**Medical Imaging Display Colour Space (mRGB)**
**Teleconference**
16 January 2014 • 15:00 (UK) / 10:00 (EST)

The meeting was called to order at 10:00 am (EST) by Craig Revie, acting chair, with the following attendees:

| | |
|---|---|
| Vipul Baxi | Omnyx |
| Mike Brill | Datacolor |
| James Chang | Sharp Laboratories |
| Wei-Chung Cheng | FDA |
| John Dalrymple | Technical expert |
| Glenn Davis | Ventura |
| Mike Flynn | Henry Ford Health System |
| Phil Green | ICC |
| Robert Horn | Agfa Healthcare |
| Po-Chieh Hung | Konica Minolta |
| Bas Hulsken | Philips Healthcare Incubator |
| Tyler Keay | Omnyx |
| Tom Kimpe | Barco NV |
| Elizabeth Krupinski | University of Arizona |
| Tom Lianza | X-Rite |
| Jim Martin | MIT |
| Takashi Matsui | EIZO Corporation |
| Masahiro Nishiboru | International University of Health and Welfare |
| Allen Olson | Leica Biosystems |
| Debbie Orf | NPES |
| John Penczek | NIST |
| Craig Revie | FFEI |
| John Sweeney | BenQ |
| Dave Wyble | Avian Rochester, LLC |
| Masahiro Yamaguchi | Tokyo Institute of Technology |
| Hideto Yokoi | Kagawa University Hospital |

Those present introduced themselves and identified their area of interest. Mr. Revie reviewed the agenda for the meeting as follows:

1. Introduction (Craig Revie)
2. Medical imaging display colour space (mRGB)

A recording of the meeting is available to download at http://www.npes.org/Portals/0/standards/2014-01-16%2010.31%20Medical%20Displays%20Working%20Group.wmv

**1. Introduction**

Mr Revie reviewed the meeting schedule for the Working Group [see attached]. There was a monthly telecom, plus additional meetings as needed. Mr Revie encouraged those present to take part in the ICC meeting in Tokyo on 3 March – a telecon will be available and the meeting will be recorded. Participants should register with Debbie Orf. Mr Revie showed the draft agenda for the Tokyo meeting [see attached].

The consensus paper from the May 2013 Summit is undergoing final edits. It is the intention to make the paper submitted to BMC medicine publicly available. A version is also being submitted to JAMA Viewpoints.

Mr Revie handed over the chair to Mr Michael Flynn, the leader of the mRGB activity in ICC MIWG.

**2. Medical imaging display colour space (mRGB)**

Mr Michael Flynn presented an outline the current status of mRGB [see attached].

Mr Flynn showed the specifications for sRGB and Adobe RGB (1998). The AAPM draft of the mRGB specification now adds 'colour managed displays', with a focus on the use of profiles within display systems. The mRGB standard is not primarily intended for print media.

The ambient luminance has now been defined, which is consistent with the ACR standard. This has a minimum luminance of 250 cd/$m^2$, which is now common in the market place. The gamut is no longer defined as sRGB, but is referenced.

The meeting discussed the way ambient illumination is defined. It was clarified that $L_{amb}$ refers to the ambient reflection off the monitor faceplate with the power off. The specified condition is commonly met in the medical specialities, which have diffuse, low levels of ambient illumination, but is difficult to achieve in other situations like theatre and emergency where ambient lighting is high and often very directional. Displays for medical imaging mostly have anti-glare coating, unlike consumer and other applications.

Mr Flynn clarified that '1/4' means ¼ of the GSDF value generated without $L_{amb}$; if the GSDF was generated including $L_{amb}$, the 2/3 limit applies. This could be clarified in an informative annex.

Mr Lianza noted that a surround specification was also needed, including the spatial extent of the surround field and whether the light is to be measured on the desk or on the region immediately surrounding the display.

Mr Flynn thanked the contributors to the discussion and undertook to consider these points in taking mRGB forward.

Mr Kimpe presented a proposal for a modified colour management framework [see attached]. He outlined use cases for mRGB, and noted that the focus is on calibration of the display, the performance of the display and the use of colour management to provide a transform from reference colour space to actual display. He classified display viewing environments into 'primary' (diagnostic) and 'secondary' (review of patient information). In primary applications, the original is passed to a calibrated display, possibly via a non colour managed application.

A problem that arose was that the GSDF calibration makes sRGB images look bad, and desaturates the display. There is a need for colour management that allows for backward compatibility. His proposal was to extend GSDF so that display grayscale is perceptually linear, and to also ensure linear colour behaviour.

The problem with using sRGB is that:

- sRGB limits the available gamut – most modern displays have a larger gamut
- An absolute calibration is not appropriate for all applications, and sRGB restricts the scope for perceptual adjustment
- If the display is calibrated to a fixed sRGB, the profile has to handle all colour correction; while currently many systems have the capability to handle adjustment on the display

Mr Kimpe showed how a perceptually linear adjustment would fit in the mRGB architecture. It was possible to have an accurate DICOM image and an accurate perceptual rendering, and the workflow would be straightforward using ICC profiles. Profiles could be generated dynamically.

Mr Hulsken noted that the profile would need to change when the display white and black point change. Mr Kimpe agreed, and noted that there was a need to determine what changes would require a new profile. The ambient illumination would also change settings, which would be a consideration for mobile devices.

In response to a question from Mr Brill, Mr Kimpe stated that to achieve GSDF calibration, the curve was applied to RGB channels, not just luminance.

Mr Flynn noted that CIE TC 1-93 is considering neutral scale for emissive displays, and recommended that the points raised should be brought up in the DICOM committee.

Mr Kimpe concluded that his proposal needed calibration targets, example profiles and a prototype framework, and offered to provide these. This was welcomed by Mr Flynn.

Mr Penczek added that at NIST they had found that following DICOM calibration, there was an error in accuracy of approximately 15 CIELAB DE*ab on Macbeth ColorChecker and fleshtone colours.

A presentation by Mr Revie on a proposed modification to the mRGB colour gamut [see attached] was not presented owing to lack of time and much of the subject matter had already been discussed in the meeting.

It was decided to hold the next meeting in May. AAPM should have a final draft of mRGB by then, and this group could provide critical review. A two-hour telecon will be scheduled.

**Actions:**

1. Raise points from meeting in AAPM (Michael Flynn
2. Provide profiles and prototype colour management architecture for perceptually linear GSDF-based calibration (Tom Kimpe)
3. Raise sRGB issues in DICOM (Tom Kimpe)
4. Provide a copy of the AAPM mRGB document to this group in advance of the May telecom (Michael Flynn)

# Colour in medical imaging task force
## 16th January 2014 teleconference

- **Meeting introduction (Craig Revie)**
  - Next meetings – save the date!
    - 20th February : teleconference (Whole Slide Imaging)
    - 3rd March : face-to-face meeting in Tokyo (13:00-17:00)
    - 20th March : teleconference (Medical photography)
    - 17th April : teleconference (Mobile)
  - Consensus paper status (Aldo Badano)
    - The paper is being edited with last-minute contributions.
    - The manuscript has already been cleared by FDA for submission.
    - Once the edits are finished and we receive the final 2 concurrence emails, it will be submitted to the journal.
    - The JAMA viewpoints will be submitted the following week.
- **Medical imaging display colour space (mRGB) (MJF to lead)**
  - review of mRGB proposal (Michael Flynn)
  - perceptually linear colour (Tom Kimpe)
  - comments on the sRGB gamut limitation (Craig Revie)
  - discussion (Michael Flynn)
- **Any other business**

# Face-to-face meeting in Tokyo

- **Meeting details**
  - MIWG meeting on 3rd March from 13:00-17:00
  - location Shinjuku, Tokyo
  - meeting will be hosted by Nikon
  - teleconference facilities will allow remote attendance
  - recording will be available from the ICC web site
  - non-members welcome to attend but must register (contact Debbie Orf)
- **Draft agenda (to be confirmed)**
  - Whole slide imaging (Craig Revie)
  - Multispectral imaging, in particular for Whole Slide Imaging (Masahiro Yamaguchi, Max Derhak)
  - Displays (Michael Flynn / Takashi Matsui)
  - Medical Photography (John Penczek / Phil Green)
  - Ophthalmic Photography (Christye Sissons / Phil Green)
- **Please consider whether we should include additional presentations**

# mRGB

# AAPM TG196 Progress

Michael Flynn
Radiology Research
Henry Ford Health System
Detroit, MI

# Reference Document: sRGB: IEC 61966-2-1

- sRGB is a standard RGB color space created cooperatively by HP and Microsoft in 1996 for use on monitors, printers and the Internet.
- the sRGB gamma cannot be expressed as a single numerical value. The overall gamma is approximately 2.2, consisting of a linear (gamma 1.0) section near black, and a non-linear section elsewhere
- IEC 61966-2-1:1999 is the official specification of sRGB. It provides viewing environment, encoding, and colorimetric details.

http://en.wikipedia.org/wiki/SRGB

IEC 61966-2-1
Colour Measurement and Management
in Multimedia Systems and Equipment
Part 2-1: Default RGB Colour Space – sRGB

# Reference Document: aRGB: Adobe RGB (1998)

- The Adobe RGB color space is an RGB color space developed by Adobe Systems in 1998.
- It was designed to encompass most of the colors achievable on CMYK color printers, but by using RGB primary colors on a computer display.
- A gamma of 2.2 is assumed.
- The color space encompasses roughly 50% of the visible colors specified by the Lab color space, improving upon the gamut of the sRGB color space primarily in cyan-greens.

**Adobe RGB (1998)**

**Color Image Encoding**

***Version 2005-05, May 2005***



http://http://en.wikipedia.org/wiki/Adobe_RGB_color_space
http://www.adobe.com/digitalimag/pdfs/AdobeRGB1998.pdf

## Reference Document:
## ACR-AAPM-SIIM standard

- The ACR-AAPM-SIIM technical guideline for electronic imaging was recently revised with participation by three professional Radiology organizations:
  - American College of Radiology
  - American Assoc. of Physicists in Medicine
  - Society for Imaging Informatics in Medicine
- The recently published guidelines contain specific recommendations for viewing conditions and display characteristics.
  - DICOM Grayscale with defined $L_{max}$ and $L_{min}$
  - D65 white point.
  - Undefined color gamut.

**ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging**

JT Norweck, JA Seibert, KP Andriole, DA Clunie, BH Curran, MJ Flynn, E Krupinski, RP Lieto, DJ Peck, TAMian

…

**Display**

1. Workstation Characteristics
   - f. Ergonomic factors
     2. Viewing Conditions
2. Display characteristics
   - a. Luminance response
     1. Ambient Luminance, $L_{amb}$
     2. Minimum Luminance, $L_{min}$
     3. Maximum Luminance, $L_{max}$
     4. Luminance Ratio, LR
     5. $L_{max}$ for Diagnostic & other
     6. Luminance vs Gray Level
     7. Calibration
     8. Quality Control
     9. White Point.
   - b. Pixel Pitch and Display Size

…

J Digit Imaging (2013) 26:38–52

http://link.springer.com/article/10.1007%2Fs10278-012-9522-2

# Addition Reference Documents & Efforts

## AAPM on-line report No. 03 (2003)

- *Assessment of Display Performance for Medical Imaging Systems*
- "The intent of this report is to provide standard guidelines to practicing medical physicists, engineers, researchers, and radiologists for the performance evaluation of electronic display devices intended for medical use."

## IEC 62563-1 (2009)

- *Medical Electrical Equipment – Medical Image Display Systems*

  *Part 1: Evaluation Methods.*
- "This International Standard provides evaluation methods for testing image display systems used in medical electrical equipment and medical electrical systems for diagnostic imaging."

## CIE TC 1-93 (formed 2013)

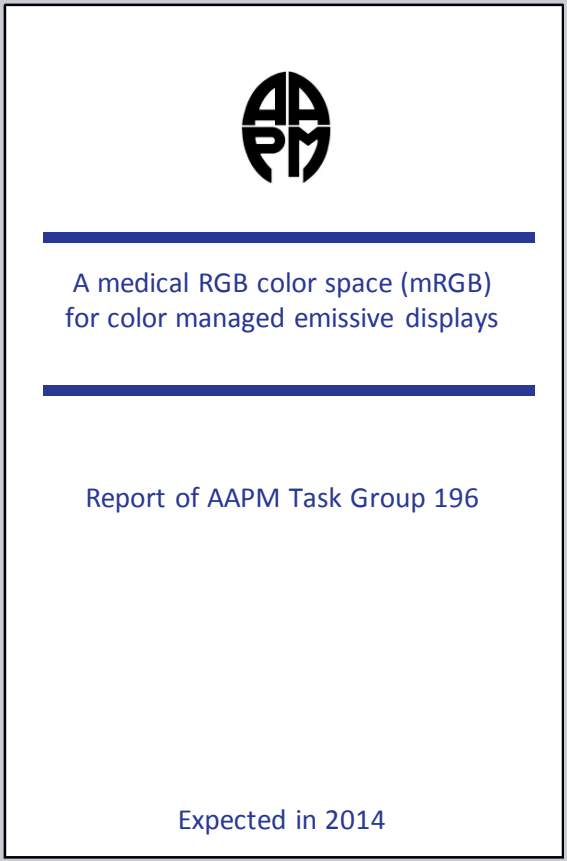
- *Calculation of self-luminous neutral scale*
- Charge: To recommend a formula or computational method for an achromatic, neutral or gray scale for self-luminous (i.e. non-reflective) surfaces. (This computation complements CIE Lightness, L*, which serves a similar purpose for reflective surfaces.)

# AAPM TG196: mRGB

AAPM Task Group No. 196
Requirements and methods for color displays in medicine.

Aldo Badano, PhD *
Paul Boynton
Wei-Chung Cheng
Danny Deroo
Michael Flynn
Patrick Le Callet
Takashi Matsui
John Penczek
Craig Revie
Hans Roehrig *
Ehsan Samei *
Peter Steven
Stan Swiderski
Gert Van Hoey
Masahiro Yamaguchi

* co-chair




http://www.aapm.org/pubs/reports/

http://www.aapm.org/org/structure/default.asp?committee_code=TG196

# Color spaces compared

(1) IEC 62563 terminology

| Specification (1) | 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- | [*] (referenced) |
| $L_{max}$ , cd/m$^2$ | 80 | 160 (125-200) | 350/420/250 | 350 (250-450) |
| $L_{min}$ , cd/m$^2$ | -nd- | 0.56 | $L_{max}$ / LR | $L_{max}$ / LR |
| Luminance Ratio (LR) | -nd- | 287.9 (230-400) | 350 (> 250) | 350 (300-400) |
| White Point | D65 | D65 | D65 | D65 |
| Gray tracking | -nd- | -nd- | -nd- | IEC MT51 |
| Surround | 20% refl. lx | Gray (D65, 2°) 20% $L_{max}$ | -nd- | Gray (D65, >2°) 20% $L_{max}$ |
| Ambient Illumination, lx | 64 (D50) | 32 (D65) (16-64) | 20-40 | -nd- |
| Veiling Glare | 1.0% | accounted | -nd- | -nd- |
| $L_{amb}$ , cd/m$^2$ | -nd- | -nd- | $L_{amb} < {}^1/_4\ L_{min}$ | $L_{amb} < [{}^1/_4 , {}^2/_3]\ L_{min}$ |

mRGB-[*] is now considered to be a color space framework.

- Neutral luminance response is the GSDF for Lmax = 250-450.
- Color primaries are to be referenced in the profile name.

  ( mRGB_s250 , mRGB_a350 , …; 3DLUTs OK )
- LR range is now specified from 300 to 400.
- Surround in now specified as the near field effecting adaption.
- Lamb now uses the 1/4$^{th}$ or 2/3$^{rd}$ criteria from AAPM TG-18.

- The mRGB color space will provide a full specification for the calibration of a medical monitor including white point, color space, luminance response, luminance ratio, and viewing conditions.
- The mRGB color space will provide a full specification for the performance of a monitor for which a manufacturer can provide firmware correction through OSD selection for the target performance.
- For monitors calibrated to the mRG color space, an ICC profile can transform image values from profile connection space to the mRGB color space.
    - This will allow color managed systems to display medical images with images values in DICOM GSDF units (p values) to be properly displayed.
    - The same system will be able to display medical images from color cameras with correct color rendering and tone scale.

*From part 5 of the AAPM approved charge, 'AAPM-IPC-IISC_TG-mRGB_Charge-v3'*

Primary (a.k.a. diagnostic)

- Primary display systems are those used for the interpretation of medical images.
- They are typically used in radiology and in certain medical specialties such as orthopedics.

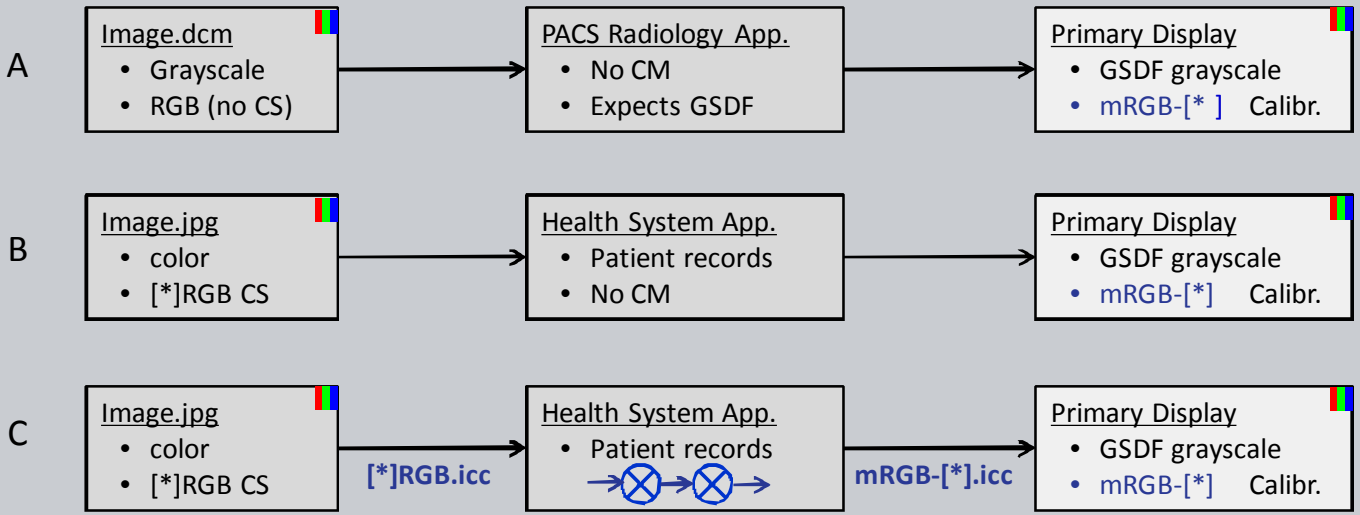
Secondary (a.k.a. review, enterprise, other)

- Secondary systems are those used for viewing medical images for purposes other than for providing a medical interpretation.
- They are usually used for viewing images by general medical staff and medical specialists other than radiologists and utilized after an interpretive report is provided for the images.

*From Section 2.5 of AAPM On-Line Report No. 3*

# Case – Primary display, radiologist workstation

Medical image presentation on a workstation with DICOM calibrated primary monitors used for medical interpretations



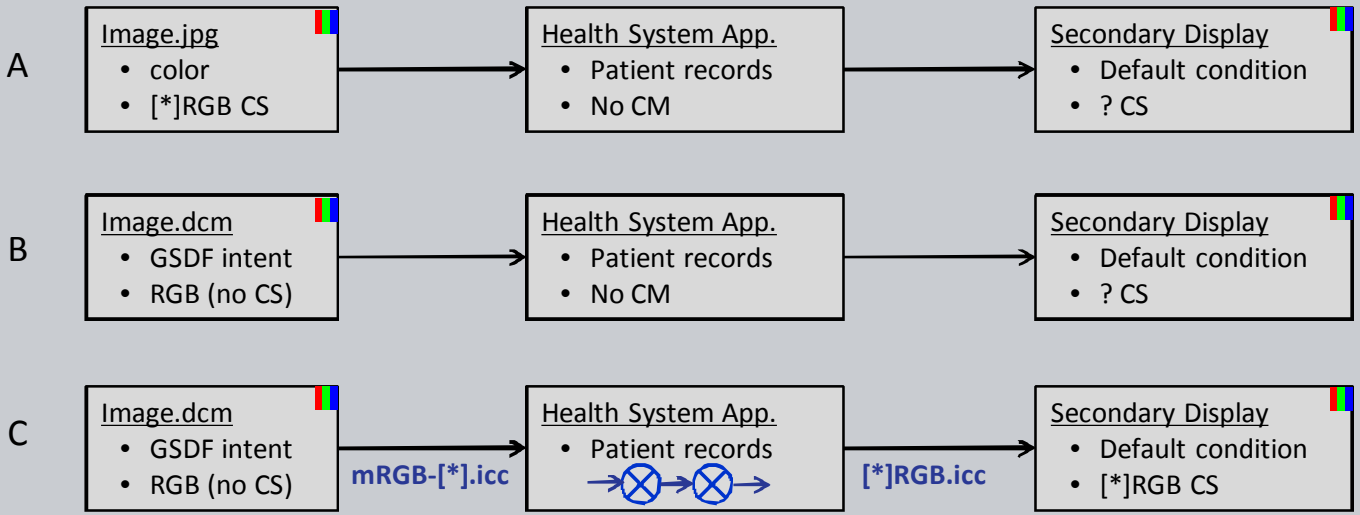

| | | |
|---|---|---|
| Case A: | Correct | Grayscale & pseudo-color DICOM images with GSDF neutral tones. |
| Case B: | Incorrect | Color photograph is presented with GSDF neutral tones. |
| Case C: | Correct | Color photograph is presented with the intended color space. |

Denotes a color managed module
Using source and display profiles

CS – Color Space
CMS – ICC Color Management (full)

# Case – Secondary display, physician workstation

Medical image presentation on a workstation with secondary monitors used for reviewing patient information.




| | | |
|---|---|---|
| Case A: | Uncertain | Color photograph is presented with the default configuration . |
| Case B: | Incorrect | Grayscale & pseudo-color DICOM images not presented with GSDF. |
| Case C: | Correct | Grayscale & pseudo-color DICOM images are mapped to GSDF |

Denotes a color managed module
Using source and display profiles

CS – Color Space
CMS – ICC Color Management (full)

# Context

- Today's medical color displays have builtin calibration such that the neutral (R=G=B) scale complies with the DICOM GSDF standard

- Most medical visualization applications today just 'send' their (processed) perceptually linear grey images (p-value images or DICOM images) to GSDF calibrated displays

# Problem statement

- Because of the builtin DICOM GSDF calibration, the color behavior of medical color displays is altered/distorted
- Applications that are assuming “sRGB” alike gamut typically look bad on DICOM GSDF calibrated color displays
- A solution needs to maintain compatibility with dedicated medical visualization software, while at the same time guaranteeing that applications that use ICC profiles look good

# Use case 1

## Standard viewing application & color medical display


Standard viewing application (eg. browser) that assumes sRGB alike behavior

Calibrated display that is compliant with

- DICOM GSDF

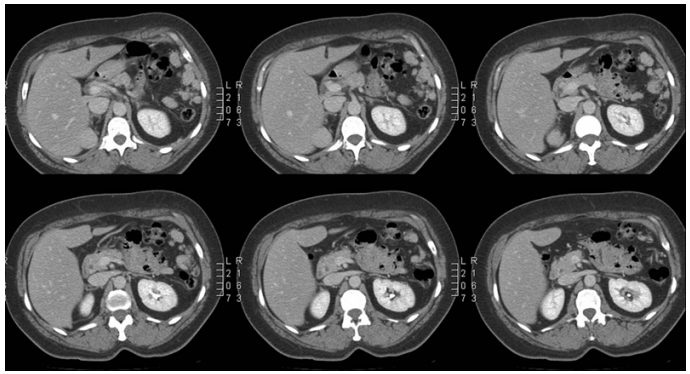
**Current situation:**

**- Colors look distorted / desaturated**

**- Greyscales look “better”**

# Use case 2a

## Medical SW / color medical display

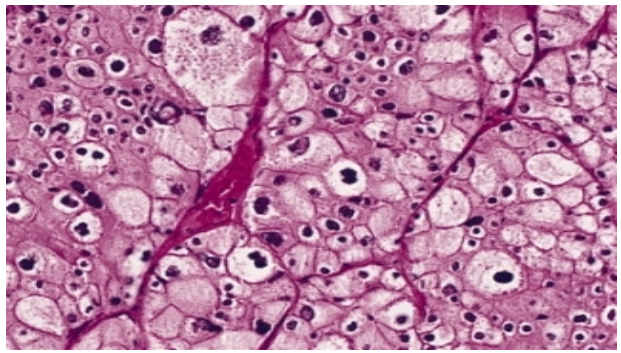



Medical SW
Greyscale images

Calibrated display that is compliant with
- DICOM GSDF

# Use case 2b

## Medical SW / color medical display

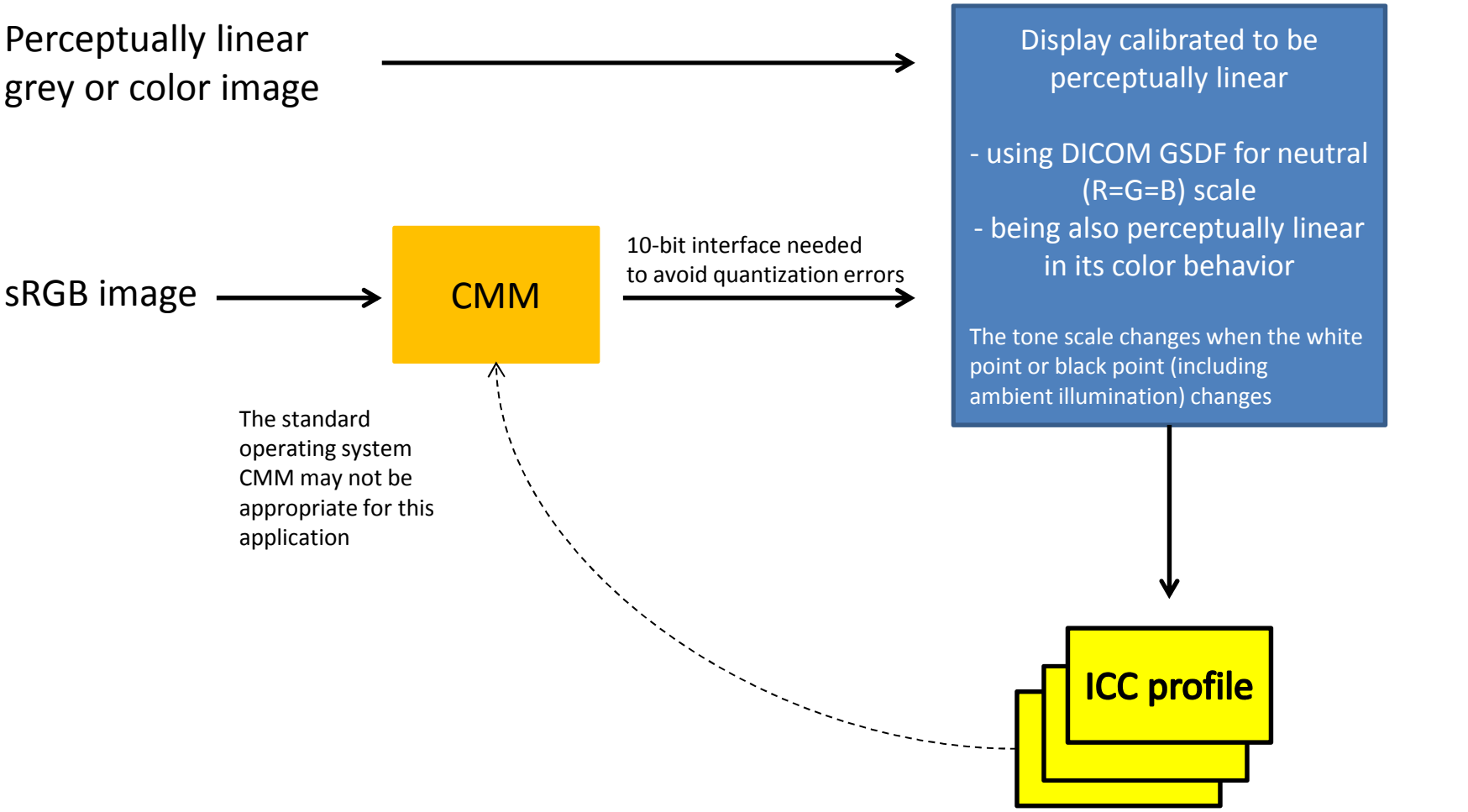



Medical SW
Color images

Calibrated display that is compliant with

- DICOM GSDF
- Perceptual linear color behavior

# mRGB proposal made by Michael Flynn with modifications suggested by Barco



# Notes

- Perceptual linear grey or color images include eg.
  - typical greyscale radiology images (DICOM images) as well as
  - (future) color medical images that assume/benefitfrom consistent perceptually linear color behavior of the display [(1)]
- Instead of providing a set of ICC profiles, it is also possible to provide a tool to generate such ICC profiles based on display characteristics (luminance, contrast ratio, calibration only to GSDF or also to be perceptually linear in color behavior)

(1) Consensus paper summit on color in medical imaging, “Consistency and standardization of color in medical imaging: a consensus report”, section displays, part on perceptually uniform color calibration

# Steps forward

- To be discussed, eg.
  - Exact calibration targets to be described
  - Example ICC profiles to be created for a number of displays
  - Barco is volunteering to create a prototype of the proposed framework and demonstrate a proof of concept

International Color Consortium

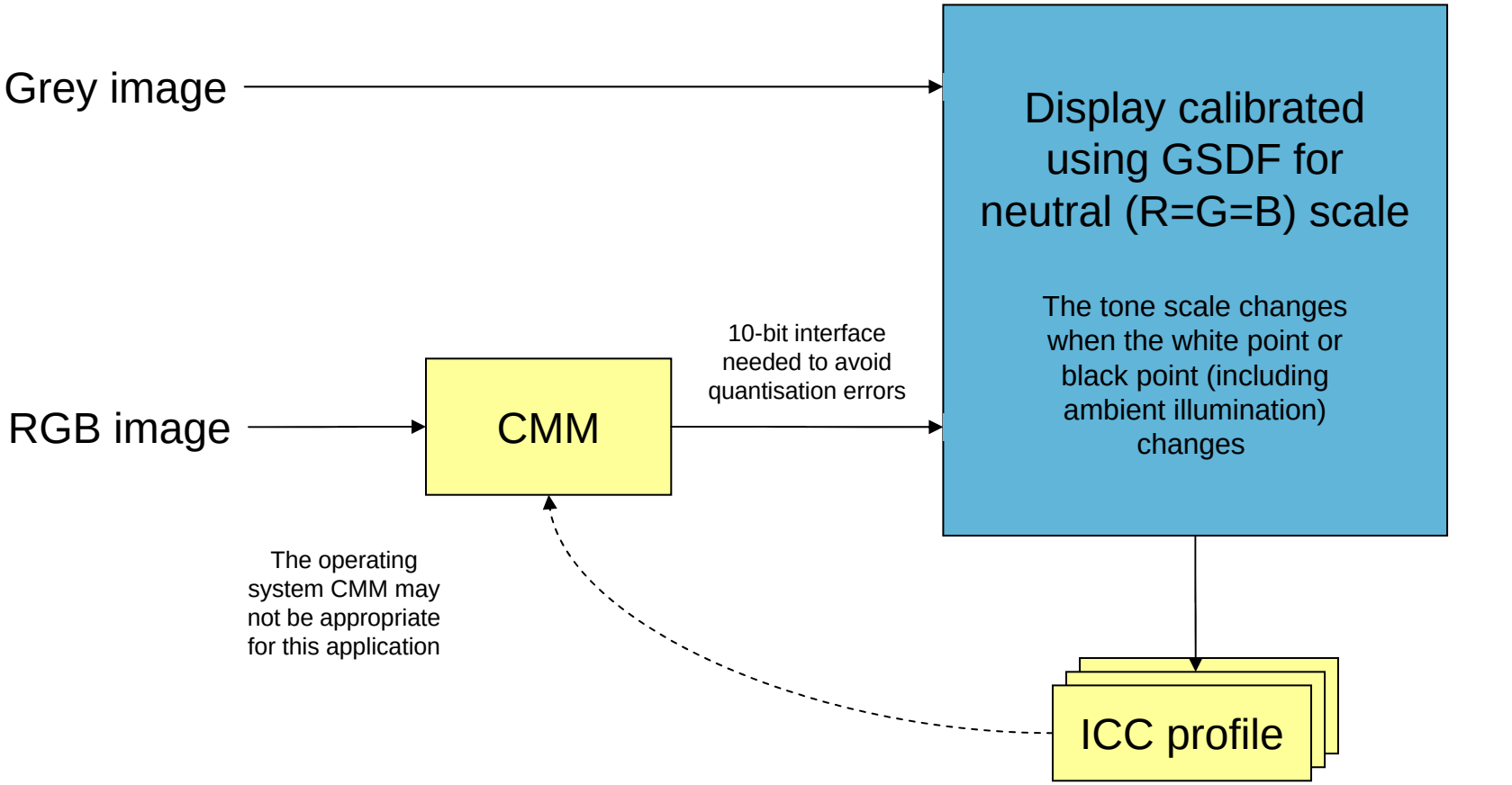
# mRGB gamut proposed modification

**W Craig Revie**

**FFEI Limited**

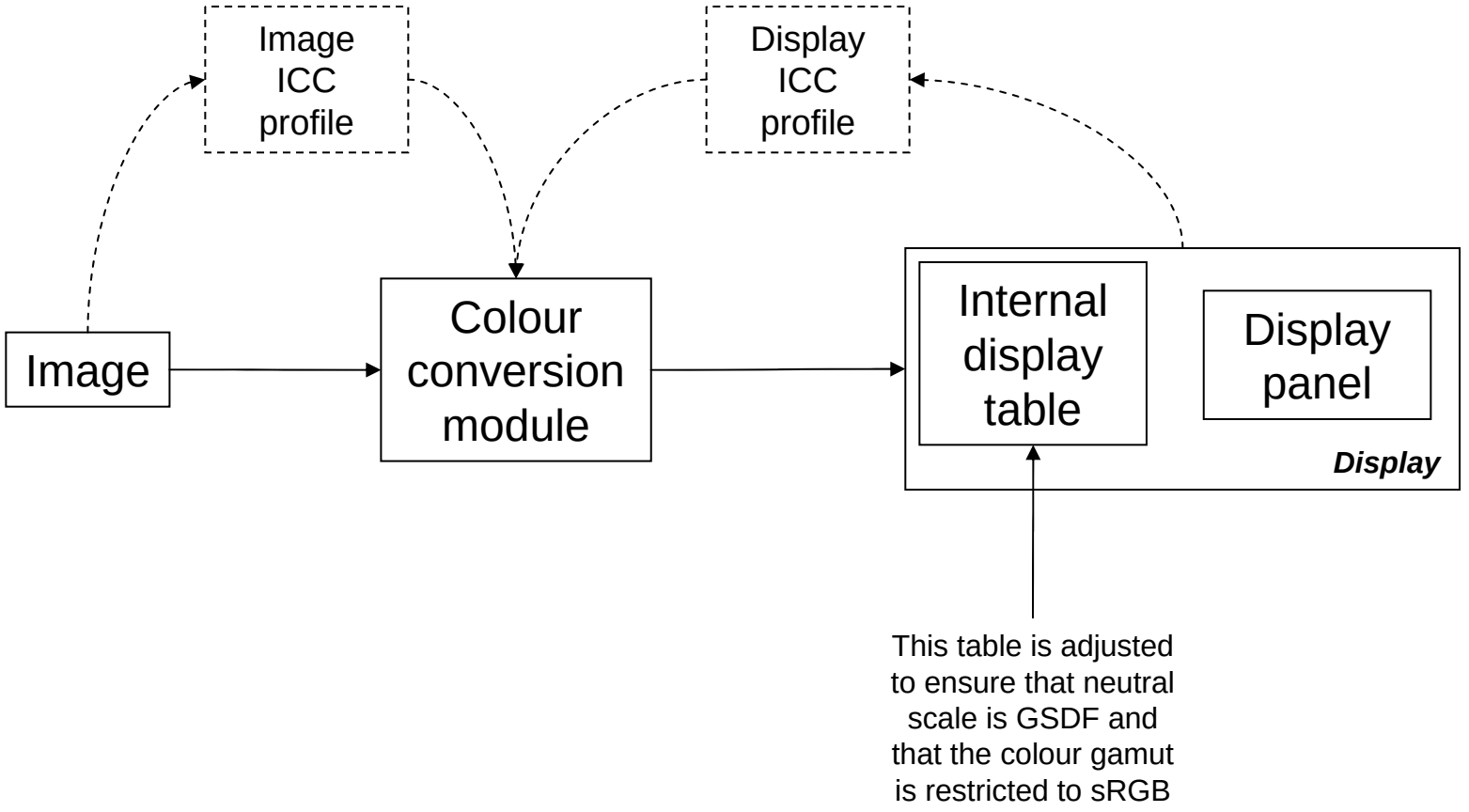
**16th January 2014**

# mRGB – intended workflow

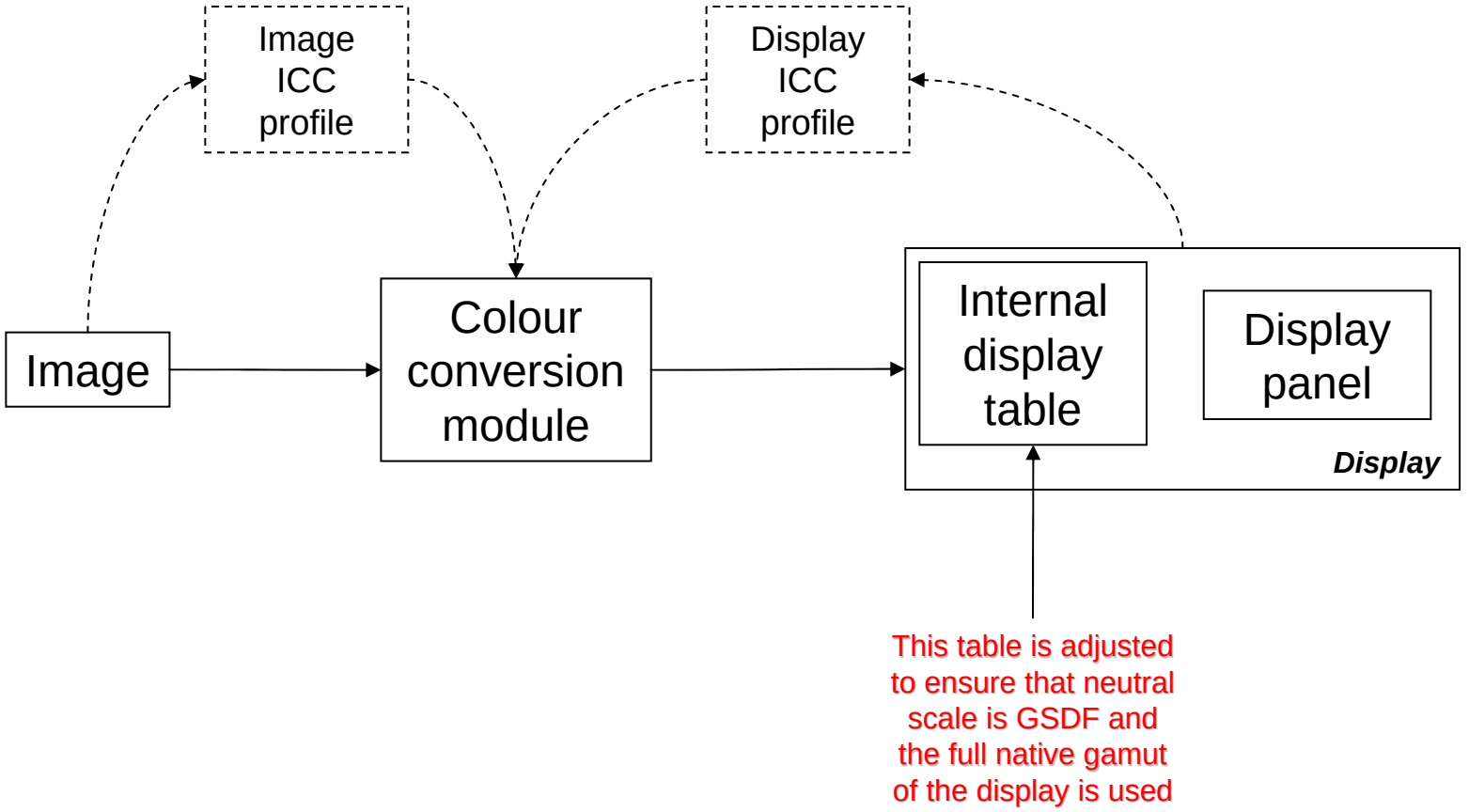



A set of example/default profiles could be developed for different white/black range and could be posted on the ICC web site

# (A) Current mRGB proposal



# (B) Alternative mRGB proposal



# Comparison of A and B

- **There is no difference in the complexity of the colour management in either case**
- **Option (A) would seem to be more difficult to achieve from the point of view of a display manufacturer**
- **For images whose colours are within the sRGB colour gamut option the result will be identical for both**
  - if the display's colour gamut is sRGB option (A) will almost always clip colours on the extremes of the colour gamut
- **For images that include colours outside of the sRGB colour gamut option (A) will clip but option (B) will not perform any clipping**
- **Option B could make use of the display's natural / designed colour gamut and would seem to provide a future-proof option**

## 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. Ix | 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- | $L_{amb} < L_{min}/4$ | $L_{amb} < L_{min}/4$ |