Taking CIE Out of the Lab

An Adaptive Color Difference Model

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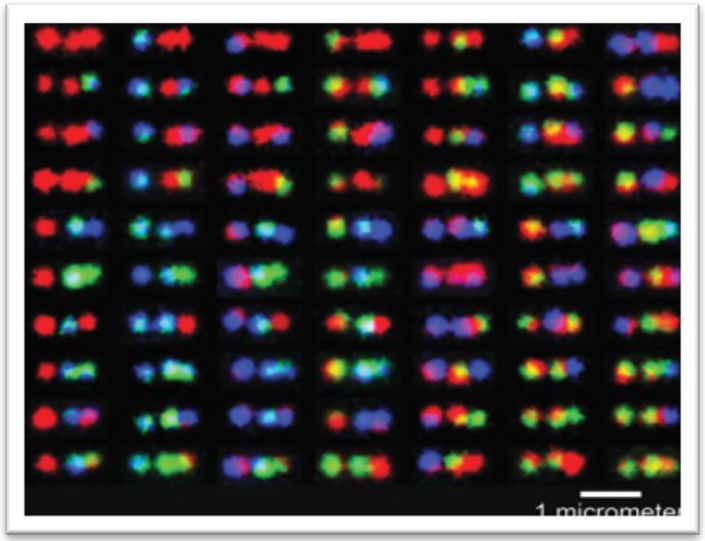
SIGGRAPH Submission 2013

University of Wisconsin, Madison
Computer Graphics

Motivation


1955
1963
1966
1970
1971
1976
1985
1989
1993
1994
1996
1997
1997
2000
2002
current
summer '09 &'10

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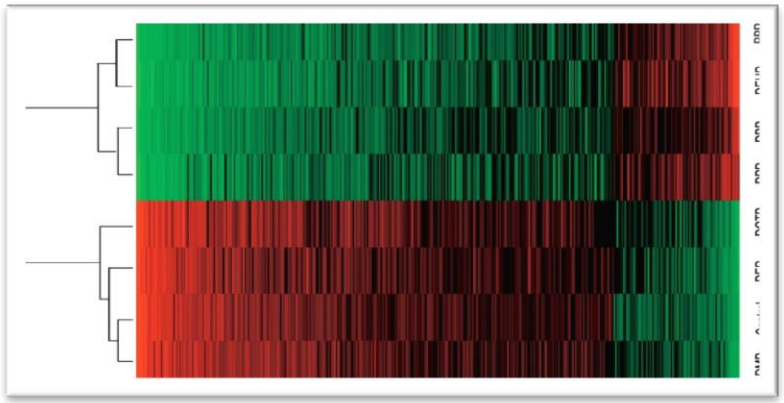
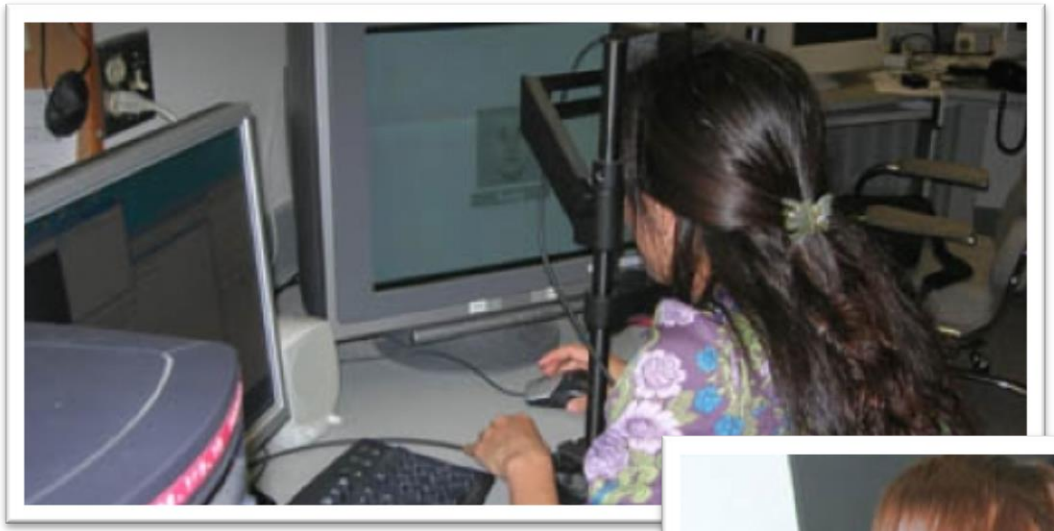


Motivation



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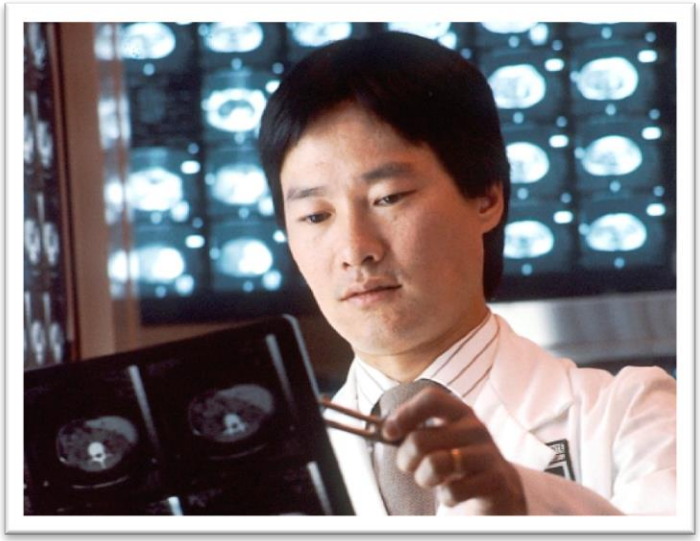
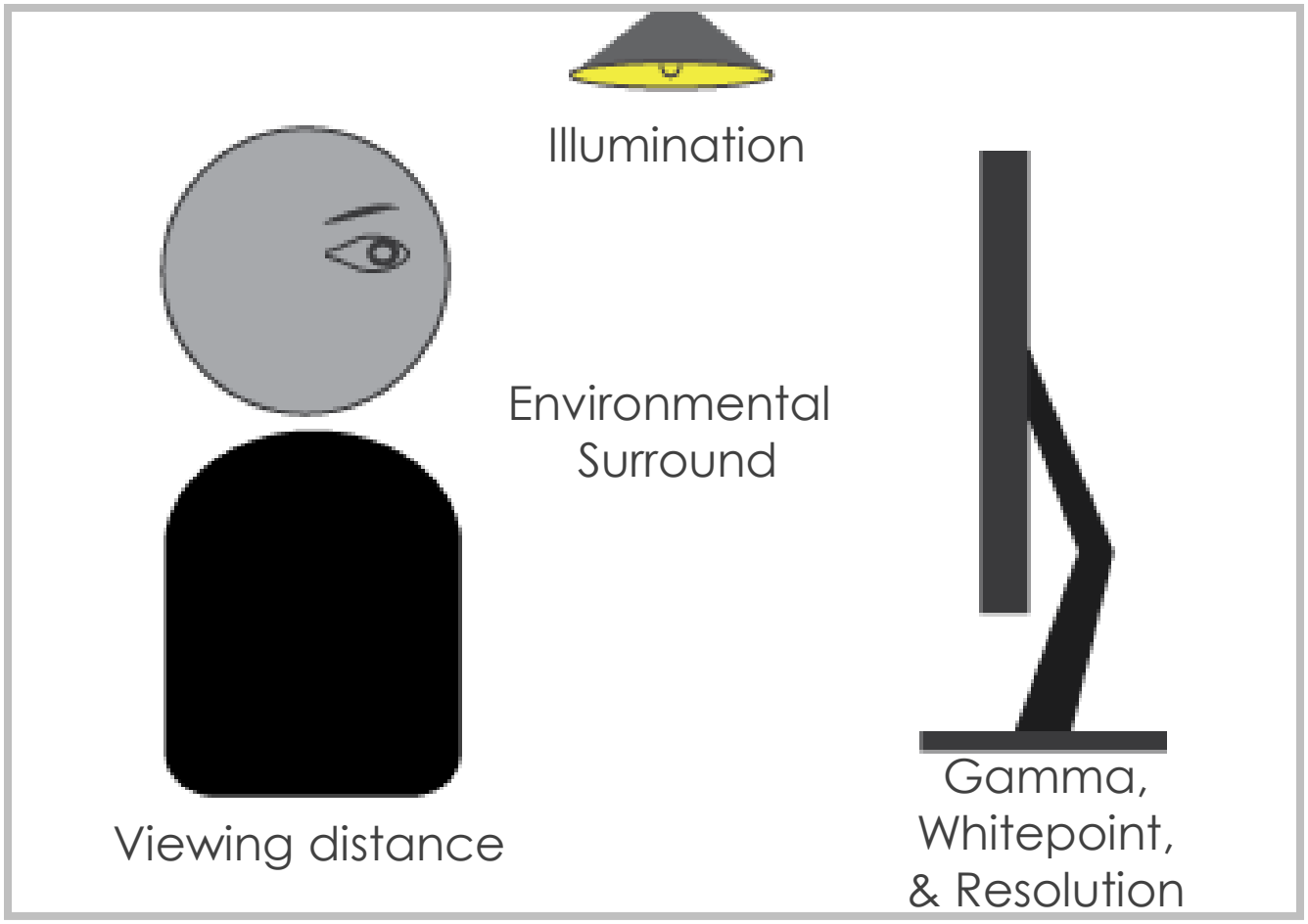


Motivation

Apparent color depends on viewing conditions.



Make informed decisions about color that hold across a variety of viewing conditions.

Our Target Model Is:

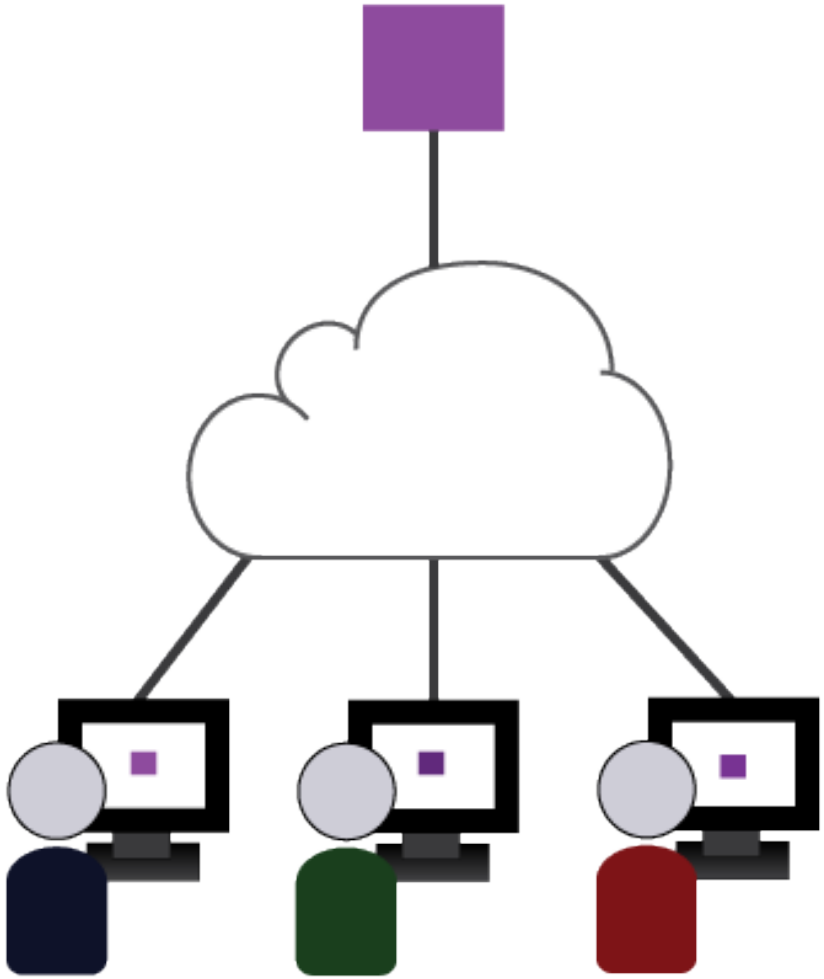
Parametric – Tuned to a range of viewers

Data-Driven – Adaptable to specific conditions

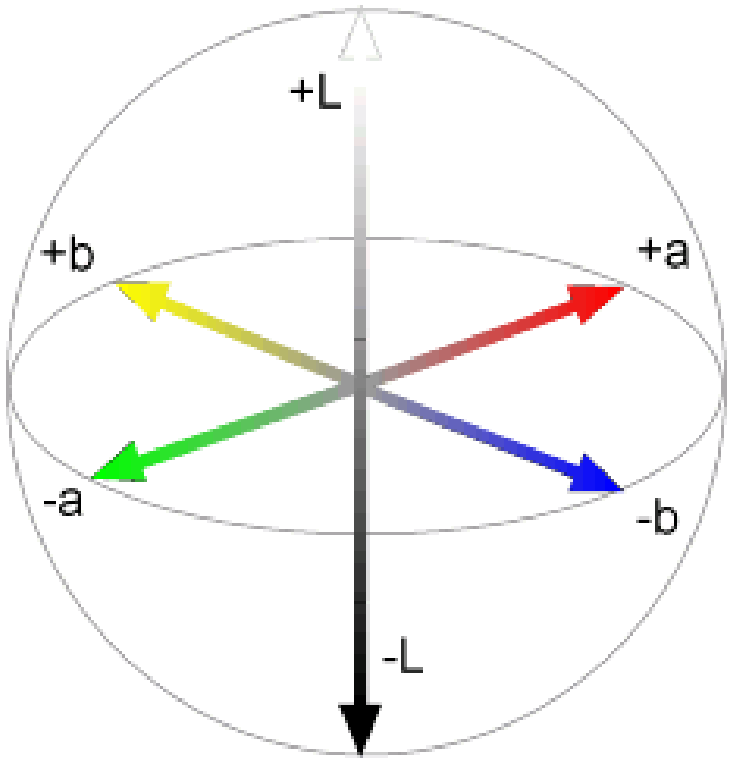
Practical – Straight-forward to use and generate

Probabilistic – Accounts for uncertainty in the data

Model Problem – Web Viewing



Theoretical CIELab Color Space

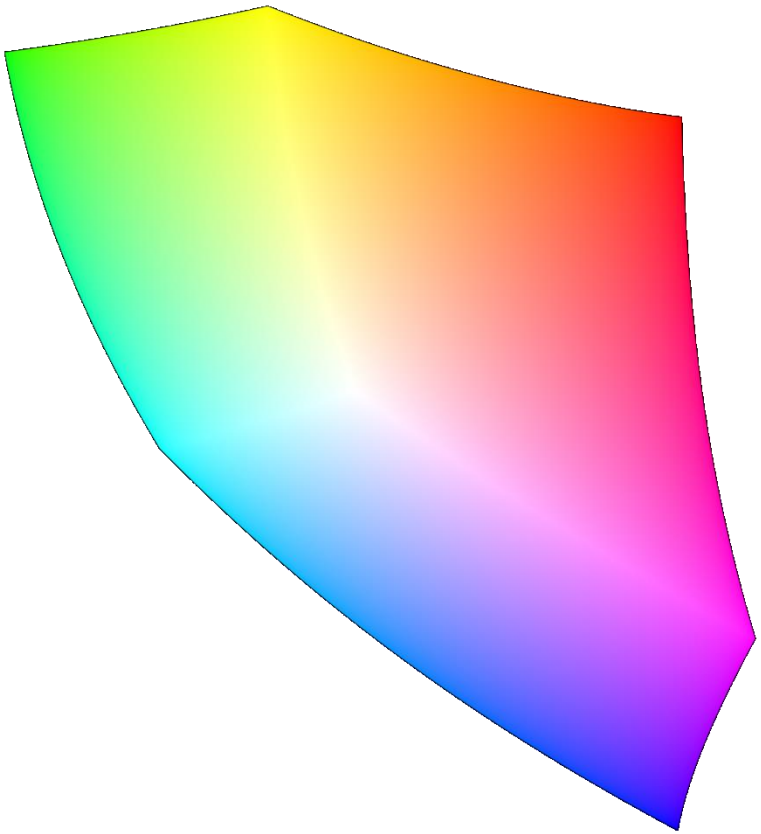


Perceptually-based color difference space

Approximately perceptual uniform

1 JND = 1 unit Euclidean distance

Practical CIELab Color Space



Bound by monitor gamut and whitepoint

Over-extended along yellow-blue

1 JND = ~2.3 units Euclidean distance

CIELab Difference Model

$$\Delta C = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

$$C_1 = (L_1, a_1, b_1)$$

$$C_2 = (L_2, a_2, b_2)$$

Adapted CIELab Difference Model

$$\Delta C = \sqrt{\left(\frac{L_1 - L_2}{s_L}\right)^2 + \left(\frac{a_1 - a_2}{s_a}\right)^2 + \left(\frac{b_1 - b_2}{s_b}\right)^2}$$

$$C_1 = (L_1, a_1, b_1)$$

$$C_2 = (L_2, a_2, b_2)$$

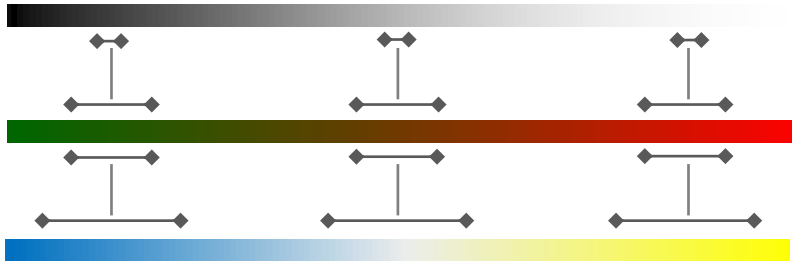
$\Delta C = 1$ is detectable for p% of viewers

$$s_x \in \boldsymbol{R}^1$$

Do CIELab's theorhetical assertions about color hold across the target viewing conditions?

Color Space Assumptions

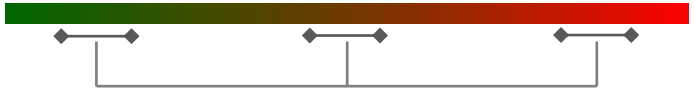
A1: Axes are perceptually orthogonal.



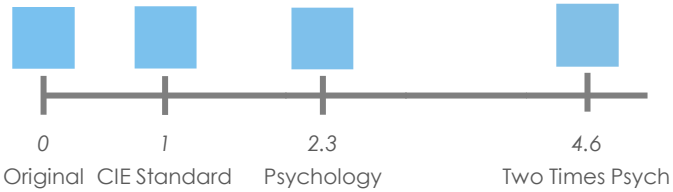
A2: Euclidean distance is an effective metric for perceptual distance.

$$\Delta C = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

A3: Axes are perceptually uniform.



A4: Axes are scaled such that one unit corresponds to one JND.



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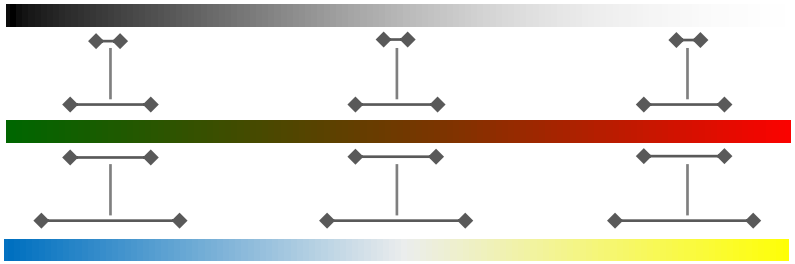

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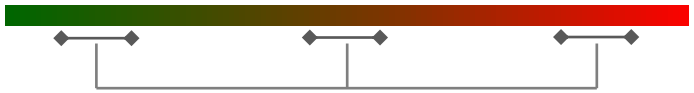

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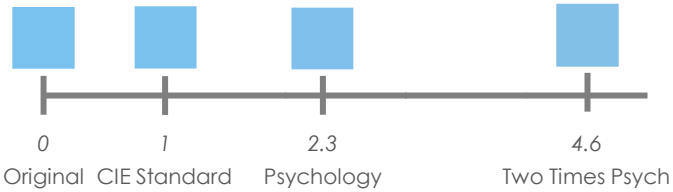

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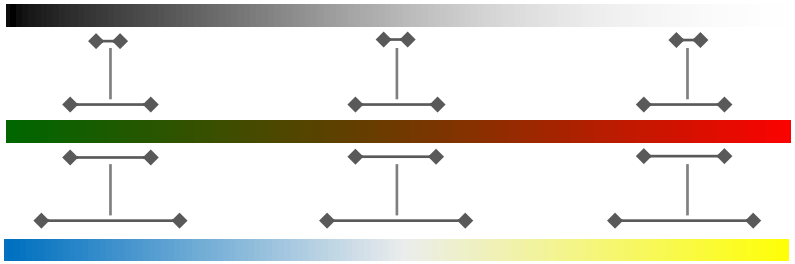

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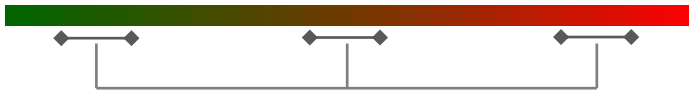

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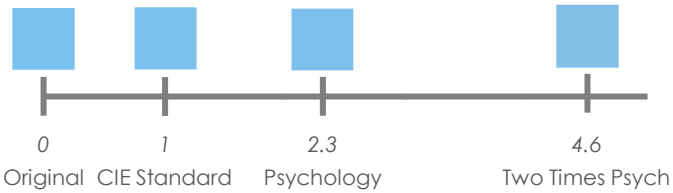

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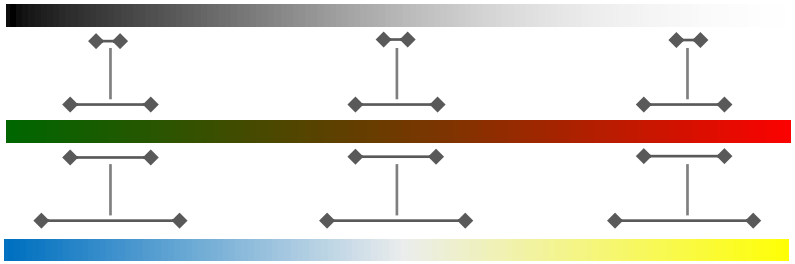

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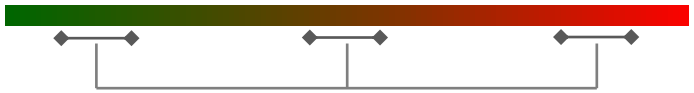

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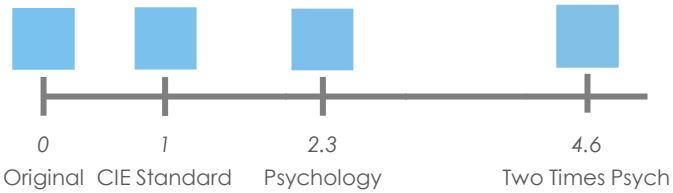
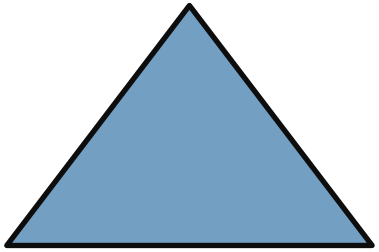
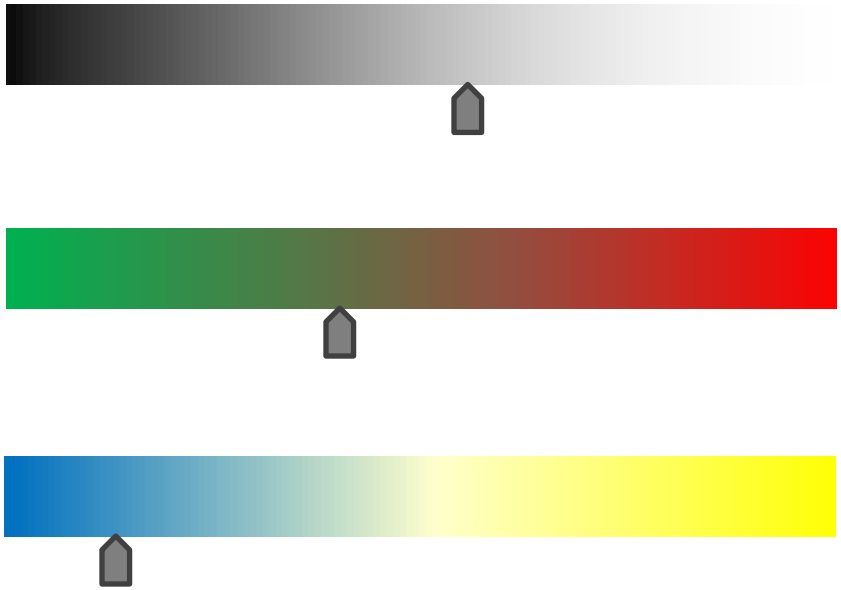


Validating Color Space

Given:

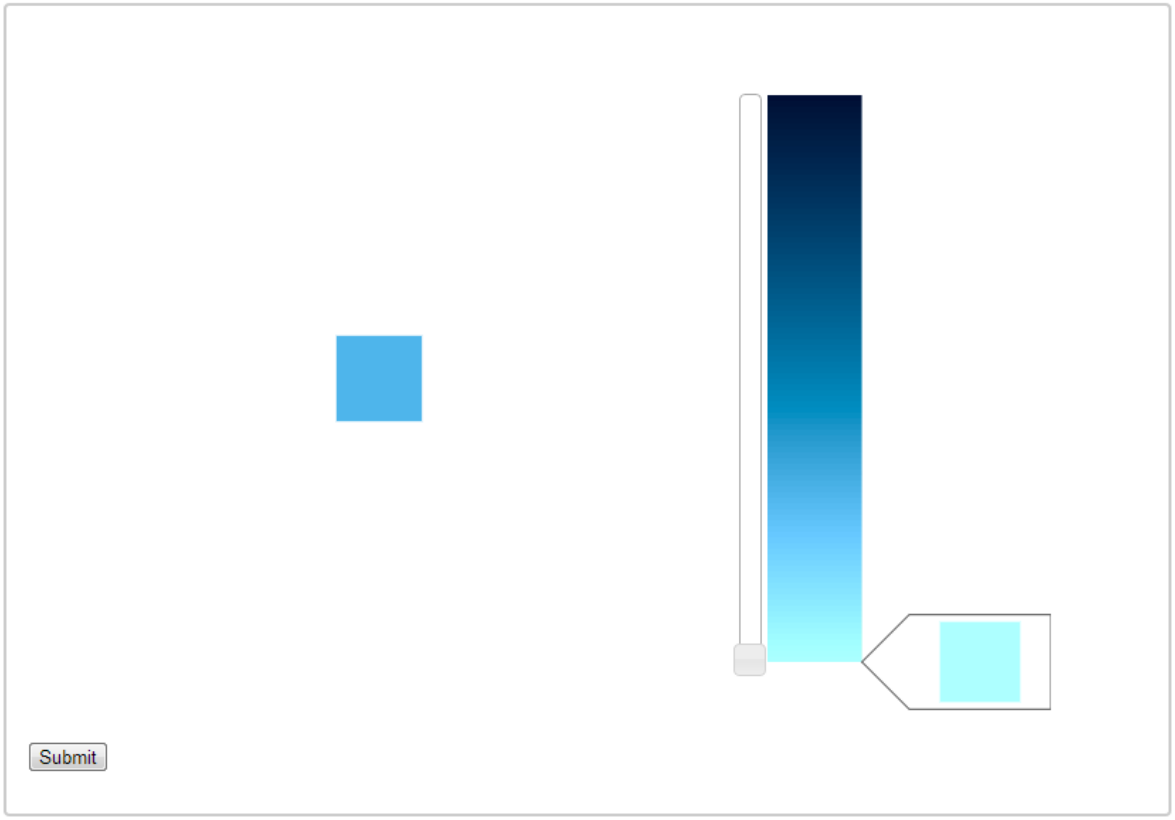




Modern Maxwell Color Matching Experiment

Validating Color Space

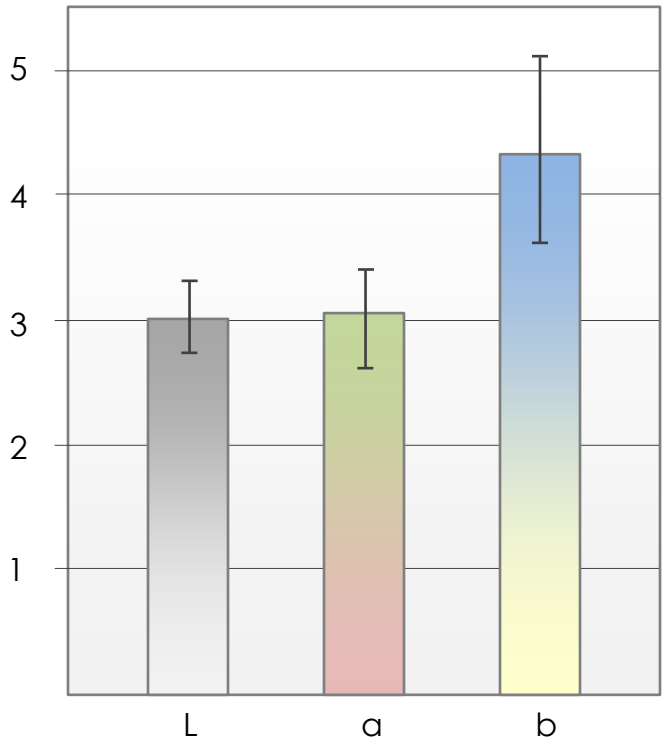
Determine color error using a single-axis Maxwell task on Mechanical Turk.



Validating Color Space – Web Viewing

A4:

Per-Axis Color Matching Error



A3:

Within Axis Color Matching Error

***L* Axis:**

$\mu = 3.025$

within: $p = 0.2008, F = 1.6437$

insert gradient from both ends of the axis

***a* Axis:**

$\mu = 3.44$

within: $p = 0.5711, F = 0.3215$

***b* Axis:**

$\mu = 4.327$

within: $p = 0.5154, F = 0.4240$

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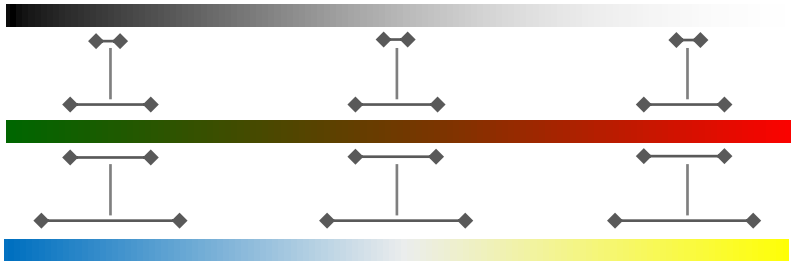

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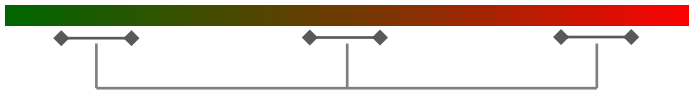

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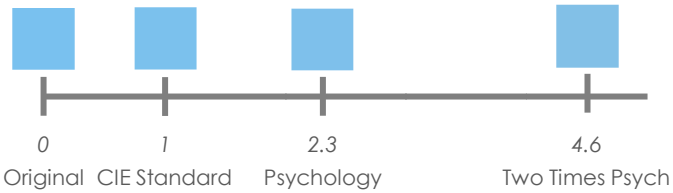
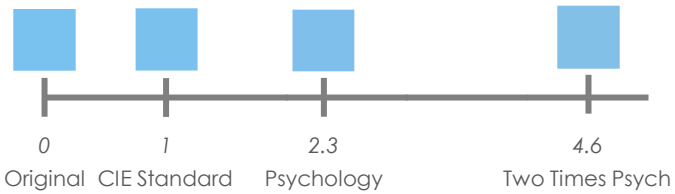


Parameters account for how different must two colors be to appear different across a variety of viewing conditions.

Adapted CIELab Difference Model

A4: Axes are scaled such that one unit corresponds to one JND.



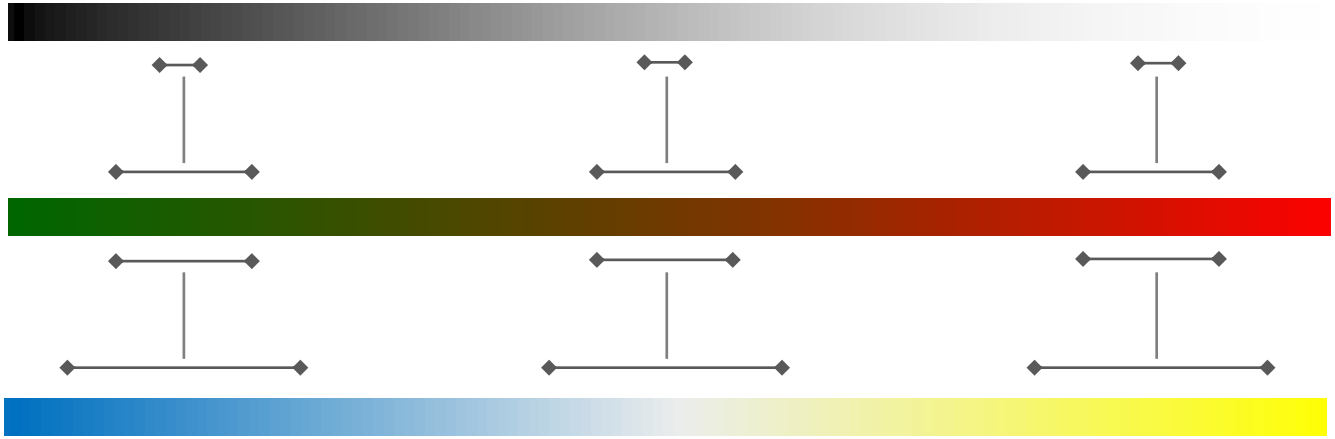
$$\Delta C = \sqrt{\left(\frac{L_1 - L_2}{s_L}\right)^2 + \left(\frac{a_1 - a_2}{s_a}\right)^2 + \left(\frac{b_1 - b_2}{s_b}\right)^2}$$

$\Delta C = 1$ is detectable for p% of viewers

$$s_x \in \boldsymbol{R}^1$$

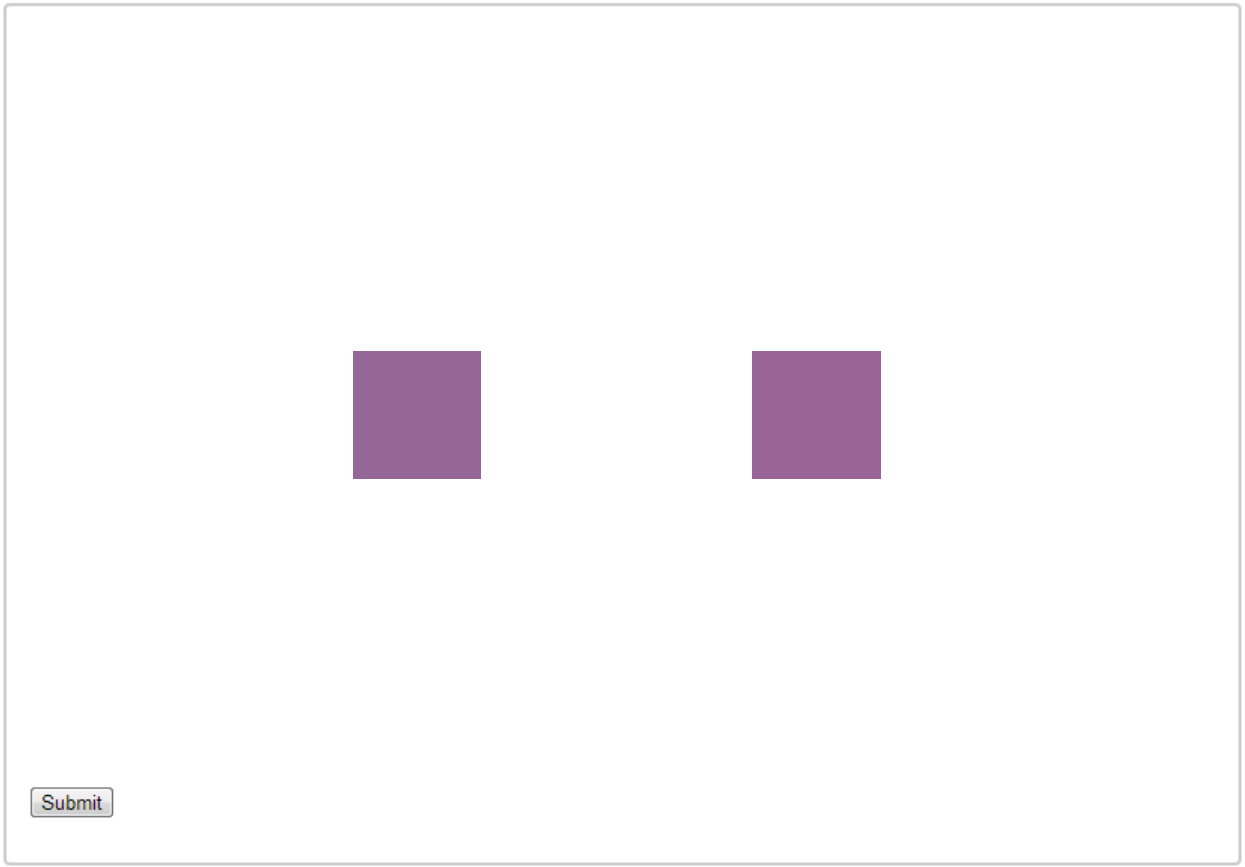
Adapting the Model

How do we scale each axis?



Adapting the Model

Do these two colors match?



Adapting the Model

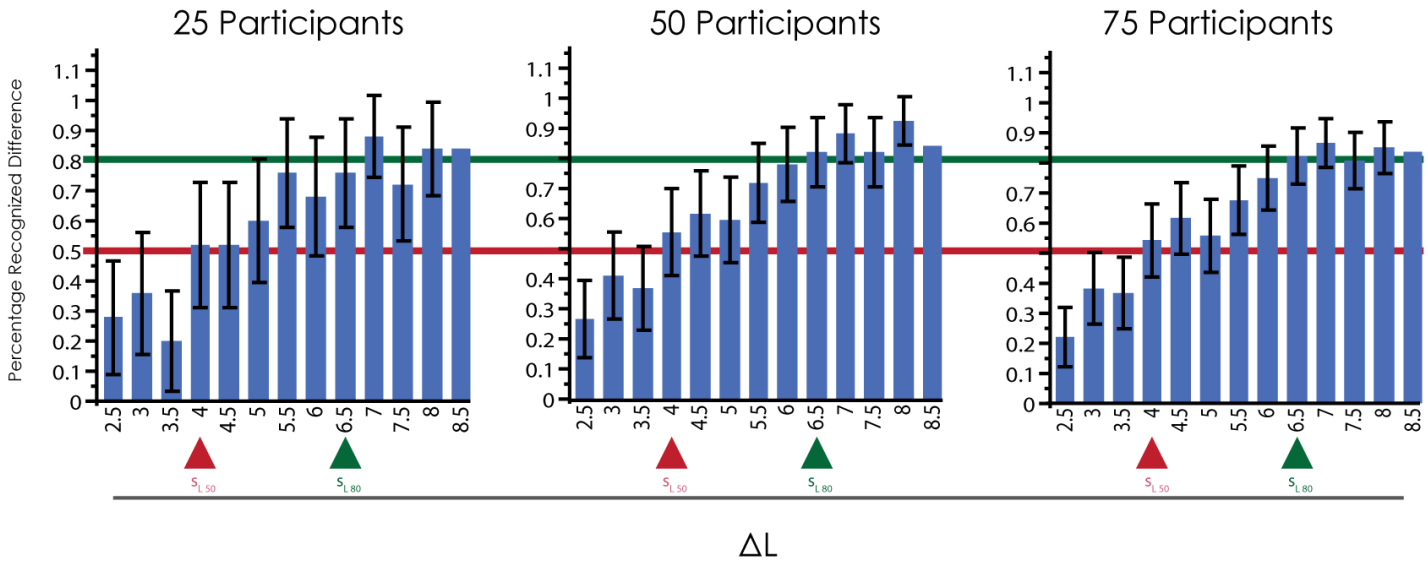
D =  -

1) Determine the **proportion of samples** where colors were accurately identified as different.

2) Fit a function to these proportions to identify the **discriminability distribution**.*

3) Identify the point at which this function equals some **threshold *p***.

Adapting the Model – Web Viewing



50% of samples are discriminable:

$s_L = 4.0$

$s_a = 5.5$

$s_b = 6.0$

80% of samples are discriminable:

$s_L = 6.5$

$s_a = 8.5$

$s_b = 9.0$

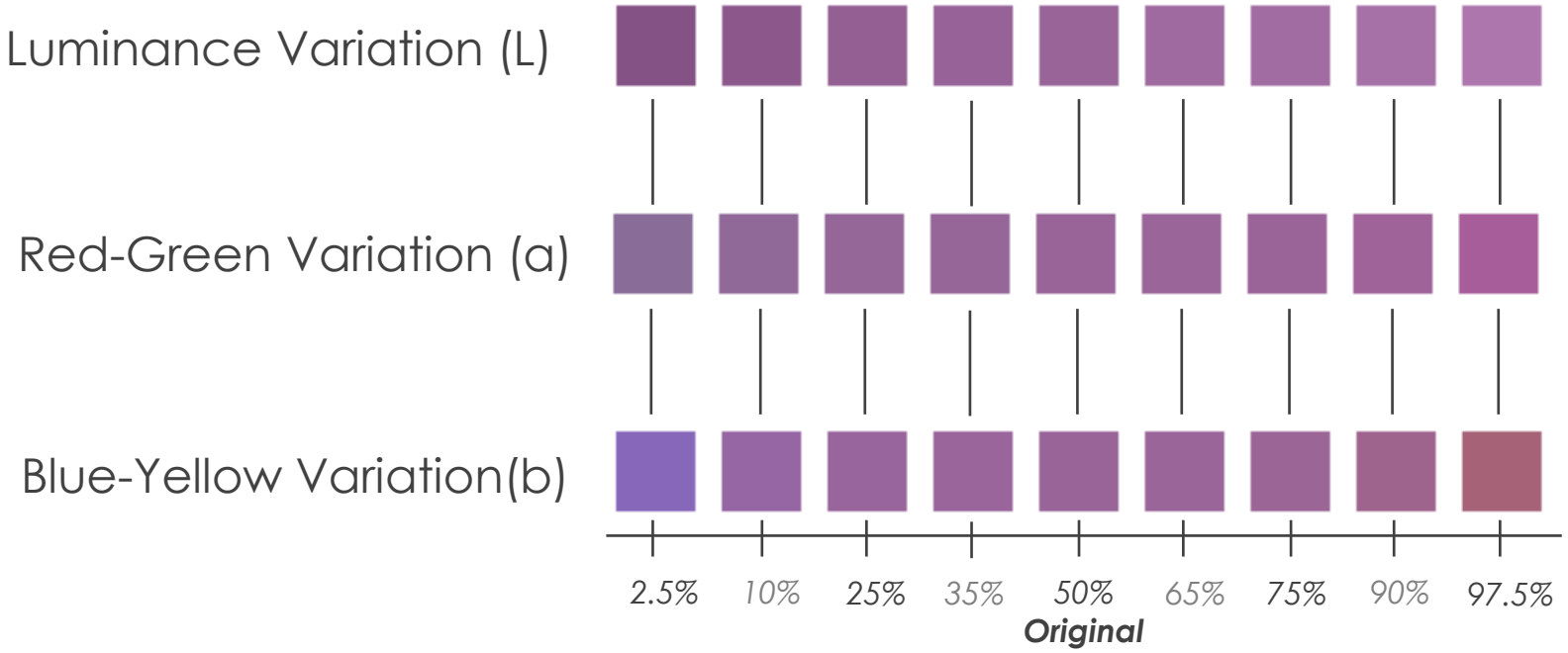
Does our adapted color difference model work for web viewing conditions?

Validating the Model – Web Viewing

$$\Delta C = \sqrt{\left(\frac{L_1 - L_2}{4.0}\right)^2 + \left(\frac{a_1 - a_2}{5.5}\right)^2 + \left(\frac{b_1 - b_2}{6.0}\right)^2}$$

$$\Delta C = \sqrt{\left(\frac{L_1 - L_2}{6.5}\right)^2 + \left(\frac{a_1 - a_2}{8.5}\right)^2 + \left(\frac{b_1 - b_2}{9.0}\right)^2}$$

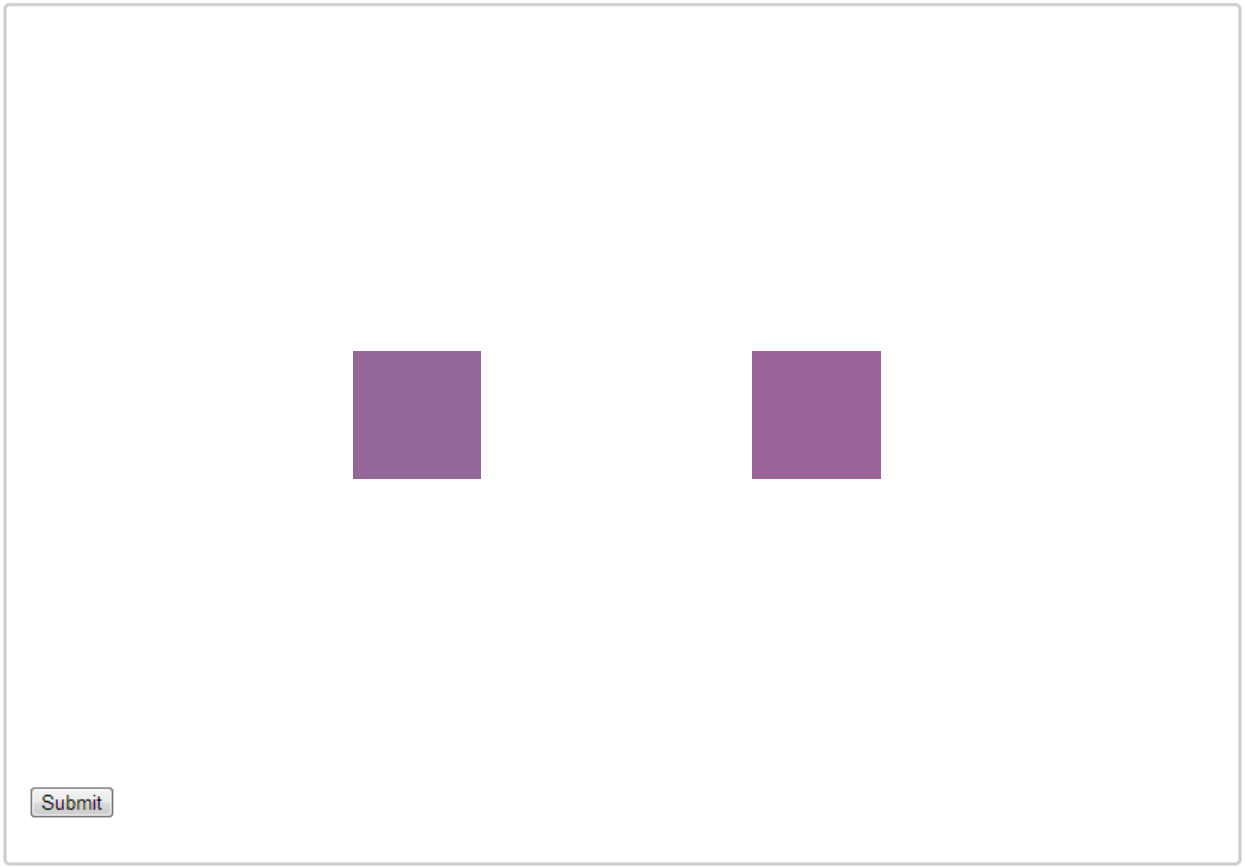
Validating the Model – Web Viewing



Unsigned Error Quantiles

Validating the Model – Web Viewing

Do these two colors match?



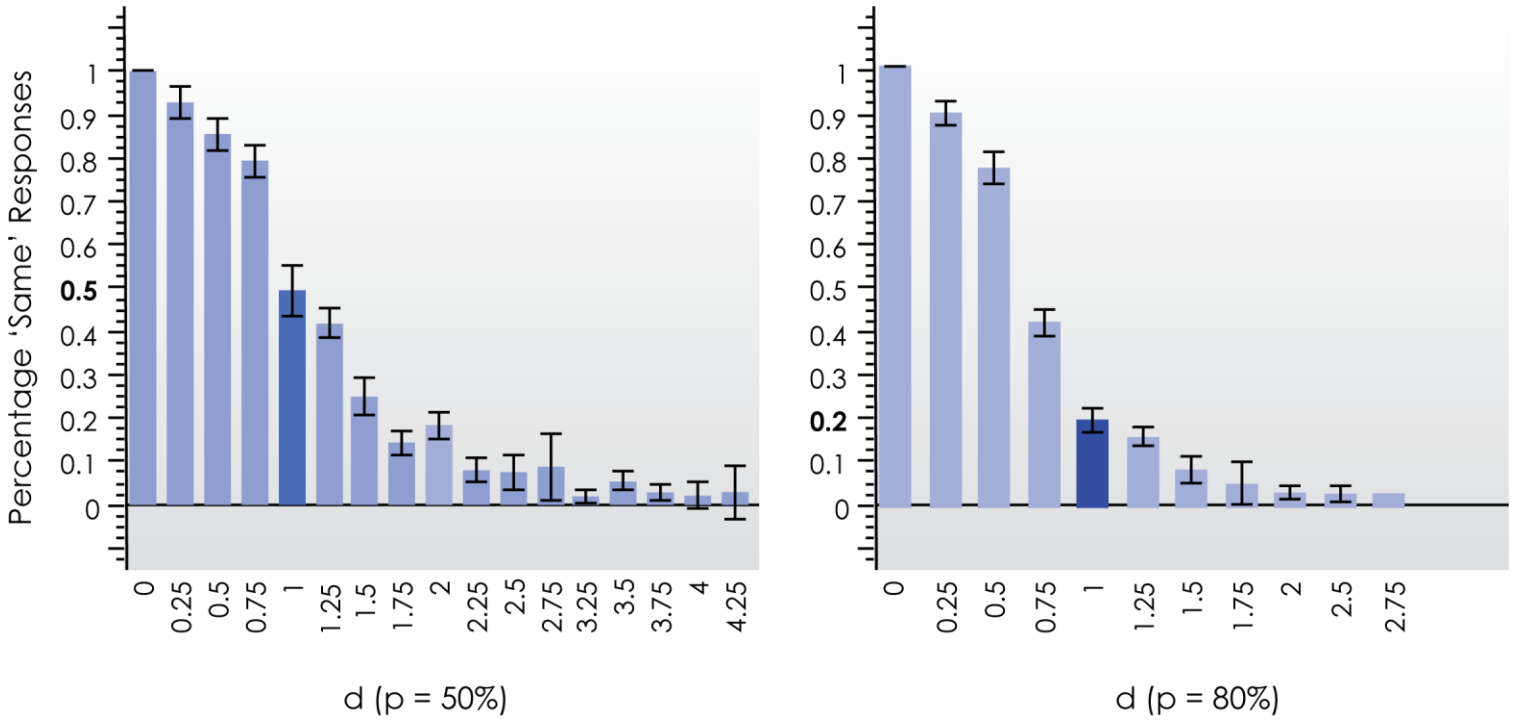
Validating the Model – Web Viewing

A4: Axes are **scaled** such that one unit corresponds to one JND.

p% *of viewers will identify a difference at d = 1*

Validating the Model – Web Viewing

Percentage Similarity for a Web-Adapted Color Difference Model at Multiple Parameter Scales



Contributions

Taking CIE **out of the Lab**

Model is **parametric**, **data driven**, **probabilistic**, and **practical**

Validation color space for **web-viewed** color

Limitations

Data-driven implies data-based

Limited validation to date

Thank you!

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Where should we send this?