ICC Working Group Meetings
Nippon-Seinenkan Hotel
160-0013 Kasumigaokamachi 7-1 Shinjuku
Tokyo, Japan

ICC Medical Imaging Working Group minutes
4 March 2014

Craig Revie, chair of MIWG, opened the meeting at 1:15pm and following self-introductions introduced the agenda as follows:

1. Introduction to the ICC Medical Imaging activities

Whole slide imaging

— 2. Quantification of liver fibrosis using whole slide image

— 3. FFEI proposal for calibration assessment slide

— 4. Multispectral imaging for WSI

Medical displays colour calibration and measurement

— 5. Overview and summary Takashi Matsui

— 6. "Perceptually Linear Color Behaviour of Display" Yu Kosugi

— 7. "Perceptually Linear Color Behaviour of Display" Tom Kimpe

— Open Discussion

Medical Photography

— 8. Recommended lighting conditions and image format for medical photography

Presentations from Digital Biocolor Society

— 9. Measurement of skin absolute spectral-reflectance-image and its application to component analysis Norimichi TSUMURA

— 10. Oxygen saturation of skin reflects blood flow and stagnation Keiko Ogawa-Ochiai

11. Ophthalmic Photography

1. Introduction to the ICC Medical Imaging activities

Mr Revie presented an overview of the working group and its history [see attached].A number of topics had been identified at the Summit on Color in Medical Imaging in May 2013, and sub-groups had been established to work on these topics. Meetings had been held by teleconference and also as part of the ICC regular meetings in Frankfurt and Vancouver in June and November 2013. Forthcoming meetings are planned in Washington DC (19th and 20th June) at the FDA White Oak Conference Center, and

Boston (30th October – 1st November) in conjunction with ICC DevCon, IS&T Color and Imaging Conference (CIC22) and the 2nd International Congress of the International Academy of Digital Pathology (IADP).

A web site had been set up as part of the ICC web site, and updates and meeting records were posted there. Those interested in participating should contact Craig Revie (craig.revie@ffei.co.uk), Phil Green (green@colourspace.demon.co.uk) or one of the project coordinators.

Whole slide imaging

— 2. Quantification of liver fibrosis using whole slide image

Dr Tokiya Abe of Keio University presented results of work on using whole slide imaging to quantify liver fibrosis [see attached]. The work was motivated by the problem that the colour of stained tissue varies between hospitals, and a classifier trained on a data set from one hospital did not work on data from another hospital. This requires a colour correction method to ensure consistency.

He had computed a colour distribution model based on tetrahedra in RGB space. He showed an example of automated fibrosis quantification using calculations from two types of fibre area. He concluded that the method successfully estimates the degree of fibrosis and that colour correction was needed to ensure consistency between hospitals.

The meeting questioned whether it would be easier to perform the analysis on chromaticity coordinates, but Abe-san stated that variability in scanning and staining made the luminance information necessary.

It was agreed that differences in staining methods are the most critical variable, and that ICC should consider looking at the possibility of standardization of staining methods across different regions.

Dr Masahiro Yamaguchi of Tokyo Institute of Technology pointed out that there are many factors influencing stain variation, and in practice stains are often prepared according to the preferences of individual pathologists. Some variables such as the glue, cover slip etc used could be taken care of within the scanner calibration process using a standard target.

— 3. FFEI proposal for calibration assessment slide

Craig Revie presented an FFEI proposal for a WSI calibration slide [see attached]. He circulated two prototype slides for inspection during the meeting, which included a colour reference slide and another with targets for assessment of scanner resolution. He noted that the FDA is preparing a guidance document for WSI microscopes in order to assist manufacturers in making a clear statement on the capabilities of a given device. The preliminary list includes colour, resolution, dynamic range and depth of field.

Mr Revie described a biopolymer developed by FFEI and Leeds University, which acted as an alternative to actual tissue. This approach worked well and avoided inconsistency. Combining stains was well modeled by a linear combination for most of the 30+ stain combinations tested, including Haematoxylin and Eosin.

The proposed colour assessment slide has actual pathology stains on a biopolymer substrate. Combinations of two specific stains are in one block, while the other block is made up of commonly used stains selected to cover the gamut of the microscope and the available pathology stains.

FFEI intend to add grey control patches, and an exposure control to indicate the amount of fading. Although no fading has been noted in dark keeping conditions, slides are expected to have a limited life expectancy of about 18 months.

The materials are relatively inexpensive, and the expensive part is manufacture and measurement Mr Revie anticipated there would be some discussion on the best way to measure. FFEI will post measurement data on a dedicated web site.

He described the suggested workflow. The slide is intended to allow assessment of the accuracy of the system. Other manufacturers are developing methods of calibration for each stage of the workflow. Of these he noted Yagi-san's method which included visual assessment using the display as backlight; and Wei-Chung's method of capturing device code values being sent to a display.

— 4. Multispectral imaging for WSI

Dr Bas Hulsken of Philips presented a summary of use cases for multi-spectral imaging in digital pathology [see attached]. He identified a number of areas where multi-spectral imaging is needed, including improved colour gamut, reproducible false-coloured images and standardized channel un-mixing. For wider adoption of multispectral imaging the limitation to 3 input channels in DICOM must be addressed.

Obtaining biomarker concentrations via linear un-mixing and capture device calibration was an important application. This could be addressed by fluorescence and by multi-channel brightfield microscopy. He considered UV fluorescence to be a physically better way of obtaining quantitative data, but brightfield fluorescence microscopy is more convenient for the operator.

Mr Max Derhak of Onyx Graphics presented a brief introduction to relevant work in IccLabs [see attached]. The goal was to obtain unmixed biomarker concentrations. This could be done by concatenating device link profiles, but this was problematic in matching intermediate device channels and the n-dimensional LUTs were cumbersome. A more elegant solution was the MCS proposal in IccLabs. This involves a Material Input profile which defines the transform from capture channels to a Material Connection Space (MCS). An image could be processed to give a visualization via a normal ICC output profiles, or to give material concentrations via MCS. Both transforms could be incorporated into a single profile.

Medical displays colour calibration and measurement

Mr Revie handed the chair to Dr Takashi Matsui of Eizo for the session on medical displays.

— 5. Overview and summary

Matsui-san gave an overview of work on displays in MIWG. He showed an outline of the mRGB proposal (led by Michael Flynn) being standardized in AAPM, and compared this with sRGB. One key goal was to have a similar appearance of an image on different displays. In radiology it was recognized that there must be consistent presentation across different devices and over time to ensure diagnostic accuracy.

One consideration was to ensure that equal changes in digital values gave equal changes in the perceived display, especially in brightness. However, absolute brightness may vary between displays. Ambient light is taken into account in mRGB.

— 6. Perceptually Linear Color Behaviour of Display (1)

Dr Yu Kosugi of Eizo presented work on perceptually linear colour displays [see attached]. The goal was to achieve perceptually linear color behavior (PLCB) i.e. equal perceptual steps with equal change in digital values. He described two approaches to achieving this: applying a GSDF curve for each R, G, B primary, or adjusting tone curves to make equal difference steps. He also described a general approach to display calibration, consisting of adjustment to tone curves, colour gamut, white point and peak luminance.

He found that additivity failure of display panels meant that RGB curves were different when calibrated to GSDF, and it was not possible to match the GSDF ideal gray curve with this approach. It was necessary to use a 3D LUT to remap colours, and in this approach it was possible to match the GSDF ideal gray. However, it may require implementation in display hardware.

In future work he intends to investigate varying the PLCB curve with peak luminance.

The meeting agreed with his conclusion that RGB GSDF and grayscale GSDF were not compatible, and it was also noted that CIELAB-based colour difference metrics including CIEDE2000 were not applicable to large colour differences.

— 7. Perceptually Linear Color Behaviour of Display (2)

Dr Tom Kimpe of Barco presented some further work on this topic [see attached]. His motivation was that perceptual linearity gave applications maximum flexibility. He had found that there was a balance between perceptual linearity and maximizing contrast, and that applying the GSDF gave better linearity than CIEDE2000 across the colour space. As with Kosugi-san, he had also implemented a LUT to achieve perceptual linearity, and found that after calibration it achieved increased contrast in clinically relevant features by

an average of approximately 50%. He proposed that guidelines for implementing a Colour Scale Display Function could be developed by ICC MIWG.

He considered that ICC profiles were an important aspect of the solution, especially where colour accuracy was important. Most DICOM modalities would benefit from PLCB.

Mr Tom Lianza of X-Rite stated that displays and cameras were not originally designed to have perceptual linearity; a camera image incorporates the inverse of the display gamma function so that images look natural when presented on a display. This implies that correction should be performed before sending to the display, which should be linear.

Mr Kimpe responded that in many modalities of medical imaging correction is not needed as images are already in a linear space.

Mr Revie asked Mr Lianza and Dr Hulsken to prepare a presentation on this topic for the next meeting.

Medical Photography

— 8. Recommended lighting conditions and image format for medical photography

Dr Phil Green presented a summary of the work on medical photography on behalf of Jon Penzcek of NIST [see attached]. Dr Green reviewed the scope and outline content of the proposed medical photography guidelines, and emphasized that the goal was to adopt existing guidelines where available rather than reinvent new ones. The resulting document could be published as an ICC publication, a journal article, and disseminated through professional bodies.

The goal was initially accurate colorimetry, although the work could be extended to other requirements including guidelines for preference-based photography.

Dr Hisashi Sano on Nikon Corporation had advised on some aspects of the recommendations. It was considered that auto white balance was not a good choice for medical photography as the scene often has a colour bias that makes white point estimation incorrect. Manufacturers provide software to process raw images, and in the case of Nikon this can replicate the effects of camera settings for in-camera rendering such as ‘vivid’

Tom Lianza recommended including a white surface in scenes, as this would help with white balance and exposure.

Presentations from Digital Biocolor Society

— 9. Measurement of skin absolute spectral-reflectance-image and its application to component analysis

Dr Masahiro Nishibori gave a presentation on the measurement of skin absolute spectral-reflectance-image and its application to component analysis on behalf of Dr Norimichi Tsumura of Chiba University [see attached]. Tsumura-san had developed a technique to extract skin colour and separate into haemoglobin and melanin components. Challenges

included optical scattering in skin, and the two different states of haemoglobin. He had developed a skin model that included depth scattering and absorption. Skin images were captured by multi-spectral camera, with multiple illumination directions. The results indicated that haemoglobin and oxygen saturation varied over time, while melanin remained constant. The system performed well for mapping and visualization of skin pigmentation.

— 10. Oxygen saturation of skin reflects blood flow and stagnation

Dr Masahiro Nishibori gave a presentation on applications of medical imaging to detection of oxygen saturation in traditional Japanese Kampo medicine on behalf of Dr Keiko Ogawa-Ochiai of Keio University [see attached]. He acknowledged that Kampo medicine is subjective and its precepts unexplained. Previous studies of Kampo medicine had related to tongue coloration and skin oxygen saturation. He found a moderate correlation between oxygen saturation on the dorsal region of the hand, and the Oketsu score derived using Kampo methods. The next step was to determine the best location for skin measurement.

11. Ophthalmic Photography

Phil Green presented a progress report on colour calibration of fundus imaging on behalf of Christye Sisson of RIT [see attached]. The motivation for this activity was that variation in retinas and cameras makes it harder to do accurate diagnosis, and there is a need for a standard approach to fundus camera calibration.

Results of initial work on this were presented. The next step is to develop a calibration target and procedures. The group is in the process of identifying ophthalmologists and others who can contribute to the work.

It was suggested that Dr Sisson discuss the use of Munsell colours in the target with the Munsell group at X-Rite. It was noted that the activity is currently based solely in the US. Japanese manufacturers who make fundus cameras include Canon and Topcon. MIWG will attempt to locate a contact at Topcon and pass this on to Dr Sisson.

The meeting closed at 5:30pm.

Action items

Action items agreed from the meeting were:

MIWG-14-14 Participate in FFEI calibration slide assessment (All interested)

MIWG-14-15 Prepare presentation slides for next meeting on capture-to-transform workflow (Lianza and Hulsken)

MIWG-14-16 Include recommendation on white surface to be included in scene in medical photography guidelines (Green and Penzcek)

MIWG-14-17 Provide contacts at X-Rite Munsell Group to Sisson (Lianza)

MIWG-14-18 Provide contact at Topcon Japan to Sisson (Revie)

Introduction to the ICC Medical Imaging activities

Craig Revie

3rd March 2014

Overview

- **Summit on Color in Medical Imaging**
  - discussed a broad range of medical imaging modalities where colour is important and identified a set of candidate work items
  - consensus paper will shortly be submitted to BMC Medicine (BioMed Central), Journal of the American Medical Association (JAMA) and will be made available via the ICC web site
- **Task force**
  - appointed following the Summit with the objective of determining the best way forward for each topic
- **ICC Medical Imaging Working Group**
  - established following the ICC meeting in Frankfurt
  - ICC web site provides full details of activities
  - regular teleconferences and face-to-face meetings in Vancouver and Tokyo
- **Next face-to-face meetings:**
  - Washington DC (19th and 20th June) at FDA White Oak Conference Center - format will be working group meetings rather than presentations
  - Boston (30th October – 1st November) in conjunction with ICC DevCon, IS&T Color and Imaging Conference (CIC22) and the 2nd International Congress of the International Academy of Digital Pathology (IADP)

Summit on Color in Medical Imaging

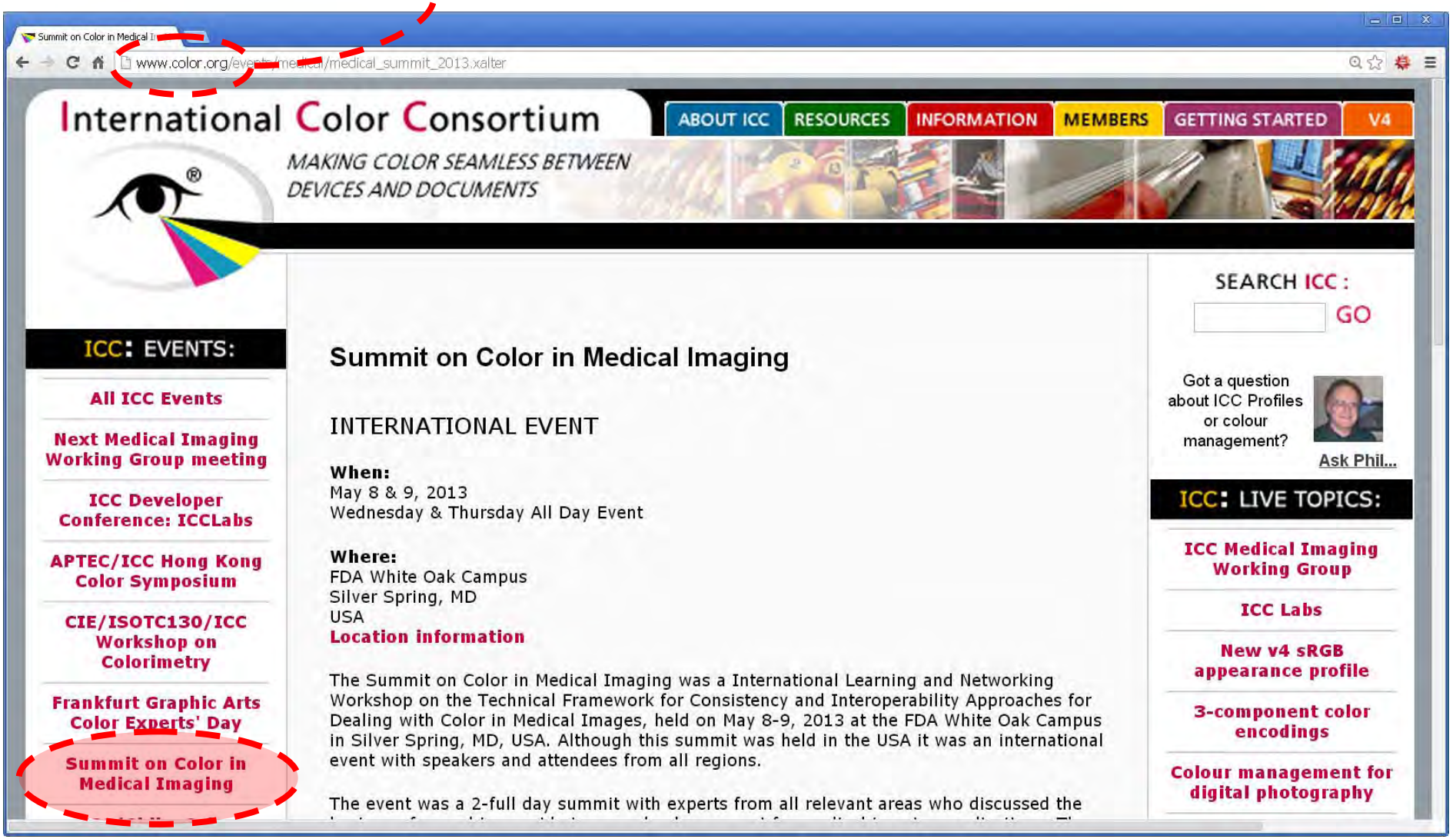
May 8th and 9th, 2013 **at** FDA White Oak Campus

- **Joint FDA / ICC event**
- **Topics included:**
  - —clinical photography, ophthalmic photography, digital microscopy, histopathology, multispectral imaging, endoscopy, laparoscopy, telemedicine, mobile displays, display devices, color measurement
  - —standards and professional group recommendations DICOM, ICC, CIE, IEC, AAPM. . .
- **Key numbers**
  - —27 speakers, 250 delegates from around 30 countries
  - —organising committee from Europe, US and Japan

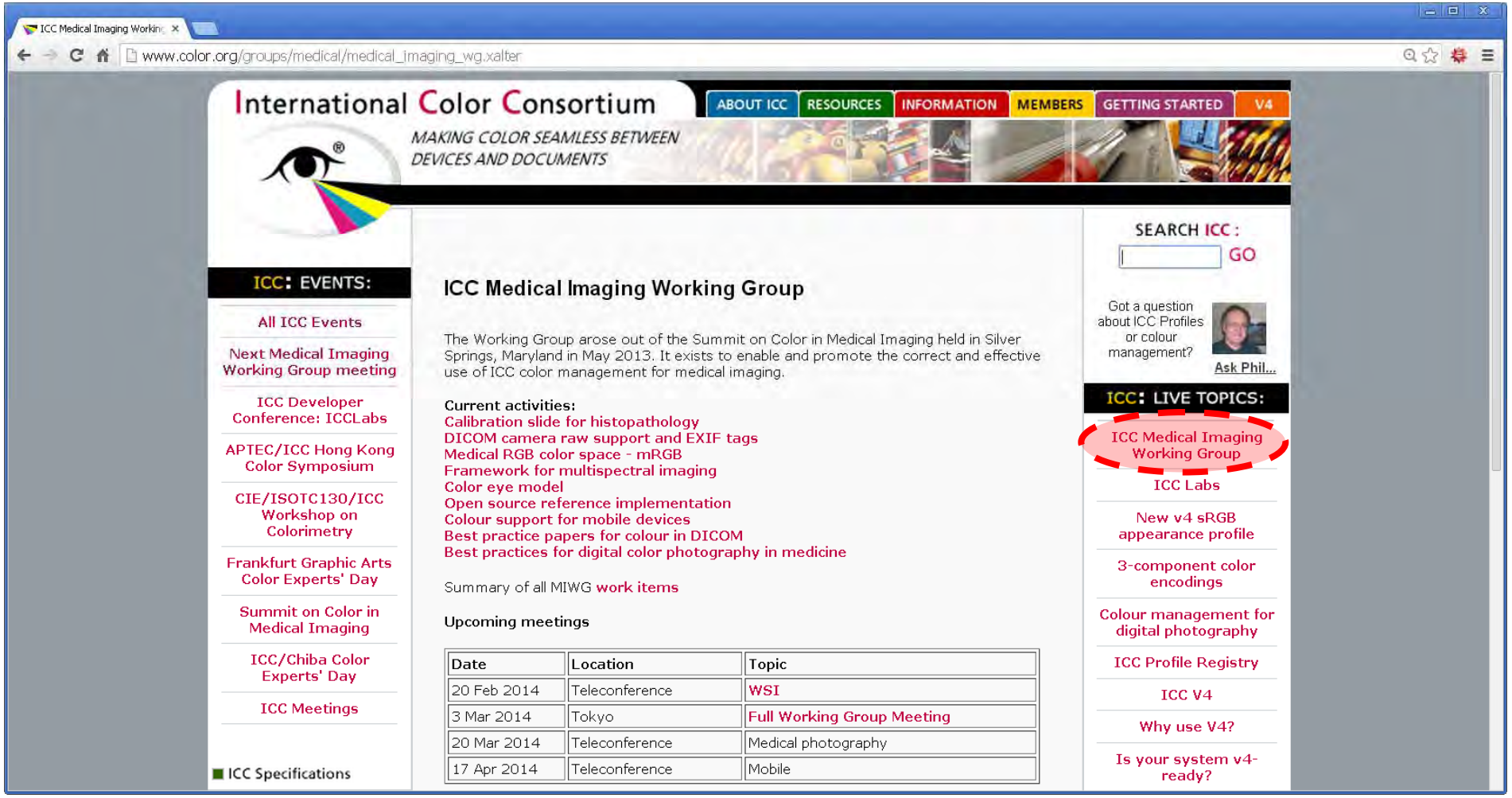
International Color Consortium

Summit on Color in Medical Imaging: speakers

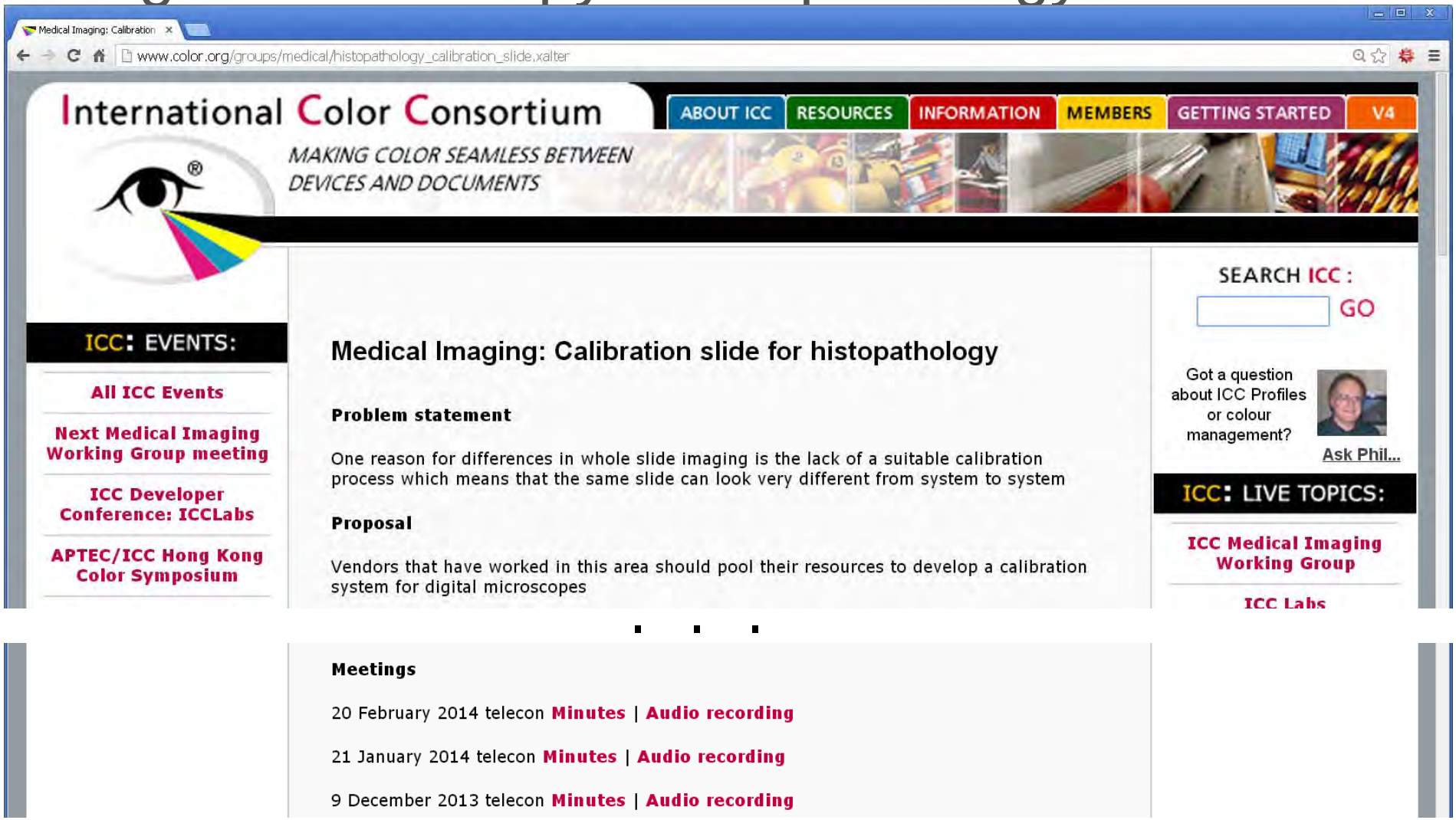
www.color.org



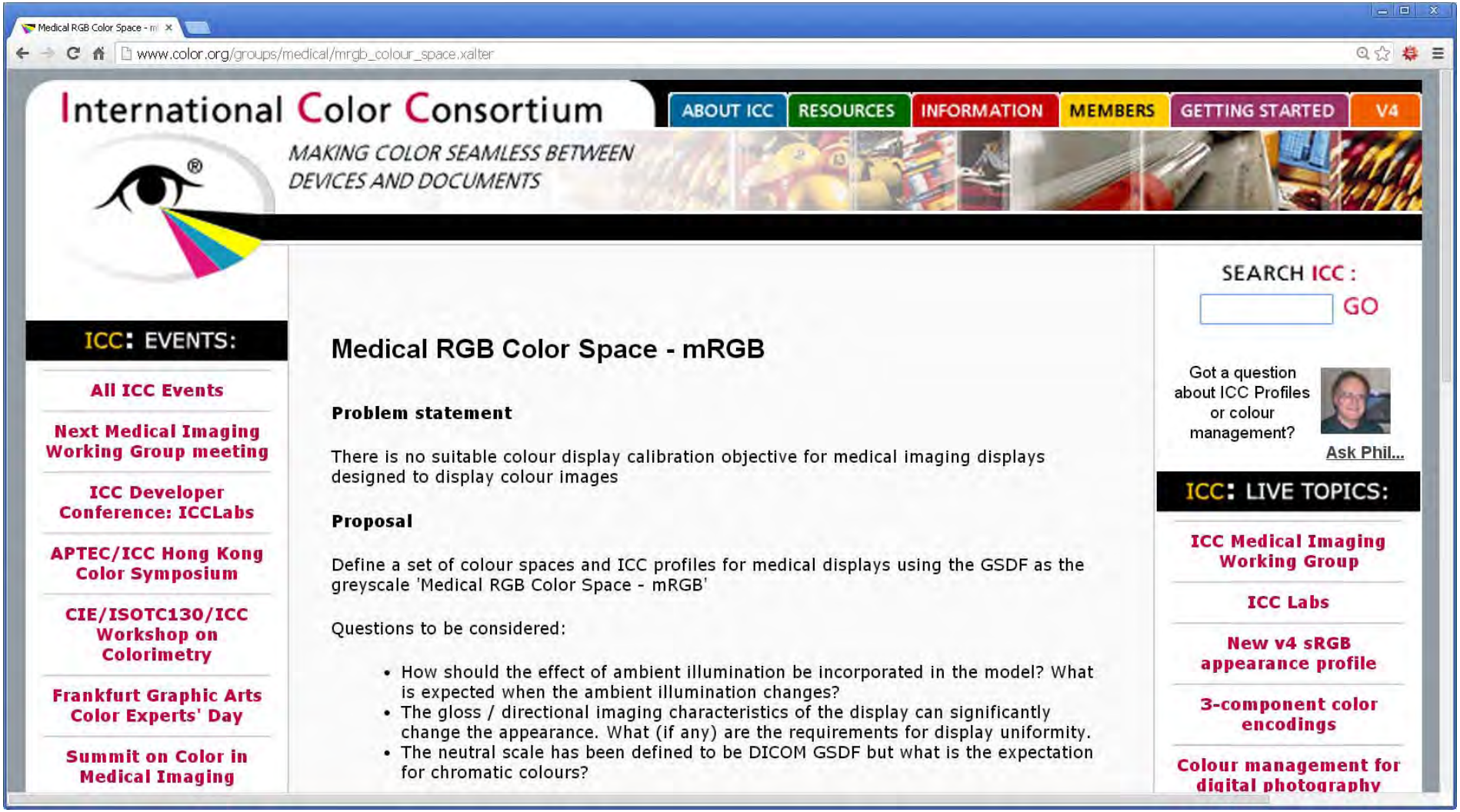
ICC Medical Imaging Working Group



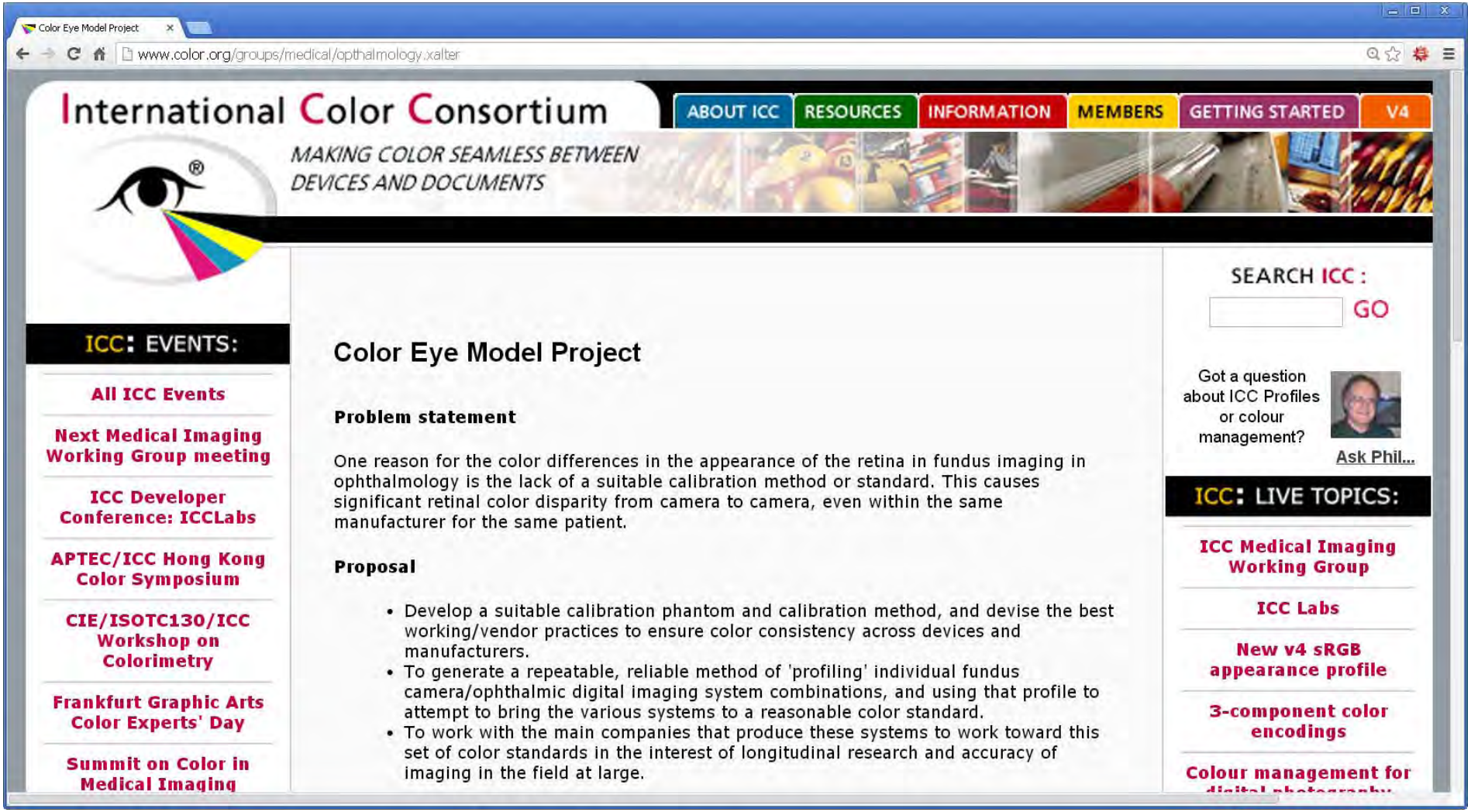
Digital microscopy / histopathology



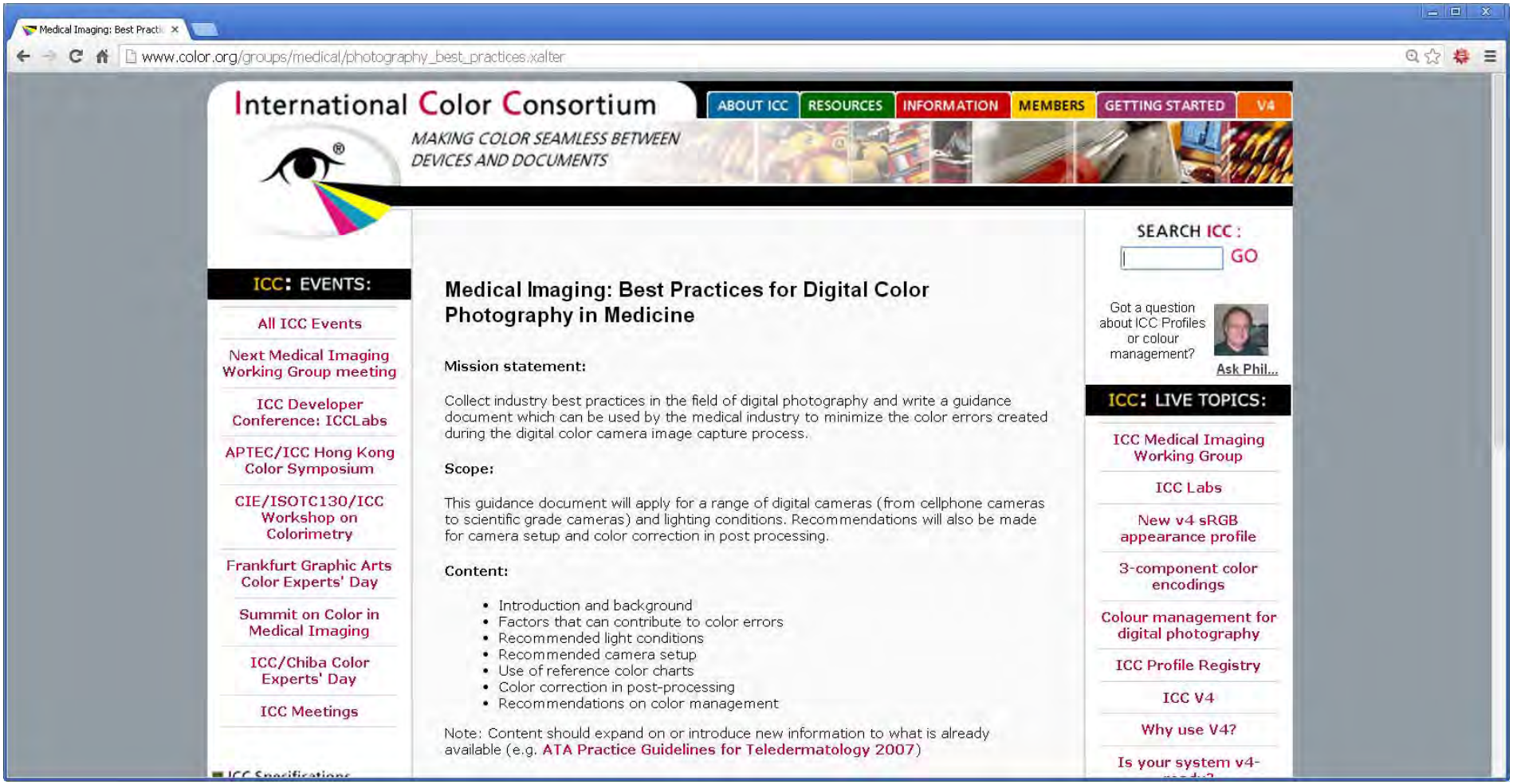
Displays


Medical RGB Color Space - mRGB
www.color.org/groups/medical/mrgb_colour_space.xalter
International Color Consortium
ABOUT ICC
RESOURCES
INFORMATION
MEMBERS
GETTING STARTED
V4
MAKING COLOR SEAMLESS BETWEEN DEVICES AND DOCUMENTS
ICC: EVENTS:
All ICC Events
Next Medical Imaging Working Group meeting
ICC Developer Conference: ICCLabs
APTEC/ICC Hong Kong Color Symposium
CIE/ISOTC130/ICC Workshop on Colorimetry
Frankfurt Graphic Arts Color Experts' Day
Summit on Color in Medical Imaging
Medical RGB Color Space - mRGB
Problem statement
There is no suitable colour display calibration objective for medical imaging displays designed to display colour images
Proposal
Define a set of colour spaces and ICC profiles for medical displays using the GSDF as the greyscale 'Medical RGB Color Space - mRGB'
Questions to be considered:
How should the effect of ambient illumination be incorporated in the model? What is expected when the ambient illumination changes?
The gloss / directional imaging characteristics of the display can significantly change the appearance. What (if any) are the requirements for display uniformity.
The neutral scale has been defined to be DICOM GSDF but what is the expectation for chromatic colours?
SEARCH ICC :
GO
Got a question about ICC Profiles or colour management?
Ask Phil...
ICC: LIVE TOPICS:
ICC Medical Imaging Working Group
ICC Labs
New v4 sRGB appearance profile
3-component color encodings
Colour management for digital photography

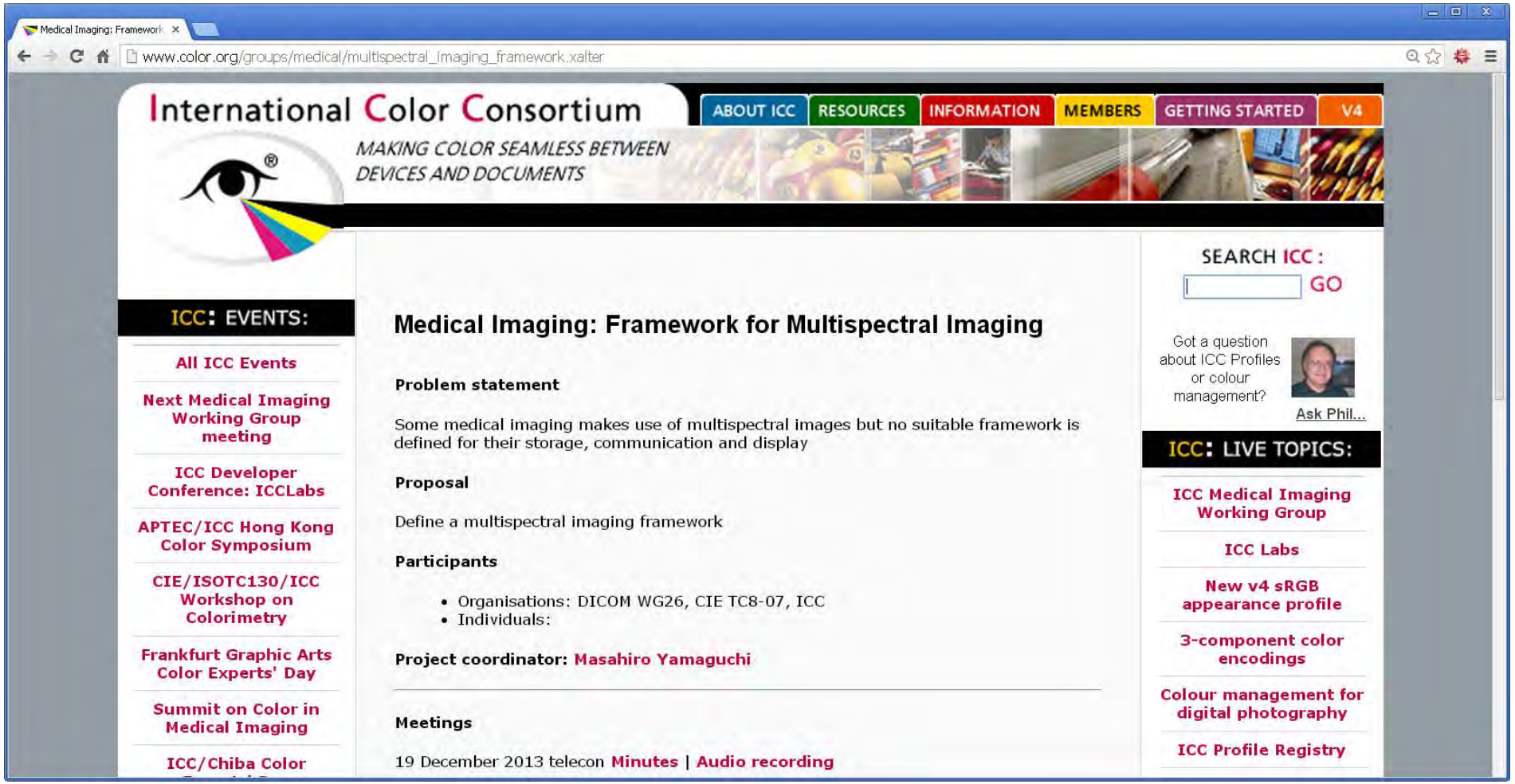
Ophthalmology



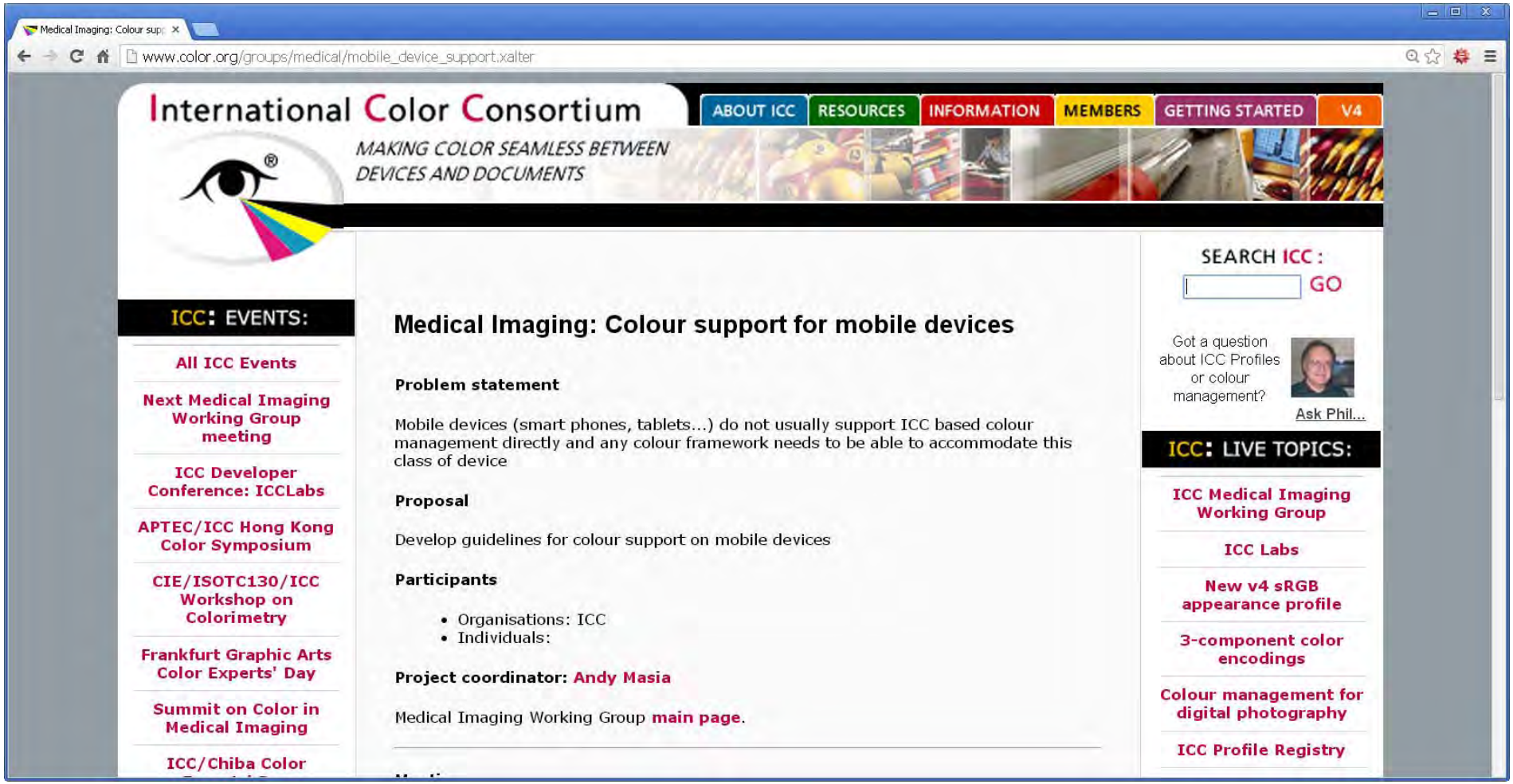
Clinical photography



Multispectral imaging



Telemedicine / mobile displays



Additional topics identified

- **DICOM camera raw support and EXIF tags**
- **Open source reference implementation**
- **Best practice papers for colour in DICOM**
- **Color connectathon**
- **Wiki for test images**

- **Although some thought has been given to these projects it is probably better to wait until progress has been made on other work that is underway**

How to join our work

Contacts:

Craig Revie (craig.revie@ffei.co.uk),
Phil Green (green@colourspace.demon.co.uk)
or one of the project coordinators

Quantification of Liver Fibrosis using Whole Slide Image

Tokiya Abe[1)], Yuri Murakami[2)], Akinori Hashiguchi[1)], Ken Yamazaki[1)], Masahiro Yamaguchi[2)] and Michiie Sakamoto[1)]

1) Departments of Pathology School of Medicine, Keio University, Shinjyuku-ku, Tokyo, Japan

2) Global Scientific Information and Computing Center, Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan

Overview

- **Quantification of liver fibrosis**
  - Topic 1 : Establishment of quantification of liver fibrosis
    - Motivation: Why require a quantification of liver fibrosis?
    - Method: How to identify two types of fiber area using Whole Slide Image
    - Experiment: Can our method reflect the degree of fibrosis？
  - Topic 2 : Development of automatic quantification
    - Motivation: Why require an automatic quantification?
    - Method: Implementation of color correction to fibrosis quantification
    - Demonstration

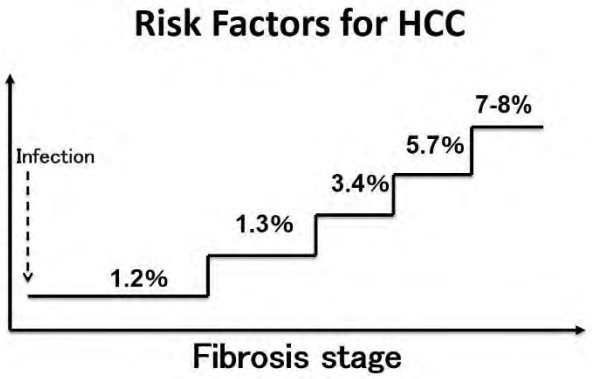
TOPIC 1 : ESTABLISHMENT OF QUANTIFICATION OF LIVER FIBROSIS

The Importance of evaluating liver fibrosis

Evaluation of liver fibrosis

Understanding
liver disease

Selecting
appropriate treatment

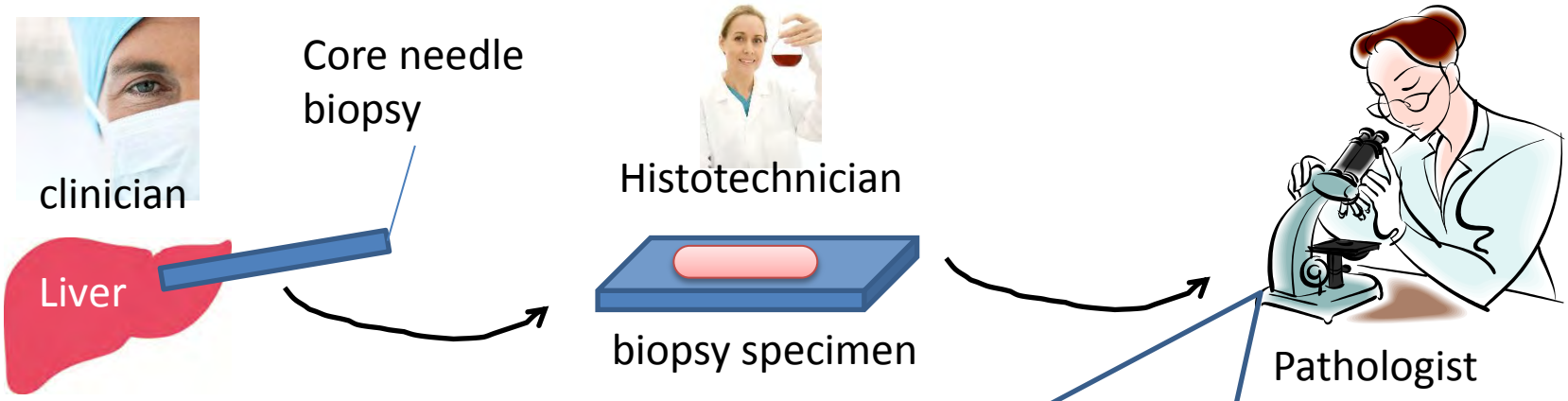


Predicting of risk factors
for Hepatocellular carcinoma

Enrich patient's quality of life

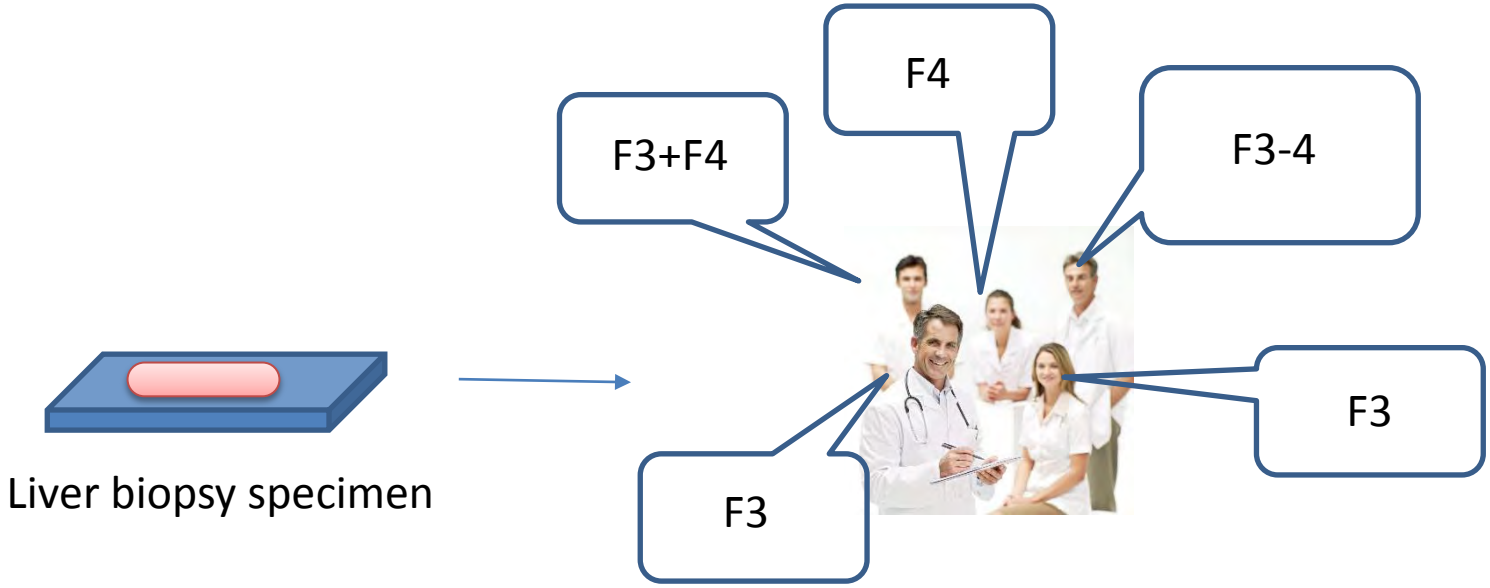
Histopathological evaluation

- **Histopathological evaluation of liver biopsy specimen**



- **Staging specimen corresponding the degree of fibrosis**

Semi-Quantitative Data



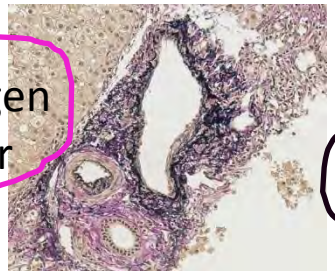
Semi-quantitative data analysis is difficult

↓

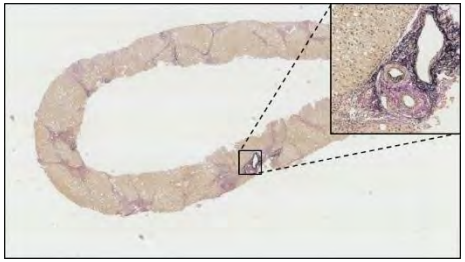
Quantification of liver fibrosis

Quantification of liver fibrosis using histological image

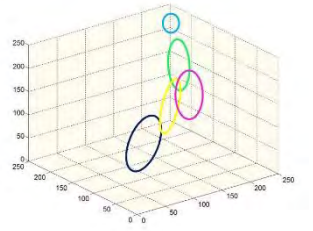
① EVG staining method



② Whole Slide Image

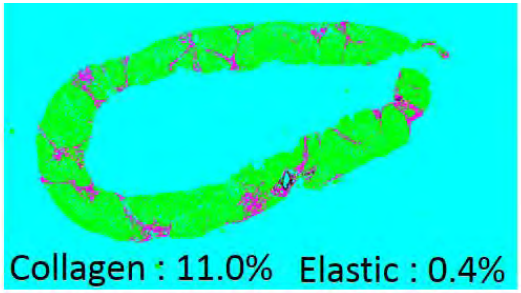


③ Color classification



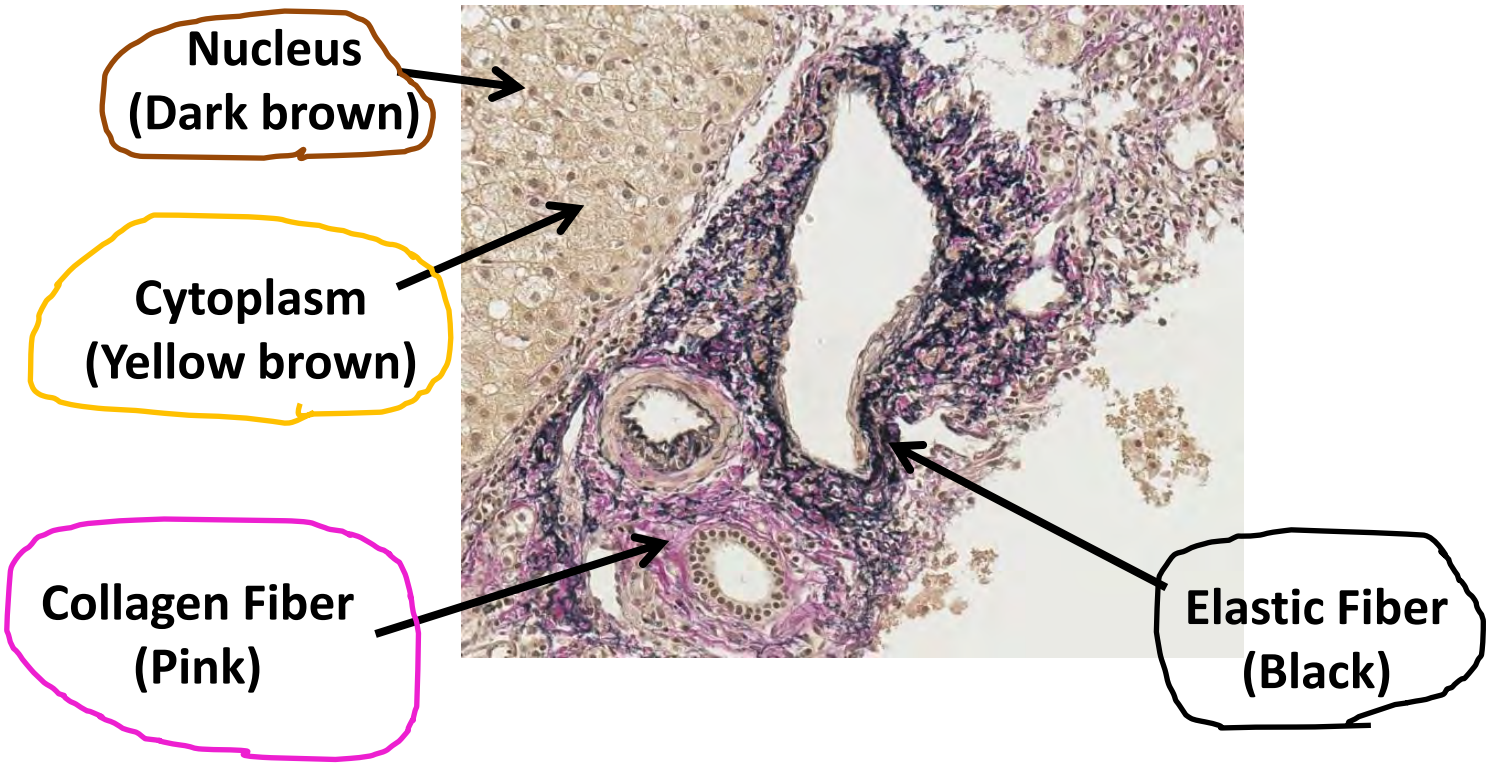
Identifying 5 classes in RGB color space

④ Two types of fiber area



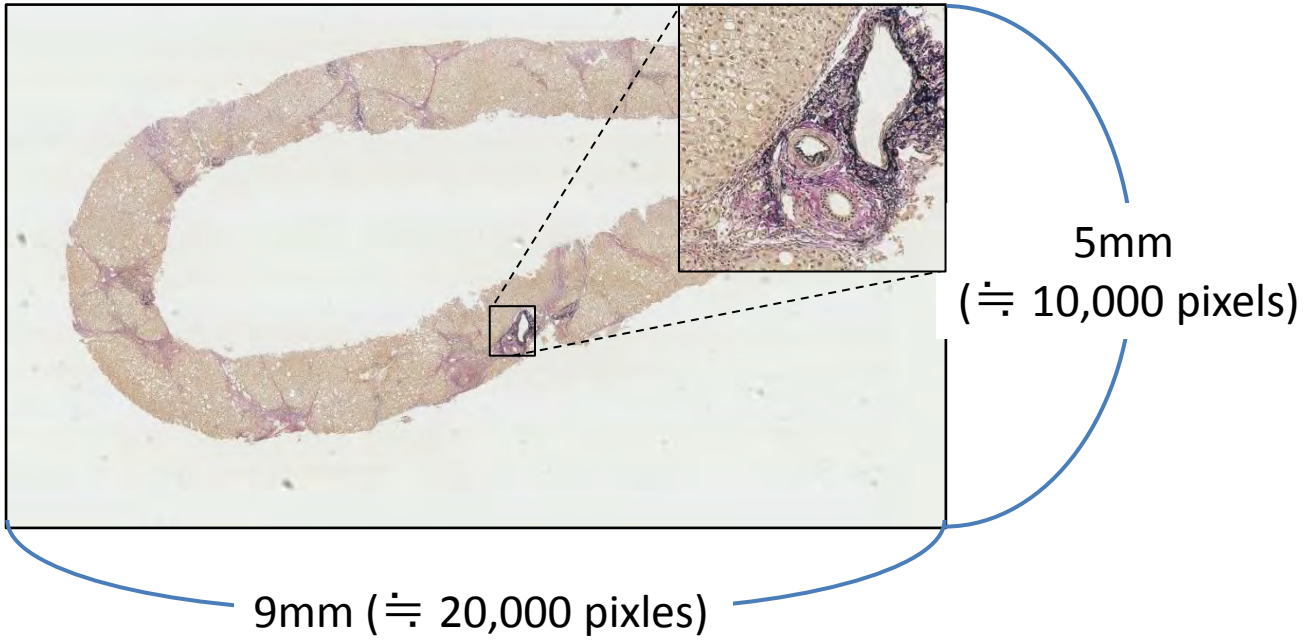
EVG staining method

EVG staining visualizes two types of fiber by different color



Whole Slide Image

Nanozoomer®



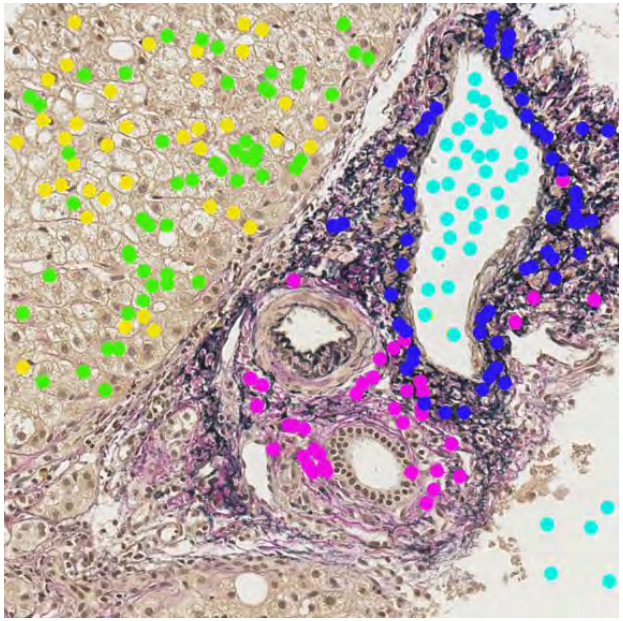
Color distribution of EVG stained tissue sample

Color analysis in RGB color space

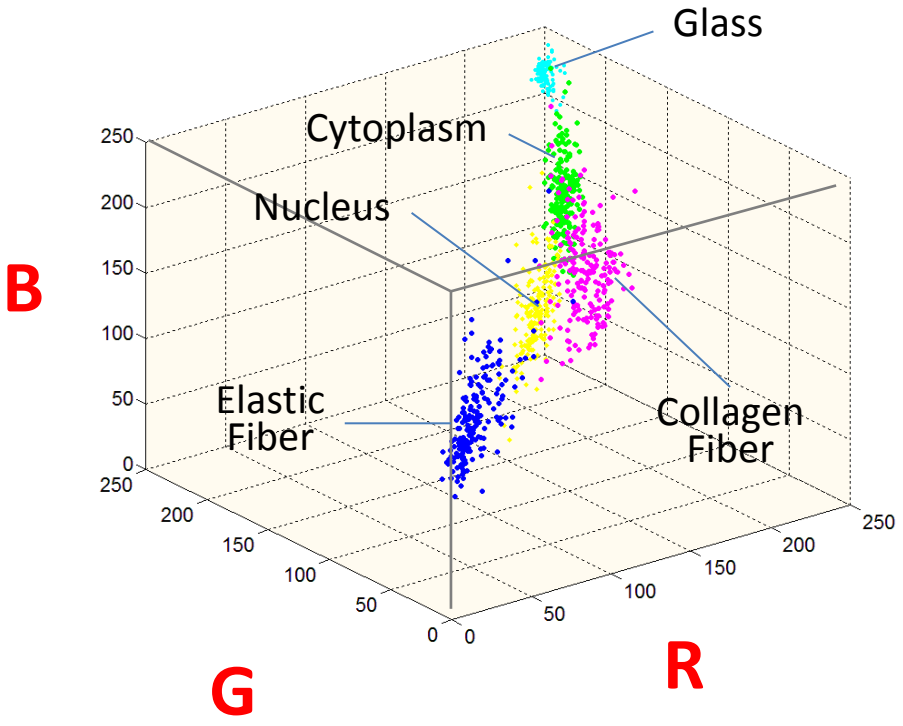
Tissue Areas

- Elastic fiber
- Collagen fiber
- Nucleus
- Cytoplasm

\+ Glass



5 Color Sampling

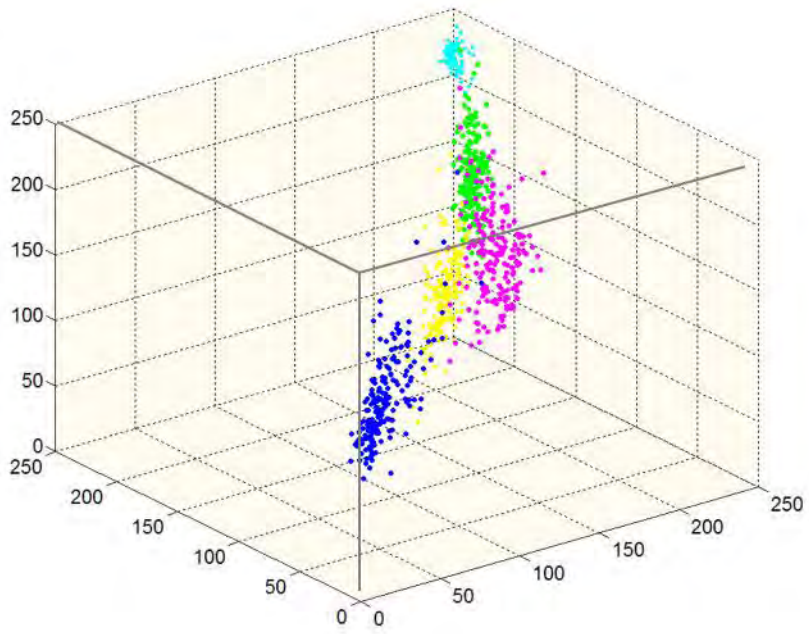


5 areas discriminable in RGB color space

Color Classification

1. Color classifier trained by sampled points of each area
2. Calculating probabilities of 5 classes to a pixel
3. Assigned into a class with maximum probability

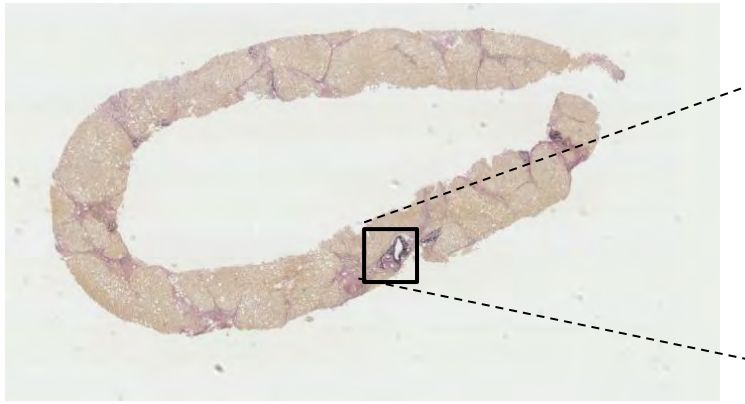
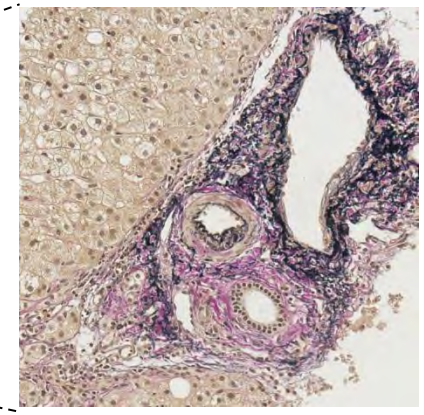
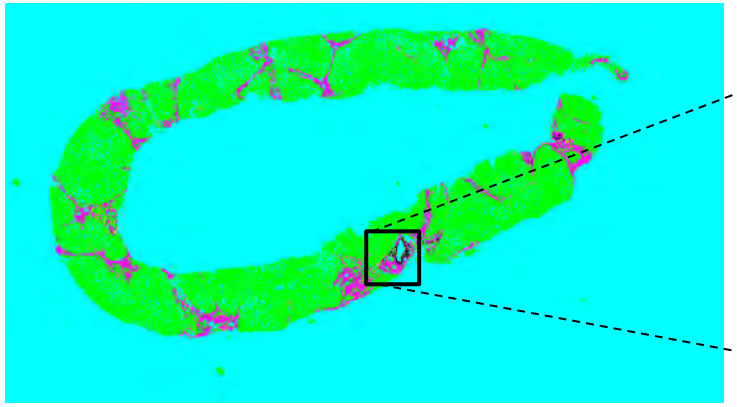
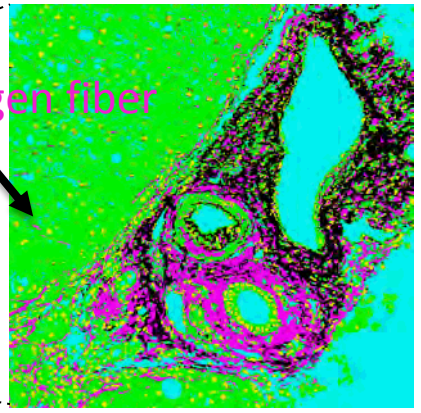
● $\boldsymbol{x}$
pixel



$P(\omega_g|\boldsymbol{x})$
$P(\omega_{cy}|\boldsymbol{x})$
$P(\omega_{col}|\boldsymbol{x})$
$P(\omega_n|\boldsymbol{x})$
$P(\omega_e|\boldsymbol{x})$

$\boldsymbol{x}$ assigned to collagen class.

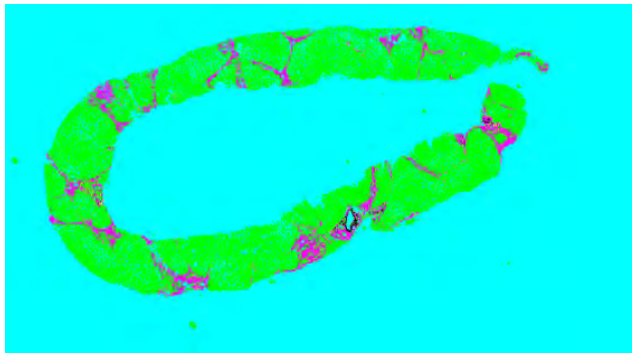
Applied to Whole Slide Image

	Whole Slide Image	Portal Area
RGB color image		
Classified image		
	9 mm × 5 mm (≒ 20,000 × 10,000 pixels)	0.5 mm × 0.5 mm (≒ 1,100 × 1,100 pixels)

Area of tissue classes (%)

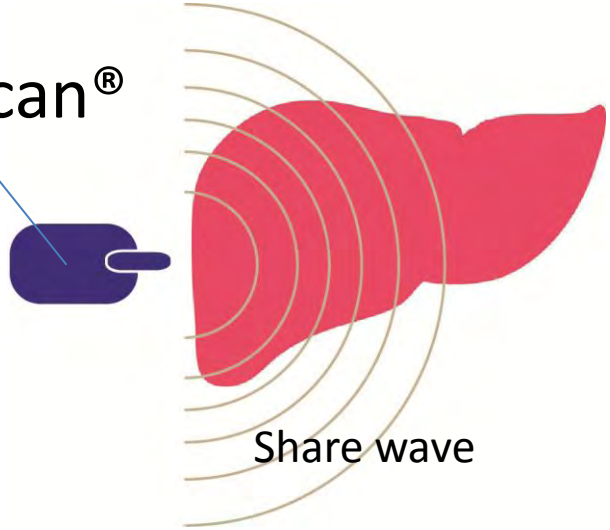
$$\text{Area of a tissue class (\%)} = \frac{\text{Pixels of a tissue class}}{\text{Sum of pixels of 4 tissue classes}} \times 100$$

Class	Collagen Fiber	Elastic Fiber	Nucleus	Cytoplasm	Tissue
Area (%)	11.0	0.4	6.8	81.9	100

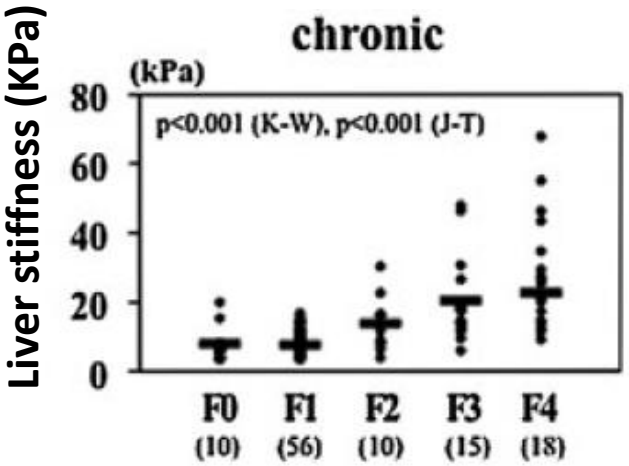


Can fiber area (%) reflect the degree of fibrosis?

Fibroscan®



Measuring liver stiffness (KPa)

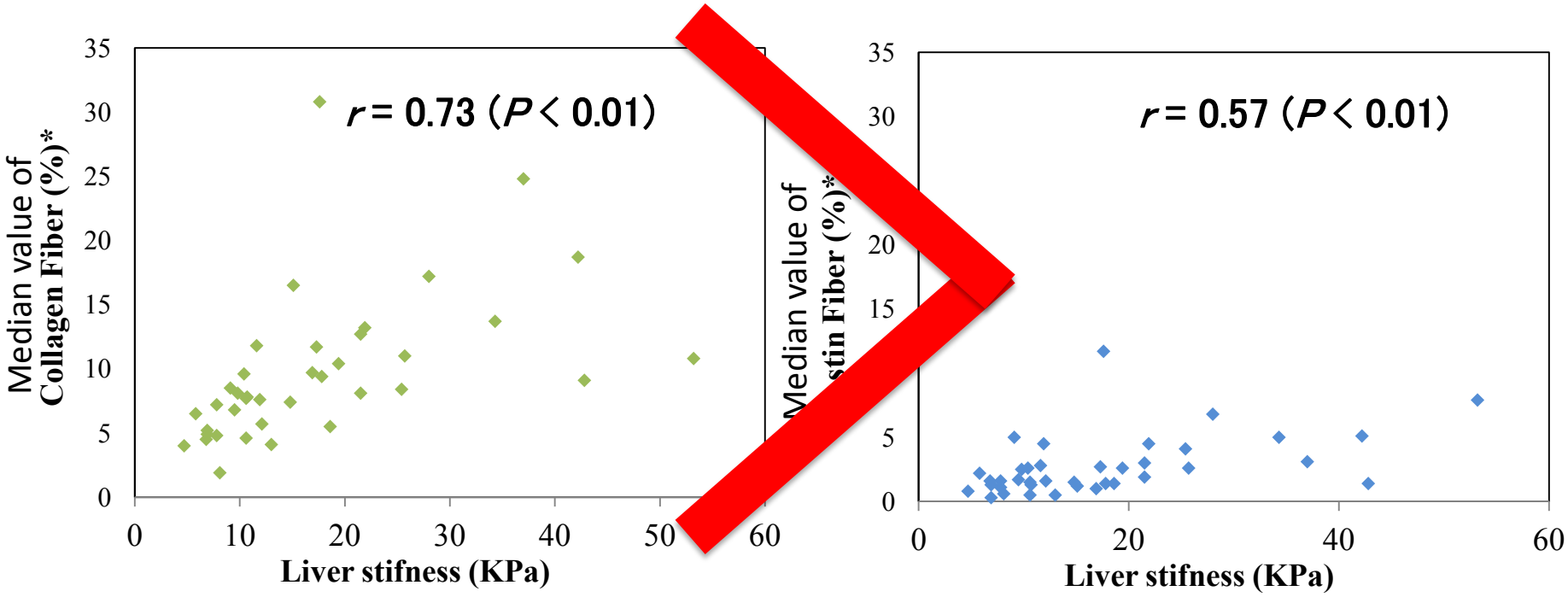


Correlate with fibrosis stage by Pathologists*

- Assumption : liver stiffness is an index of the degree of fibrosis.

*H.Ebinuma H et al. Evaluation of liver fibrosis by transient elastography using acoustic radiation force impulse: comparison with Fibroscan(®). J Gastroenterol 2011; 46: 1238–48.

Two types of fiber area correlate with stiffness



Probably due to an increase in elastic fiber in the late stages of the liver disease

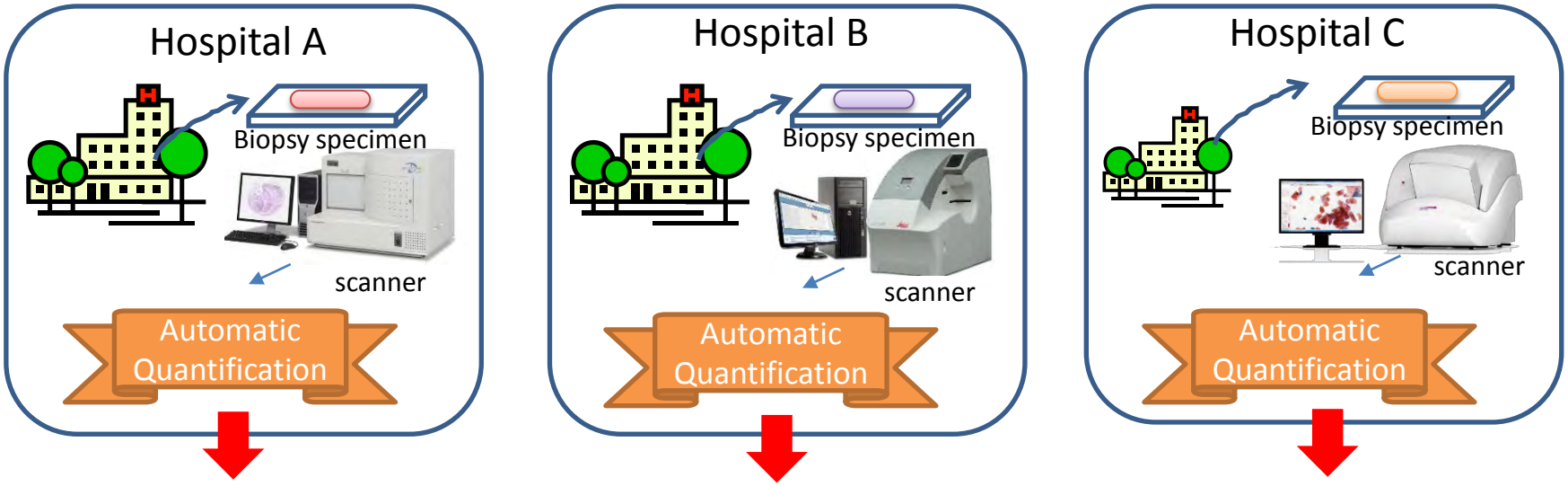
Understanding the mechanism of liver fibrosis progression.

T.ABE et al 'Quantification of Collagen and Elastic Fibers Using Whole-Slide Images of Liver Biopsy Specimens' *Pathol Int.* 2013;63:305-10

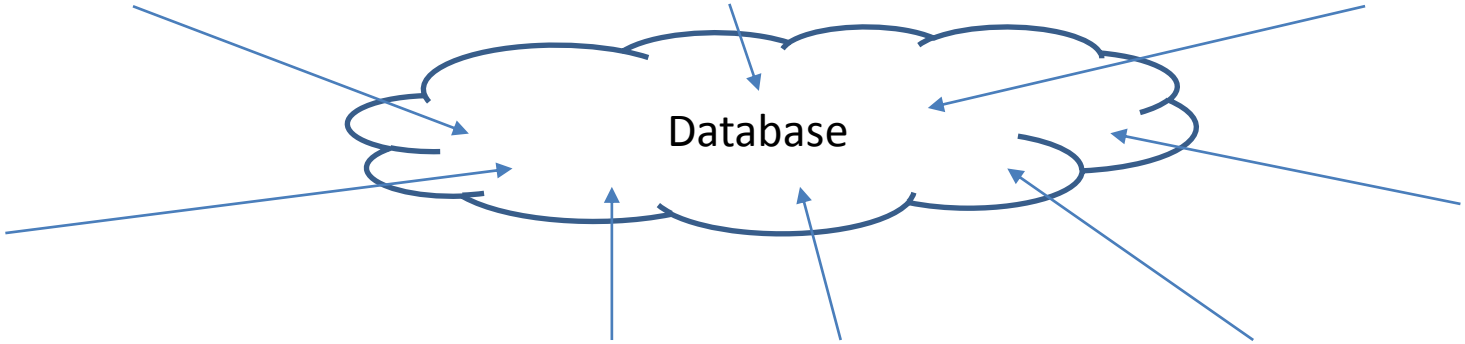
TOPIC 2 :DEVELOPMENT OF AUTOMATIC QUANTIFICATION OF LIVER FIBROSIS

To reveal the mechanism of liver fibrosis progression

Require measuring a lot of cases ≒ Require much hospital's corporation



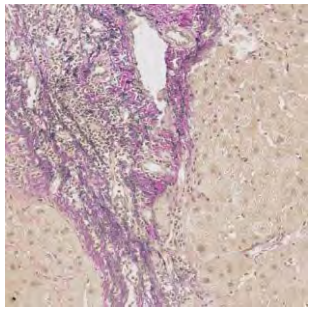
Fibrosis value（A） Fibrosis value（B） Fibrosis value（C）

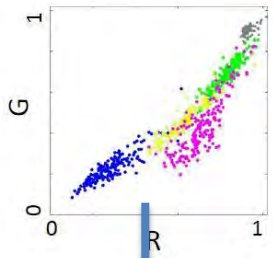


Automatic quantification is necessary

Color variation in histological images

Hospital A

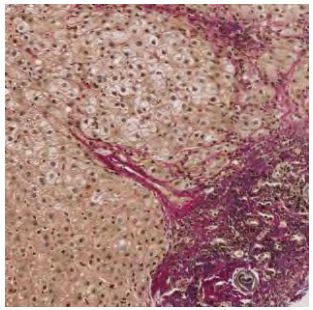


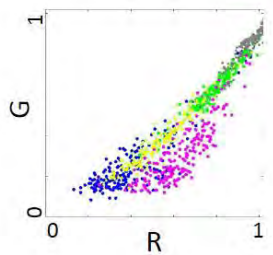


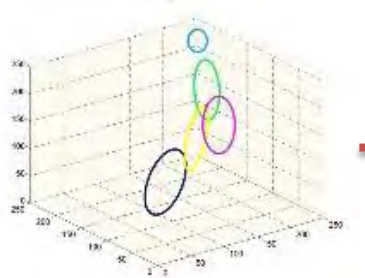
Color of stained tissue vary considerably between hospitals

Different staining condition

Hospital B







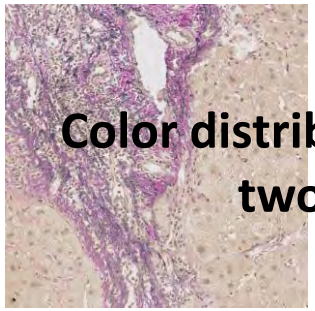
Classifier trained by sampled points from Hospital A

Color Correction of EVG stained tissue Image

Mar. 3, 2014
Tokiya Abe

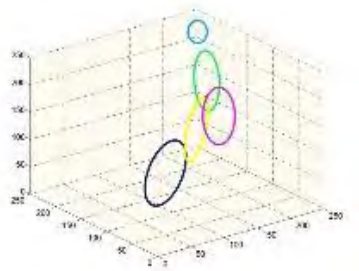
Reference Image (Hospital A)

Test Image (Hospital B)

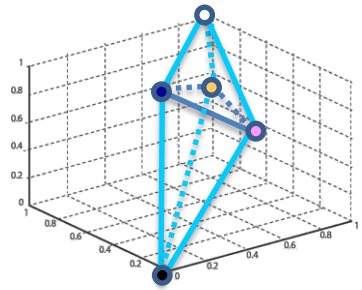


Color distribution model represented by two triangular pyramids

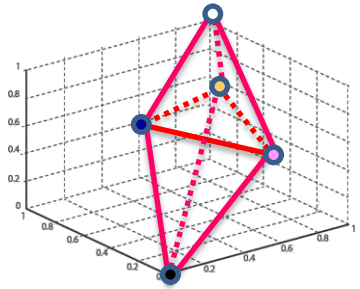
Classifier trained by sampled points from reference image



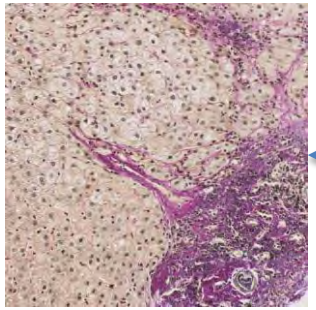
Estimation of two triangular pyramids



Estimation of two triangular pyramids



Corrected Image



Fitting（Reference←Test）

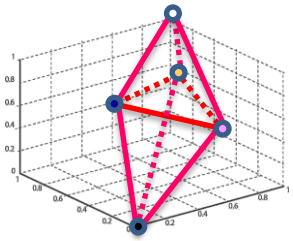
Y. Murakami et al 'Color correction for automatic fibrosis quantification in liver biopsy specimens' J *Pathol Inform* 2013; **4**: 37.

Automatic fibrosis quantification

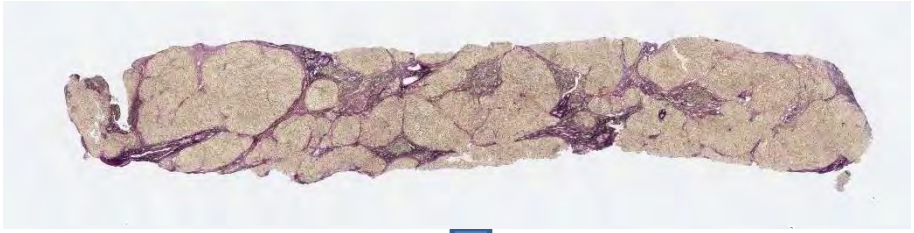
①Acquisition of WSI

②Automatic color sampling

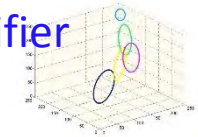
③Estimation of two triangular pyramids



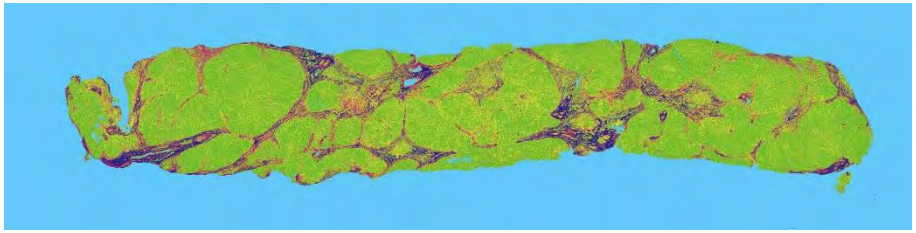
④Color correction



classifier



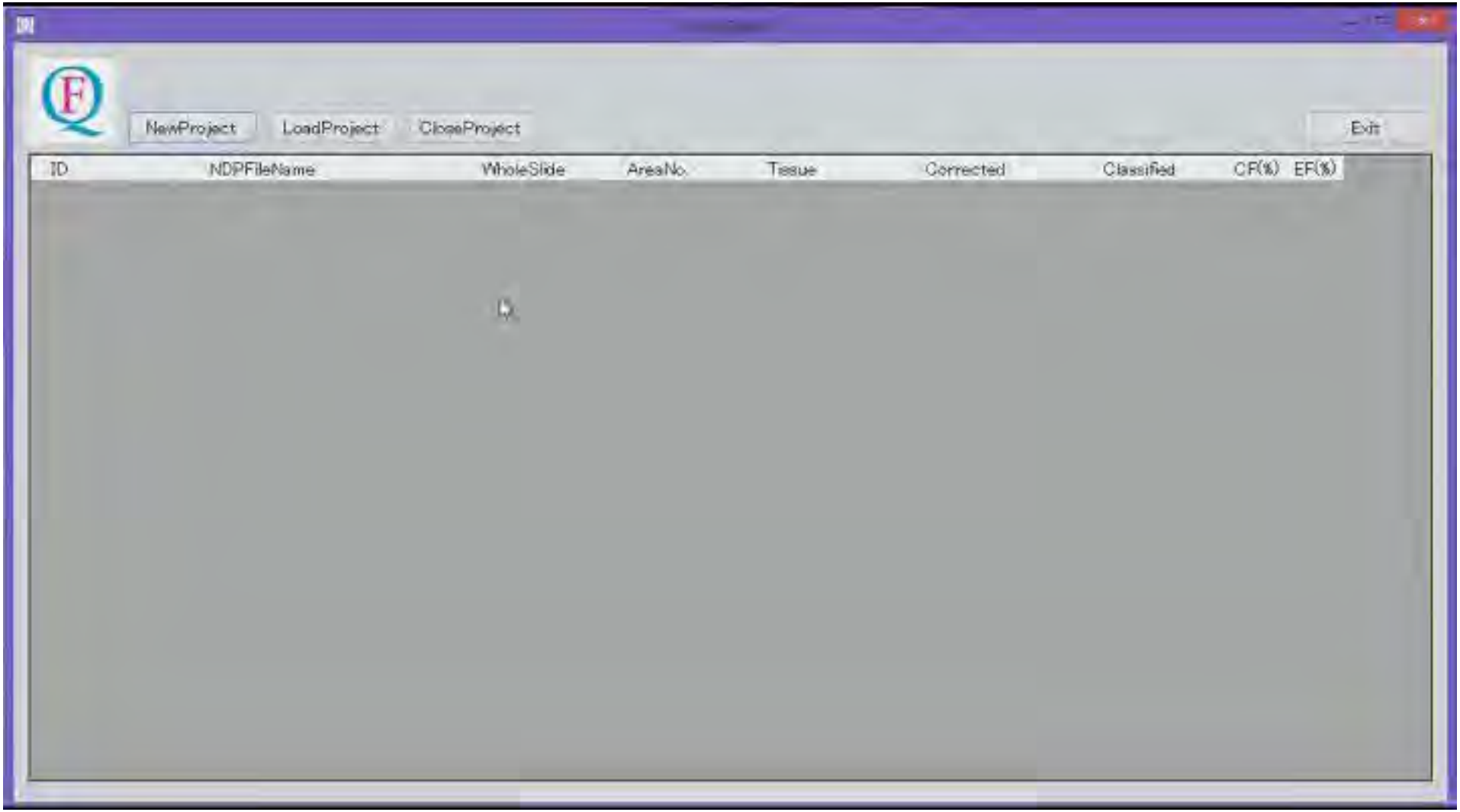
⑤Color Classification



⑥Calculating two types of fiber area

Collagen (%)	Elastin (%)
7.1	7.3

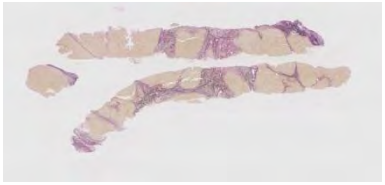
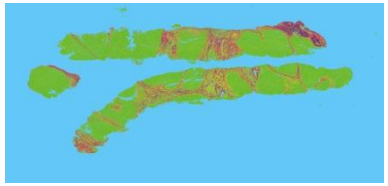
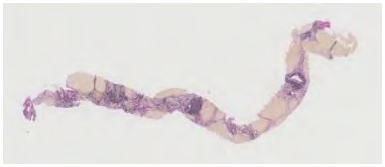
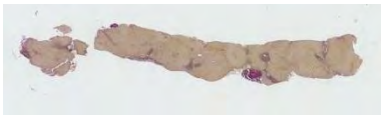
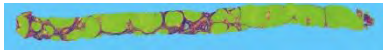
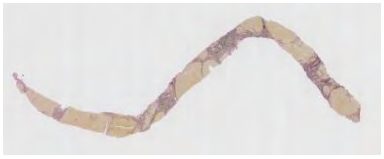
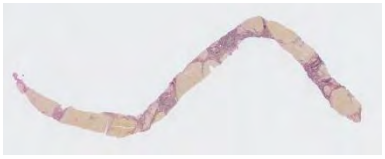
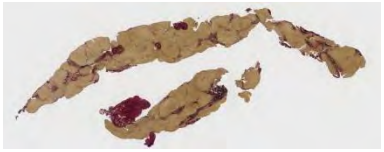
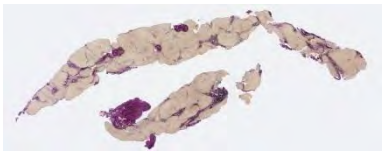
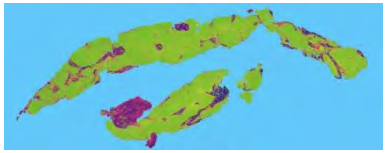
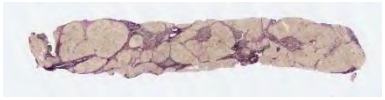
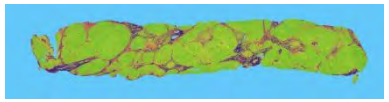
Demonstration



This software is supported by New Energy and Industrial Technology Development Organization (NEDO), JAPAN

Results

Mar. 3, 2014
Tokiya Abe

Hospital	Original	Color corrected	Classified	CF(%)	EF(%)
A	 Reference			8.1	2.4
A				17	10.2
B				4.4	1.3
B				8.7	13.1
C				13.6	2.3
D				5.5	7.9
D				7.1	7.3

Applying more than **500** cases from many hospitals

Conclusion

- **Quantification of liver fibrosis**
  - Topic 1 : Establishment of quantification of liver fibrosis
    - Motivation: Evaluating liver fibrosis contribute QOL of patients
    - Method: Whole Slide Image and 5 color classifier
    - Result: Two types of fiber correlated with liver stiffness.
    - Our method is successful to reflect the degree of liver fibrosis
  - Topic 2 : Development of automatic quantification
    - Motivation: A lot of cases is necessary to reveal the mechanism of the fibrosis progression
    - Method: Color correction based on two triangular pyramids for fibrosis quantification
    - Automatic quantification is successful to apply more than 500 cases from many hospitals

Special Thanks to Histotechnician

For their high quality of work to keep staining condition

Satoshi Kusakari, Hitoshi Abe, Yuko Hashimoto Minako Suzuki, Kiyora Nakajima, Kazuo Suzuki, Azumi Kobayashi, Yuka Kenzaki

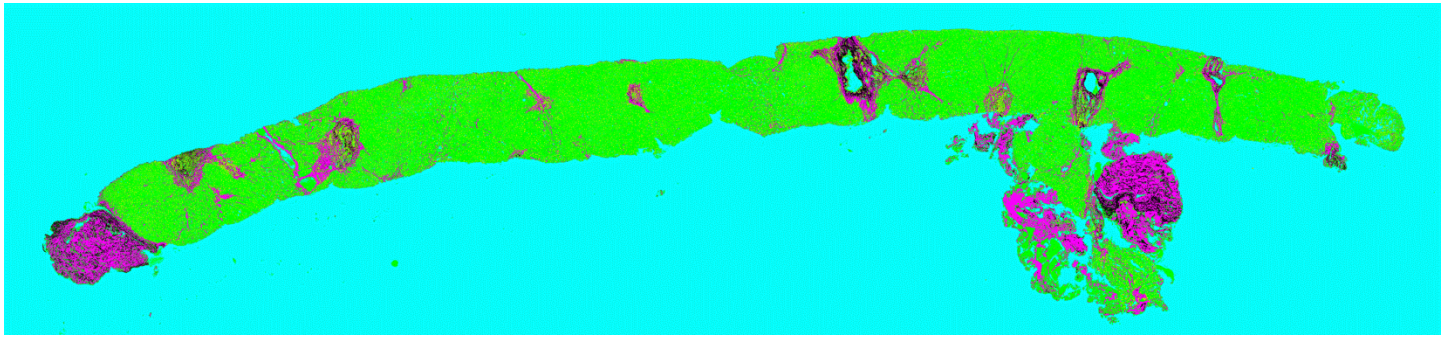
Acknowledgment

This research is supported in part by New Energy and Industrial Technology Development Organization (NEDO), JAPAN

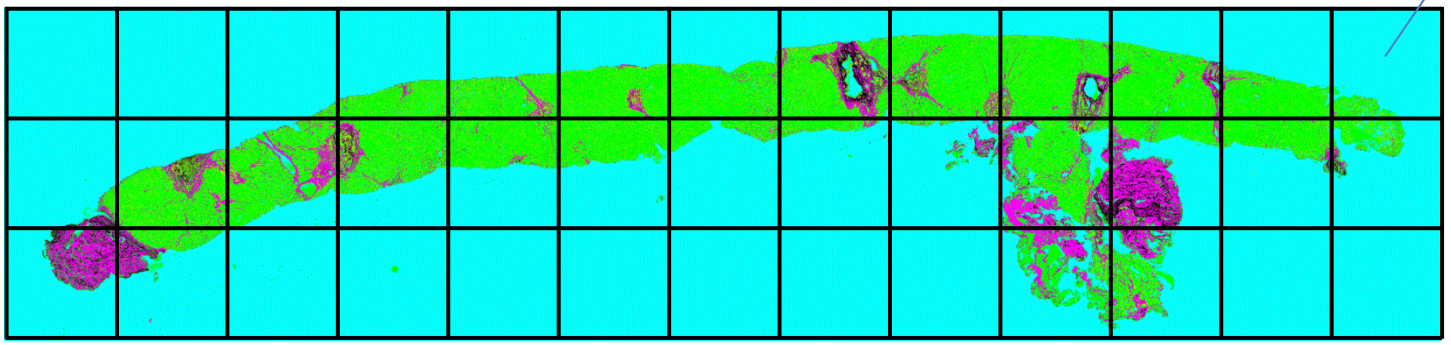
Questions?

Median Value of Fiber area (%)

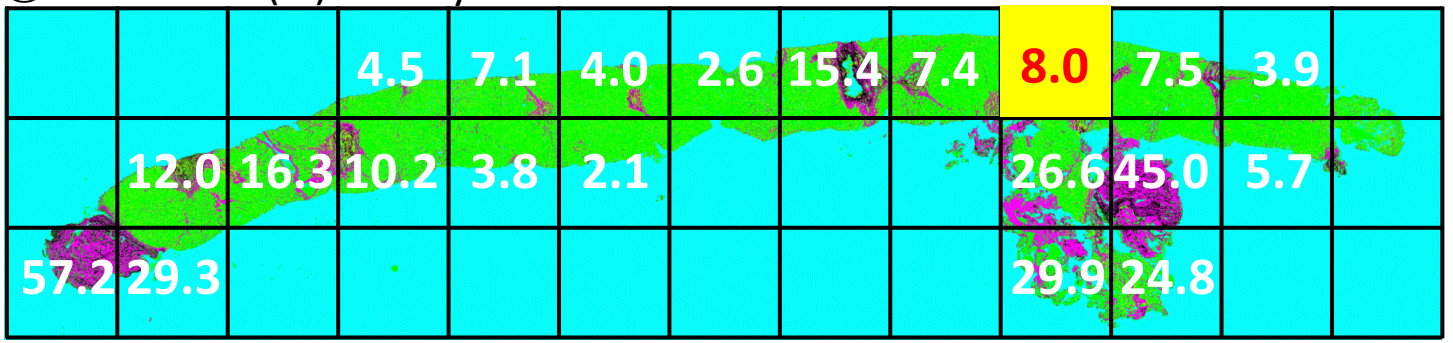
①Classified WSI



② The WSI was divided into small tiles of 1 × 1 mm²

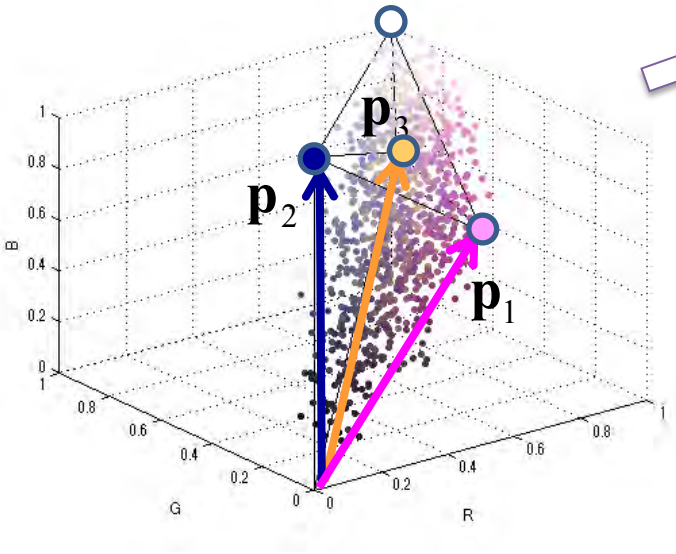


③ Fiber area (%) on any tile



④ The median value fiber was determined ⇒ **8.0%**

Color Correction



Color distribution model represented by two triangle pyramids. Two pyramids are specified by three primary vectors *P1, P2* and *P3*

RGB image signals (**c**) is represented by the additive mixture of the primary vectors (*P1, P2* and *P3*)

Primary vector of **test** image

$$\mathbf{c} = w_1\mathbf{p}_1^{test} + w_2\mathbf{p}_2^{test} + w_3\mathbf{p}_3^{test}$$

Corrected $$\mathbf{c}' = w_1\mathbf{p}_1^{ref} + w_2\mathbf{p}_2^{ref} + w_3\mathbf{p}_3^{ref}$$

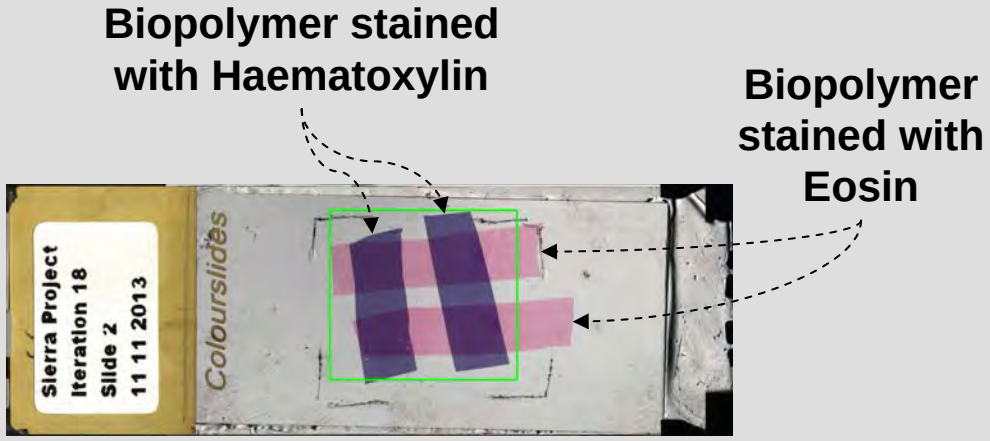
Primary vector of **Reference** image

FFEI proposal for calibration assessment slide status update

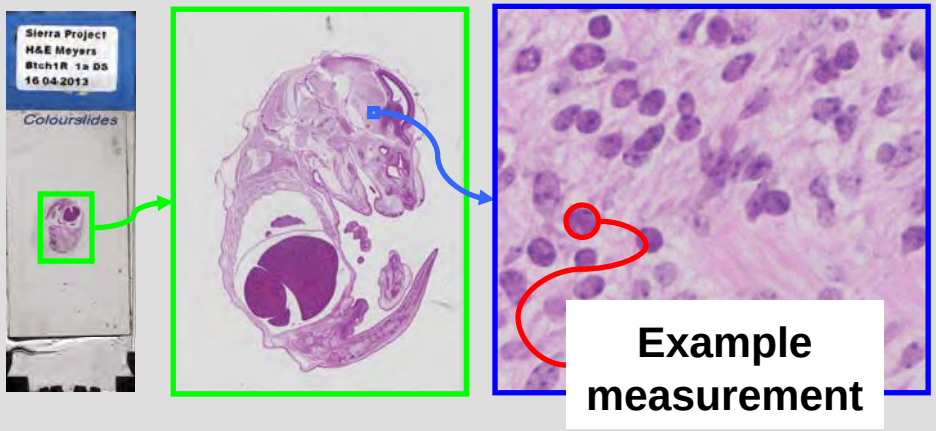
Craig Revie on behalf of George Hutchinson
FFEI Limited

Stained biopolymer compared with stained tissue

Stained biopolymer

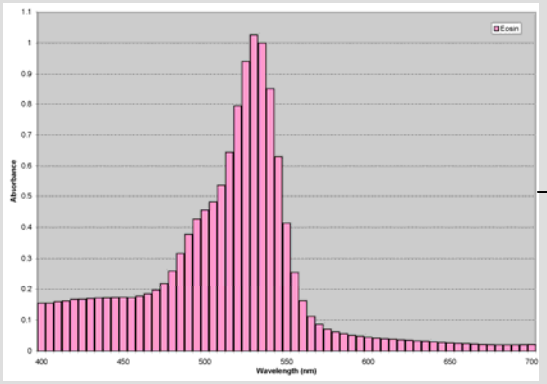


Stained tissue



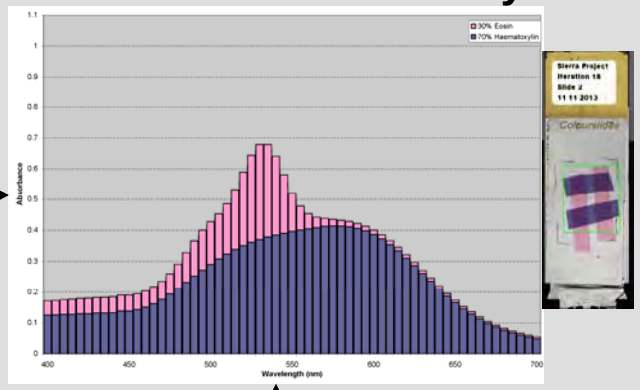
Behaviour of stains (example shows H&E)

Eosin

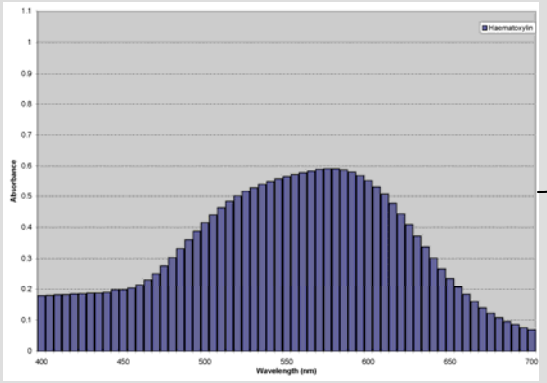


30%

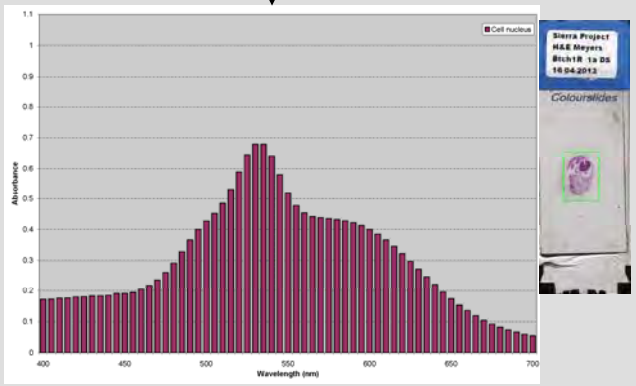
30% Eosin + 70% Haematoxylin



=



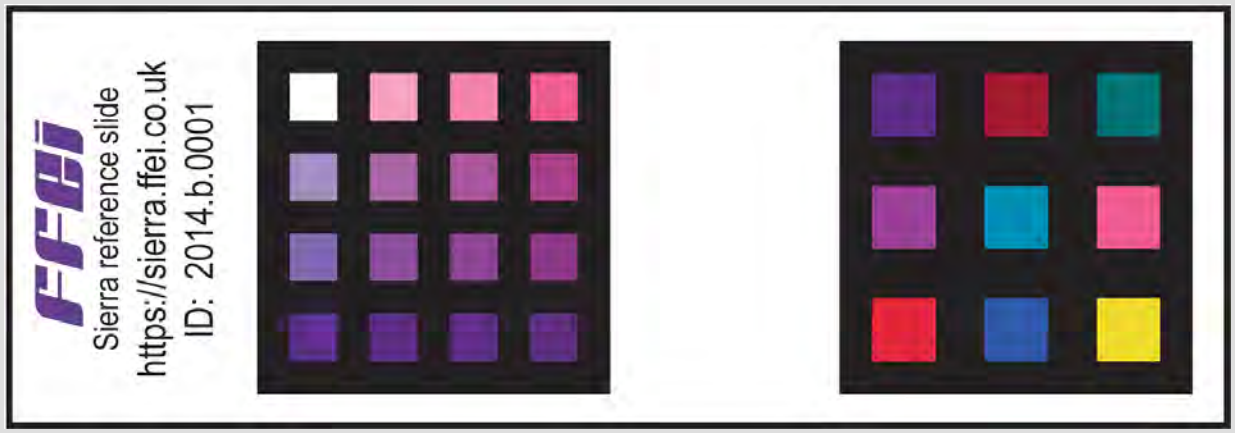
70%



Haematoxylin

Example colour spectrum is simple linear addition of 30% Eosin and 70% Haematoxylin

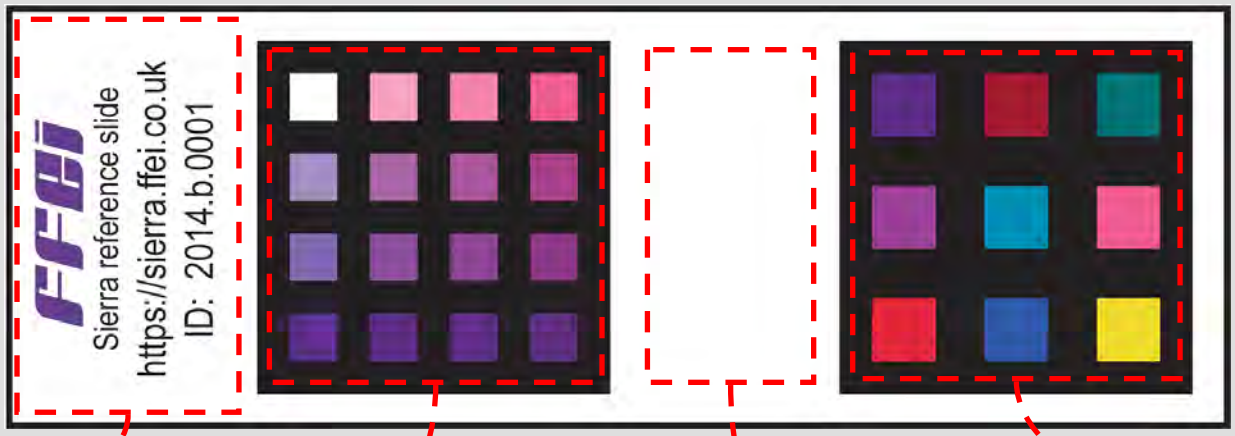
Calibration assessment slide



Slide uses FFEI's biopolymer staining technology to create a set of typical pathology colours

Unlike real pathology samples, coloured patches are uniform and are relatively easy to measure

Calibration assessment slide



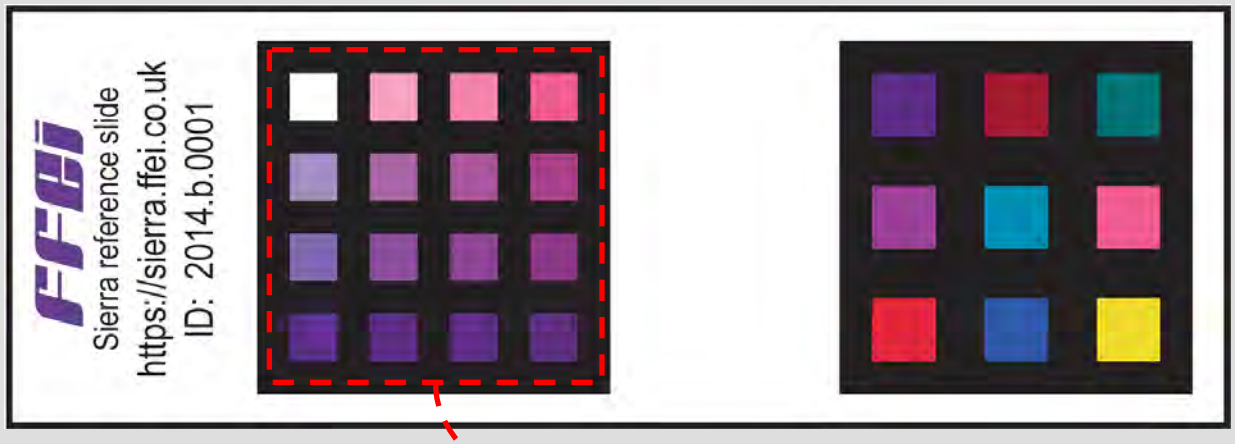
Slide identification area

H&E stain assessment area

Control patches area

Extended / visual assessment area

Calibration assessment slide

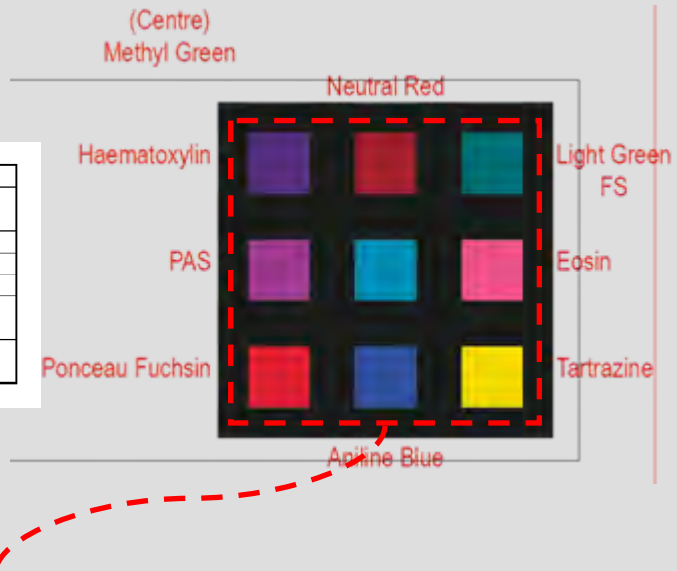


H&E stain assessment area

- 15 colours from the gamut of colours that appear on H&E stained slides and a 'reference white'

Calibration assessment slide

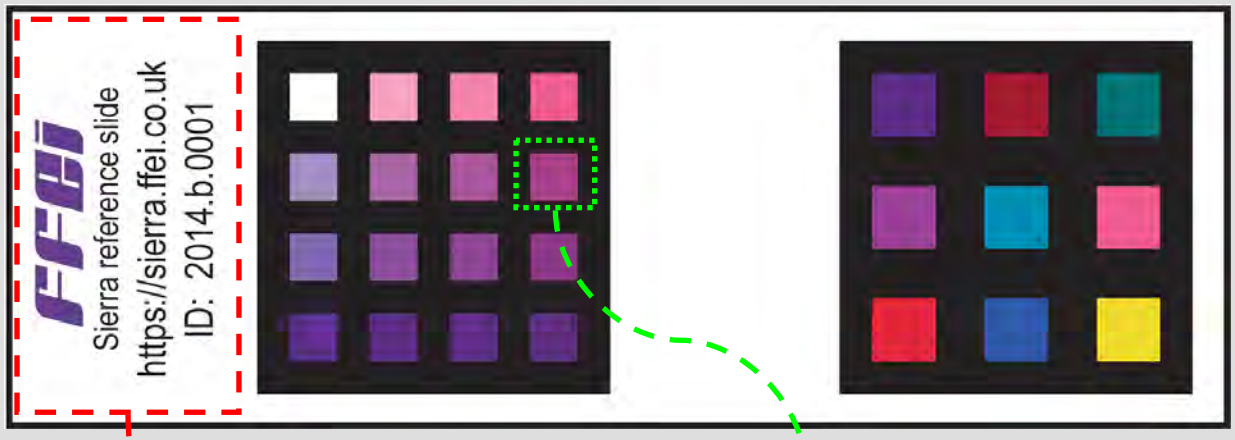
Stain	Staining protocol
Haematoxylin	Mayer's H&E, Harris H&E, H-DAB, PAP, Congo Red for Amyloid, Masson's Trichrome
Eosin	Mayer's H&E, Harris H&E, PAP
PAS	Periodic acid-Schiff, Alcian Blue PAS,
Ponceau Fuchsin	Ziehl Neelsen, Millers elastic Van Gieson, Masson Trichrome
Neutral Red	Gram Neutral Red
Aniline Blue	MSB
Methyl Green	Methyl Green
Light Green SF Yellowish	Papanicolaou, Jones methenamine silver, Masson trichrome
Tartrazine	Shikata

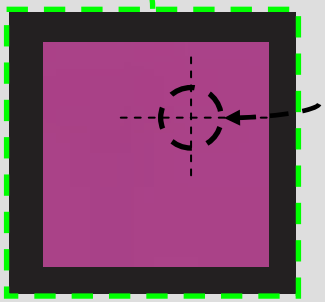


Extended / visual assessment area

- 9 stains that form the basis of a number of commonly used staining protocols
- set of colours selected to cover the gamut of colours found in stained pathology samples

Calibration assessment slide





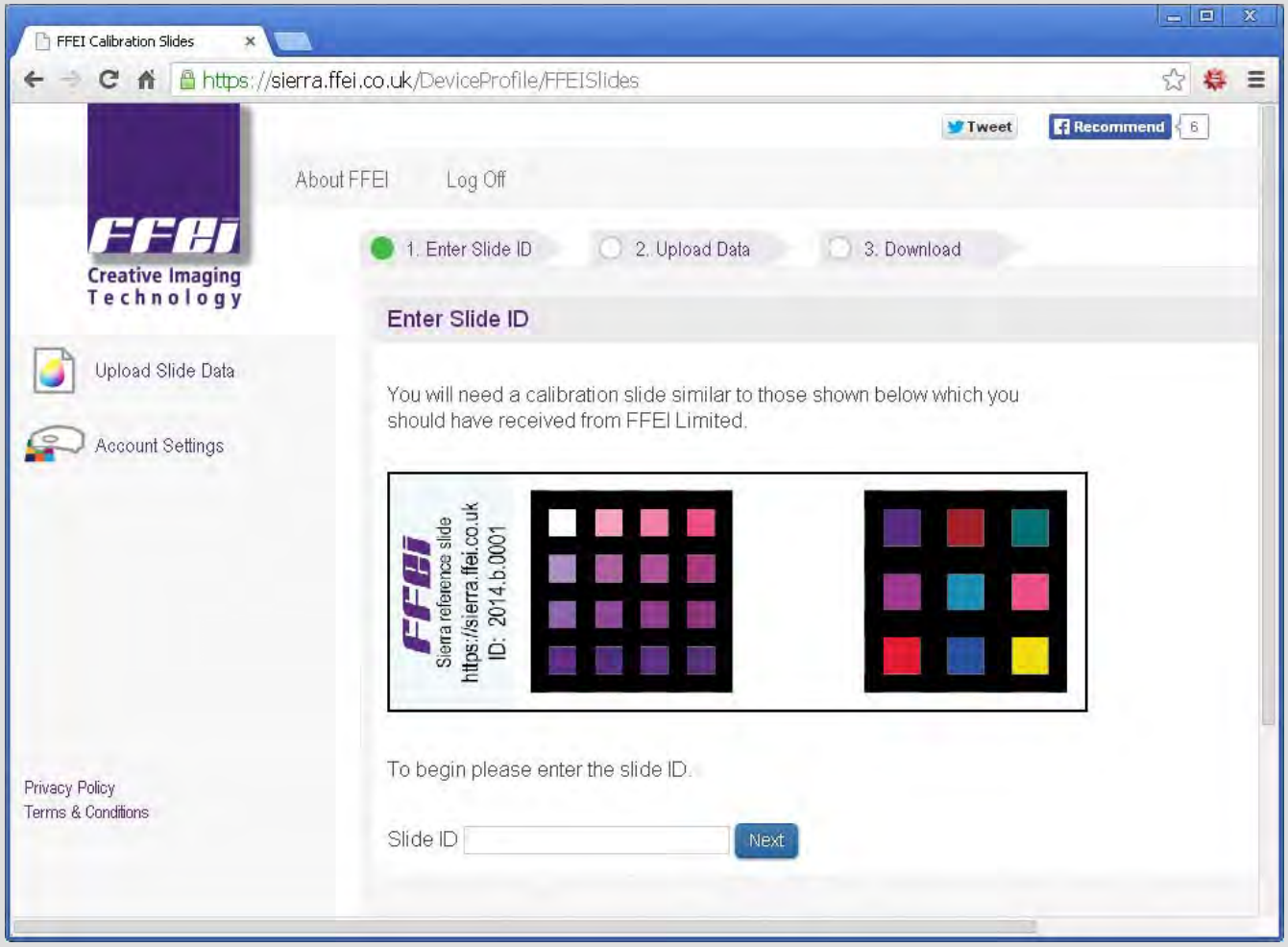
Individual measurement point

Slide identification area

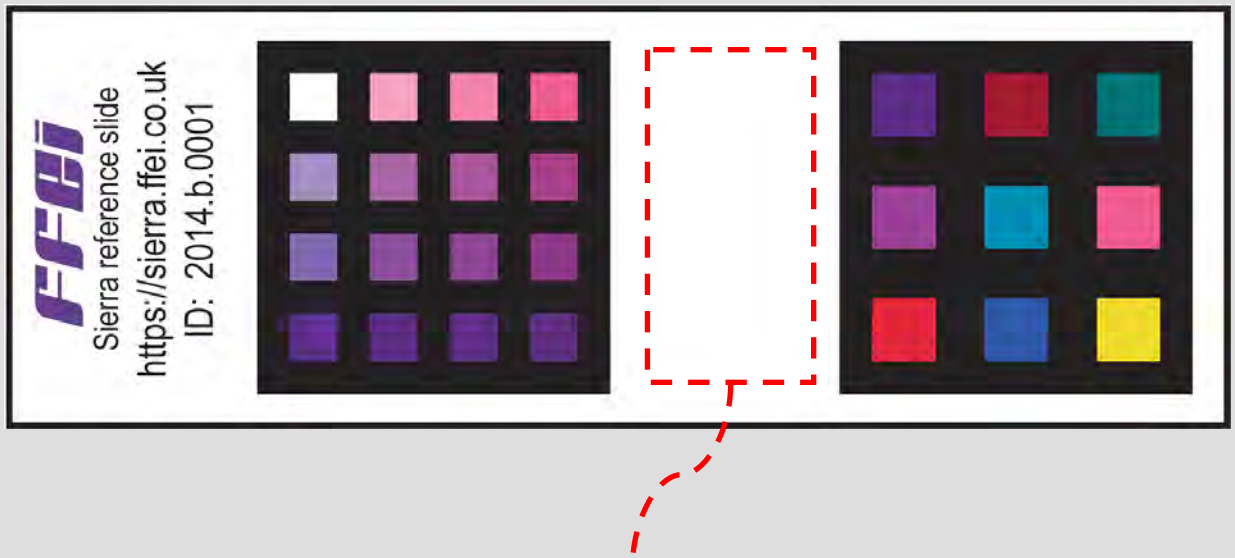
- measurements for each slide and other data can be shared on a web site developed by FFEI (https://sierra.ffei.co.uk)

Average measurement value for each patch and colour of identified measurement point will be available

https://sierra.ffei.co.uk



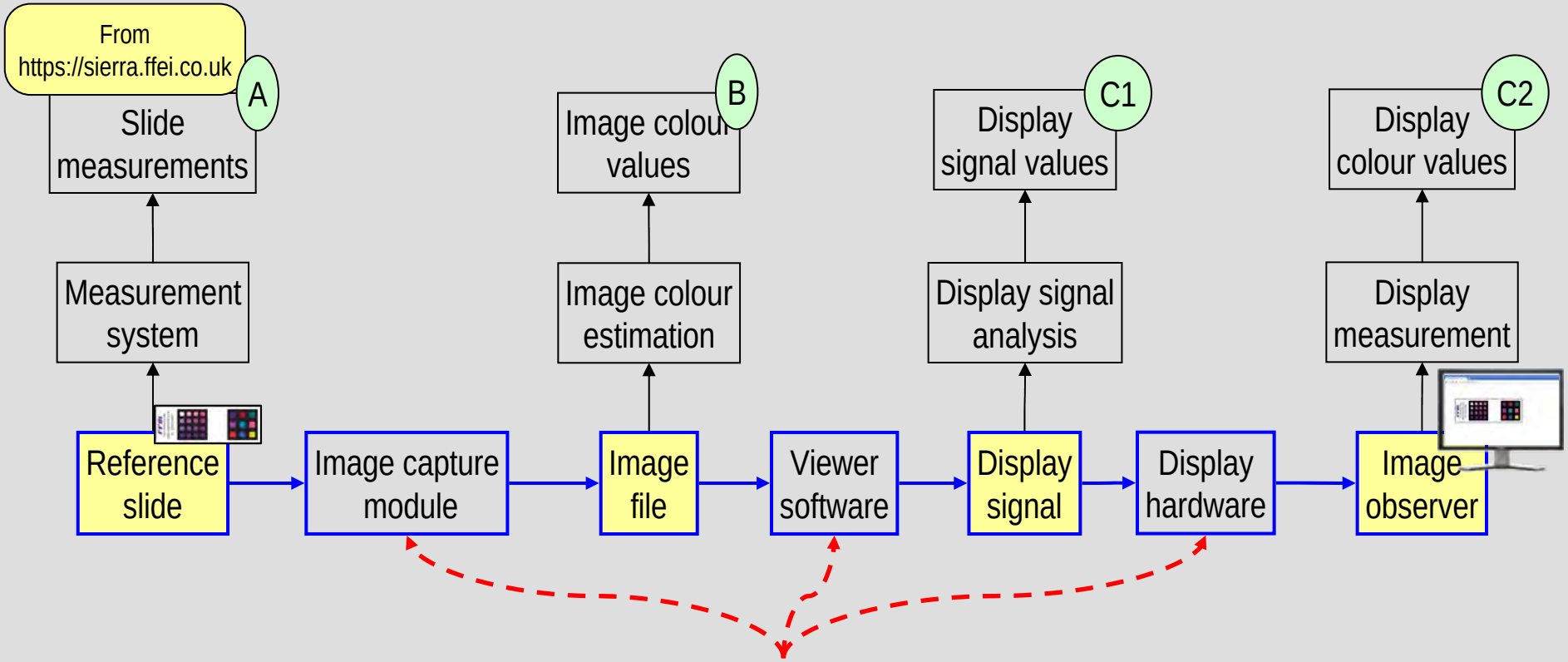
Calibration assessment slide



Control patches area

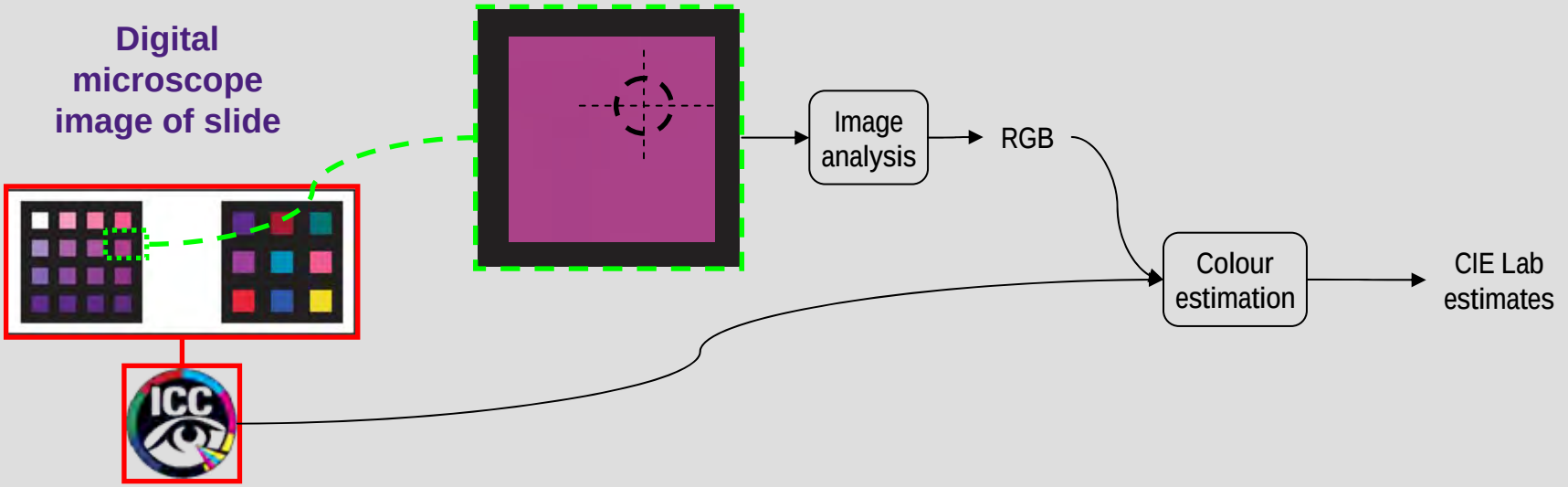
- will include additional patches to be used to indicate when the slide must be replaced (TBD)
- possibly add a set of neutral patches

How we expect the slide will be used



System components are calibrated using manufacturer's calibration method
The aim of the calibration assessment slide is to demonstrate / check that the system is able to handle colour with sufficient accuracy

Assessment step B: image colour values



ICC profile for calibrated digital microscope

Image processing software identifies average image RGB value for entire patch and image RGB value for the identified measurement point

These values are used in conjunction with the ICC Profile to determine the colour as seen by the digital microscope (CIE Lab estimates)

These values can then be compared with the slide measurements to determine the accuracy of the digital microscope capture system

Assessment step C1: Virtual Display

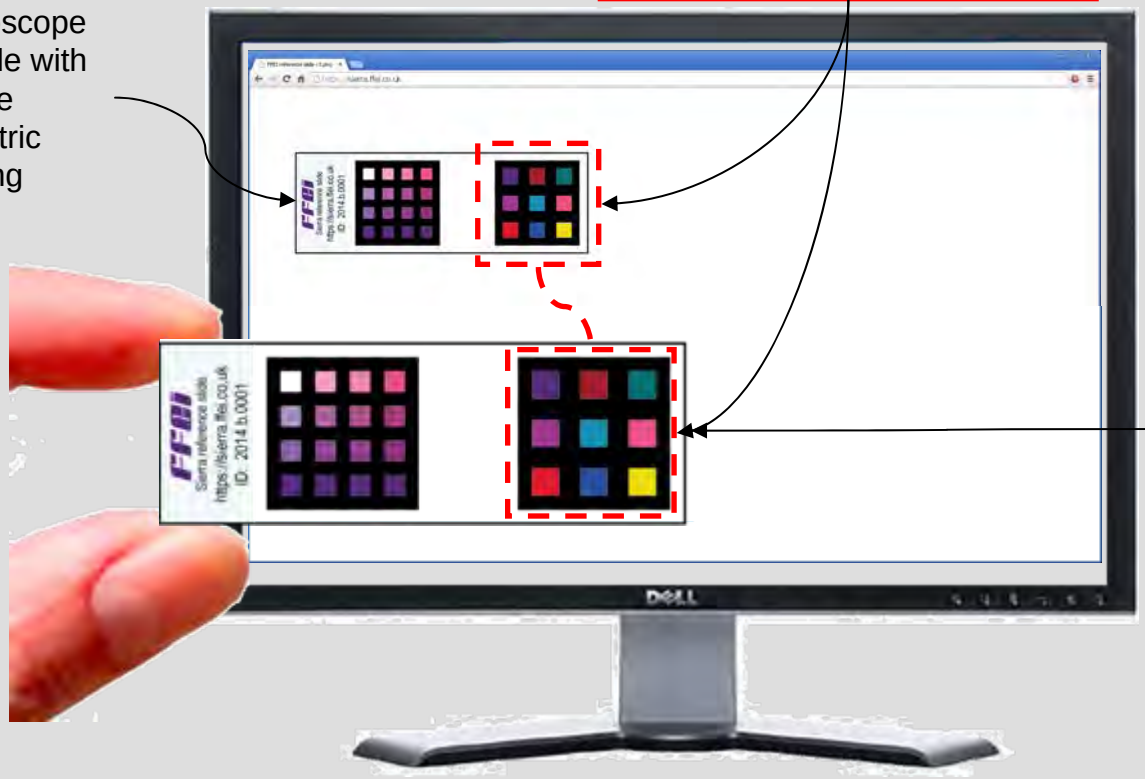
- Method proposed by Wei Chung Cheng (or similar) can be used to calculate average image RGB value for entire patch and image RGB value for the identified measurement point
- This data can be used in conjunction with the display ICC profile to calculate the colour values being presented for display

- See http://www.color.org/groups/medical/VDCP.xalter for details of the Virtual Display Color Processor proposed by Wei Chung

Assessment step C2: visual assessment

System should only be used to view digital microscope slides if these two sets of colours are closely matched

Digital microscope image of slide with Relative Colorimetric rendering



Microscope slide is illuminated by the display back light

Viewing conditions for the microscope slide and slide image are identical

Based on a method developed and promoted by Yukako Yagi and Pinky Batista

Round-robin slide assessment proposal

- **Objectives**
  - check that all of the vendors are able to scan the slide and produce an image / ICC Profile
  - check that colour errors can be estimated reliably for this image by the participants
  - identify additional patches needed
- **Procedure**
  - FFEI manufacture, measure and scan slide
  - each company measures (where possible) and scans slide
  - slide returned to FFEI for measurement by the 'initial' measurement system to ensure that patch colours have not changed
  - measurements and scans to be shared between participants only
    - we could use https://sierra.ffei.co.uk for this purpose
- **If necessary second revision of slide created**
  - set of patches modified to include other or additional stains
  - geometry modification
  - . . .
- **Result of round robin assessment published**
  - will show the current calibration capability
  - can be used to define requirements for calibration assessment

Participants

- FFEI Limited (will manage the round-robin process)
- FDA (Aldo Badano, Wei-Chung Cheng)
- MGH (Yukako Yagi, Pinky Batista)
- Leica Biosystems (Allen Olson)
- Philips (Bas Hulsken – to be confirmed)
- Ventana (Scott Forster – to be confirmed)
- . . . others . . .

Call for participation

FFEI is currently exploring a number of options to fund the development and commercialisation of this slide

Contact George Hutchinson at FFEI

George.Hutchinson@ffei.co.uk

(or craig.ffei.co.uk)

Use cases for multi-spectral In digital pathology

Bas Hulsken
Philips Digital Pathology (Philips Group Innovation)
3 March 2014

PHILIPS

Needs for multi-spectral in digital pathology

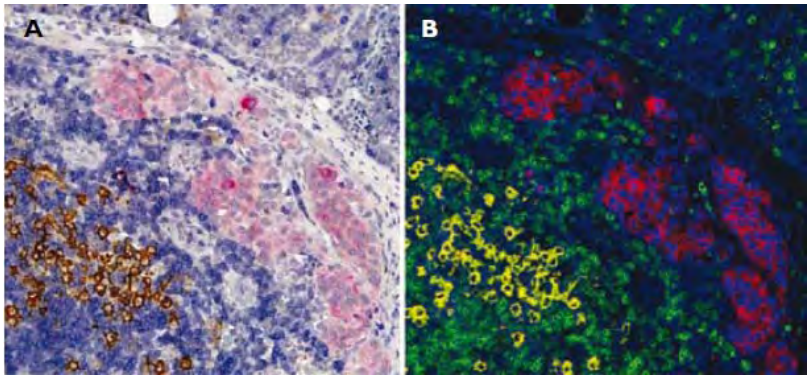
- Improved true color (wide gamut) rendering with 4 or more channels
- Standardized way to store and exchange multi-spectral image data
  - Reproducible fake color images (e.g. for fluorescent imaging)
  - Standardize channel un-mixing while preserving raw data

Current limitations in DICOM

- Only 3 input channel ICC v4 profiles are available in DICOM
  - 3 channels is too limited for most fluorescent & multi-spectral use cases
  - ICCv4 profiles describe transformations to 3 channel PCS, which will lead to information loss for all multi-spectral uses cases where true color rendering is not the sole objective.

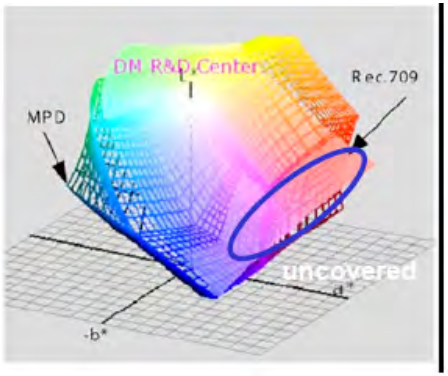
Use case: 4+ channels for wide gamut true color images& spectral analysis

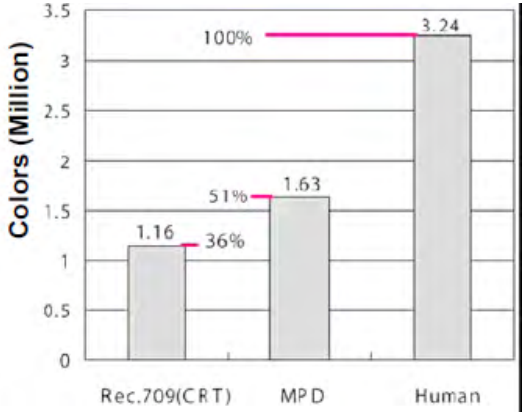
- Most Whole Slide Imaging devices are using LED illumination, this allows:
  - narrow band illumination with >3 channels for wide gamut imaging
  - narrow band illumination for spectral analysis of images, e.g., for "fluorescence-like" segmentation (for display& algorithms)



Multi-spectral bright field segmentation

Source:ttp://www.rms.org.uk/Resources/Royal%20Microscopical%20Society/infocus/infocus%20June%2009%20-%20Mansfield%20_%20Levenson%20Article.pdf





5 channel HDTV, **Source:** Journal of Imaging Science and Technology, Volume 49, Number 6, November/December 2005 , pp. 594-604(11)

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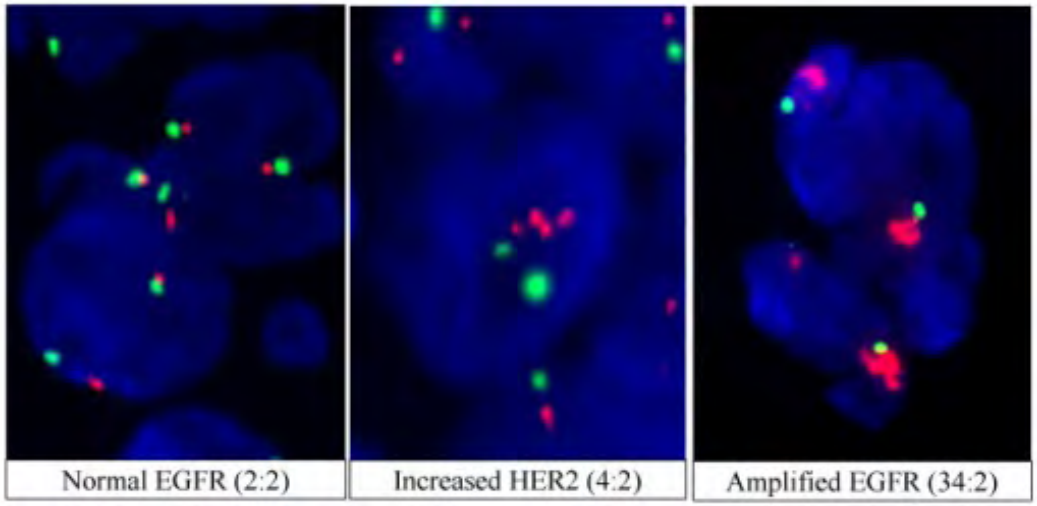
Use case: FISH assay with 4+ channels, marker separation for algorithms and display

- Remove raw capture channel crosstalk to get one channel per biomarker and auto-fluorescence suppression, for display and algorithms.
- Define standardized pseudo color display for each bio-marker
- Allow capture device calibration to get quantitative bio-marker concentrations



http://biosearch.berkeley.edu/image.php?img=images%2Fopensearch%2Fartid%3D1952070%26blobname%3D1471-2407-7-128-4.jpg&pmid=17626639&fig=4

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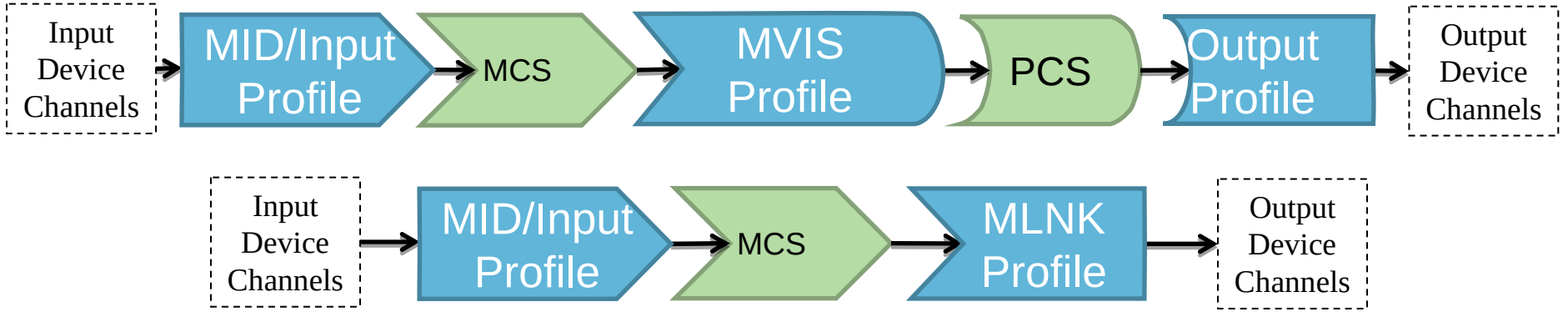
Multispectral Imaging using MCS

- **One proposed approach to solving these problems would be to successively apply device link profiles**

- **Intermediate device channels must exactly match**
- **This can quickly become unwieldy!**
- **MCS Proposal extends on this by making the Intermediate Device Channels concept more dynamic and configurable**



Medical Display and Colour Calibration & Measurement

Thank you, Craig.
[Good afternoon, everybody.
I'm Takashi Matsui from EIZO Corporation, a display manufacturer in Japan.
Since 2005, I've been engaged in the image quality control standardization of medical displays under IEC as a representative of Japan Industrial Association of Radiological Systems, in short, JIRA. My participation of this meeting is just an extension of that kind of standardization activities.]
Craig suggested me to be the moderator of this session maybe because the meeting is held in Japan I'm located.
Though this is my first experience to be a moderator in this kind of meeting, I'll do my best. [ ]: Skipped

The primary goal of this session is to share the latest status of discussions on display calibration for color medical images especially with Japanese members and participants. Of course, the progress of the discussions during the session is desirable.

So, to achieve the goal, I'll first summarize the recent discussions focusing on main topics, which I hope useful as a preface to Part 2.

In Part 2, we have two speakers from different display vendors about the same topic "Perceptually Linear Color Behavior of Displays" though it is up to each speaker whether to focus on the specific topic only or also to mention other topics he thinks important.

Agenda for Part 1

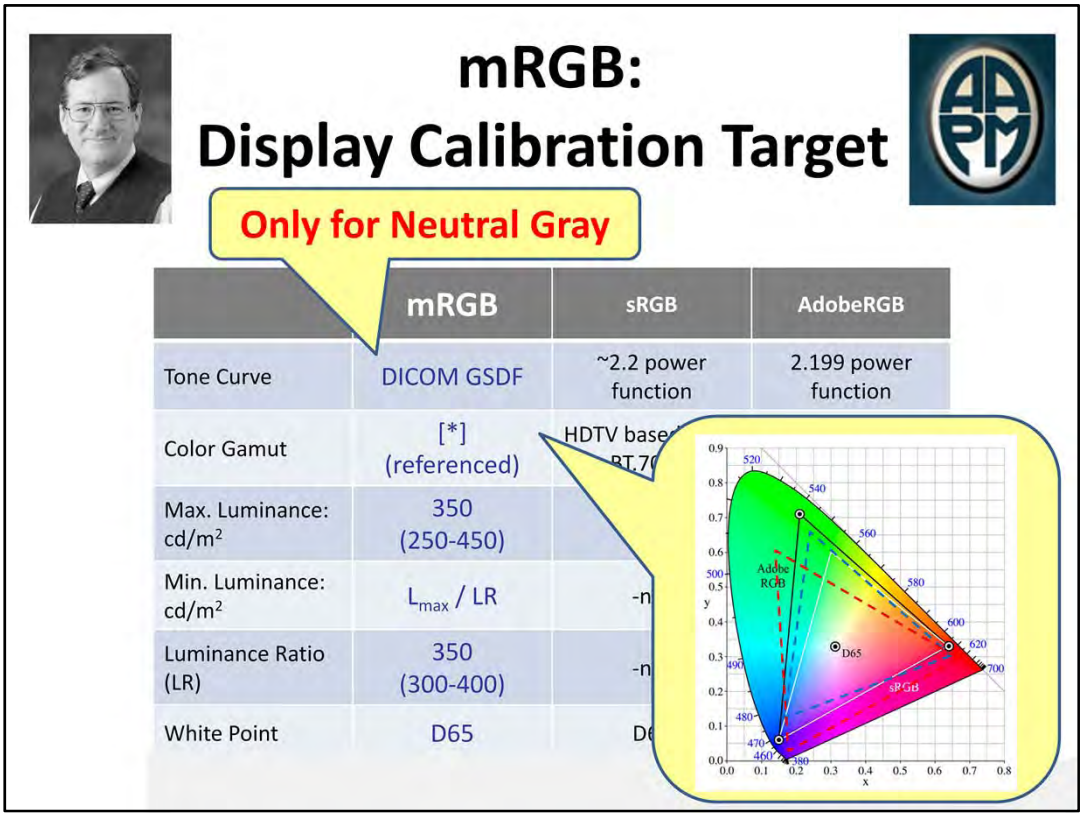
- **mRGB: Display Calibration Target**
  - vs. sRGB, AdobeRGB
  - vs. DICOM GSDF
- Usage Scenario
- Other Topics

This is an agenda for Part 1.
I'll first explain mRGB comparing with concepts or terms with which you are familiar.
The precedent in the realm of radiology will be also mentioned.
Then I'll introduce usage scenario of the assumed architecture and other important topics.

mRGB: Display Calibration Target

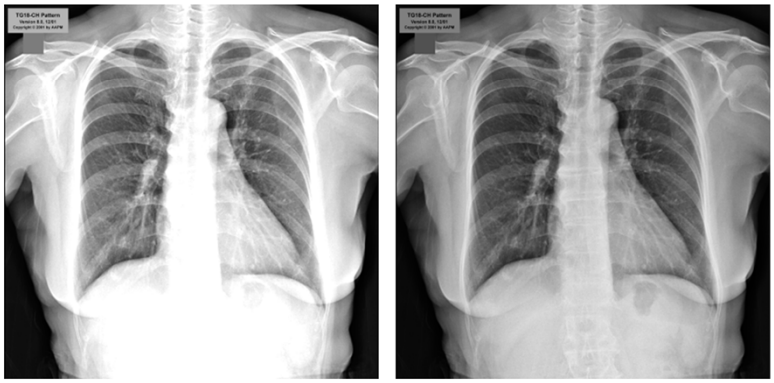
	mRGB	sRGB	AdobeRGB
Tone Curve	DICOM GSDF	~2.2 power function	2.199 power function
Color Gamut	[*] (referenced)	HDTV based ITU-R BT.709-5	'Wide' (extended G)
Max. Luminance: cd/m^2	350 (250-450)	80	160 (125-200)
Min. Luminance: cd/m^2	L_{max} / LR	-nd-	0.56
Luminance Ratio (LR)	350 (300-400)	-nd-	287.9 (230-400)
White Point	D65	D65	D65

"mRGB" is calibration target for medical displays to display clinical color images under discussion in AAPM Task Group 196.
This table shows a comparison of mRGB drafted by Dr. Flynn, the chair of imaging informatics subcommittee of AAPM and existing color space standards, sRGB and Adobe RGB. The comparison table itself was made by Dr. Flynn.
As you know, a calibration target for displays usually consists of tone curve, luminance range and white point.
Even chromaticity of the primaries or color gamut can be sometimes adjusted.
The main difference of the new calibration target from the conventional ones is that [Click] [Click]



The chromaticity coordinates of primaries are not defined in the former. Or in other words, we can say that the gamut is left to each display device. Also a new tone curve is defined for the former [Click].
mRGB can be called a relative calibration target in contrast with conventional color space standards as an absolute calibration target.

Realize Similar Appearance of Images Regardless of Display Differences



As a relative calibration target, mRGB is intended to realize similar appearance of color images somehow regardless of characteristics differences of display devices like brighter or darker or [Click]

Realize Similar Appearance of Images Regardless of Display Differences

narrow color gamut or wide color gamut.
Since the similar effort was already done for monochrome images in the realm of radiology,
I'll explain what was already accomplished there in order to clarify what is intended with mRGB from the next slide,

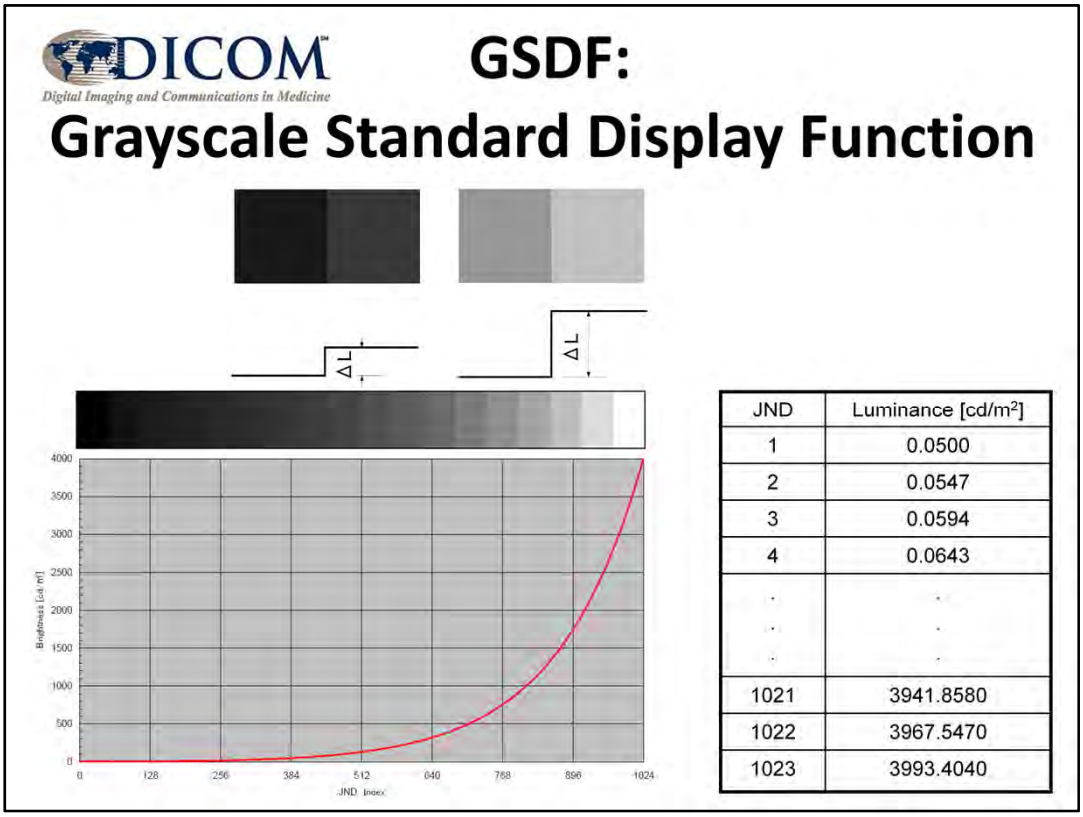
Consistent Presentation

In the realm of radiology, the most important mission of medical diagnostic displays is to provide consistent presentation of clinical images.
And the consistency must be guaranteed across multiple-display devices and over time.
Otherwise [Click]

Consistent Presentation

- **Otherwise diagnostic accuracy may be damaged!!**

Diagnostic accuracy may be damaged.



JND	Luminance [cd/m^2]
1	0.0500
2	0.0547
3	0.0594
4	0.0643
.	.
.	.
.	.
1021	3941.8580
1022	3967.5470
1023	3993.4040

Since x-ray image is just a shadow of a targeted object on the digital sensors and subtle shading is the only clue to detect lesions, grayscale characteristics is the most crucial concern for display devices.

GSDF was defined to provide some level of similar appearance for a given image between presentation systems of different luminance ranges e.g. light boxes with films (1000 cd/m2 <) and relatively darker displays at that time CRT around 200 cd/m2).

The similar appearance is supposed to be realized through perceptual linearization, which means equal changes in digital values cause equal changes in perceived brightness.

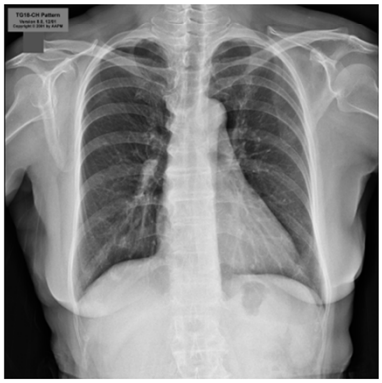
Since the sensitivity of human eyes cannot be expressed in a simple function, experiments were done to measure all the minimum luminance differences that the average human eyes can perceive and the results were collected up to a table of luminance values

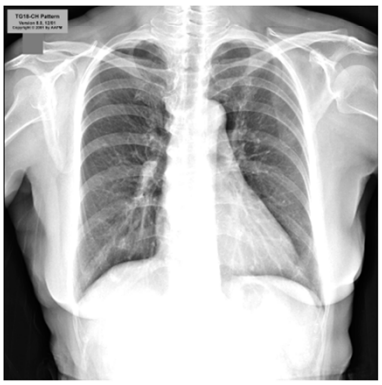
The minimum difference to be perceived is called Just Noticeable Difference or JND and roughly speaking, GSDF or Grayscale Standard Display Function is the collection of JNDs from 0.05 cd/m^2 to 4000 cd/m^2.

A display is calibrated so that available # of JND within a certain luminance range can be equally assigned to each tone levels e.g. 2.5 JND for displays calibrated to maximum luminance: 400cd/m^2 and minimum luminance: 1cd/m^2.

GSDF: Similar Appearance of Monochrome Images

On display screen calibrated to GSDF regardless of luminance difference





Again GSDF is intended to realize similar appearance of monochrome images somehow regardless of luminance setting difference of display devices.

mRGB: Conceptual Extension of GSDF: Realize Similar Appearance of Color Images Regardless of Display Differences

- Tone Curve Assumed for Neutral Gray is GSDF
- How about Tone Curve of R, G & B?

Perceptually Linear Color Behavior (PLCB)

  - Appropriate metric also
    - Difference threshold like Delta E2000?
  - To be discussed in Part 2

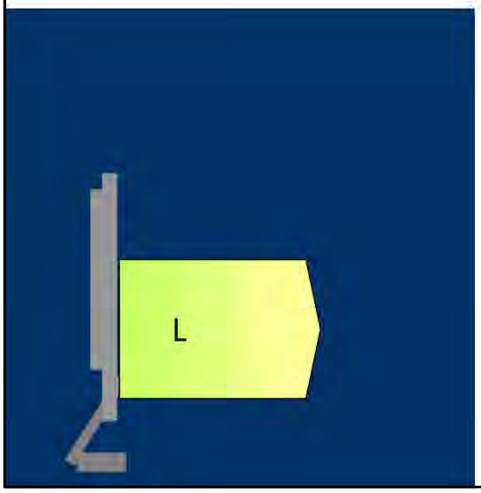
So we can say that mRGB is a conceptual extension of GSDF.
As for the tone curve of neutral gray, there is already a consensus that it should be DICOM GSDF.
So the remnant issue is that what to do with tone curves of R, G & B.
Only one thing sure is that perceptual linearization similar to that of GSDF will be necessary also for color channels.
Dr. Kimpe from Barco called the required characteristics of color channels “Perceptually Linear Color Behavior” in short, “PLCB”.
So in Part two of this session, two speakers from different display vendors will propose what to do with tone curve for R, G and B channels and an appropriate metric for PLCB.

On Displays Calibrated to mRGB…

- Monochrome images targeted for GSDF displays should be **displayed properly w/o Color Management (CM)**
- Color images targeted for PLCB displays should be **displayed properly w/o CM**
- Color images targeted for conventional displays should be **displayed properly w/ CM**

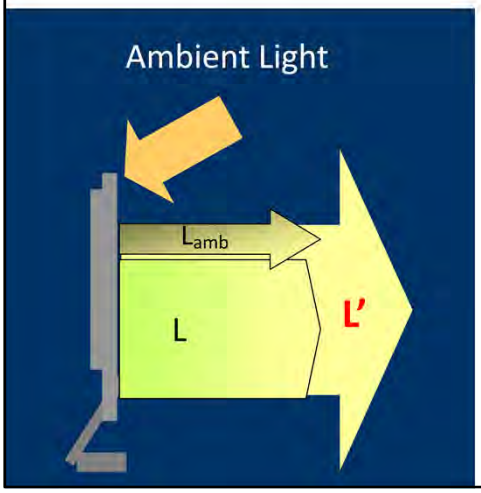
Usage scenario assumed is that on the screen of displays calibrated to mRGB,
Monochrome images targeted for displays calibrated to GSDF should be displayed properly w/o color management (CM)
Color images targeted for displays calibrated to mRGB should be displayed properly w/o CM
Color images targeted for conventional displays calibrated to e.g. gamma = 2.2 should be displayed properly w/ CM

Other Topics under Discussion: "Ambient Light/Surround"

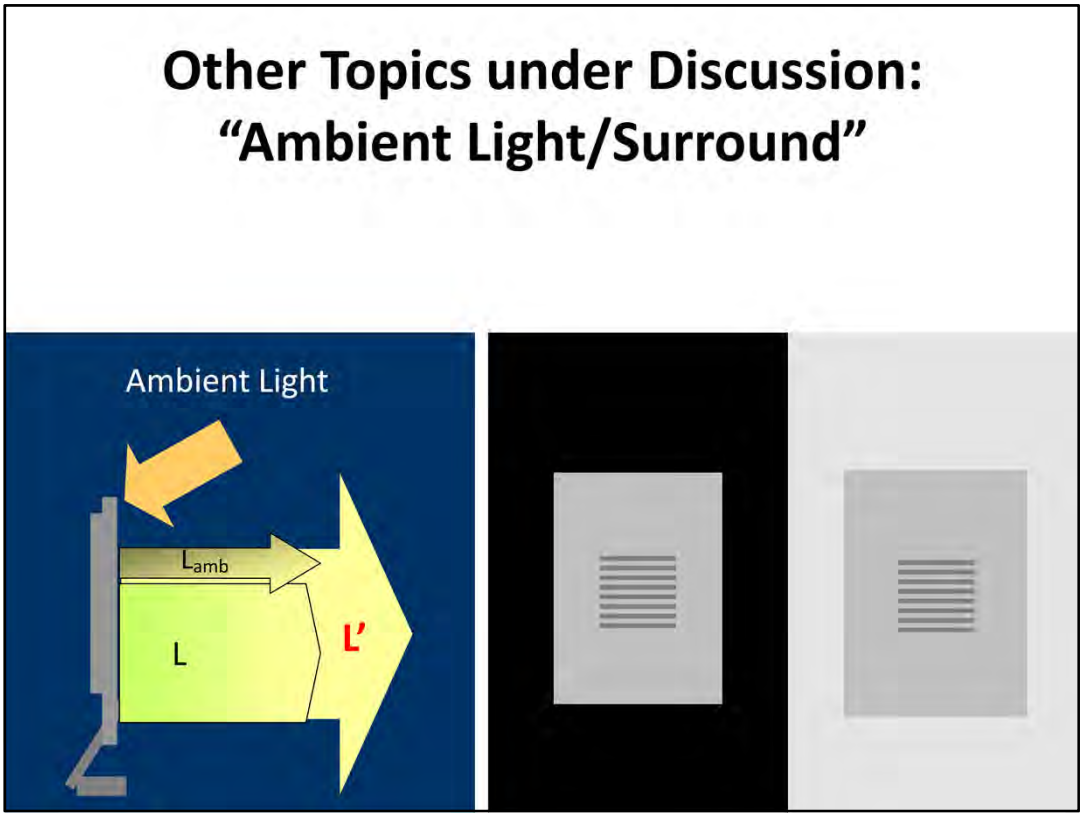


In conventional GSDF calibration, the effect of the ambient light is taken into account.
That means that the target of the calibration is not the light directly emitted from the display screen "L", but "L'", the sum of L and the diffused reflected light "Lamb"[Click][Click].

Other Topics under Discussion: "Ambient Light/Surround"

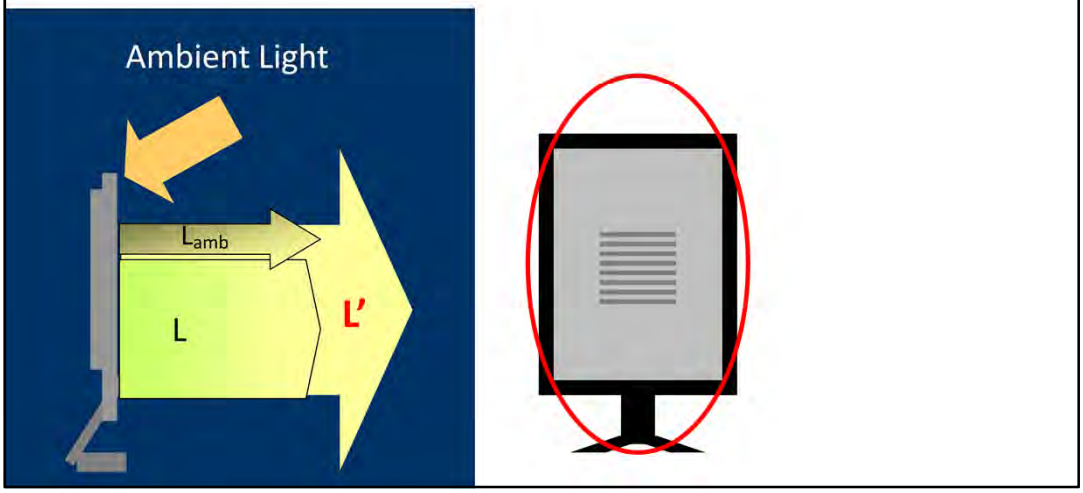


Though the surround may certainly affect image appearance as the right diagrams shows [Click],



this kind of effect (called visual illusion) has not been investigated at least in the realm of radiology as far as I know.
The related research I know was targeted to reduce eye strain due to the luminance difference between the bright display screen and the dark surround by decreasing the difference between the two. We certainly feel a kind of eye strain when watching display screen in a very dark environment.
To concentrate on the clarification of PLCB in Part 2, [Click]

Other Topics under Discussion: "Ambient Light/Surround"



It may be easier to assume that there is no ambient light and we can ignore it or the ambient light is constant and we don't have to watch it and put the issue of visual illusions on the shelf for a while.

Conclusions

- **"mRGB"** is alternative calibration target for medical displays to display clinical color images
- mRGB is intended to realize **Similar Appearance** of color images **Regardless of Display Differences**
- **"Perceptually Linear Color Behavior (PLCB)"** may be a key to realize similar appearance of color images

In closing of Part 1, I would like to summarize the points of my presentation.

"mRGB" is an alternative calibration target for medical displays to display clinical color images
As a relative calibration target, mRGB is intended to realize similar appearance of color images somehow regardless of characteristics differences of display devices.
"Perceptually Linear Color Behavior (PLCB)" may be a key to realize similar appearance of color images on various display screens calibrated to mRGB.

Part 2: What is “Perceptually Linear Color Behavior (PLCB)”?

- Yu Kosugi (EIZO)

- Tom Kimpe (Barco)

The next speaker is Yu Kosugi from Eizo.
Yu Kosugi joined Eizo in 2006 and has been engaged in the development of diagnostic displays.
He recently joined international standardization project within Eizo and this meeting marks his debut on the international stage.

The next speaker is Tom Kimpe from Barco.
Tom Kimpe received his masters in computer engineering from University of Ghent, Belgium in 2001. He also obtained a PhD from the same university on the topic of image quality of medical displays. In 2010 he finalized a Masters in Business Administration at the Vlerick Management School. Since 2001 Tom has been working in Barco's Healthcare Division. He has taken the positions of development engineer, project manager, innovation manager, VP of Technology and Innovation and Chief Technology Officer of Barco's Healthcare Division. His main topics of expertise are (medical) display technology, image quality modeling and human perception.

Part 3: Open Discussion

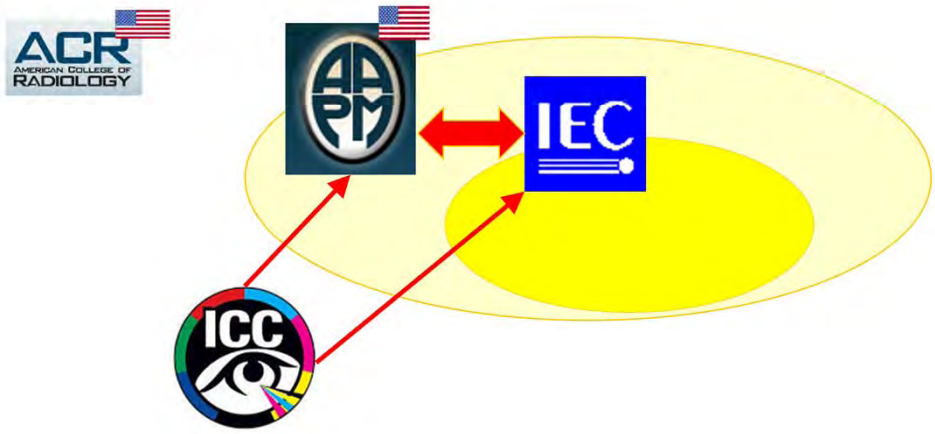
Backup

mRGB

	ACR	mRGB	sRGB	AdobeRGB
Luminance Response	DICOM GSDF	DICOM GSDF	~2.2 power function	2.199 power function
Color Gamut	-nd-	[*] (referenced)	HDTV based ITU-R BT.709-5	'Wide' (extended G)
L_{max} , cd/m^2	350/420/250	350 (250-450)	80	160 (125-200)
L_{min} , cd/m^2	L_{max} / LR	L_{max} / LR	-nd-	0.56
Luminance Ratio (LR)	350 (> 250)	350 (300-400)	-nd-	287.9 (230-400)
White Point	D65	D65	D65	D65
Gray tracking	-nd-	IEC MT51	-nd-	-nd-

mRGB is

Related Organizations (AAPM TG196, IEC SC62B MT51, ICC)



extracting the essence.

Ideal Calibration for Medical Color Display

EIZO Corporation

Yu Kosugi

Kensuke Nagashima

Yusuke Bamba

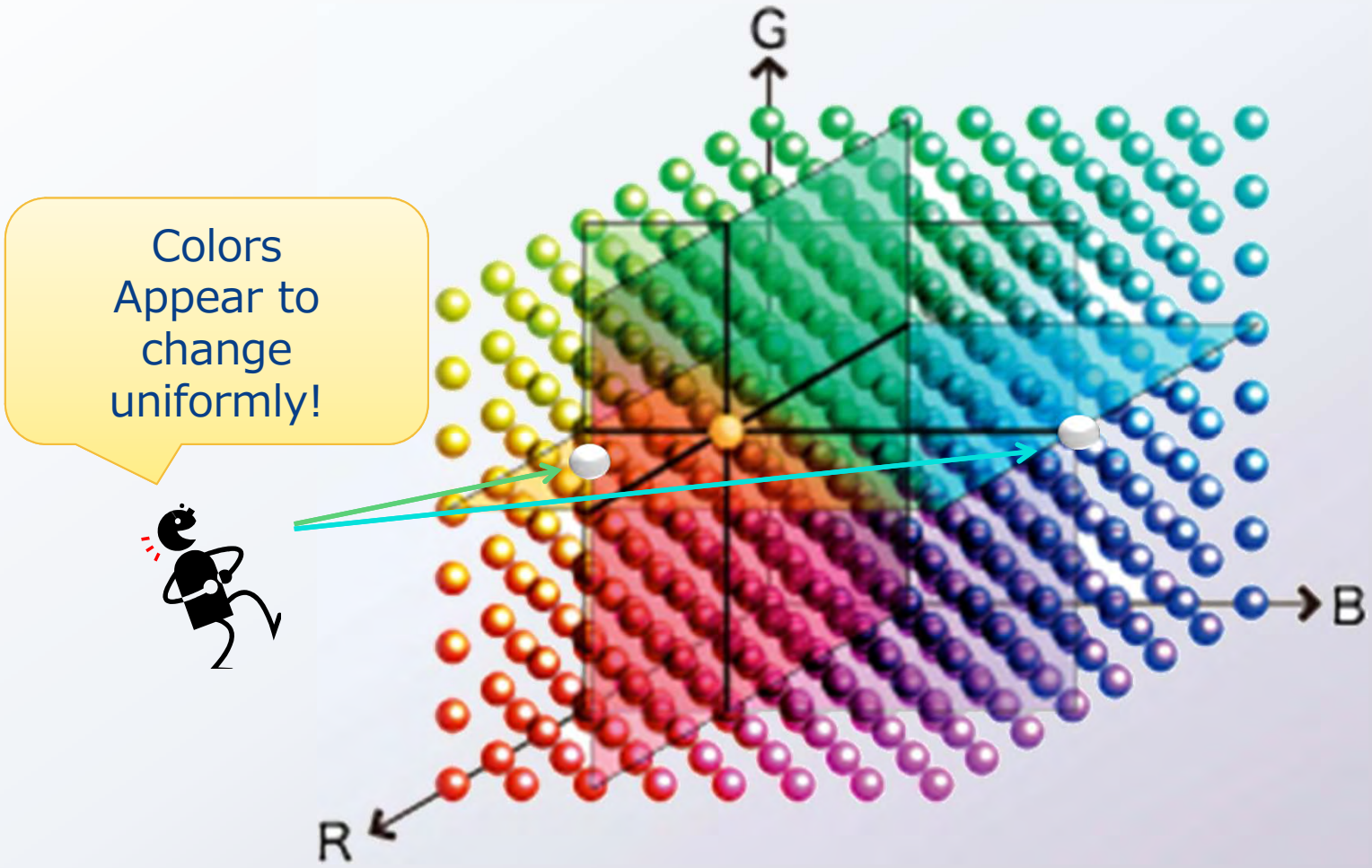
Yoichi Ohoto

March 3rd, 2014

Agenda

- EIZO's Understanding of Perceptually Linear Color Behavior (PLCB)
- Trials of GSDF Application for Color Channels
- Results and Suggestions
- Conclusion

Perceptual Liner Color Behavior



Hypothesis

- Apply GSDF to Gray Channel
- Options for R, G & B Channel
  - A) Apply GSDF to Each Tone Curve
  - B) Establish Perceptually Linear Tone Curve Similar to GSDF
  - C) Adjust Tone Curve so that All Delta Es of Adjacent Tone Level Becomes Equal or Close

GSDF Application ~Option A~

Method 1

- Conventional GSDF
  - Adjustment Prioritizing Tone Curve and Chromaticity of Gray
  - ✓*Effect on each RGB channel?*

Method 2

- RGB GSDF
  - Adjustment Prioritizing Tone Curve of R, G & B
  - ✓*Effect on gray channel?*

General Display Calibration

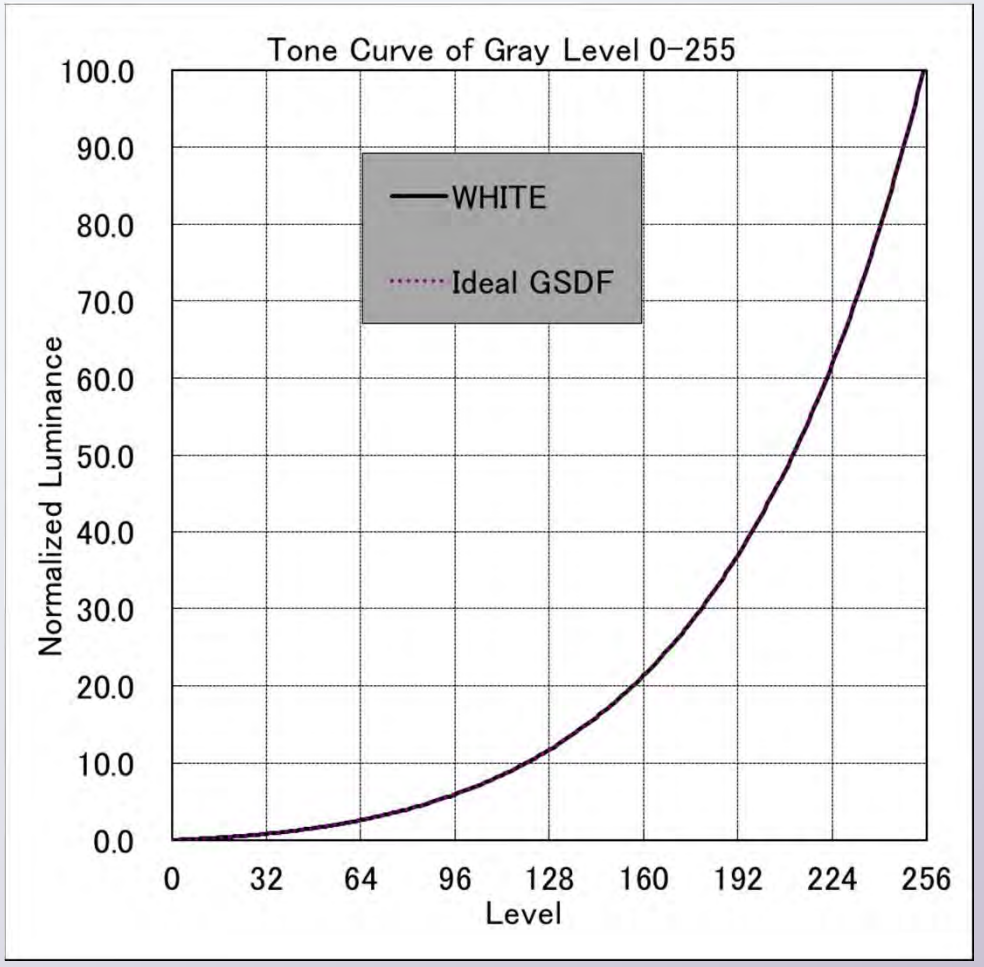
- **Tone Curve Adjustment**
  - Target Tone Curve : such as 2.2, 2.4, GSDF or etc.
  - Prioritize Gray Balance or Contrast
    - Gray Balance
    - Contrast
- **Gamut Adjustment**
  - Target Gamut : such as sRGB, AdobeRGB or etc.
- **White Point Adjustment**
  - Target White Point : such as6500[K], 5000[K] or etc.
- **Luminance Adjustment**
  - Target L_{min}, L_{max}

Measurement Environment

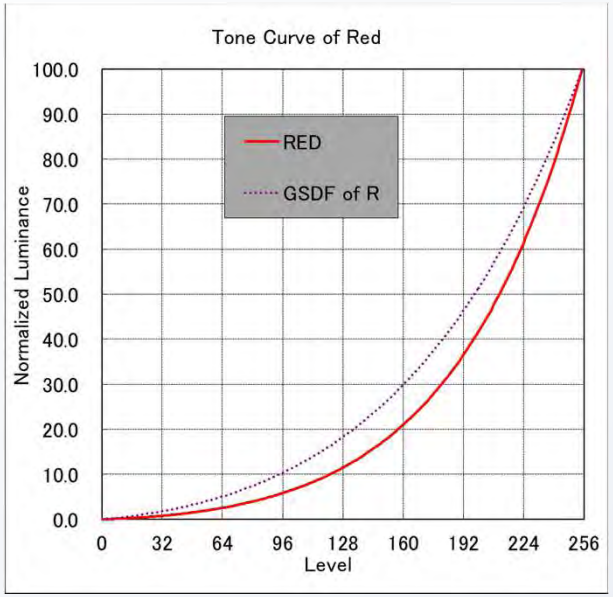
- **Display**
  - EIZO Color Management Monitor
  - Resolution 1920 x 1200
- **Colorimeter**
  - CA-310 by Konica Minolta
- **Environment**
  - In a Darkroom

Method1 : Conventional GSDF Calibration

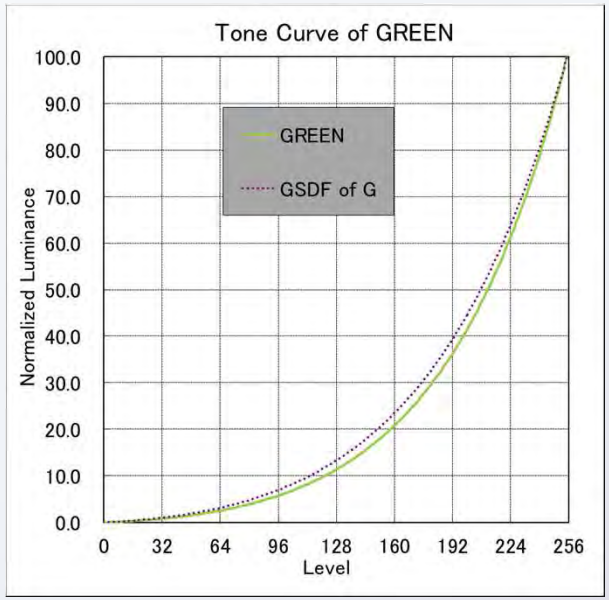
Calibrated w/	
Color Temperature :	6500K
Minimum Luminance :	0.5cd/m²
Maximum Luminance :	250cd/m²



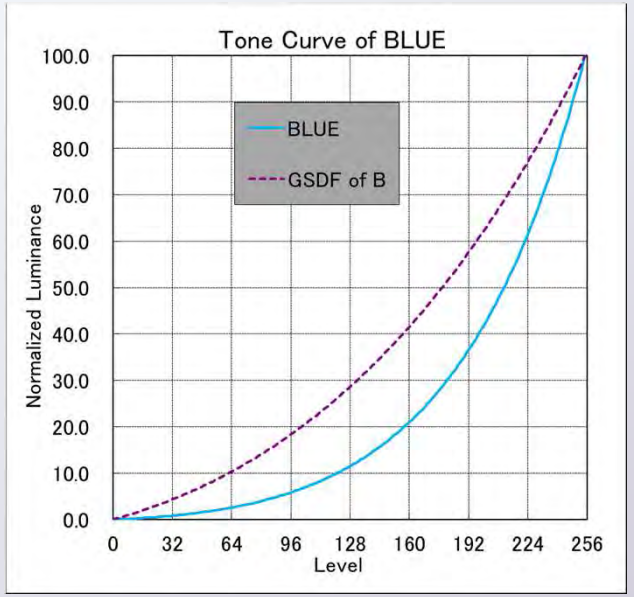
Method1 : RGB Tone Curve = GSDF?



Red Tone Curve



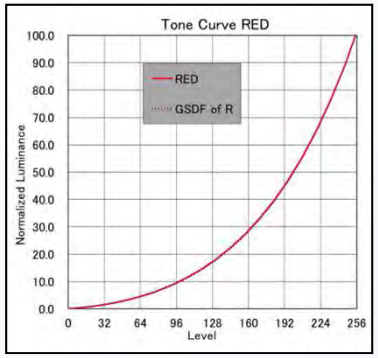
Green Tone Curve

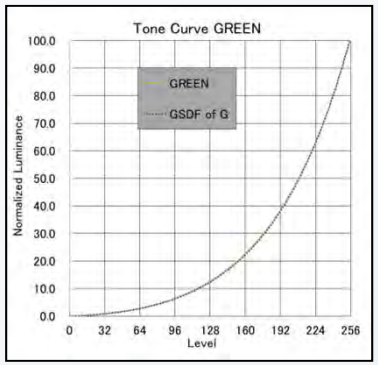


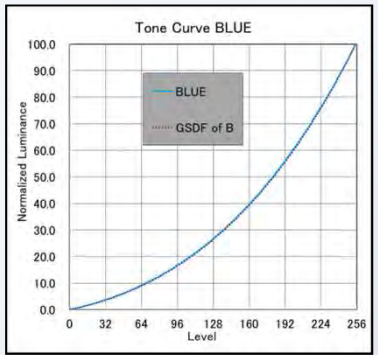
Blue Tone Curve

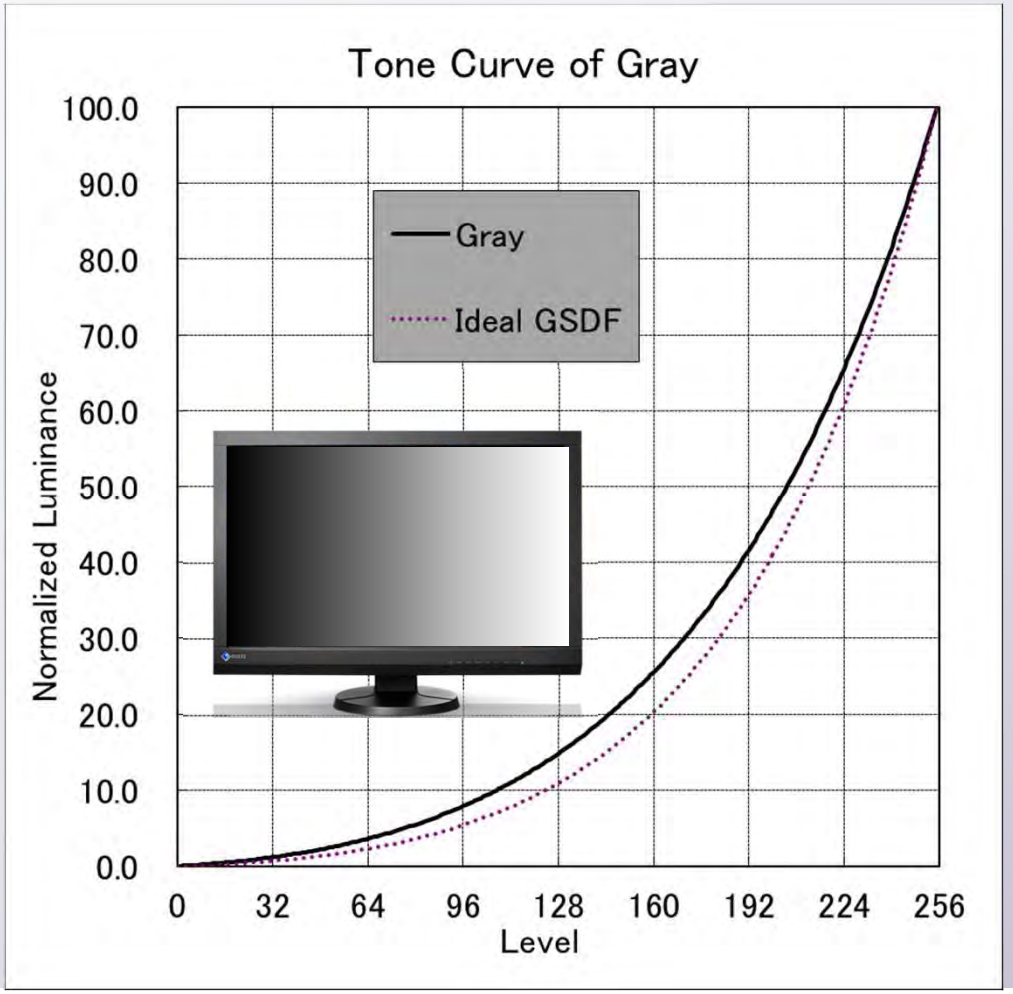
- Each Tone Curve is not GSDF
- Major Factor is Failure of Additive Mixture of Color

Method2 : RGB GSDF Calibration
Gray Tone Curve = GSDF?









Solution to Realize GSDF in All Channels

- **3D-LUT**
  - Re-map one color to another

*) 3D-LUT:3D lookup table (http://en.wikipedia.org/wiki/3D_lookup_table)

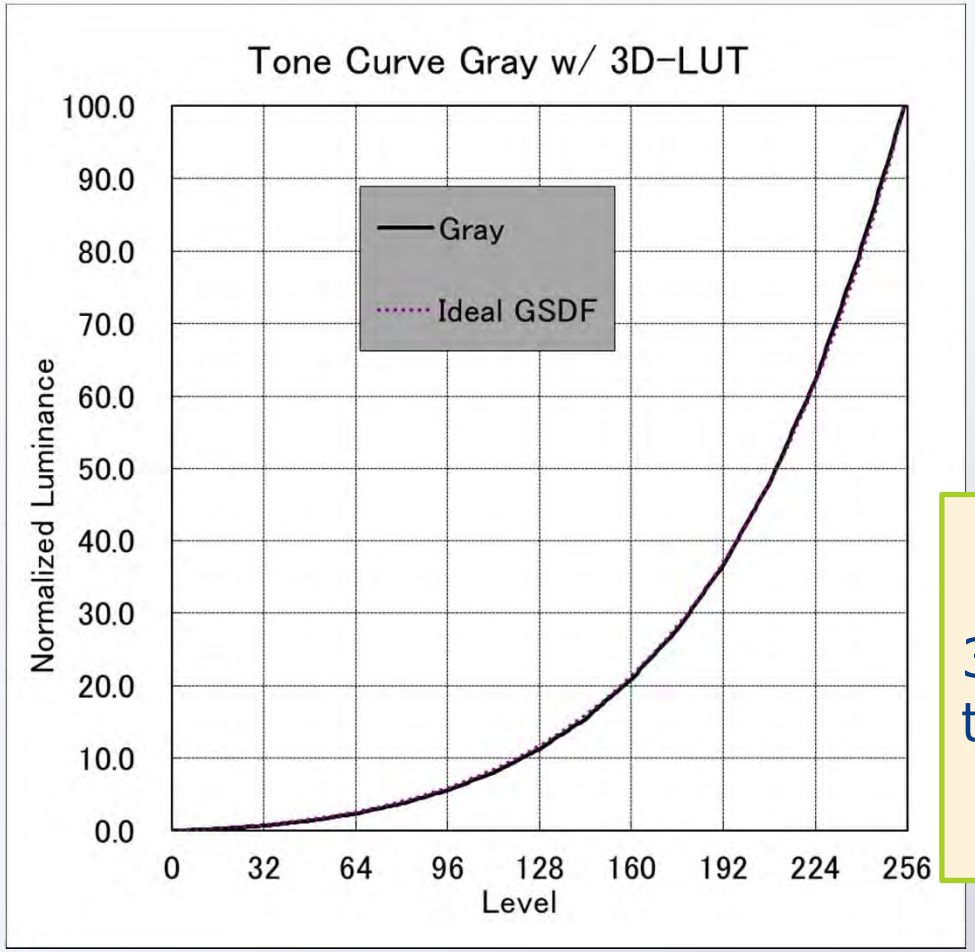
Procedure

1. Measure stimulus value of some points of intersection on the lattice in color gamut

2. Create 3D-LUT which realize GSDF Tone curve in R,G,B and Gray scale.

3. Set this 3D-LUT to the Display

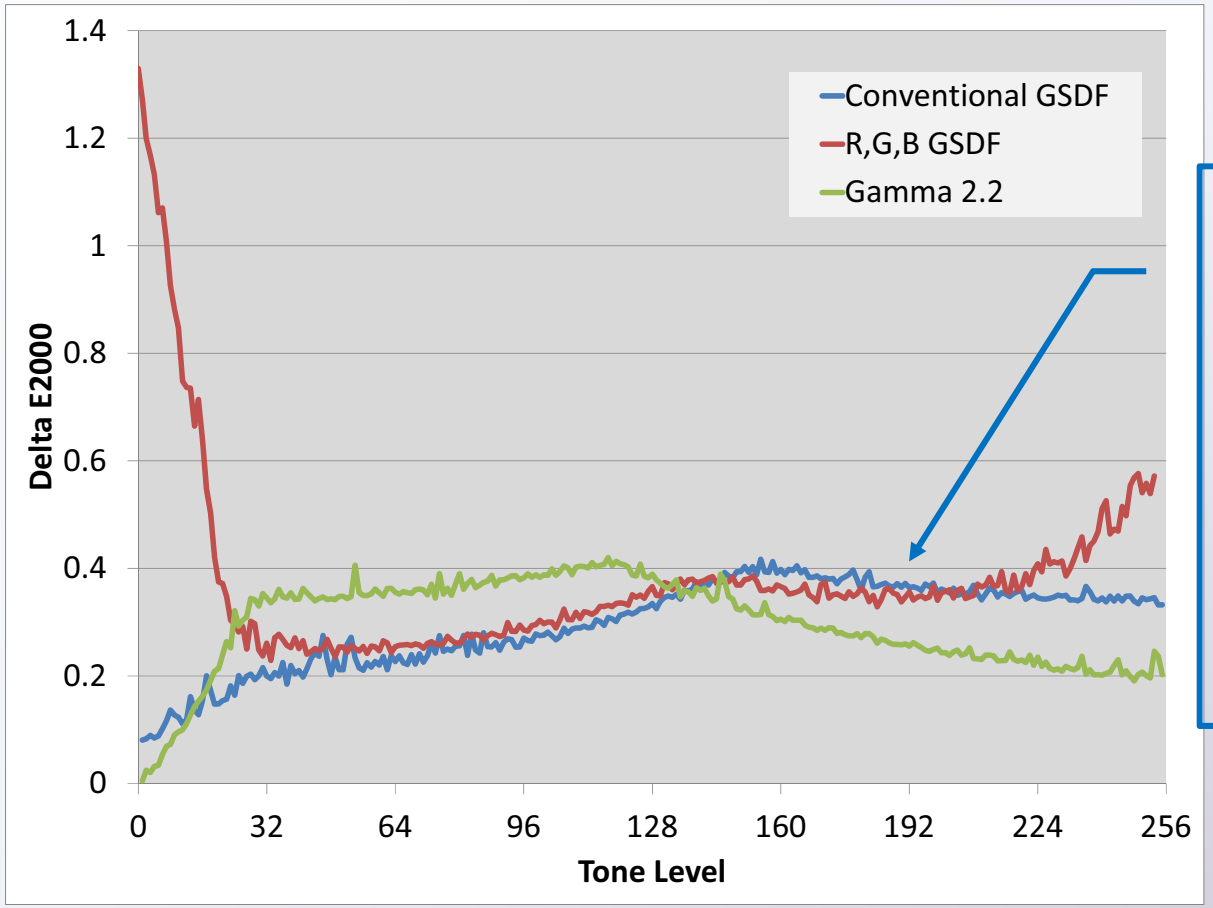
R, G, B and Gray Channels = GSDF? w/ 3D-LUT



Gray tone curve is almost ideal GSDF curve

3D-LUT can be one of the option to realize GSDF in all channels

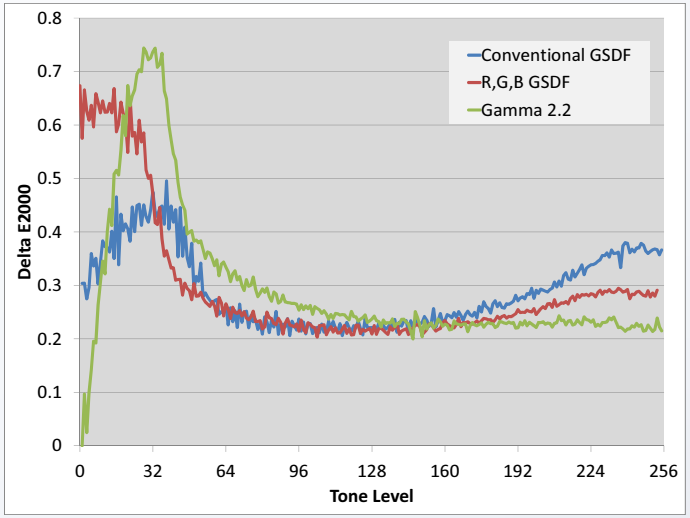
DeltaE2k between Adjacent Tone in Gray Channel

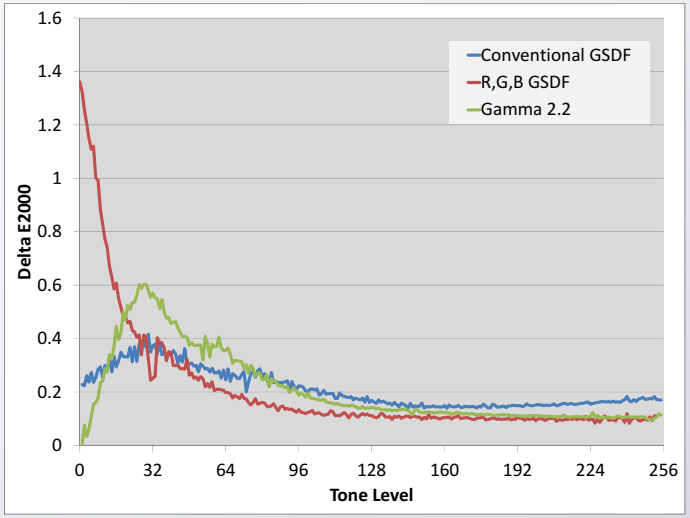


- Color difference is uniform through all of tone levels
- Close to PLCB

DeltaE2K between Adjacent Tone in RGB Channel

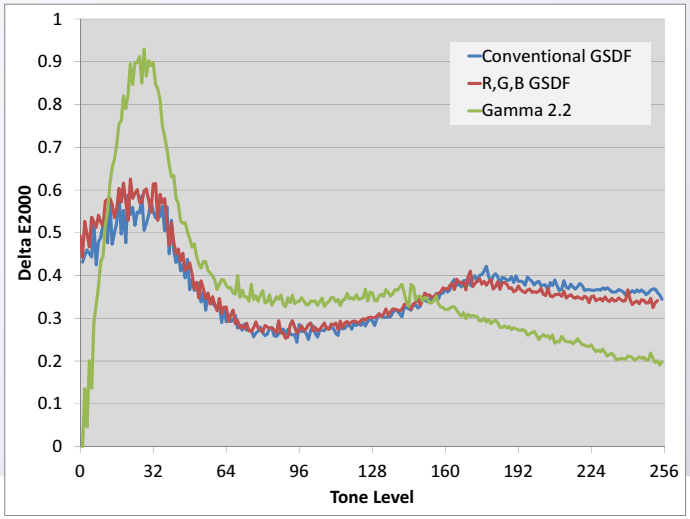
Red





Blue

Green



There is little difference between
RGB GSDF and 2.2

Results of GSDF Application to RGB

- **Conventional Calibration can NOT Realize GSDF in All Channel**
  - Particular Method like 3D-LUT may be necessary
- **Comparison of Perceptual Linearity w/ Delta E2K shows Conventional GSDF Calibration is better than RGB Calibration**
  - Gray GSDF shows the best result in delta E2K
  - There is little difference between RGB GSDF and 2.2
- **RGB GSDF does NOT Seem to Appropriate Option for PLCB**

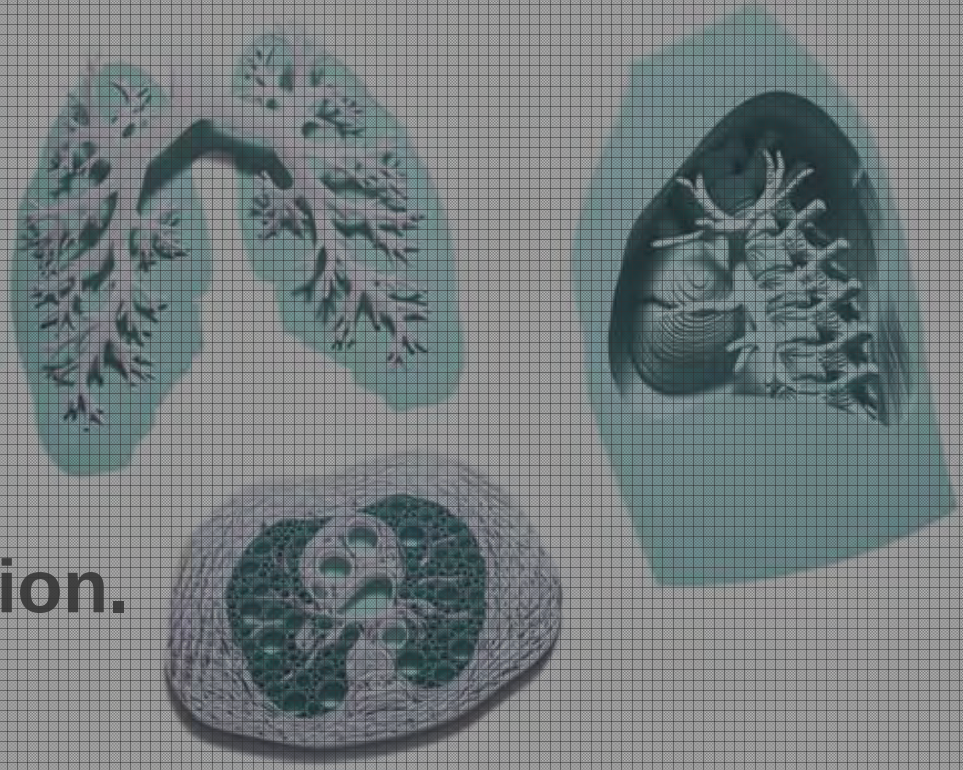
If PLCB Realized in Future…

- **Tone curve of PLCB should differ with luminance setting e.g. 200 cd/m² vs. 400cd/m²**
  - vs. e.g. same tone curve regardless of luminance setting difference for gamma = 2.2
- **Mixed color of same RGB composition reproduced differently even on same display of different luminance settings**
- **New evaluation method may be necessary**

Conclusion

- **EIZO's Understanding of PLCB**
  - Uniform Color Gamut where the color difference is equal or close between adjacent lattice points representing tone levels
- **Particular Method may be Necessary**
  - To realize GSDF on all channels
  - The same may be true of other options not tried yet
- **RGB GSDF is NOT the appropriate solution for PLCB**
  - Reconsideration for PLCB
- **Continue to work on the other approaches**

Thank you
for your kind attention.



End

Perceptually Linear Color Behavior of Display (PLCB)

Tom Kimpe (tom.kimpe@barco.com)
Albert Xthona

ICC Medical Imaging Working Group meeting
March 3rd
Tokyo, Japan

Introduction – previous work

- Why perceptually linear color behavior [1] ?
  - (medical) Displays suffer from color variability and instabilities
  - Standardizing and calibrating the behavior of color medical displays will result into consistency and safeguard quality
  - Absolute calibration does not allow for technical advances and limits every display to the worst display that can be accepted
  - Perceptual linear color behavior spaces colors evenly and provides applications the best palette

[1] Tom Kimpe, "Color behavior of medical display systems", Summit on Color in Medical Imaging, Co-organized by FDA and ICC, May 8-9, 2013, http://www.color.org/events/medical/Kimpe.pdf (Accessed Aug 8th 2013)

Perceptually Linear Color behavior (PLCB)

- What?
  - Redistributing the points within the achievable color gamut of the display such that, while respecting boundary conditions, points are as much as possible at equal perceptual distance from each other

- Boundary conditions
  - Neutral grey needs to follow DICOM GSDF
  - Display luminance and contrast can not be reduced
  - Display color gamut can not be reduced
  - Large color shifts are not acceptable

Note: CSDF (color standard display function) refers to a potential extension of GSDF that describes PLCB of medical color displays, and in particular specifies acceptable tolerances and calibration/measurement/QA methodologies

Why these boundary conditions?

- Based on learnings from extenstive vision research done by the (medical) community and over 10 years of practical clinical experience with DICOM GSDF
  - DICOM GSDF [2] is a proven standard that seems to work well and needs to be respected for neutral grey images.
  - Increasing display luminance, contrast (, color gamut) has shown to improve performance for detection and classification tasks
  - Introducing large color shifts is not acceptable as it results into useability problems and problems with diagnostic confidence

[2] Digital Imaging and Communications in Medicine (DICOM) Part 14; grayscale standard display function. Available at: http://medical.nema.org/dicom/2003/03_14PU.pdf (last accessed Aug 8th 2013)

Quantifying perceptual linearity of color (1)

- Perceptual distance metric

  - DeltaE2000 [3]: distance metric, which can be used to build a perceptually uniform color space

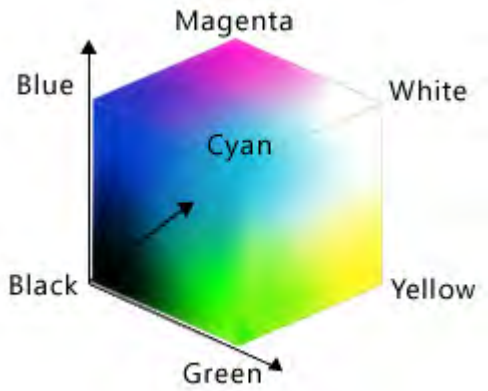
$$\Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}}$$

  - Although it may not be the best possible perceptual distance metric, it is a generally accepted standard and therefore seems a good starting point

[3] Sharma, Gaurav; Wencheng Wu, Edul N. Dalal (2005). "The CIEDE2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations". Color Research & Applications (Wiley Interscience) 30 (1): 21–30. doi:10.1002/col.20070

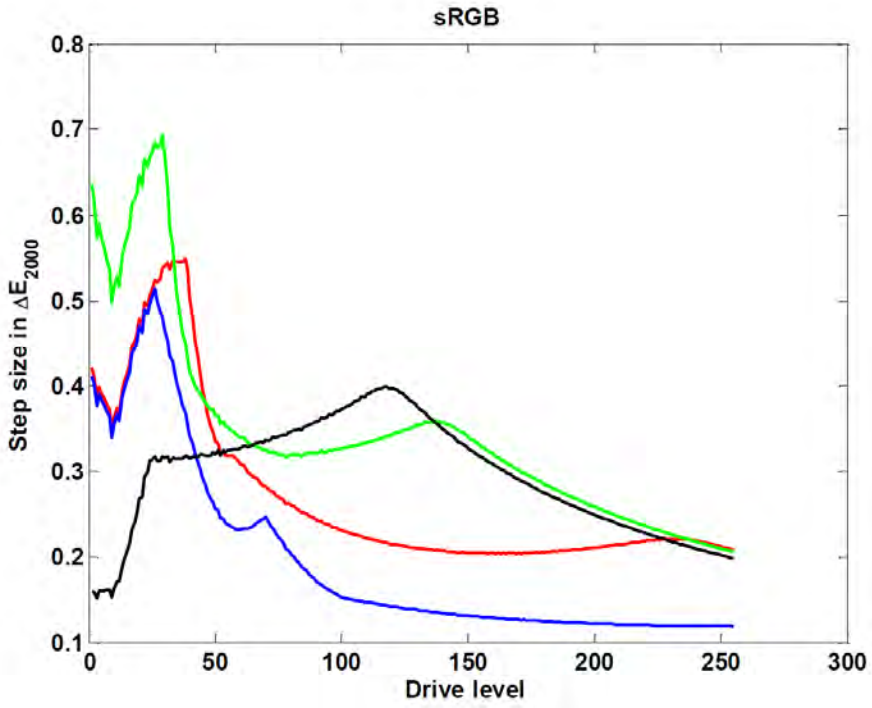
Quantifying perceptual linearity of color (2)

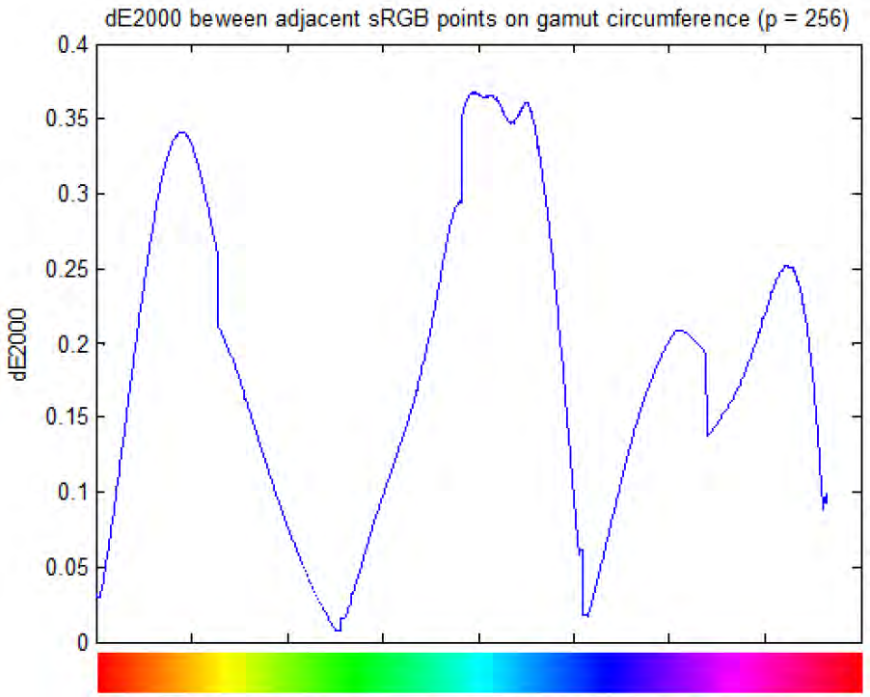
- Quantification of perceptual linearity can be done by means of
  - measuring color & luminance of color/grey patches (or similarly measuring transfer curves)
  - calculating DeltaE2000 distance between the measured points (and calculating aggregated statistics)
  - convenient visual representation is the deltaE2000 distance along a line through the color cube of the display



Perceptually linear color behavior of sRGB display

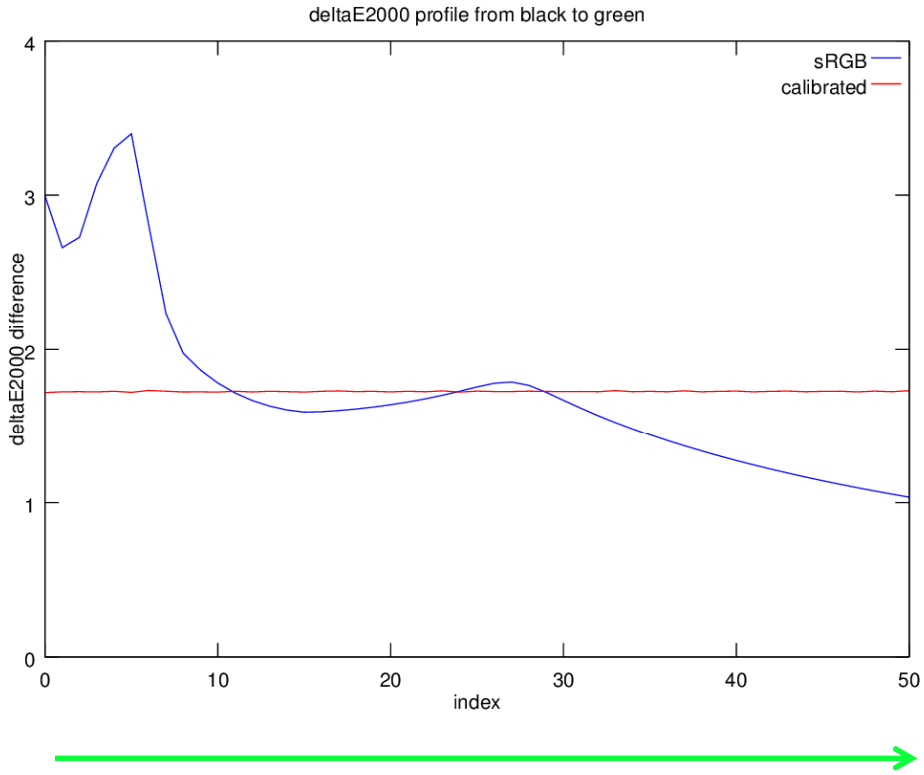
- sRGB displays are not perceptually linear at all

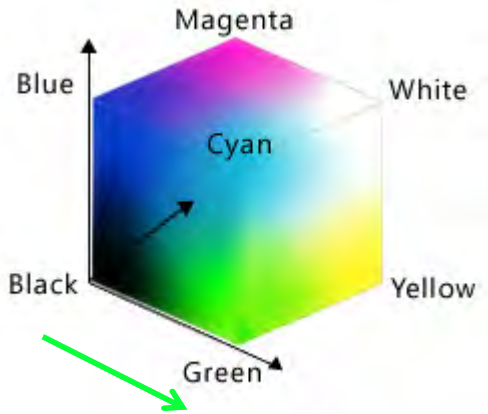




PLCB after calibration (redistribution)

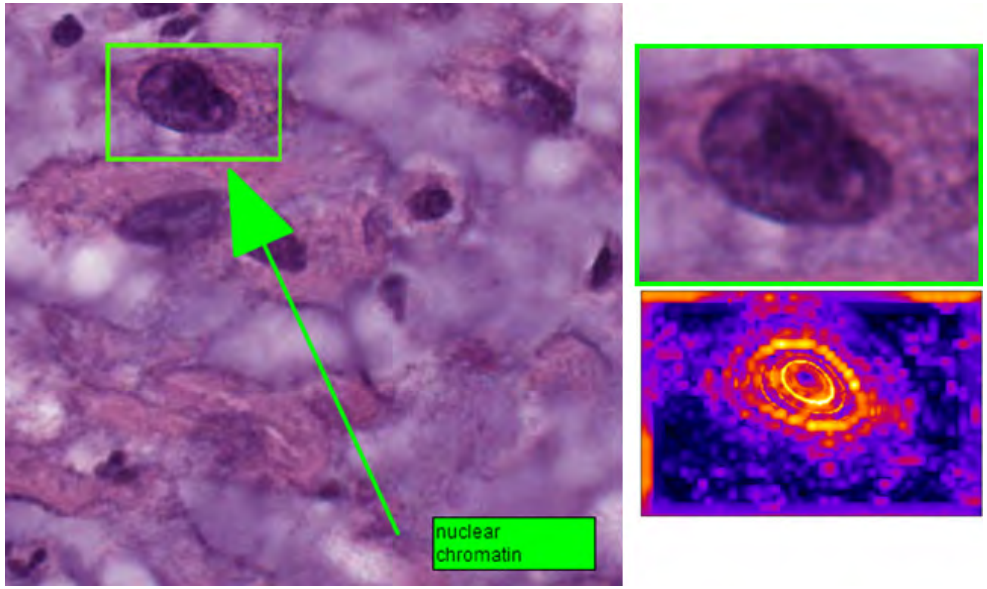
- Example plot of the green primary line in the color cube





Clinical relevance of PLCB

- Preliminary results available [4]
  - CSDF can increase perceived contrast of clinically relevant features of digital pathology images with ~50%
  - Confirmation of these findings is needed



[4] Tom Kimpe, Johan Rostang, Ali Avanaki et al. "Does the choice of display system influence perception and visibility of clinically relevant features in digital pathology images?", SPIE medical imaging 2014.

Next steps / decisions to be taken

- How will this PLCB of displays fit in mRGB?
  - Should mRGB state that for primary reading the display should have PLCB?
  - In that case, should an extension of GSDF (eg. “CSDF”) specify the measurement/calibration/QA methods?
- Should defining CSDF then be a seperate task in ICC MIWG?
- How will all of this fit in ICC?
  - Note: Barco is still volunteering to provide to the community a reference implementation and sample ICC profiles


Questions
Answers

Medical Photography

Tokyo

3 March 2014

Medical Photography

- **Mission**
- Collect industry best practices in the field of digital photography and write a guidance document which can be used by the medical industry to minimize the color errors created during the digital color camera image capture process.
- **Scope**
- This guidance document will apply for a range of digital cameras (from cellphone cameras to scientific grade cameras) and lighting conditions. Recommendations will also be made for camera setup and color correction in post processing.

Content

- Introduction and background
- Factors that can contribute to color errors
- Recommended light conditions
- Recommended camera setup
- Use of reference color charts
- Color correction in post-processing
- Recommendations on color management

- Note: Content should expand on or introduce new information to what is already available (e.g. ATA Practice Guidelines for Teledermatology 2007)

- **Document distribution:**
- ICC publication
- Journal article
- Collaboration with other organizations (e.g. American Telemedicine Association)
- **Participants**
- Ives Vander Haeghen, University of Ghent Hospital
- Stein Olav Skrovseth, Norwegian Centre for Telemedicine
- Elizabeth Krupinski, Arizona State University
- Aldo Badano, FDA
- Phil Green, ICC
- **Project coordinator:** John Penczek NIST/Univ. of Colorado

Issues

- **Lighting conditions**
- **Camera settings**
- **Image format**

- Illuminant
- White balance
- Colour encoding / colour space
- RAW vs JPEG

Nikon recommendations (Hisashi Sano)

- **Lighting conditions**
- White balance setting in camera is important. We can choose white balance mode between Auto(AWB),Manual(MWB) and Preset(PWB).
- MIWG person might use AWB as white balance, but it would be better to set MWB or PWB, because those modes have stability than AWB.
- **Image format**
- There isn’t significant difference between Jpeg and Raw about color appearance.
- But Raw would be better for this usage, because we can edit images by application software when we use Raw format.
- We can adjust especially white balance by various way on such a software.

NIST response

Your recommendations are in line with my expectations. NIST conducted a study on the color accuracy of cameras in auto mode under various lighting. We found that the Auto mode did relatively well with sources approximating D65, but could create significant color errors for other sources (like incandescent and cool white fluorescent lamps).

I would think that it would be useful to also give guidance as to what should be in the background of the image. Many people like to do color comparisons using a gray background. I would think that this would be useful for medical photography as well, at least to reduce the amount of stray light from the background.

I had thought that using Raw formats always eliminated the post-processing, which should yield better results with color-correction methods. Is your suggestion on using the “Neutral” mode just for the compressed formats, or the Raw format as well?

Next meeting

- **20 March 2014 Conference call**

Medical Applications

Measurement of skin absolute spectral-reflectance-image and its application to component analysis

Norimichi TSUMURA, Ph. D
Graduate School of Advanced Integration Science
& Department of Informatics and Imaging Systems, Chiba University

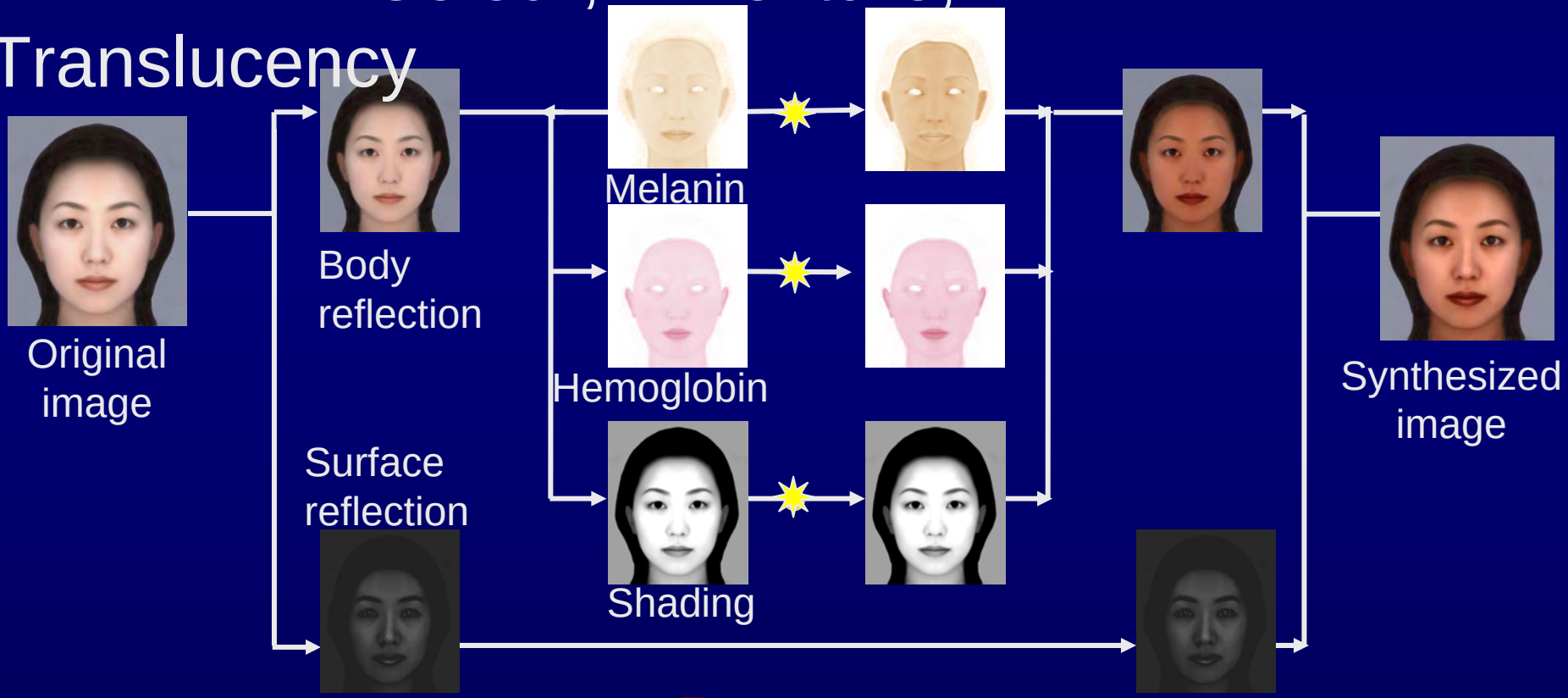
Skin color analysis and synthesis

(Tsumura et al., SIGGRAPH2003)

can be used for skin appearance control:

Colour, Texture,

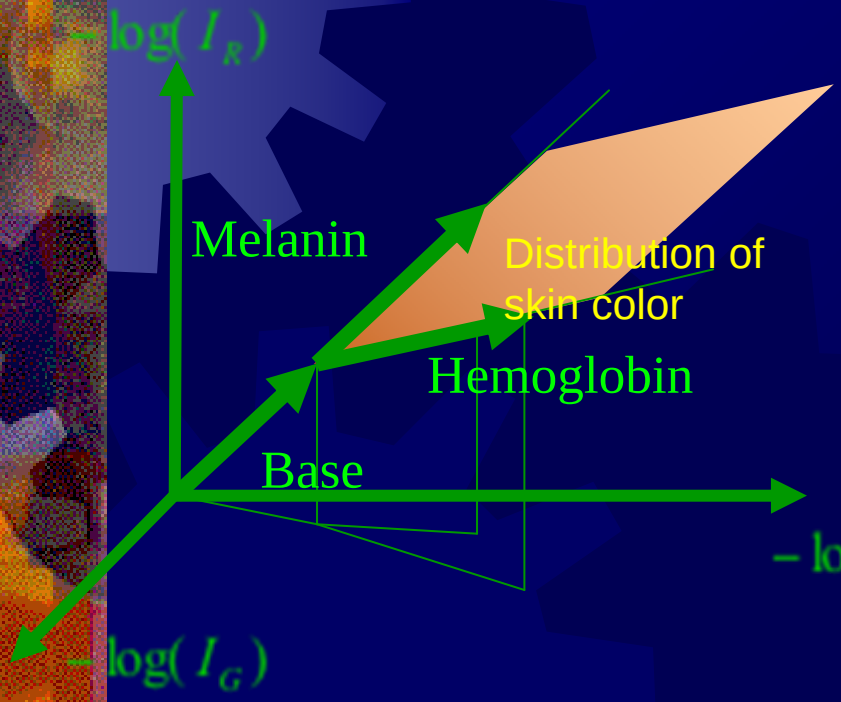
Translucency



Problems of two components skin color model

1. Lambert Beer law does not hold in skin reflectance

2. Hemoglobin has two states.
   oxy-hemoglobin and deoxy-hemoglobin



Precise model and analysis are required in medical imaging, sensibility communication, cosmetic imaging and so on.

Oxygen saturation

Blood: Transport nutrition and oxygen for metabolism

Hemoglobin (red pigment)

Oxy-hemoglobin

$[HbO_2]$

Deoxy-hemoglobin

$[Hb]$

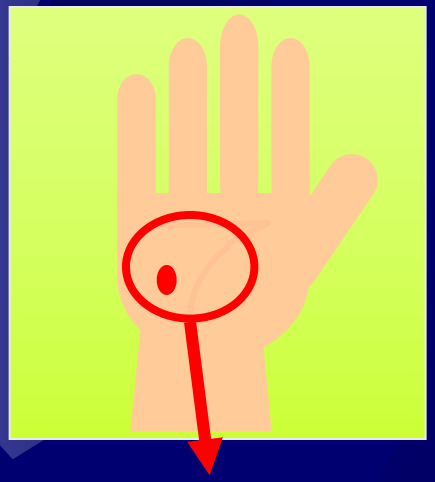
Oxygen saturation $s = \frac{[HbO_2]}{[HbO_2]+[Hb]}$

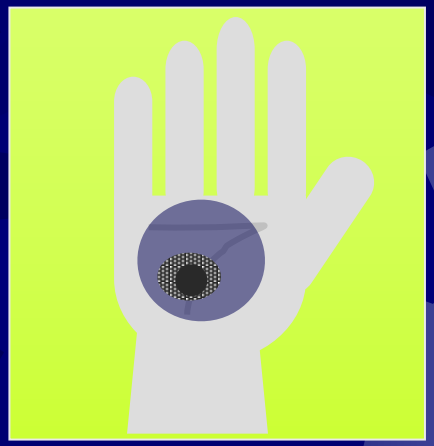
$= \frac{\text{Density of oxy-hemoglobin}}{\text{Density of total hemoglobin}}$

Mapping pigmentation in human skin

Appearance of diseased part

2-D information for oxygen saturation





Real distribution of diseased part

Variation of oxygen saturation

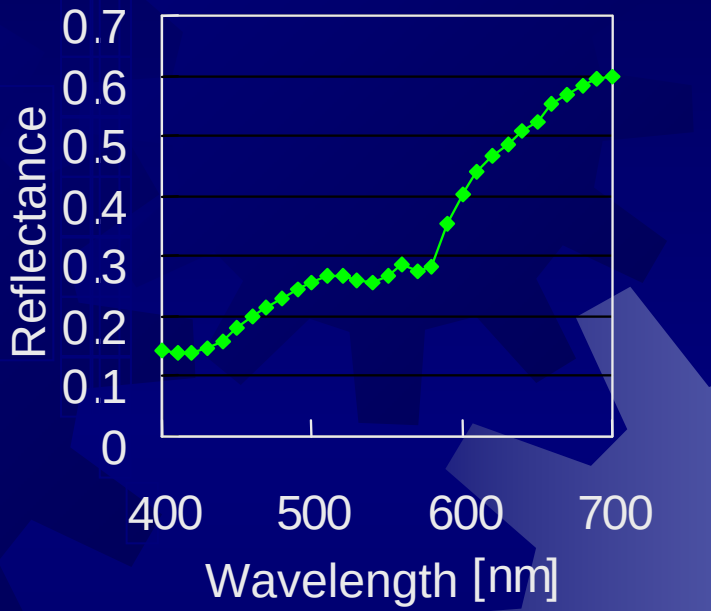
Variation of oxygen saturation is expected to indicate the real distribution of diseased part in the skin.

Simulation of skin spectral reflectance

Skin model
- Depth
- Scattering
- Absorption

Skin color simulation

(Monte Carlo simulation)

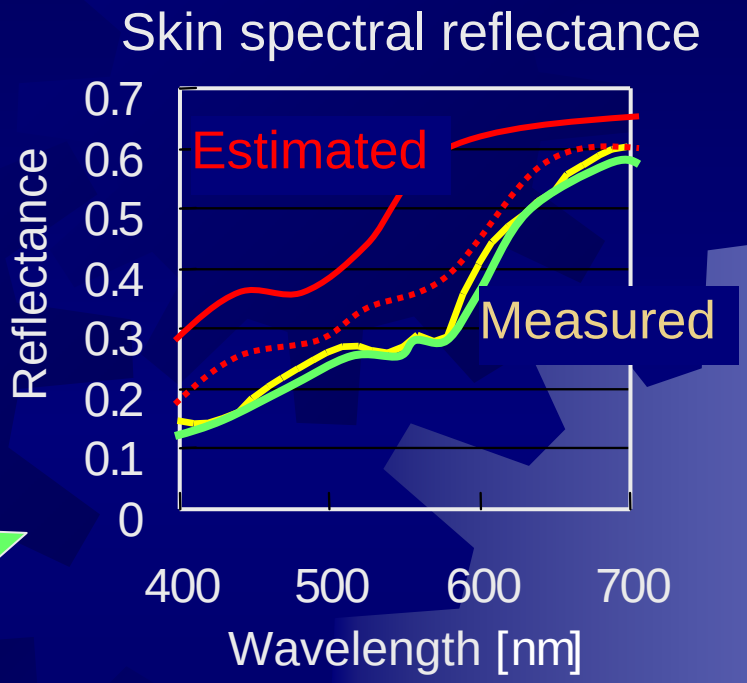


Skin spectral reflectance

Hemoglobin density(C_h)
Melanin density(C_m)
Oxygen saturation(s)

Estimation of pigmentation from measured reflectance

Skin model
- Depth
- Scattering
- Absorption



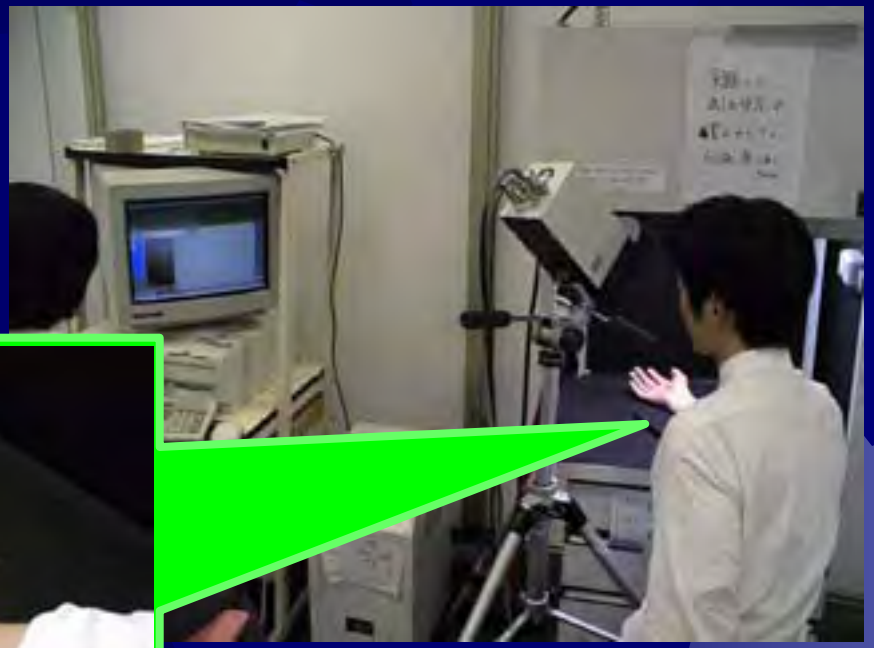
Hemoglobin density(C_h)
Melanin density(C_m)
Oxygen saturation(s)

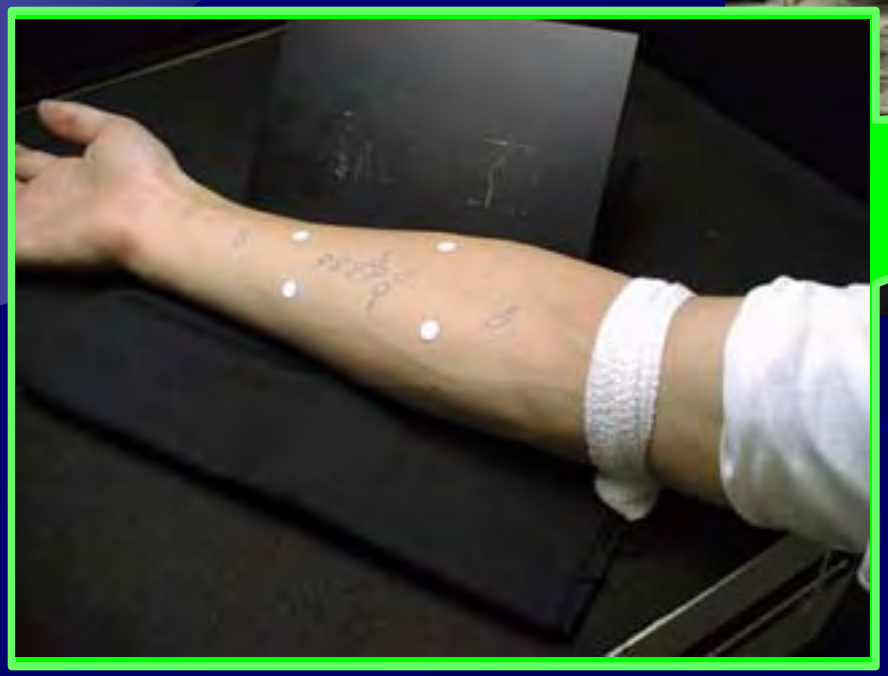
Modify

Error

Preliminary experiment

Imaging system

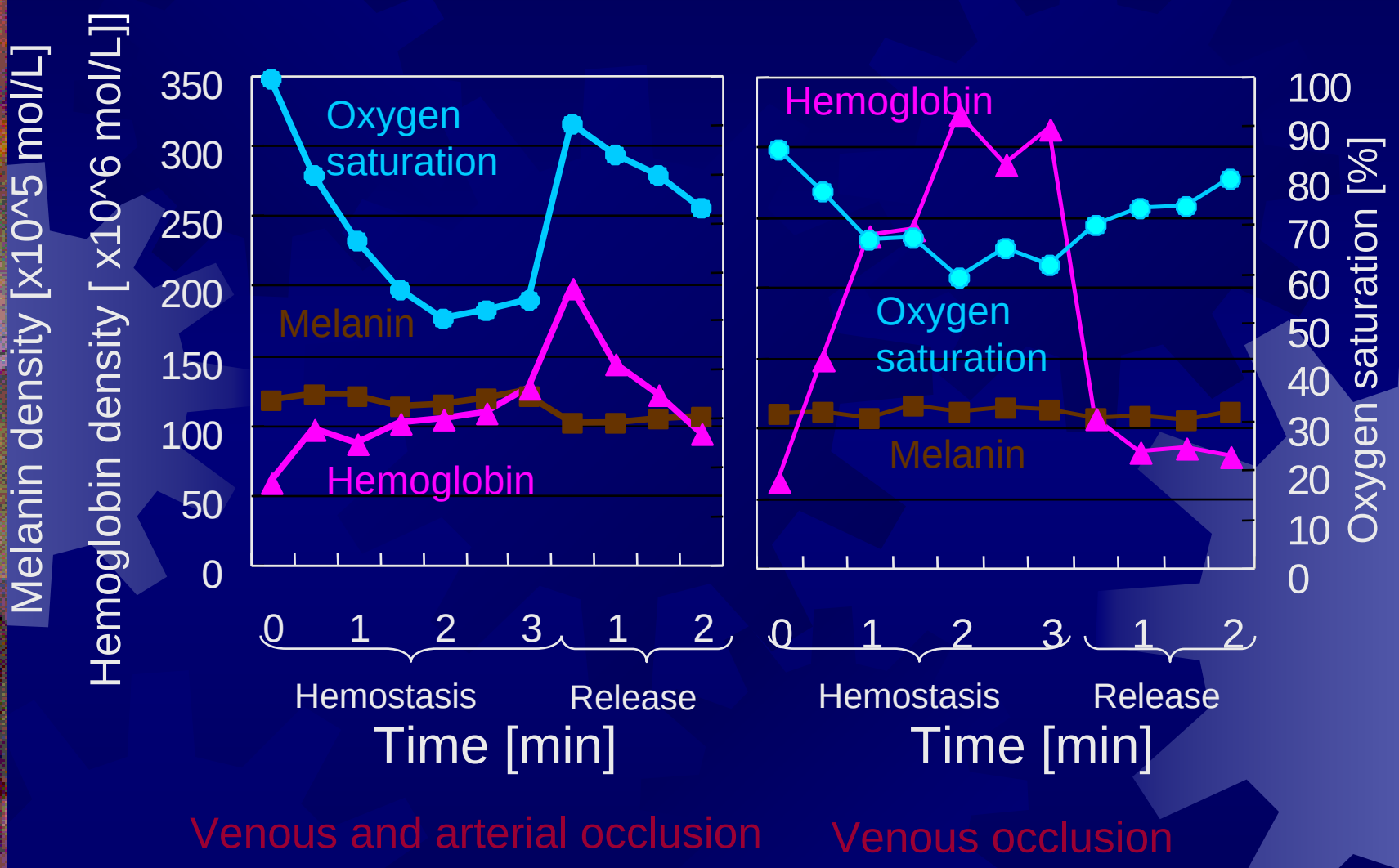




Forearm

hemostasis → release

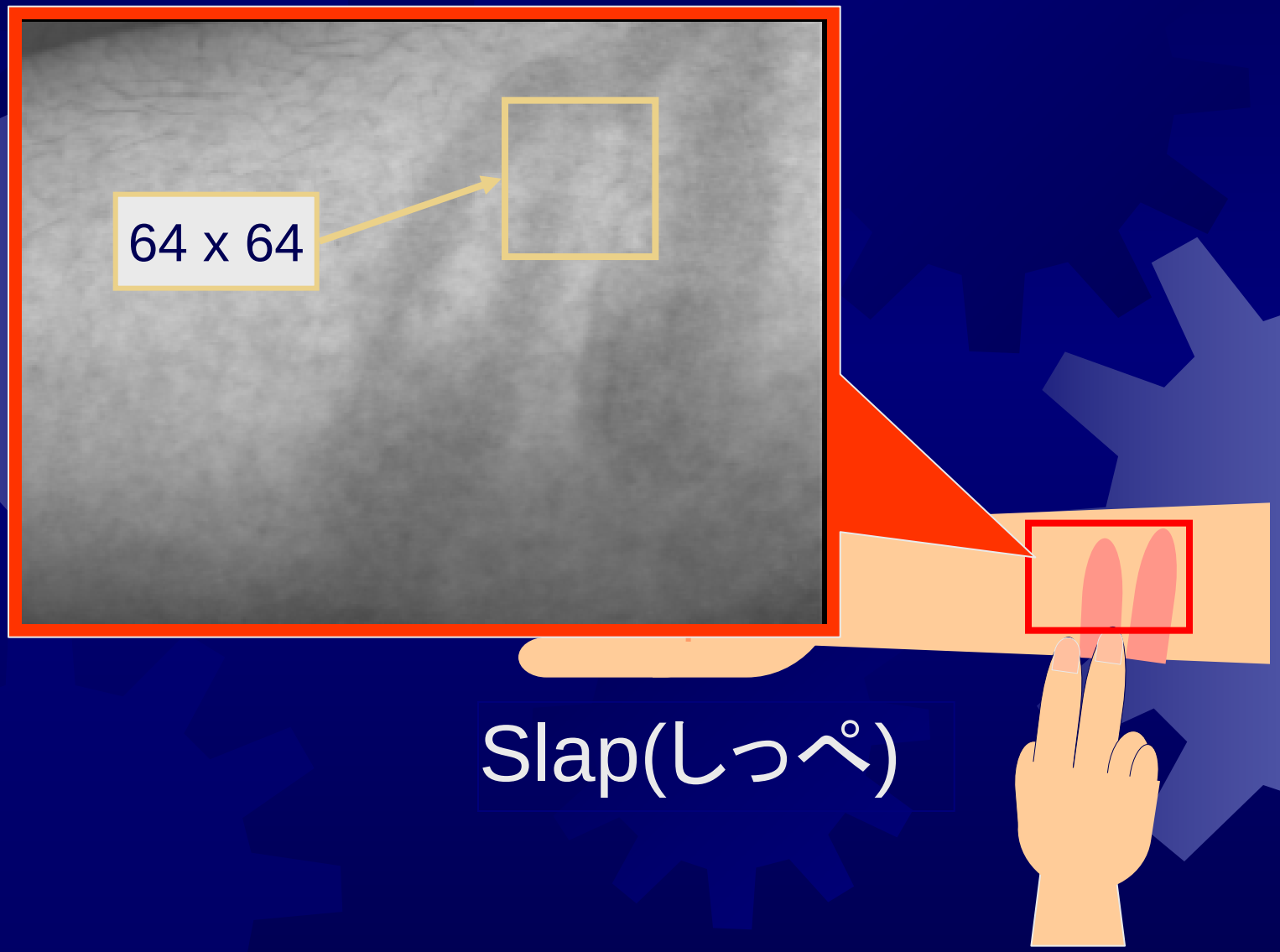
Results of the analysis



Venous and arterial occlusion

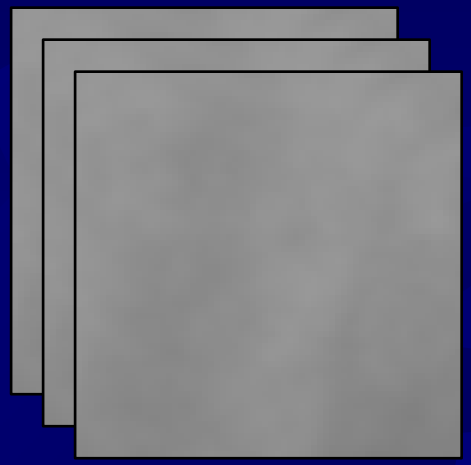
Venous occlusion

Estimation of 2-D map of pigmentation

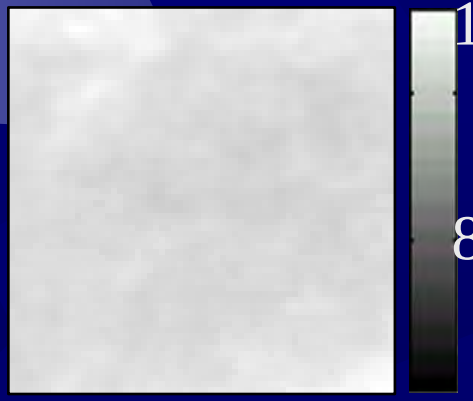


Slap(しっぺ)

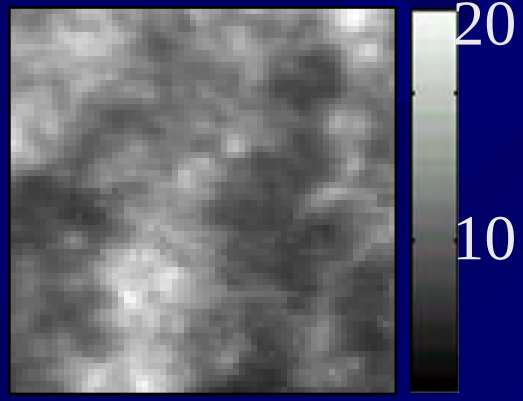
Estimated maps of pigmentation



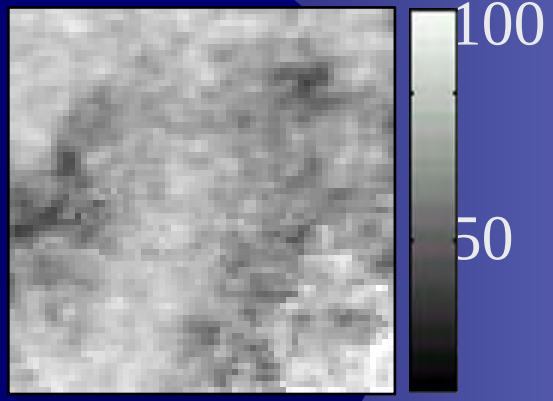
Spectral image
(580, 610, 640[nm])



Melanin density
[x 10^5mol/L]

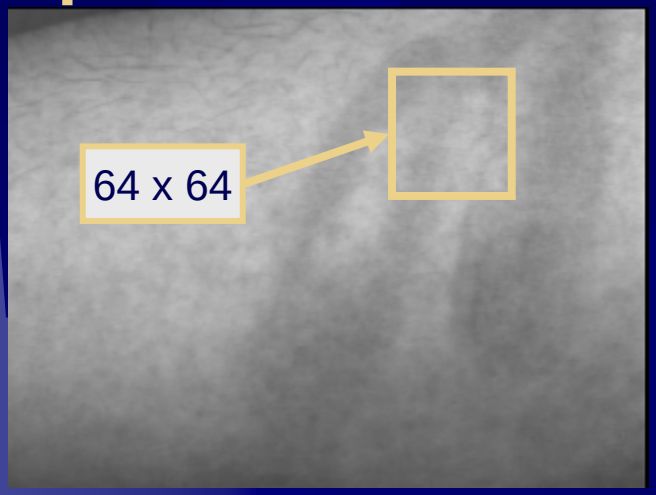


Hemoglobin density
[x 10^5mol/L]



Oxygen saturation
[%]

Spectral reflectance image



Spectral image of object

Spectral image of reference white plane

The shape of skin is 3 dimensional, so that the absolute spectral reflectance is not obtained in the wide range of skin because of shading.

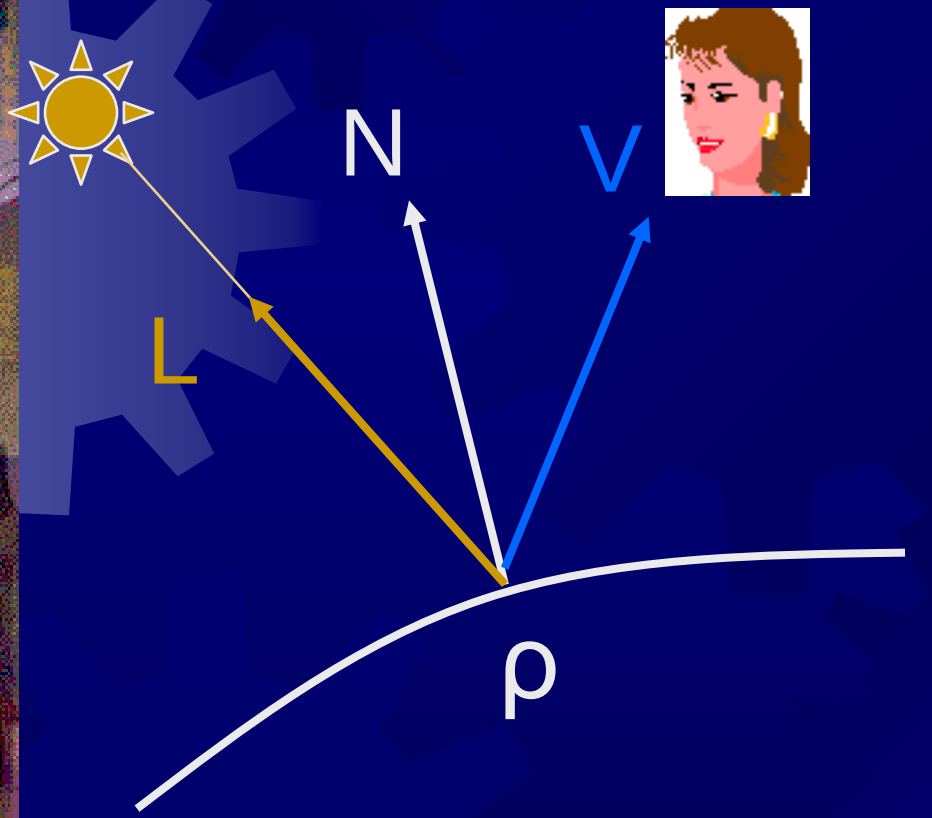
[Relative reflectance] = a × [Absolute reflectance]

a: Shading parameters ← 3D shape

Photometric stereo technique

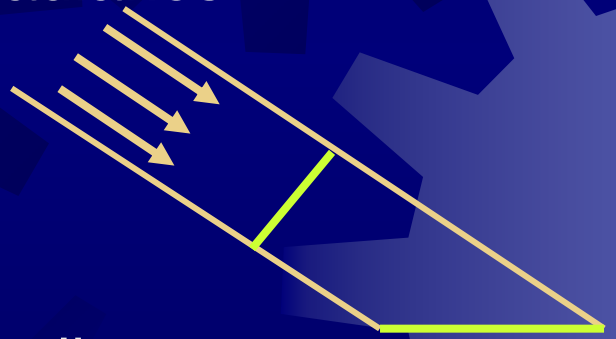
Lambertian surface

I (Intensity)

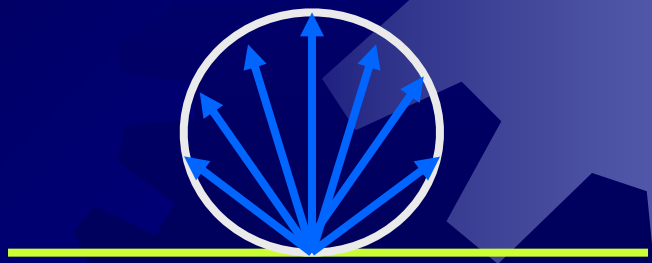


$$I = \rho L^{t} N$$

Irradiance



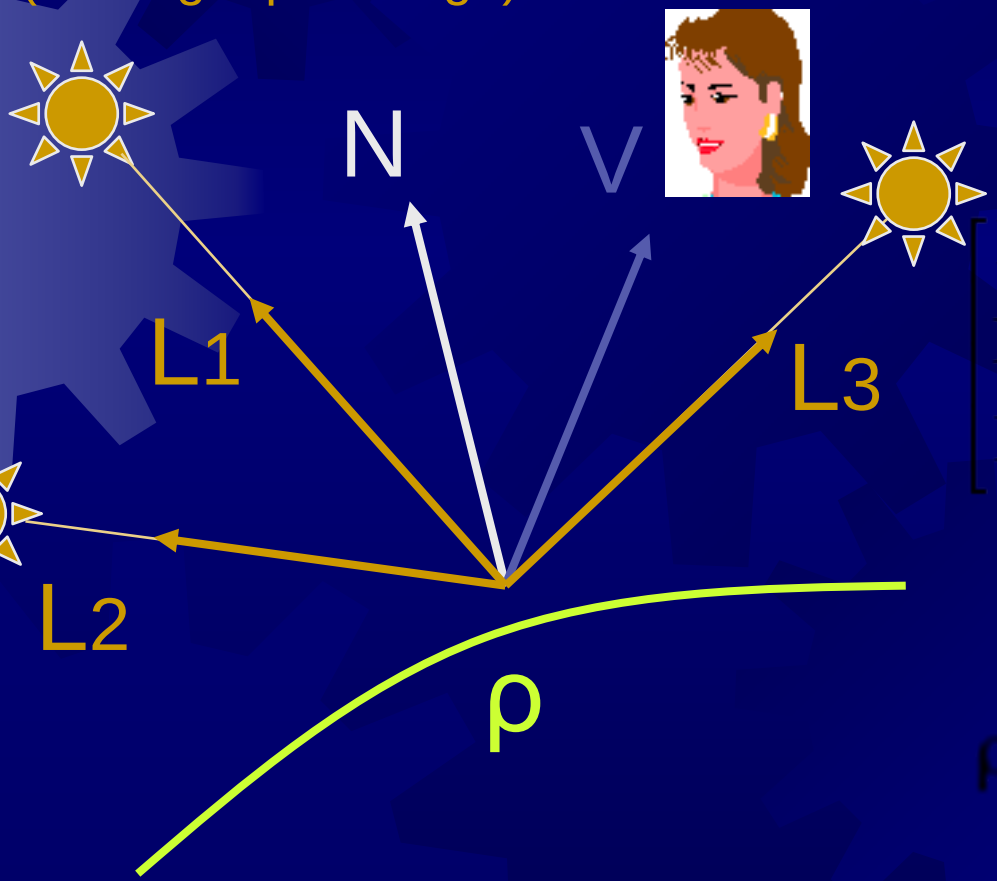
Radiance



Estimation of normal vector and absolute reflectance

Three lights
(One light per image)

I_1, I_2, I_3



$$I_1 = \rho L_1{}^t N$$

$$I_2 = \rho L_2{}^t N$$

$$I_3 = \rho L_3{}^t N$$

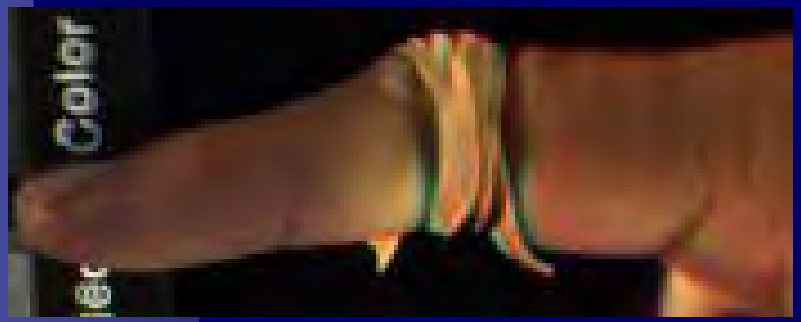
$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} \mathbf{L}_1^t \\ \mathbf{L}_2^t \\ \mathbf{L}_3^t \end{bmatrix} (\rho \mathbf{N})$$

$$\rho \mathbf{N} = \begin{bmatrix} \mathbf{L}_1^t \\ \mathbf{L}_2^t \\ \mathbf{L}_3^t \end{bmatrix}^{-1} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}$$

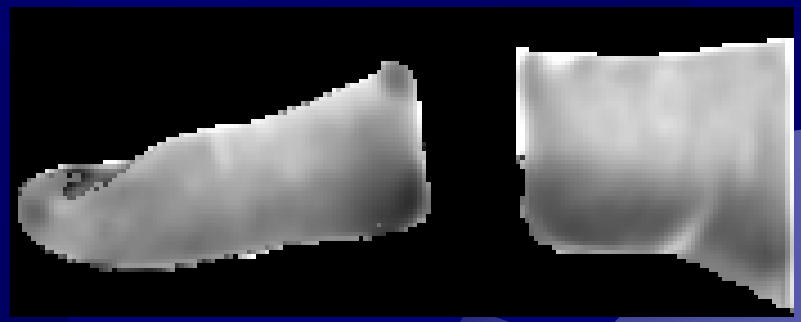
Experiments

Experiments

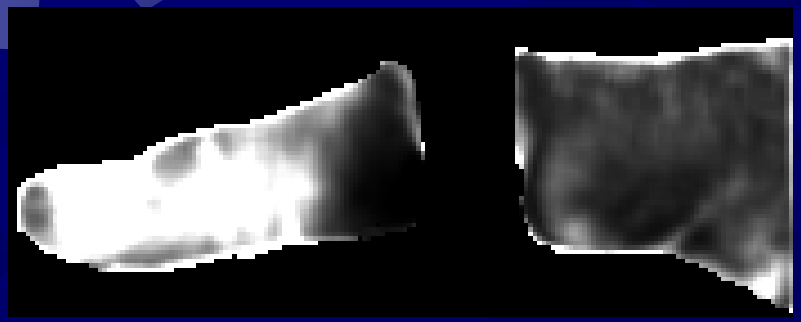
Experimental results



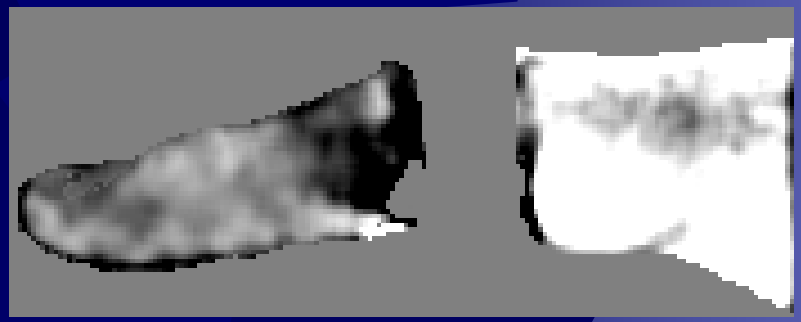
Absolute value under D65



Melanin



Total hemoglobin



Oxygen saturation

Conclusion

- Optical imaging, computer vision, computer graphics techniques were combined to map and visualize pigmentation in wide range of skin.

Medical Vision

OXYGEN SATURATION OF SKIN REFLECTS “OKETSU”

Satoshi Yamamoto[1], Norimichi Tsumura[2], Tomokazu Yoshizaki[3], Keiko Ogawa-Ochiai[4]

[1)]Keio University, [2)]Chiba University, [3)]Kanazawa University, [4)]Kanazawa University Hospital, JAPAN

Contents

- Background and purpose
- Subjects
- Methods
- Results
- Conclusion

Kampo medicines (Japanese traditional medicine)

- In Japan, “Modern” medicine is widespread, and Japanese traditional medicine “Kampo” is also available.

“Kakkonto”
Well-known Kampo in Japan

Extract of herbal combination

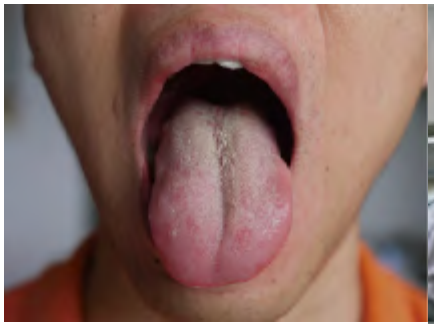
Kampo medicines (Japanese traditional medicine)

- Today, freeze-dried herbal extract formulations are mainly used, which are included under the coverage of the public health insurance system in Japan.

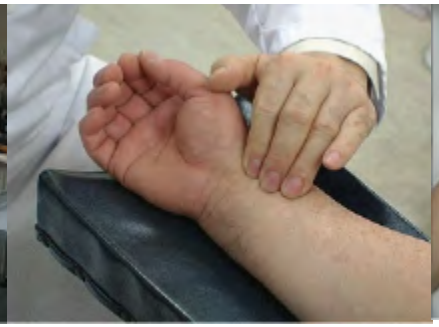
Freeze-dried “Kakkonto”

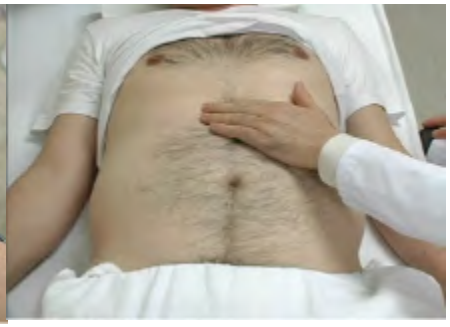
Diagnosis of Kampo

- Kampo medicines are prescribed under the diagnoses of medical doctor with traditional methods and criteria.


Tongue inspection


Audio exam. / Interview

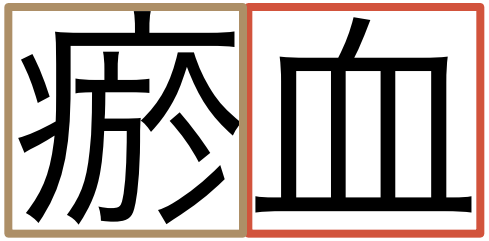

Pulse palpation


Abdominal palpation

Although these methods are subjective and somewhat mysterious, our ancestors must have found some changes in the human body by these methods.

Oketsu

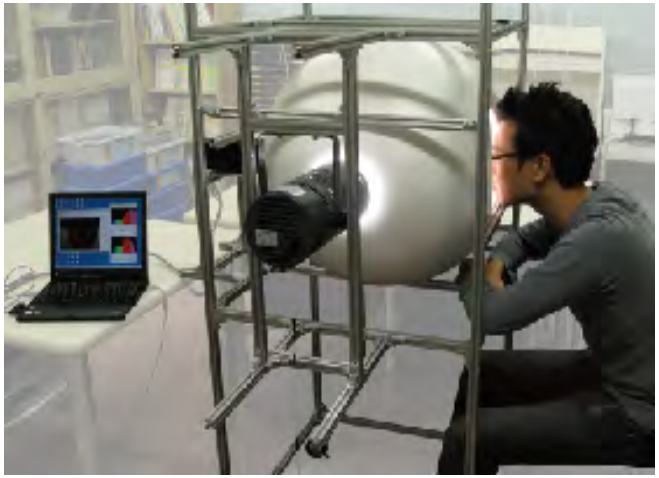
- Oketsu is one criterion in Kampo which is denoted as “blood stagnation”, viscous blood and slow flow.

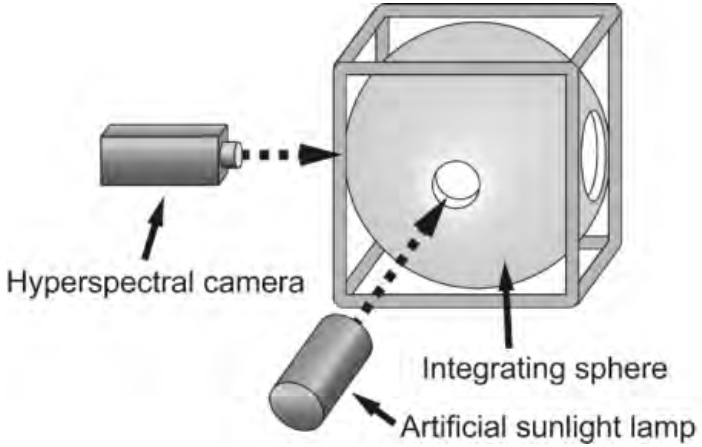
Slow flow  Blood

- Oketsu causes many symptoms correlated with menstrual phase, such as premenstrual syndrome (PMS).

Previous study #1

- Tongue color analysis was useful to facilitate diagnosis of Kampo medicine.





The system is too large and complex for clinical use at outpatient facility.

Previous study #2

- Skin oxygen saturation was estimated from skin color spectrum with the optical path-length matrix method (OPLM), and it was stable among the age groups.

This study was for healthy subjects.

Upcoming clinical trial is necessary to find clinical meaning of the skin oxygen saturation.

Purpose

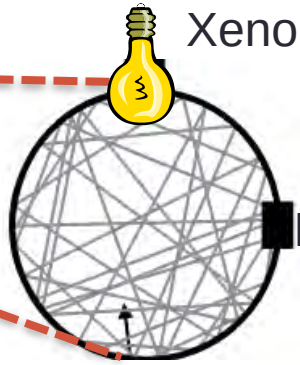
- Determine correlation among skin oxygen saturation, Oketsu score, and hemoglobin concentration.
- Turn the empirical observations into objective factors.
- Skin oxygen saturation would be a subjective method to reflect systemic blood flow and Oketsu status, and revives traditional methods / observations as an effective diagnostic tool.

Subjects

- 20 outpatients of Kanazawa University Hospital or Japanese Red Cross Kanazawa Hospital
  - All mongoloids, 2 males, 18 females, 50.1±14.4 y.o.
- Measurements
  - Diffuse reflectance was measured at two locations.
  - Oketsu score was measured by a Kampo physician.

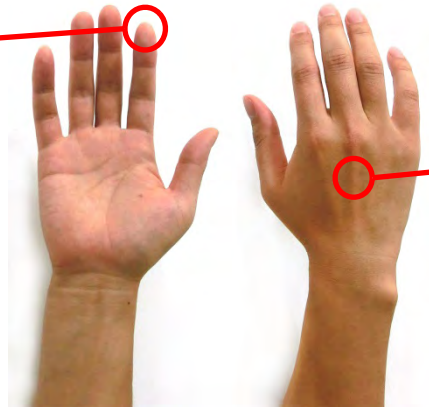
Measuring spectral reflectance

Spectrophotometer KONICA MINOLTA CM2600-d



- Reflectance was measured at two locations.

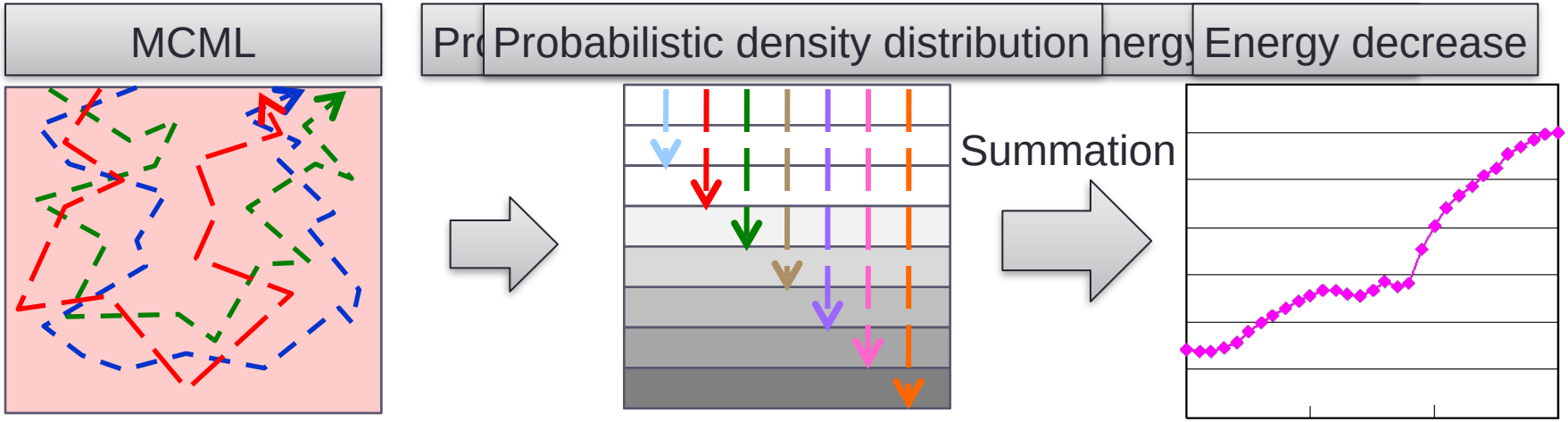
Tip of 1st finger



Dorsal surface

Optical path-length matrix method (OPLM)

- OPLM is a fast method to estimate spectral reflectance of the skin model with certain parameters.
  1. Calculate probabilistic density distribution of optical path-length by Monte Carlo for Multi-Layered media (MCML)
  2. Apply decrement of energy after the Beer-Lambert law
  3. Calculate spectrum by summation



Repeated MCML is not necessary for repeated computation with revised values.

Estimating O_2 saturation with iterated OPLM

Skin model

Known values

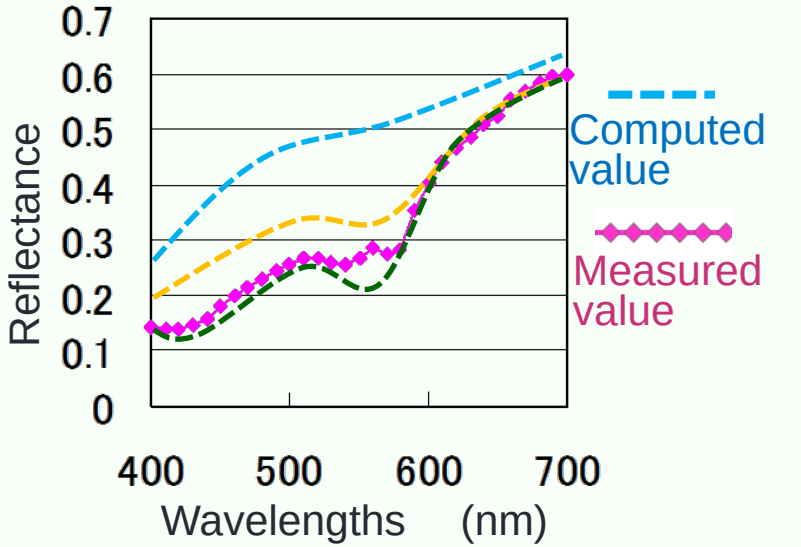
- Thickness of the skin
- Scattering coefficient
- Absorption cross section
- Anisotropic factor
- Refractive index

Unknown values

- Melanin concentration
- Hemoglobin concentration
- Oxygen saturation

OPLM

Spectral reflectance



RMSE

Revised values

Oketsu

- Oketsu is one criterion in Kampo which is denoted as “blood stagnation”, viscous blood and slow flow.

- In Oketsu persons, blood is much viscous.
  - Blood or serum viscosity is significantly higher.
  - Capillary blood flow in eye conjunctiva is much slower.

In Kampo classics, there are many findings to determine Oketsu, while weight of each findings are calculated previously as Oketsu scores with multiple regression.

Oketsu scores

Symptoms		mal	femal
Dark-rimmed eyes		10	10
Dark pigmentation of facial skin		2	2
Rough skin		2	5
Livid	Lips	2	2
	Gingiva	10	5
	Tongue	10	10
Vascular spider		5	5
Subcutaneous hemorrhage		2	10
Palmar erythema		2	5

Inspection

Resistance and/or tenderness on:	mal	femal
Rt. para-umbilical region	5	5
Lt. para-umbilical region	10	10
Umbilical region	5	5
Cecal region	5	2
Sigmoidal region	5	5
Subcostal region	5	5

Abdominal palpation

Hemorrhoids	10	5
Dysmenorrhea		10

Interview

Full points for severe level of symptoms, and half points for moderate level

< 20 : “non-Oketsu” < 40 : moderate “Oketsu” ≥ 40 : severe “Oketsu”

Correlation analysis

- Correlation among the calculated values were computed by using the Pearson's product-moment correlation coefficient.

Results

Correlation among hemoglobin concentration (Hb), oxygen saturation (O_2 sat), and Oketsu score.

Fingertip

	O	Oketsu
Hb	***0.17***	***0.13***
O		0.16

Dorsal surface of hand

	O	Oketsu
Hb	***0.26***	***0.42***
O		0.55

r: correlation coefficient

Oxygen saturation showed large correlation with Oketsu score at dorsal surface of hand.

Hemoglobin showed medium correlation with Oketsu score at dorsal surface of hand.

Conclusion

- We demonstrated correlation between Oketsu score and hemoglobin concentration / oxygen saturation on dorsal surface of the hand.
- Oketsu score showed small correlation at fingertip. The difference between two locations is thought to be due to physiological and anatomical differences.
- For the future works, we need to determine the position where we can stably measure skin color spectrum to estimate oxygen saturation of systemic skin.

Thank you very much for your attention.

Satoshi Yamamoto *may-s@umin.net*

“Keishi”
Cinnamon

“Shakuyaku”
Peony root

“Tounin”
Peach kernel

“Bukuryo”
Hoelen

“Botampi”
Moutan bark

Components of “Keishibukuryogan”,
chief prescription for Oketsu status

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Report: Ophthalmic Imaging Standards

Christye P. Sisson, CRA, MS

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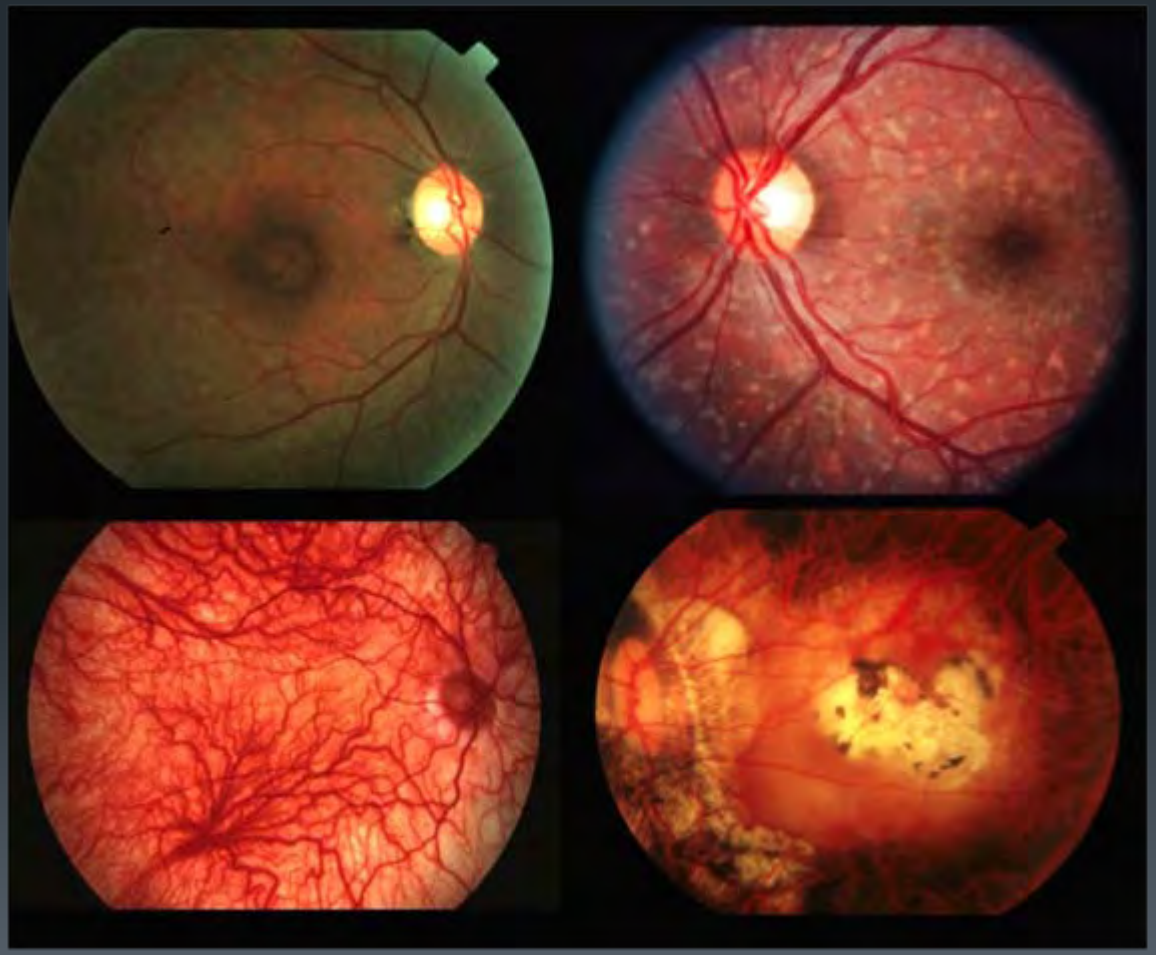
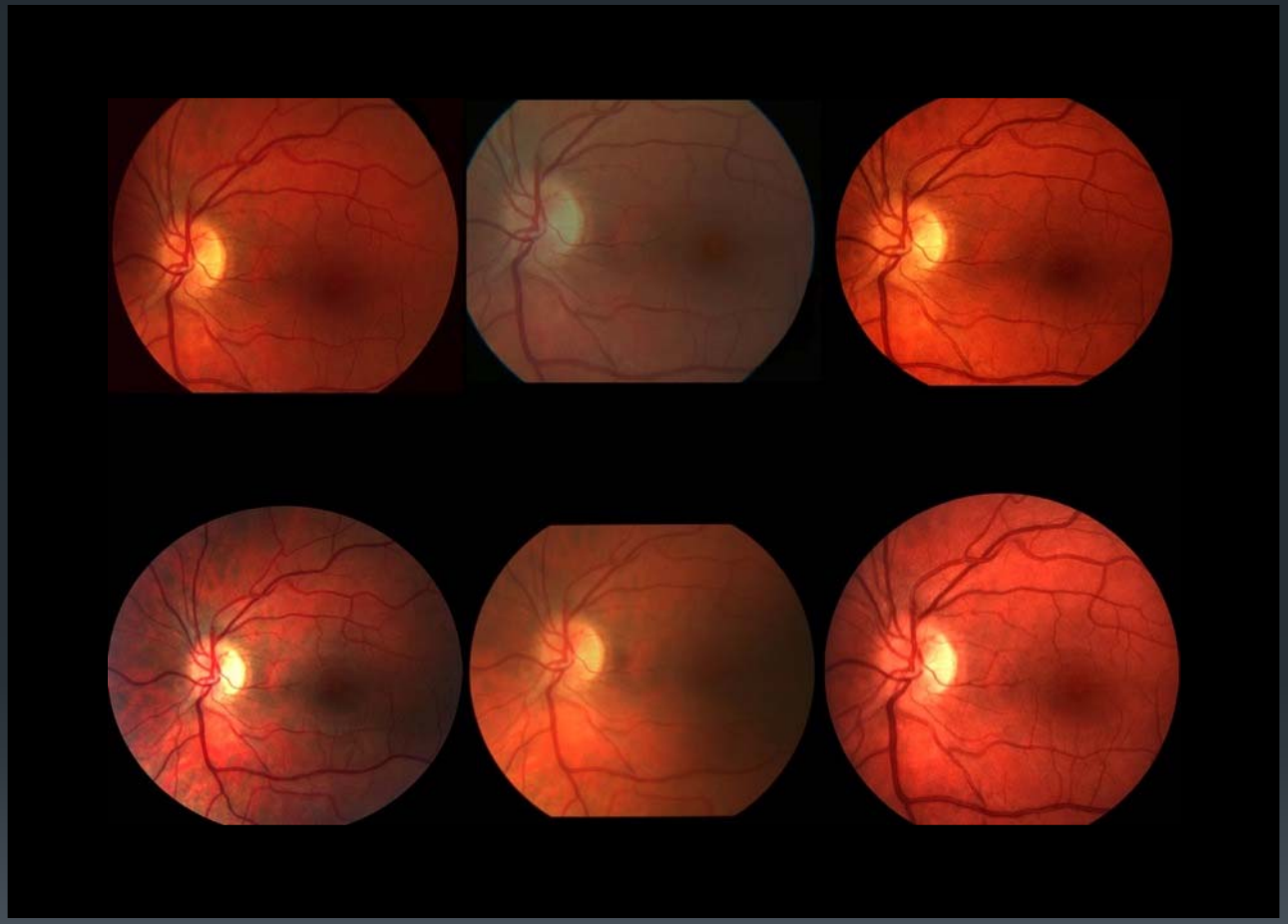
Program Chair, Photographic Sciences, School of Photographic Arts and Sciences

Retinal Color Variation Across Populations

Determined by ethnicity, pigmentation, disease process



Problem Summary: Image Variables

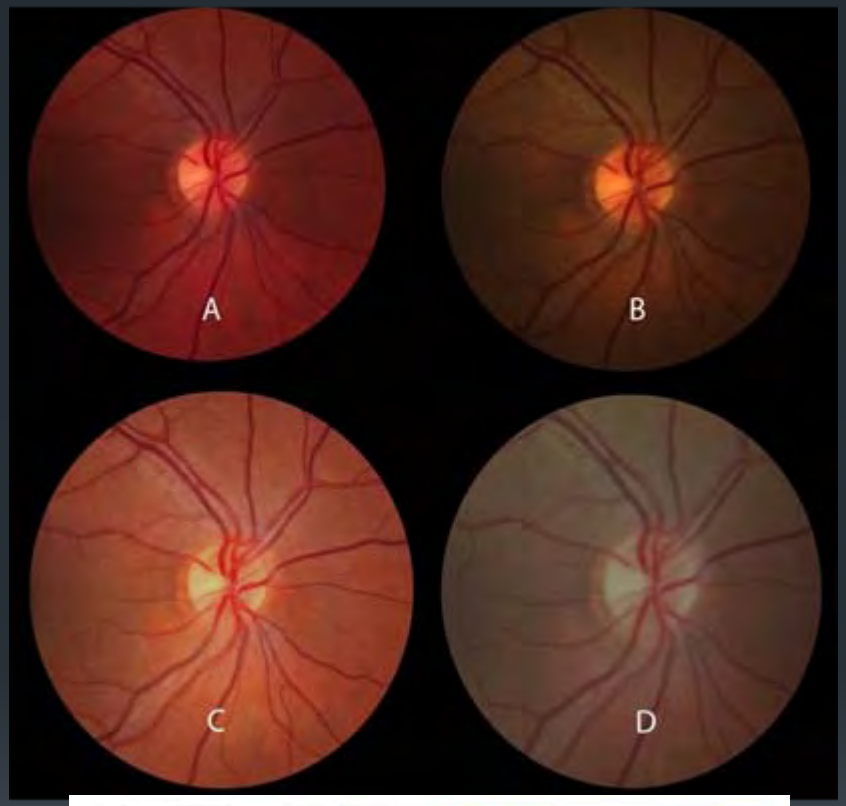


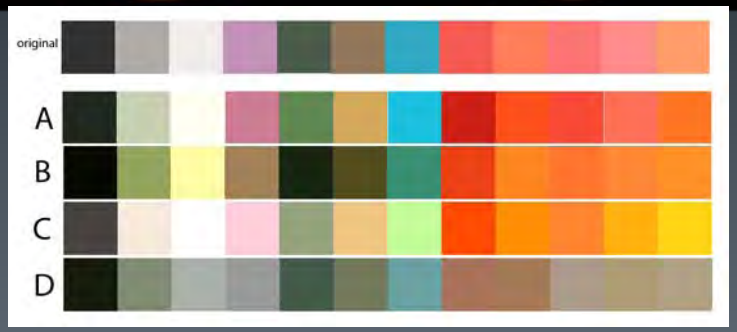
- One reason for the color differences in the appearance of the retina in fundus imaging in ophthalmology is the lack of a suitable calibration method or standard. This causes significant retinal color disparity from camera to camera, even within the same manufacturer for the same patient.

Premise

- It is potentially possible to profile a fundus camera, at least individually, to provide for greater camera-to-camera consistency
  - Applying transforms to RAW images in system would be ideal
- What we as ophthalmic imagers and practitioners believe to be “correct” retinal color is not correct at all
- A standard approach to color calibration is needed to begin to regulate input variables

Captured vs. Processed





Before

After

Objectives

- Develop a suitable calibration phantom and calibration method, and devise the best working/vendor practices to ensure color consistency across devices and manufacturers.
- To generate a repeatable, reliable method of “profiling” individual fundus camera/ophthalmic digital imaging system combinations, and using that profile to attempt to bring the various systems to a reasonable color standard.
- To work with the main companies that produce these systems to work toward this set of color standards in the interest of longitudinal research and accuracy of imaging in the field at large.

Progress Update

- Web meeting in January
  - Draft white paper revised
  - Discussion of manufacturer vs. end user implementation of color standardization
    - Testing to be done to determine viability of manufacturer adoption of model
  - Action items identified, including:
    - Identification of working colors for development of color target
    - Protocol for image capture comparison
- Testing currently underway
  - Determination of color shift from center to edge of image to determine color target size
    - Will also determine number of color patches used as well as overall size of target
    - Testing on multiple cameras to determine inconsistencies
- Color identification
  - Choosing colors representative of retinal pigmentation as well as greyscale to determine gamma thresholds
  - Using Munsell painted patches to use as colors for target

Timetable

- Phase I
  - Identify colors to use in target
  - Determine color change from image center to image edge among different cameras
  - Determine individual target size
- Phase II
  - Design/identify a model eye to replicate human eye conditions that will also allow us to place color target
  - Design and optimize the workflow for target capture on a limited number of cameras to ensure consistent outcome
  - Determine method of integration for resulting color profile
- Phase III
  - Distribute the color eye model to either manufacturers or end users (or both)
  - Analyze resulting data to identify trends
  - Determine the most efficient implementation of color profile

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