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Color Theory – Part 4

Color Tolerances

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Color Tolerances

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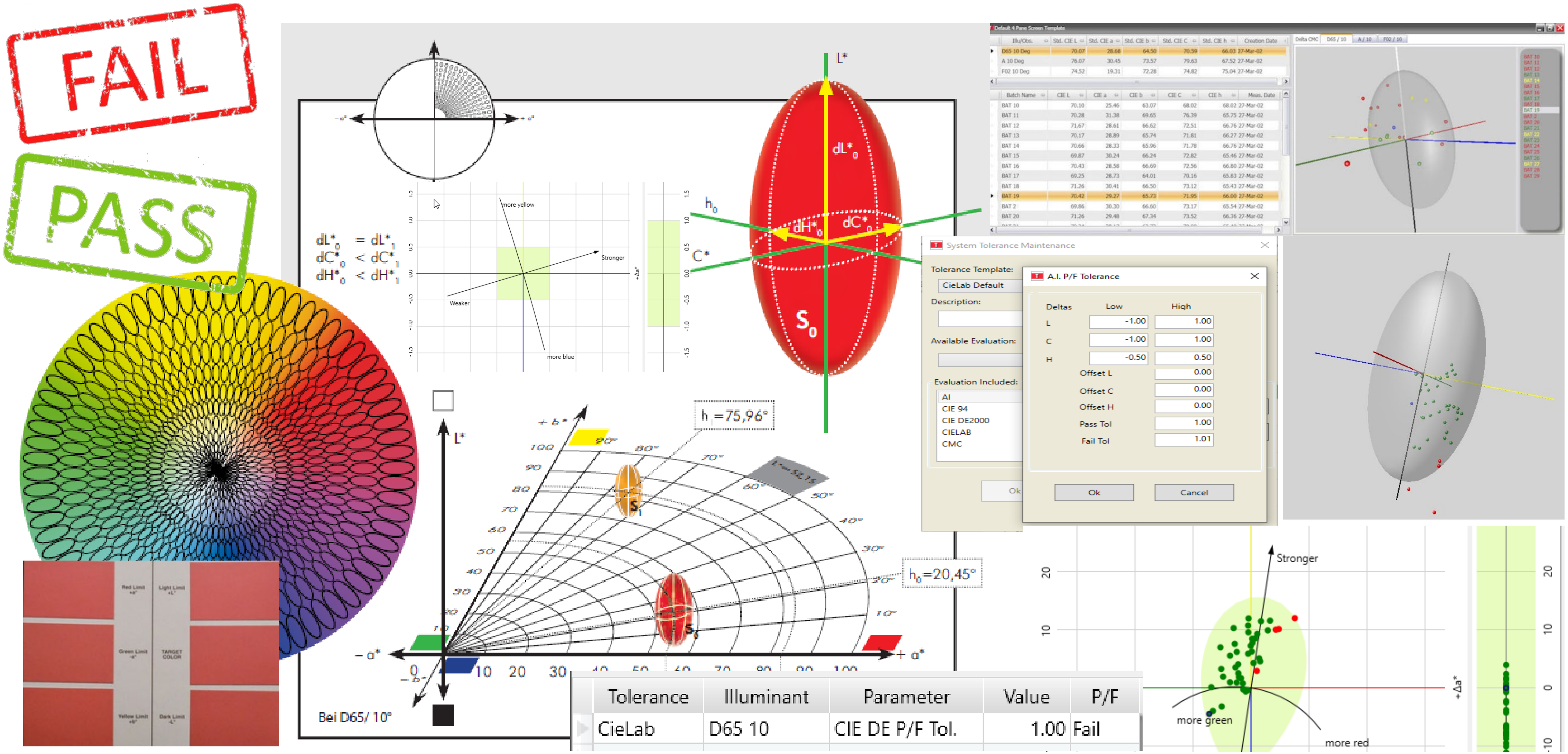

Review - A Colorimetric Description

Defining a numerical system for color perception

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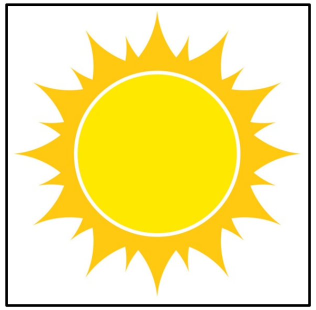
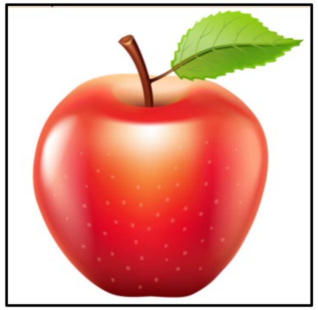
We have described the visual color perception process by showing how the light source, object and observer are together responsible for color perception.



Natural Daylight

x



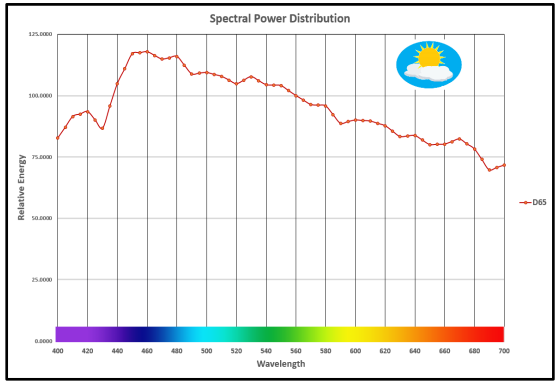
Object (Apple)

x

Human Observer

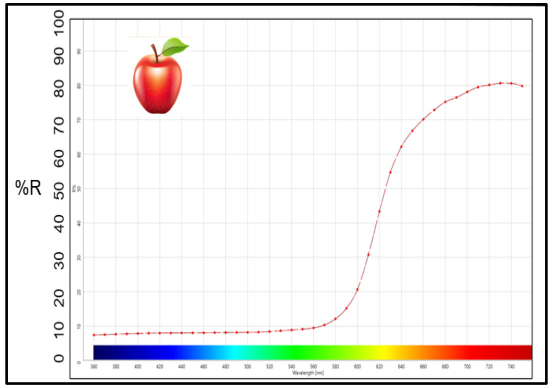
= Color Perception

With the Standard Observer, we can now develop a numerical specification:



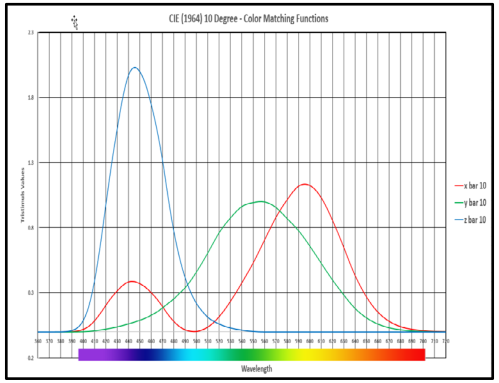
Daylight Illuminant Numerical Data

x



Reflectance Curve Numerical Data

x



CIE Standard Observer Numerical Data

= Colorimetric Description

Review

Standard Observer / Metamerism

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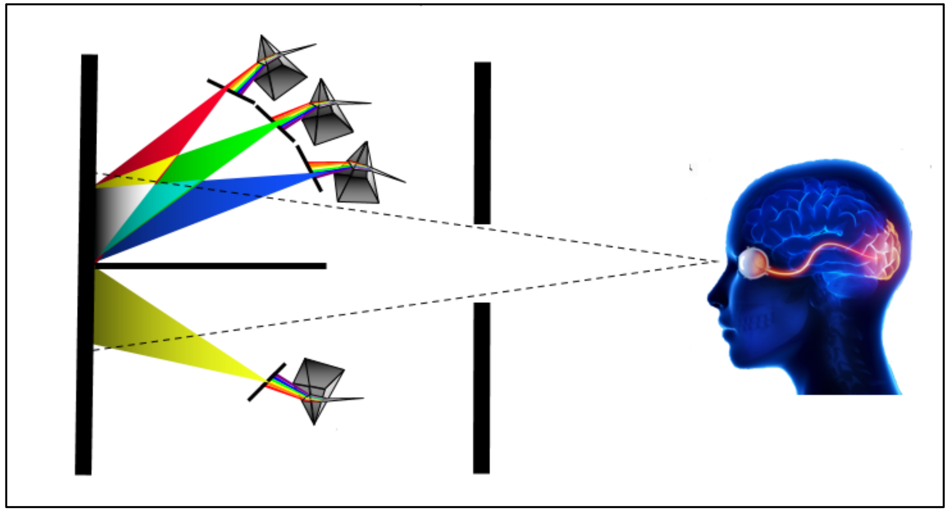

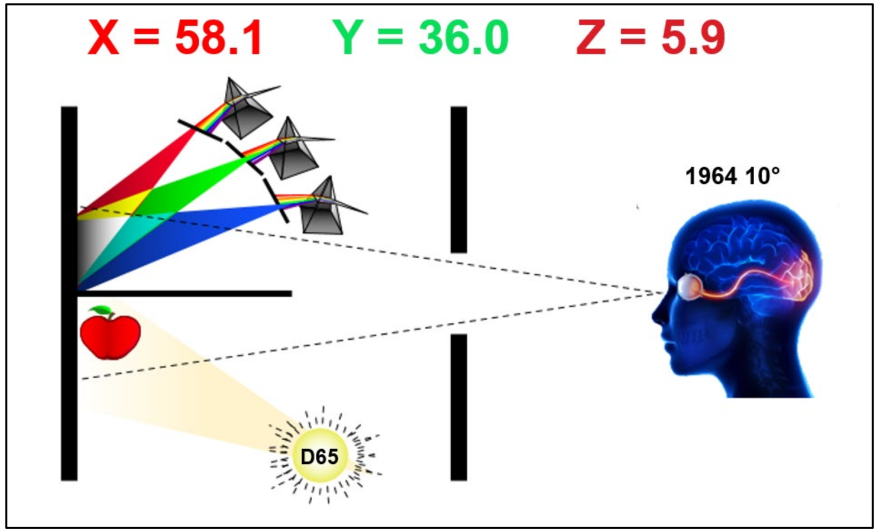

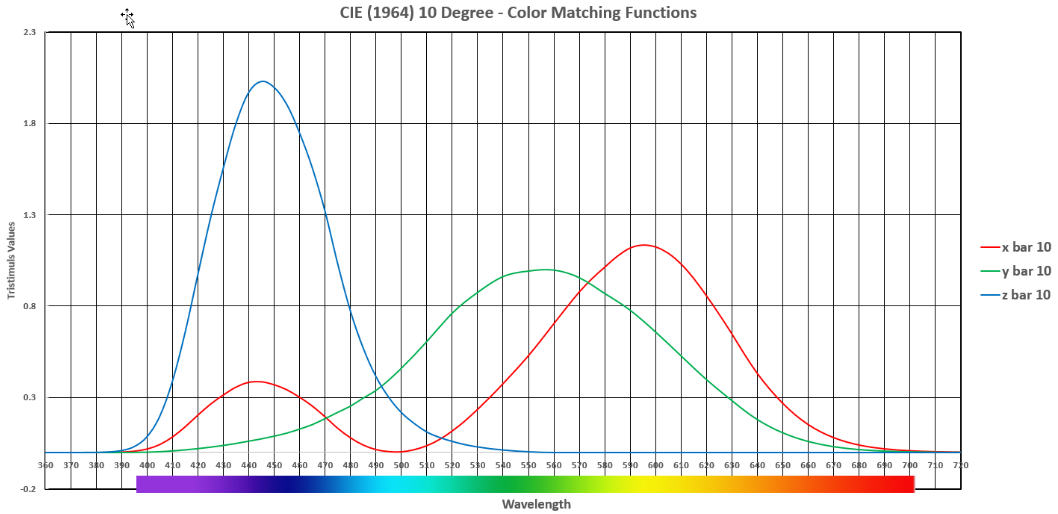

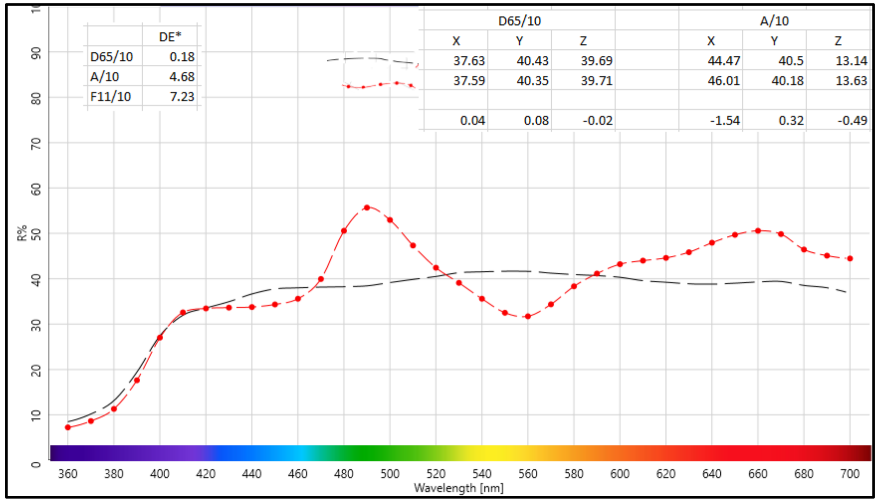

Review - CIELAB

3 Dimensions of Color – Hue, Chroma, Lightness

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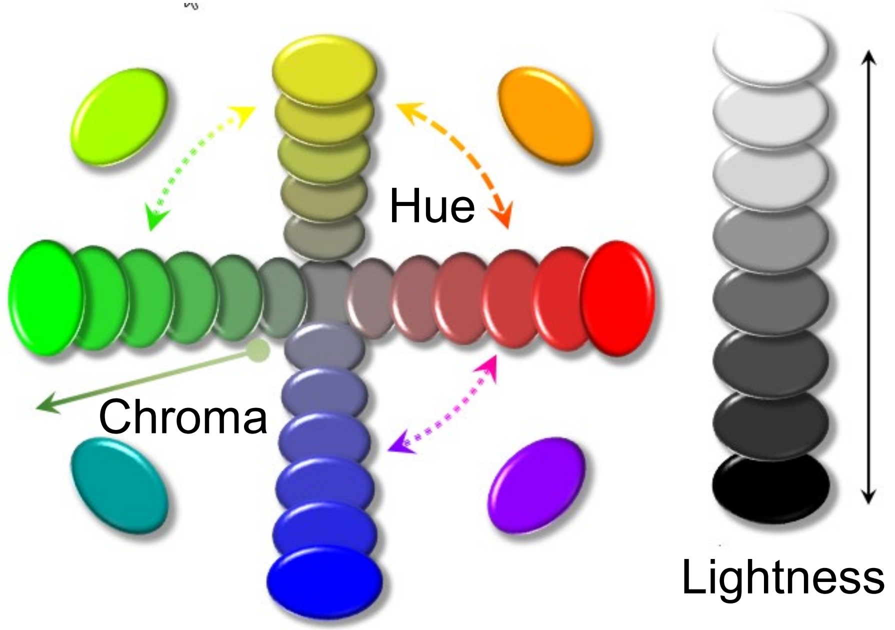
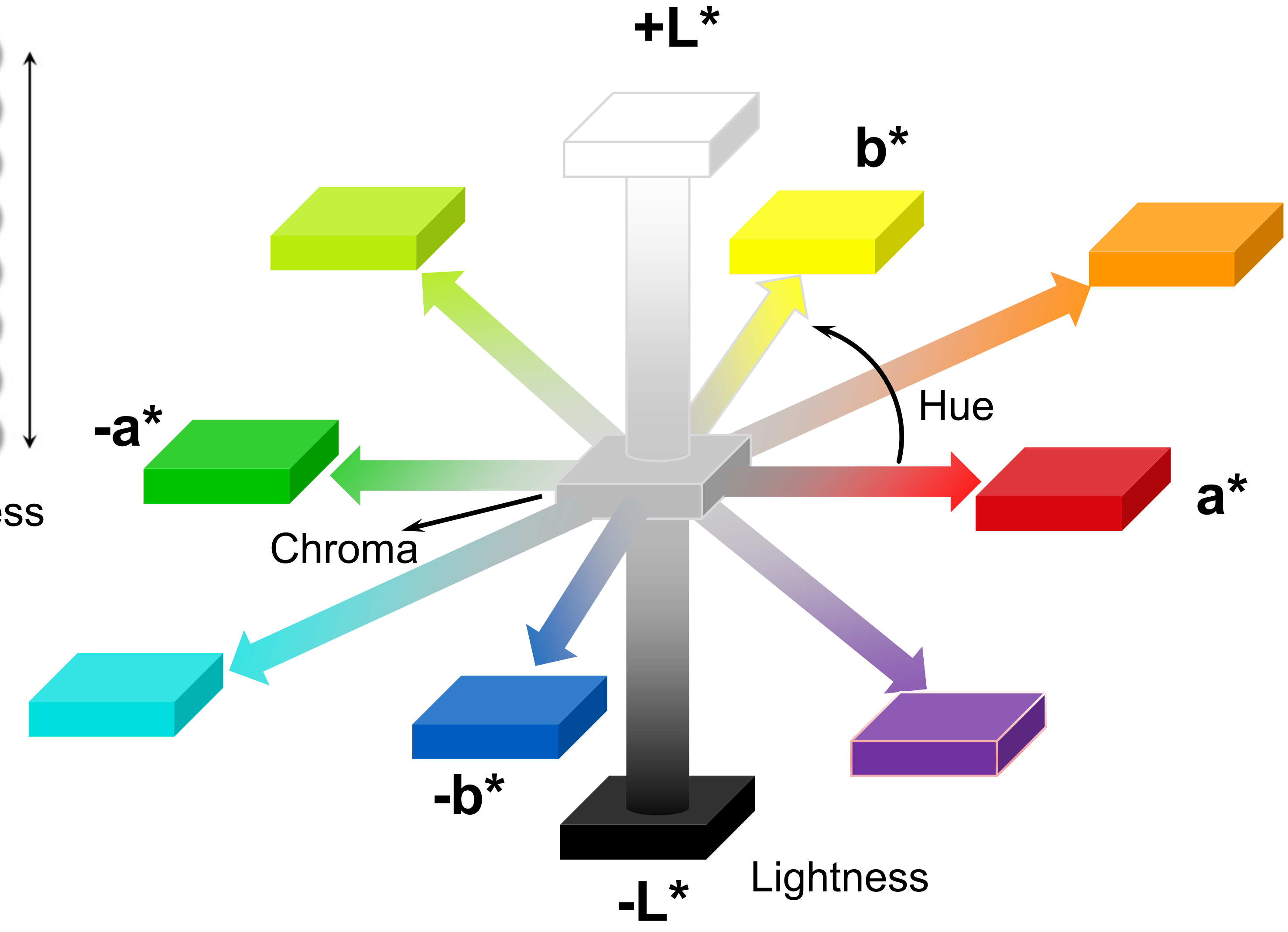
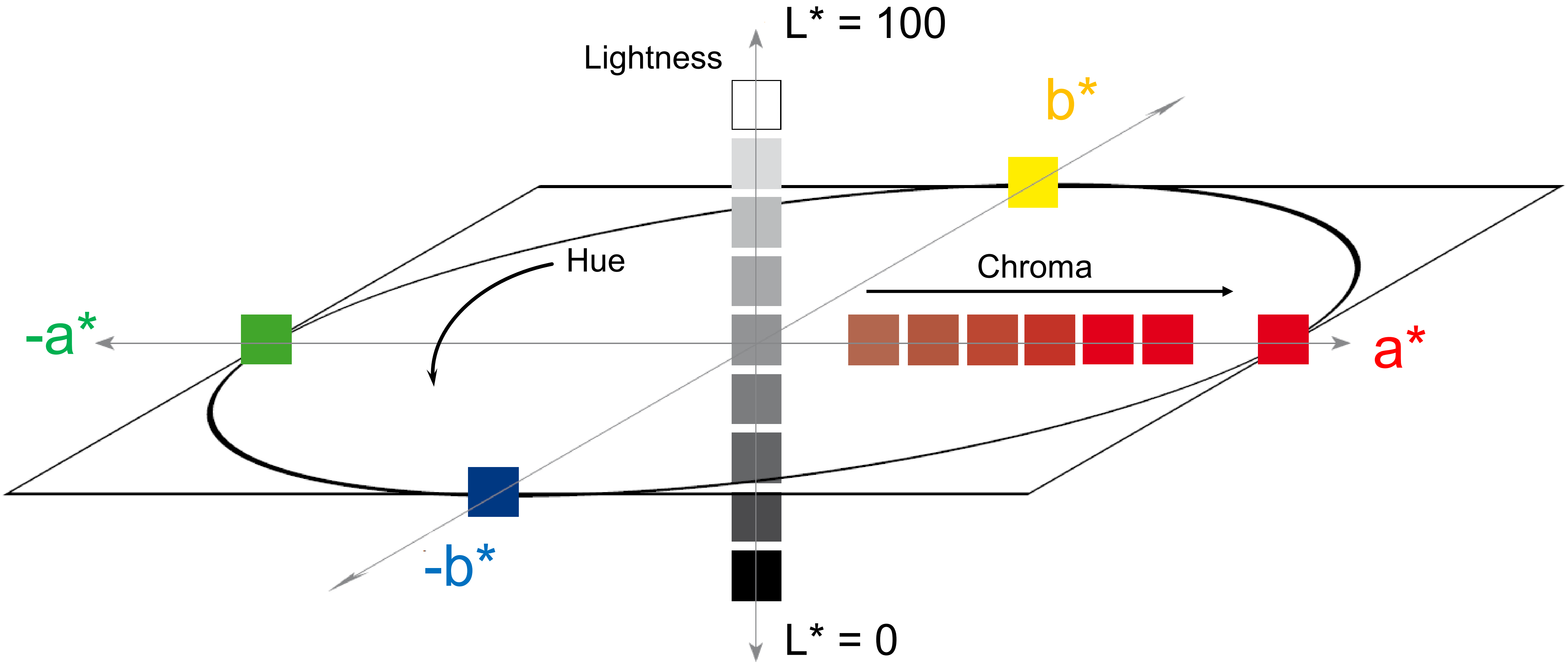




Review - CIELAB

*CIE L*a*b* Color Space*



Review - CIELAB Color Difference

Red Apple 1 and Red Apple 2

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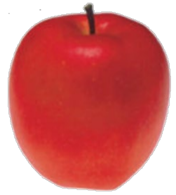
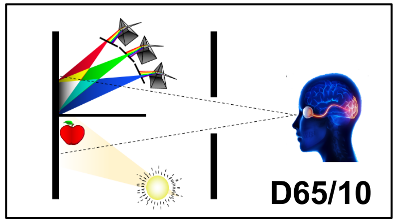
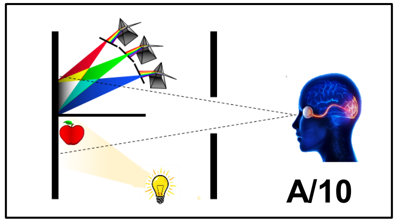
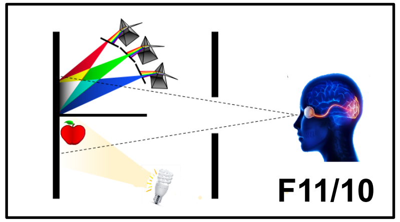
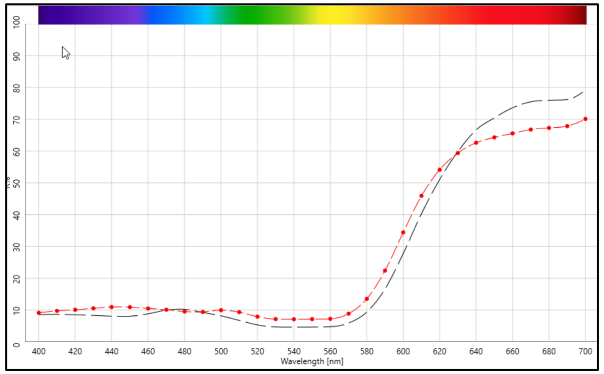


Red Apple 1



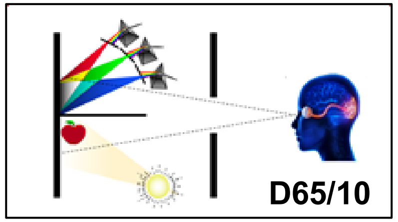


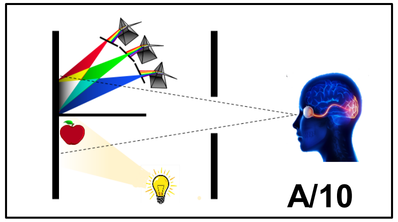


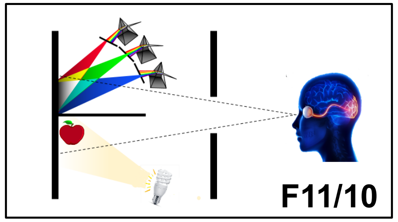


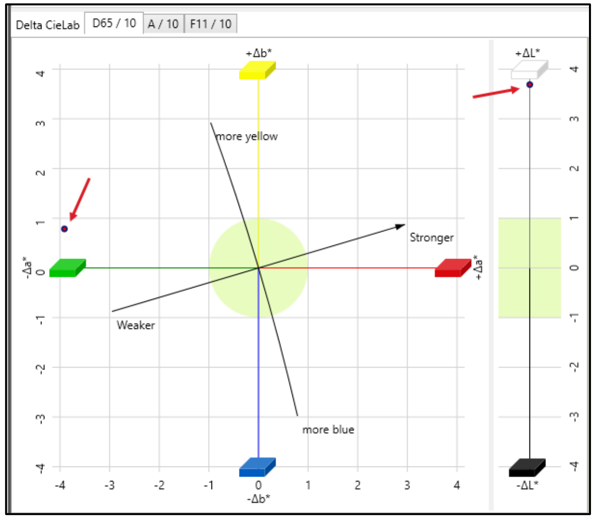
Current Illumi	Std. Name	Std. CIE X	Std. CIE Y	Std. CIE Z	Std. CIE L	Std. CIE a	Std. CIE b	Std. CIE C	Std. CIE h
D65 10 Deg	Red Apple 1	21.65	13.60	9.29	43.65	48.50	14.38	50.58	16.51
A 10 Deg		34.21	18.83	3.06	50.49	51.01	26.02	57.26	27.03
F11 10 Deg		26.83	15.91	5.58	46.86	47.48	20.42	51.68	23.27

Red Apple 2





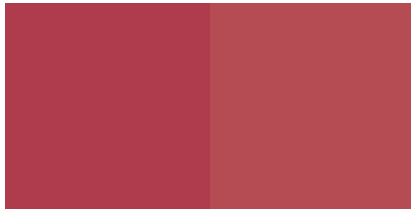




Current Illumi	Batch Name	Batch CIE X	Batch CIE Y	Batch CIE Z	Batch CIE L	Batch CIE a	Batch CIE b	Batch CIE C	Batch CIE h
D65 10 Deg	Red Apple 2	24.30	16.28	11.16	47.34	44.58	15.16	47.09	18.78
A 10 Deg		37.04	21.62	3.62	53.62	46.57	26.30	53.49	29.45
F11 10 Deg		30.77	19.11	6.90	50.82	45.29	20.79	49.84	24.66

CIELAB Color Difference – DL*, Da*, Db*, DC*, DH*, DE*

Current Illumi	Batch Name	CIE DL	CIE Da	CIE Db	CIE DC	CIE DH	CIE DE
D65 10 Deg	Red Apple 2	3.69	-3.92	0.78	-3.50	1.93	5.44
A 10 Deg		3.13	-4.44	0.28	-3.78	2.34	5.44
F11 10 Deg		3.96	-2.19	0.37	-1.85	1.23	4.54



Update - Color Difference

CIELAB Polar Coordinates – DL, DC*, DH**

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$C^* = (a^{*2} + b^{*2})^{1/2}$

$h = \tan^{-1}(b^*/a^*)$

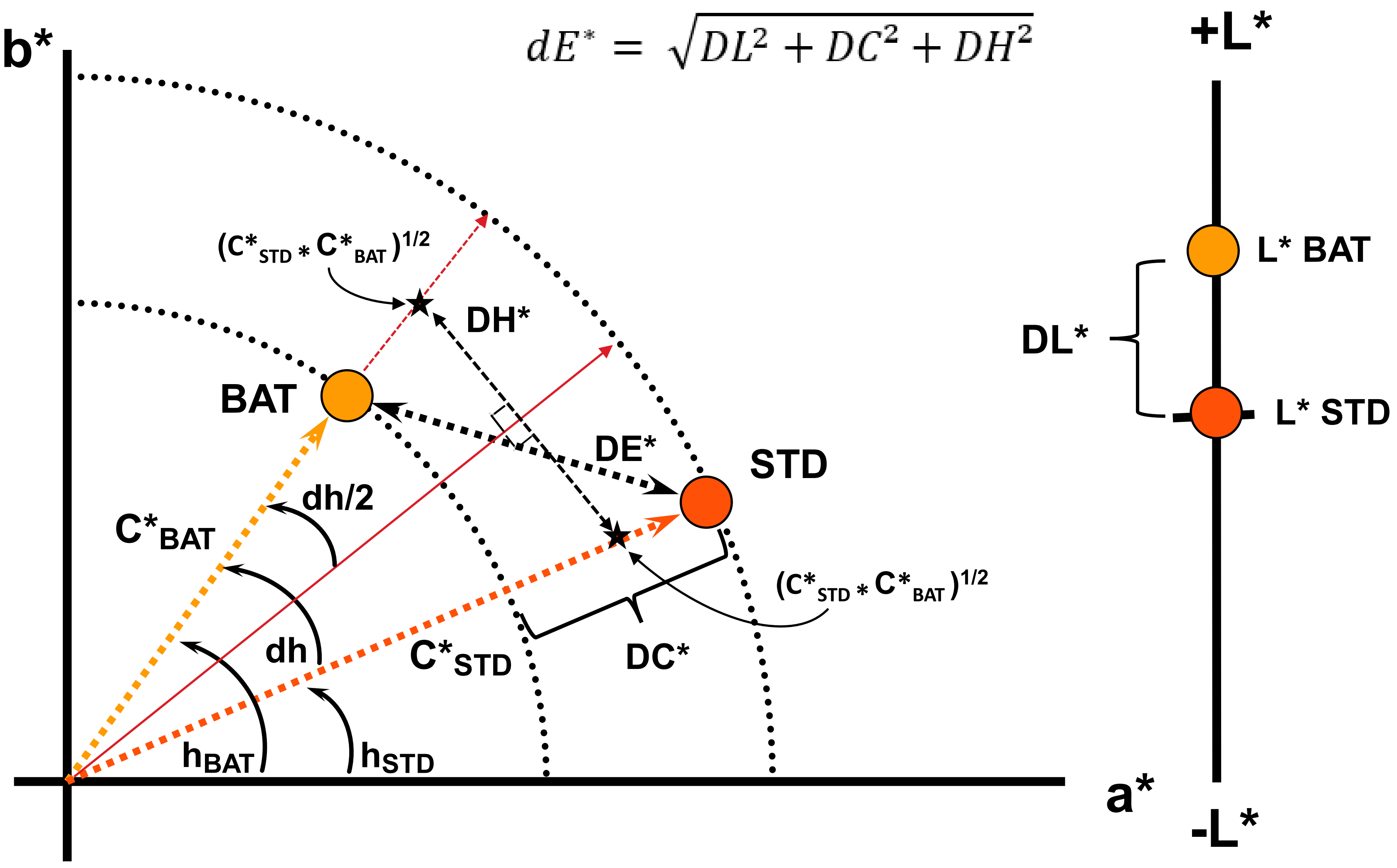
$DL^* = L^*_{BAT} - L^*_{STD}$
(+ is lighter)
(- is darker)

$DC^* = C^*_{BAT} - C^*_{STD}$
(+ is more chroma)
(- is less chroma)

$dh = h_{BAT} - h_{STD}$

$DH^* = 2(C^*_{STD} * C^*_{BAT})^{1/2} \sin(dh/2)$
(+ is counter-clockwise)

$DE^* = (DL^2 + DC^2 + DH^2)^{1/2}$



Color Tolerances

Acceptability versus Perceptibility

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Perceptibility defines a just-noticeable difference between a standard and a batch.

Acceptability is the largest acceptable difference between a standard and a batch.

Color tolerances are the colorimetric limits that define when a product is acceptable.

Realistic tolerances are usually based on the maximum acceptable color difference rather than on a minimum perceptible difference.

A color tolerance is the amount of color difference or variation that is commercially acceptable.

Color tolerances will vary across industries. A good tolerance represents a compromise between the capability of the process and the customer's requirements.

DE* Tolerance

Defines a Sphere in CIELAB Color Space

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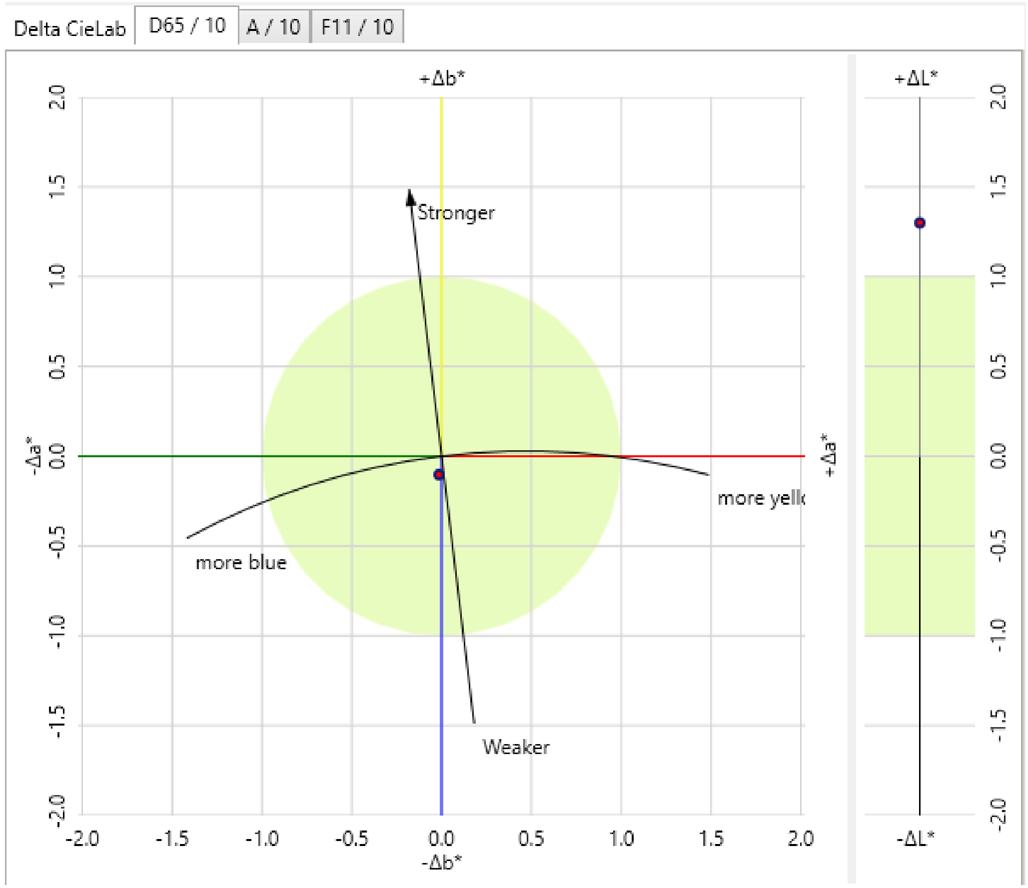
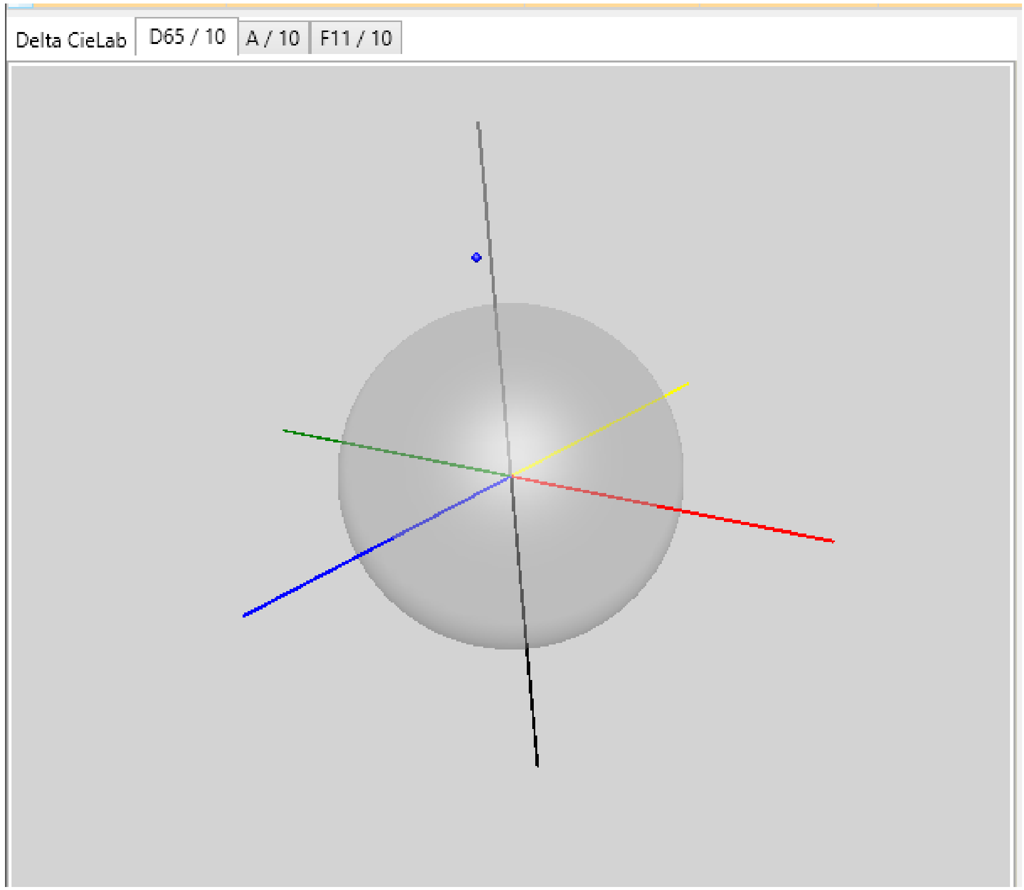
DE* tolerance of 1.0 defines a sphere with a radius of 1.0 CIELAB Units.

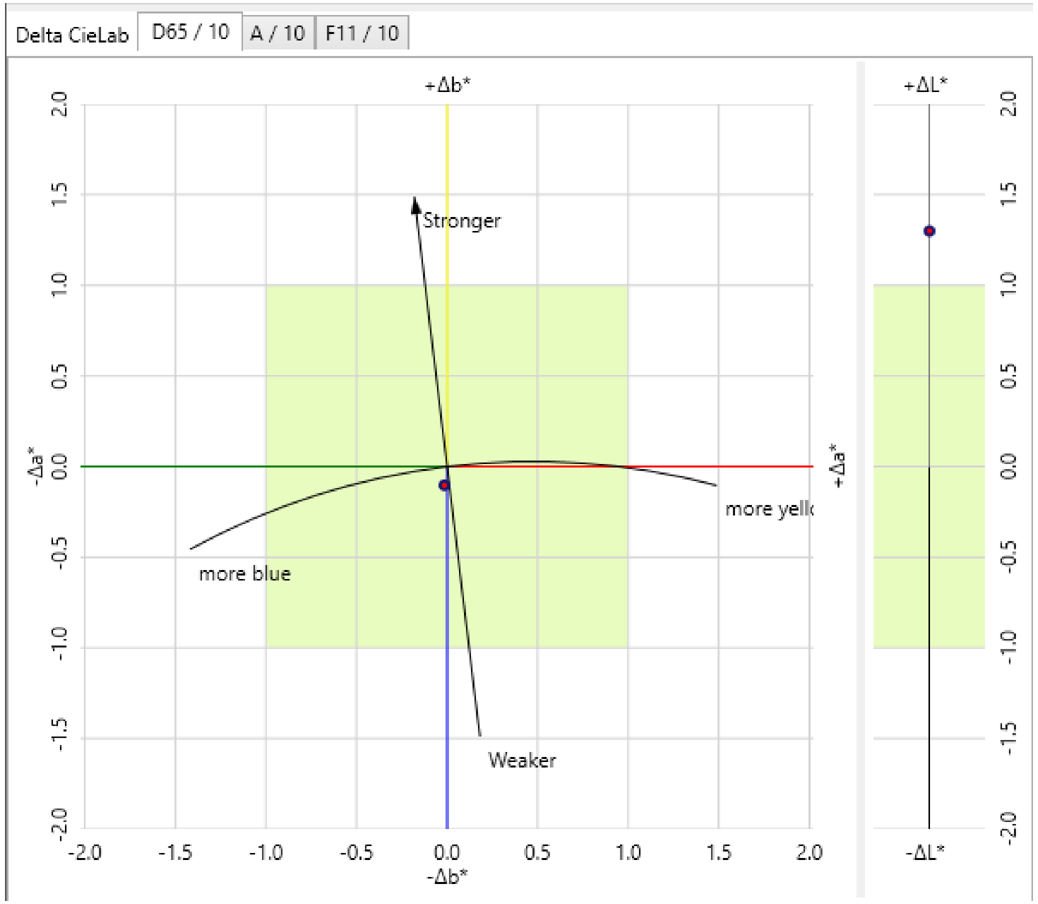


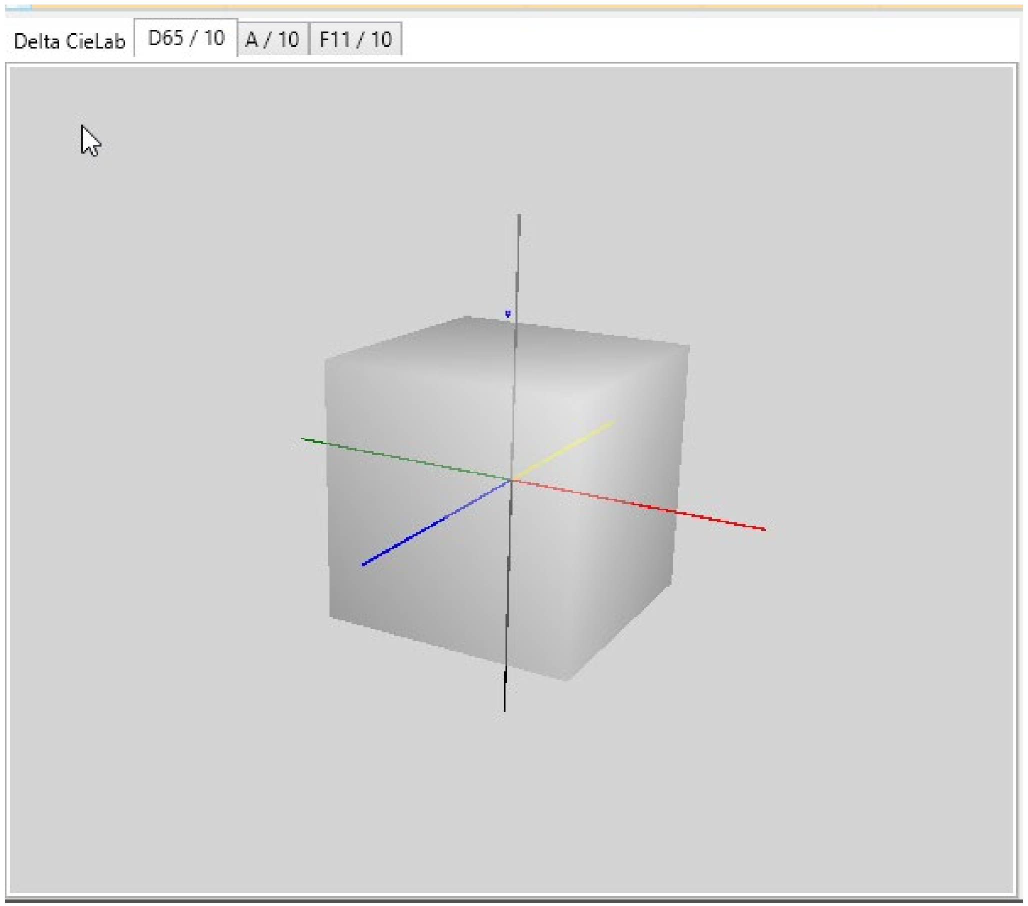


DE* Tolerance

Defines a Box in CIELAB Color Space

DL*, Da*, Db* tolerance of 1.0 defines a box in CIELAB space.

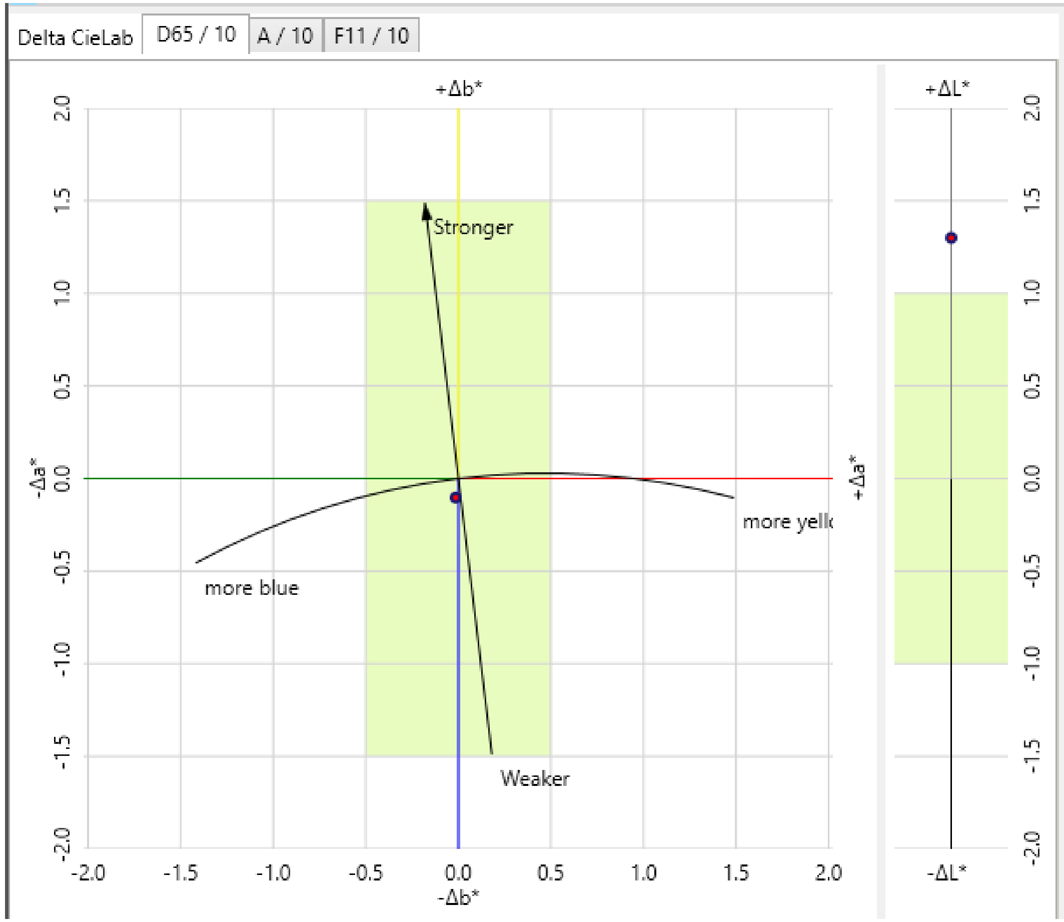


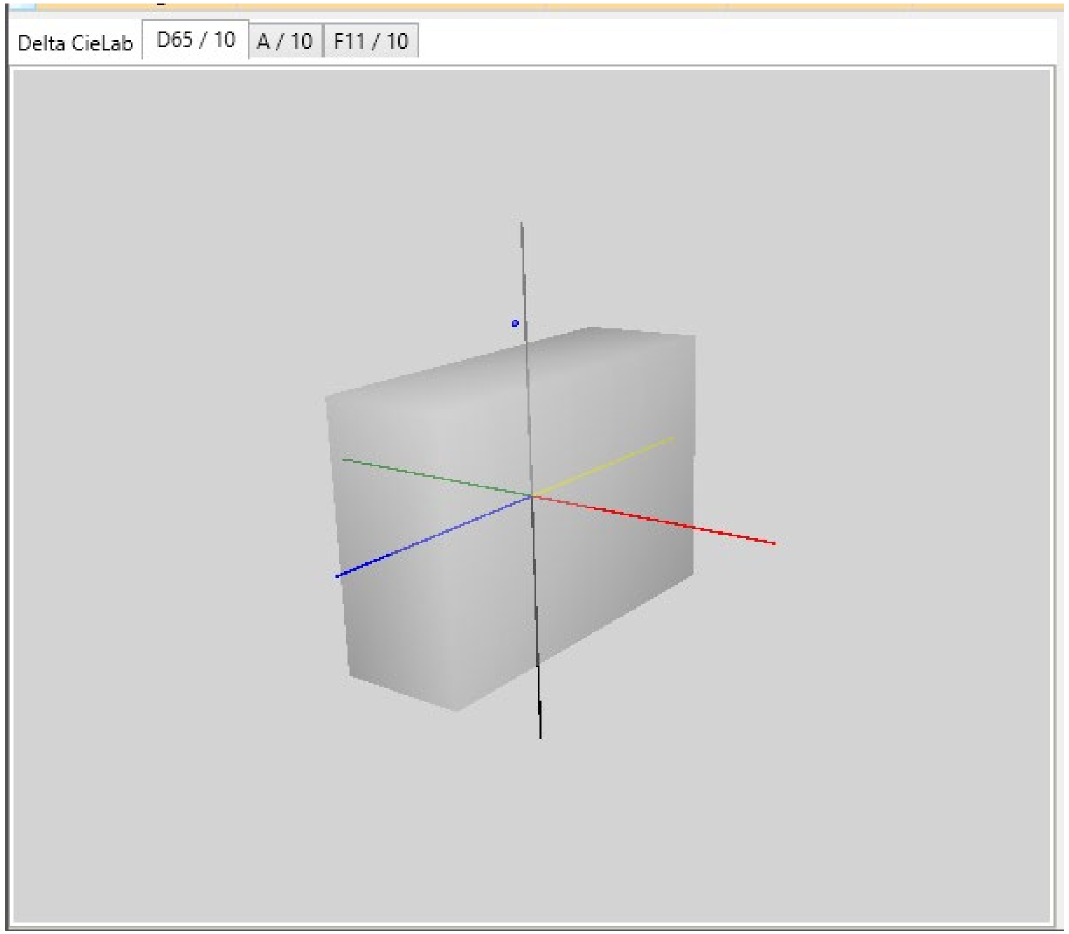


DE* Tolerance

Defines a Box in CIELAB Color Space

Tolerance DL* = +/-1.0, Da* = +/- 0.5, Db* = +/- 1.5 defines a box in CIELAB space.





Tolerance Determination

From Historical Batch Data

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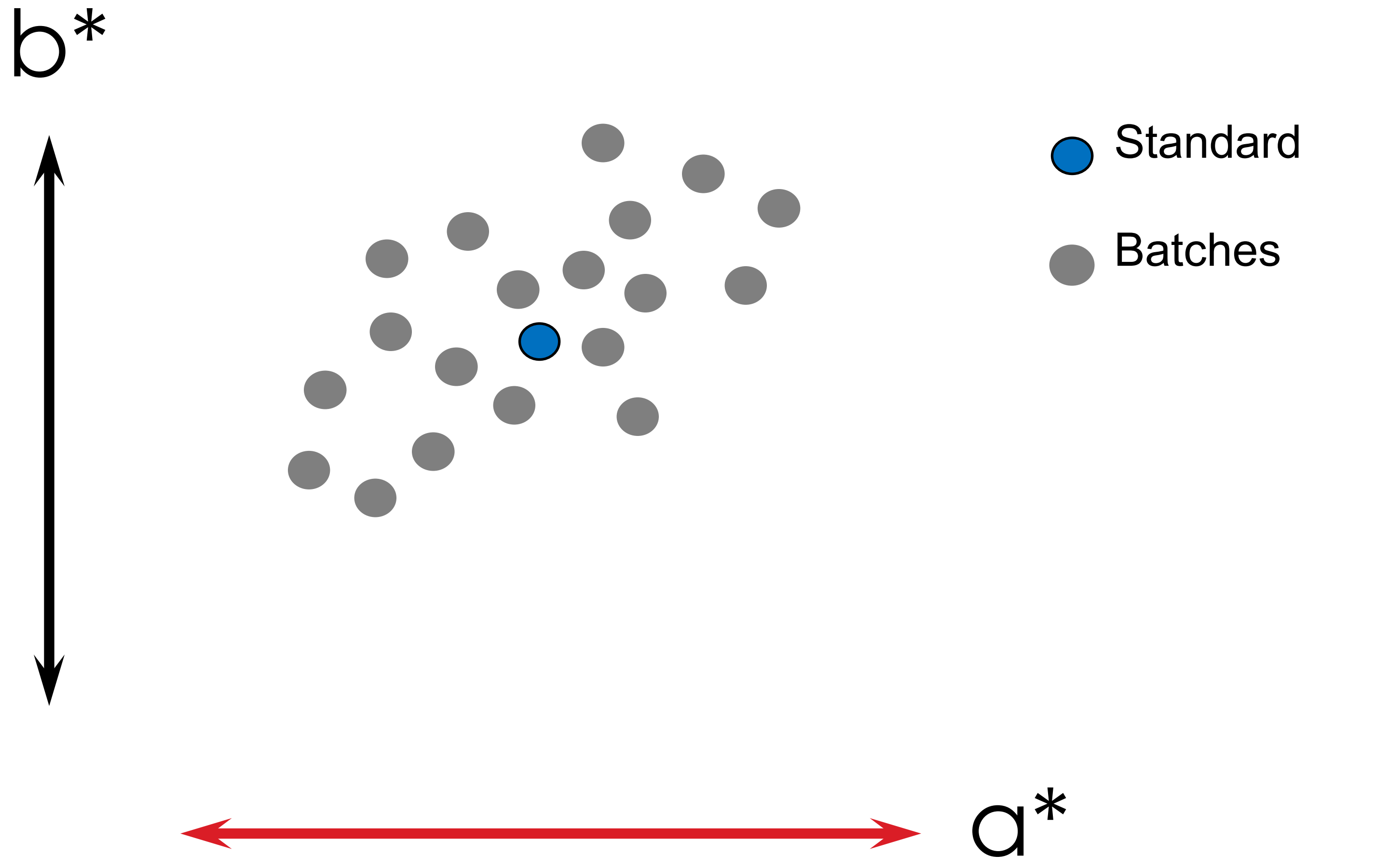

Batches to the Standard shown in a*/b* plane.

Tolerance Determination

Visually Evaluate Each Batch as Pass or Fail

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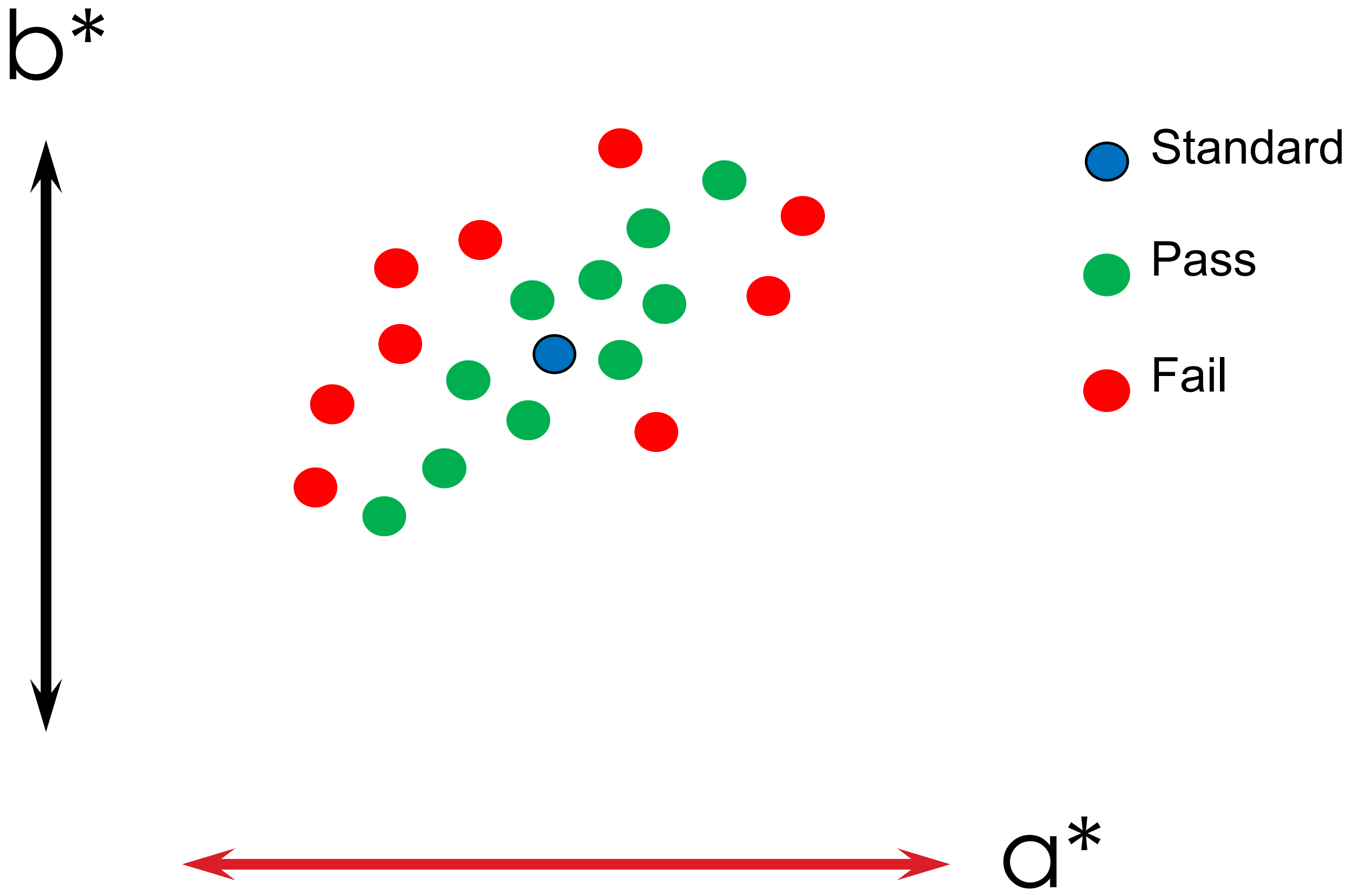

Batches are marked either as visually acceptable (Pass) or unacceptable (Fail).

Tolerance Determination

DE - Spherical Tolerance*

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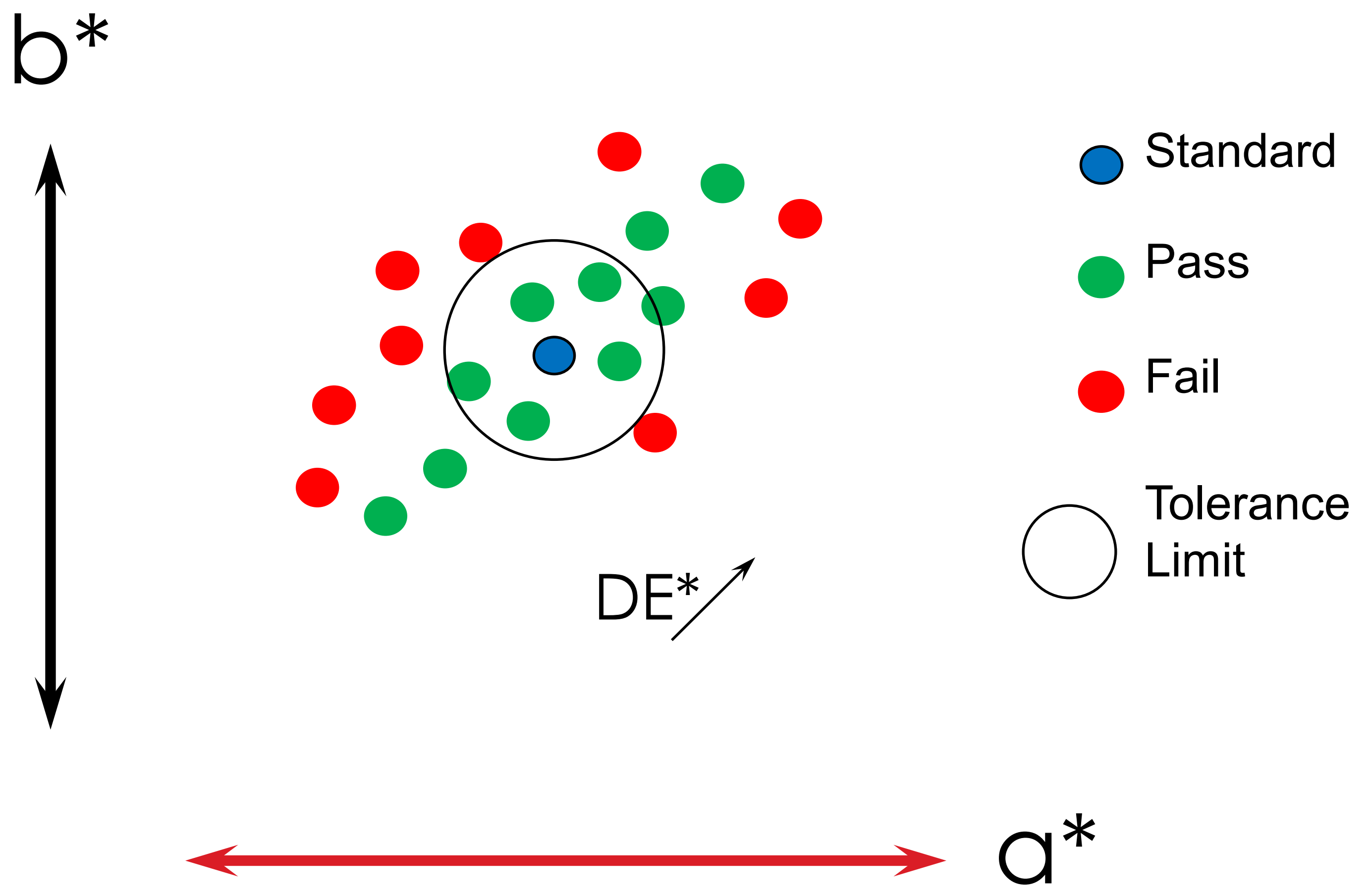

A single DE* value cannot include the Pass batches and exclude the Fail batches.

Tolerance Determination

Rectangular DL Da* Db**

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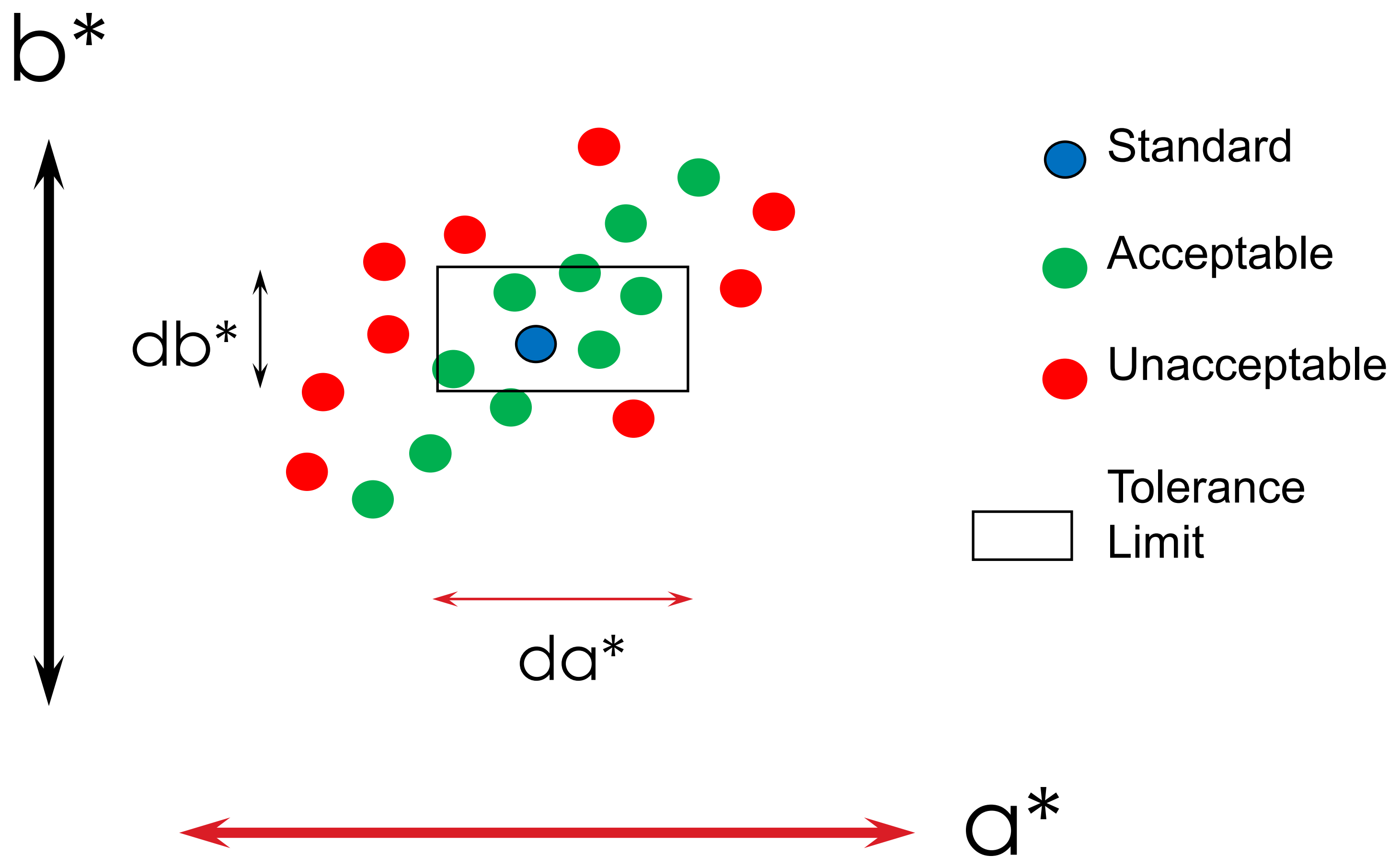

A rectangular da* and db* value cannot include acceptable batches and exclude unacceptable batches.

Tolerance Determination

Polar L C* h*

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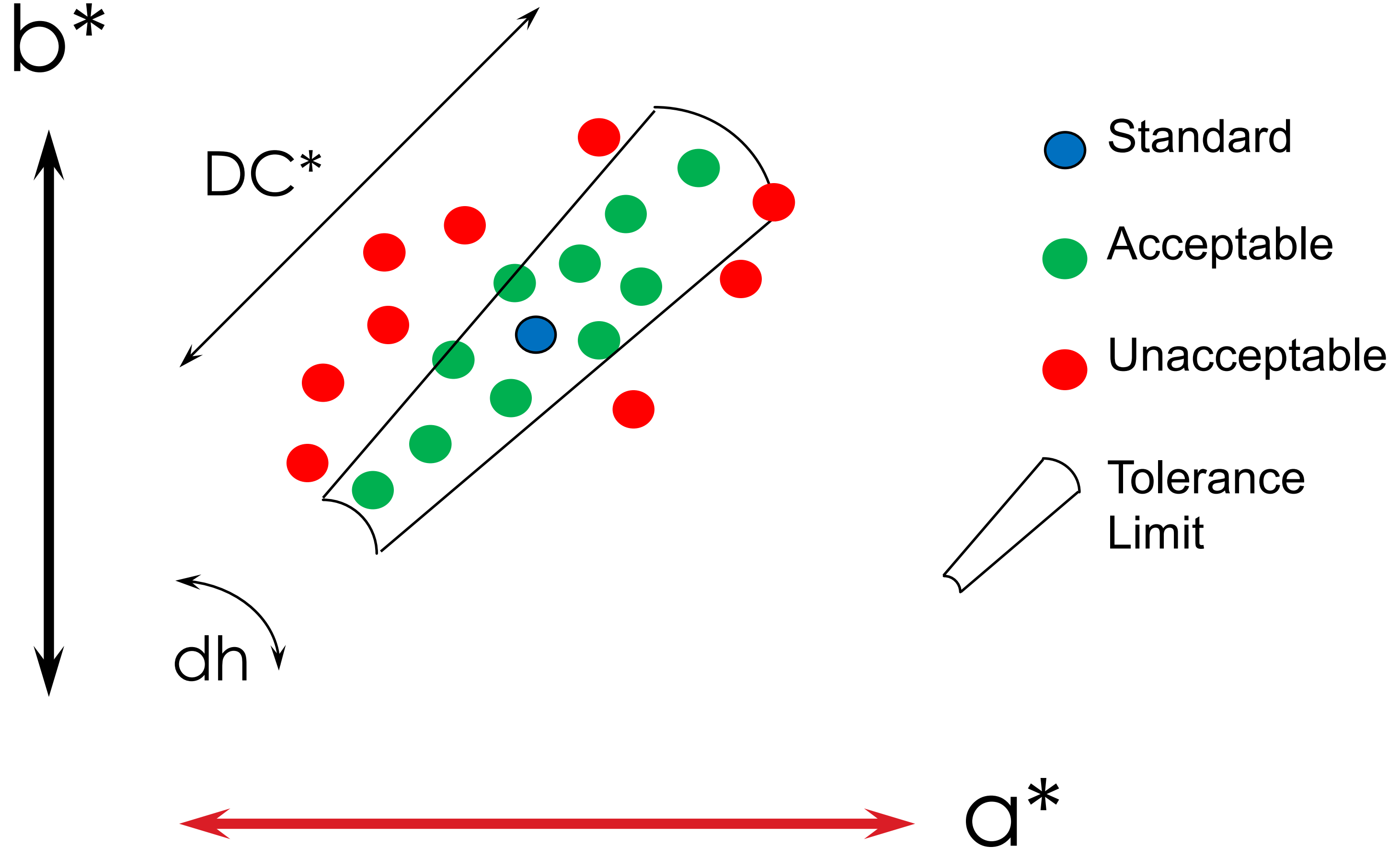
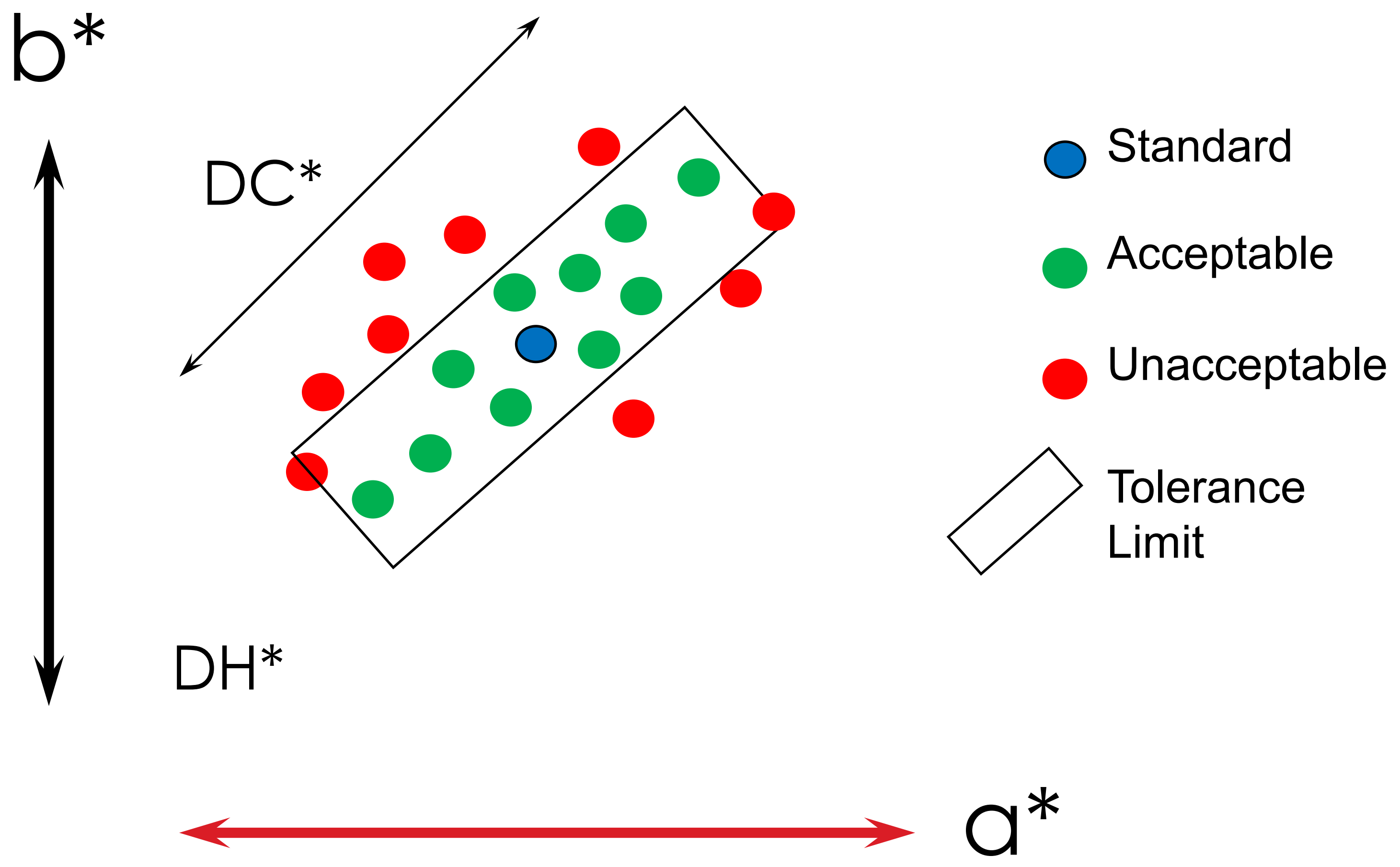


A tolerance based on dh and DC* gets close but still can't quite get there.

Tolerance Determination

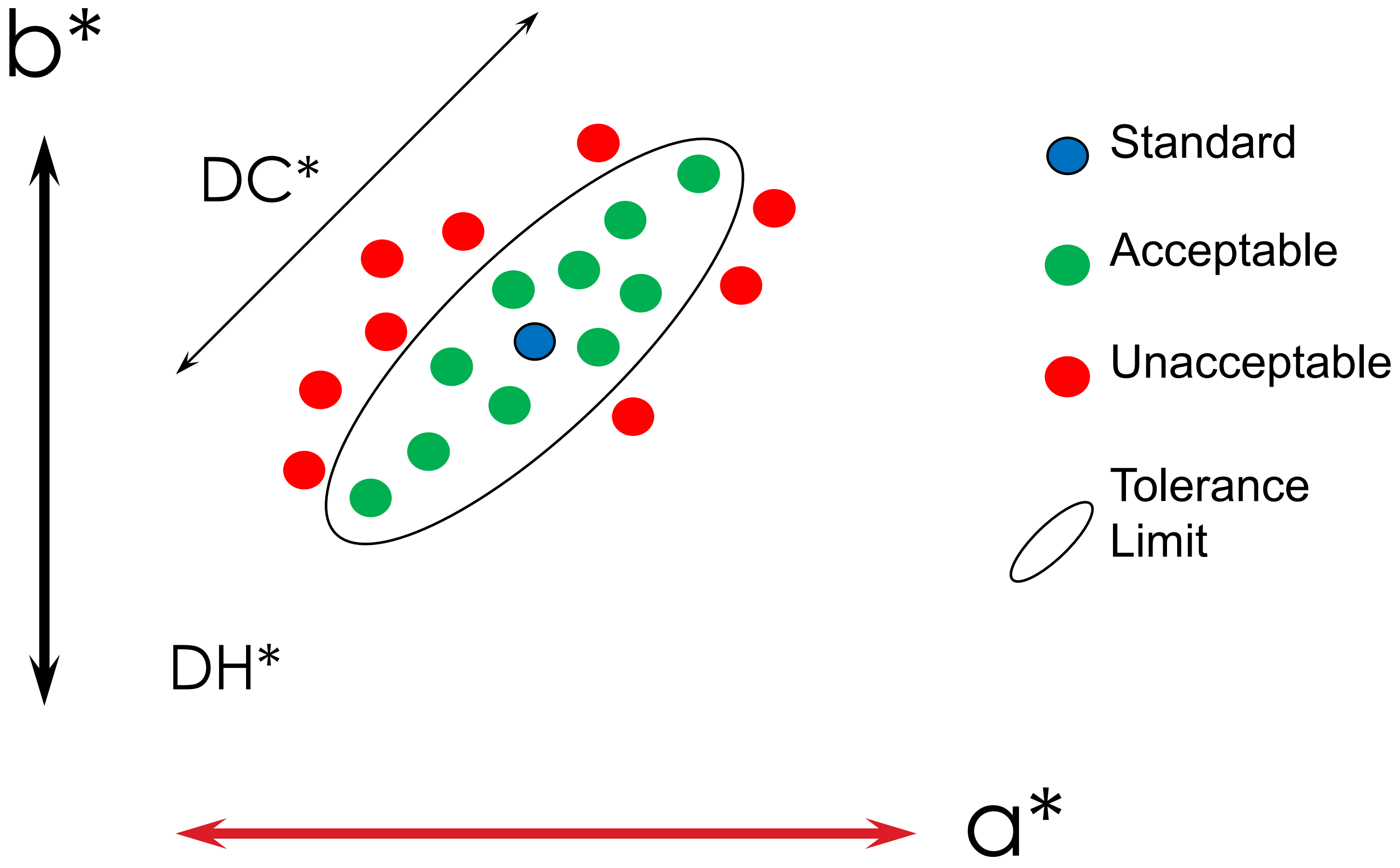
Rectangular L C* H**



A tolerance based on DH* and DC* also gets close but still can't quite get there.

Tolerance Determination

Ellipsoidal L C* H**



An elliptical tolerance based on DH* and DC* can include the acceptable batches and exclude the unacceptable ones.

CMC Color Difference Equation

Ellipsoidal Tolerancing

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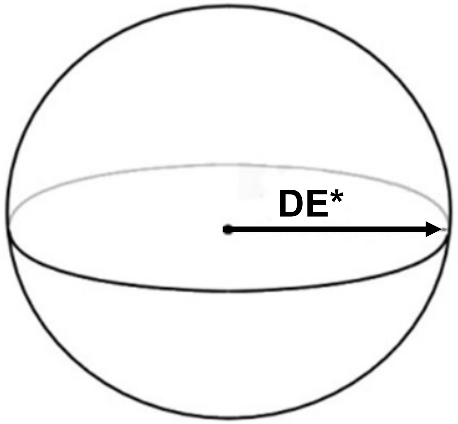
DE*



$$\Delta E^*_{CMC(l:c)} = \left[\left(\frac{\Delta L^*}{lS_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{cS_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{S_H}\right)^2\right]^{1/2}$$

S_L = Lightness Tolerance

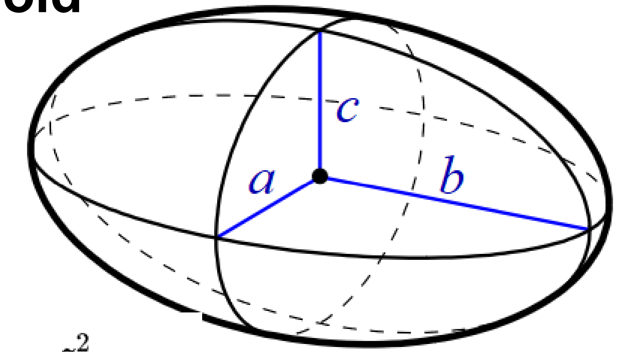
S_C = Chroma Tolerance

S_H = Hue Tolerance

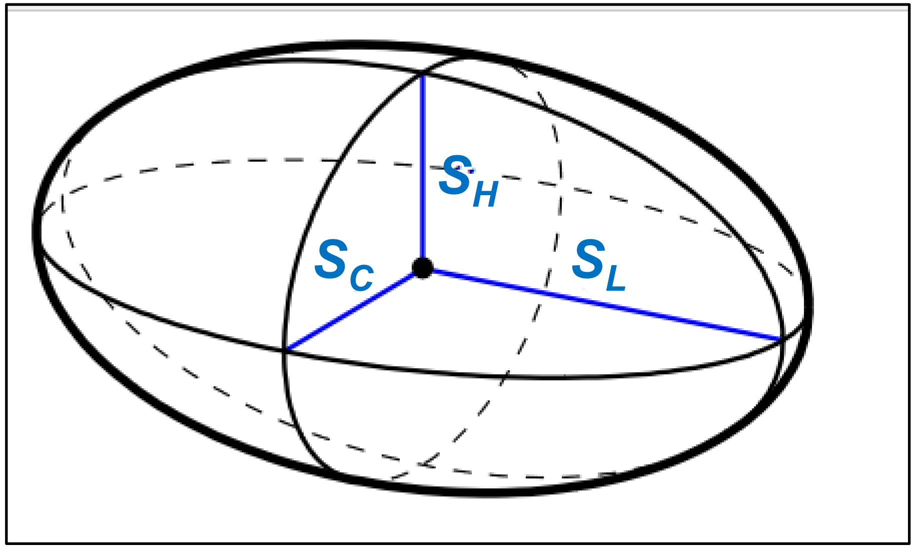
l = Lightness Adjustment Factor

c = Chroma Adjustment Factor

Ellipsoid



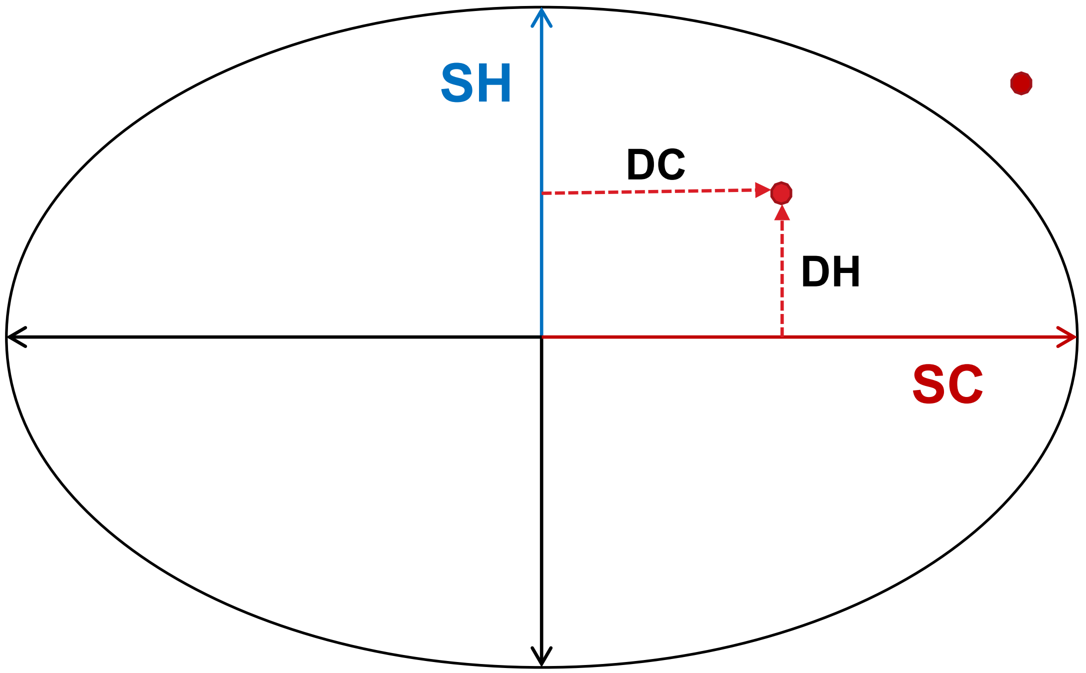
$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$$

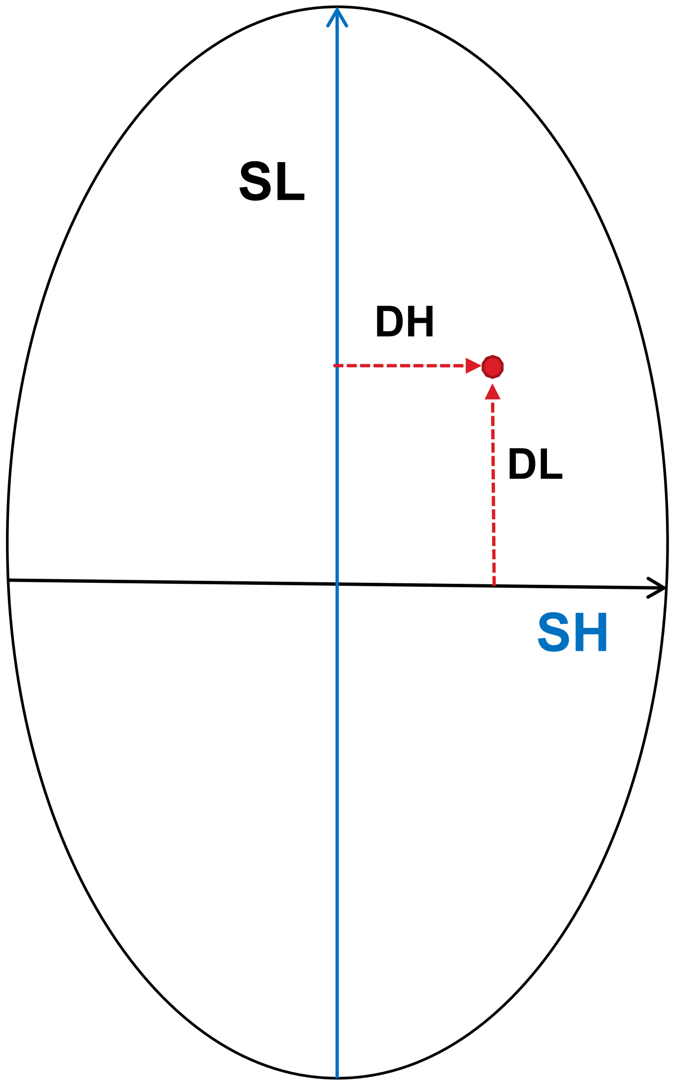


CMC Color Difference Equation

Pass/Fail Considerations

$$\Delta E^*_{CMC(l:c)} = \left[\left(\frac{\Delta L^*}{lS_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{cS_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{S_H}\right)^2\right]^{1/2}$$





DL* / SL **DC* / SC** **DH* / SH**

CMC Color Difference Equation

Meaning of the Value of the CMC DE

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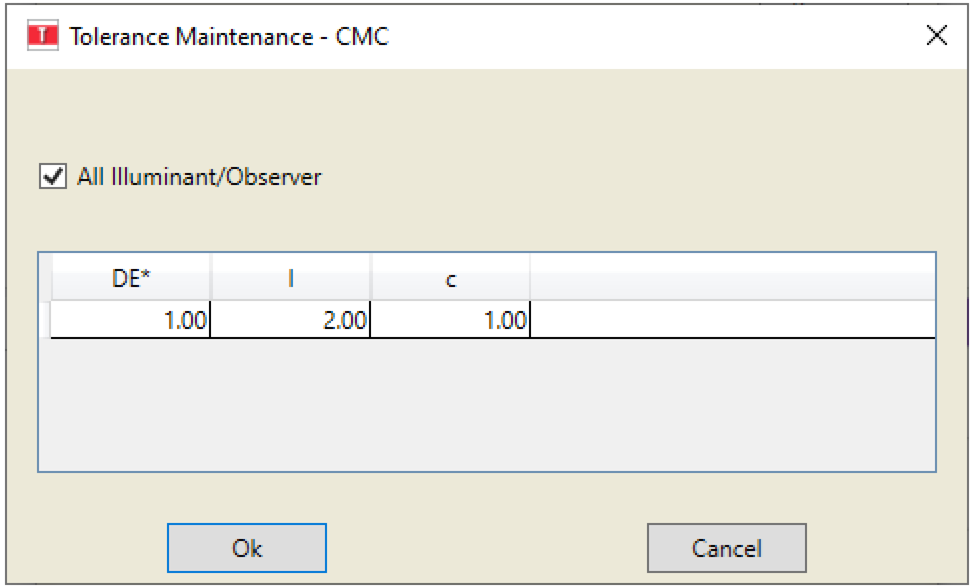

$$\Delta E^*_{CMC(l:c)} = \left[\left(\frac{\Delta L^*}{l S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{c S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{S_H}\right)^2\right]^{1/2}$$

l = Lightness Factor

Allows adjustment of DL* Semi-axis

c = Chroma Factor

Allows adjustment of DC* Semi-axis

$DE^*_{CMC} = 1.0$

Batch is on surface of ellipsoid.

$DE^*_{CMC} < 1.0$

Batch is inside ellipsoid (Pass)

$DE^*_{CMC} > 1.0$

Batch is outside ellipsoid (Fail)

CMC Color Difference Equation

Changing the Value of the CMC Lightness Factor from 1 to 2

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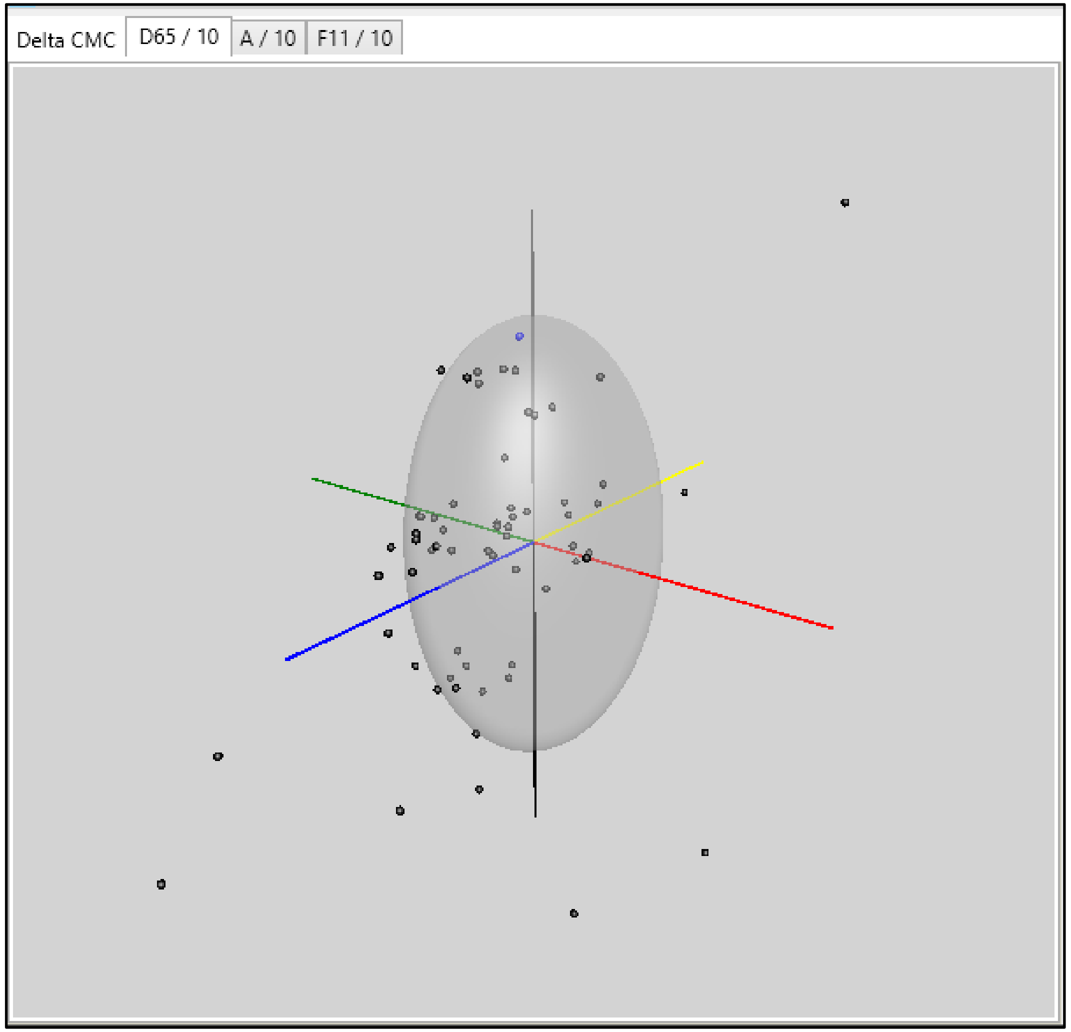
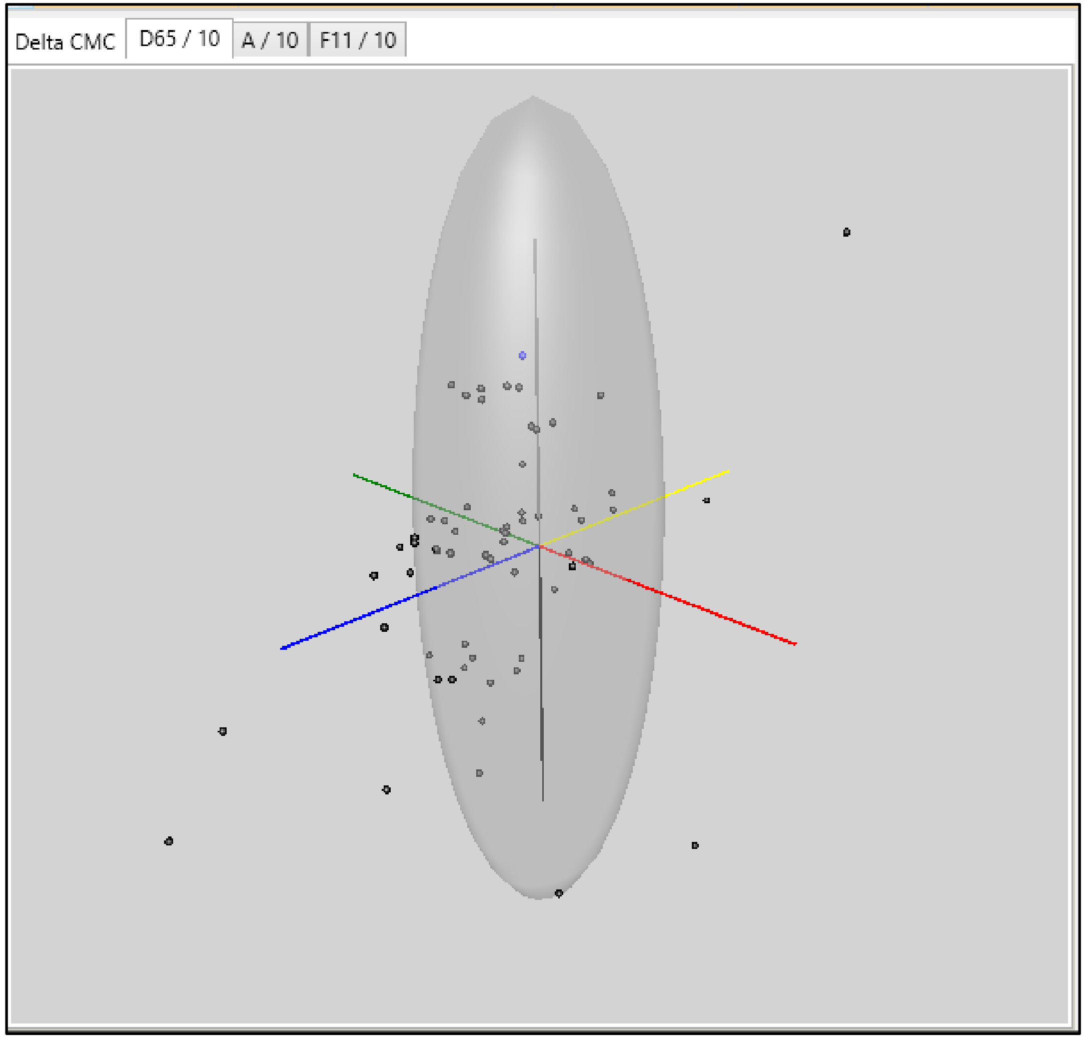
$l = 1 \quad c = 1$



$l = 2 \quad c = 1$



CIE 2000 Color Difference Equation

Meaning of the Value of the CIE 2000 DE

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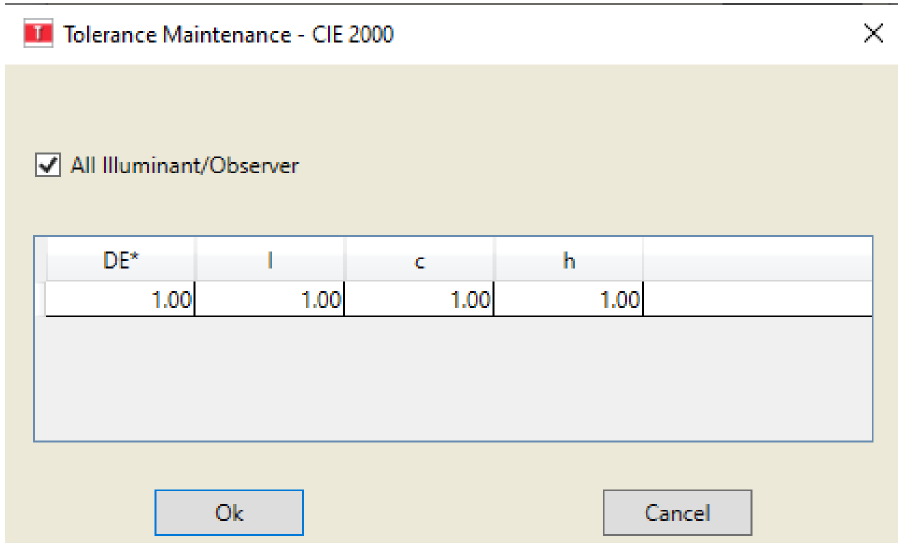


$$\Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}}$$

Includes lightness, chroma and hue weighting factors
Improved gray colors
Improved performance for blue colors using rotational factor

K_L = Lightness Factor
Allows adjustment of DL* Semi-axis

K_C = Chroma Factor
Allows adjustment of DC* Semi-axis

K_H = Hue Factor
Allows adjustment of DH* Semi-axis

S_L = Lightness Tolerance

S_C = Chroma Tolerance

S_H = Hue Tolerance

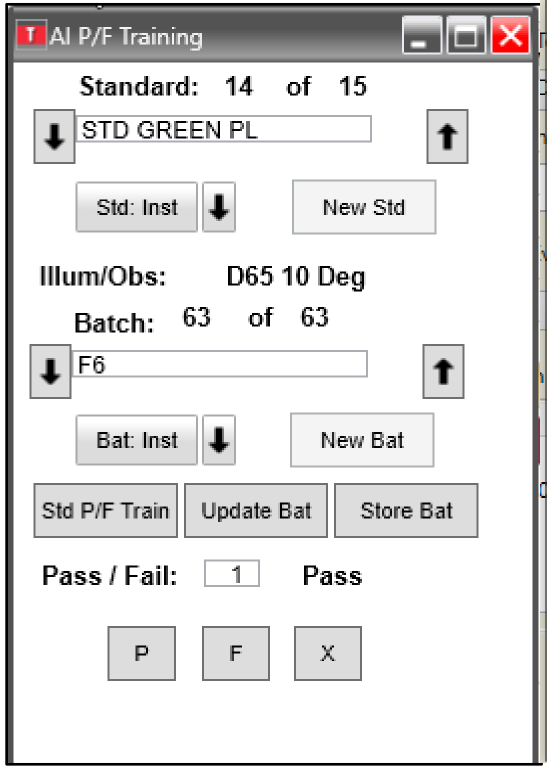
DE^*_{00} = 1.0
Batch is on surface of ellipsoid.

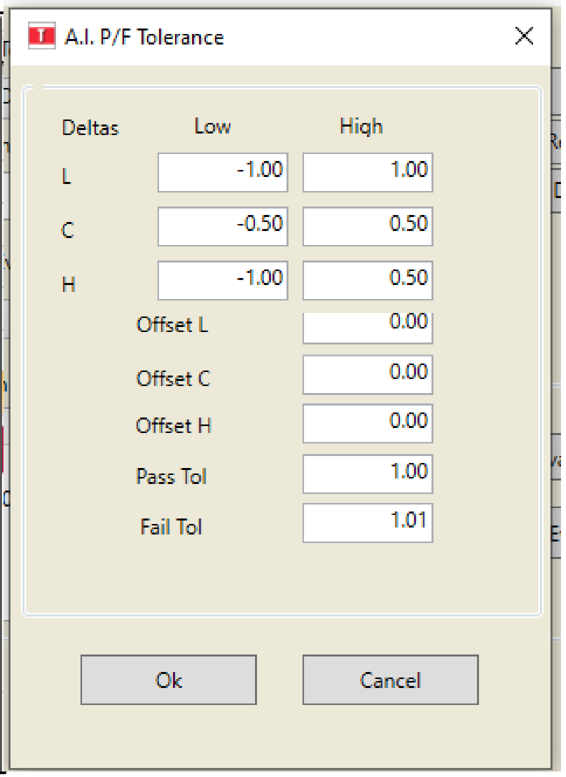
$DE^*_{00} < 1.0$
Batch is inside ellipsoid (Pass)

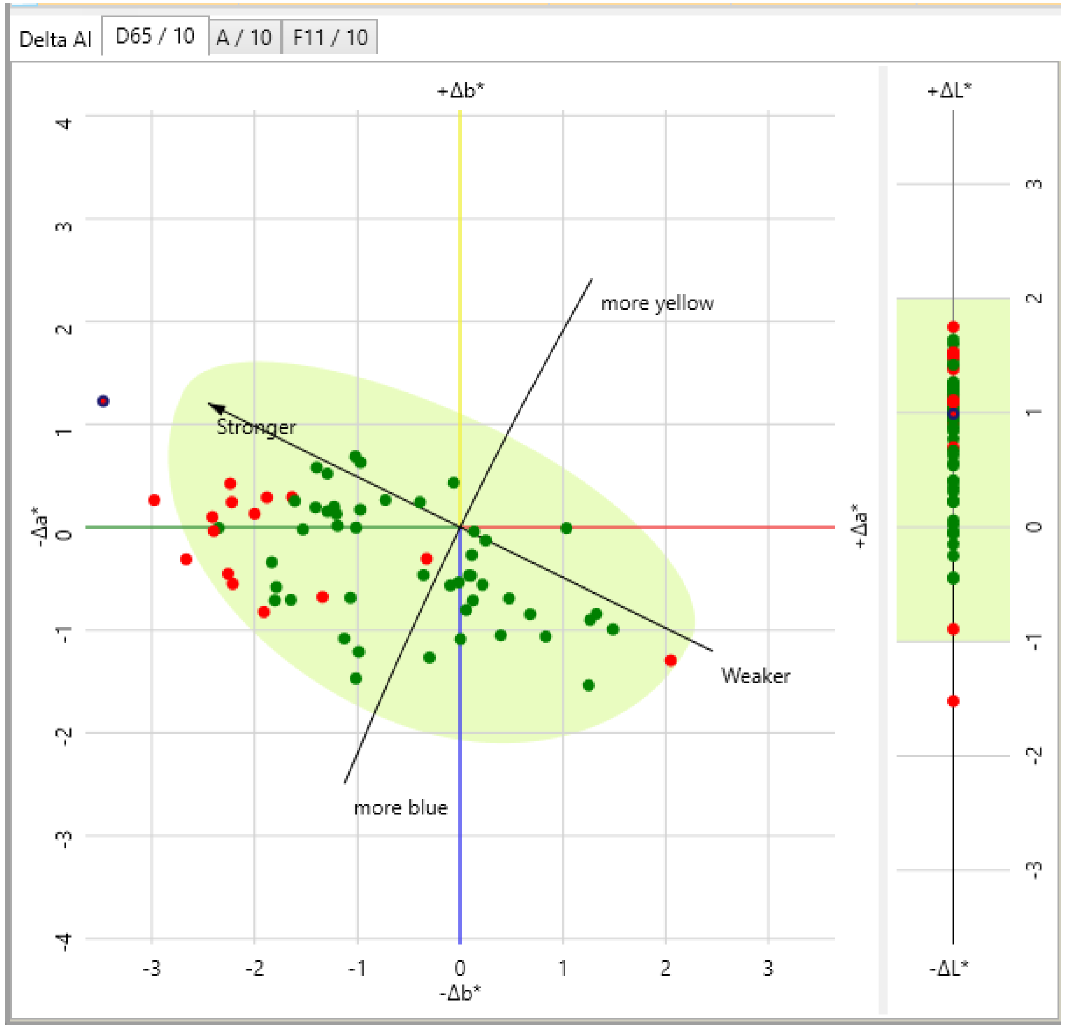
$DE^*_{00} > 1.0$
Batch is outside ellipsoid (Fail)

AI Pass/Fail

Computer Generated Tolerance Based on Visual Acceptability







User can mark each batch as either a pass or fail and the program will try to create an ellipsoid that includes the pass samples and excludes the fail samples.

AI Generated Tolerance

Light Gray Sample

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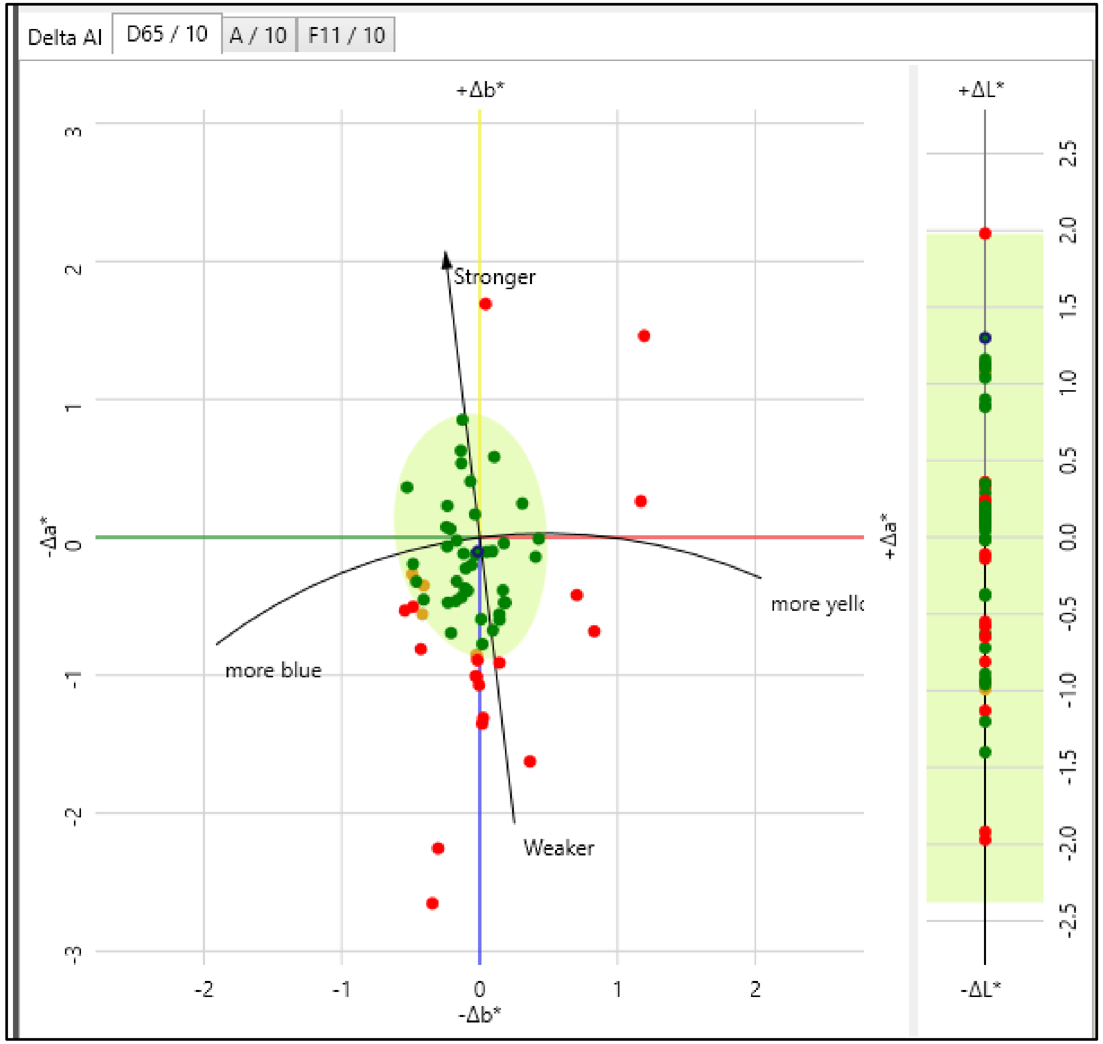

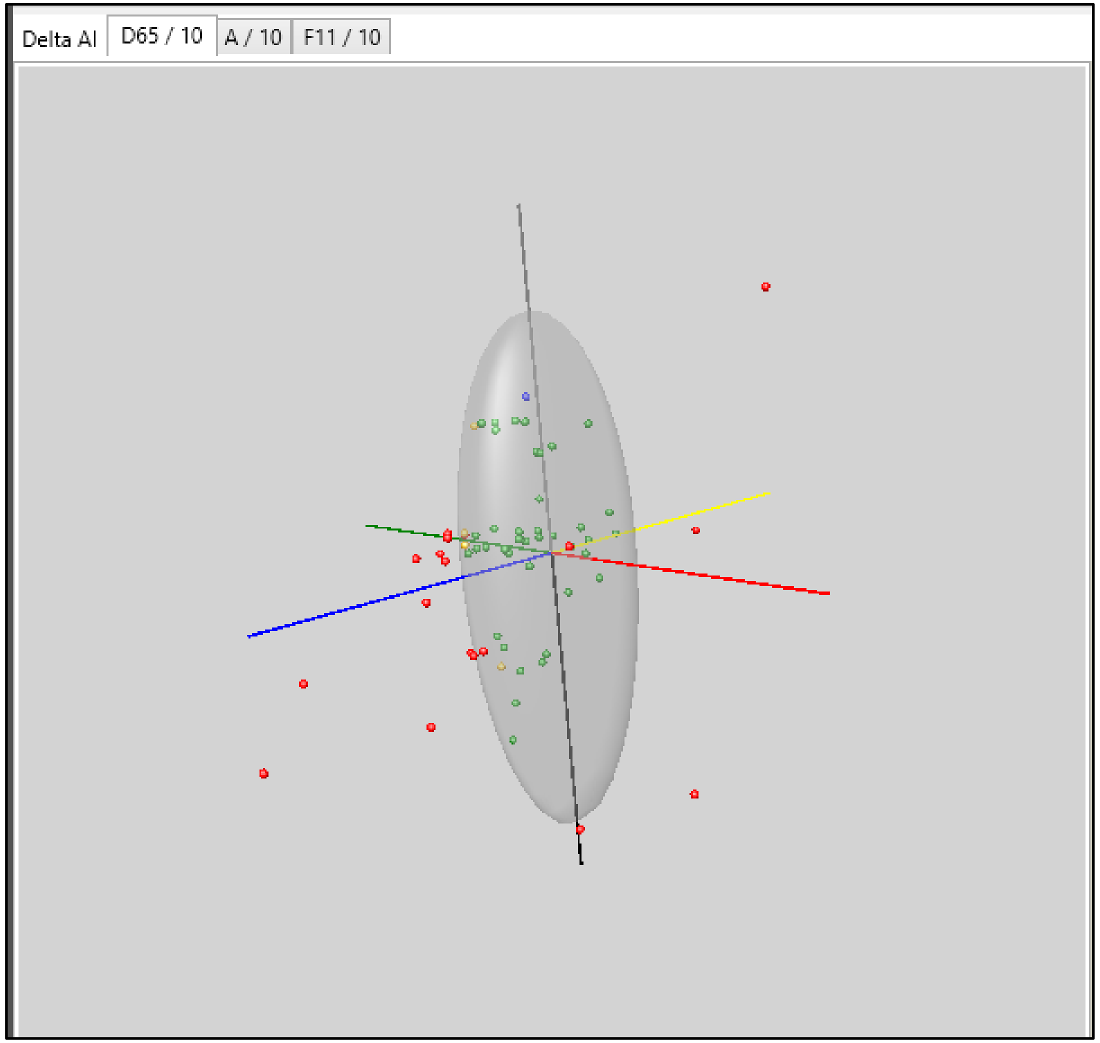

AI Generated Tolerance

Yellow Gold Sample

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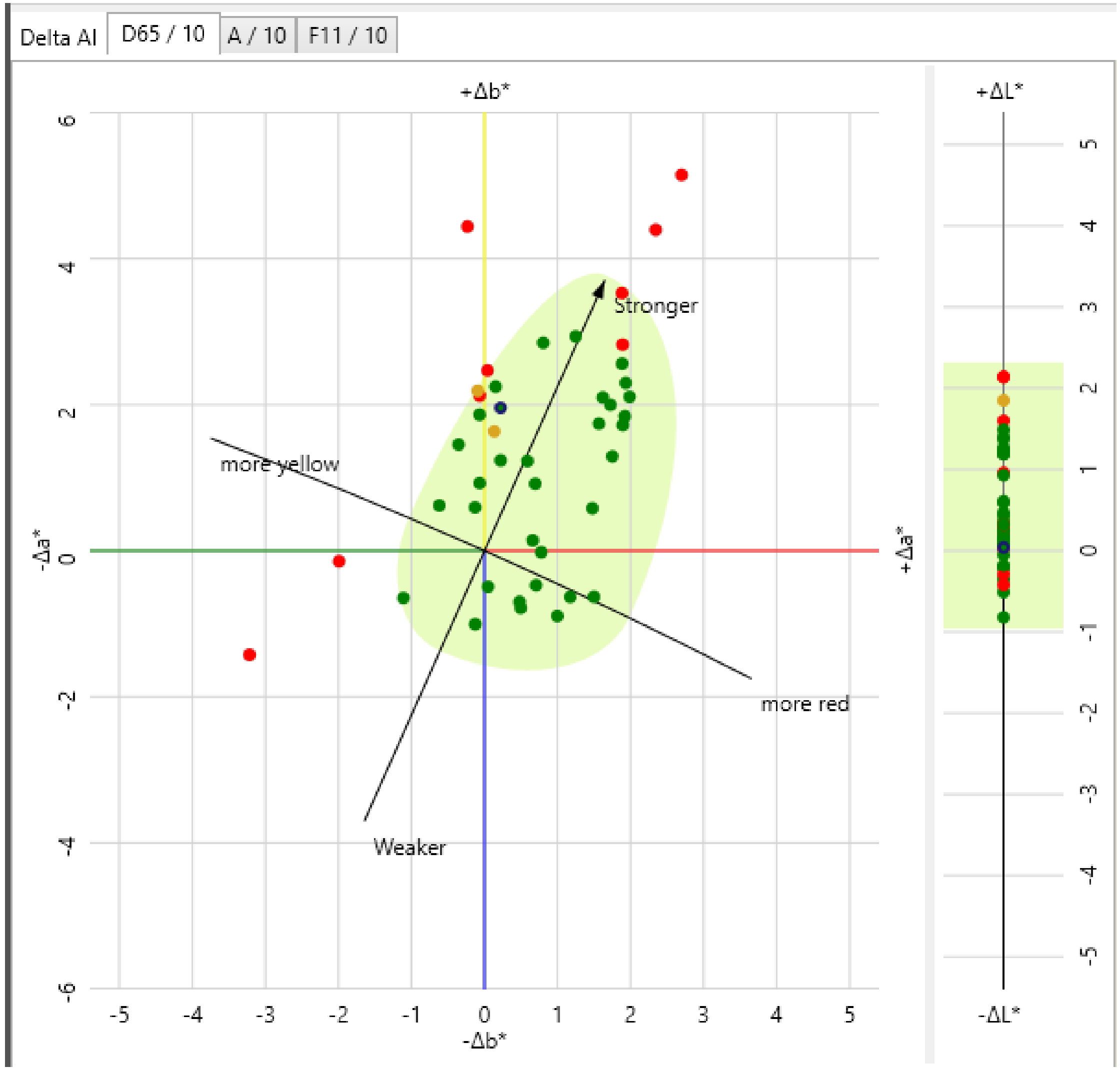

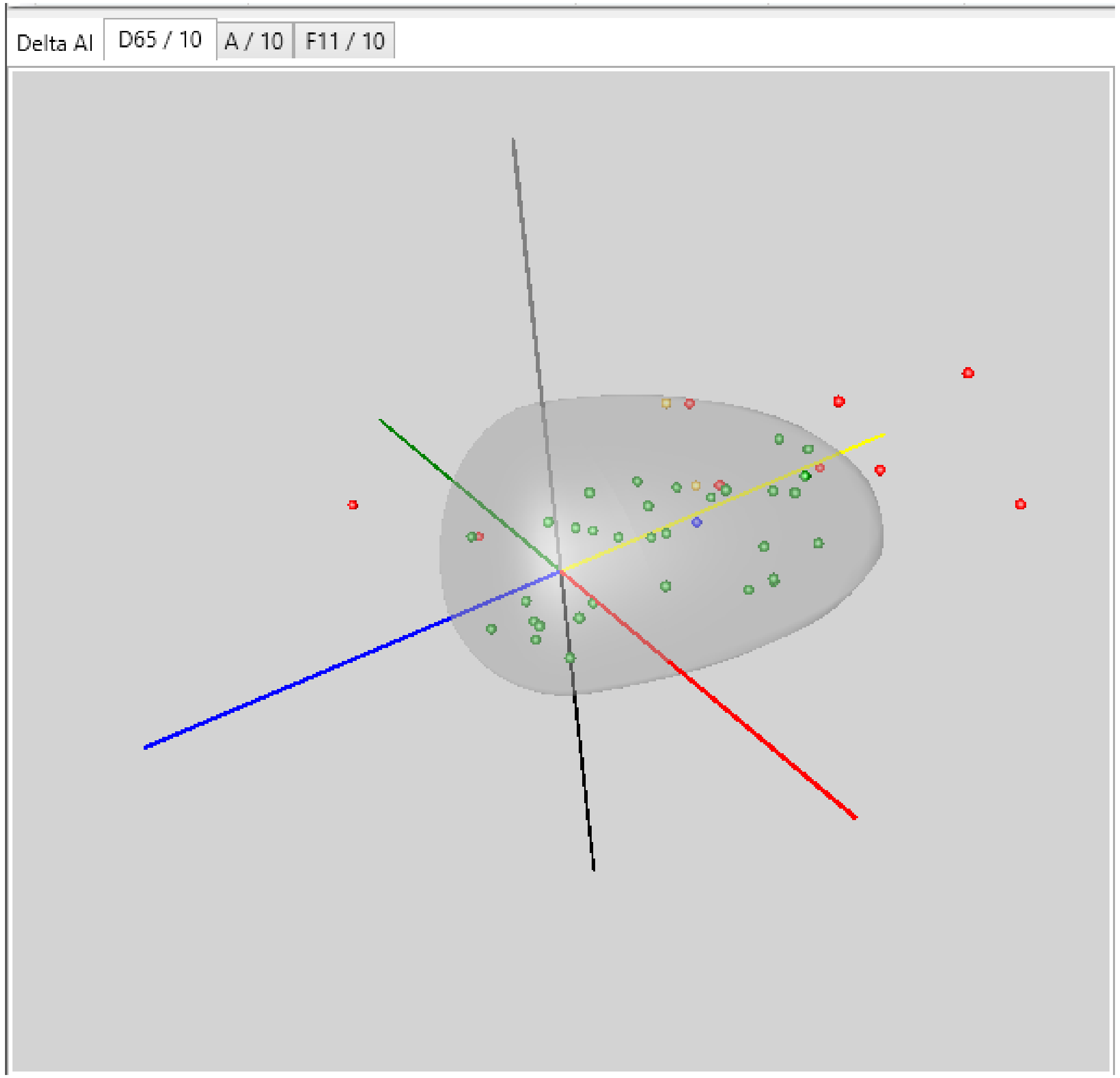

AI Generated Tolerance

Orange Sample

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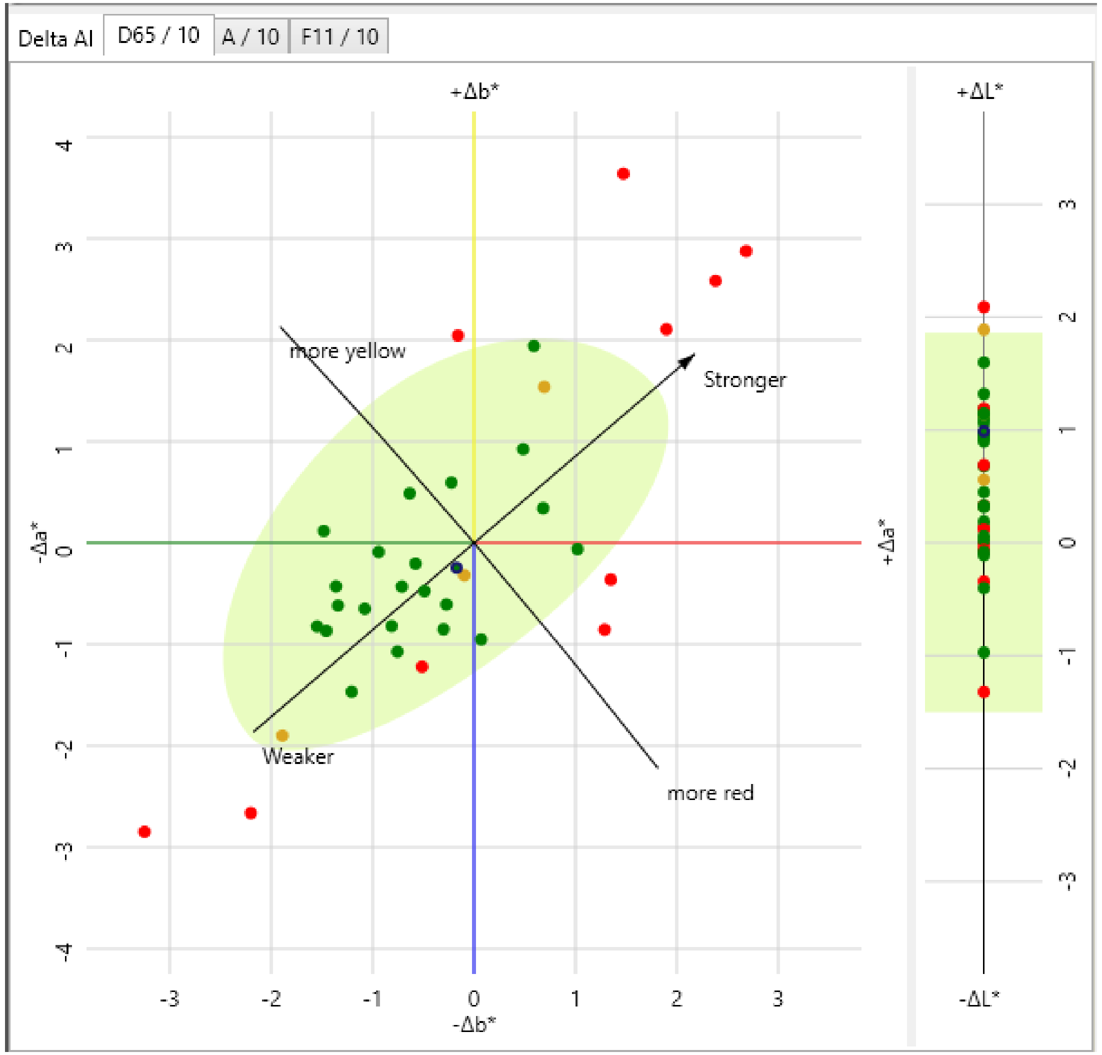

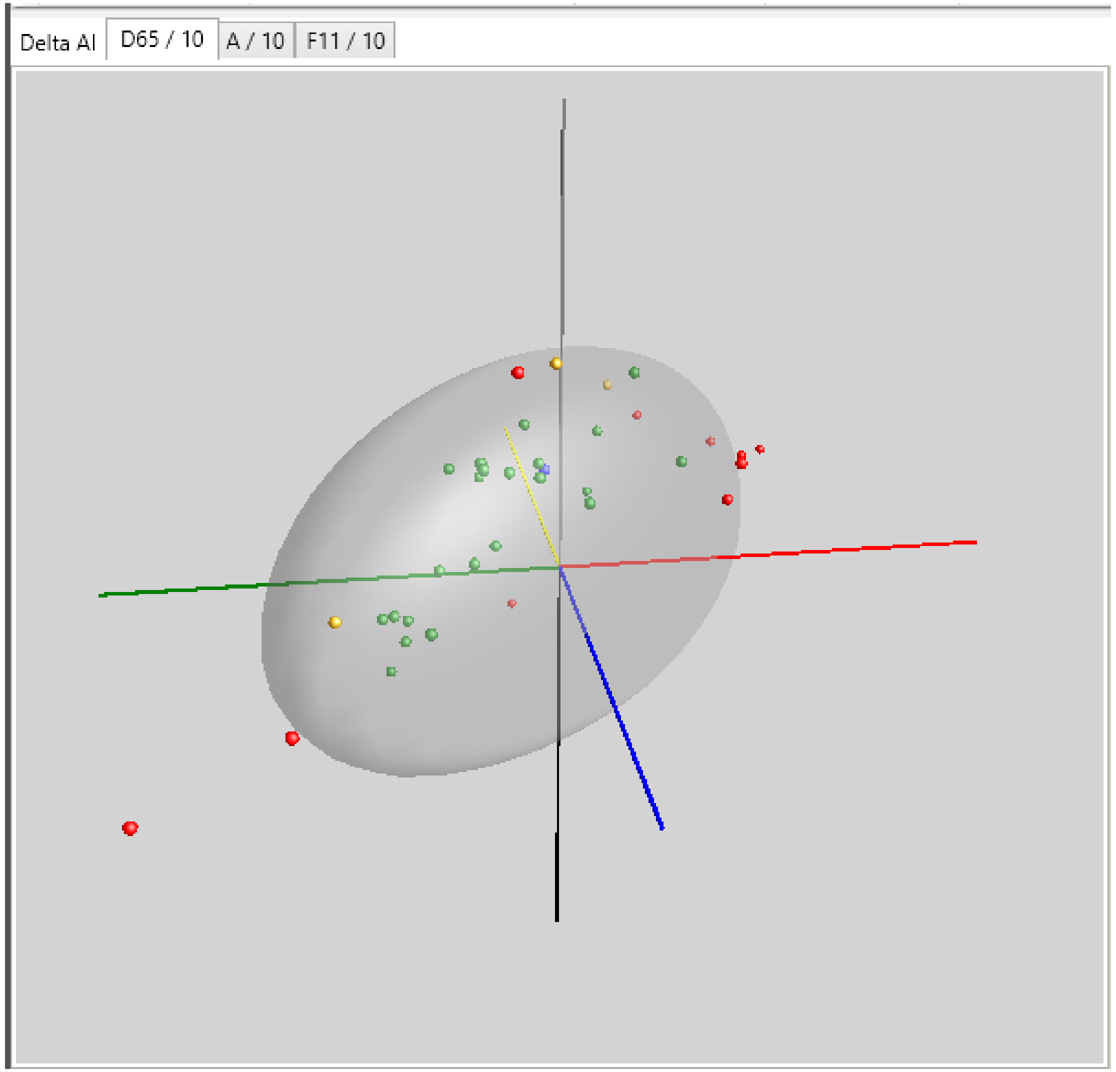

AI Generated Tolerance

Green Sample

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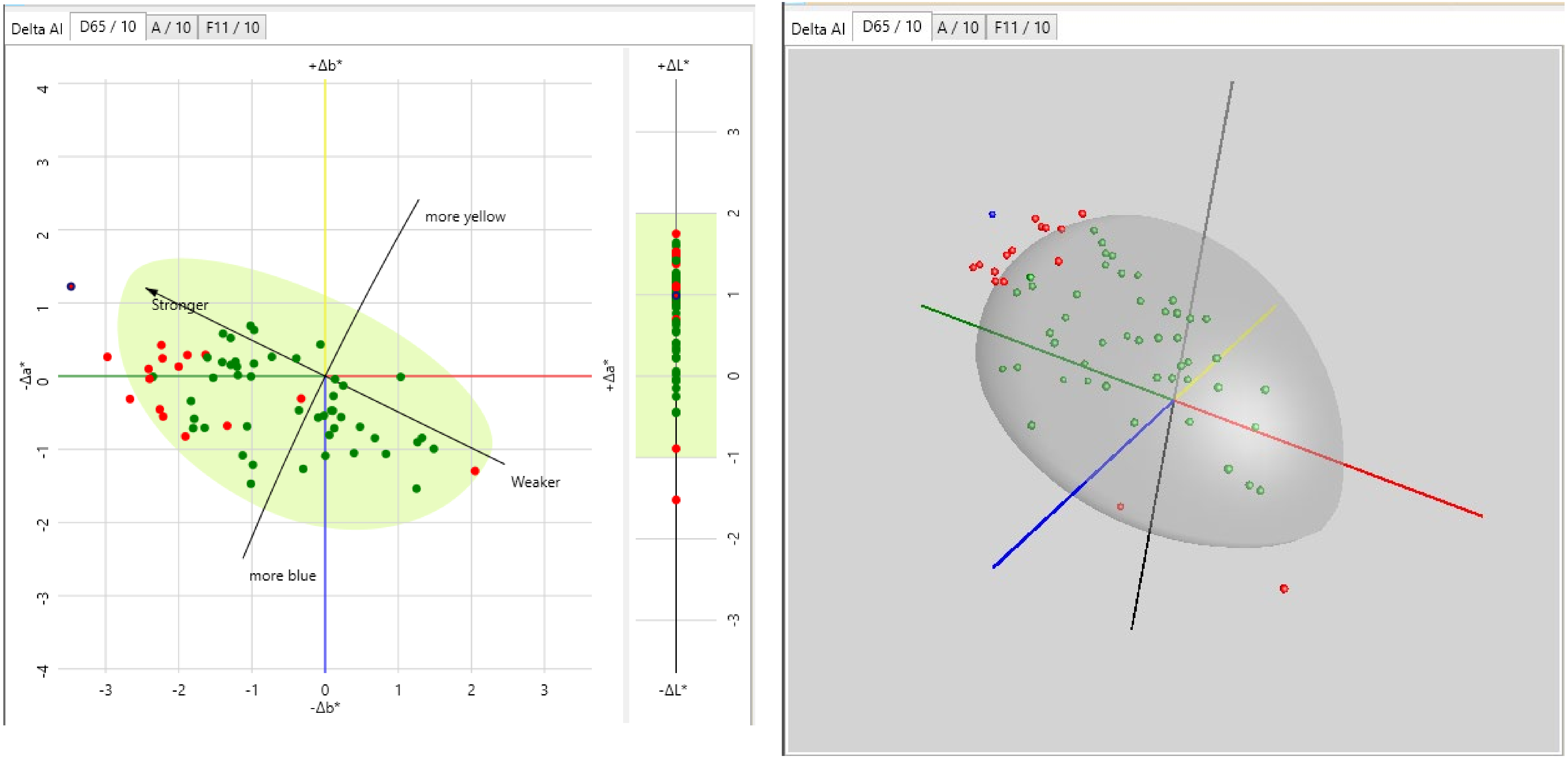

Demo

Datacolor TOOLS examples

Webinar – Questions and Comments

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CMC vs CIE2000
Are the differences between them worth changing?
Are there negatives where CIE2000 isn't as good?
What if mill is using CMC and Retailer is using CIE2000?
Different DE*'s – CIELAB, CMC, CIE2000, DIN99, CIE94 – What to use?

If Spectrophotometer uses D65 light source, does the illuminant for Lab need to be specified?

Cases where DE is very close, but samples are visually far apart.
Cases where DE is very large, but samples look good?

Color difference most accurate for color matching?
Metamerism in architectural coatings?

DE* calculated by DL*,Da*,Db* same as by DL*,DC*,DH*? Yes.

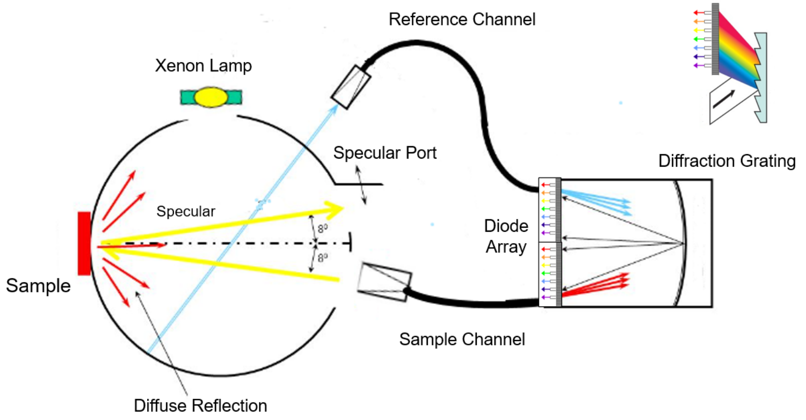
DE's to different materials, any limitations?

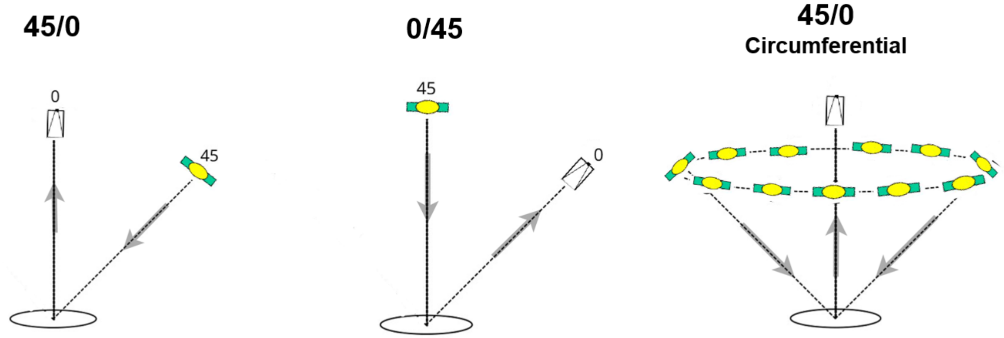
Vector direction in color space?

Next session:

We will talk about visual and instrumental evaluations

- Instrument Geometry
- Integrating Sphere – d/0, 0/d
- SCI, SCE
- 45/0, 0/45
- Visual Evaluation
- Light Booths
- Follow-up on Questions





Want to learn more?

Sign up at Datacolor Academy for classroom style lectures and demonstrations covering useful color topics in select venues around the globe

Some useful reading material:

Do You Know How Humans See Color?

Follow Datacolor Blog for more useful information datacolor Academy

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