Medical Imaging Display Color Space (mRGB)
Teleconference
19 June 2014 • 09:00 (EST)

The meeting was called to order at 09:00 am (EST) by Craig Revie, acting chair, with the following attendees:

Rich Amador	Canon U.S.A., Inc.
Chris Bai	BenQ Corporation
Pinky Bautista	MGH PICT center
Vipul Baxi	Omnyx Integrated Digital Pathology
Wei-Chung Cheng	Federal Drug Administration
David Clunie	Bioclinica & PixelMed
Brian Cote	Eizo Corporation
Scott Forster	Roche Ventana
Phil Green	Gjøvik University College, Norway
Bas Hulsken	Philips Healthcare Incubator
Po-Chieh Hung	Konica Minolta
Francisco Imai	Canon U.S.A., Inc.
Bryan Kennedy	KARL STORZ Imaging
Stephen Lansel	Olympus
Changjun Li	Liaoning University of Science and Technology
Takashi Matsui	Eizo Corporation
Efrain Morales	KARL STORZ Imaging
Allen Olson	Leica Biosystems
Craig Revie	Fujifilm Corporation
Christye Sisson	Rochester Institute of Technology
John Sweeney	BenQ Corporation
Dave Wyble	Avian Rochester, LLC
Kaida Xiao	Technical Consultant
Albert Xthona	Barco NV
Masahiro Yamaguchi	Tokyo Institute of Technology
Brettle David	James's University Hospital Leeds

After a sound check for remote participants, those attending introduced themselves and identified their area of interest. Mr. Revie summarised future meetings of the ICC Medical Imaging Working Group and handed the chair to Mr Albert Xthona.

Mr Xthona reviewed the agenda for the meeting as follows [see attached]:

1. Introduction
2. Define use cases to be supported
3. Discussion on architectural choices
4. Come to conclusion on architecture for color display systems

A recording of the meeting is available to download at http://www.npes.org/Portals/0/standards/2014-06-19%2009.02%20New%20Meeting.wmv

1. Introduction
Mr Xthona outlined the history of medical imaging and the problem of representing reality [see attached]. When imaging first came in, the variability in images was recognised and there was a desire to standardise. The introduction of GSDF helped to achieve consistency. He summarised the goal of the session as agreeing an architecture for the display of medical color images.

2. Use cases
Mr Xthona summarised the possible use cases as:
1. Direct representation of grayscale images
2. Direct display of medical RGB images with no color management
3. Display of medical RGB images with color management

It was noted that case 3 (RGB with color management) was more a future case, and that a further possibility was simultaneous display of gray and RGB images with color management. In some cases the representation of text and metadata also needed to be included.

2.1 Grayscale. It was necessary to check compliance with GSDF. Often hardware LUTs were used to achieve GSDF calibration.

Displays are often 12-14 bits per channel to permit rescaling of tone curves to match GSDF. In practice non-medical displays are also used, with no GSDF calibration. There is increasing use of mobile displays for review, but for primary diagnosis medical displays are recommended and in many countries required by law.

2.2 Direct display of RGB. Different imaging modalities are supported, but the main application is pseudocolor and the task is usually detection or quantification. Annotations and text could be considered as another pseudocolor case.

2.3 RGB with color management. The main application currently is medical photography, and there is a need to work on a compatible approach that handles color correctly. The current ICC framework handles interpretation of color satisfactorily. A future possibility is that if display properties are known, software could transform images appropriately – e.g. to achieve perceptually linear behaviour. The meeting also discussed the case of synthetic images (e.g. for simulation of prostheses), where consistency or accuracy may be important but there is no original.

Dr David Clunie observed that DICOM perceptual linearization is not consistent with a CIE or ICC approach, and can generate contouring / quantization on 8-bit systems. There was a need to achieve the desired behaviour without compromising precision or contrast.

It may not be possible to support the three use cases outlined simultaneously, but it was not necessarily essential to support legacy cases. In the multi-modality case of mammography, where e.g. MRI and CT images might be viewed simultaneously, the precision of gray was critical but not of color. The meeting agreed there were three categories of consistency requirements: critical importance, needs to look acceptable, and unimportant. It also agreed that these may not be possible in a unified display architecture.

It was felt that case 2 implies that users do not care about consistency. It was possible to develop best practice guidelines for such cases, especially for legacy images, while case 3 represents the path for the future.

Mr Xthona showed the display system components [see attached]. The Displayport supports double precision images, but in practice implementations are limited to 8 bits per channel, although some demonstration systems are higher.

Mr Xthona reviewed architectural choices for medical displays, and posed four questions:

- Is DICOM GSDF compliance a requirement?
- Is it possible to calibrate a display simultaneously to sRGB and to perceptually linear behavior?
- Is a new ICC rendering intent for 'perceptually linear color behavior' needed?
- Should mRGB be used to encode color images for non color management-aware applications?

Dr David Clunie stated that the purpose of the GSDF was to achieve consistency in medical displays so that grayscale contrast is always the same. It was originally intended to show a match between a display and a radiology film viewed side by side. If consistency can be achieved by other means, GSDF may not be needed. In modalities where color accuracy is important, such as dermatology, colors would not match since GSDF would conflict with calibration for color accuracy (particularly on hybrid systems), and color management using ICC profiles would be the best solution.

It was noted that if the pipeline is limited to 8 bits per channel, quantization is likely when mapping to GSDF.

The meeting then addressed the second of the questions above. The idea is essentially to extend the perceptually linear behaviour of GSDF to color, which would ensure consistency in presentation of RGB images. It was observed that in ICC color management the exchange space (the Profile Connection Space) is CIELAB-based, and therefore perceptually linear to the same degree as the CIELAB system. It was suggested that using the ICC Media-relative Colorimetric rendering intent with Black Point Compensation (MRC+BPC) should achieve the same results as the GSDF pipeline.

Dr Po-Chieh Hung presented some work on micro and macro color differences [see attached]. He showed differences in color arising from using GSDF against L*. The full presentation will be discussed in a future teleconference.

It was agreed that it was important to preserve linearity of luminance, but not necessarily of color. The CIELAB colour space provides an approximate uniformity of colour.

Dr Bas Hulsken suggested that there was no use case for mixing radiological and color images. The need for consistency of user interface was noted.

Most non-GSDF images are encoded as sRGB, but modern displays exceed the sRGB dynamic range and color gamut. It was suggested that the imaging pipeline could include gamut expansion to an extended gamut intermediate encoding before compressing as needed to the actual display gamut. Dr Po-Chieh Hung suggested that image sharpening might allow a reduction in the number of colors needed.

Dr John Penczek stated that his goal was to preserve the accuracy of sRGB, and it was noted that this could be achieved if the workflow honoured the embedded sRGB ICC profile.

Mr Xthona observed that this works for images where the profile is embedded, but (addressing Q3 above) currently-available rendering intents do not support re-scaling for perceptually linear color behaviour; one useful task would be to define such a rendering intent. Mr Craig Revie responded that PLCB is similar to MRC+BPC, and this could be investigated further. There was a need to understand the use cases to map and how the mapping should be constrained. An option was to indicate the desired perceptual uniformity of the image through an additional tag. It was agreed that it was important to retain consistency with the existing architecture as far as possible.

Mr Xthona showed a strawman architecture proposal. He summarised the discussion during the meeting, noting there was agreement on the following:

a. The use cases as defined in 2. above.
b. The need to support each of the use cases.
c. The need to define the accuracy of the ICC architecture for use case 3.

The next step would be to take the proposed architecture for medical display color and test using the existing ICC architecture to determine its accuracy. Tests could include physical, numeric and analytical.

Mr Xthona agreed to prepare a summary of the meeting for the Friday plenary with the FDA and to plan a teleconference to continue the discussion. The meeting closed at 12:00.

Action items:

MIWG-14-30 Test accuracy of ICC architecture in reproducing medical color images (all)
MIWG-14-31 Prepare summary for FDA plenary (Xthona)
MIWG-14-32 Plan teleconference to continue discussion on medical display architecture (Xthona)

Goal of this session of MIWG Displays

- Agree upon a visualization architecture that supports

  the different ways that
  color medical images are used

  in clinical practice

Structure of this session

1. Define the use cases that need to be supported
2. In depth discussion on important architectural choices to be made
3. Coming to conclusion on architecture of the color visualization system

1. Use cases

1. Use cases - Overview

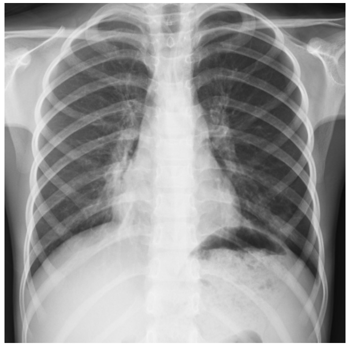
- Direct representation of greyscale medical images
  (current practice today)

- Direct representation of medical RGB images without color management (current practice today)

- Representation of medical RGB images with correct color management (*mostly* future practice)

1.1. Use case 1 – Greyscale medical images

- Eg. Radiological images

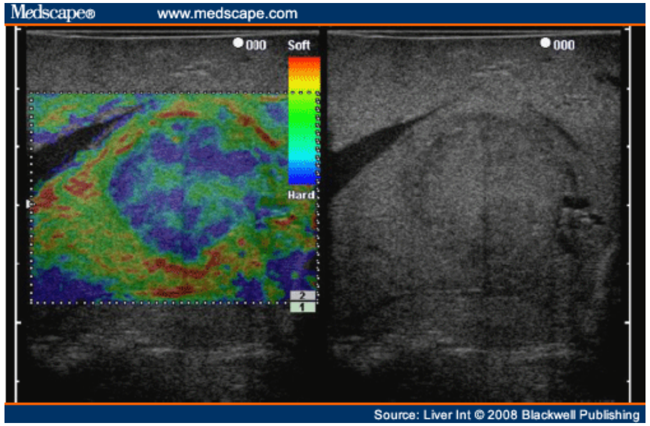


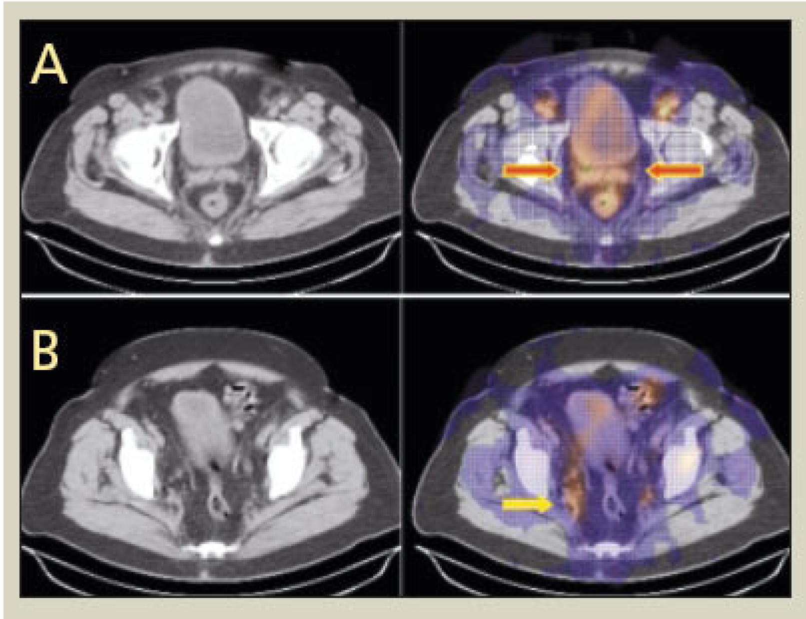
- Specifics
  - Applications forward greyscale images to the display and expect the display to be DICOM GSDF compliant with clearly defined tolerance levels
  - Displays have builtin LUTs (12-14 bit) and dynamically change LUTs based on realtime embedded sensor measurements in order to meet DICOM GSDF compliance
  - Frequent use of “window level”
  - Most important for these images: “detection of subtle signals”

1.2. Use case 2: direct representation of medical RGB images (1)

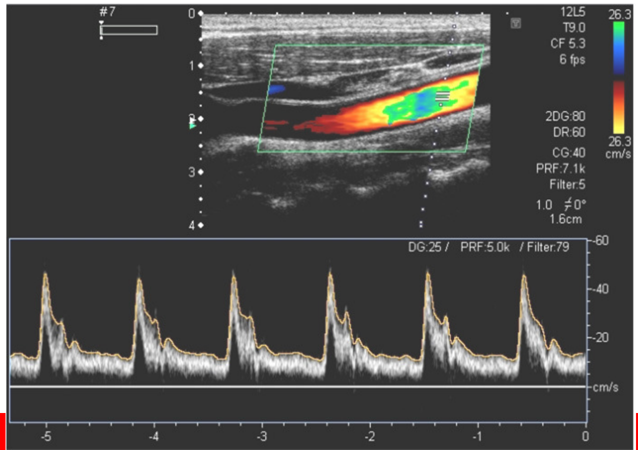
- Eg. Quantitative imaging applications, biomarkers, nuclear medicine, multimodality imaging

Source:
www.medscape.com



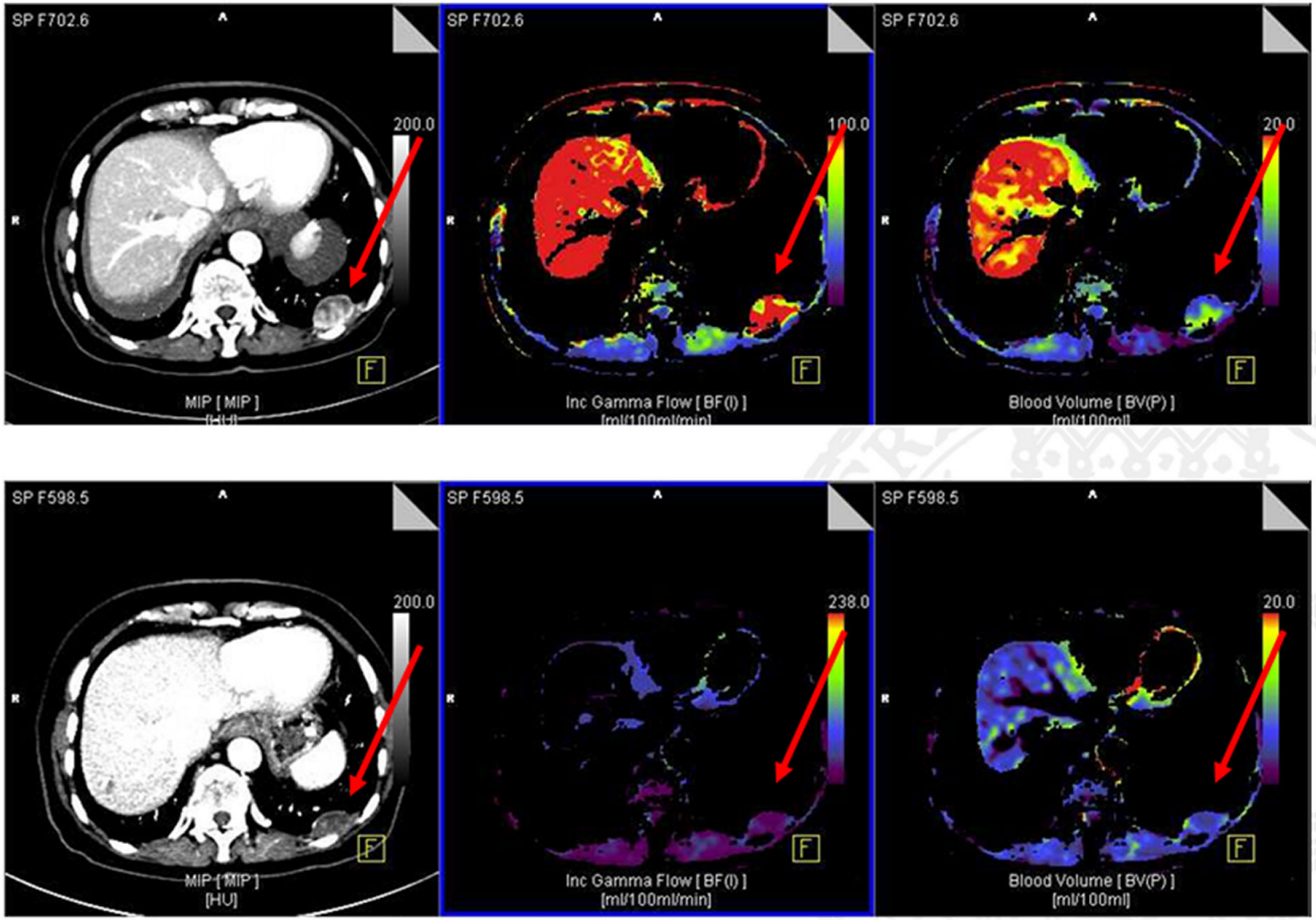


Source:
http://www.intechopen.com/books/design-and-architectures-for-digital-signal-processing/progress-of-doppler-ultrasound-system-design-and-architecture



Source: http://www.intechopen.com/books/design-and-architectures-for-digital-signal-processing/progress-of-doppler-ultrasound-system-design-and-architecture

BARCO
Visibly yours



Source: http://health.siemens.com/ct_applications/somatomsessions/index.php/research-clusters-enable-transfer-of-basic-research-to-clinical-routine/

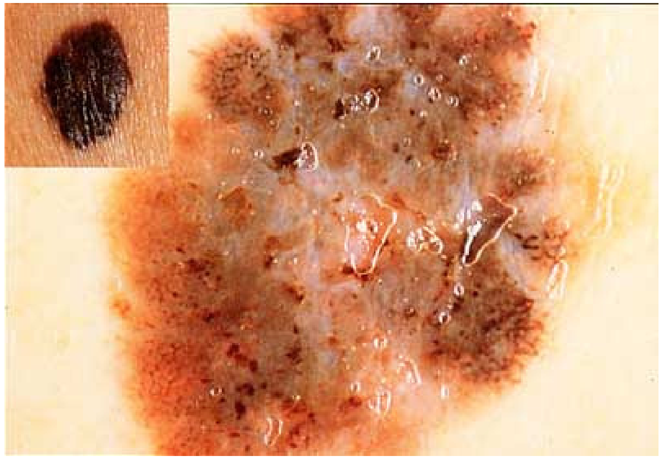
BARCO
Visibly yours

1.2. Use case 2: direct representation of medical RGB images

- Specifics:
  - The vaste majority of medical viewing applications today do not have color management and just forward color RGB data to the display
  - Some applications implicitly “assume” sRGB behavior
  - Colour typically is artificial and represents either relative or calculated values
  - Tasks to be performed are typically either “detection tasks” or “quantification tasks”, which means that it is important to “detect subtle things” or to “determine from the image what the underlying value is”

1.3. Use case 3: representation of medical RGB images with color management (1)

- Eg. Medical photography / dermatology



Source: http://www.medilor.be/catalogue/dermatoscope.htm

- Specifics:
  - Absolute correct color is important
  - Applications use typically ICC framework to achieve this

Visibly yours

1.3. Use case 3: representation of medical RGB images with color management (2)

- Very important note:
  - Of course it is possible to build visualization software that correctly uses a Color Management System (use case 3) and that is used for visualization of content that was described in use case 1 and 2. But that is not current practice today and therefore we also need to support use cases 1 and 2.
  - Ideally, over time (but this will take many years), use case 1 & 2 will be replaced by use case 3

- Do we agree that we need to be compatible with the three use cases discussed before?

2. Components of a medical color display system

2.1. Components of a color medical display system

- GPU with driver
- QA/Calibration software application
- Viewing application
- Presentation LUT
- (color management framework)

- Displayport: standard 8 bit per color channel and demo implementations today up to 10 bit

- Several LUTs for calibration
- Luminance & color sensors
- Realtime stabilization circuitry
- Postprocessing for Uniformity correction, response time improvement, ...

2.2 Important architectural choices to be made (1)

- Do we agree that DICOM GSDF compliance is a must-have?
- Do we agree that it should be possible to calibrate the display to sRGB as well as to perceptually linear behavior?
- Is it beneficial to define a new ICC rendering intent for ‘perceptually linear color behavior’?
- Should mRGB be used to encode color images for applications that do not support color management (use case 2)

- Choice for specific “standard behavior” of the display
  - Eg. GSDF, sRGB, PLCB?
  - Relevant question to be considered: is it easier to achieve sRGB from GSDF/PLCB, or easier to achieve GSDF/PLCB from sRGB?

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2.2 Important architectural choices to be made (2)

- Position of the LUTs for “calibrating the display”
  - Inside the display or inside the GPU?
  - Minimal required bit depth to achieve accurate calibration (for achieving DICOM GSDF, for achieving PLCB, for achieveing absolute correct color behavior)?

- (Application) LUT for window/leveling & color presentation optimization
  - Needed for color application?
  - Position of this LUT? Before or after CMM?

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2.2 Important architectural choices to be made (3)

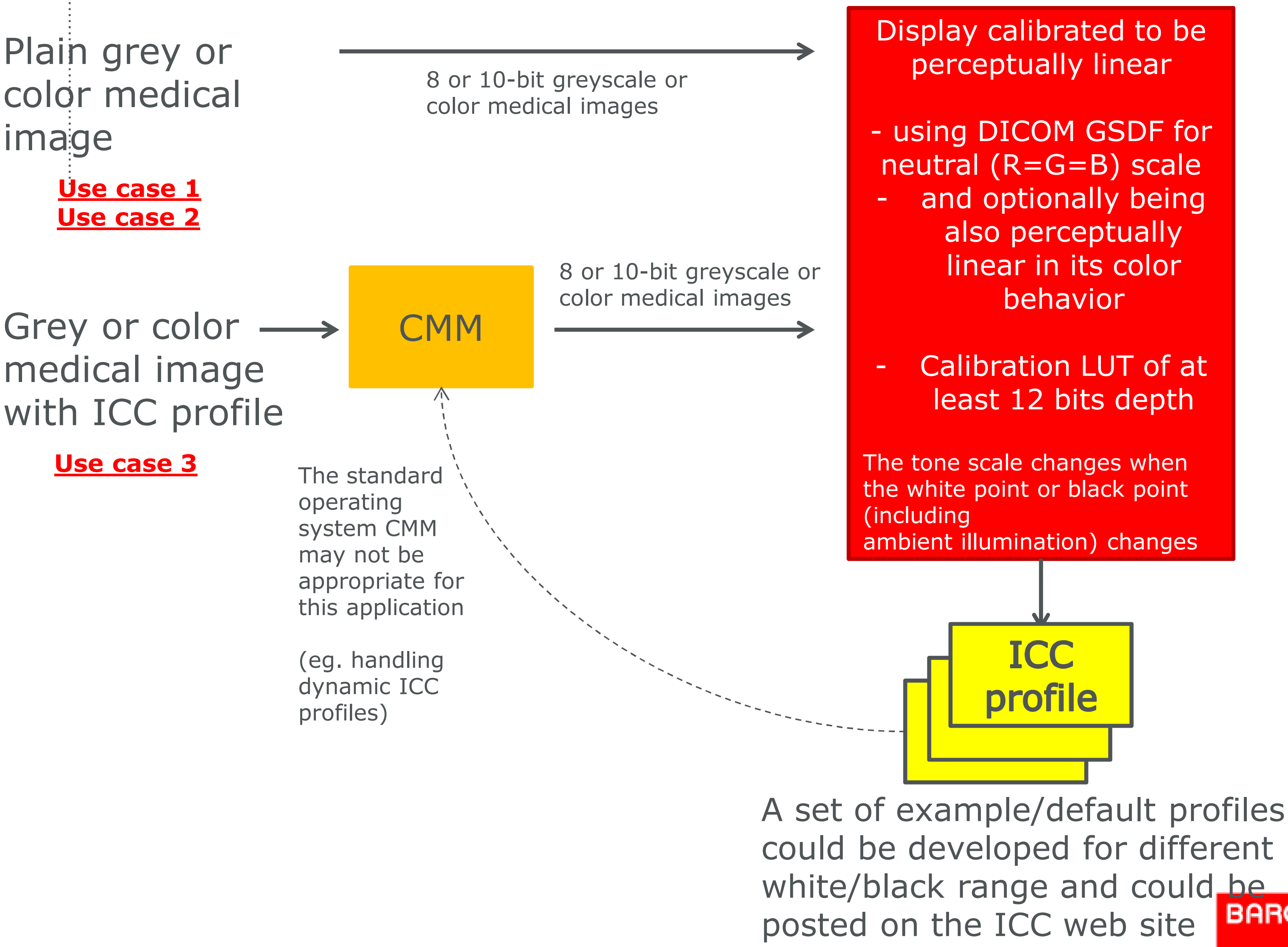
- Stabilization of the display
  - Handled internally by the display or by an external process?
  - Difference between luminance/color/GSDF stabilization?
  - Relevant to be considered it the influence that real-time behavioral changes of the display has on the entire color management chain (dynamic ICC profiles)

What can we learn from greyscale medical displays?

- High bit depth is needed for accurate greyscale DICOM GSDF calibration (12 bits or more)
- Calculating GSDF calibration LUT requires knowledge on absolute (current) luminance behavior of the display
- This calibration LUT needs to be as close as possible to the "LCD panel"

3. Possible architecture for a color medical display system

- In this section I would like to interactively with the group challenge/verify that the proposed architecture indeed can support/be compatible with all presented use cases



Plain grey or color medical image
Use case 1
Use case 2
8 or 10-bit greyscale or color medical images
Display calibrated to be perceptually linear
- using DICOM GSDF for neutral (R=G=B) scale
- and optionally being also perceptually linear in its color behavior
- Calibration LUT of at least 12 bits depth
The tone scale changes when the white point or black point (including ambient illumination) changes
Grey or color medical image with ICC profile
Use case 3
CMM
8 or 10-bit greyscale or color medical images
The standard operating system CMM may not be appropriate for this application
(eg. handling dynamic ICC profiles)
ICC profile
A set of example/default profiles could be developed for different white/black range and could be posted on the ICC web site

A Consideration of Image Display Method that Micro- and Macro- Color Differences Coexist

Po-Chieh Hung

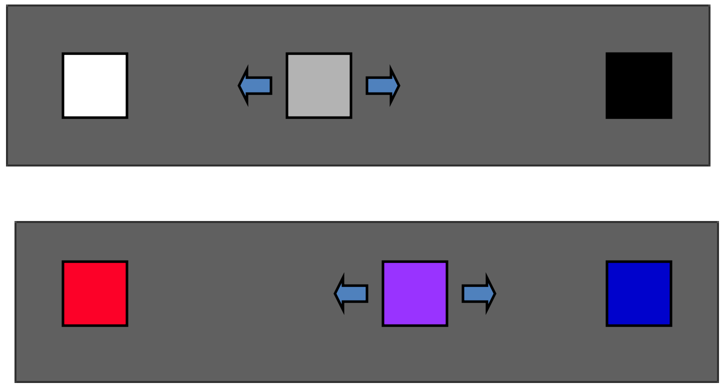
Konica Minolta Laboratory U.S.A., Inc.

Outline

- Types of color differences
  - Micro (JND)
  - Macro (scaling)
- Gray Scale Display Function
- Basic Idea
- Preliminary test
- Summary

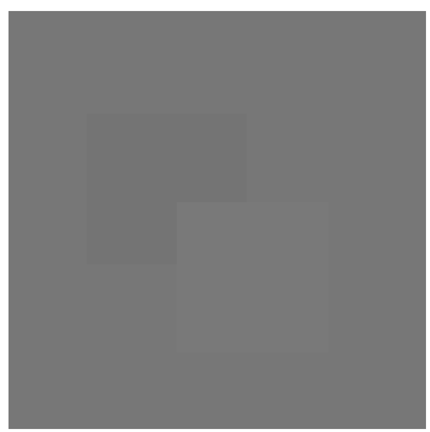
Two Types of Color Differences

Macro (By Scaling)



e.g.
Munsell Color System
CIE L*a*b* color space

Micro (By JND)



e.g.
GSDF
MacAdam’s ellipses (Standard Deviation of Color Matching)

Two Types of Color Differences

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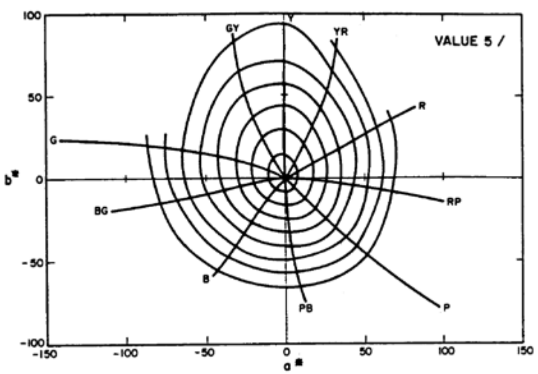
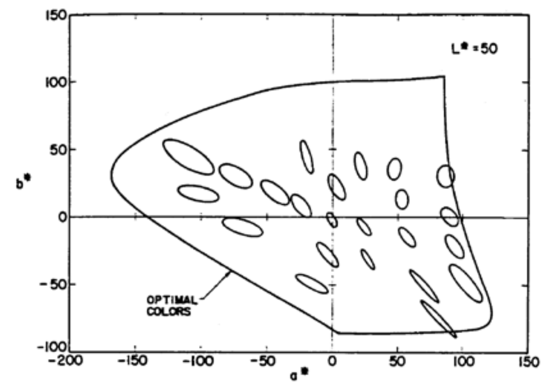
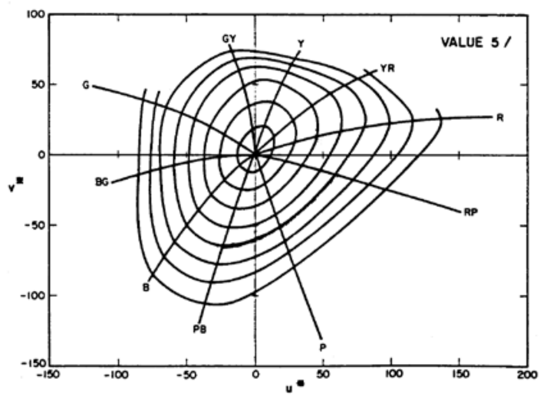
Comparison of CIE L*a*b* and L*u*v*

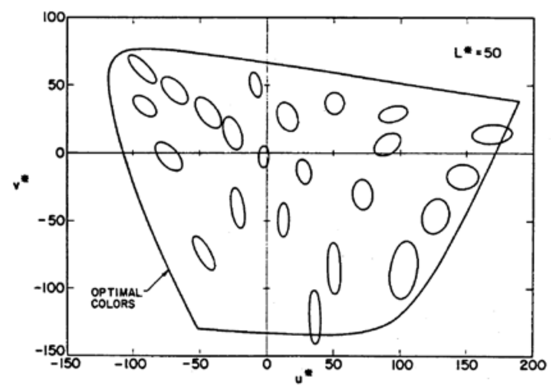
L*a*b*





L*u*v*





Munsell color space **MacAdam's ellipses**

A. R. Robertson, The CIE 1976 color-difference formulae, Color Research and Application, 2, 1, pp. 7-11 (1977).

As a Result...

$$1_{jnd} + 1_{jnd} + 1_{jnd} + 1_{jnd} + 1_{jnd} \neq 5_{scale}$$

Micro color difference

Macro color difference

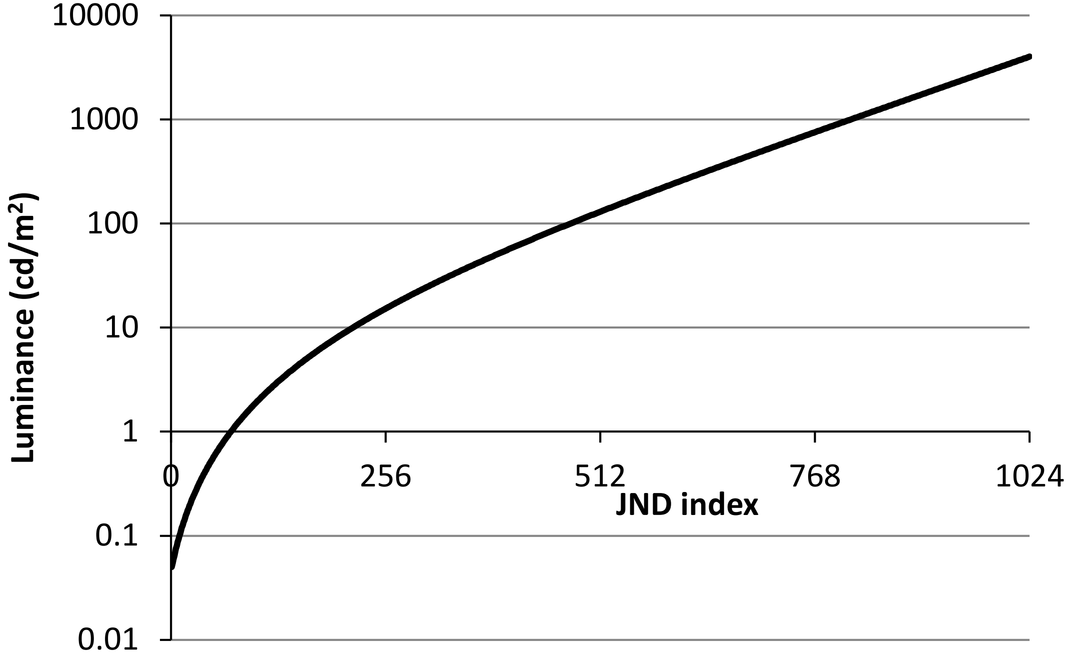
Color difference is not linear

Gray Scale Display Function

Grayscale Standard Display Function: The mathematically defined mapping of an input JND index to Luminance values defined in PS 3.14.

$$\log_{10} L(j) = \frac{a + c \cdot Ln(j) + e \cdot (Ln(j))^2 + g \cdot (Ln(j))^3 + m \cdot (Ln(j))^4}{1 + b \cdot Ln(j) + d \cdot (Ln(j))^2 + f \cdot (Ln(j))^3 + h \cdot (Ln(j))^4 + k \cdot (Ln(j))^5}$$

$a = -1.3011877,$
$b = -2.5840191 \cdot 10^{-2},$
$c = 8.0242636 \cdot 10^{-2},$
$d = -1.0320229 \cdot 10^{-1},$
$e = 1.3646699 \cdot 10^{-2},$
$f = 2.8745620 \cdot 10^{-2},$
$g = -2.5468404 \cdot 10^{-2},$
$h = -3.1978977 \cdot 10^{-3},$
$k = 1.2992634 \cdot 10^{-4},$
$m = 1.3635334 \cdot 10^{-3}.$

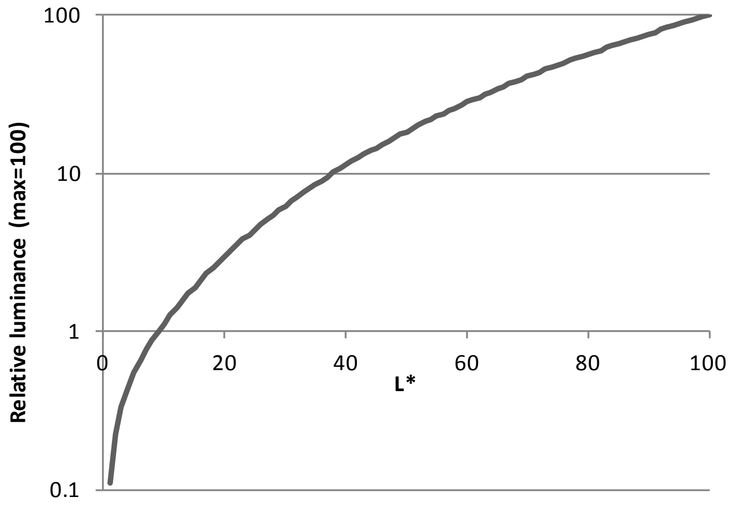


PS 3.14-2011, Digital Imaging and Communications in Medicine (DICOM), Part 14: Grayscale Standard Display Function, National Electrical Manufacturers Association.

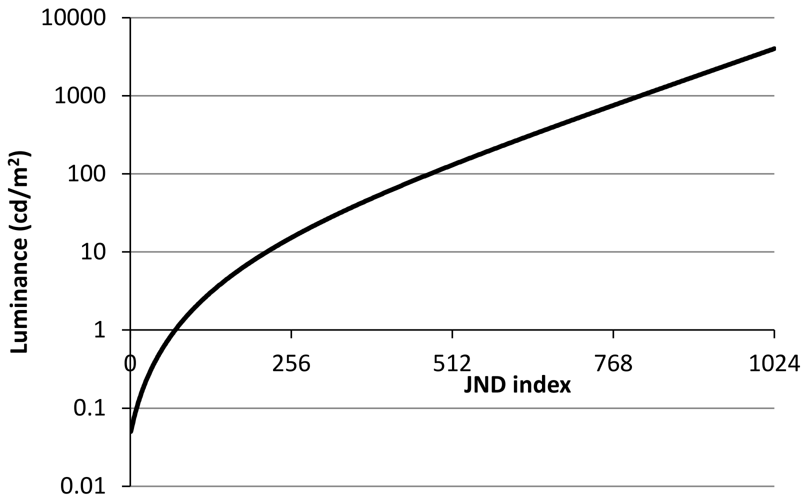
Essential Difference between GSDF and L*

L*: Relative against white point

GSDF: Absolute to luminance



L*

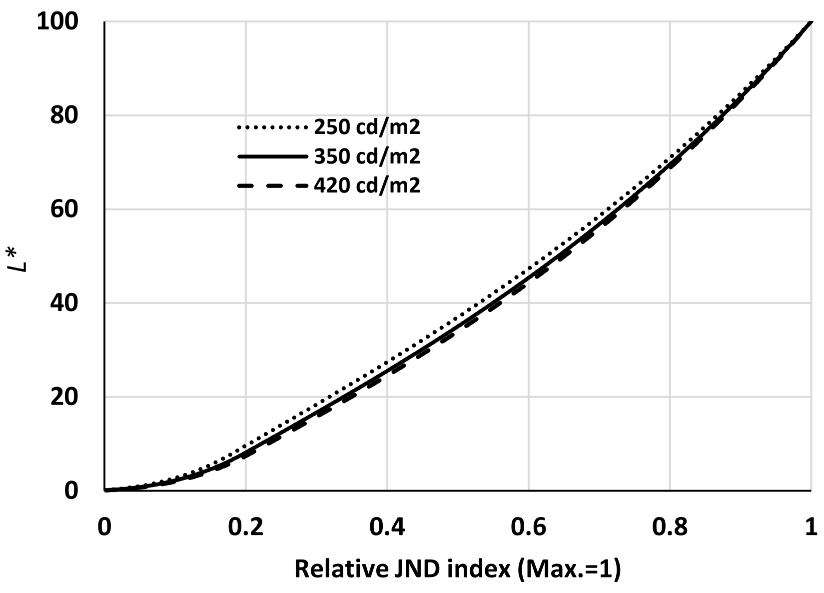


GSDF

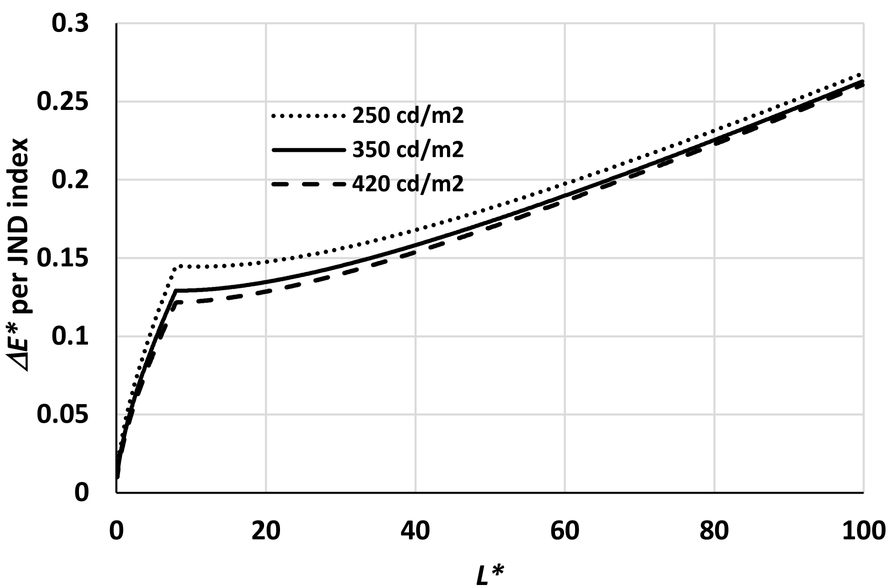
They look similar at a glance, but…

What would happen if GSDF is used for Color Space?

When it is plotted in L* axis under the conditions of different Luminance levels…



L* vs GSDF JND



L* vs ΔE* (ΔL*)

mRGB Color Space (not final)

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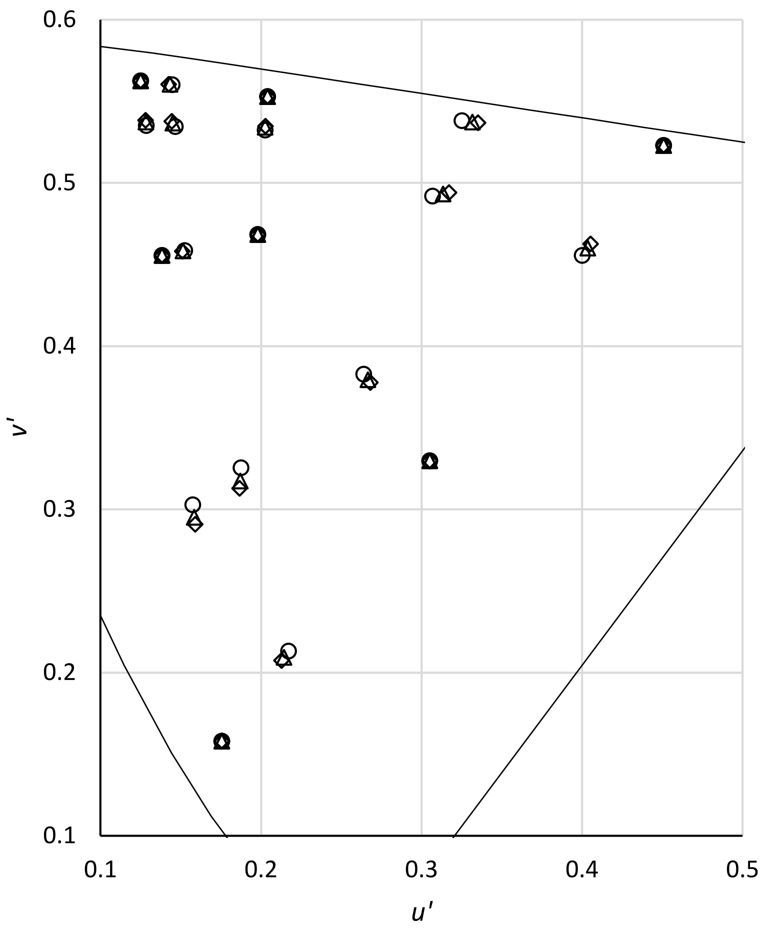
Color spaces compared   * IEC 62563 terminology

Specification*	sRGB	aRGB	ACR	mRGB
Luminance Response	~2.2 power function	2.199 power function	DICOM GSDF	DICOM GSDF
Color Gamut	HDTV based ITU-R BT.709-5	'Wide' (extended G)	-nd-	sRGB (aRGB option ?)
L_{max} , cd/m^2	80	160 (125-200)	350/420/250	350/420/250
L_{min} , cd/m^2	-nd-	0.56	L_{max} / LR	L_{max} / LR
Luminance Ratio (LR)	-nd-	287.9 (230-400)	350 (> 250)	350
White Point	D65	D65	D65	D65
Gray tracking	-nd-	-nd-	-nd-	IEC MT51
Surround	20% refl. lx	Gray < 20% L_{max}	-nd-	20% L_{max}
Ambient Illumination, lx	64 (D50)	32	20-40	-nd-
Veiling Glare	1.0%	accounted	-nd-	-nd-
L_{amb} , cd/m^2	-nd-	-nd-	$L_{amb} < L_{min}/4$	$L_{amb} < L_{min}/4$

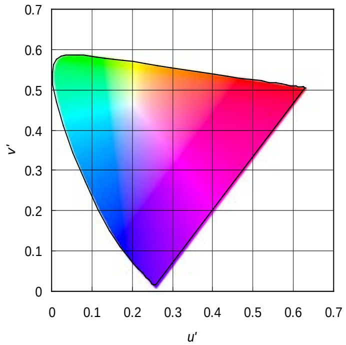
AAPM TG196   http://www.color.org/groups/medical/Flynn.pdf

What would happen if GSDF is used for Color Space?

Causes chromaticity shift!



○: 250 cd/m²
△: 350 cd/m²
◇: 420 cd/m²



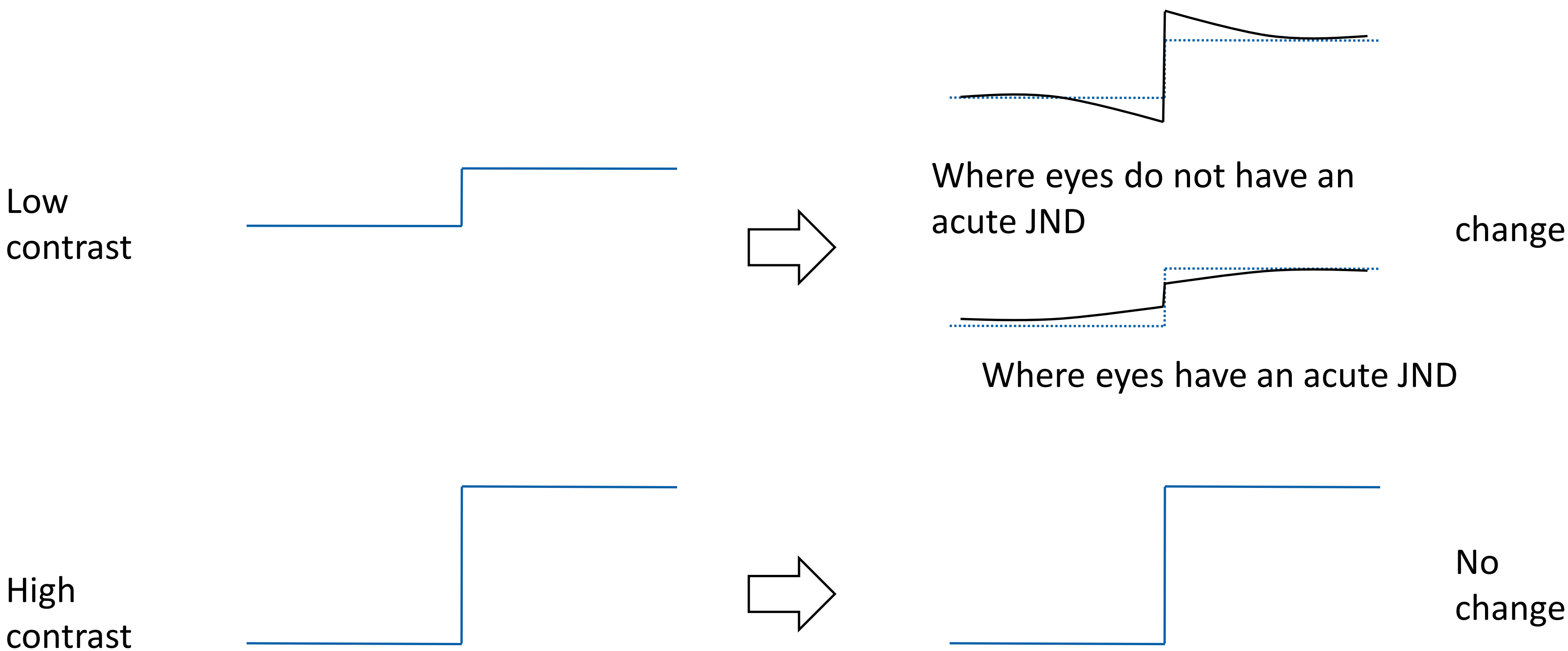
Can Both Color Differences Be Coexisted?

Proposal:
Employ "Color space adaptive to local image"
= Local spatial adjustment

[Criteria to achieve it]
a) Low spatial frequency image and high contrast image are displayed as same as usual color reproduction.
b) Targeted spatial frequency component for non-high contrast image is displayed as similar to micro-color difference (JND).

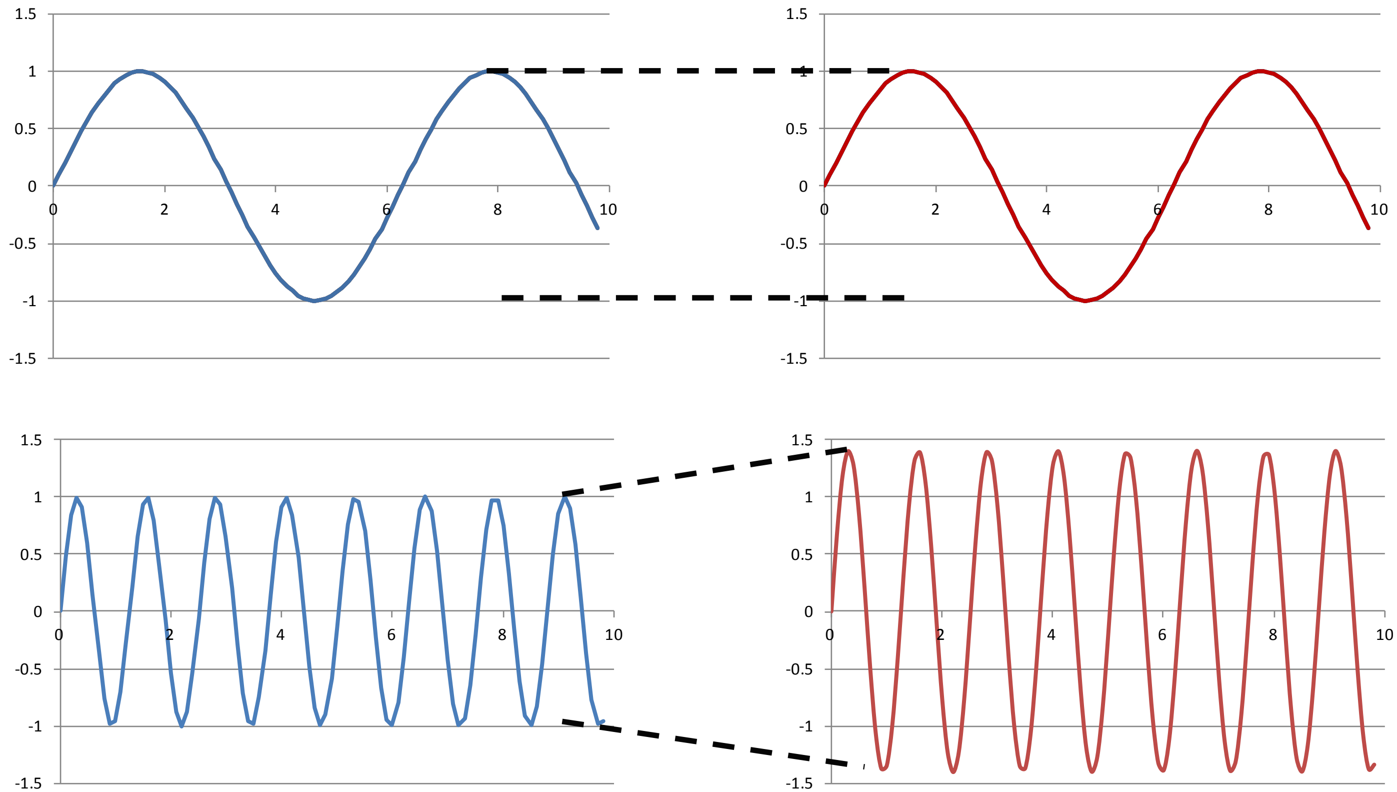
Can Both Color Differences Be Coexisted?

Desired effect (Conceptual): Step wedge



Can Both Color Differences Be Coexisted?

Desired effect (Conceptual)



No enhancement

Enhanced

Low frequency

High frequency

Preliminary Test

Assumption:

- **Gray scale**
- **Edge enhancement using convolution**

Enhancement model:

$$P'(x, y) = P(x, y) + Coeff \cdot \varepsilon \quad Coeff = f(Ave, \delta)$$

Edge element:

$$\varepsilon = \sum_{j=-N}^{N} \sum_{i=-N}^{N} P(x+i, y+j) \cdot W(i, j) \qquad \sum_{j=-N}^{N} \sum_{i=-N}^{N} W(i, j) = 0$$

Luminance level:

$$Ave = \frac{1}{(2N+1)^2} \sum_{j=-N}^{N} \sum_{i=-N}^{N} P(x+i, y+j)$$

Edge amount:

$$\delta = |\varepsilon|$$

Preliminary Test

Exact Equations Used

1D Simplified functions are used.

$$\varepsilon = 2.0 \cdot P(x) + 0.5 \cdot (P(x-1) + P(x+1))$$
$$-0.5 \cdot (P(x-3) + P(x+3))$$
$$-1.0 \cdot (P(x-4) + P(x+4)).$$

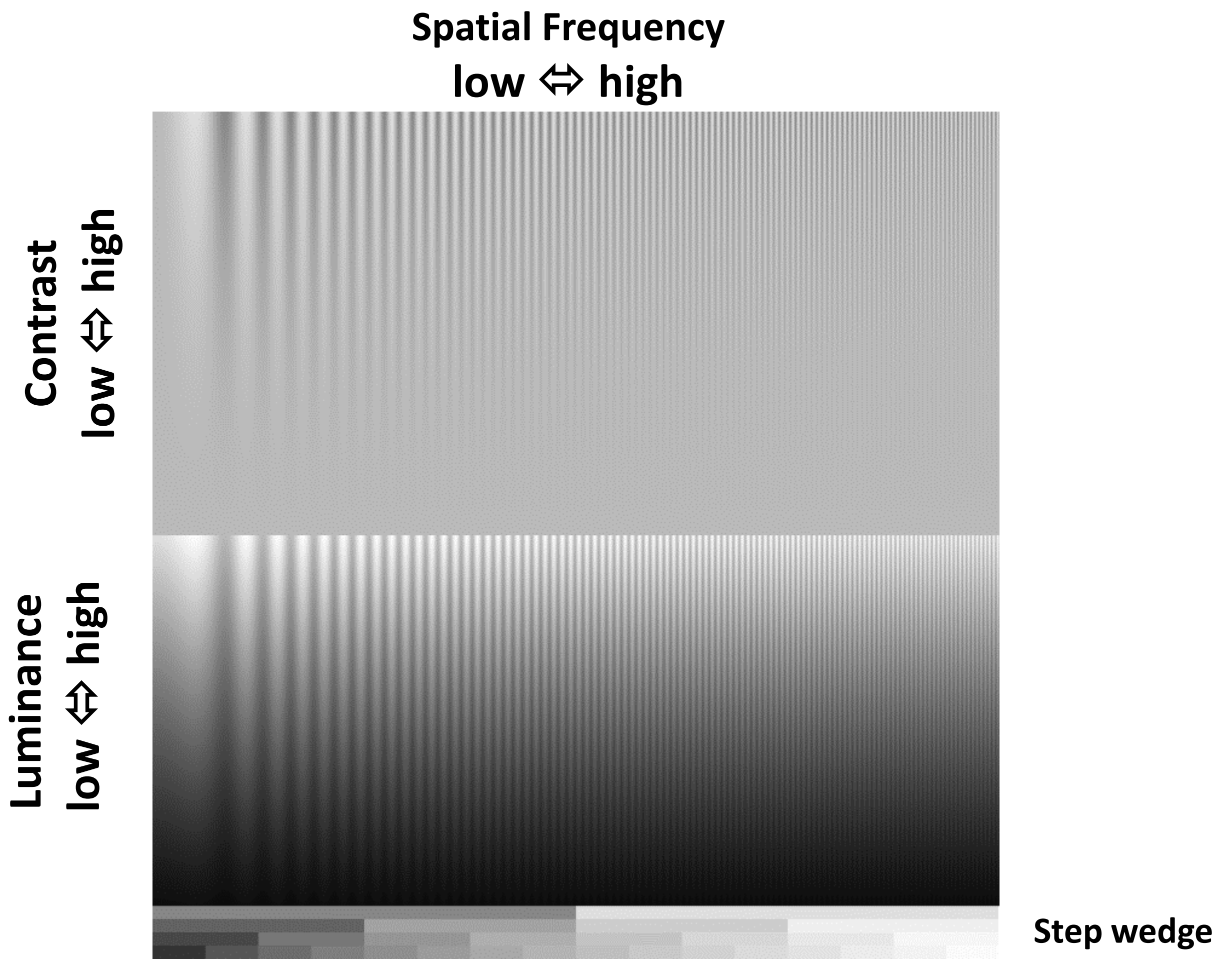
Parameters are adjusted trial and error basis

$$Coeff = (Ave + 0.5) \cdot \left(0.12 \cdot 4^{-abs(\varepsilon)}\right)$$

Experiment

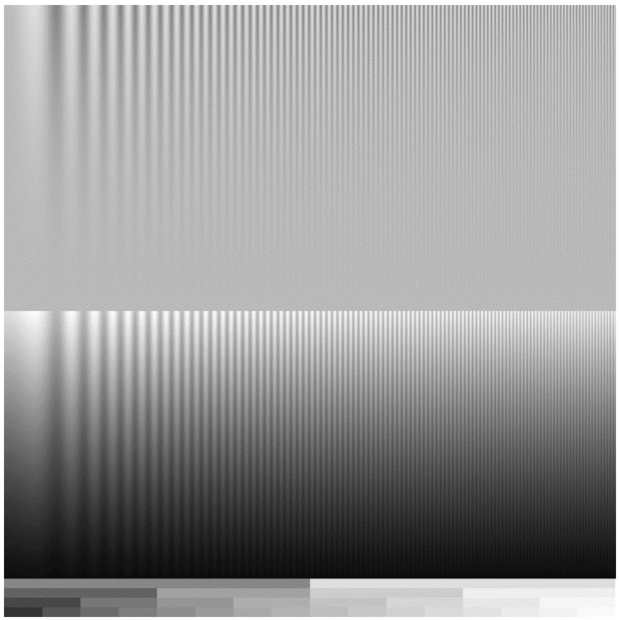
Test image:

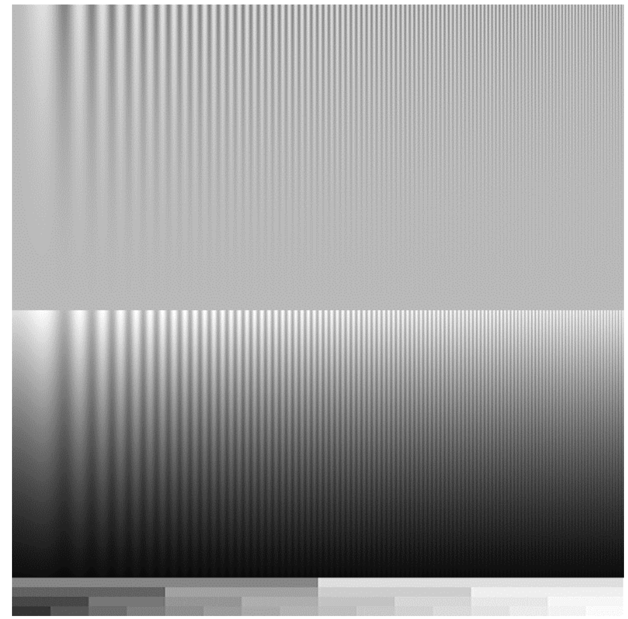
1D Chirp function image with step wedges

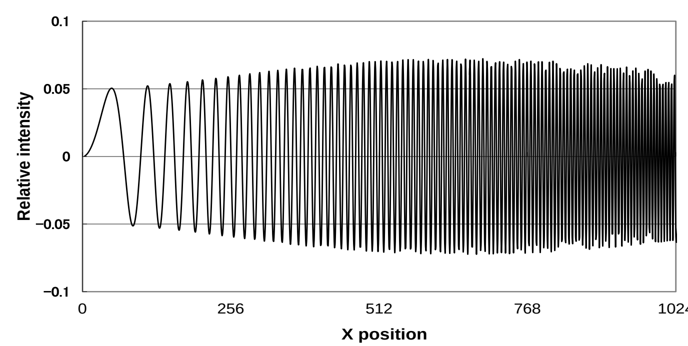


Experiment: Evaluation

Result of this algorithm







Discussion

KONICA MINOLTA

Limited usage of GSDF for tonal scale

- Specify luminance level(s)?

Expansion to chroma direction?

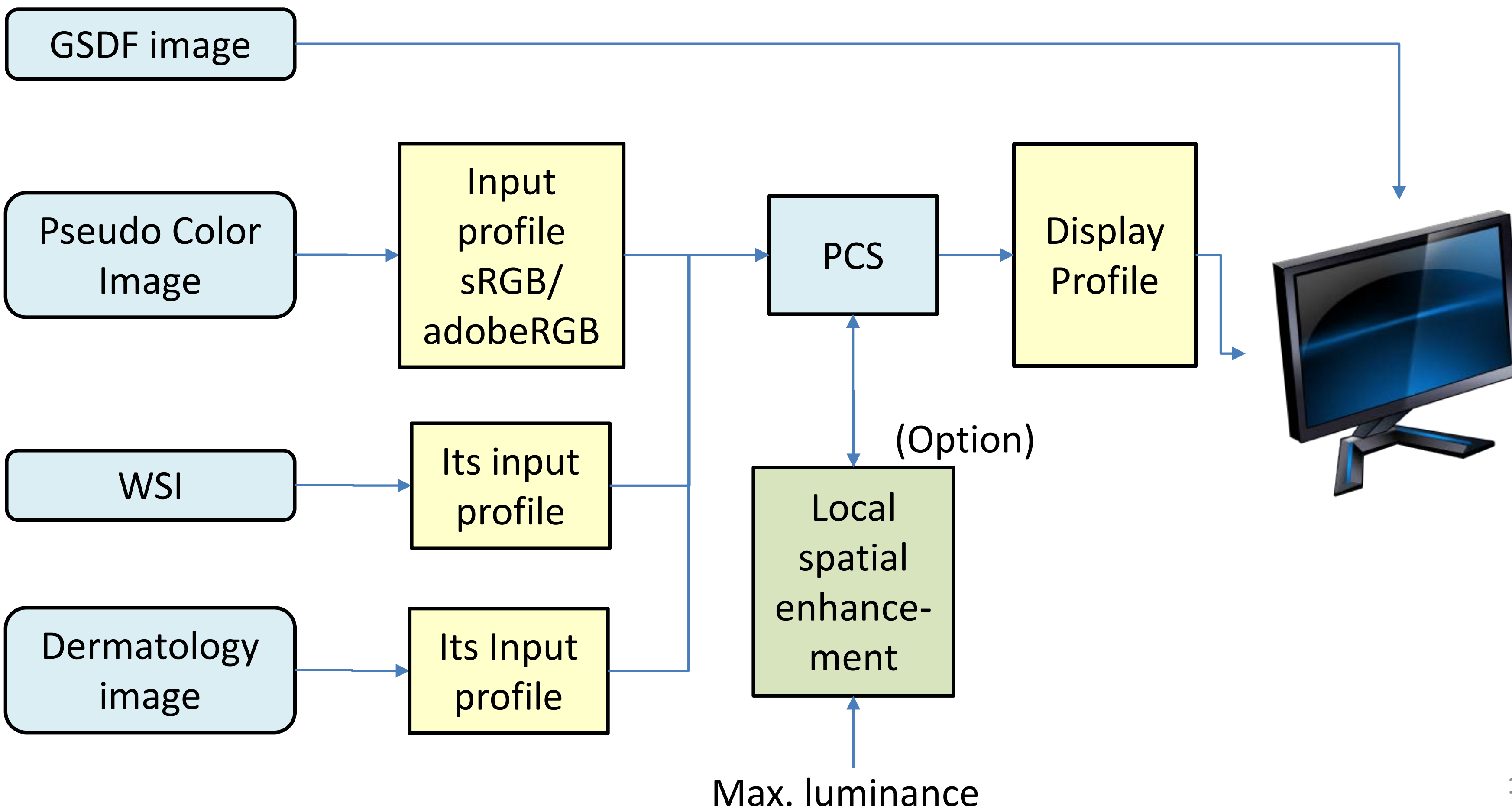
- E.g. Delta E 2000

How to optimize equations and parameters

- Computational load
- Spatial Frequency characteristics
- Actual test

One Idea

Without mRGB.



Summary

- Pointed out an issue between Micro- and Macro- Color difference
- Proposed a solution using adaptive color space and gave the criteria
- Tested the space for gray scale with simple parameters and verified a possibility to satisfy the criteria

Thank you for your kind attention!