were available in one full presentation. They were also grouped into sixteen albums, grouped by the topics in Systemic Pathology. They were available to all. The student access was followed by Google Analytics. This provided a detailed analysis of student use. At the end of the course, a questionaire was distributed, assessing their impression of the wiki format and soliciting strengths and weaknesses. Over one hundred sets of comments were obtained. Most comments were favorable, describing particular features that they liked, such as ease of use, sharing of notes, aids in exam preparation, and allows students to work together. Negative comments were mostly directed to technical issues of accessing and using the site.

Conclusions: The use of a wiki as described has a number of important advantages in Pathology Education. It trains the students in the more sophisticated skills that they will use as professional pathologists or as clinicians: (1) Telepathology—it enables them to gain skill in putting up slides on the internet, sharing and discussing the observations. This parallels the process of Tumor Boards and and consultation for group concensus. (2) Archiving and Retrieval—It models the challenge faced by hospitals, diagnostic labs and physicians in maintaining a collection of slides in a form that is easily accessible, always available and universally sharable. With the album feature, slides can be multiply stored, by patient name, by pathology, by tissue type and so on. (3) Image Analysis—While not generally used in an undergraduate lab, familiarity with a wiki format allows them to jump easily to capturing and storing images found in the literature or provided by colleagues or the diagnostic lab pathologist's report that have been stained for tumor markers other diagnostic staining techniques.

Experience with the use of a wiki in Pathology Education has been quite satisfactory from both the faculty and the student's point of view. It has a number of training advantages in the ever-expanding world of Digital Pathology.

2:20 **Ten Years of Experience Teaching Oral Pathology to Dental Students Using Whole Slide Imaging (WSI): What Have We Learned?,** *Janusz Szymas, Department of Clinical Pathology, Poznan University of Medical Sciences (Poland), and Mikael Lundin and Johan Lundin, Institute for Molecular Medicine Finland FIMM (Finland)*

Introduction: This study brings together key findings following our ten-year experience of using whole slide imaging (WSI) for teaching oral pathology to dental students. It not only provides invaluable information about students and teaching assistants, it is also an incredibly rich resource for research into the student experience with WSI as a vehicle for understanding oral pathology by students. We summarise the results of two analyses: an analysis of the scores obtained by students at practical exams in 2005 – 2014 and an analysis of the surveys that followed.

Methods: We used 225 whole slide images (WSIs) covering 15 entities in oral pathology to teach and then evaluate 544 dental students during the practical exam concluding the Oral Pathology course. All WSIs were linked with still macro- and microscopic images, CT and MRI pictures, and clinical data organised into virtual cases, and supplemented with text files, a glossary, PowerPoint presentations and animations on the web. After their examinations, the students rated the use of the software, the quality and ease of handling of WSIs, and the effective use of virtual cases during the laboratory practicals. In order to provide a comprehensive coverage of studied subjects and allow reliable comparisons between students of different years and groups, the same basic questionnaire and practical exam system have been used all the time. This enabled us to look in detail at preferences of individual students as well to obtain characteristics of student groups and years, such as study subjects.

Results: A comparison of the results of students of different years showed a high degree of stability in terms of scores over time. Throughout all the years of the study (2005 – 2014), the correct student answer rates ranged from 91.3% – 98.0%, with an average of 94.4% ± 2.4. However, at the end of every academic year, there were some student groups which scored high and some which scored low. Differences between these groups were statistically significant (p-value < 0.050) in all academic years except one (2009 – 2010). Unfortunately, the rotation of teaching assistants in our Department is high but we could identify at least three teachers whose groups permanently scored high or highest during the exam during the study period as well as a couple of unsuccessful teaching assistants. The research results that we report here confirm that the differences in results between student years and groups, albeit small, are real and are not artefacts. We have also shown that a vast majority of dental students at Poznan University of Medical Sciences regarded a possibility of using WSIs at their convenience as highly desirable (average > 9 on a 1-10 scale).

Conclusions: WSI is a promising tool for both teaching students oral pathology during laboratory practicals and for practical examinations. Nevertheless, despite widely available self-study possibilities, good teachers still create a substantial value. The potential of research using WSI is high. Further work could assess the impact of the students perception of WSIs on their decision making during practical exams and on their scores, especially in terms of the way they watch the images.

2:40 **Exploring Viewing Behavior Data from Whole Slide Images to Predict Correctness of Students' Answers during Practical Exams in Oral Pathology,** *Slawomir Walkowski[1], Mikael Lundin[2], Janusz Szymas[3], and Johan Lundin[2]; [1]Poznan University of Technology (Poland), [2]University of Helsinki (Finland), and [3]Poznan University of Medical Sciences (Poland)*

Background: The use of whole slide images (WSIs) allows tracking and recording how a histological slide is viewed. Gathered data about viewing behavior while interpreting WSIs may result in a variety of analyses. When the tracking is done during an exam, we can discover how students view WSIs. Moreover, we may try to correlate their way of viewing slides with correctness of the answers they give. Especially, we can potentially find out to what extent a specific viewing behavior is likely to result in a correct or incorrect answer from a student.

Method: To record viewing behavior, we utilized a software-based view path tracking method, which does not require any specialized equipment. It gathers information about subsequently viewed fragments (view fields) of WSIs. The method was used during exams in oral pathology in Poznan University of Medical Sciences in Poznan, Poland in years 2012-2013. Each dental student was given 50 exam questions with a WSI attached to each of them. The students were informed about and agreed on the tracking. Stored data and further analysis results are anonymous and so far without any impact on the final students' evaluation and scores. The WSI viewing system used during the exam was WebMicroscope (Fimmic Ltd, Helsinki, Finland) and the view path tracking method is an integrated, but optional part of it. In total, we collected information about approximately 150,000 view fields coming from about 170 dental students viewing WSIs during the exams. Gathered data was analyzed numerically, with some help from generated visualizations. A set of statistics was calculated per student per question and it included, for example, number of view fields, magnification level, and dispersion of view fields. Statistical methods were used to assess the correlation between calculated metrics and correctness of students' answers. We also utilized machine learning approaches to check to what extent viewing behavior data can be used to predict a correct or incorrect answer coming from a student. For this purpose, we used gathered and processed data as a labeled set of instances.

Results: Three exams were successfully conducted with the view path tracking turned on, which resulted in a dataset covering students' WSI viewing behavior. The aggregated metrics depicted certain viewing patterns. Analysis of the calculated statistics allowed finding some correlations between metrics' values and exam answers. When used as features for machine learning, the metrics helped in estimating probabilities of answers' correctness.

Conclusion: Software-based view path tracking appears to be a useful method of discovering WSI viewing behavior and investigating decision making process of dental students who take a practical exam in oral pathology. Analysis of collected data provides interesting insights into how the slides are viewed, how the viewing patterns correlate with students' answers and what the potential of the view path tracking data is when predicting correctness of the answers.

3:00 **MGH Whole Slide Imaging Teleconsultation Practice in Dermatopathology,** *Nicholas C. Jones, Rosalynn M. Nazarian, Lyn M. Duncan, and David C. Wilbur, Massachusetts General Hospital and Harvard Medical School (USA)*

Background: Non-subspecialized pathologists frequently request expert consultation in challenging dermatopathology cases. Traditional consultation practice utilizing shipment of glass slides is costly, slow, and of limited educational benefit to the referring physician. Whole slide imaging (WSI) has been suggested as a potential method of overcoming these limitations in the current glass slide consultation practice, but there have been concerns regarding the adequacy of image quality for interpretation of challenging dermatopathology cases. We aimed to investigate the performance of WSI in challenging dermatopathology consult cases.

Method: 52 consecutive clinical consultation dermatopathology cases sent from a community hospital to an academic medical center were sampled and diagnosed by traditional microscopic examination and by whole slide image examination. Matched pairs of diagnoses were evaluated for diagnostic accuracy rates via a masked adjudication process.

Results: 2 of 52 cases (3.8%) had major discrepancies. After adjudication the WSI diagnosis was preferred in one case and the glass slide diagnosis was preferred in the other. 13 of 52 cases (25%) had minor discrepancies, with the WSI diagnosis preferred in 6 cases, the glass slide diagnosis preferred in 4 cases, and with no preference in 3 cases. Differences in diagnosis were primarily due to interobserver variability and thresholding inherent in challenging dermatopathology consult cases and not due to image quality.

Conclusions: Overall, the sampled accuracy rates of both WSI and glass slide techniques were equivalent. These results suggest that WSI may be feasible for even challenging dermatopathology consultation cases.

Biography: Nicholas Jones is a clinical pathology imaging technician at MGH Pathology with areas of interest in digital pathology laboratory management, pathology imaging informatics, and clinical validation studies.

Dr. Rosalynn Nazarian is a dermatopathologist at MGH and an Assistant Professor at Harvard Medical School. She volunteers as a consultant on challenging telepathology cases providing web based diagnostic and educational support to physicians practicing in East Africa and participates in the digital pathology consultation pilot study.

3:20 **Digital Pathology Data Brokerage: A Standard Recommendation for Complex Digital Pathology Information Web-Services,** *Aristidis G Anagnostakis, Technological Educational Institute (TEI) of Epirus (Greece); Agelos Pappas, Smartcode Software Development (Greece); and Yves Sucaet and Wim Waelput, Pathomation (Belgium)*

Abstract: A novel recommendation for the Digital Pathology Information Web-Services (DPIWS) standard is presented, with respect to specific characteristics of the informative content of discourse. The recommendation establishes a common software interface for the exchange of digital pathology (DP) images and related meta data over the web, independently of storage, encoding and internal handling details. The proposed structure is implemented and tested in a "Pathomation" software environment.

Background: One of the major obstacles to establishing and adopting effective telepathology processes over time has been their lack of information brokerage standardization [1].

Digital pathology information is characterized by a complex structure and high data volumes. Effective handling and sharing demands in-depth inter-disciplinary skills which, along with industrial vendor proprietary formatting and data locking, makes essential information brokerage a challenging process.

Digital pathology imagery and annotation distribution is, to date, partially covered by specific portions of Digital Imaging and Communications in Medicine (DICOM) and Open Microscopy Environment (OME) standards. In addition, DP information sharing bears significant similarities to other disciplines (e.g., Geographical Information Systems), the distribution of which has been highly standardized for decades.

The proposed recommendation (DPIWS) delivers a standard web interface definition allowing requests for DP information elements handling and sharing across the web, through platform-independent and image format-agnostic calls.

Methods: DPIWS comes as an independent recommendation. It strictly conforms to and expands the DICOM Standard [2], with respect to the Open Microscopy Environment [3], and the Open Geospatial Consortium Web Map Service (WMS) & Web Feature Service (WFS) Standard [4].

Digital pathology images are partially covered by the DICOM Standard, according to the procedures of the DICOM Standards Committee 2011-Part 3: Information Object Definitions under VL Microscopic Image Information Object Definition Content Constraints A.32.2 and VL Whole Slide Microscopy IOD Content Constraints A32.8. In addition, generic URL requests for retrieving a DICOM Visual Light Image are defined under DICOM 2011-Part 18: Web Access to DICOM Persistent Objects (WADO). However, the response is a single, standard encoding image with all annotations rendered (burned) on the image; no method for requesting or handling annotations in any form other than an image is identified.

Meta data, like annotations, on microscopy images are, on the other hand, exhaustively covered by the Open Microscopy Environment – Model and Formats 2013-06 Documentation in a well-structured manner. 2-D and 3-D regions of interest (RoI) may be defined and treated and a series of annotation elements identified and supported; this makes OME an appropriate tool for handling DP annotations.

In addition, the Open Geospatial Consortium (OGC), through Web Map & Web Feature Services (WFS), effectively defines the web-handling of multiple-layered, complex raster images and vector data, making it the ideal interface to (a) uniformly query and retrieve composite large-scale DP images consisting of superimposed multi-resolution raster vector and textual annotation layers; and (b) uniformly share the results across the web, despite the complexity and structure of the requested content.

Results: DPIWS is an interdisciplinary standard, designed to address the specificities of DP information brokerage needs.

For this, it (a) conforms to DICOM: images treated internally and served by DICOM-compliant systems may distribute content to DPIWS compliant clients, as is; (b) adopts the OME annotation structure to form annotation-handling requests based on well-structured XML OME annotations; and (c) adopts and extends the WFS interface for information web-handling and delivery operations.

Building DPIWS-compliant services will eventually eliminate the risk of long-term vendor content locking, thereby boosting the digital transition in the field of pathology.

Conclusions: A standard for DP information brokerage across the web is

defined, implemented and tested in a real-life, cloud-based, distributed operating environment. The standard effectively manages the specificity of DP information by leveraging well-established interdisciplinary methodologies.

3:40 **Image File Management to Support International Telepathology,** *Liron Pantanowitz[1], Jeffrey McHugh[2], William Cable[2], Chengquan Zhao[2], and Anil V. Parwani[2]; [1]Department of Pathology and [2]Department of Information Services, University of Pittsburgh Medical Center (USA)*

Background: Telepathology practice across international borders has become increasingly popular. Two years after the University of Pittsburgh Medical Center (UPMC) launched a telepathology consultation service with KingMed Diagnostics Laboratory in Guangzhou, China, latency issues occurred when viewing Whole Slide Images (WSI). Our aim was to explore various image file management solutions to improve the viewing experience of digital consult cases.

Methods: WSI files generated by Kingmed when scanning glass slides for consultation initially resided on a Hammamatsu server, using the NDP.serve database management system. These remote files were securely accessed using a custom portal via the Internet. To try solve ongoing latency issues, WSI files were instead transferred from China to the UPMC data center using an open source product (Fast Data Transfer, developed by CERN). This was a command line utility placed into a batch process. A faster high speed file transfer software solution (Aspera) was subsequently employed. This commercial software allowed immediate file transfers to occur without a user initiating the transfer.

Results: Viewing digital consult cases from Pittsburgh in the USA with WSI files residing on a server in China negatively impacted viewing of images. Image display deteriorated to about 2 minutes/case. Transferring files with the open source product provided transfer speeds of 2-3MB/second, but suffered from intermittent dropped connections. Employing the commercial software permitted more reliable transmission of digital files with 75-100MB/second transfer speeds.

Conclusion: Successful global telepathology requires dedicated image management. Transfer of files to local servers delayed the process by up to 24 hours, but greatly improved the overall turn-around time of digital consultations. This was partly negated by employing high speed file transfer software. Transfer of digital files helped overcome network latency issues experienced with China, and enhanced the viewing experience for end-user digital consultants.

Poster Paper Session

4:00 – 5:30 PM

Lobby and Foyers

ImmunoCount-A Novel Open-Source Quantification Software for Immunohistochemical Proliferation Marker Ki67*, *Justin Lee, MGH PICT Center, Massachusetts General Hospital (USA)*

Whole Slide Imaging (WSI) based Digital Pathology Network between Pakistan and USA Microimaging: Seeing the Unseen in Living Patients, *Fatima Absar MGH PICT Center, Massachusetts General Hospital (USA)*

Background: In 2007, a modern digital pathology facility was conceived at the Telemedicine Center of the Holy Family Hospital (HFH), Rawalpindi, Pakistan, in collaboration with the pathology department of the Massachusetts General Hospital (MGH), Boston, US [1]. A pathologist from HFH was trained at MGH and was provided equipment with the relevant software installed. Between December 2011 and August 2012, weekly hour-long teleconferences were held between the two centers, where static histopathology images were discussed using PowerPoint. The following month, Pakistan's first Whole Slide Imaging (WSI) scanner was installed at the Telemedicine Center at HFH; however, before it could become functional, their pathologist left the country. The aim of the project had been for MGH to provide digital pathology support to HFH and other facilities in the country, however, the untimely exit of the trained pathologist had led to a breach in communication and a hiatus in the activities. In early 2013, we reestablished the connection, utilizing the Telemedicine Center, but this time with pathologists from the Federal Government Poly Clinic (FGPC) Hospital, Islamabad. Due to the needs of teleconsultation in Pakistan, we have changed the protocol to organize teleconsultation to fit the current situation.

Method: To date, eight histopathology cases have been discussed. These cases were from tissues that ranged from the Genitourinary System, Central Nervous System, Gastrointestinal System and Soft Tissue areas. At present, a consultant histopathologist and his team of four trainee pathologists from FGPC Hospital are the participants from Pakistan side. The pertinent case slides are sent to HFH three days ahead of time by hand. They are scanned using the Panoramic Desk (40x objective lens version), 3D Histech LTD, Hungary, as a slide scanner. Each slide takes approximately thirty minutes to be scanned. One to two slides are scanned per case. When slides are ready for discussion, a coordinator at MGH is notified via email, who then arranges a teleconference via "GoToMeeting," Citrix Online, CA, USA. During the conference, the screen controls are handed over to HFH, who present the case and display the related WSIs using the MIRAX viewer. The pathologist from MGH discusses the case and captures screenshots of the relevant areas using his desktop. The Telemedicine Center at HFH have provided a network server IP address to MGH for them to access the WSI storage database at any time.

Result: The teams conducted their first teleconference in September 2013. Subsequently, hourly meetings are held as per the requirement of FGPC, where 3-4 cases are studied. Out of the eight cases that have been discussed, the pathologist at MGH was in agreement with the FGPC diagnosis for two of the cases. His diagnosis was the same for three of the cases but after consultation with other subspecialists at MGH. He suggested a different diagnosis for one case. For two of the cases, he suggested further immunohistochemical staining. At the local front, the scanner is being used at the weekly multidisciplinary meetings at HFH. These are attended by physicians from other facilities, including, the surgical, histopathology, radiology, oncology and nuclear medicine departments at HFH, FGPC Hospital, Nuclear Medicine Oncology and Radiotherapy Institute (NORI), and the Capital Development Authority (CDA) Hospital, Islamabad.

Conclusion: As the groundwork for teleconferencing had already been laid, all that was required was to bridge the communication gap to coordinate the activities between both centers. In this phase, we are focused more on utilizing the WSI scanner in both local and online meetings.

*No abstract available

These discussions are a learning opportunity for pathologists and trainees at the Pakistan side, and expose the US side to rare cases. Although there is no current funding for the project, it has been successful due to the mutual interest and dedication shown by both sides. We have now been able to establish regular teleconferences using WSIs and our aim is to increase their frequency as required.

Reference: [1] Yukako Yagi, Imtiaz Qureshi, Asif Zafar Malik, David C Wilbur, Challenges in Establishing the WSI based Digital Pathology Facility and Telepathology Network between Pakistan and USA, 102nd USCAP Annual Meeting, Baltimore, Maryland March, 2013

Registration Between Pathological Image and MR Image for Comparing Different Modality Images of Brain Tumor, *Yuka Nakamura, Takuya Tanaka, Takashi Ohnishi, Hideaki Haneishi, and Noriaki Hashimoto, Chiba University (Japan); Jennie Taylor, Massachusetts General Hospital (USA); Matija Snuderl, Langone Medical Center (USA); and Yukako Yagi, Massachusetts General Hospital Pathology Imaging and Communication Technology (PICT) Center and Harvard Medical School (USA)*

Magnetic Resonance Imaging (MRI) is a preferred modality for brain tumor detection and preoperative localization. However, invasive regions of tumor are often unclear in MR image and thus it is difficult to identify tumor from MR image. Therefore, for revealing the relationship between cells and genetic information of the tumor of MR image, it is required to compare pathological images with MR images on the same regions. In this study, we deal with glioblastoma among brain tumors. However, it would be difficult to compare them directly because pathological images are deformed through tissue specimen making. Thus, registration from MR image to pathological image is performed through the macro image of gross section which is taken before cutting the brain into blocks. Pathological image to be compared with MR image is combined from multiple histology images and deformed by referring the macro image. The detail of this technique is described in another paper submitted to this conference IADP2014. In this paper, we assume to have obtained such a pathological image. It is necessary to search appropriate curved plane from MR image because macro image to be referred in merging pathological images has a possibility to be extracted as a curved plane from brain. [See Appendix 08 for short paper and figures.]

Analysis of Color Consistency in Retinal Fundus Photography: Application of Color Management and Development of a Eye Model Standard, *Christye P. Sisson, Susan Farnand, and Mark Fairchild, Rochester Institute of Technology, and Bill Fischer, University of Rochester Medical Center, Flaum Eye Institute (USA)*

Background: Color variation in retinal fundus photography represents a significant gap in the standardization of color for fundus cameras. Fundus cameras are used in in the context of ophthalmology as a method of documenting a patient's retina to monitor pathology over time. This form of ophthalmic imaging is also used in clinical trial research and increasingly, tele-ophthalmology, as a stand in for an in-person examination. Given the increased reliance on these images as representation's of the appearance of a patient's eye, it becomes important to identify inconsistencies between devices and provide the most accurate rendering of the retina possible.

This research aims to identify these inconsistencies and reconcile them by proposing an eye color model standard. The authors could not identify other attempts to reconcile retinal color at capture, only after the fact image adjustment (Hubbard, et al) or application of current color management practices (Bull). *[See Appendix 09 for short paper and figures.]*

Stromal Filters in Automated Immunostain Scoring, *Kunal Patel[1], Anthony Bui[1,2], Greg Riedlinger[1], and Yukako Yagi[1]; [1]Massachusetts General Hospital and [2]Boston Children's Hospital (USA)*

Introduction: KI-67 is a marker for cell proliferation which binds a nuclear antigen and is thus a prime antibody in immunohistochemistry. Scoring methodologies derived from KI-67 immunostaining have shown promise as predictors of lethality in a range of cancers1. The most common scoring method is the labelling index, a ratio of KI-67 positive cells to the entire population1.

Manual calculation of a labelling index can be a time consuming process for pathologists, who count cells in a bright field. Automated scoring algorithms and programs have been written to generate labelling indices, but they are non-specific with respect to cell type and most often skew results by including stromal cells in the index. This problem is particularly relevant in breast cancer, where tumors are often located in a field of fibro-adipose tissue. We have adapted algorithms for immunostain scoring and tested 2 stromal cell filtration algorithms which remove these cells based on their elongated nuclear morphology.

Methods: An automated scoring algorithm was adapted from Immunoratio2 and written in Python programming language. Within this scoring program, two methods of stromal filtration were tested. The first filtered cells below a threshold defined by the isoperimetric quotient of labeled cells, while the second used a shape property known as the Hu moment invariant. The algorithm was applied to a dataset of breast cancer images, and results were correlated with non-stromal filtration and a pathologist score.

Results: Preliminary results show that algorithms with stromal filtration correlate better with pathology results than non-filtered counterparts. Additionally, the Hu moment invariant is a better variable for stromal cell filtration due to its non-reliance on perimeter. Deviation of automatic scores from pathologist-scored results are directly correlated with the amount of stromal tissue in the image field.

Conclusions: Stromal cell filtration is a promising technique in the development of automatic scoring algorithms. Additional methods should be explored to address the filtration of non-elongated stromal nuclei. With improvements in usability, it can be integrated into whole slide imaging systems in the near future.

References

[1] Banin Hirata, B. K. et al. Molecular Markers for Breast Cancer: Prediction on Tumor Behavior. Dis. Markers 2014, 513158 (2014).

[2] Tuominen, V. J., Ruotoistenmäki, S., Viitanen, A., Jumppanen, M. & Isola, J. ImmunoRatio: a publicly available web application for quantitative image analysis of estrogen receptor (ER), progesterone receptor (PR), and Ki-67. Breast Cancer Res. 12, R56 (2010).

Pathological Diagnosis with a Whole Slide Imaging System, *Daiki Taniyama, Kazuya Kuraoka, Akihisa Saito, Miho Tanaka, Yoko Kodama, Junichi Sakane, Yukari Nakagawa, Naoko Yasumura, Toshinao Nishimura, and Kiyomi Taniyama, National Hospital Organization Kure Medical Center and Chugoku Cancer Center, Kure, Japan*

Background: Whole slide imaging (WSI) is increasingly popular in pathology. At our institute, we utilize a WSI system, an automated slide preparation (ASP) system, an auto-stainer and specified software as an

ancillary method in making pathological diagnoses of samples submitted as routine work.

Methods: Diagnosis: A VS800 (OLYMPUS, Tokyo, Japan) in a WSI system and anAS-400 (KURABO, Tokyo, Japan) for the ASP system were used. Up to 100 slides consisting of biopsy, endoscopic mucosal resection (EMR), or endoscopic submucosal dissection (ESD) specimens were scanned and stored digitally in one set and the digital images were viewed on a monitor in a separate room using a VS800 viewer. Ocular observation using a conventional microscope was used when necessary to look at the specimens directly. One-hundred-sixty-six biopsy specimens were analyzed to evaluate the basic ability of the current WSI system in making a pathological diagnosis.

Auto-analysis: Immunohistochemistry (IHC) findings for breast cancer samples by a labeled streptavidin biotinylated-peroxidase (LSAB) method using a Benchmark XT (Roche, Basel, Switzerland) were analyzed automatically using a NanoZoomer 2.0-HT (Hamamatsu Photonics, Hamamatsu, Japan) as a WSI system and specified software (Genie, Vista, CA) for image analysis. Twenty-five breast cancer specimens were auto-analyzed to provide IHC of estrogen receptor (ER), progesterone receptor (PgR), HER2,Topoisomerase (Topo) II alpha, and Ki-67. The results were compared with those by ocular observation.

Results: Diagnosis: Of 166 biopsy samples, direct ocular observation was necessary in only 13 (7.8%) to confirm the pathological diagnosis that was made by the WSI system. Difficulty in making a diagnosis was found in seven (4.2%), and inadequate focus or scanning in small parts of specimens was observed in 19 (11.4%) samples. EMR and ESD specimens were also scanned. In addition to HE stain, EVG stain or D2-40 immunostain was also scanned and viewed on the same screen when necessary. Comparison of different stains for the same area became much easier on one or two separate monitors in the WSI system.

Auto-analysis: For all antibodies, except for HER2, concordant results were obtained in 24 ER positive cases. The Ki-67 index (r=0.96) and TopoII alpha index (r=0.95) also showed a significant correlation ($p<0.001$). For HER2, all four specimens with a Hercep-score of two by ocular observation, and one by auto-analysis, revealed no HER2 gene amplification.

Conclusion: Pathological diagnosis utilizing a WSI system is useful, although there continue to be some issues that need to be addressed. The transference of a whole histological slide into digital form enables the evaluation and interpretation of pathology samples with analytical software in a manner where several observers can join together or by an individual at anytime. Well-organized auto-analysis is more likely to result in an objective observation and provide a means by which to standardize IHC methods for breast cancer.

FRIDAY NOVEMBER 7, 2014

Color Image Processing

Session Chairs: Craig Revei, FFEI Limited, and Masahiro Yamaguchi, Tokyo Institute of Technology

9:00 – 10:00 AM

Amphitheater

9:00 **Whole Slide Image Analysis System for Quantification of Liver Fibrosis,** *Tokiya Abe[1], Yuri Murakami[2], Masahiro Yamaguchi[2], Yoshiko Yamashita[3], Tomoharu Kiyuna[3], Ken Yamazaki[1], Akinori Hashiguchi[1], Yutaka Yasui[4], Masayuki Kurosaki[4], Namiki Izumi[4], and Michiie Sakamoto[1]; [1]Department of Pathology, School of Medicine, Keio University; [2]Global Scientific Information and Computing Center, Tokyo Institute of Technology; [3]Medical Solutions Division, NEC Corporation; and [4]Department of Gastroenterology and Hepatology, Musashino Red Cross Hospital (Japan)*

Background and Aims: Histological evaluation of fibrosis after a liver biopsy is crucial for evaluating the pathology of patients with chronic liver disease. We have reported image analysis allow quantification of liver fibrosis using Elastica van Gieson (EVG) stained whole-slide images (WSIs) of liver biopsy specimens [1]. In this paper, a whole slide image analysis system for quantification of liver fibrosis was developed to apply a large number of cases in routine practice. *[See Appendix 10 for short paper and figures.]*

9:20 **Staining Correction in Digital Pathology with Dye Amount Look-up-table (LUT),** *Pinky A. Bautista and Yukako Yagi, Department of Pathology, Massachusetts General Hospital (USA)*

Automated image analysis of histology images is affected by the staining variations in histology slides. In general, training images are used to optimize the parameters of an image analysis system. Color, being one of the dominant features of stained tissue samples, is being commonly utilized as feature for to segment or classify the different stained tissue components. However, the colors impressed on the tissue components vary with the staining condition of the sample. Hence, when the staining conditions of the slides for the training and test images differ the accuracy of the analysis results would likely degrade. In this work we present a method to correct the staining condition of the histology images by constructing a look-up-up table of the stained pixels' dye amounts. The present method allows the user to not only correct the staining condition of a given histology image with respect to the staining condition of the reference slide, but to also re-create his/her preferred staining condition for the given image. The results of our experiments with Hematoxylin and Eosin (H&E) stained tissue images showed the effectiveness of the present method.

9:40 **A New 2D Histogram in HSV Space For Color Image Retrieval,** *K. Elasnaoui, B. Aksasse, and M. Ouanan, Faculty of Science and Technology Errachidia (Morocco)*

The problem we consider that is about finding similar images in a large database. The most efficient algorithms use local image descriptors. In this paper, we propose a new algorithm based on the intersection of 2D histograms in HSV space. The proposed histogram is based not only on the intensity of pixels but also on a 3x3 window. This approach overcomes the drawback of the classical histogram which ignores the spatial distribution of pixels in the image. By comparing its performances to

several methods of the state of the art, we will show that the developed method presents several advantages. The proposed histogram is faster, reduce memory consuming and it doesn't require learning. For validation of our results, this algorithm will be applied to search similar images in a database of over than 1000 images. Finally, we show that the proposed algorithm is efficient than the method of searching by the intersection of classical histograms in HSV and RGB spaces.

10:00 —10:40 AM Coffee Break

IADP Special Lectures 2: Digital Pathology and Imaging Applications

Session Chairs: Arvydas Laurinavicius, Vilnius University, and James Michaelson, Massachusetts General Hospital

10:40 AM – 12:00 PM

Amphitheater

10:40 **Digital Pathology – How Far Are We From Automated Tissue-based Diagnosis?,** *Klaus Kayser, Charité – Universitätsmedizin Berlin (Germany); Stephan Borkenfeld, IAT Heidelberg (Germany); Amina Djenouni, Pathology Institute, Batna (Algeria); Herbert Kaltner, Maximilians University (Germany); and Gian Kayser, Institute of Pathology, University of Freiburg (Germany)*

Background: Tissue based diagnosis (TBD) includes all diagnostic procedures that are performed on human tissue for disease classification and treatment. It s computerized information analysis is called Digital Pathology. Herein we will discuss the present stage of IT tools and the assumed clinical perspectives on medical performance and treatment.

Theory: Basically, TBD investigates the function and structures of biological meaningful individual units, such as macromolecules, genes, nuclei, cells, vessels, organs, etc. All functions are bound to structures that ensure a reliable and effective information and energy exchange. Disturbance of structures induces less effective or complete loss of functions. The complex interactions at molecular biological level (macromolecules) and their continuous reproduction require extensive computations in addition to the sophisticated biochemical analysis systems. Nearly all assessable information is of visual nature, or can be visualized. Thus, image content analysis applied in a sophisticated manner might be one key procedure to assist human image interpretation or to even replace it.

Image content information includes information that can be derived from predefined functional units (objects), their spatial arrangement (structure), pixel derived features prior of after image transformations (texture), and syntactic compositions of objects or of pixel based primitives (syntactic structure analysis). Statistically significant clusters can represent either new biological significant units (for example tubular arrangement of specific (endothelial) cells form a vessel, spatial composition of cells of different nature (cellular sociology) form a bronchus), or other new items such as entropy flow charts, diffusion densities, etc. All these parameters form a powerful set of image information features. They can be considered to be independent from each other, and calculated independently for their specific clinical significance (disease association).

Present status: The development of whole slide image scanners, their implementation into laboratory and hospital information systems, and of internet based open access image measurement systems permit the construction of automated disease classifiers with inbuilt image quality control and monitoring. The prerequisites include image standardization (of gray value range, distribution, magnification in relation to object measurements, etc.), detection of regions of interest (ROI), standardized image transformation procedures, and sophisticated statistical algorithms of flexible and self learning classifiers.

Perspectives: No technical constraint seems to exist that would prohibit a self learning automated disease detection system based upon TBD. Individual bricks are already available, and have been tested in still crude but promising trials. Internet test forums such as EAMUSTM or the recently created Virtual International Pathology Institute (VIPI, diagnomx.eu/vipi) can be considered to be milestones in developing IT support in TBD and surgical pathology. The pathologist and the medical community can decide about velocity and support, not about <yes> or <no>.

11:00 **Computational Cancer Pathology*,** *Andrew H. Beck, Harvard Medical School, Beth Israel Deaconess Medical Center (USA)*

11:20 **The Role of Micro CT in the Imaging of Cancer,** *M. Griffin, P. Anand, R. Tang, M. Lewin-Berlin, A. Bui, J. Singh, K. Patel, W. Sarraj, J. Gilbertson, Y. Yagi, D. Kopans, R. Moore, A. Ly, M. Saksena, G.P. Nielsen, G. Harris, N. Gershenfeld, B. Smith, and J. Michaelson, Massachusetts General Hospital (USA)*

Abstract: The absence of real-time, detailed, 3D, information on the composition surgical specimens presents an enormous challenge in surgical oncology and pathology. The problem is especially pressing for breast cancer, where as many as ~1-in-3 patients undergoing lumpectomy have been found, upon pathological examination of the slides, to be margin positive. These patients need to return to the hospital for re-excision, sometimes multiple times, in order to achieve negative margins. A solution may be found in a relatively new technology, Micro CT, a high resolution X-ray imaging method, that has been widely used in industry and materials science, but little used in medicine. Over the past three years, we have imaged a great variety of surgical specimens with three Micro CT machines (a SkyScan 1173 Micro CT, an Xradia MicroXCT-200, and a Nikon Metrology XTH225). Our findings indicate the Micro CT is able to provide 3D images of surgical specimens, which can identify, within 10 minutes, most of those breast cancer patients later found to be margin positive on pathological analysis, as well as to identify a small number of patients whose cancers appear to be margin positive on Micro CT alone. Micro CT can also identify lymph nodes in cancer specimens, including nodes not detected by pathological dissection. These findings suggest that Micro CT has a considerable potential for providing the surgeon and pathologist with rapid, accurate, actionable information on the status of the surgical specimen while the patient is still in the OR.

12:00 — 1:30 PM Lunch Break

IADP Closing Joint Keynote

Session Chairs: Klaus Kayser, Humboldt University (Charite), Institute of Pathology, and Yukako Yagi, Massachusetts General Hospital and Harvard Medical School

1:30 – 2:20 PM

Amphitheater

1:30 **Human Factors in Telepathology: The 21st Century Agenda*,** *Ronald S. Weinstein, Arizona Telemedicine Program (USA)*

*No abstract available