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

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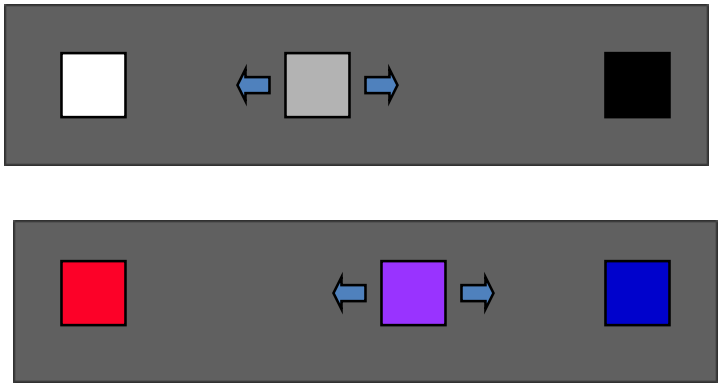
Outline

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

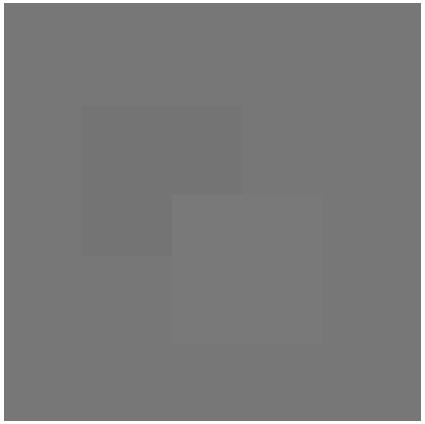
Two Types of Color Differences

Macro (By Scaling)



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

Micro (By JND)



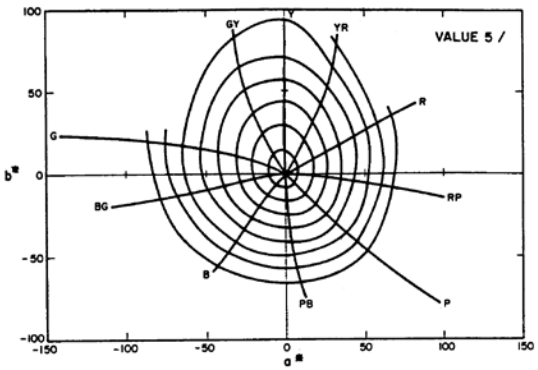
e.g.
GSDF
MacAdam's ellipses (Standard Deviation of Color Matching)

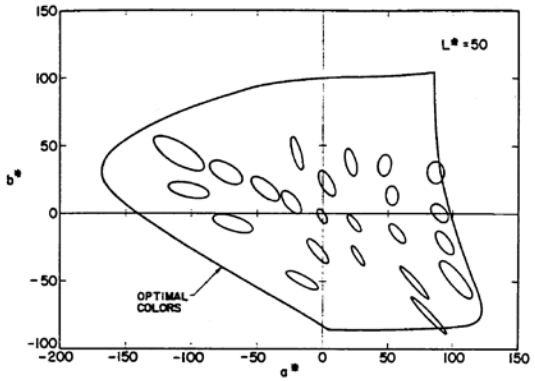
Two Types of Color Differences

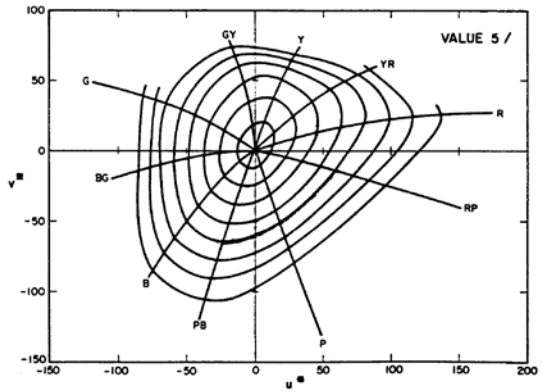
Comparison of CIE L*a*b* and L*u*v*

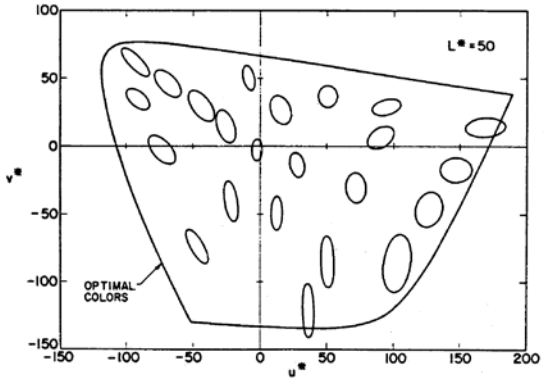
*L*a*b**

*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…

$$\underbrace{1_{jnd}+1_{jnd}+1_{jnd}+1_{jnd}}_{\text{Micro color difference}}+1_{jnd} \neq 5_{scale}$$

Macro color difference

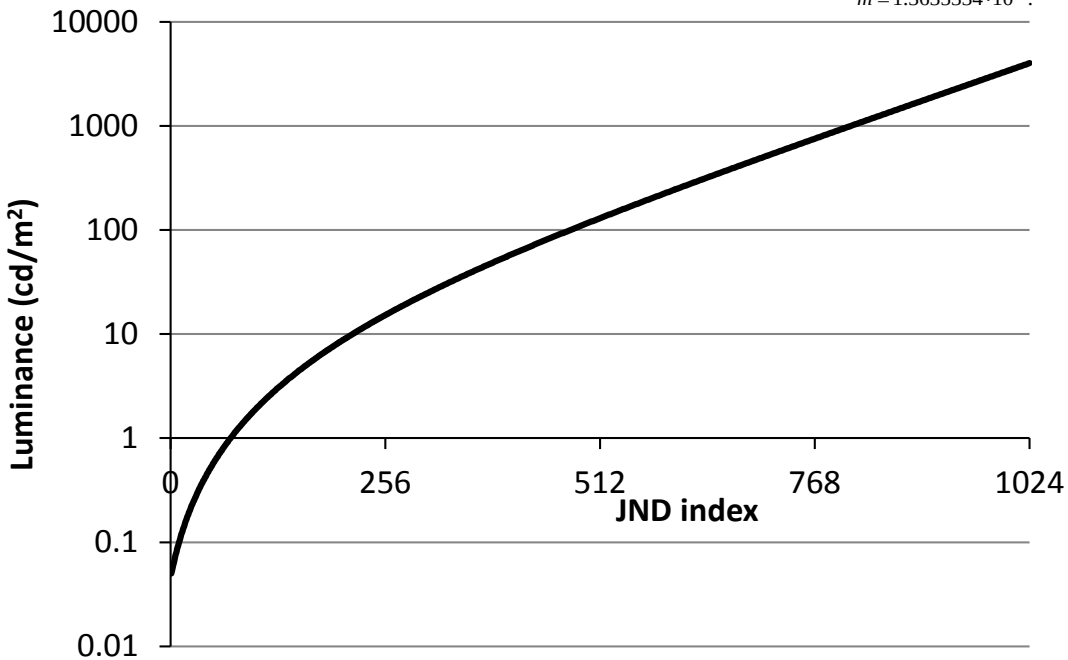
Color difference is not linear

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.

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

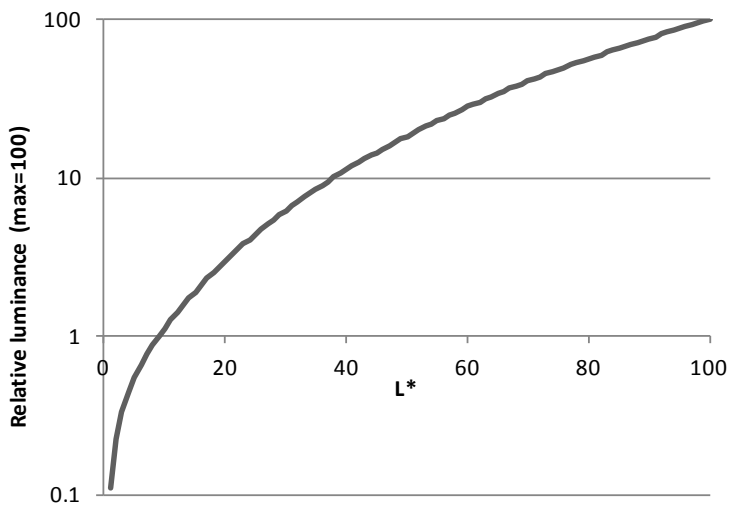
$a = -1.3011877,$
$b = -2.5840191 \cdot 10^{-2},$
$c = 8.0242636 \cdot 10^{-2},$
$d = -1.0320229 \cdot 10^{-1},$
$e = 1.3646699 \cdot 10^{-2},$
$f = 2.8745620 \cdot 10^{-2},$
$g = -2.5468404 \cdot 10^{-2},$
$h = -3.1978977 \cdot 10^{-3},$
$k = 1.2992634 \cdot 10^{-4},$
$m = 1.3635334 \cdot 10^{-3}.$



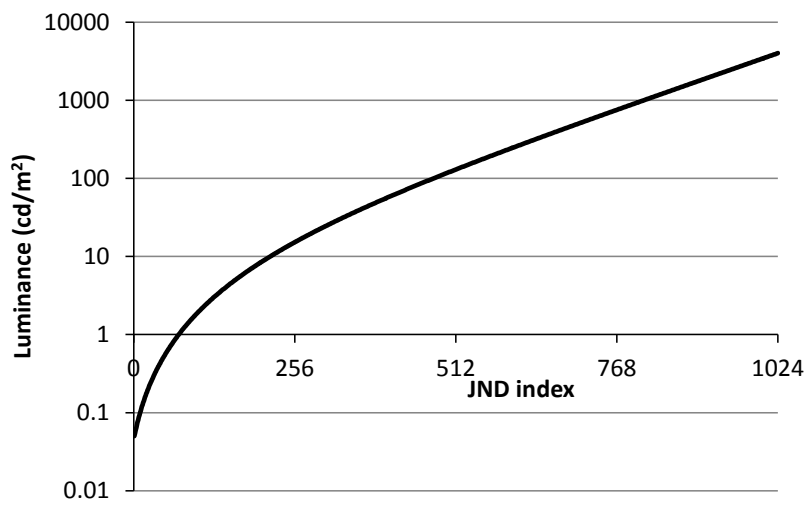
PS 3.14-2011, Digital Imaging and Communications in Medicine (DICOM), Part 14: Grayscale Standard Display Function, National Electrical Manufacturers Association.

Essential Difference between GSDF and L*

L*: Relative against white point
GSDF: Absolute to luminance



L*

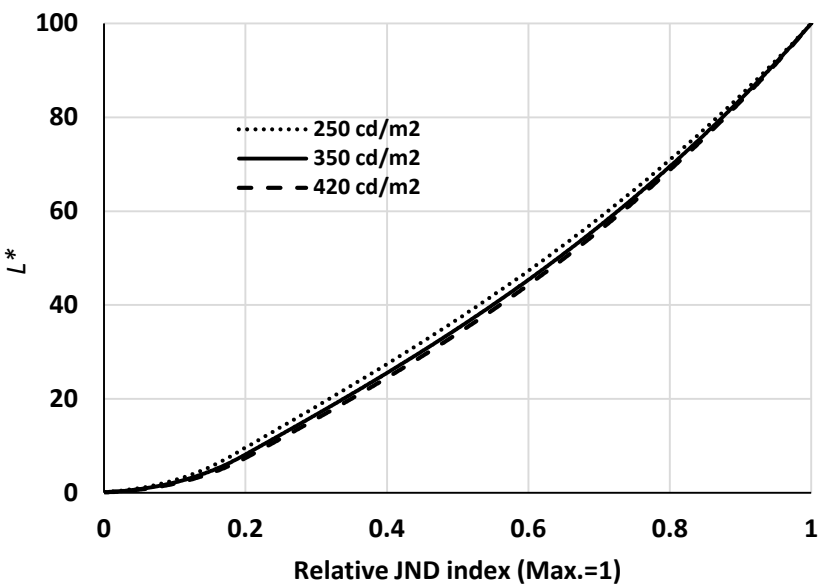


GSDF

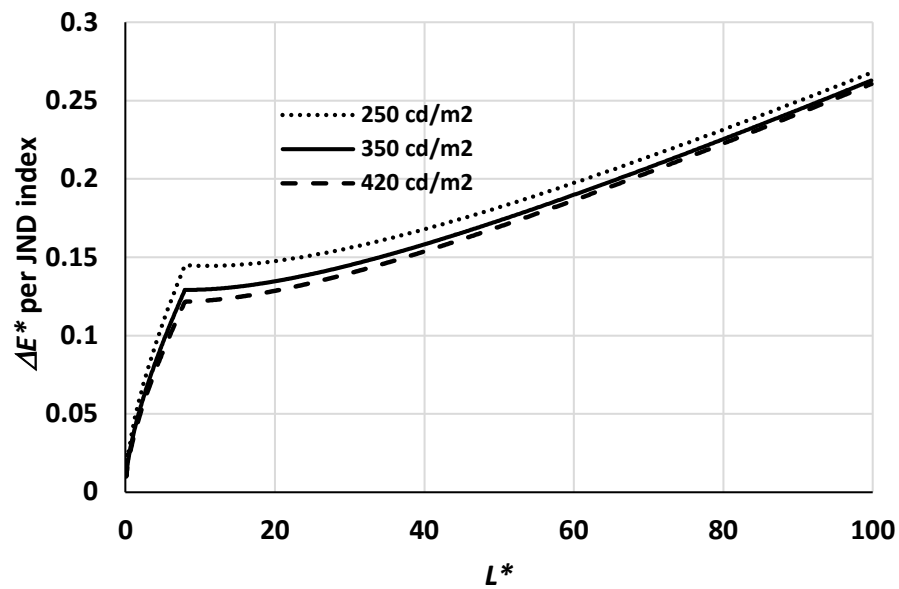
They look similar at a glance, but…

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

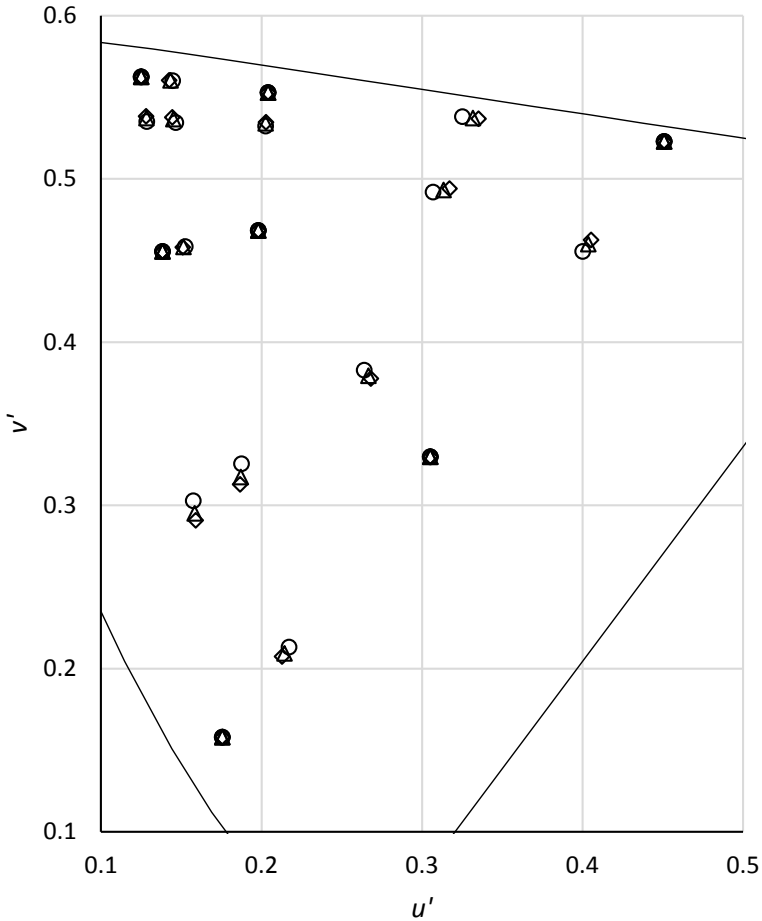
Specification*	sRGB	aRGB	ACR	mRGB
Luminance Response	~2.2 power function	2.199 power function	DICOM GSDF	DICOM GSDF
Color Gamut	HDTV based ITU-R BT.709-5	'Wide' (extended G)	-nd-	sRGB (aRGB option ?)
L_{max} , cd/m^2	80	160 (125-200)	350/420/250	350/420/250
L_{min} , cd/m^2	-nd-	0.56	L_{max} / LR	L_{max} / 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

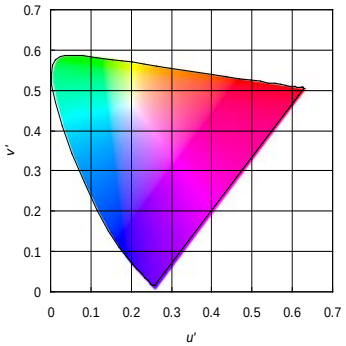
http://www.color.org/groups/medical/Flynn.pdf

What would happen if GSDF is used for Color Space?

Causes chromaticity shift!



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



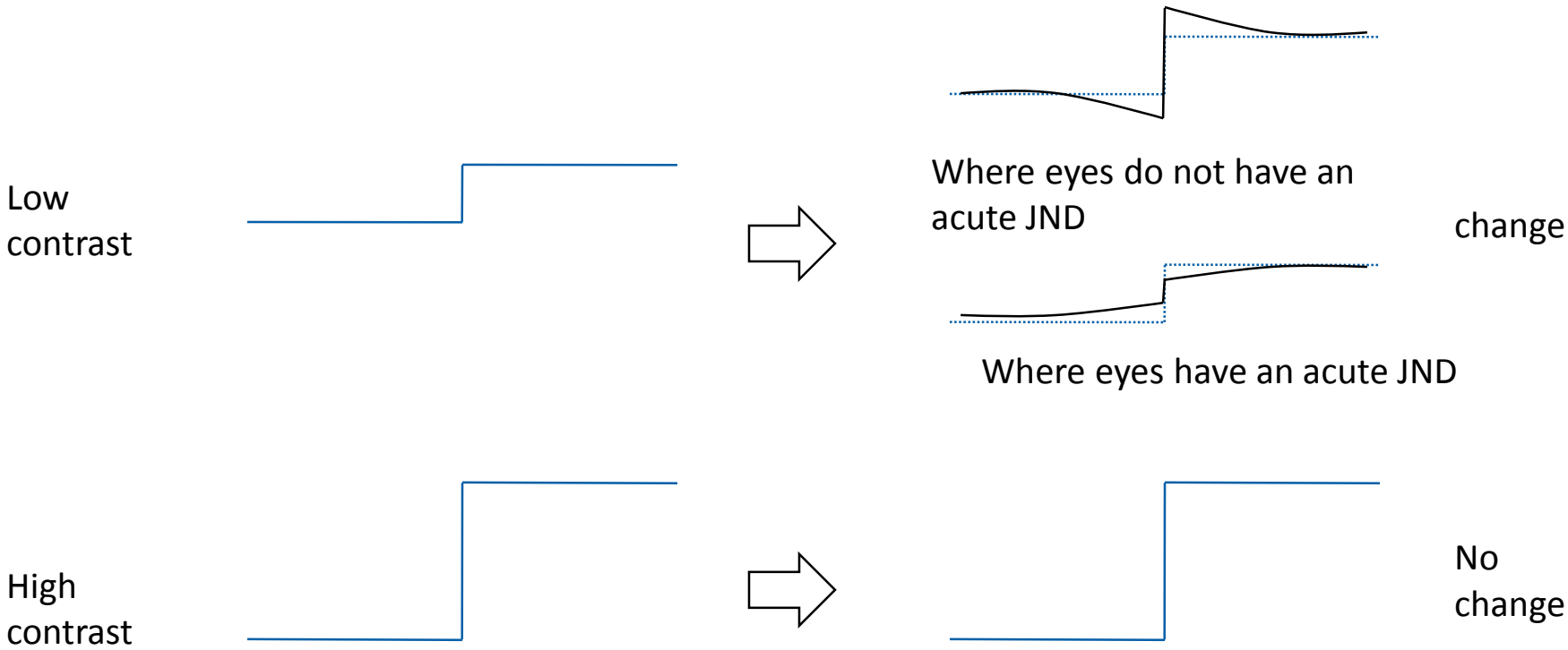
Can Both Color Differences Be Coexisted?

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).

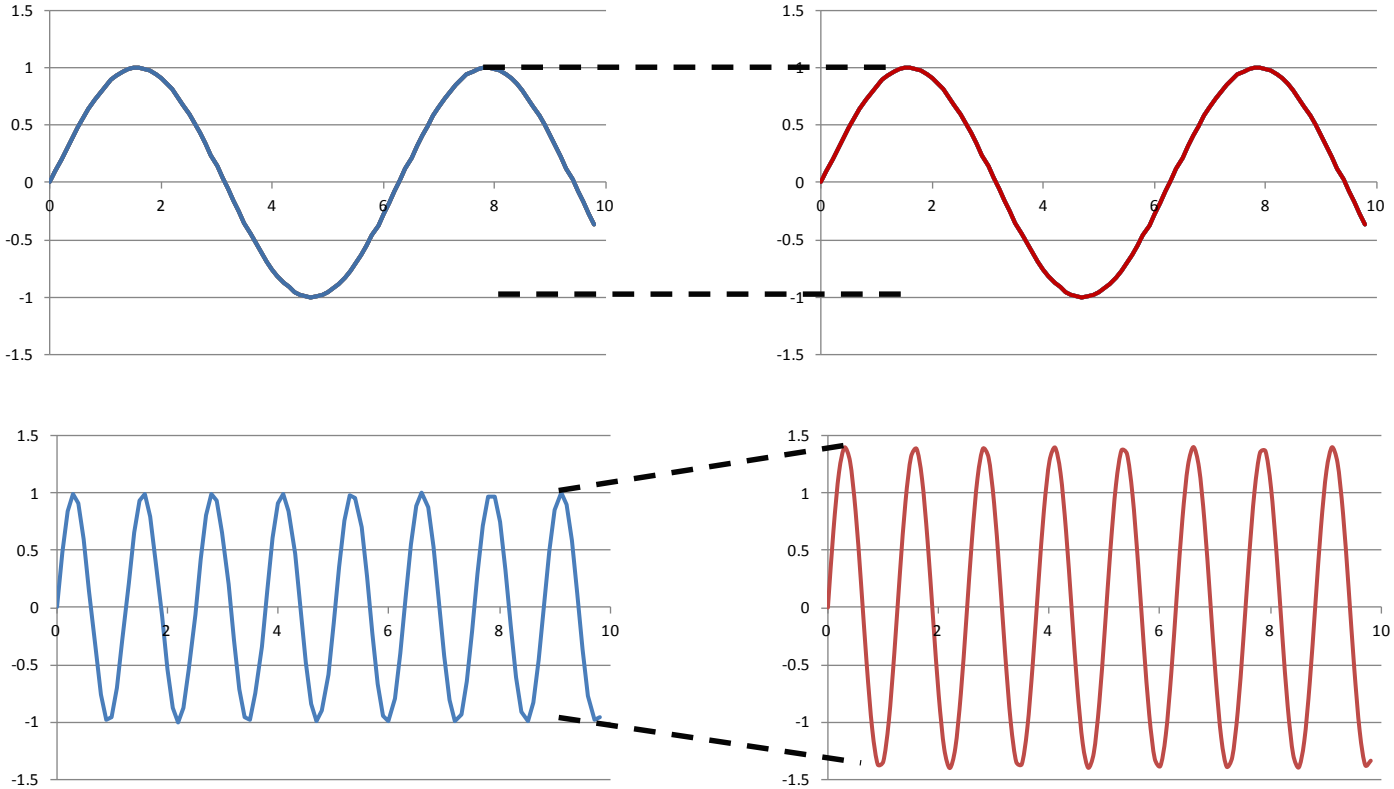
Can Both Color Differences Be Coexisted?

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:

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

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

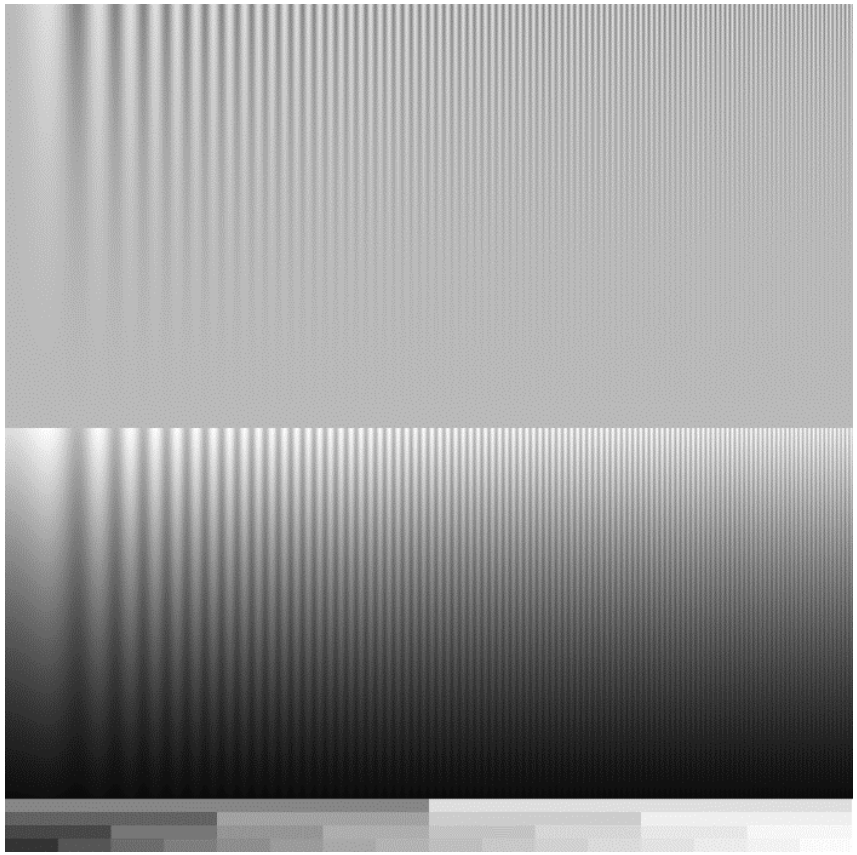
Test image:

1D Chirp function image with step wedges

Spatial Frequency
low ⇔ high

Contrast
low ⇕ high

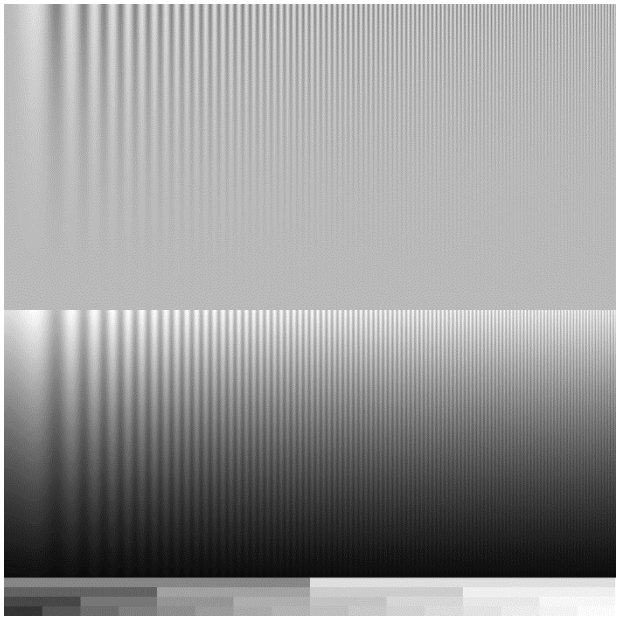
Luminance
low ⇕ high

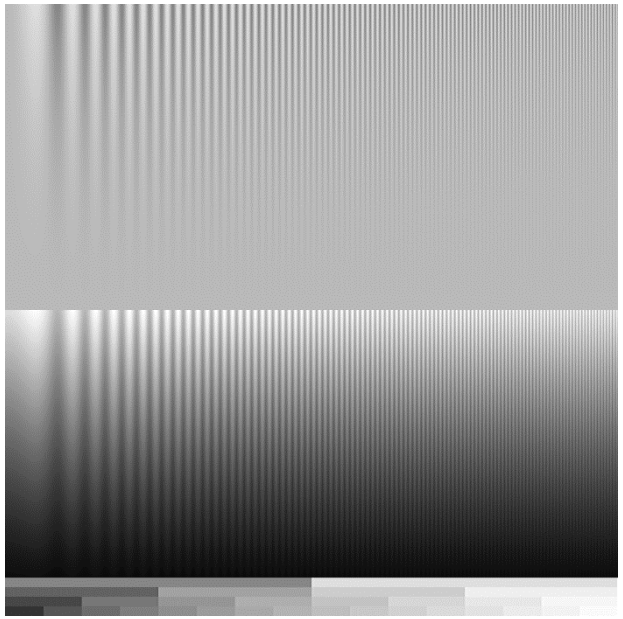


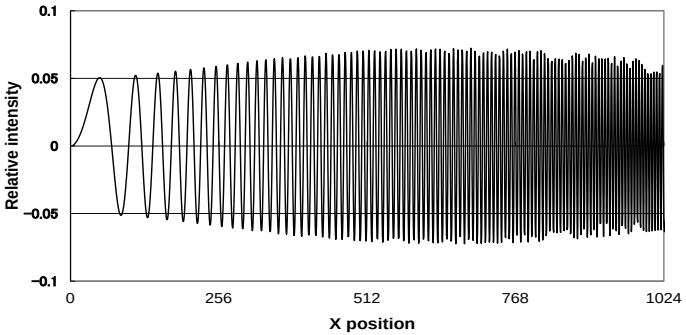
Step wedge

Experiment: Evaluation

Result of this algorithm







Discussion

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Limited usage of GSDF for tonal scale

- Specify luminance level(s)?

Expansion to chroma direction?

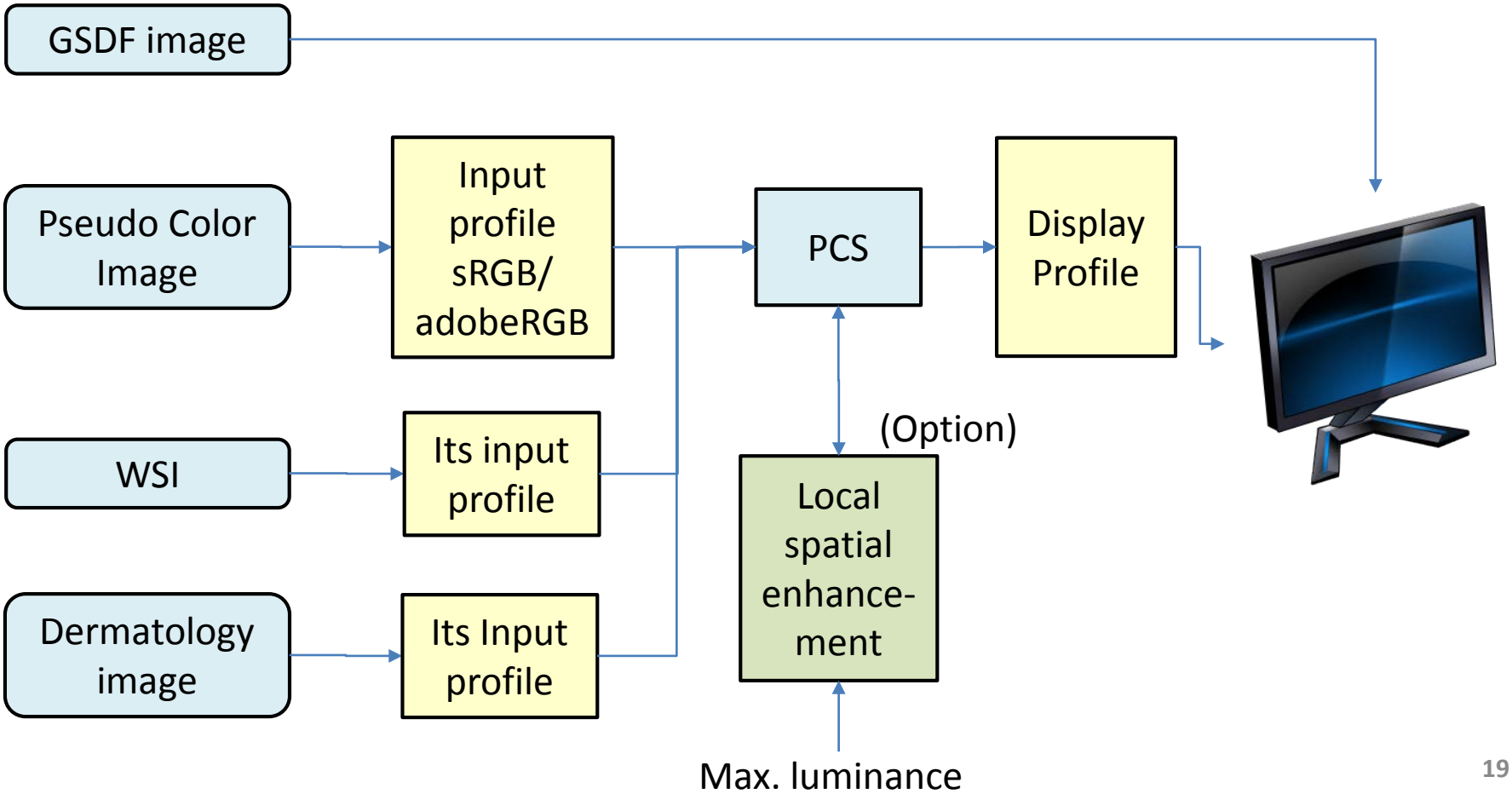
- E.g. Delta E 2000

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!