Color Correction for Optical See-Through Displays Using Display Color Profiles

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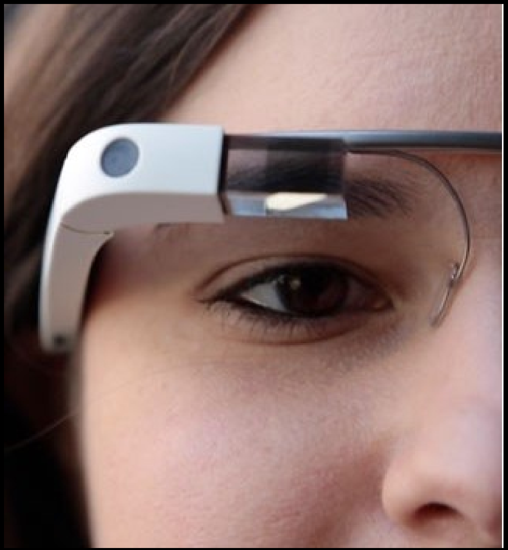
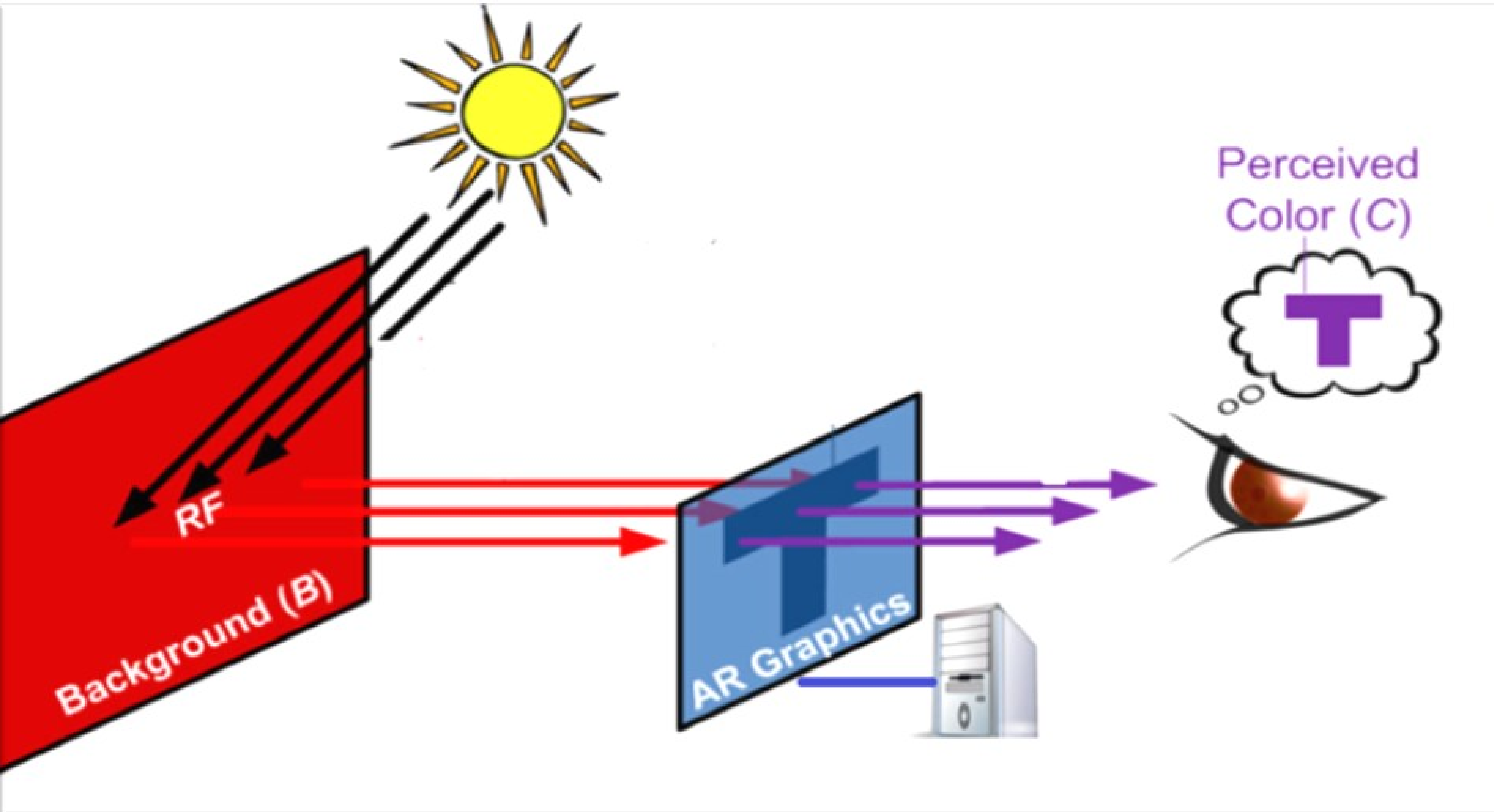
INTRODUCTION

Optical see-through displays (OSTD) allow users to view digital content and physical objects simultaneously.



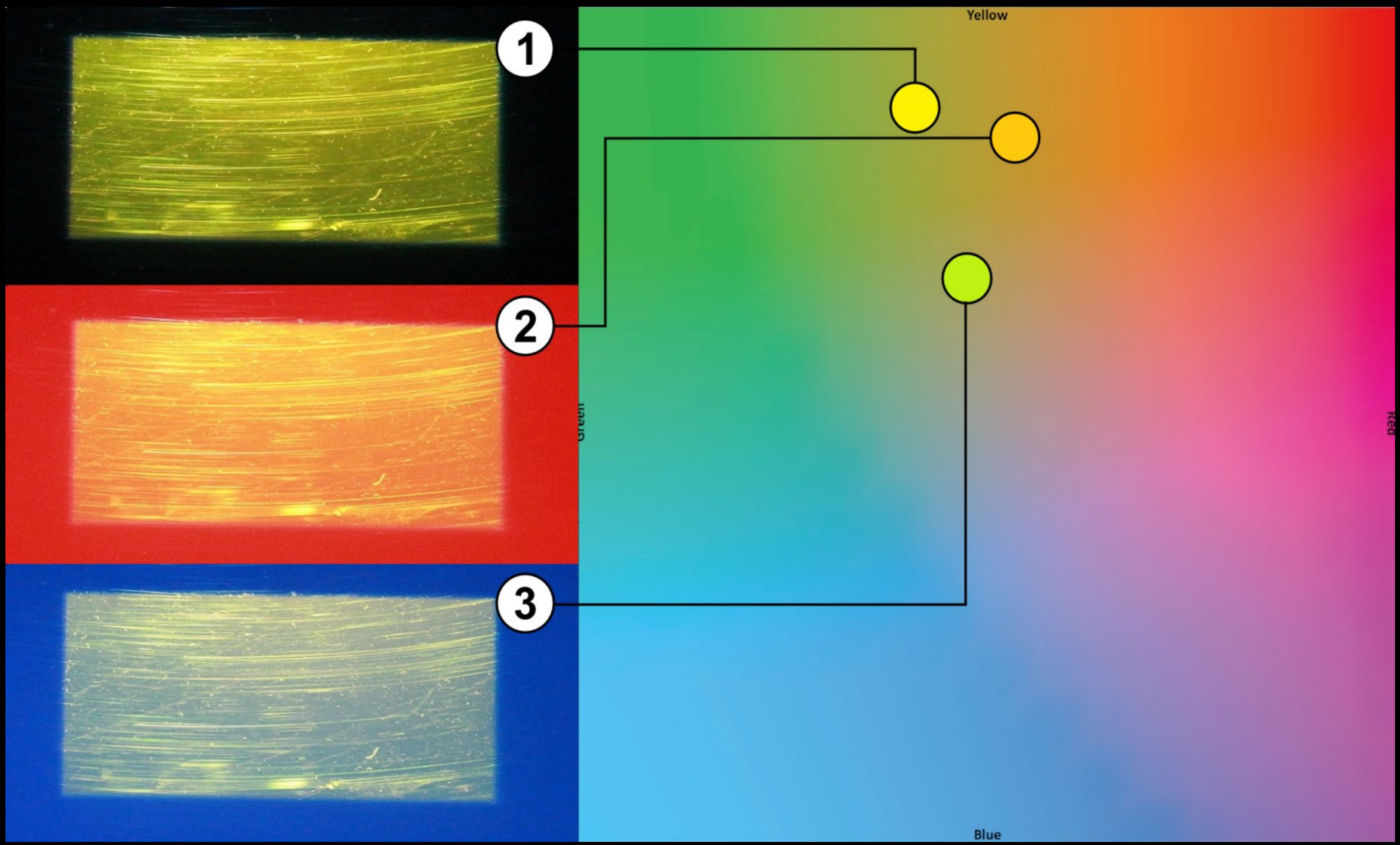
Additive OSTD: Has its own light source

Subtractive OSTD: Filter external light source



Gabbard et al - More than meets the eye: An engineering study to empirically examine the blending of real and virtual color spaces , VR 2010

Real world background color affects the displayed contents on the digital display

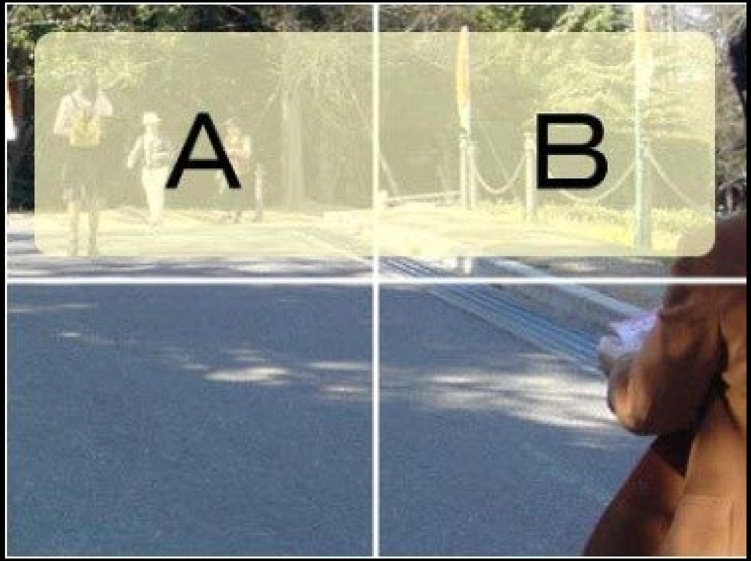


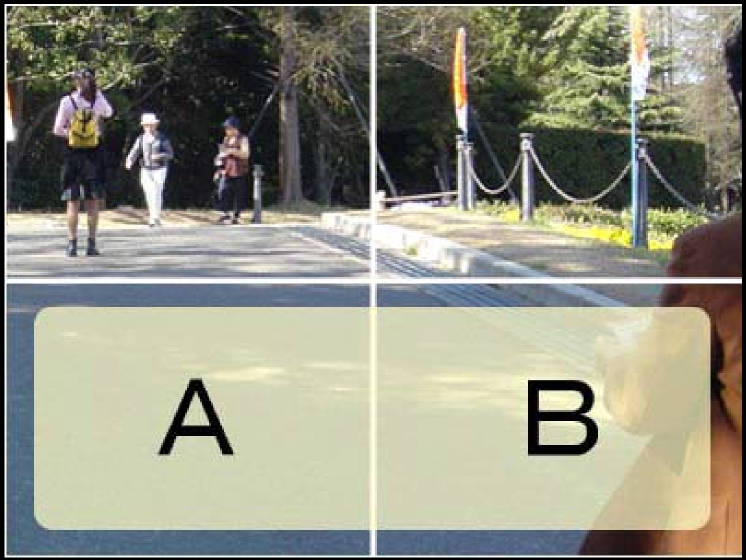
1
2
3
Yellow
Green
Red
Blue

Usability Problem

Kerr et al :Wearable mobile augmented reality: evaluating outdoor user experience. VRCAI ’11

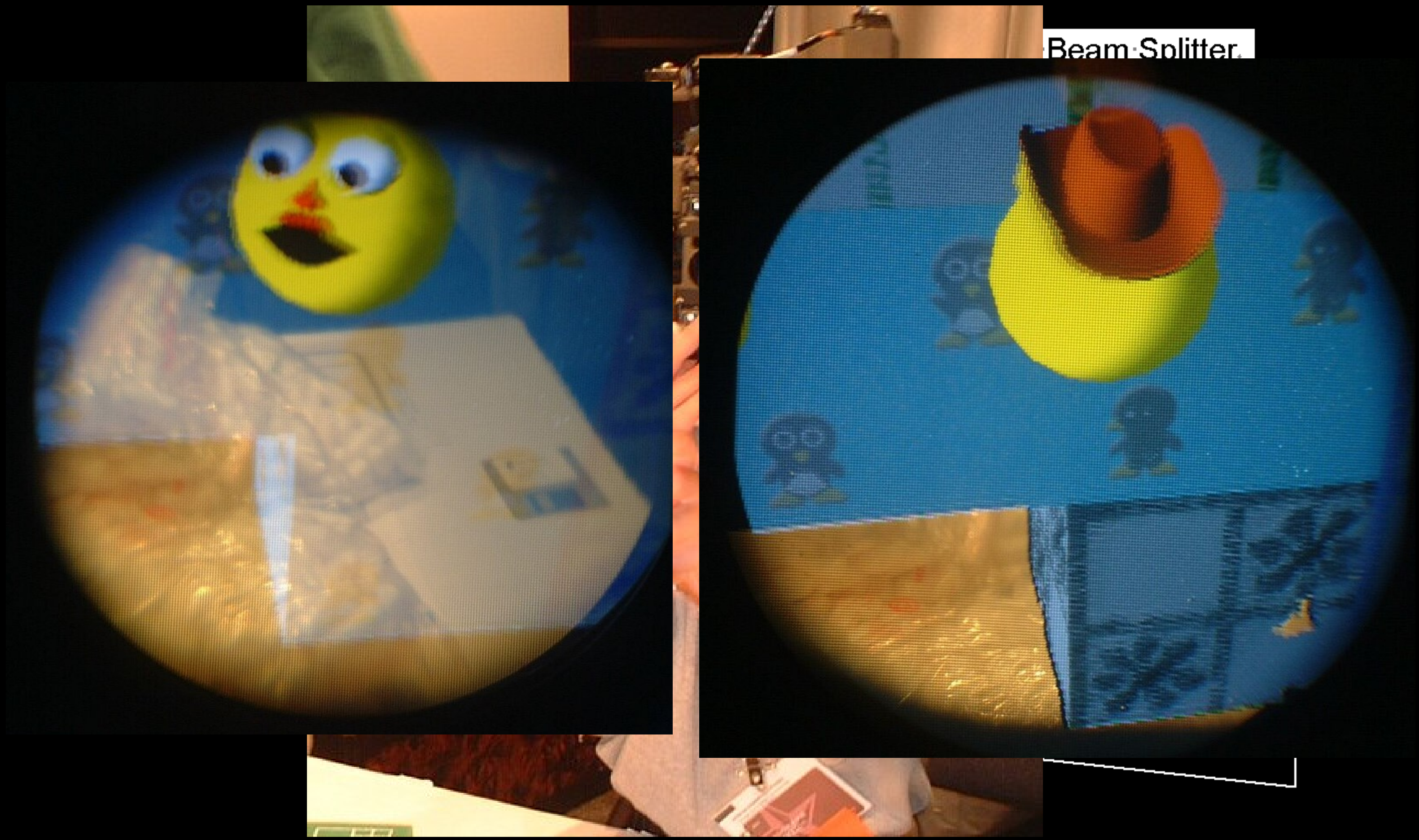
Content Based Solutions





Tanaka et al, An information layout method for an optical see-through head mounted display focusing on the view ability. ISMAR 08

Hardware Based Solution



Kiyokawa et al, An Occlusion-Capable Optical See-through Head Mount Display for Supporting Co-located Collaboration. ISMAR 2003

How We differ ?

- We aim not to change the location of UI elements

  or
- Add new hardware components

we wanted to manipulate the color shown by the display; an approach known as Color Correction.

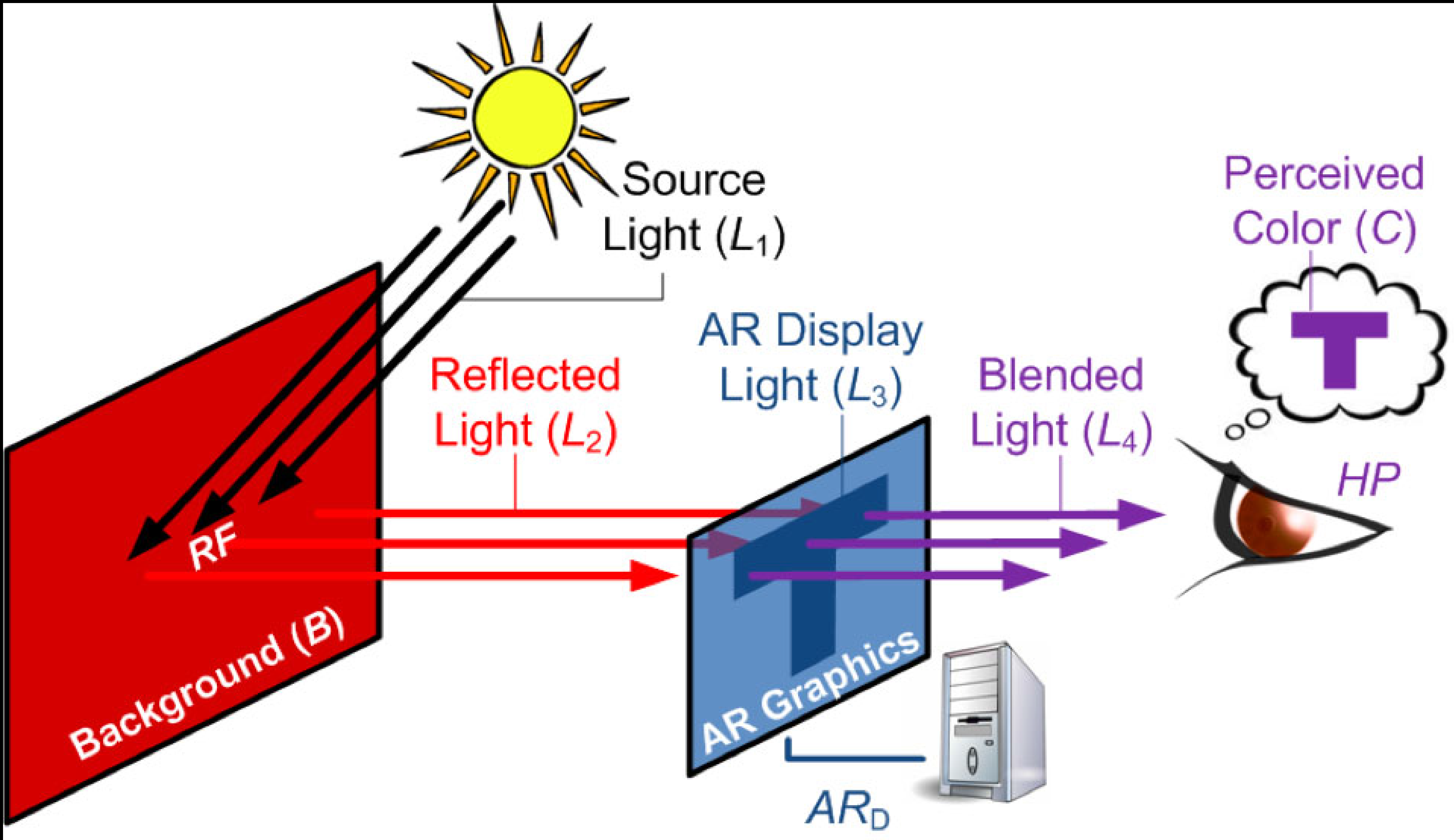
Color Correction

Involves in the system finding an alternate digital color which, upon blending with the background comes closer to the desired digital color

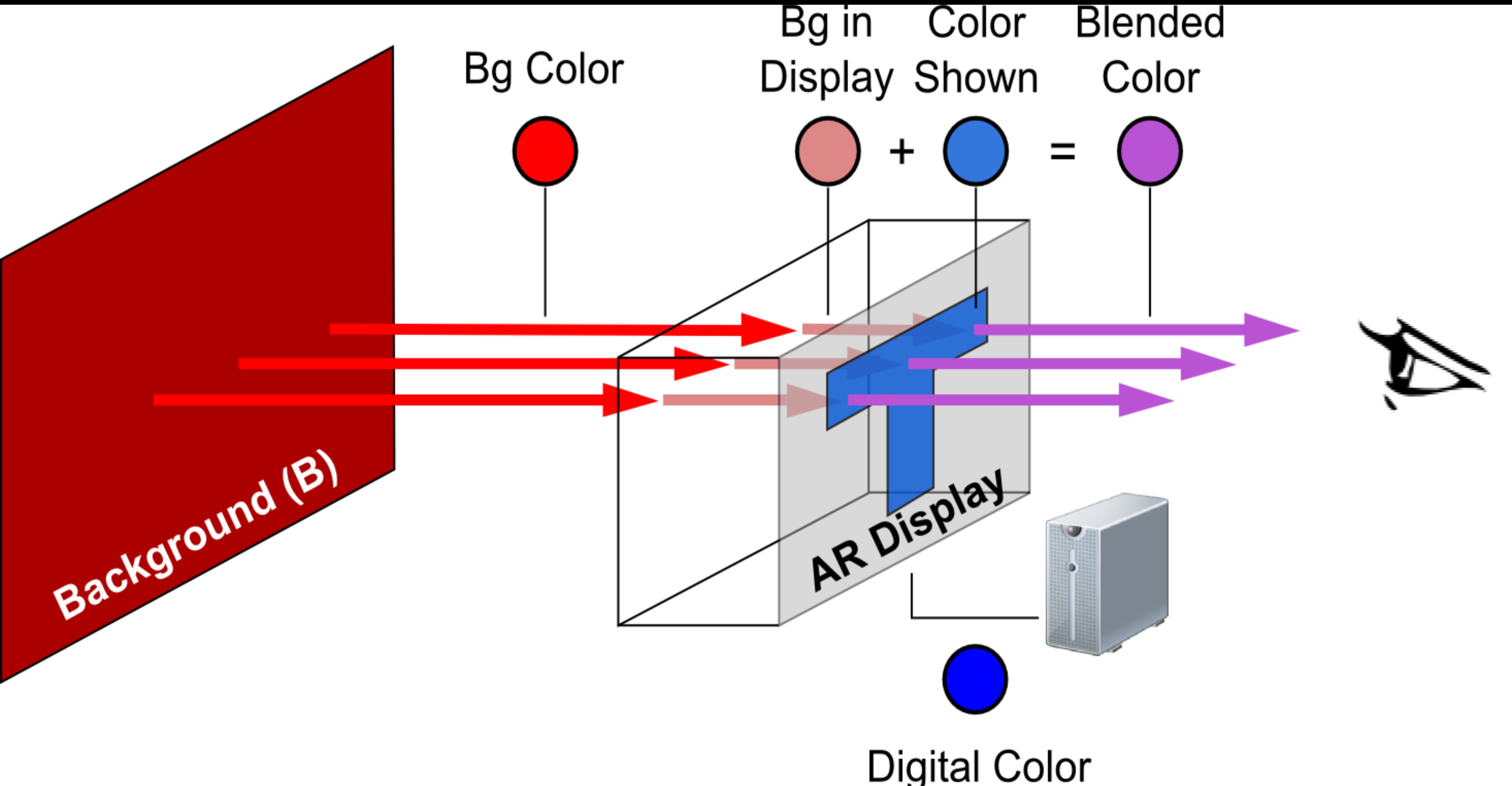
Background

- To pick a alternate color we need ability to predict how colors blend on a given display.

- We propose a new color blending model that can predict how colors blend on a OSTD



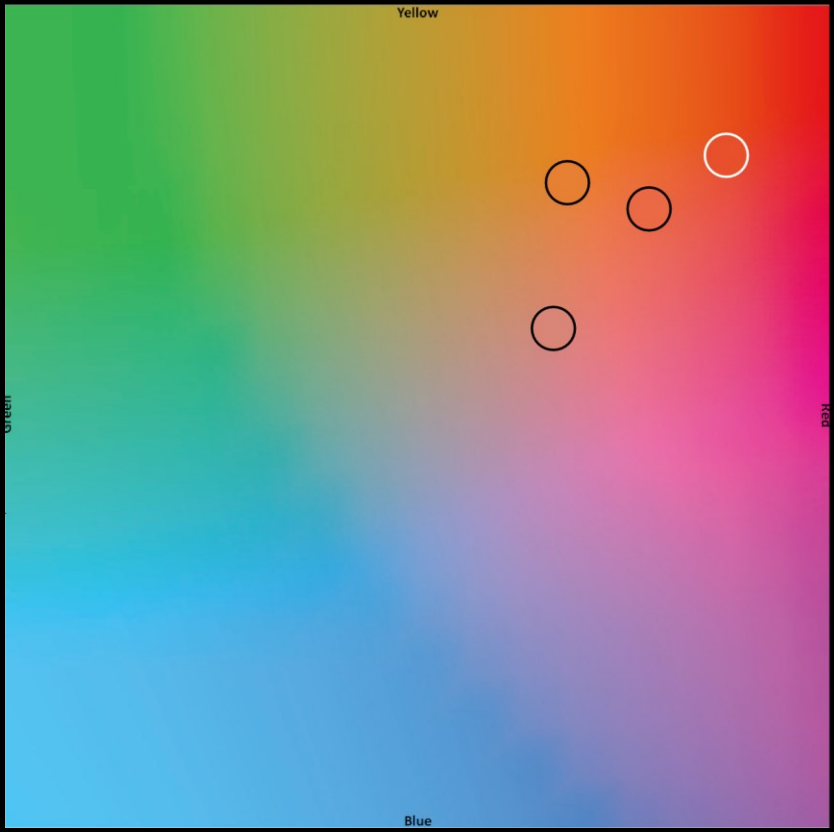
Gabbard et al, More than meets the eye: An engineering study to empirically examine the blending of real and virtual color spaces. In Virtual Reality Conference (VR), 2010



Blended Color = f_{render}(Digital Color) + $f_{material}$(Bg Color)

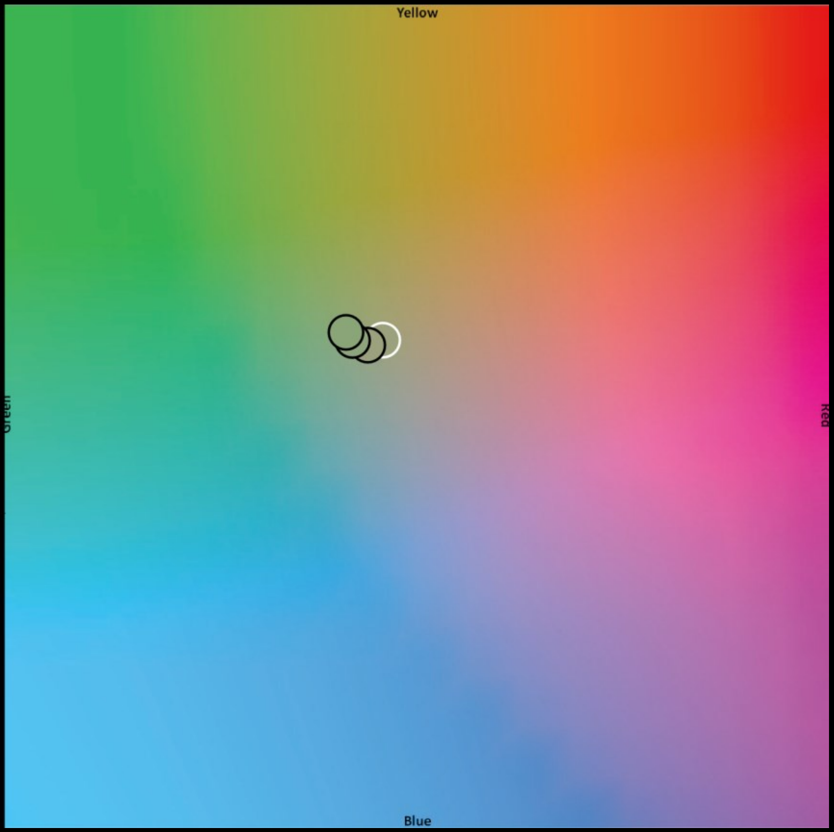
Color Blending Model

Foreground Colors



Render Distortion Function

Background Colors



Material Distortion Function

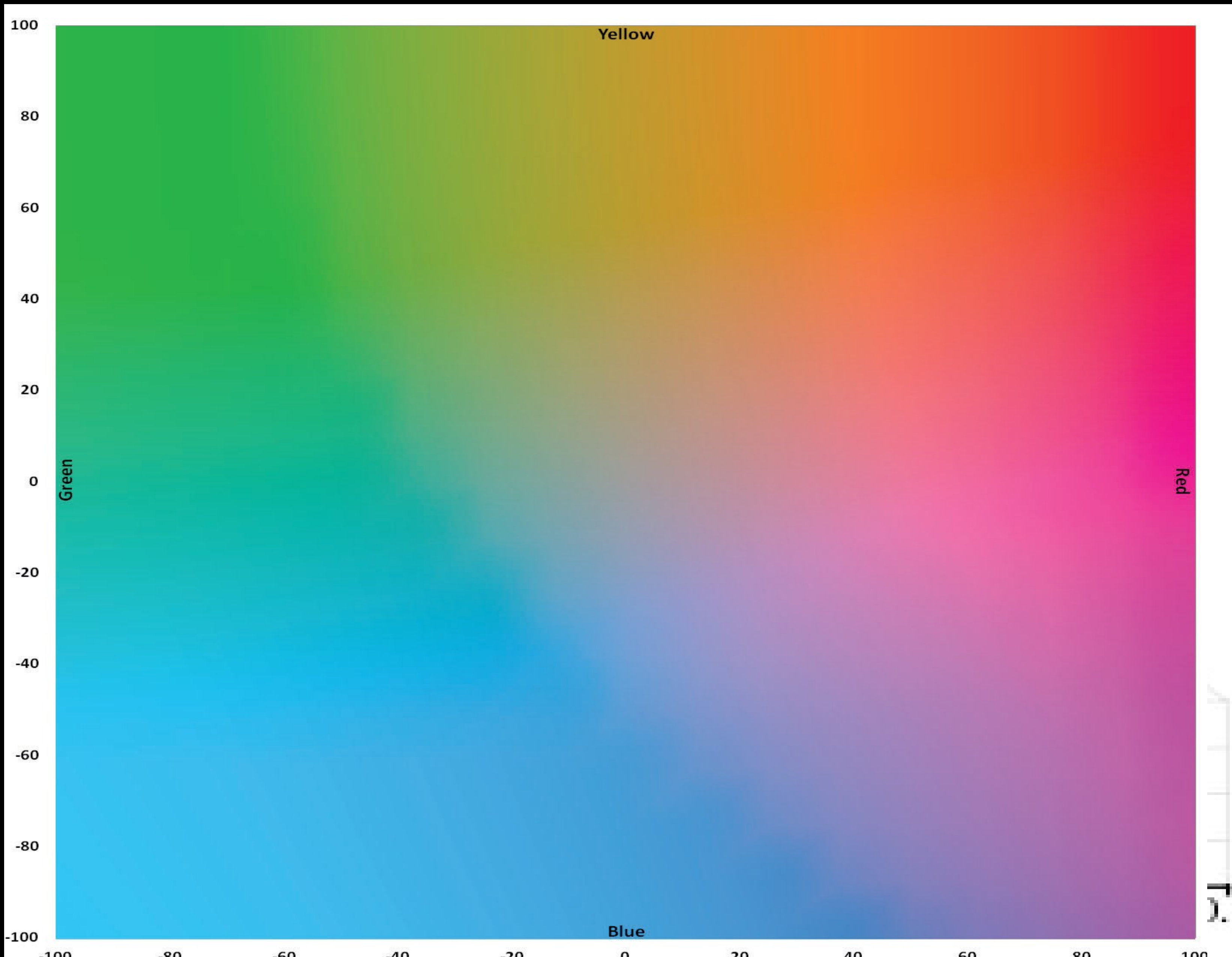
Contribution

- A new Color blending Model for OSTD
- Introduce Binned Profile (BP) – To handle Render Distortion
- Color Blending Model Based on BP- BP Method
- BP Based Color Correction

Color Correction in OSTD

Weiland et al, Colorimetric and photometric compensation for optical see-through displays.


F-16
01568

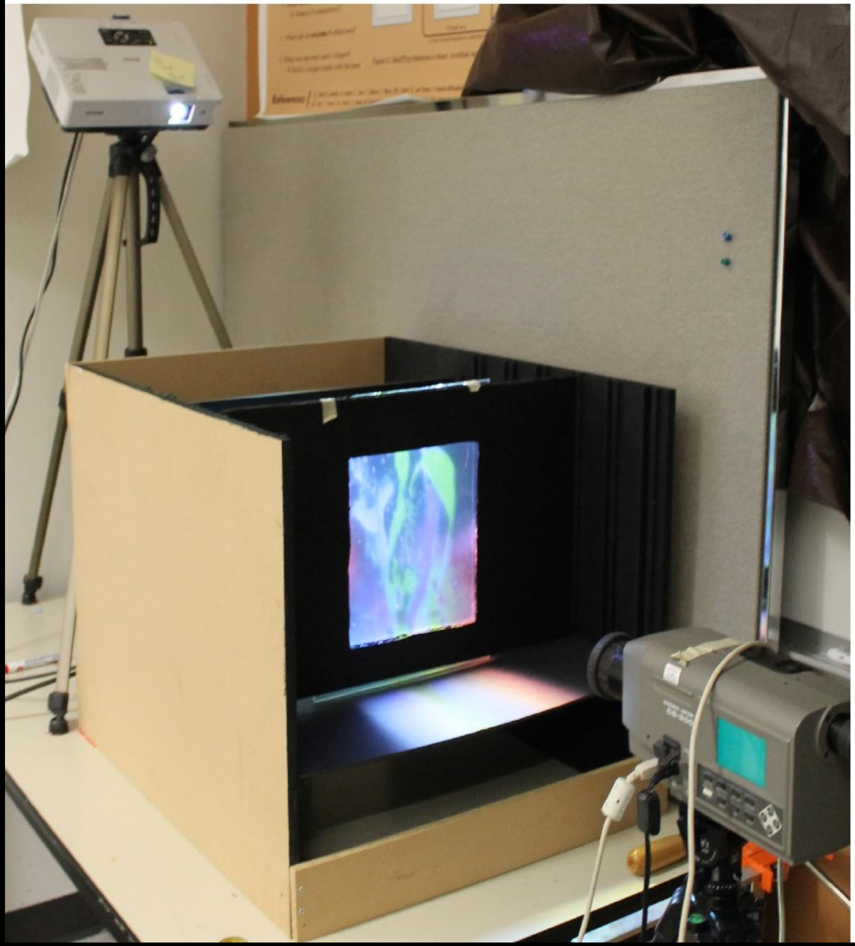

Yellow
Green
Red
Blue
100
80
60
40
20
0
-20
-40
-60
-80
-100
-100
-80
-60
-40
-20
0
20
40
60
80
100

Experimental Test-Bed

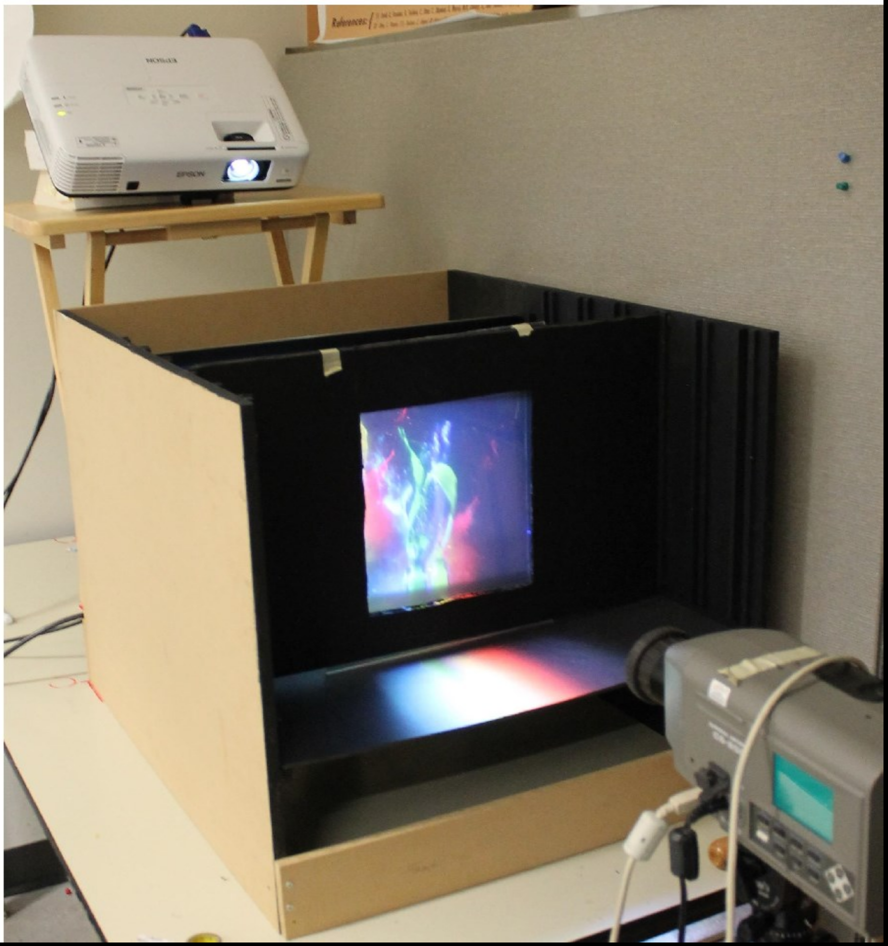
- Three OSTD were used
  - 2 Projection based
  - 1 T-OLED

Projection based

p2200 OSTD



p3700 OSTD



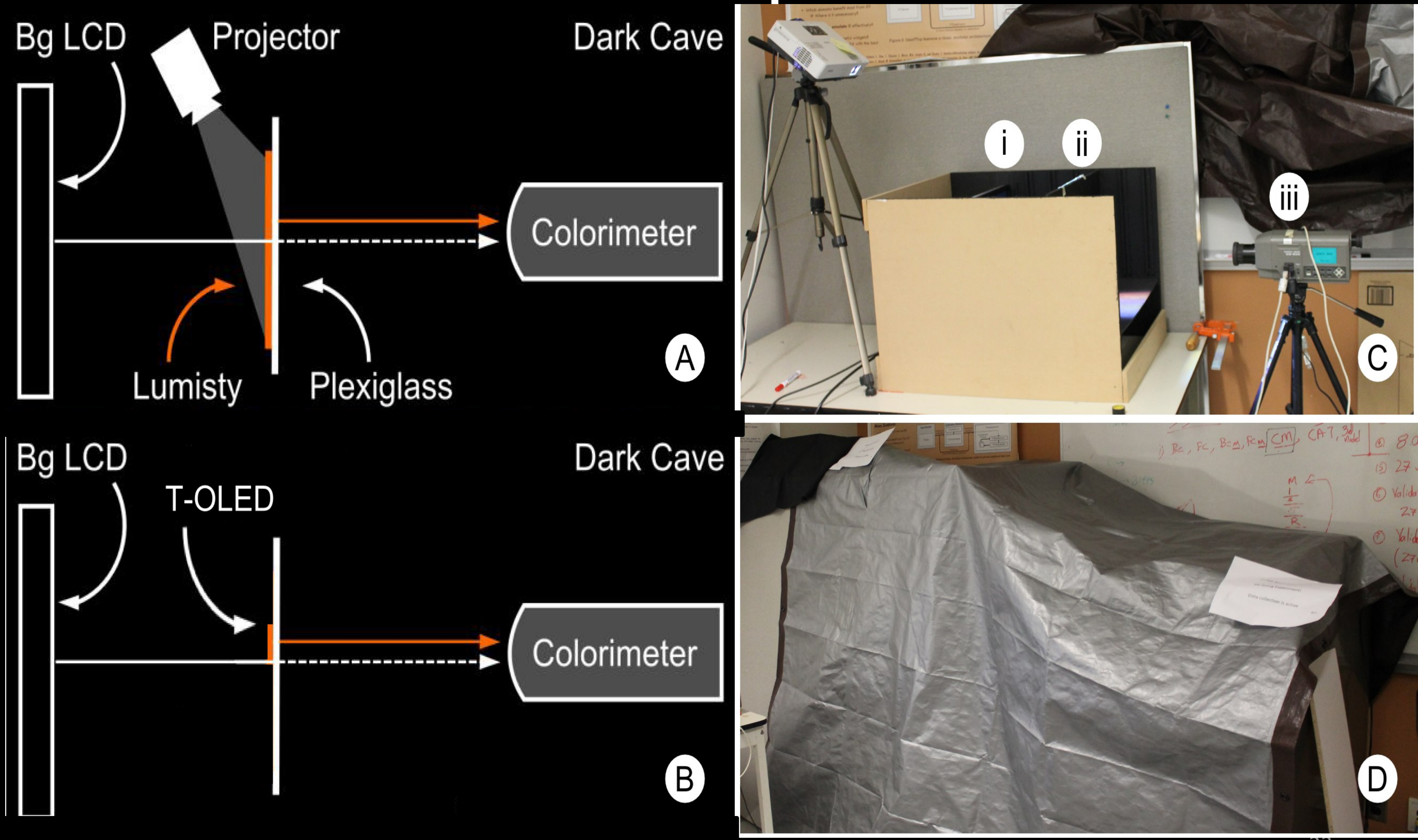
T-OLED

Background colors for experiment

Picture from Wikipedia

23 Macbeth chart colors used as background

Setup



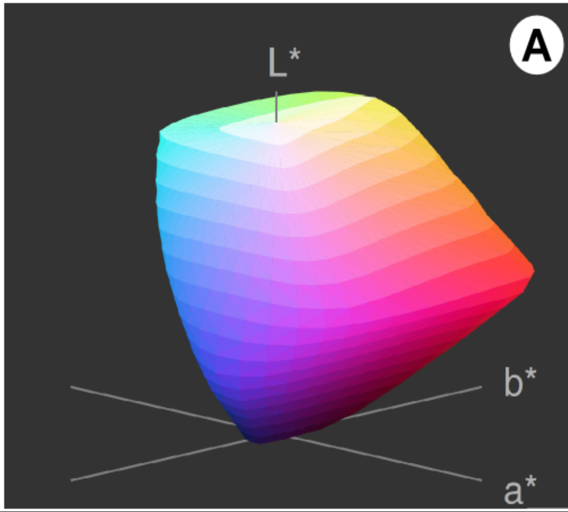
Bg LCD
Projector
Dark Cave
Colorimeter
Lumisty
Plexiglass
A
i
ii
iii
C
Bg LCD
Dark Cave
T-OLED
Colorimeter
B
D

The Binned Profile

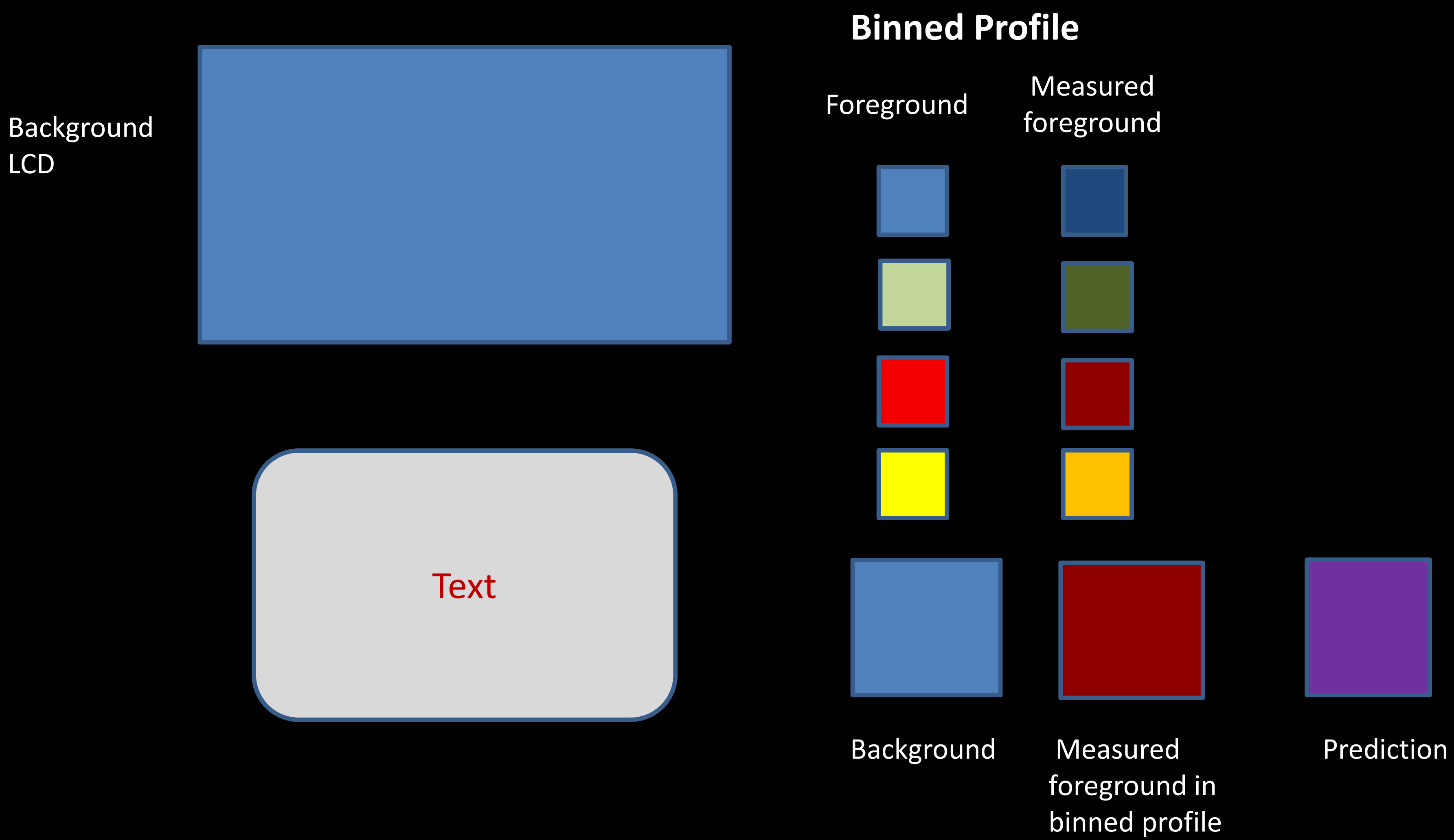
- Divides sRGB color space (over 16 million colors) into a smaller set of 8376 perceptually different bins.
- We translated the sRGB gamut into the CIE LAB color space and divided it into bins of 5X5X5
- This approach guaranties all colors inside a bin are within one Just Noticeable Difference (1 JND ~ 2.3 in Euclidean distance)
- we measured how each bin is rendered by each of our three displays on a black background
- Create a look up table which is Binned Profile

sRGB colors in LAB space

CIE LAB



BP Method Color prediction



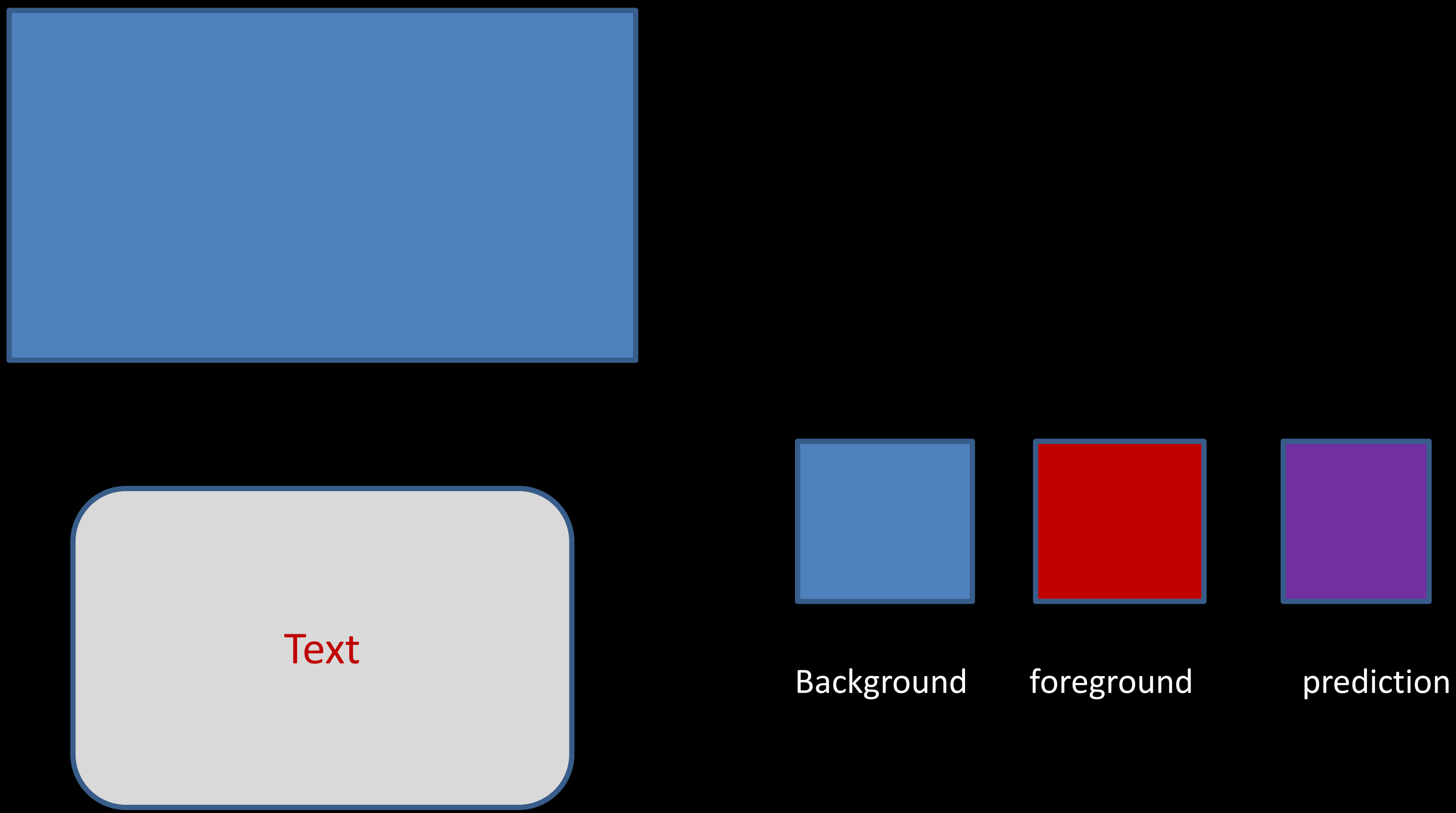
We tested the validity of this method against

– Direct Method
– CAT Method

Direct Method

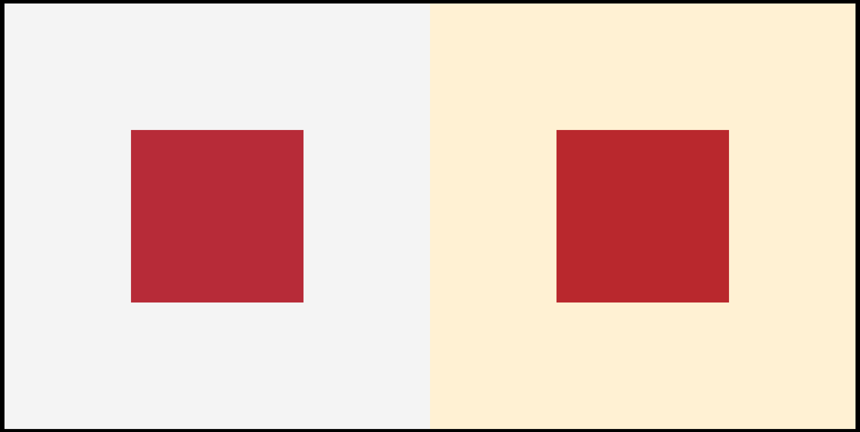
- Synonymous to Weiland et al work
- The digital color is simply added to the background
- It ignores both render and material distortion

Direct Color Prediction method



Chromatic Adaptation Transform (CAT)

- CAT are established methods to estimate the colors a display can render based on the brightest white it can emit.

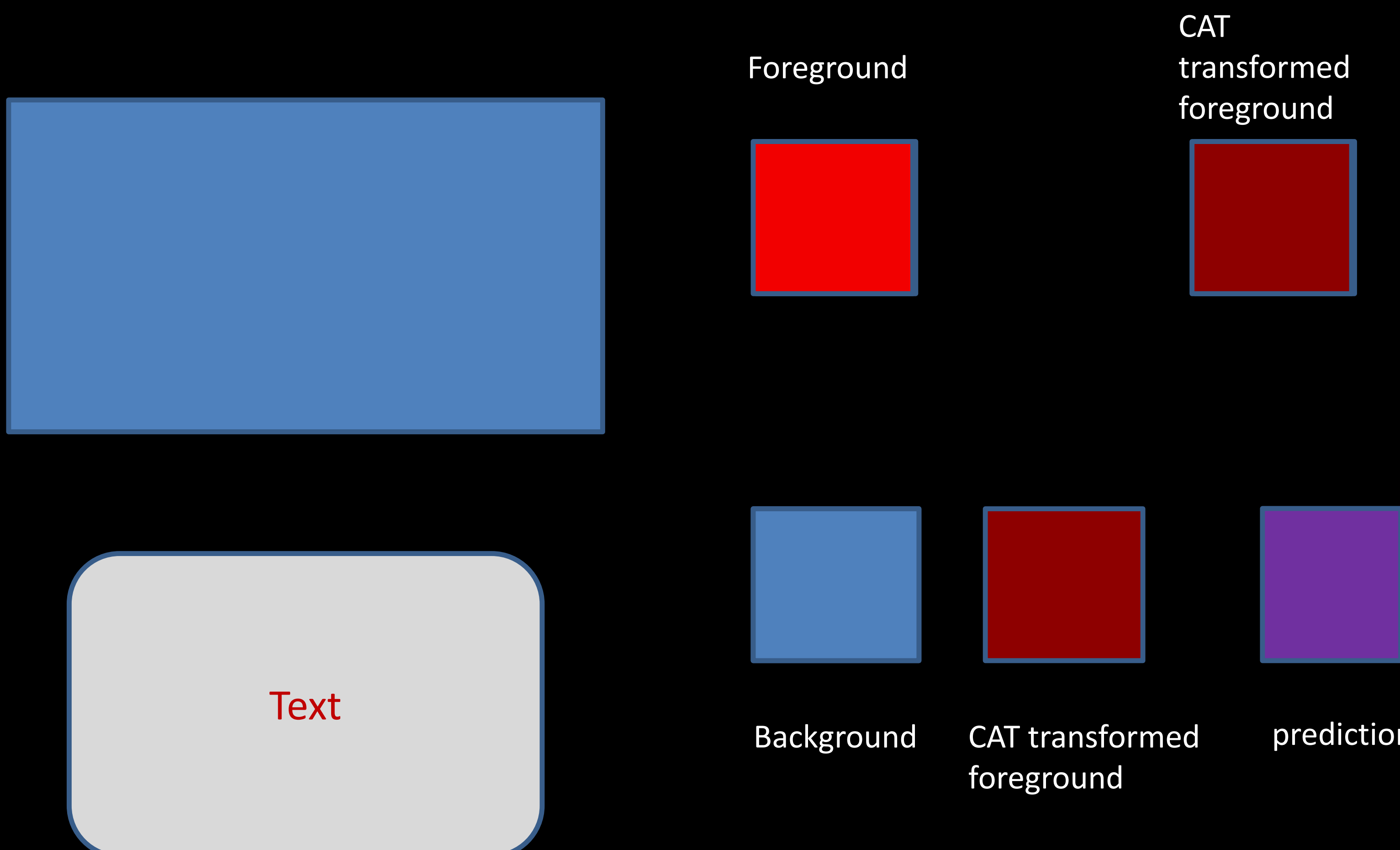


Pictures from Lindbloom website

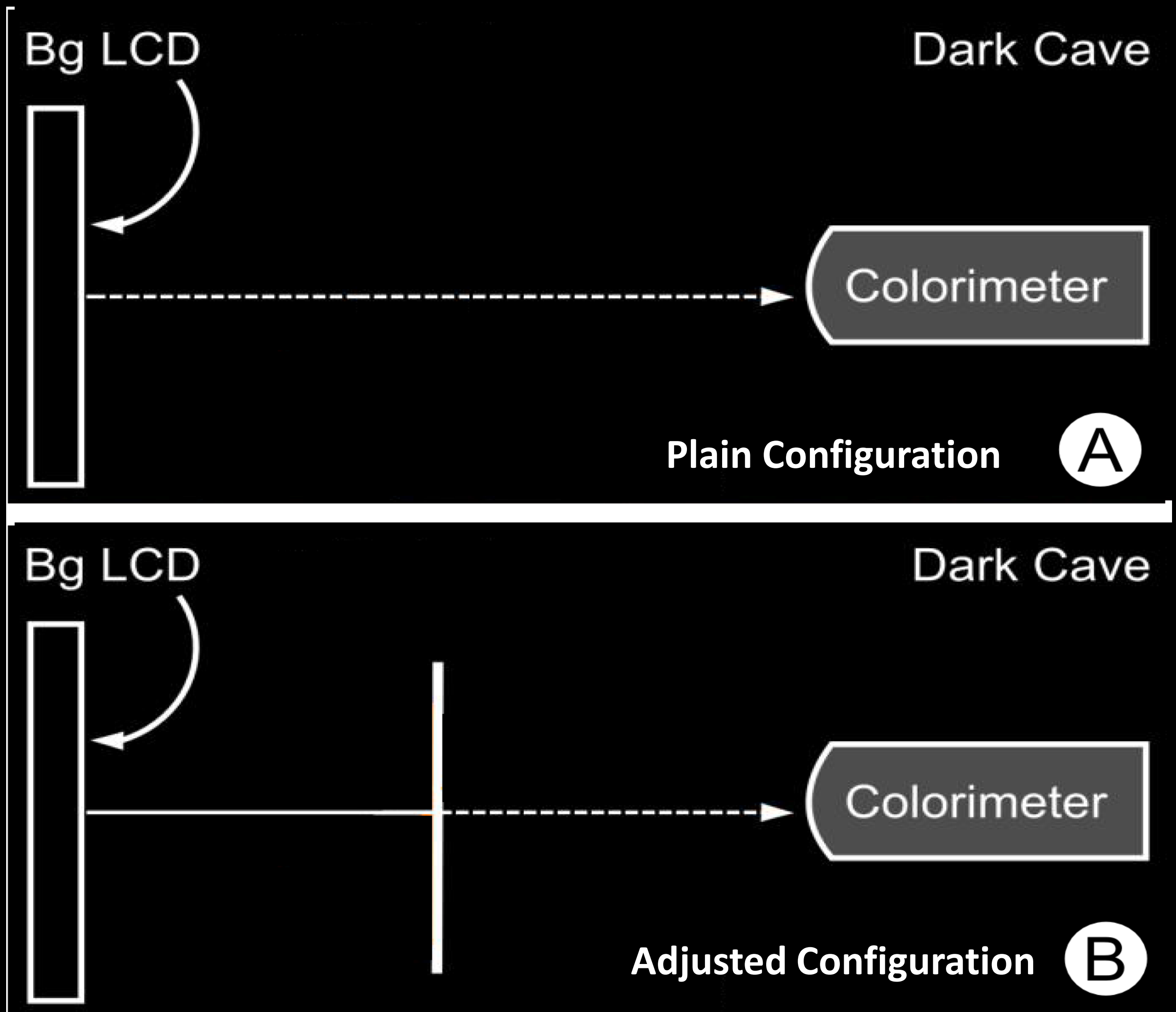
Chromatic Adaptation Transform (CAT)

- Bradford
- Von Kries
- XYZ Scaling

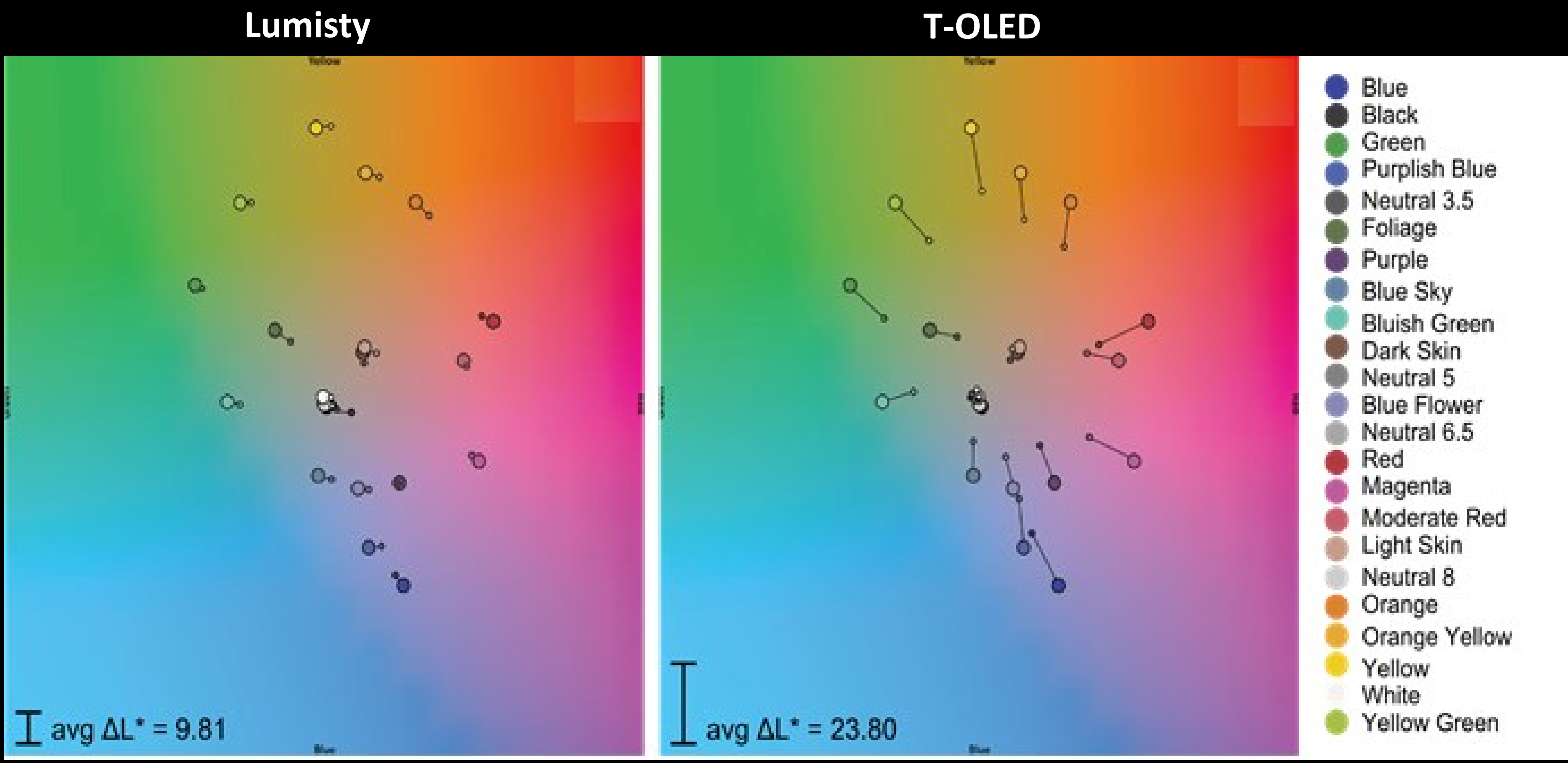
CAT Method


Foreground
CAT transformed foreground
Text
Background
CAT transformed foreground
prediction

Background Configuration



Material Distortion Function



Data Collection

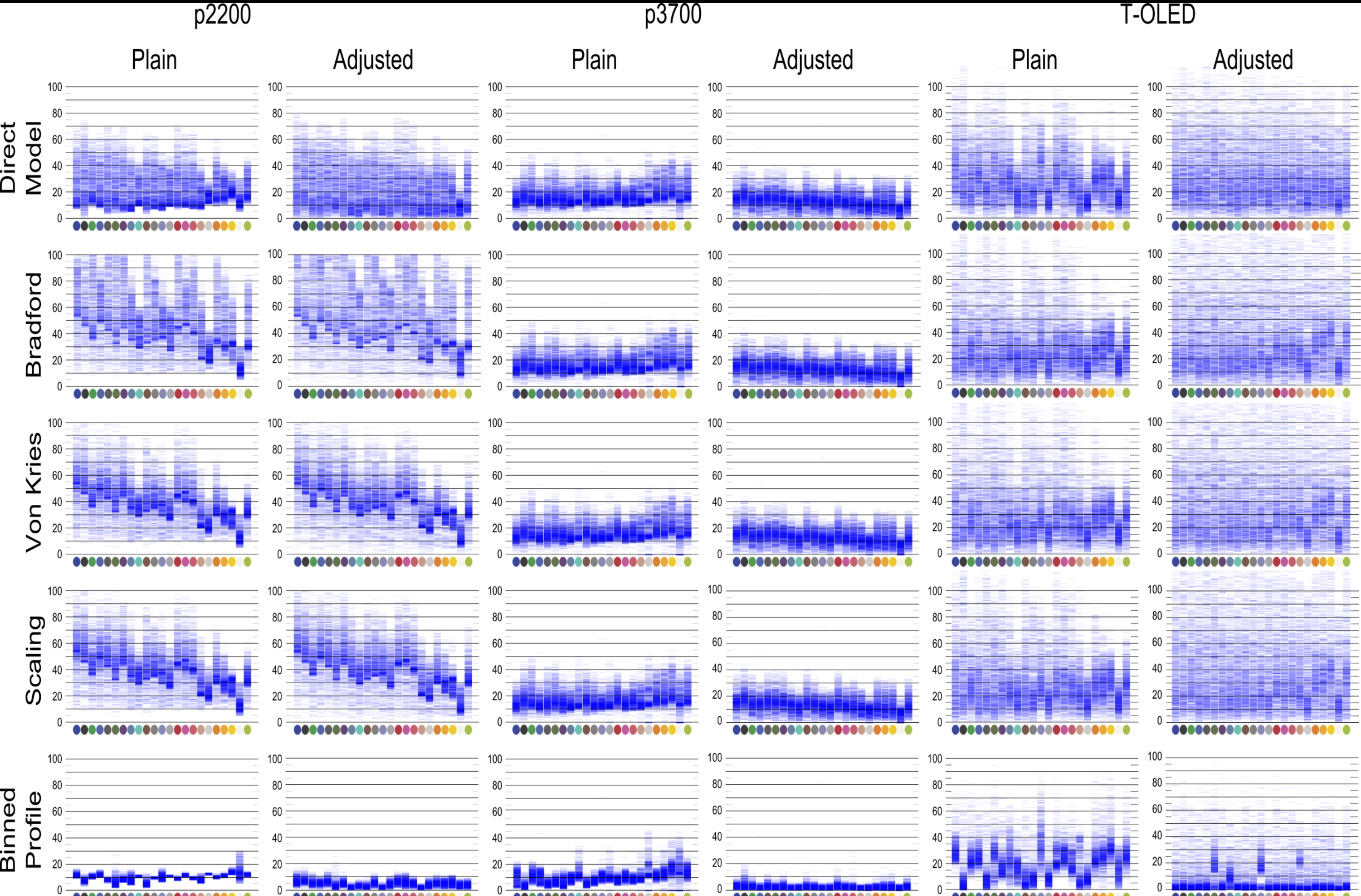
Color blends measured:

- 23 Bg color , 838 random digital colors
- 23 X 838 = 19, 274 blend measurements per display
- 19, 274 X 3 = 57, 822

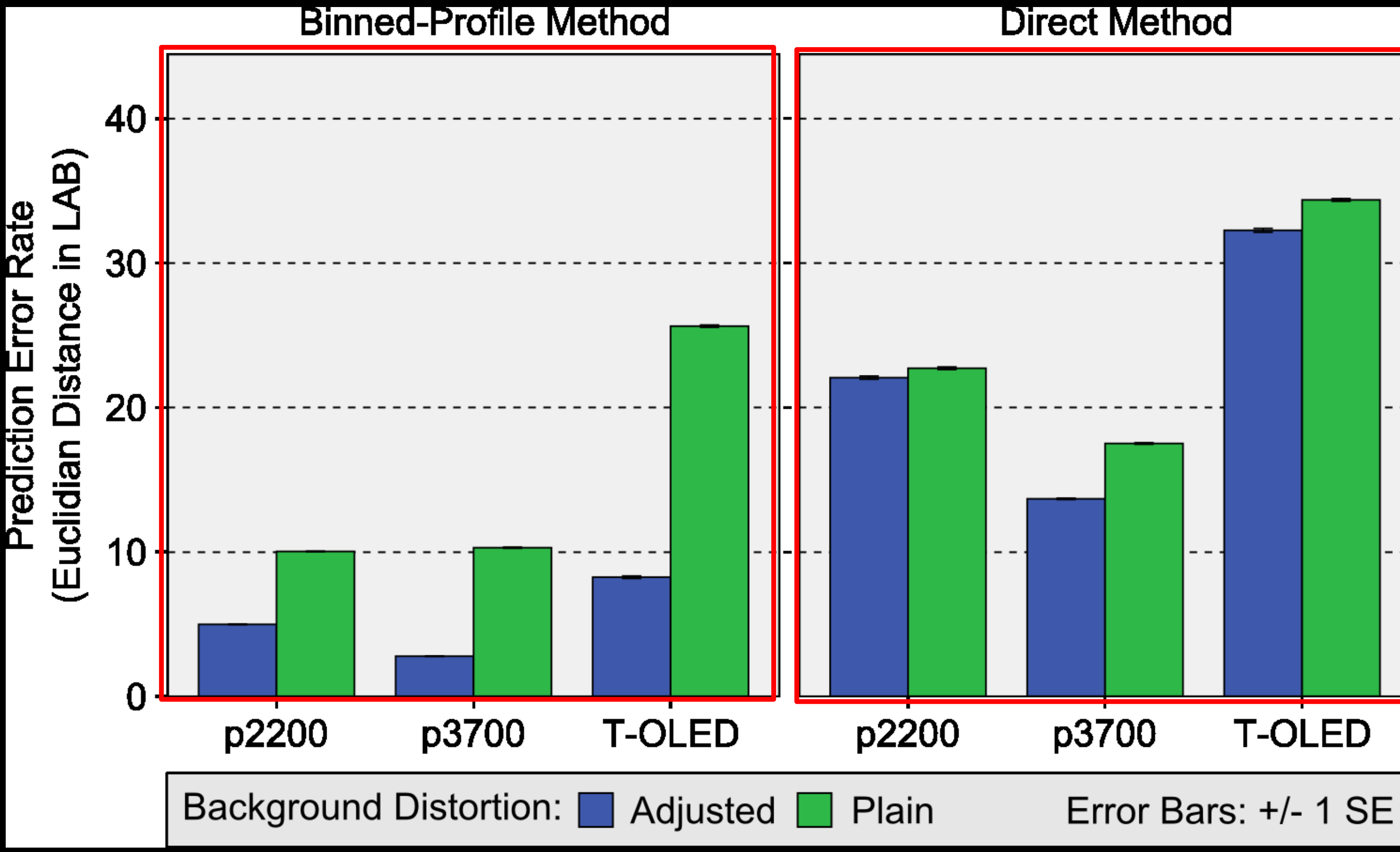
Color blend predictions :

- Display color method (5 methods), background configuration(2 configurations) and display (3 displays)
- 5 X 2 X 3 X 23X 838 = 578,220.

Euclidean distance in LAB color space between each prediction and the actual measurement gave the prediction error.


p2200
p3700
T-OLED
Plain
Adjusted
Plain
Adjusted
Plain
Adjusted
Direct Model
Bradford
Von Kries
Scaling
Binned Profile

Quantitative analysis



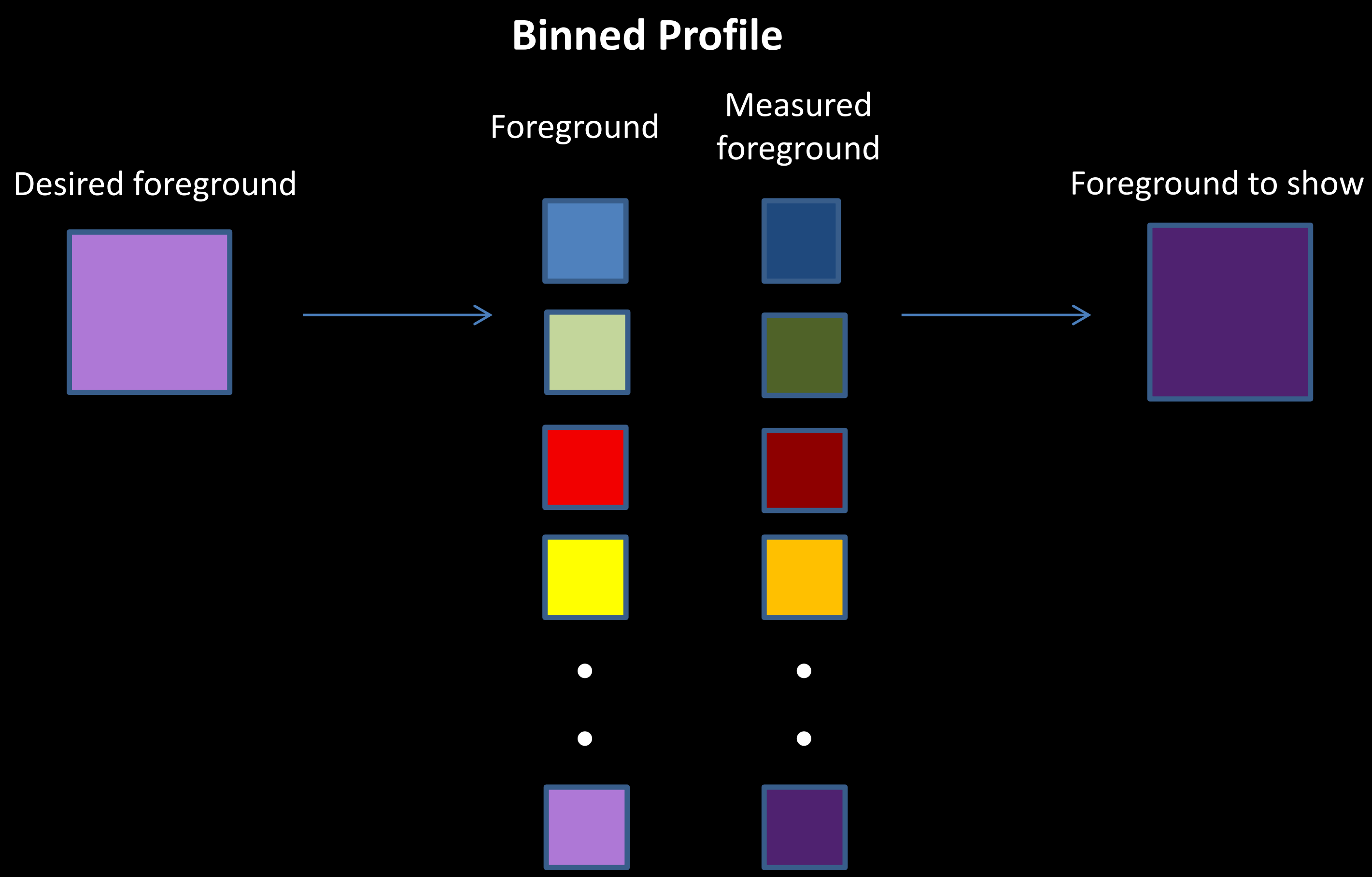
Kruskal-Wallis test was done, Sig <0.0001

Color Correction

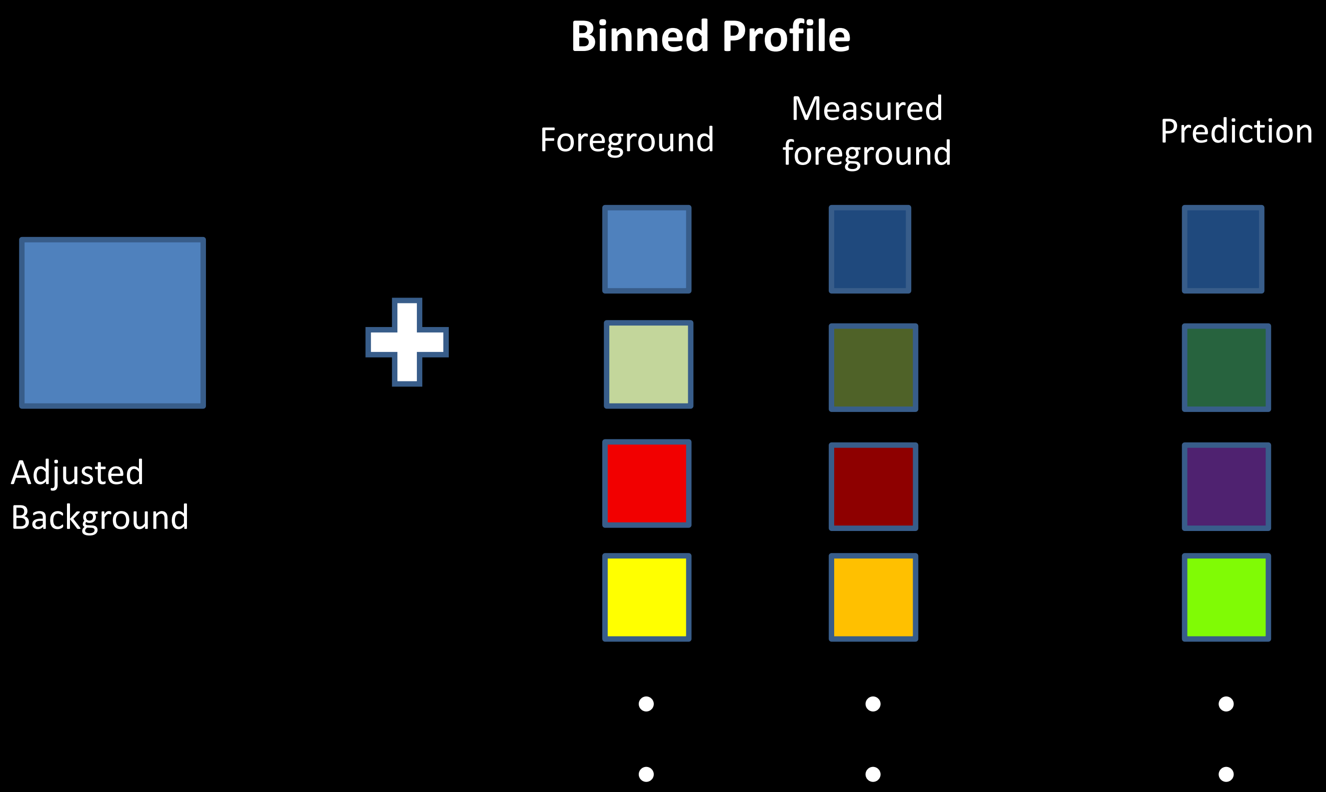
- We developed a color correction algorithm based on BP method

- Input to this algorithm is BP of that OSTD, Desired foreground color, Background Color

Step 1: Foreground Look up

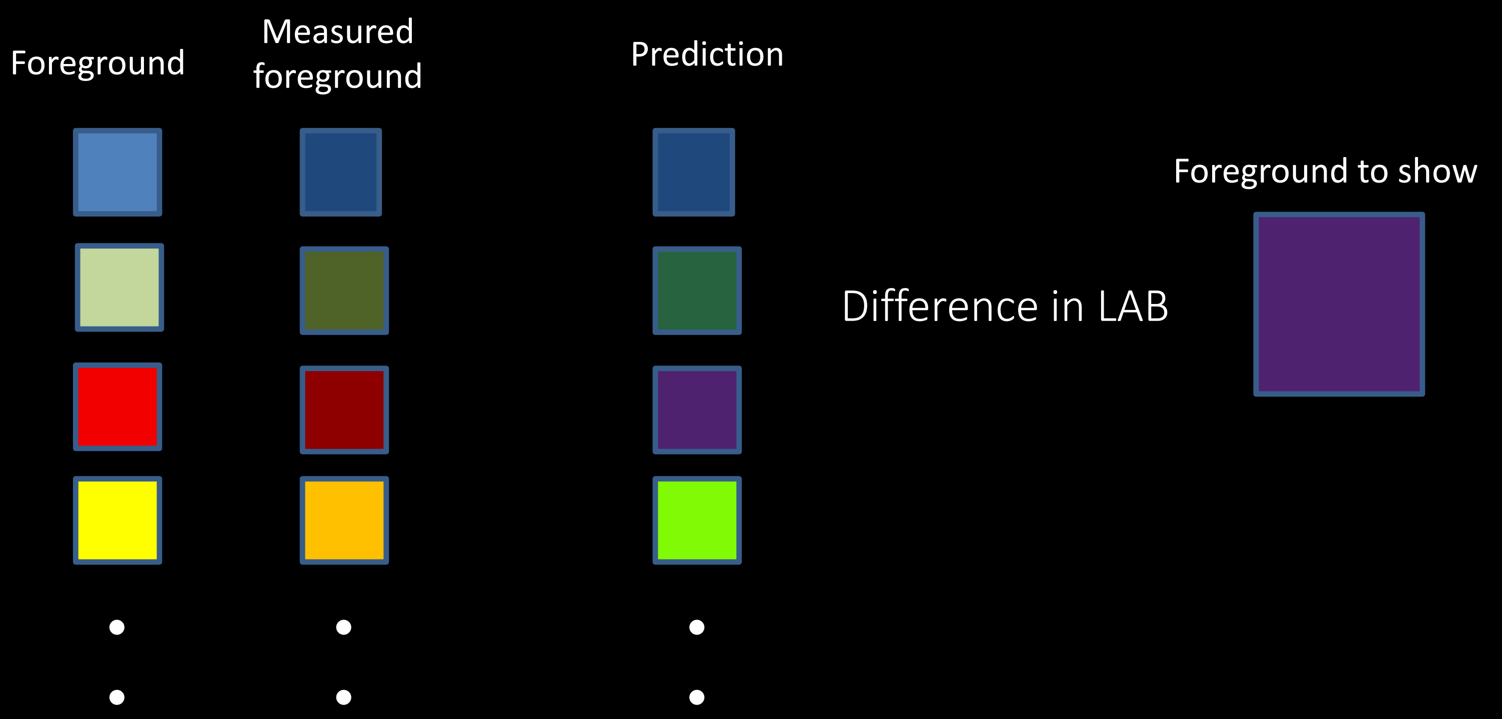


Step 2: Color Blend Prediction



Step 3:Prediction Comparison

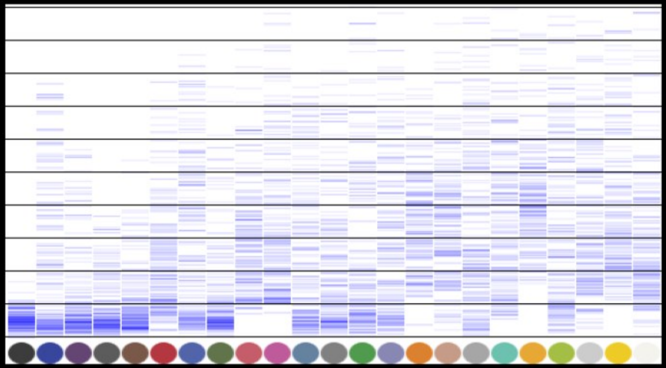
Binned Profile

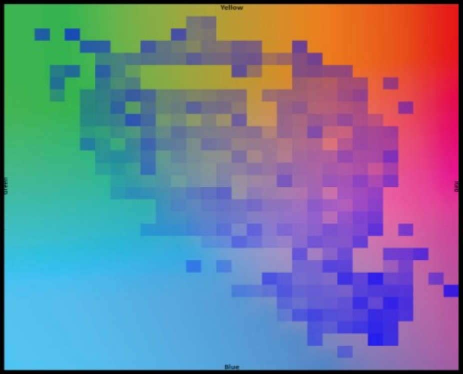


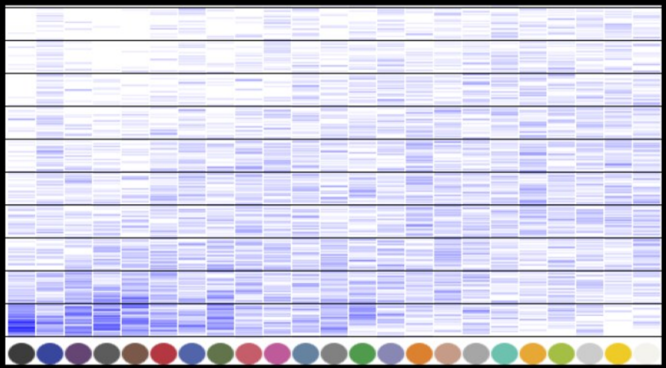
Data Collection

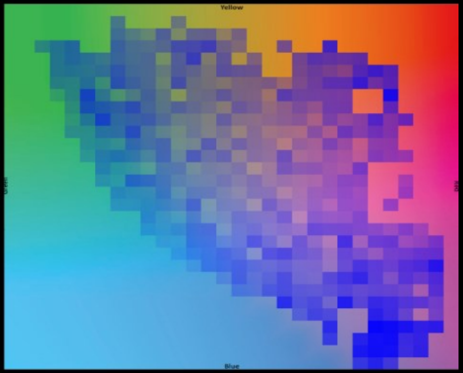
- 23 ColorCheck chart's adjusted backgrounds
- 200 random display colors for each background
- 23 X 200X 3 = 13, 800

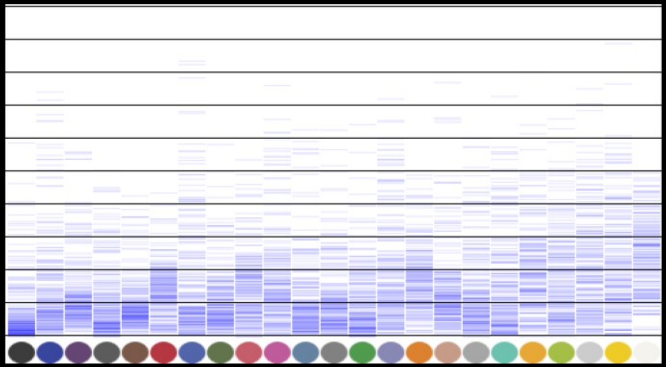
Euclidean distance in LAB color space between each desired foreground measured and the actual measurement gave the correction error.

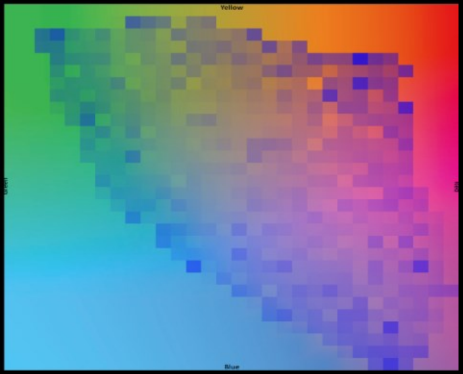



Yellow
Blue

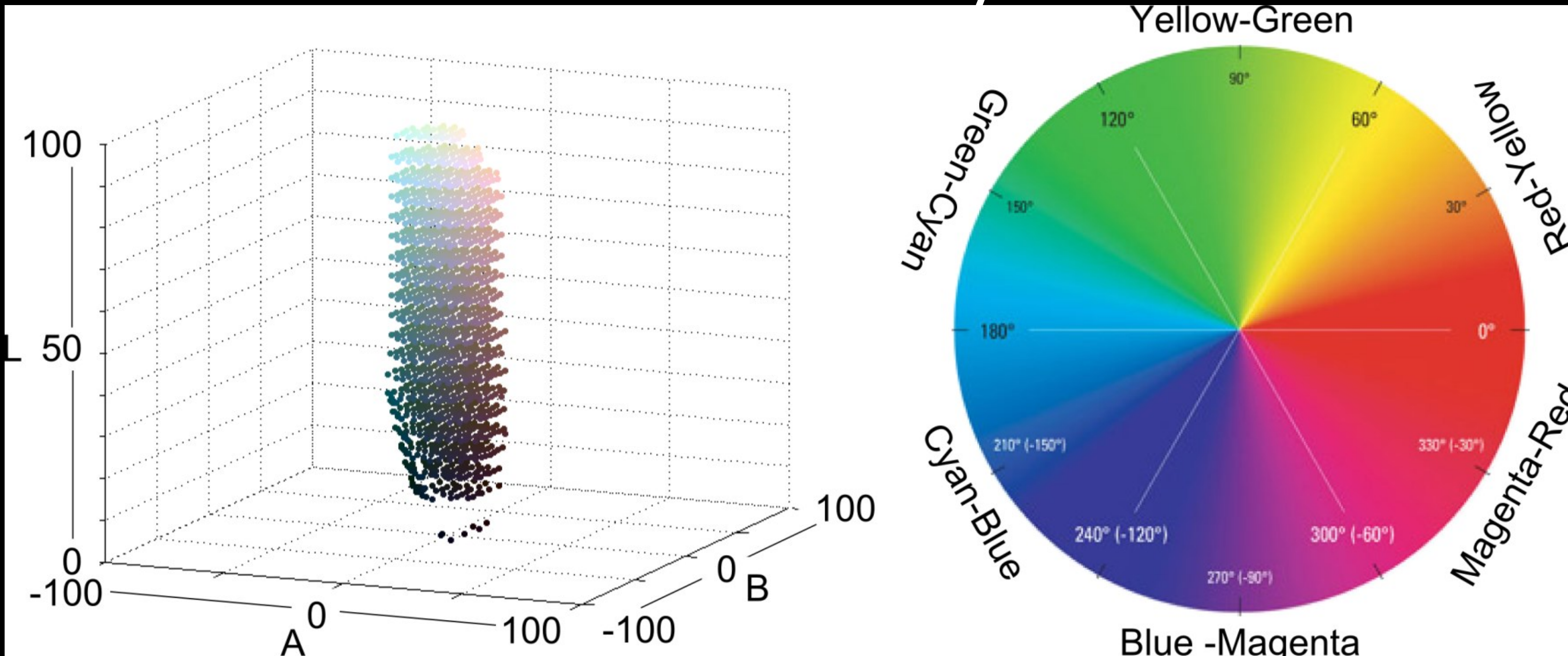



Yellow
Blue

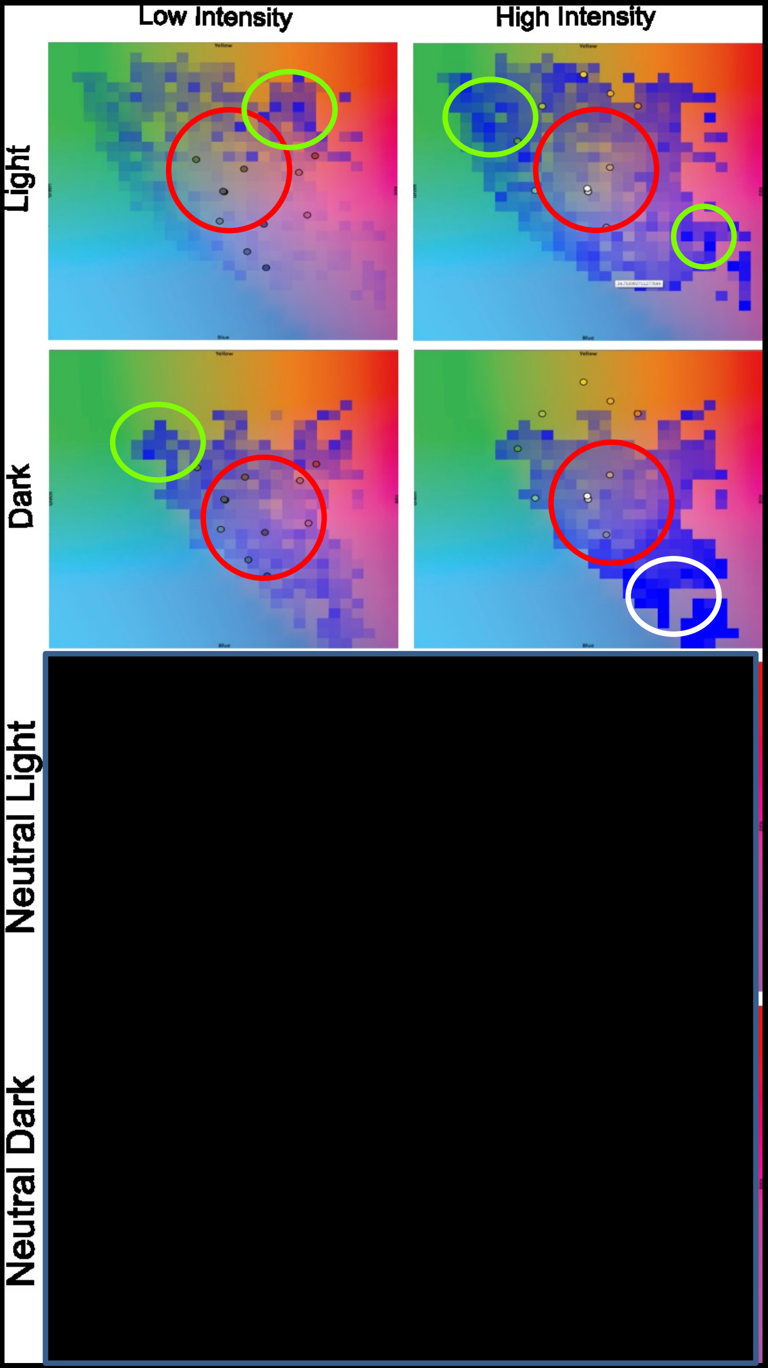



Yellow
Blue

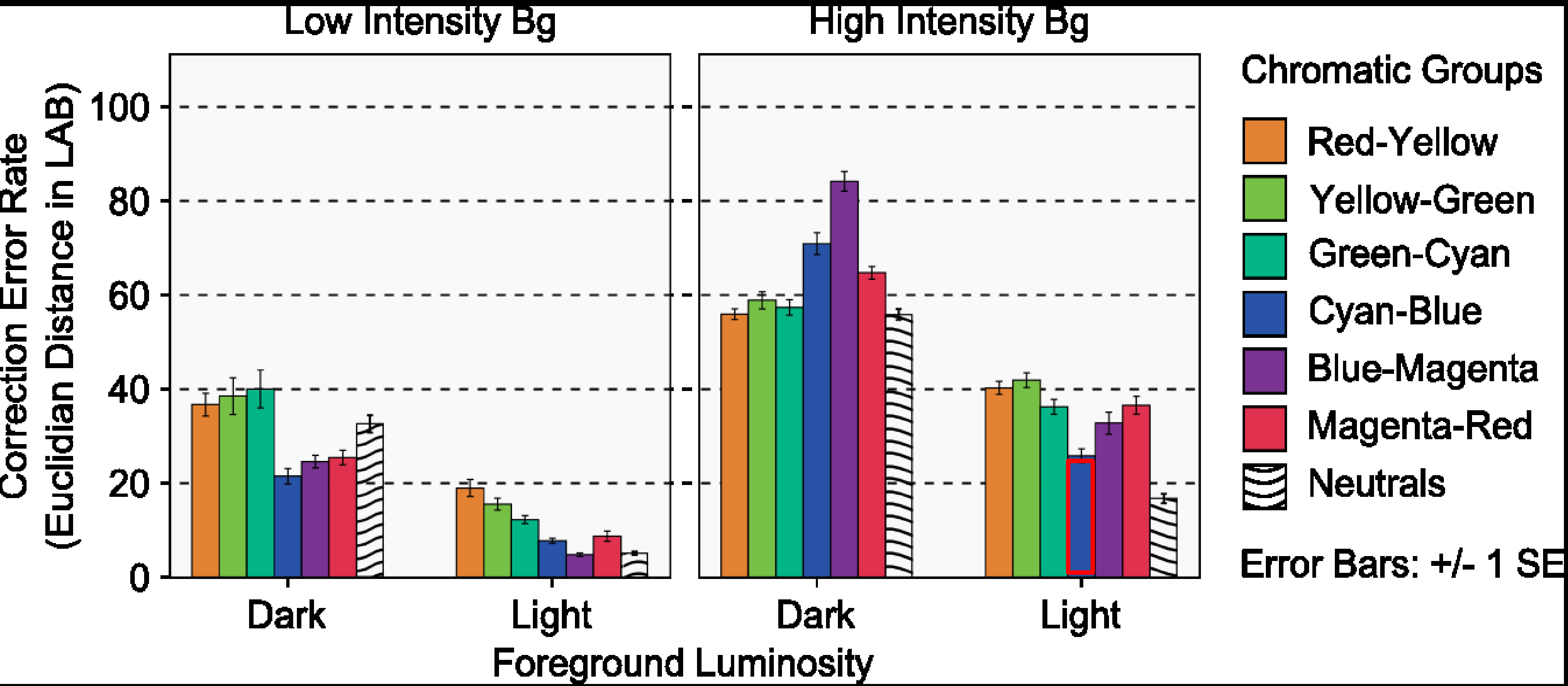
Color Analysis



Low Intensity


Low Intensity
High Intensity
Light
Dark
Neutral Light
Neutral Dark

Quantitative Analysis



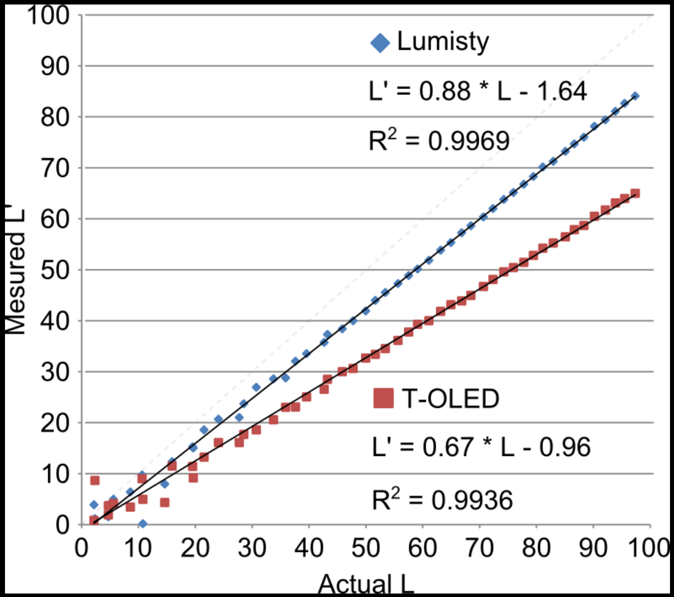
Kruskal-Wallis test was done, Sig <0.0001

Research Implication

Practical Applicability

- Usage of camera to capture the background?

- How to capture account for the Material Distortion?



Display Hardware

- Is smaller display profile better?

- Should the OSTD rescue the intensity of the BG?

Design Implications

- light neutral colors for information that needs to be preserved best
- If more hue is needed, designers can use light colors in the CyanBlue region
- Dark colors should be avoided for text and color-encoded information
- Use age of color themes based on the background will be wise

Future Work

Acknowledgements

- Dr. Juan David Hincapié-Ramos
- Dr. Pourang Irani
- Dr. David R. Flatla

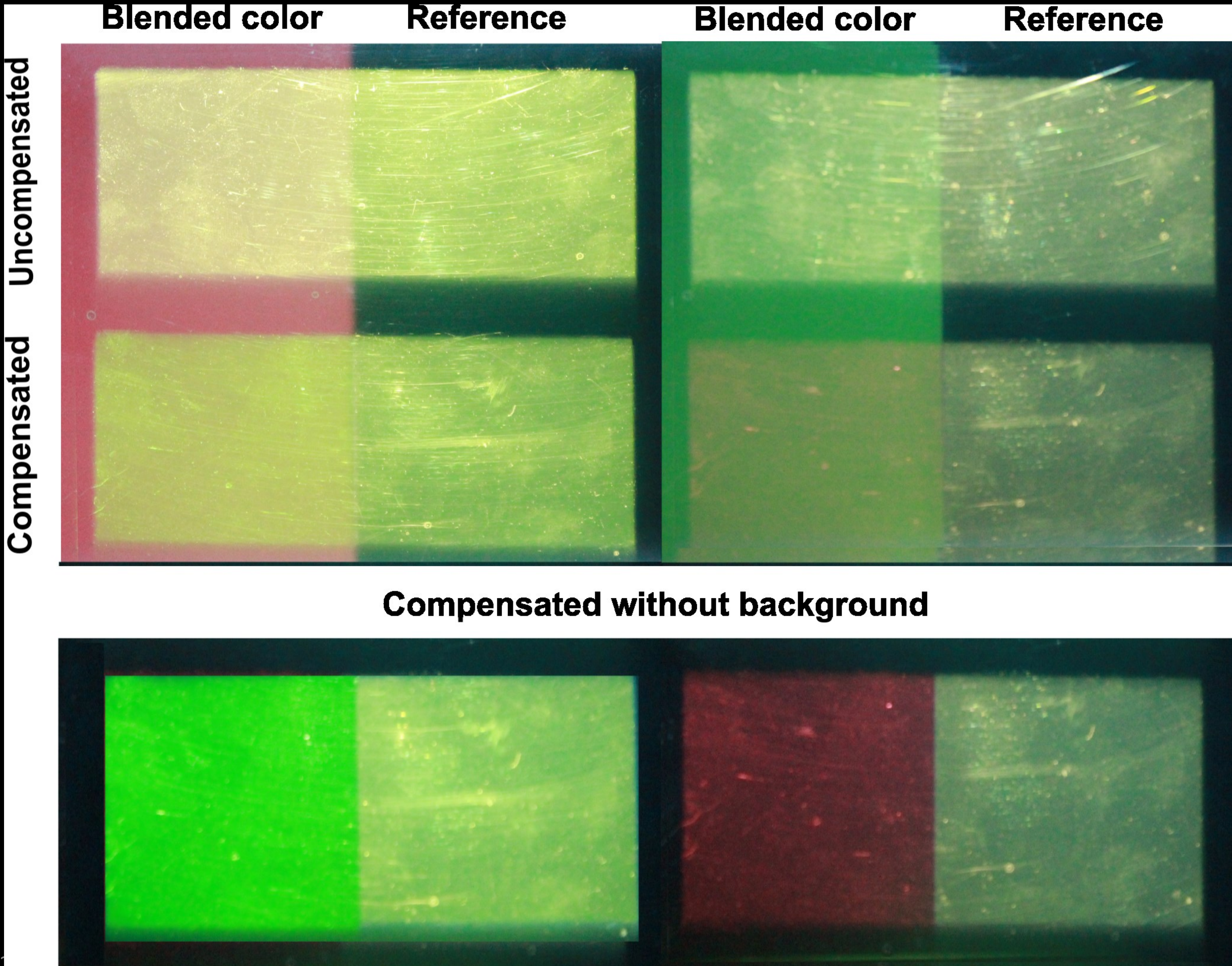
- Spl thanks to Jango Guo
- NSERC and peers at HCI lab In university of Manitoba

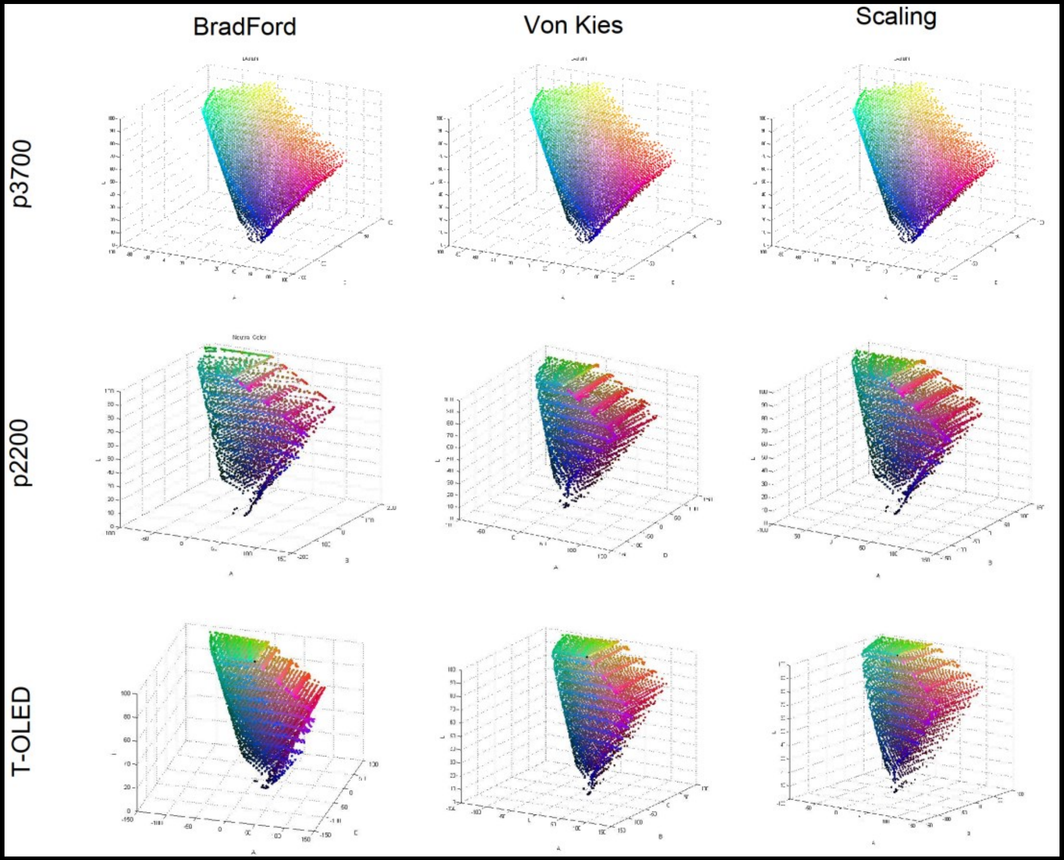
Presented by,

Srikanth Kirshnamachari Sridharan

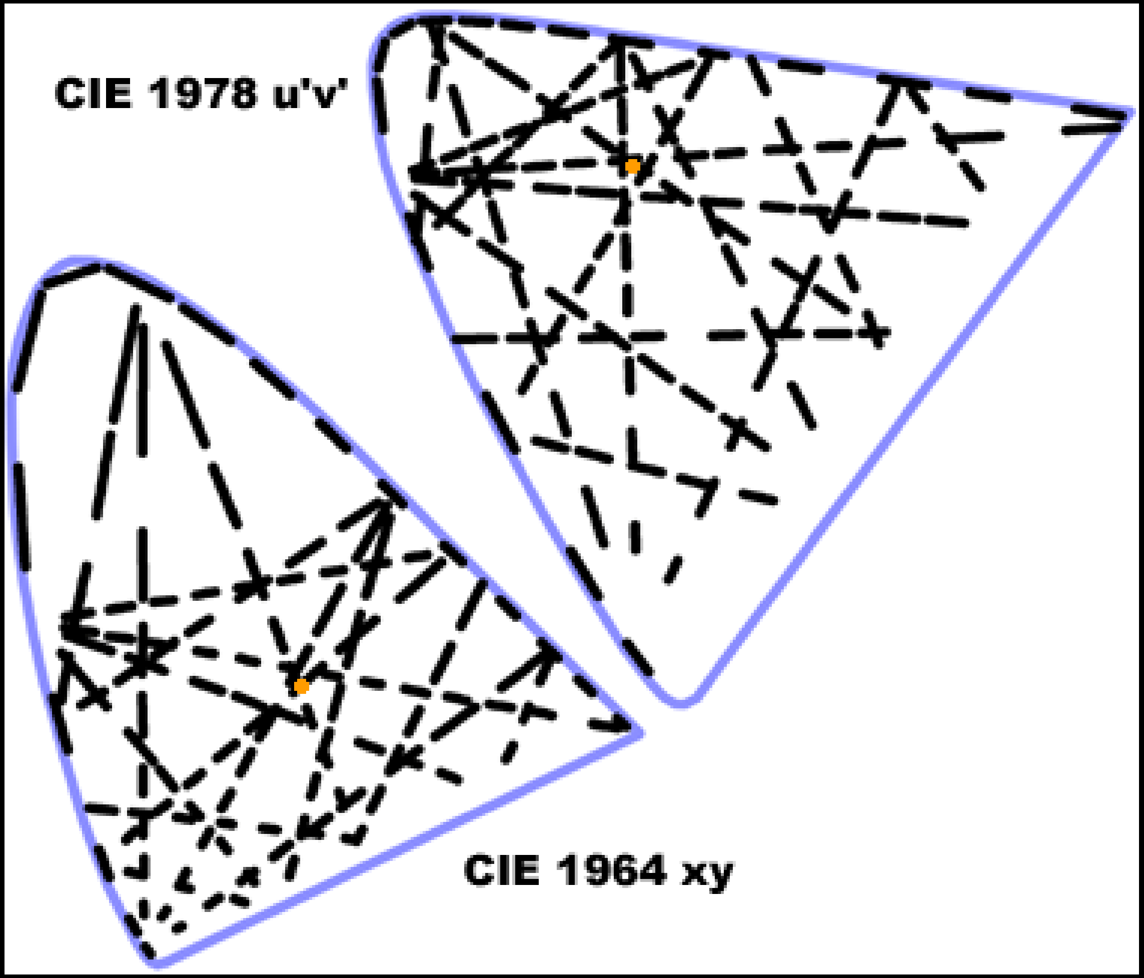
THANK YOU, QUESTIONS

Annexure

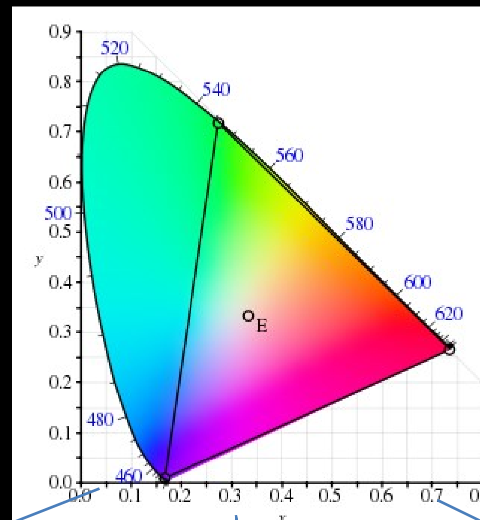

Blended color
Reference
Blended color
Reference
Uncompensated
Compensated
Compensated without background


BradFord
Von Kies
Scaling
p3700
p2200
T-OLED

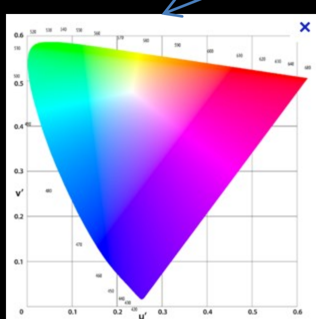
Just Noticeable Difference

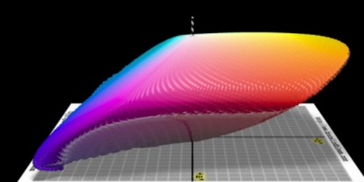


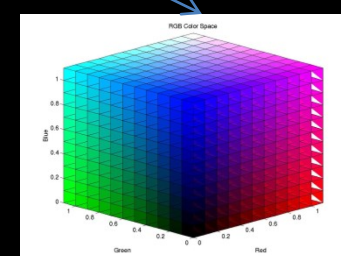
Spaces Derivation



XYZ







LUV

LAB

sRGB

Pictures from Lindbloom’s website and wikipedia