Color Behavior of Medical Displays

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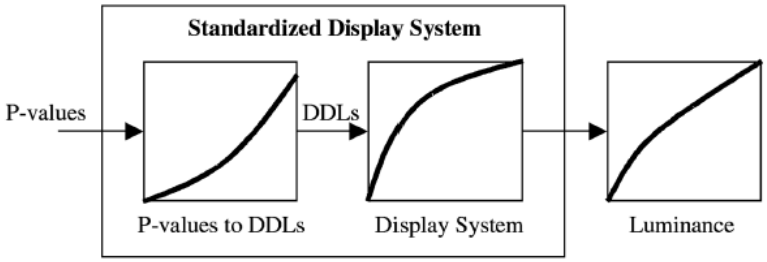
Learning from the past: medical greyscale display calibration

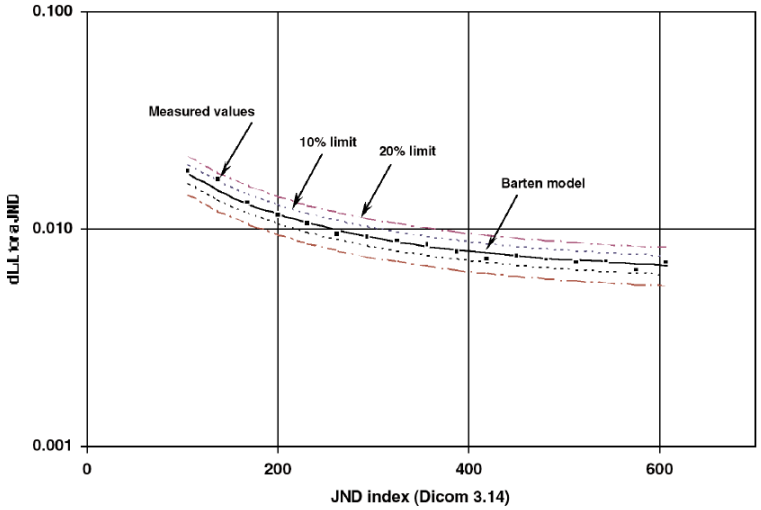
Why is there a need for display calibration?

- Clinical performance must not differ:
  - On the same display over time
    - Eg. one could see a pathology today on a particular display, but not anymore 6 months from now.
  - In between display systems of the same type or of other type
    - Eg. in a reading room full of display systems one could see a subtle pathology on one display but not on another display.

Calibration in (greyscale) medical imaging (1)

- DICOM GSDF: perceptually linear display ensures that
  - Differences in grey scales are visible (If #greys < available JND)
  - All grey level transitions look equally large (perceptually linear)
  - Images look similar even on different display systems
    (A subtle image feature on one DICOM calibrated display can be seen on every other DICOM calibrated display)





Digital Imaging and Communications in Medicine (DICOM) Part 14: Grayscale Standard Display Function. Available from: http://medical.nema.org/dicom/2004/04_14PU.PDF

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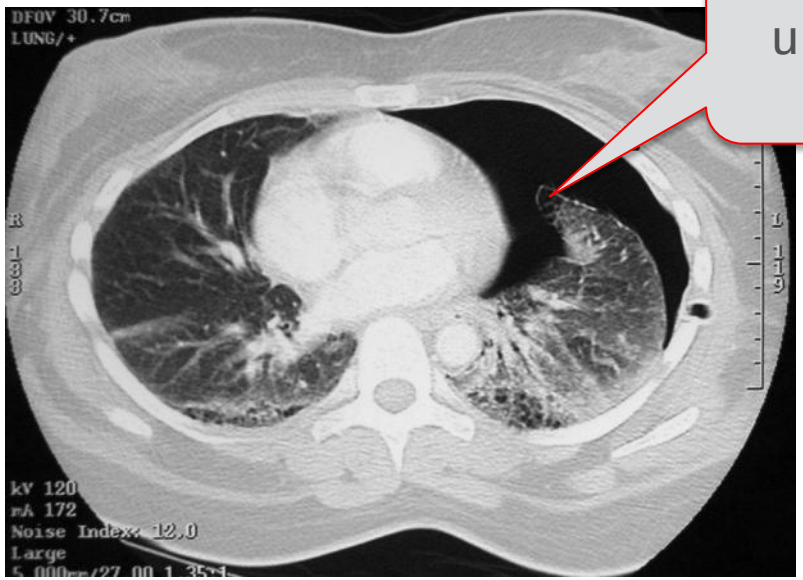
Calibration in (greyscale) medical imaging (2)

- Studies have shown the potential of GSDF to improve clinical performance.
- Regulatory authorities throughout the world have enforced DICOM GSDF calibration for all primary diagnosis displays.
- Provides flexibility for vendors of scanners, software, displays since all are compatible with each other.
- This also largely simplifies the regulatory clearances/approvals.

DICOM GSDF calibration & presentation LUTs

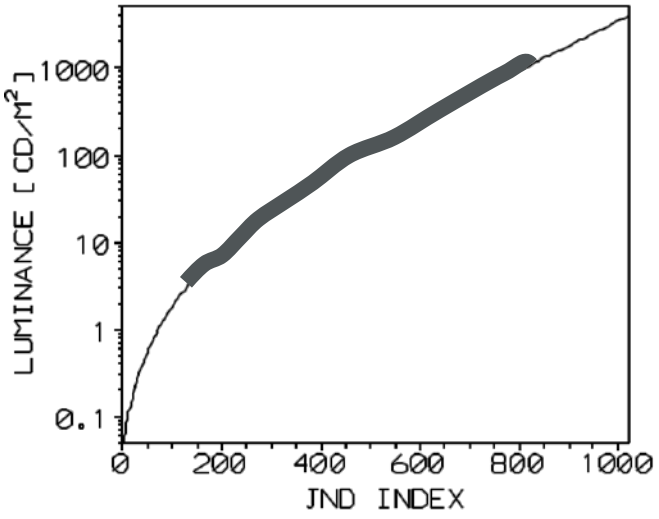
- Calibration LUT:
  1. Make images appear similar on all calibrated displays.
  2. Balance the differences throughout the dynamic range (perceptually linear)
- Presentation LUT: Emphasize particular subrange of image

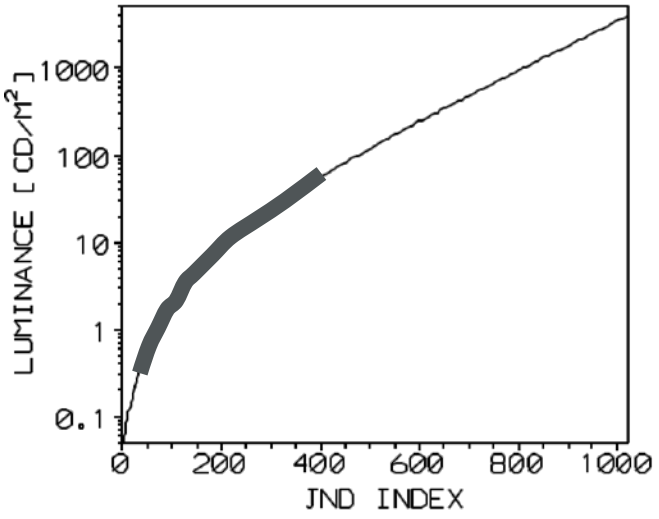


Presentation LUT set up to visualize *lung* details

Why not absolute luminance calibration?

- That would limit the dynamic range to that of the intersection of the worst displays that can be used
- It would block innovation and improvement in display technology that come over time





Grayscale display evolution: luminance & contrast

Color displays today…

Luminance

205 300 450 600 1000

CRT ⟷ LCD

Perceived Contrast (JNDs)

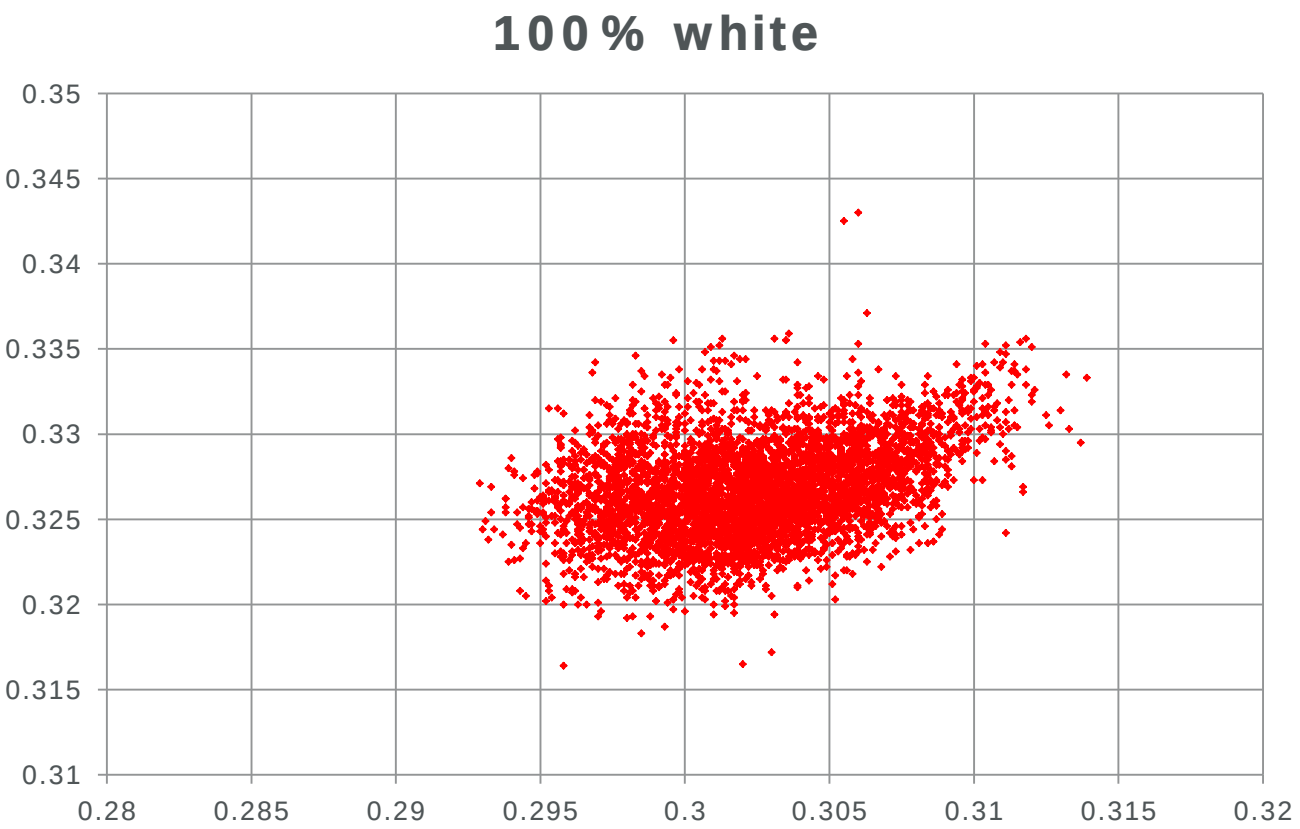
575 625 690 660 725

Good thing we did not set absolute standard here

1990 1995 2000 2005 2010 2015 2020

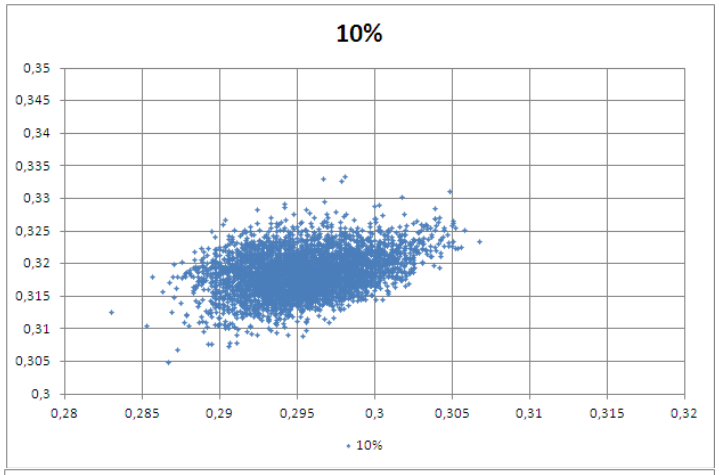
Behavior of medical color displays

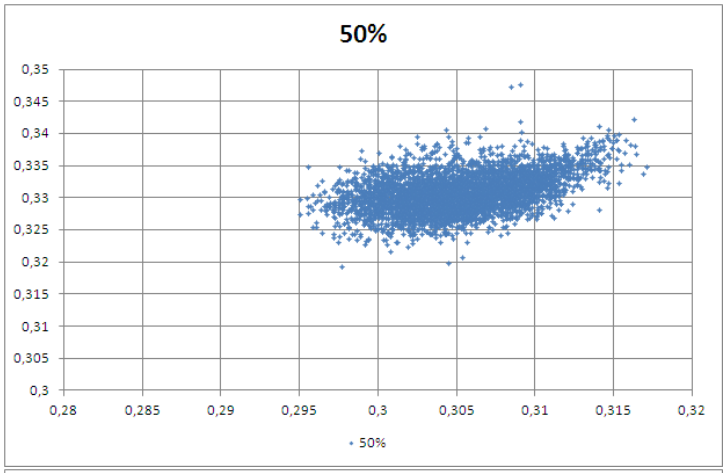
White point variation of color displays (1)

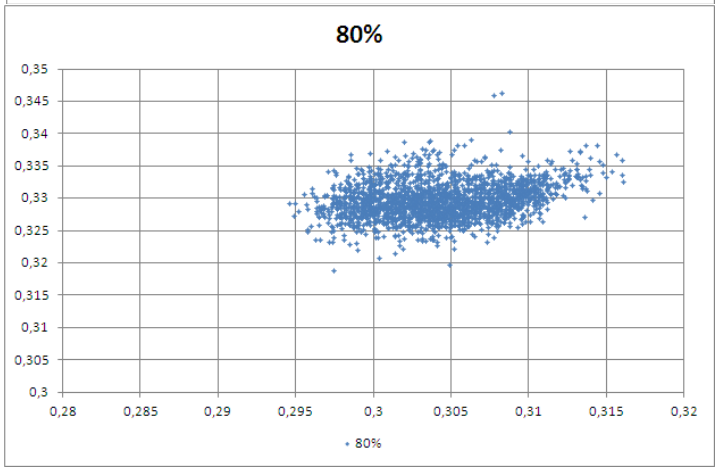


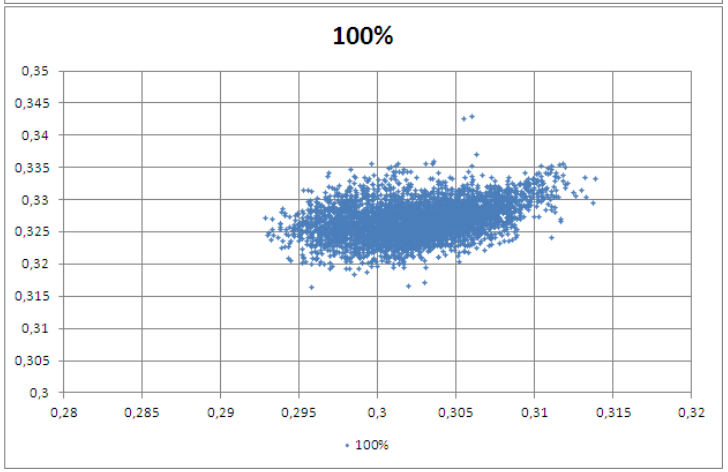
- (x,y)-coordinates of 4355 color displays during manufacturing measured with Minolta CA-210

White point variation of color displays (2)







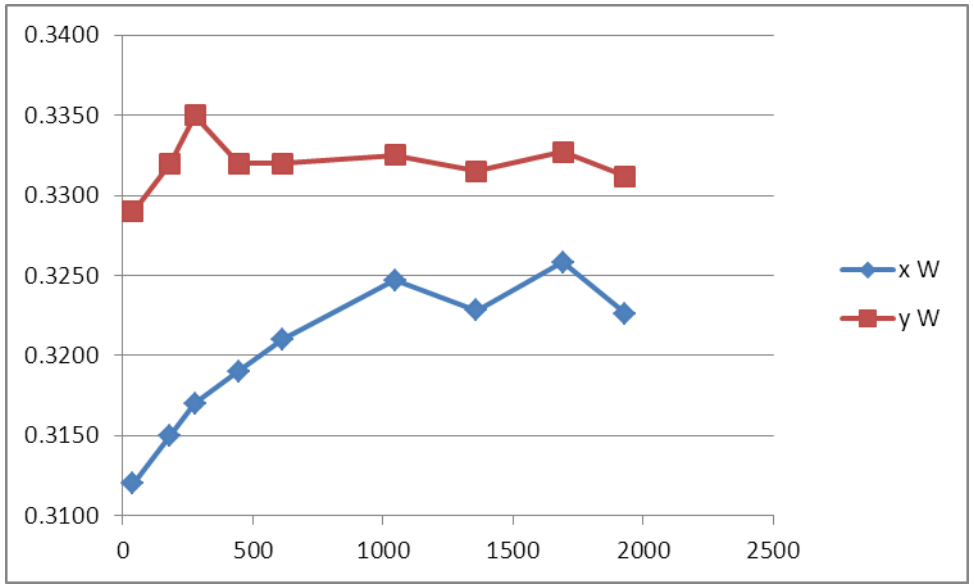


average x				average y			
10%	50%	80%	100%	10%	50%	80%	100%
0,295541	0,305264	0,30468	0,302362	0,318526	0,330656	0,329633	0,326694

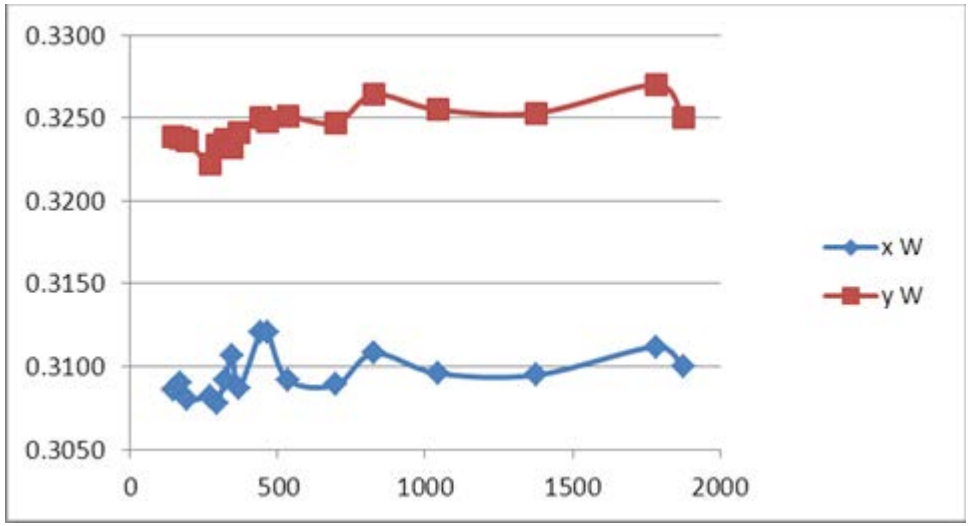
standard deviation x				standard deviation y			
10%	50%	80%	100%	10%	50%	80%	100%
0,00325	0,003833	0,003731	0,003606	0,00318	0,002928	0,002805	0,002755

Color point stability of displays over time

- CCFL backlight



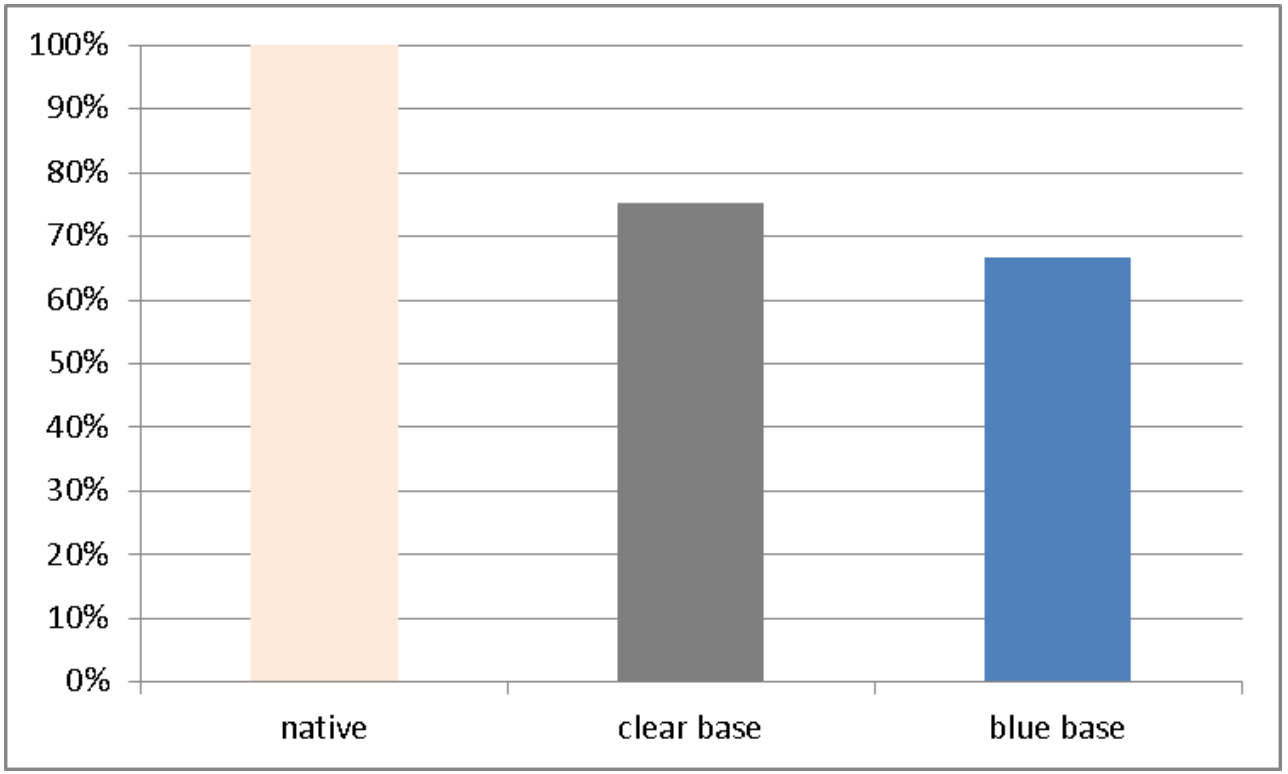
- LED backlight



Loss of luminance when absolute color (non-native color) required

- Typically there is a loss of luminance when adjusting white point

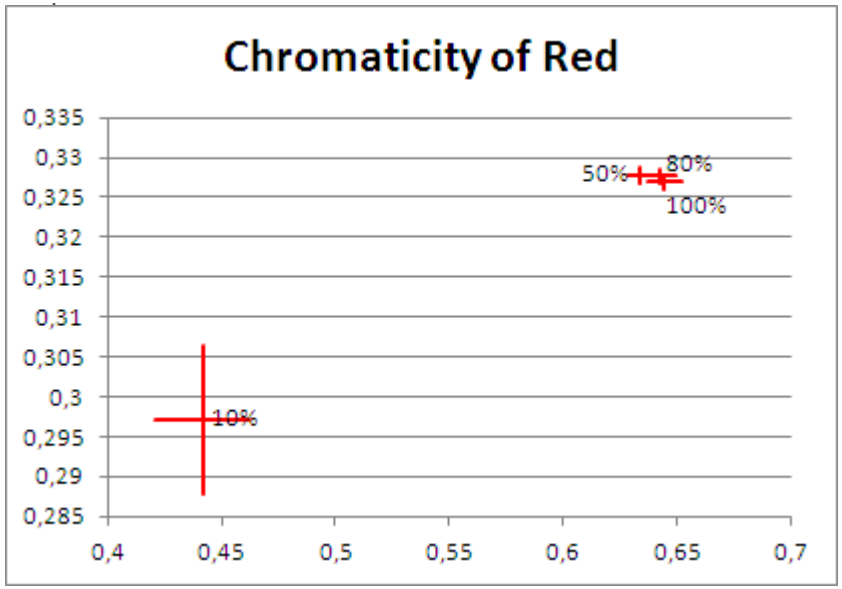
  Example: loss for CB & BB for 6MP at 1 year old

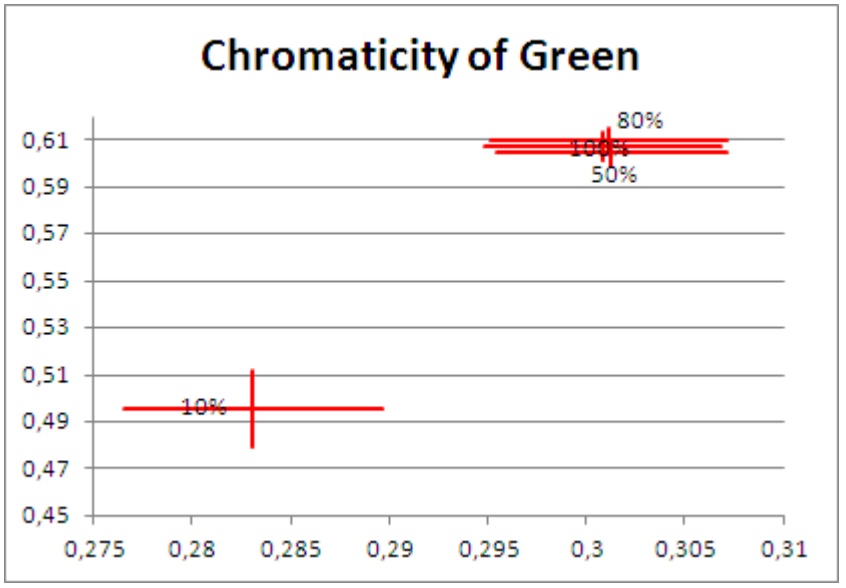


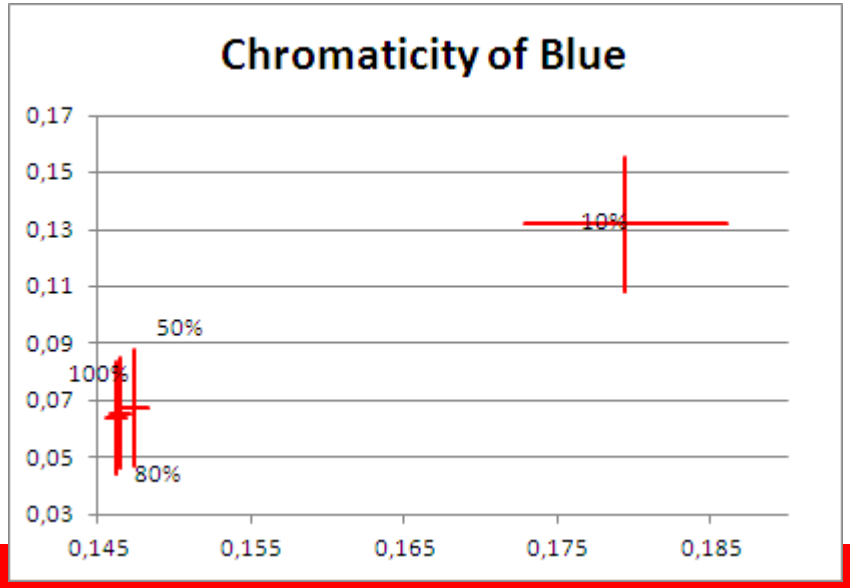
Gamut variation of color displays (1)

- 27 color displays have been measured during manufacturing in dark room conditions and after initial warm-up / stabilization
- The entire color gamut was measured with a calibrated Minolta CA-210 in steps of 15/255 (for all combinations of colors)

Primary variation of color displays (1)







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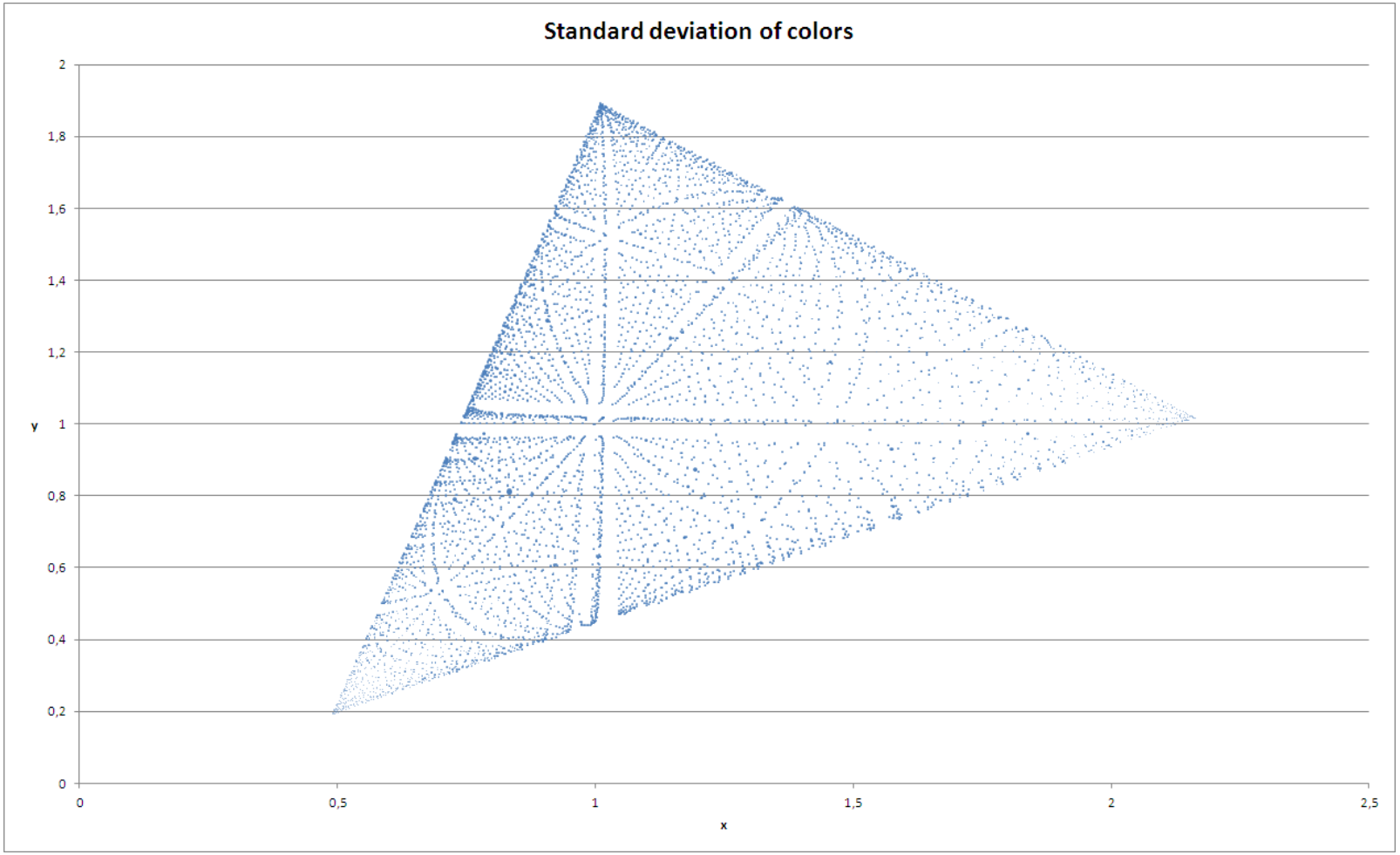
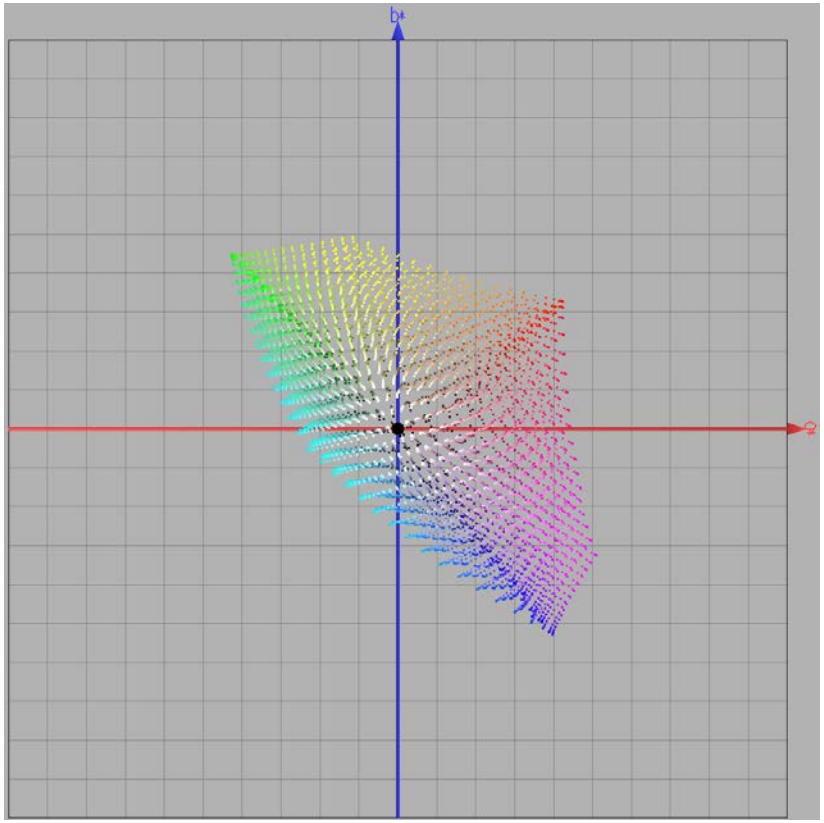
Differences in gamut shape

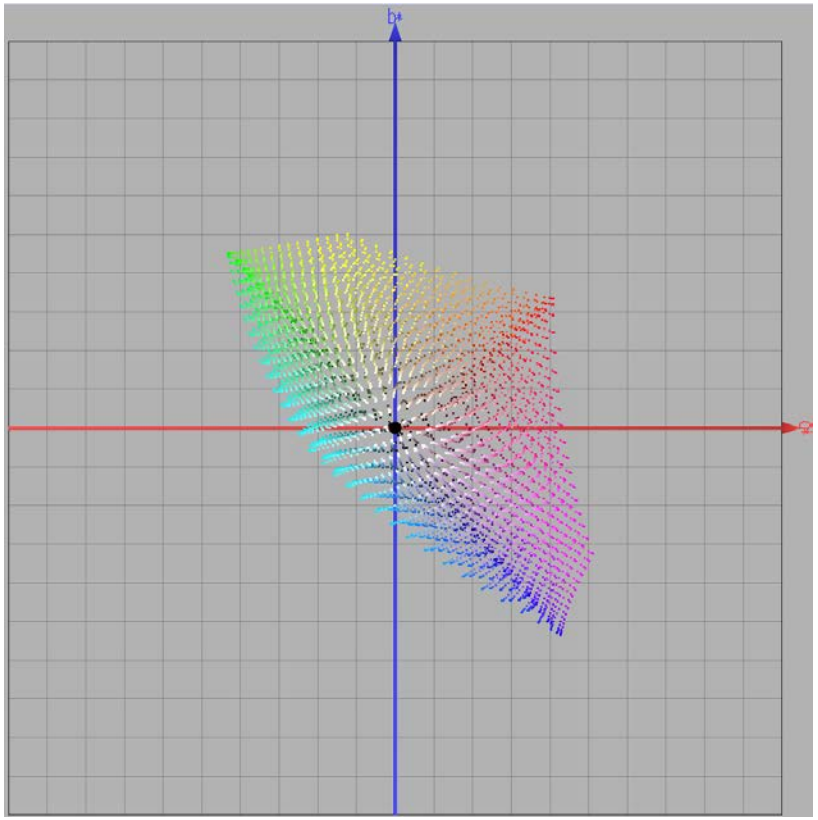
- After correction for differences in whitepoint



True gamut (shape) variation (1)

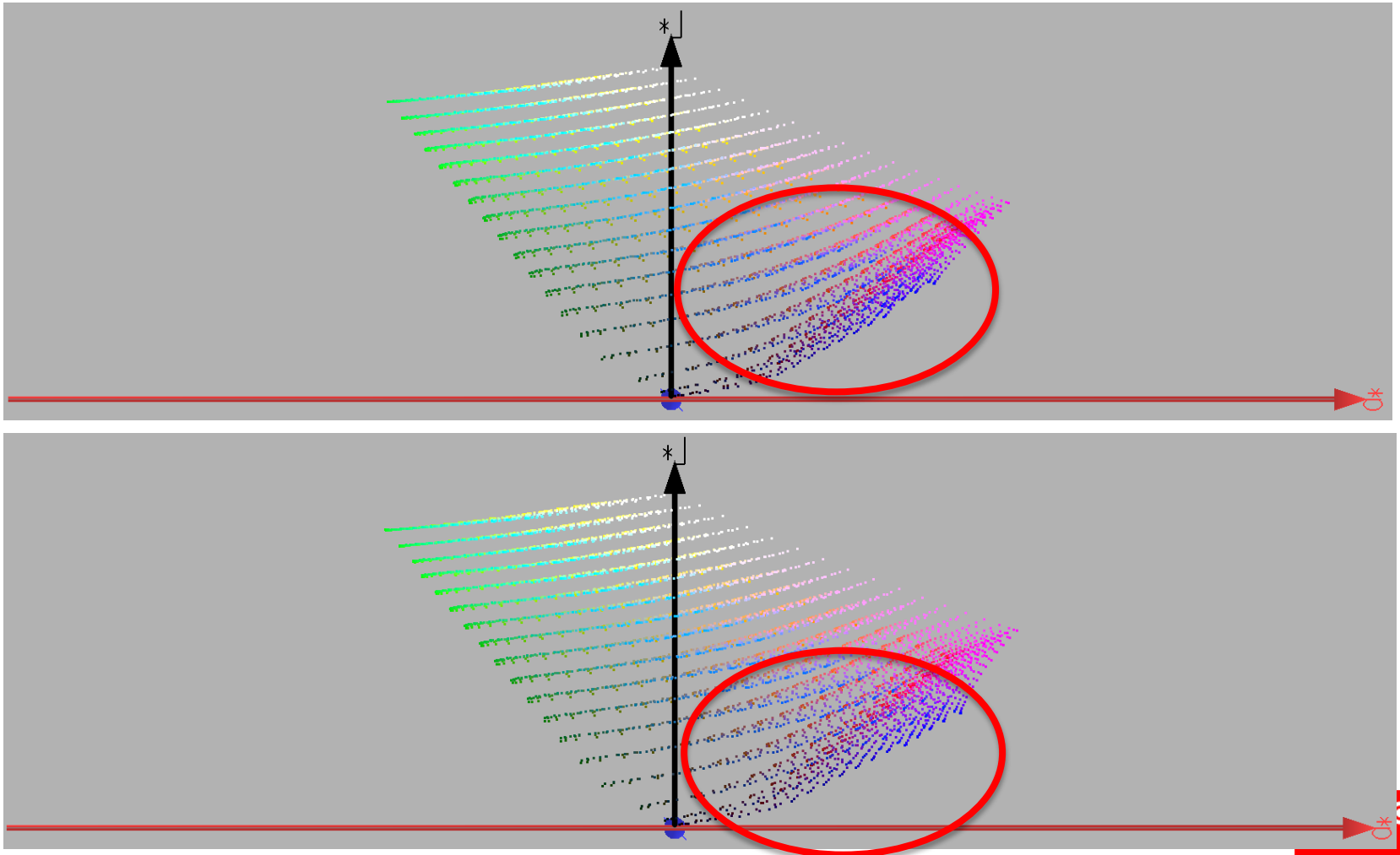
- Example gamut of two displays





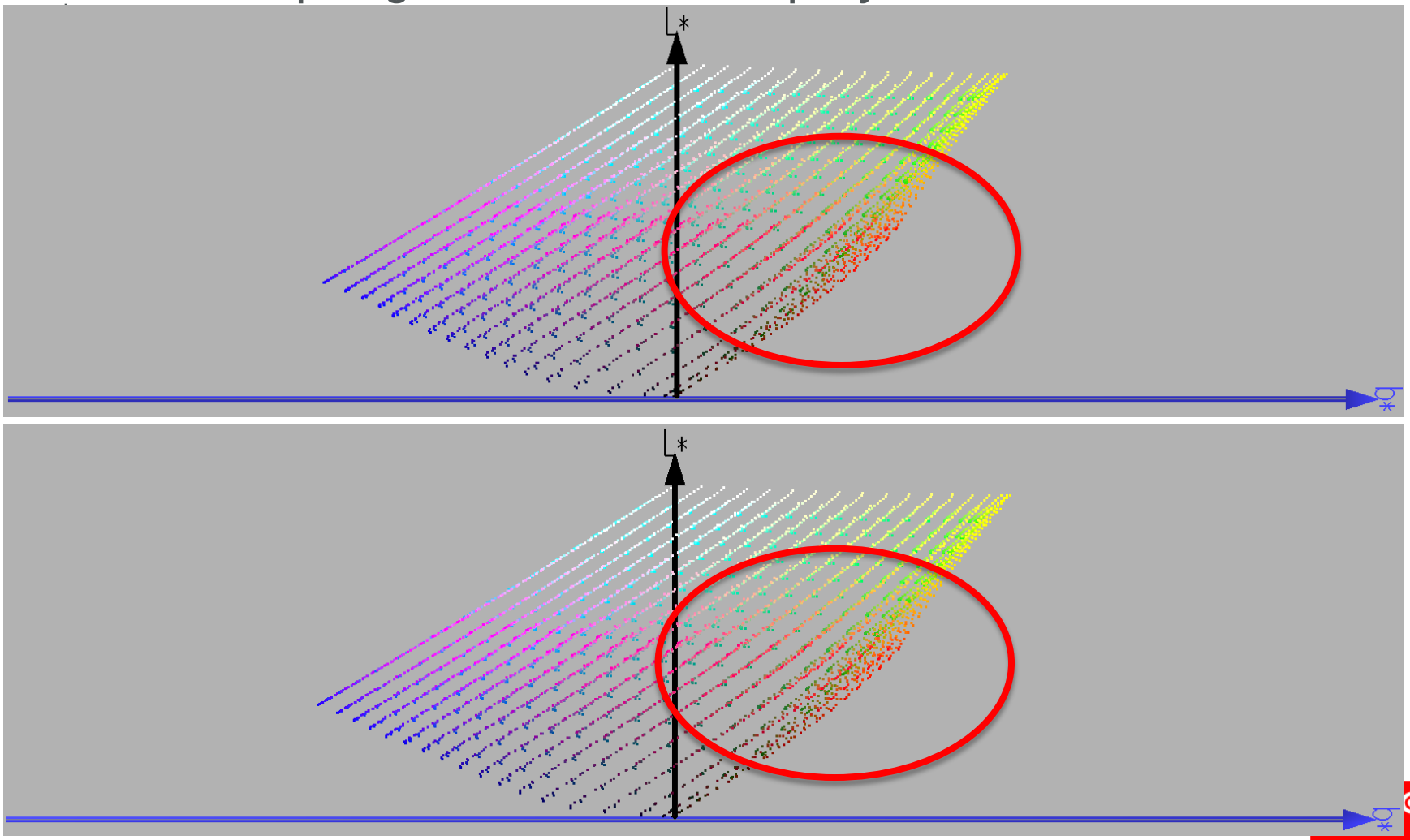
True gamut (shape) variation (2)

- Example gamut of two displays



True gamut (shape) variation (3)

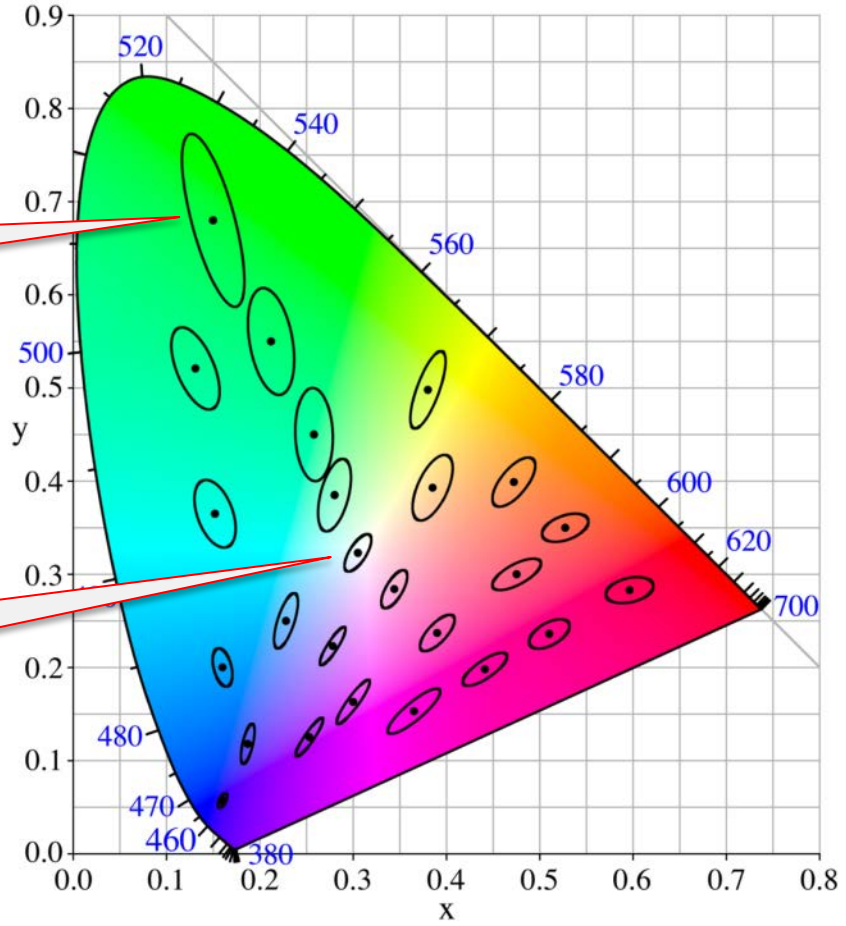
- Example gamut of two displays



Concept of delta-E

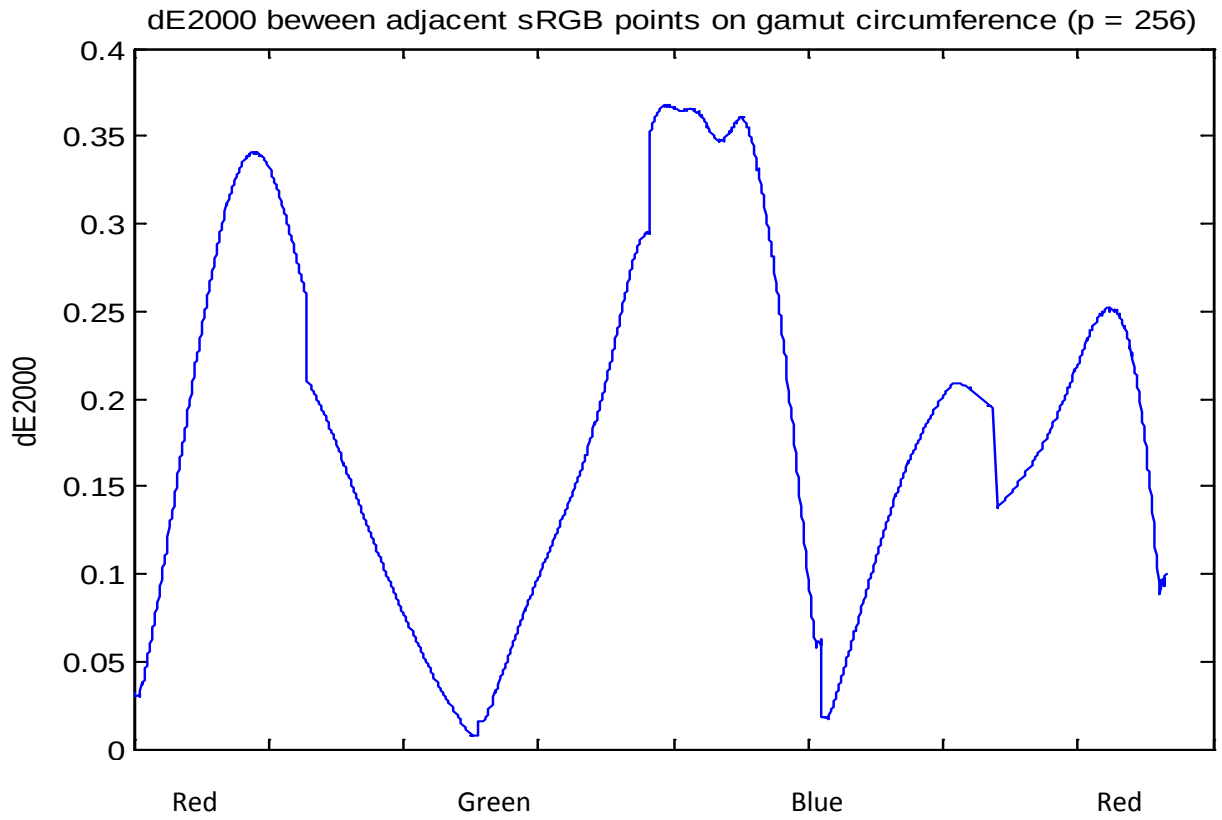
Some differences need to be quite large to be noticed

Our eye more readily discerns other differences



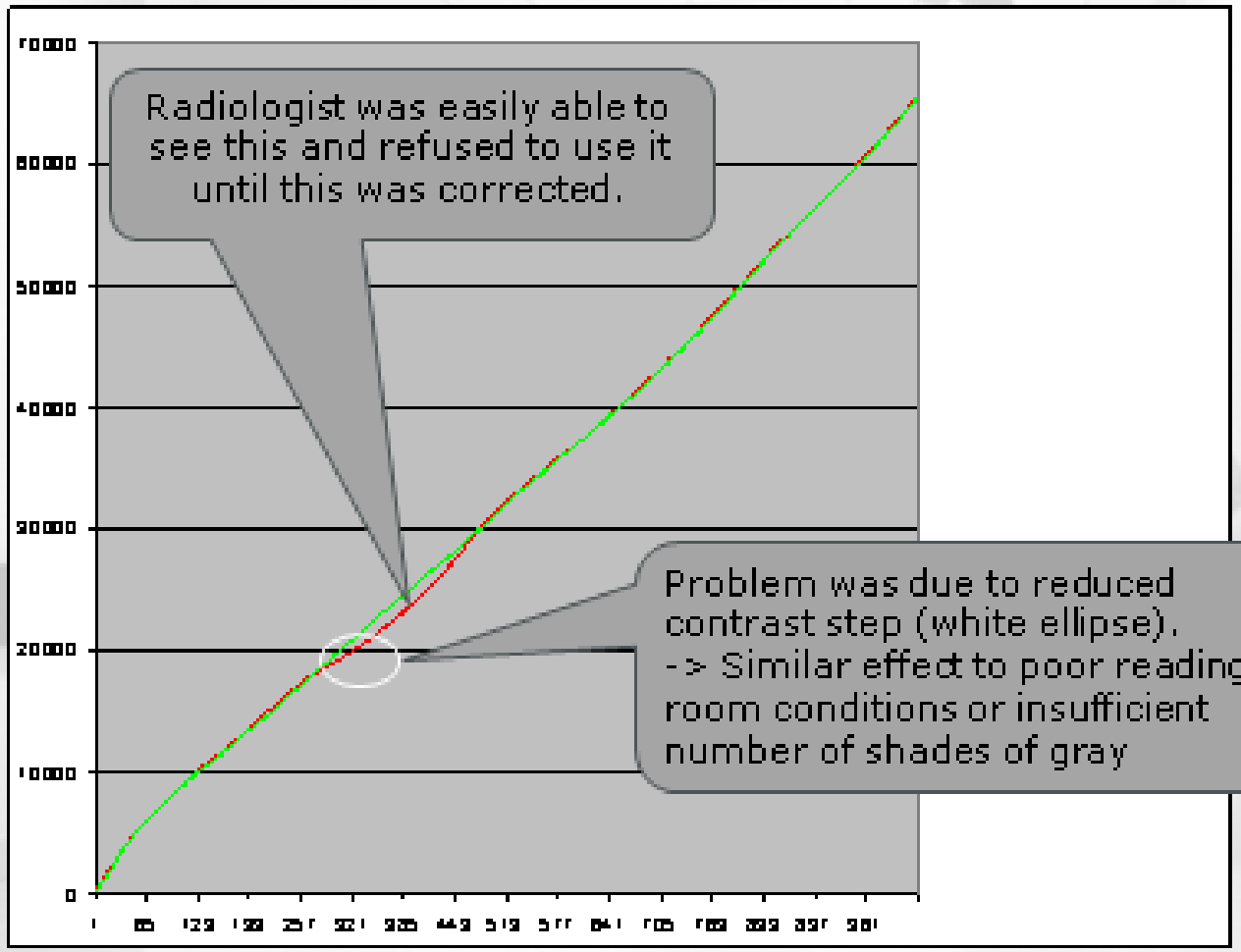
Delta-E steps - sRGB example

- difference between adjacent hues more or less noticeable as measured by delta-E
- more useful steps available if steps are similar size

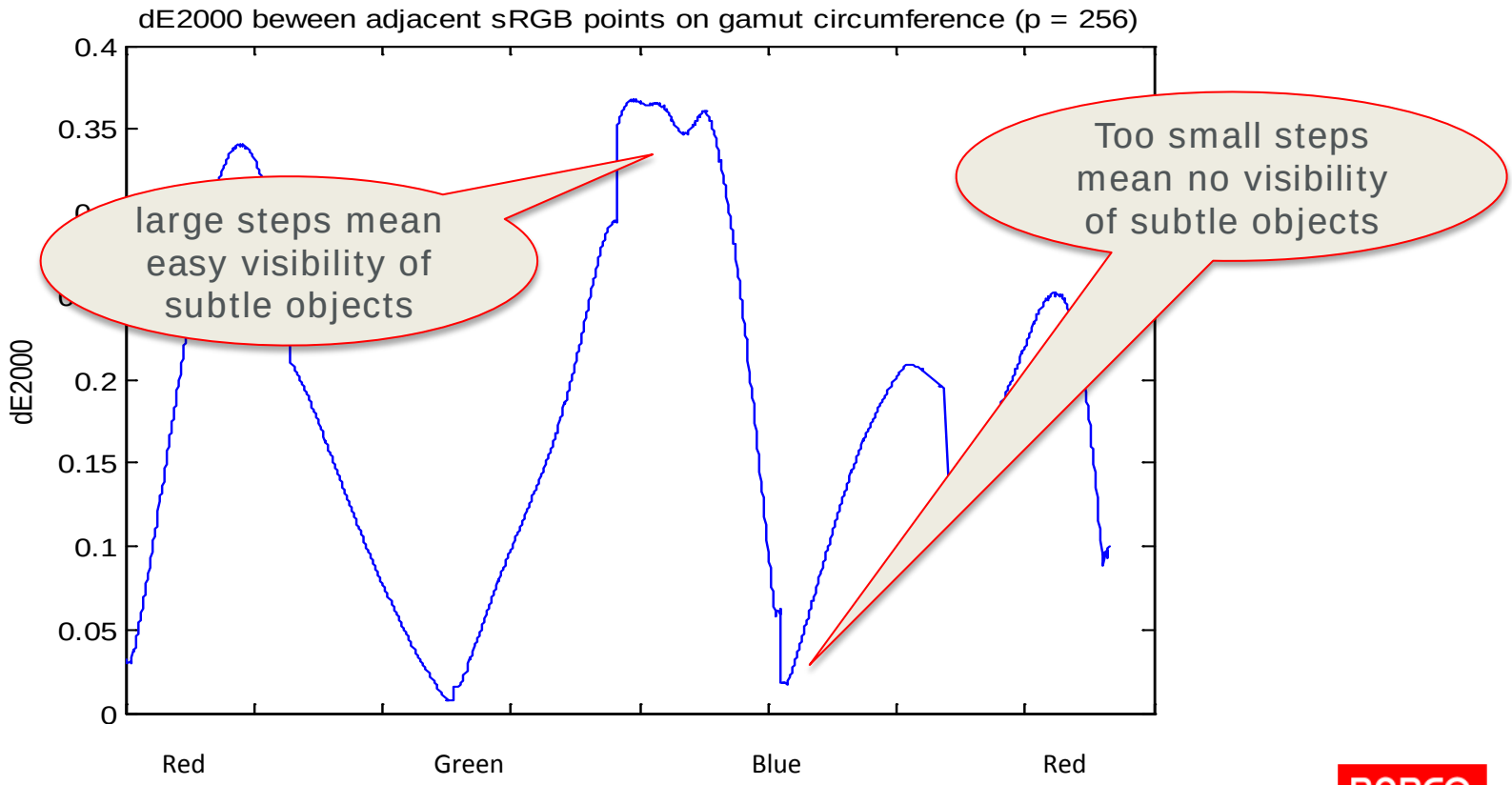


Historical Example (2005) – Uneven JND steps

Calibration error with Coronis 5MP Mammo using MediCal Pro 2.03.09; solution is to upgrade to 2.03.10



uneven Delta-E: analogous Uneven JND

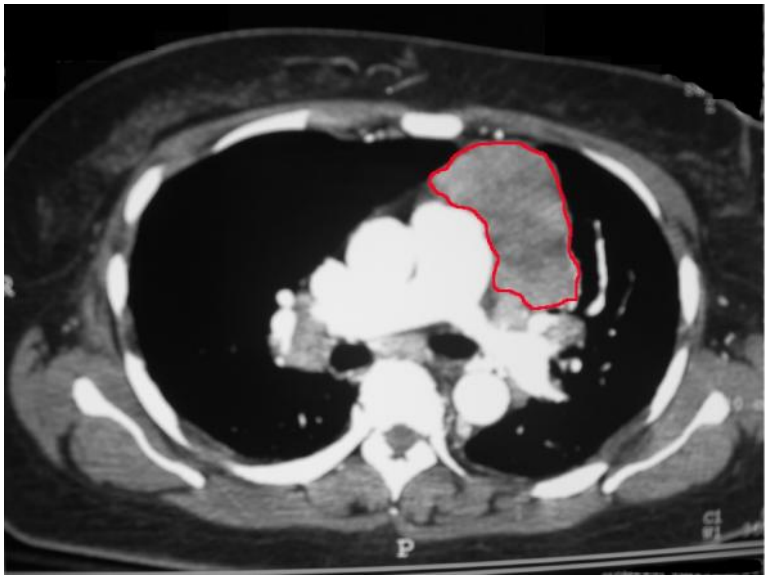


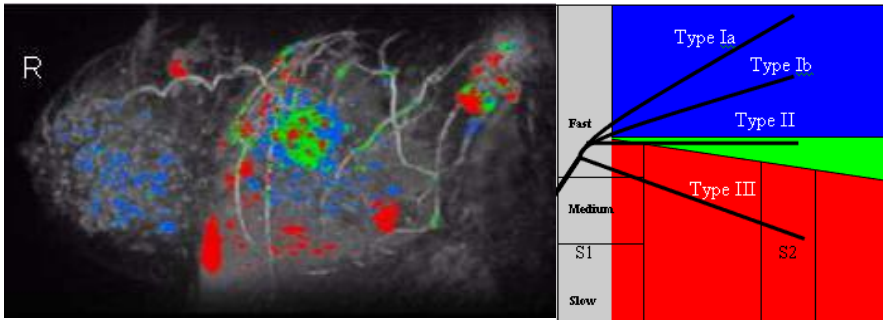
Color in medical imaging?

What does it mean?

Annotations

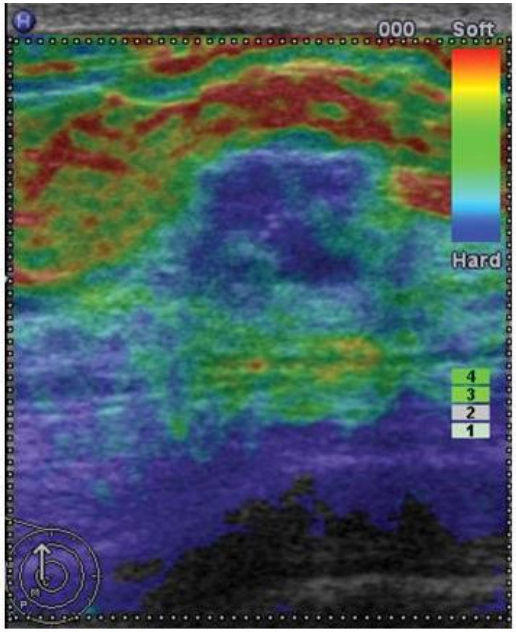
- Annotation
- Threshold indication with distinct steps



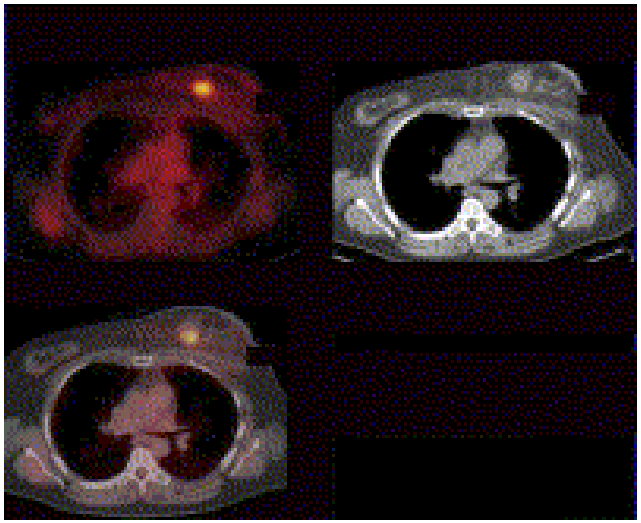


Pseudo- and true color modalities

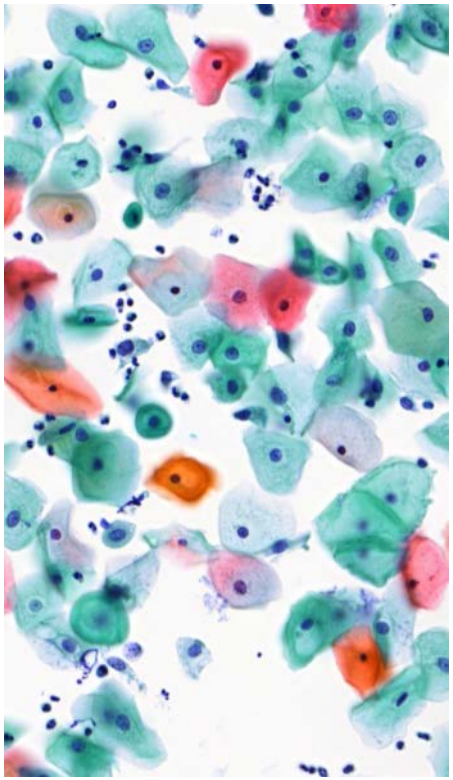
- Report continuous measure of calculated value
- Use color channel for to fuse second modality
- Visible light modalities



ultrasound stiffness calculated



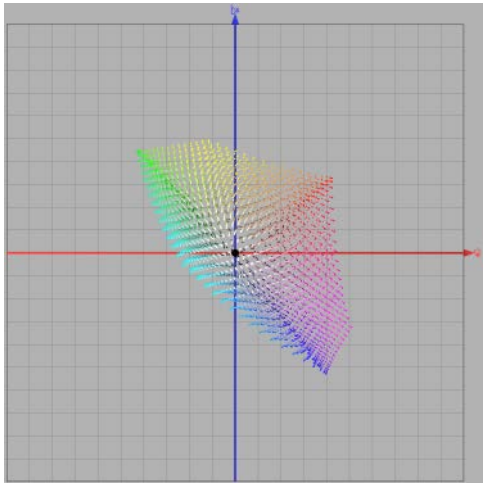
PET – CT Fusion



microscopy

Color doppler image from Cho N, et al. Radiology 2012; 262:80-90

Proposal for calibration framework for medical color displays



Color Calibration is necessary

- Even high-end displays show substantial (visible) variation in color characteristics and color behavior over time
- This conflicts with the desire to make clinical performance independent of the specific display system used and of the lifetime of the display
- Putting display color stability requirements in place and meet these by calibration is necessary

Different (clinical) requirements for different color modalities

- For a limited number of modalities, absolute color accuracy may be a requirement.
- For most other modalities there seems to be no need to reproduce colors accurately in absolute terms.
- The community would benefit from clear guidance or standards per modality or type of modality.

Color Calibration proposed based on perceptual optimization, not absolute

- Absolute color display calibration comes at a significant cost (contrast, luminance, lifetime). It does not allow for technical advances and limits every display to the worst display that can be accepted.
- Therefore it seems that, wherever possible, perceptually linear color calibration seems a good solution
- Spacing things evenly *gives applications best palette*

sRGB is very limiting {80 cd/m2, not in line with evolution of primaries expected soon}

Medical Color display ecosystem similar to greyscale medical imaging

- Modality Equipment
  1. Produce for-presentation images with attached rendering intent
  2. Produce for-processing images for later use
- Display (and Print) Calibration LUT Goals
  1. Evenly spread out *possible-to-express* shades of gray and color
  2. Export characterization through standard mechanism, ICC
- Presentation LUT Goals
  1. Allow appliations to focus on subset of image data range
  2. Assure consistent presentation of prepared images across platforms and media (CPI)

Questions?

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