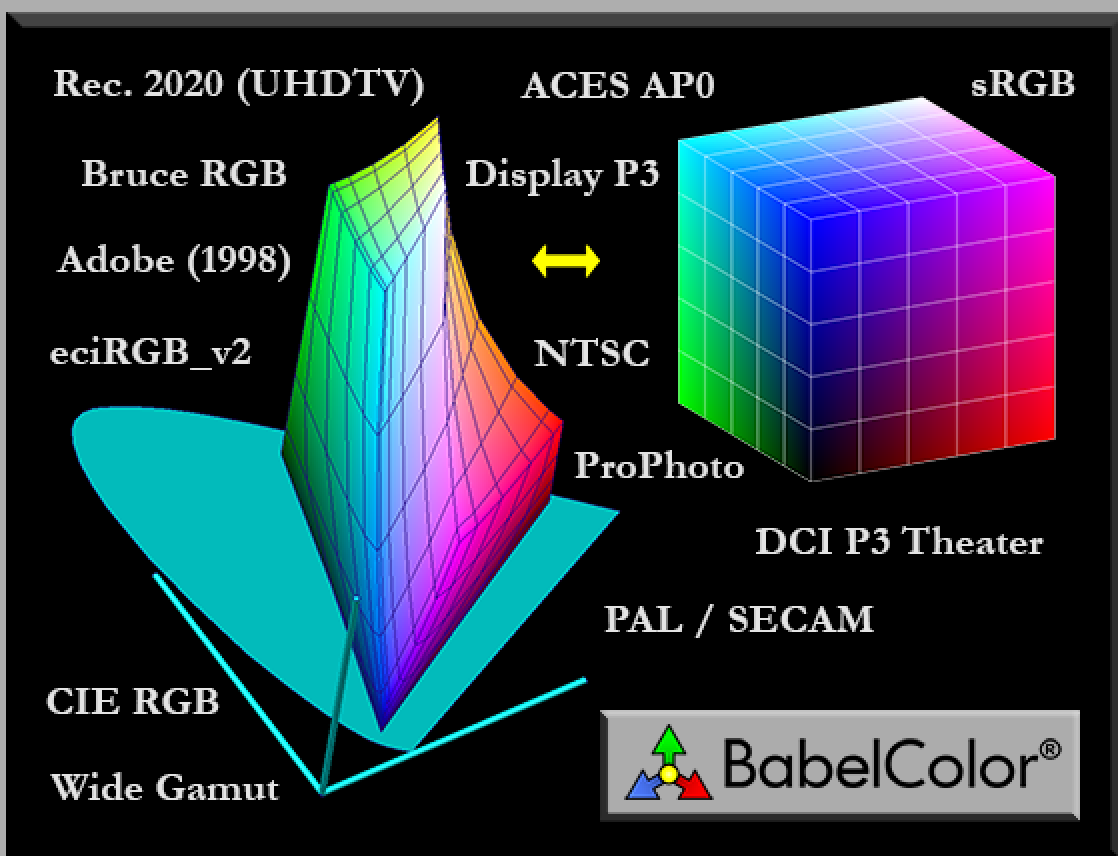
Color Translator & Analyzer (CT&A)

help manual



Version 6.0.7

Color Translator & Analyzer (CT&A) help manual

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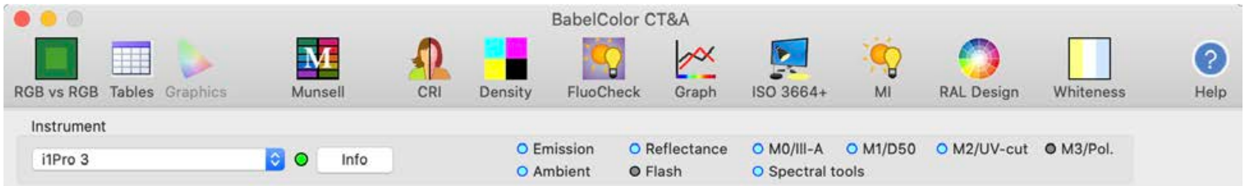
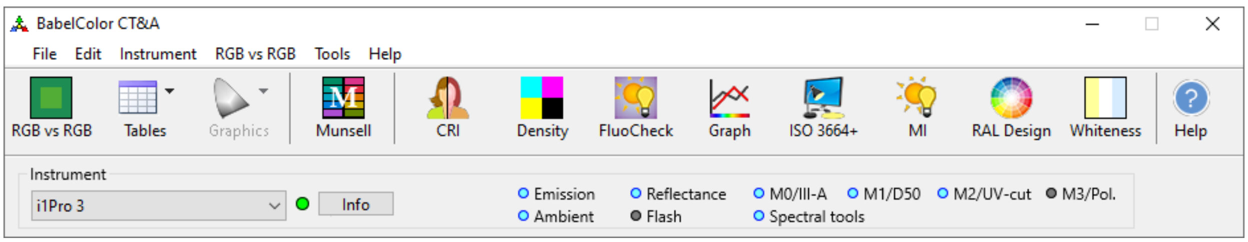
1.1 CT&A overview

The program's full name is "**Color Translator & Analyzer**", but we often use the shorter form, "**CT&A**". The program top window contains a toolbar with icons that open each set of tools in separate windows. The icons are separated in four groups. The first group, with three icons, is associated to the RGB vs RGB tool, a tool which accepts tristimulus type color space inputs such as L*a*b* and RGB (click here for a list of the color spaces that can be used for input). The second group, with one icon, opens the Munsell tools where you can convert FROM and TO Munsell notation. The third group, with eight icons, is associated to tools which require spectral data in order to provide a measurement; these tools are collectively called **spectral tools**. The last group has one icon, which opens the Help documentation, this document.

macOS 10.15 Catalina:



Windows 10 toolbar window:



The **RGB vs RGB** and **Munsell** tools are bidirectional color-space **Translator** and comparator tools, essentially the "**T**" of CT&A. You can use the **RGB vs RGB** tool to compare two colors which are within a predefined or custom RGB space, or which are part of color chips catalogues, herein called "Color Decks." You can convert a color from a Color Deck to an RGB space or find the closest color from an RGB space in a Color Deck. Of course, RGB space to RGB space and Color Deck to Color Deck conversions are also possible. Inputs can be converted to many other color spaces, such as "xyY", "XYZ", "Munsell HVC", and others. The RGB vs RGB tool does not require a color measurement instrument although data can be inputted using such an instrument, which has to be purchased separately (a list of supported instruments is available here).

The **Munsell** tools enables you to convert from Munsell notation to an RGB space and L*a*b*, and the other way around, from an RGB space or L*a*b* to Munsell notation. It can also convert measurements made with the supported spectrophotometers to Munsell.

Important: Four **spectral tools** (CRI, ISO3664+, MI, RAL Design) can use a file as input, with NO connected instrument, or input from from an instrument, if available. The other spectral tools only accept an input from an instrument. Except for the FluoCheck tools, all spectral tools accept input from an i1Pro, i1Pro 2, or i1Pro 3 spectrophotometer, manufactured by X-Rite; the FluoCheck tools require an i1Pro 2 or i1Pro 3. Please note that the Eye-One Display i1Display Pro, Spyder5 and SpyderX are colorimeters which measure only tristimulus data and cannot be used with the spectral tools.

The spectral data is processed and **Analysed**, this is the "**A**" of CT&A, to provide the required information.The spectral tools are grouped in eight windows:

- **Color Rendering Index (CRI):** The CRI tools comprise the current CRI method (CIE 13.3: 1995) and three proposed replacement metrics: the Color Quality Scale (CQS, NIST Version 9.0.3), the CRI2012 (nCRI Version 12.0), and the TM-30 Method (you can switch between versions TM-30-15 and TM-30-18/TM-30-20, the latter being harmonized to CIE 224:2017). It also computes specifically designed metrics for gamut area (GAI: Gamut Area Index) and memory colors (MCRI: Memory Color Rendering Index). The CRI tools accept file input with spectral data provided in either 5 nm or 10 nm intervals; a connected instrument is not required. A dedicated export dialog enables you to generate customized text reports.

- **Density:** The Density tools offers a basic Reflection Density tool as well as more advanced Dot Area, Apparent Trap, Print Contrast, Hue Error, Grayness, and Saturation measurement tools. You can save a text report with all the results.
- **FluoCheck:** The FluoCheck tools provide numerical data on the color stability of one or two samples under the M0, M1, and M2 Measurement Conditions as defined in ISO 13655 (Ref. 42). A Fluorescence Index (FI) is obtained by measuring a sample using either M0 (i.e. Ill-A) or M1 (i.e. D50), and M2 (i.e. UV-cut), and computing the color difference between the two measurements. When two samples are compared, a Fluorescence Metamerism Index (FMI) is obtained by using the M2 measurements of the two samples, and either the M0 or M1 measurements (a different FMI is computed relative to M0 and M1). You can save a text report with all the results plus the measurements spectrums.
- **Graph:** The Graph tools enable you to compare two spectrums and perform simple math operations between them. Measurements can be taken in reflectance, emission, ambient and flash modes. Tristimulus and color space data for both Standard Observers (2 degree CIE1931 and 10 degree CIE1964), and many standard illuminants is also shown. An image of the graphs can be saved and the tool data can be exported in a CGATS formatted text file.
- **ISO 3664+:** The ISO 3664+ tools can be used to measure selected requirements of ISO 3664 and other standards referred by it, including ISO 12646, with additional flexibility in setting the individual goals. For example, you may want to verify how close your display is to a D50 white point, instead of D65 as specified by ISO 3664. Within seconds, obtain the illuminance, the chromaticity, the color temperature, the Color Rendering Index (CRI, as per CIE Publication 13), the spectral quality index as per ISO 23603/CIE Standard 12 (an update of CIE Publication 51), and the brightness uniformity of a light booth or of your room illumination setup. The ISO3664+ tools accept file input with spectral data provided in 10 nm intervals; a connected instrument is not required. You can save detailed data reports or print a one page formatted sheet which is ideal for compliance-type reports.
- **Metamerism Index (MI):** The Metamerism Index (MI) tools provide numerical data on the stability of a sample under various illuminants using the Color Inconstancy Index (CII, CIECAT02). When two samples are compared, a MI index is automatically computed using two methods (CIE 15:2004 and HunterLab). The MI tools accept file input with spectral data provided in 10 nm intervals; a connected instrument is not required. In addition to many standard Illuminants, you can measure or upload the spectrums of up to two ambient illuminants for visualization and computation. You can save a text report with all the results plus the measurements spectrums or a CGATS formatted text file which contains only the measurements spectrums.
- **RAL DESIGN:** The RAL DESIGN tool is used to directly obtain the color of a measured sample in RAL DESIGN notation. You can save a text report with all the results plus the measurements spectrums. The RAL DESIGN tool can also convert spectral data from a file; a connected instrument is NOT required. The file data is immediately converted and saved in a CGATS format text file.
- **Whiteness:** The Whiteness tools are designed to measure the whiteness, brightness, fluorescence, and opacity of printing papers. Please note that fluorescence measurements require either an i1Pro 2 which supports the M0 and M2 Measurement Conditions, or an i1Pro which is NOT UV-cut **plus** a thin transparent UV filter (not provided). The other measurements require compliant white or black backings, which are also not provided; however, you can easily check a backing compliance with the Whiteness tools. An image of the graphs can be saved and the tool results and measurements can be exported in a CGATS formatted text file.

Click here for a **QuickStart guide** on the **RGB vs RGB** tool.

Click here for a **QuickStart guide** on the **Munsell** tool.

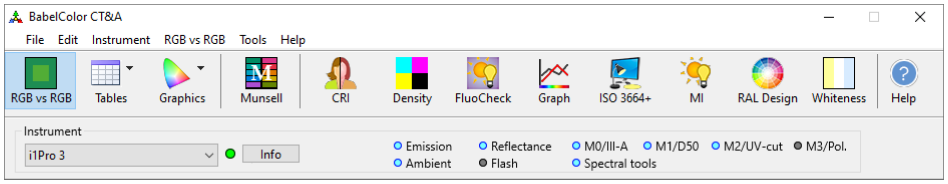
Click here for a **QuickStart guide** on the **spectral tools**.

Click here for **technical data, definitions, and theory**.

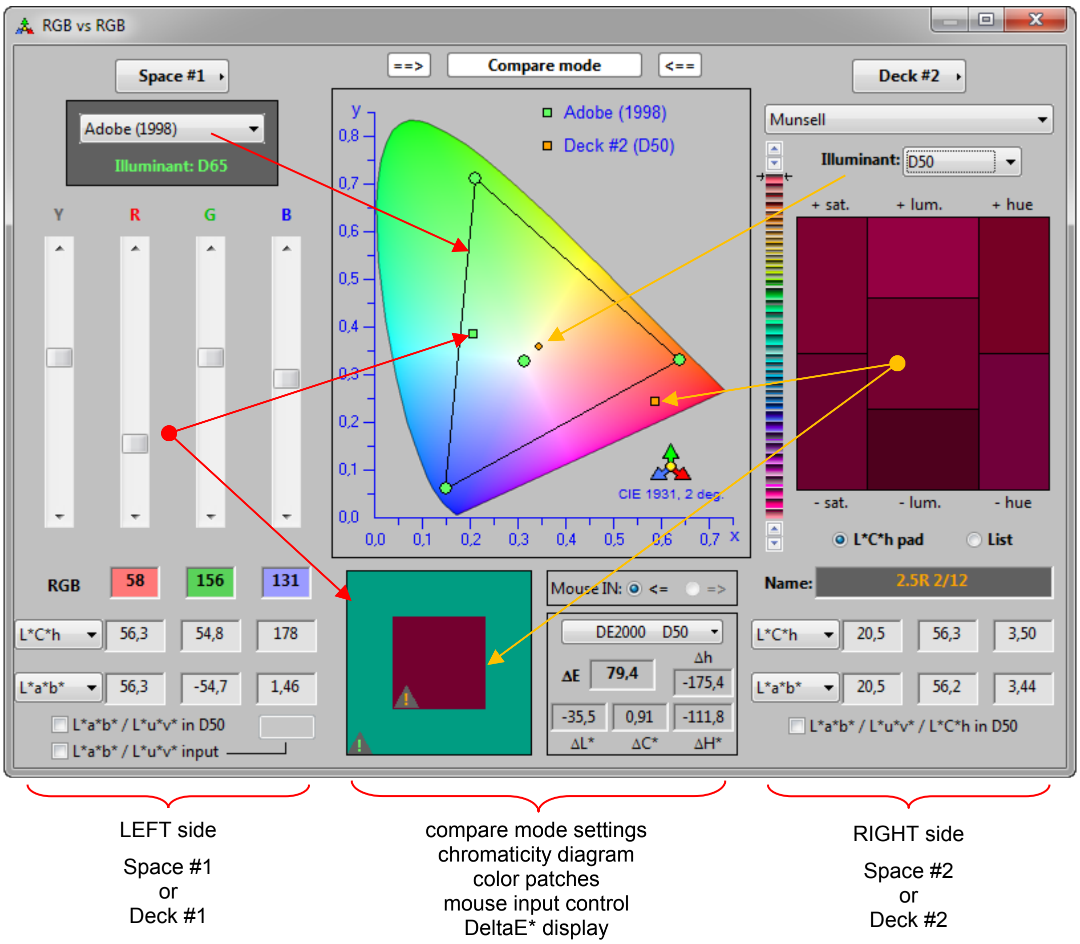
Click here for **tutorials**.

1.1.1 QuickStart: RGB vs RGB

To open the RGB vs RGB tool, just click on the corresponding toolbar button, on the far left. You can also select "Show window" in the "RGB vs RGB" menu, or select "RGB vs RGB" in the "Tools" menu.



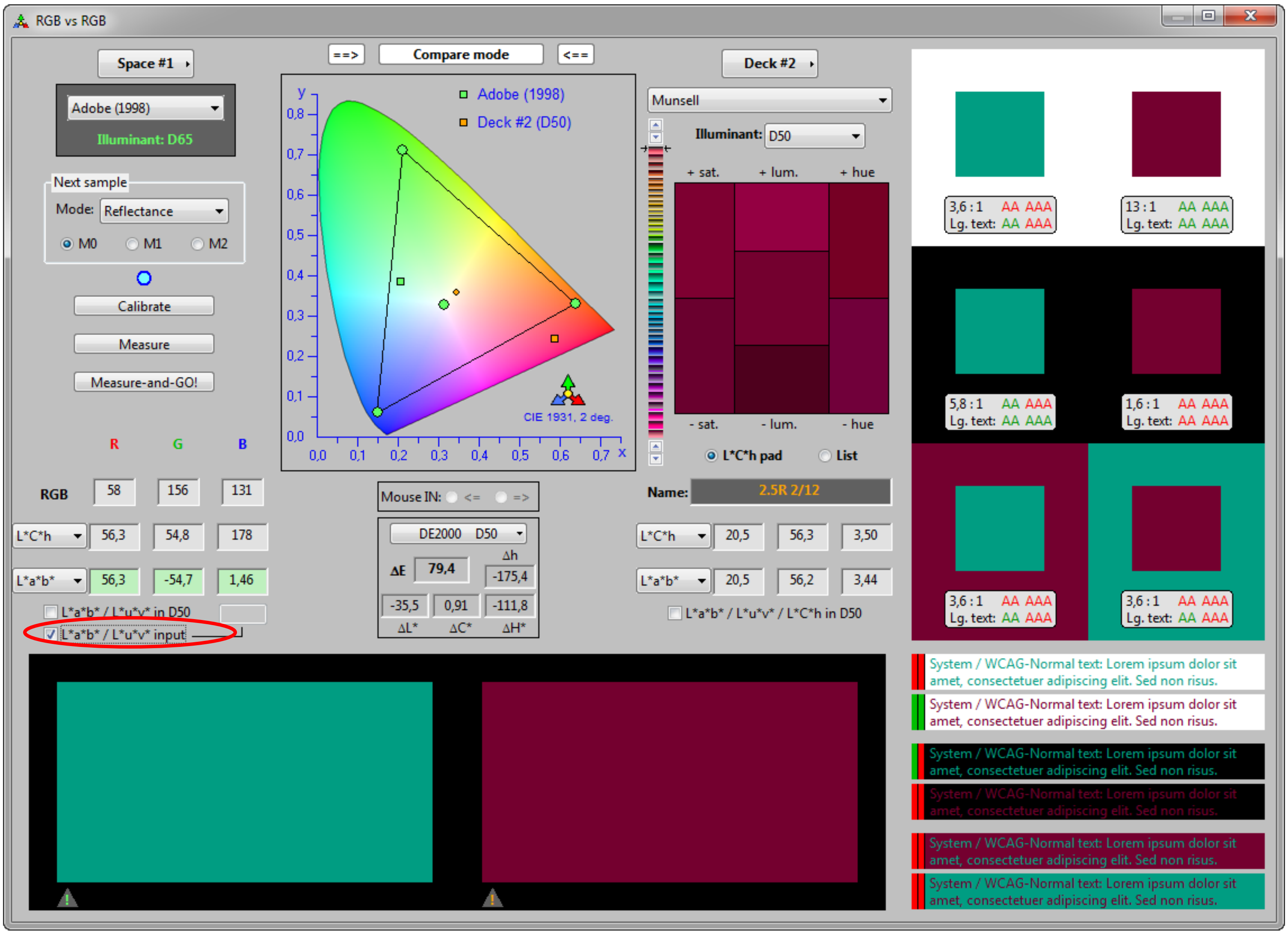
The screenshot just below represents the RGB vs RGB window without its additional patch layouts; these additional patches are shown on the next page.



- The LEFT and RIGHT sides both offer the selection of either "RGB Space mode" or "Color Deck mode".
- Within the RGB Space interface, data can be inserted in RGB, L*a*b* or L*u*v* coordinates, depending on the input mode (see display/input boxes). Data fields with a grayish background do not accept input.
- In the image shown above, input for Space #1 can be done either with the sliders or the RGB input fields.
- In addition, for a Space, data can be inputted by clicking in the "xy" chromaticity diagram window (CIE1931, 2 deg.); the input is directed to the space selected in the mouse input control window.
- L*a*b*, L*u*v*, L*a*b* (D50), or L*u*v* (D50) are alternate input modes for all RGB spaces; they are selected with the checkboxes in the bottom of the space interfaces.
- For a Deck, input can be done by clicking in any color patch surrounding the center patch, by selecting a color within the multi-color strip, or by clicking the arrows on the top and bottom of the strip. A color chip selection mode based on a scrolling patch list can also be selected by clicking on the "List" radio button.
- In "Compare mode", shown above, the inputs are independent of one another.
- In "Convert mode", input on one side is converted on the other side; the side being converted "TO" has all inputs disabled.

- The color-difference between the two spaces colors is shown in the DeltaE* display which also shows the individual contributions of DeltaL*, DeltaC*, and DeltaH*, as well as Delta_h; fourteen DeltaE* variants are offered.
- A color patch of each space is shown below the chromaticity diagram. CT&A is color-managed and all colors are processed through the display profile (the display profile is automatically updated if the window is moved between monitors in a multi-monitor system); any clipping between the actual space color and the display space is flagged with a clipping indicator (exclamation point) in the bottom-left corner of the color patch.

In the screenshot below, we see the RGB vs RGB window enlarged to show extra patches and colored text.

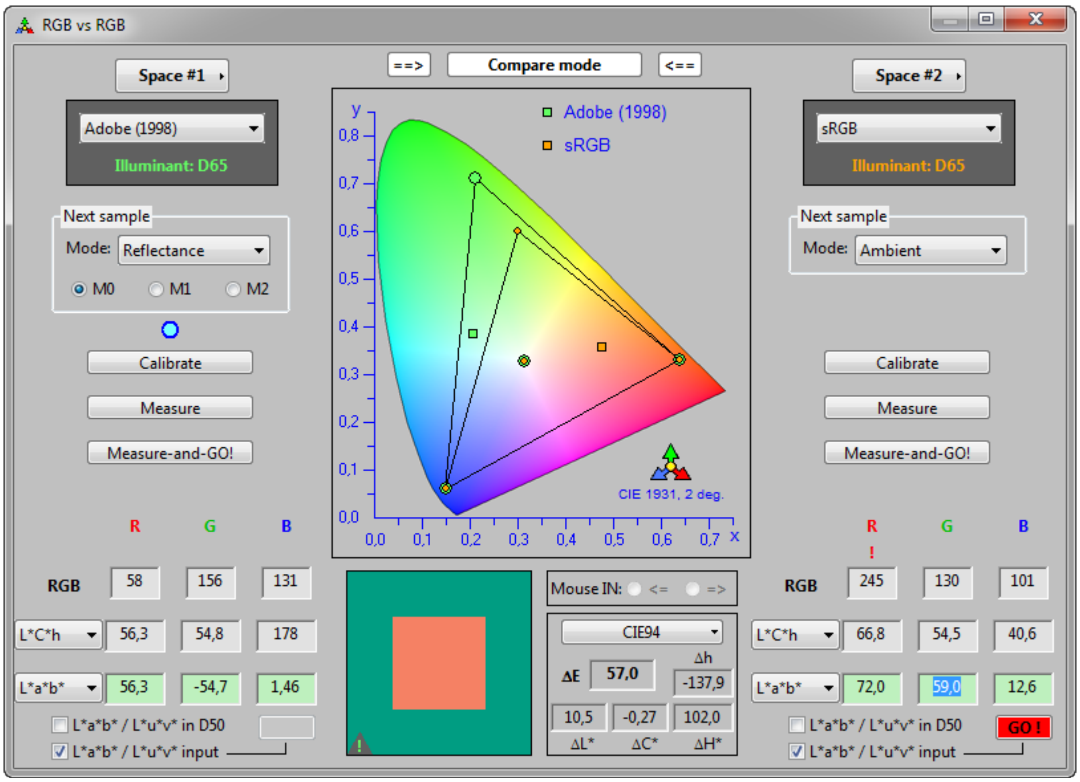


In the bottom-left, we see larger patches presented side by side; you can select a gray, white or black background by just clicking on the patches. In the top-right, we see the patches on different backgrounds simultaneously. In the bottom-right, we see text of each color on white and black backgrounds, as well as on a background of the other color; the text content, the font, and the font style and size can be edited.

The numbers which appear in the six labels located within the patches on the right indicate the Contrast Ratio of the two colors used in each patch combination, as defined in the Web Content Accessibility Guidelines (WCAG) 2.0. The colors of "AA" and "AAA" symbols (**Green**=Pass; **Red**=Fail) indicate compliance at these two contrast conformance levels, AAA being the highest, for both *Normal text* (first label line) or *Large text* (second label line). The two red or green vertical bars in the text area indicate if the contrast requirements are met for the currently selected text size and style, which can be categorized as either *Normal text* or *Large text*.

We have also checked the "L*a*b* / L*u*v* input" checkbox in Space #1. When this box is selected, you can enter L*a*b* or L*u*v* values for this space instead of RGB values; you can also enter data by measuring it with one of the supported colorimeters or spectrometers.

In the screenshot below, we can enter L*a*b*/L*u*v* data on both sides. You will notice, when entering data manually in the L*a*b* or L*u*v* data fields, that the other data displays (RGB, L*C*h, etc.) for this space are **NOT** automatically updated, and a red button with "GO!" written in it appears: GO ! . To update the other data displays, you should first enter all L*a*b* or L*u*v* values and then click on the GO! button (alternately, press the **Return** or the **Enter** key). This manual refresh procedure was devised because the L*a*b* and L*u*v* spaces can describe the entire visible spectrum while the R'G'B' spaces only represent a subset of it. When entering data, it is very likely that the color described by the input data is outside of the R'G'B' space gamut, and clipping will occur; in such a case, clipping will be flagged by one or more red exclamation points located below the "R", "G", and "B" labels. If you press the "GO!" button when clipping is flagged, the software will select the closest color corresponding to the input data within the RGB space.



Here is a short procedure on how to make measurements using a connected instrument.

- If an instrument is properly connected and detected by the program, the "Calibrate", "Measure", and "Measure-and-GO!" buttons will be enabled; also, the measurement mode menu will offer only the modes supported by the connected instrument. In addition, if using an i1Pro series spectrophotometer, a large blue indicator will appear above a "Calibrate" button when the RGB vs RGB window is selected (brought to the front). The blue indicator identifies the space for which a measurement will be done if you press the instrument button; you can also press any "Measure" or "Measure-and-GO!" button (Note: Pressing the instrument button is equivalent to press the "Measure-and-GO!" button). If both spaces can accept input by measurement, the blue indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the other side if required, or do a right-click to lock it on a given side. You can also do a left-click on a locked indicator; the indicator will change side and the new position will be locked.
- Setup-1: Select a measurement "Mode" in the "Next sample" group: Emission, Ambient, Reflectance, Flash. Different modes can be used for each space. For reflectance measurements, and if you are using an i1Pro 2 with the "i1Pro / i1Pro 2 (XRGA)" driver, an i1Pro 3, or an i1Pro 3 Plus, you can select the "Measurement Conditions": M0 (Ill-A), M1 (D50), M2 (UV-cut). If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument.

- The "Illuminant" used to process the measurement will be the one assigned to the RGB space. For reflectance measurements, if this illuminant is not one of the standard illuminants supported by the program (A, C, D50, D65, or E), the measurement will have to be done by first selecting the "L*a*b* /L*u*v* in D50" checkbox; the measurement will then be converted internally to the illuminant of the RGB space. The "Observer" is 2 degree, by default, in all RGB spaces.
- Setup-2: Calibrate the measurement mode shown in the "Next sample" group by clicking the "Calibrate" button.
- When a measurement is made in "Emission", "Ambient" or "Flash" mode, the photometric quantity, cd/m^2, lux, or lux-sec, and the Correlated Color Temperature (CCT, in kelvin) is shown for this sample, just above the "RGB" label. Please note that the CCT may not be provided if the measured coordinates are too far from the central "Illuminant" zone of the chromaticity diagram.

For more information on the **RGB vs RGB** tool, go to the following section:

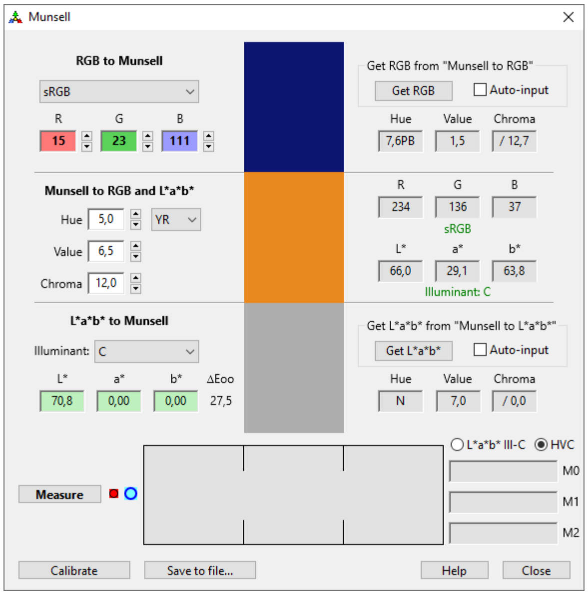
- RGB vs RGB tool
- Text and WCAG data
- Custom RGB space dialog
- Mode Settings (Compare, Convert, etc.)

Click here for **technical data, definitions, and theory**.

Click here for **tutorials**.

1.1.2 QuickStart: Munsell tools

To open, click on the Munsell icon in the toolbar, or select “Munsell” in the "Tools" menu.



- The Munsell tools can accept user-typed input and input from a supported spectrophotometer. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use these tools.
- Please note that some controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated.
- Click on "Save to file..." to save a report of the tools data, including the measured spectral data if applicable.

User-typed input

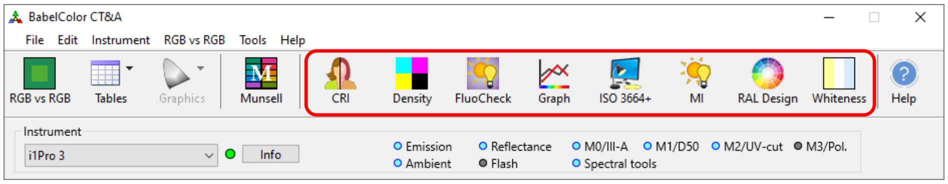
- Input is on the left side of the window and output on the right side. From top to bottom you can: input RGB and get Munsell **Hue Value/Chroma** (HVC); input Munsell HVC and get both RGB and L*a*b* outputs; input L*a*b* and get Munsell HVC.
- The RGB space for both input and output is selected in the RGB input section. The list of RGB spaces is the same as the one available in the RGB vs RGB tools, including the Custom RGB space. You can thus define a Custom RGB space in the RGB vs RGB tool and use it in the Munsell tools.
- The illuminant assigned to both input and output L*a*b* is selected in the L*a*b* input section. The list of illuminants comprises many standard Illuminants, including the **Custom illuminant** assigned to the **Custom RGB space** in the **RGB vs RGB tool**.
- Using popup menus available with a right-click over the input and output fields, as well as dedicated buttons and checkboxes of the interface, you can assign the output of a conversion to the input of another. You can thus evaluate the overall “roundtrip” accuracy of the conversion. This accuracy is affected by rounding, clipping, interpolation and extrapolation accuracy, and the sparsity of the Munsell reference database.
- The CIELAB or CIEDE2000 color difference between the input L*a*b*, which may come from a reference or a measurement, and output L*a*b*, from the Munsell to L*a*b* conversion, is shown in the L*a*b* input section. Do a right-click over the Delta-E data fields to select the color difference formula.

Instrument input

- For instrument input, it is assumed that your instrument is properly connected and detected, as discussed in the beginning of this section, and that the "Calibrate" and "Measure" buttons are enabled.
- If you are using an i1Pro 2 with the "i1Pro / i1Pro 2 (XRGA)" driver, an i1Pro 3, or an i1Pro 3 Plus, all measurements will be taken with the three "Measurement Conditions", M0 (Ill-A), M1 (D50), and M2 (UV-cut). If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument and data will not be shown for the other measurement conditions (Note: Munsell coordinates are provided only in reflectance mode).
- Setup-1: If using an instrument, calibrate it by clicking on the "Calibrate" button.

1.1.3 QuickStart: Spectral tools

To open a set of spectral tools, either click on the corresponding button on the toolbar, or select it with the "Tools" menu. The spectral tools are surrounded by a red line in the screenshot below:



Four spectral tools (**CRI**, **ISO 3664+, MI**, **RAL Design**) can use a file as input, with NO connected instrument, or input from from an instrument, if available. The other spectral tools only accept an input from an instrument. The FluoCheck tools require an i1Pro 2 or i1Pro 3, all other spectral tools accept inputs from an i1Pro, i1Pro 2, or i1Pro 3 spectrophotometer, manufactured by X-Rite. The **Density** and **Graph** tools also support the **M3 Measurement Conditions** when using the **i1Pro 3 Plus**, which has a Polarizer head adapter. Here are the possible configurations:

Spectral tool	Instrument	File input with NO instrument	Note on file input
CRI	i1Pro, i1Pro 2, i1Pro 3 w / Ambient adapter	**Yes**	5 nm or 10 nm spectrum (1+ spectrum(s) / file)
Density	i1Pro, i1Pro 2, i1Pro 3 M3 w / i1Pro 3 Plus	No	
FluoCheck	i1Pro 2 (M0/M1/M2) i1Pro 3 (M0/M1/M2)	No	
Graph	i1Pro, i1Pro 2, i1Pro 3 M3 w / i1Pro 3 Plus	No	
ISO 3664+	i1Pro, i1Pro 2, i1Pro 3	**Yes**	Ambient source: 10 nm spectrum (1 spectrum / file) Emission source: 10 nm spectrum (1 spectrum / file)
MI	i1Pro, i1Pro 2, i1Pro 3	**Yes**	Ambient source: 10 nm spectrum (1 spectrum / file) Ref./Sample: 10 nm spectrum (1+ spectrum(s) / file)
RAL Design	i1Pro, i1Pro 2, i1Pro 3	**Yes**	A file is converted to another file in CGATS format. Input data: 10 nm spectrum (1+ spectrum(s) / file)
Whiteness	i1Pro (M0) i1Pro 2 (M0/M1/M2) i1Pro 3 (M0/M1/M2)	No	You can load a UV filter spectrum from a file. Filter data: 10 nm spectrum (1 spectrum / file)

Important: For all spectral tools which do not support file input, you need to have an i1Pro, i1Pro2, or i1Pro 3 spectrophotometer **connected** to the computer on which CT&A is running.

Note: Some versions of the i1Pro and i1Pro 2 are not fitted with an ambient adapter. These instruments are usually bundled with dedicated software sold by a third party vendor (i.e. NOT X-Rite).

Before taking measurements, the instrument must be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate" and data entry buttons of the tools' window being enabled (some data entry buttons and controls will remain disabled and some data fields will not be available if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Note: In Windows, if the i1Pro/ i1Pro 2 or i1Pro 3 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Instrument button support: When a spectral tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears next to a data entry button ("Get OP", "Get Ref.", "Test", etc.), as shown in the Spectral tools screenshots of this section. This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button. If the tool requires or supports more than one data entry field, the indicator automatically changes location after making a measurement.

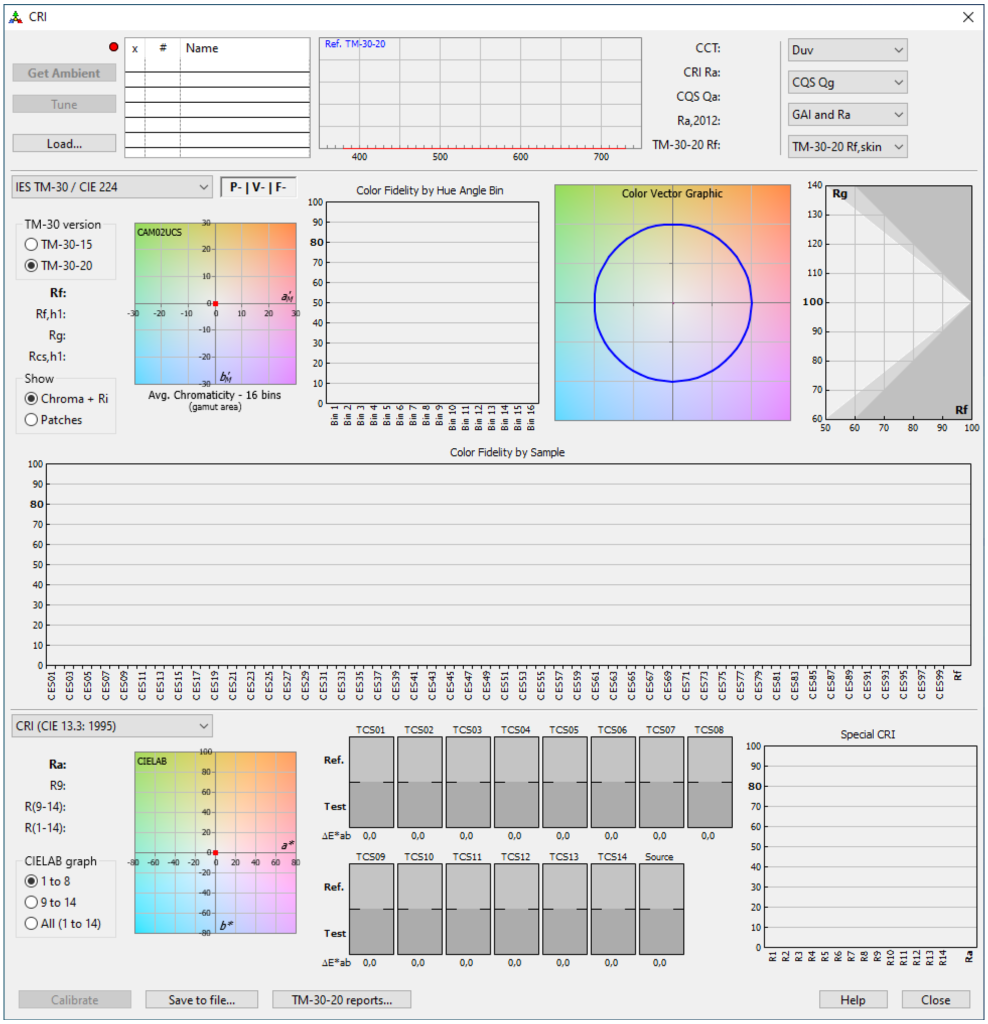
You can click (left-click) on the indicator to move it to the previous measurement if required, or do a right-click to lock it on a given measurement. You can also do a left-click on a locked indicator; the new position will be locked.

In each tool, only the measurement modes (Ambient, Emission, Reflectance, or Flash) compatible with the tool and the instrument can be used. Some tools require/offer more than one measurement mode. At all times, you can calibrate the current tool measurement mode by clicking the "Calibrate" button located in the bottom-left of each tool window.

The "**Save to file...**", "**Save image...**", "**Save report...**", "**Save meas...**", and "**Print report...**" buttons are shown in the bottom of a tool window when the related features are available. Clicking the "Close" button will close a tool window without erasing the current data; opening the tool again using the toolbar or the "Tools" menu will bring back a tool window in its last used state. However, all tool data should manually be saved before closing the program since this data is not automatically saved with this action.

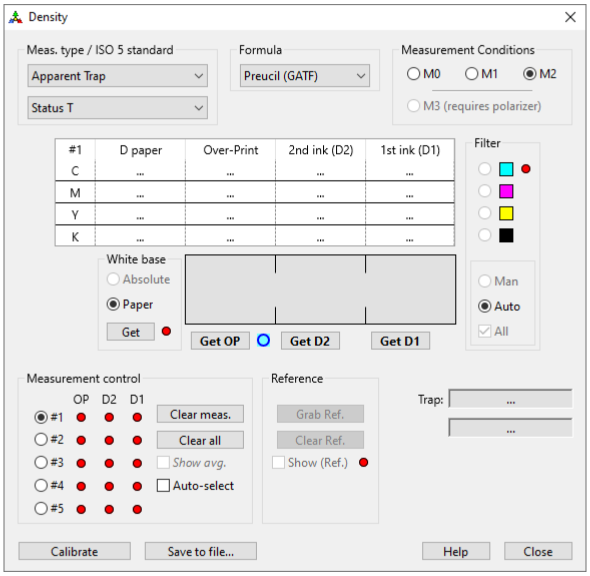
A short introduction on how to use the spectral tools follows.

CRI Tools



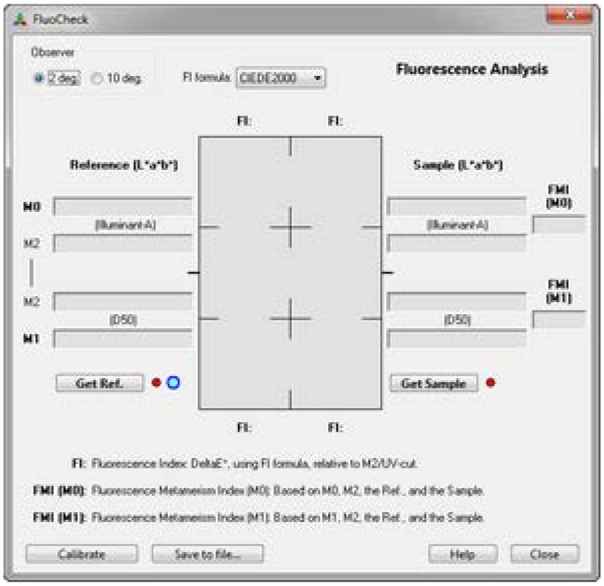
- The CRI tools can accept input from a file or from a supported instrument. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use these tools. Information of the supported metrics is presented in the CRI tools description section.
- Please note that only the interface and processed data related to the standard CRI (CIE 13.3: 1995) is shown when the program is not activated. The interface and processed data for the other metrics is not available.
- For instrument input, it is assumed that your instrument is properly connected and detected, as discussed in the beginning of this section, and that the "Get Ambient", "Tune" and "Calibrate" buttons are enabled. It is also assumed that your instrument supports the use of an ambient adapter as some versions of the i1Pro and i1Pro 2 are sold without this capability.
- The instrument should be calibrated before making any measurements. Click on the "Calibrate" button of the CRI window and follow the indications to perform an "Ambient" mode calibration.
- File input: At any time, you can use a data file as input in place of a measurement. A file may contain one or more spectrums. Acceptable file formats are described in the CRI input file requirements section. There are two methods to open/load a file:
    - 1st method: Click on the "**Load...**" button and select the file to open with the file input dialog.
    - 2nd method: Drag-and-drop the file to open on the "**Load...**" button OR on the **table** located beside the input buttons. You can also drag-and-drop multiple files at a time.
- When the table contains multiple measurements, select the measurement for which you want to see the processed data by clicking in one of the first two columns of a row. Do a right-click on the measurements table to erase all measurements or only the selected ones, or rename all measurements.
- Click on "Save to file..." to open the CRI file options dialog. You can save all data in a single file or each measurement in a separate file, or both.
- Click on "TM-30-20 reports..." to open the TM-30-20 report selector dialog. You can save TM-30-20 reports as images formatted as per the recommended “Simple”, “Intermediate” or “Full” formats.

Density Tools



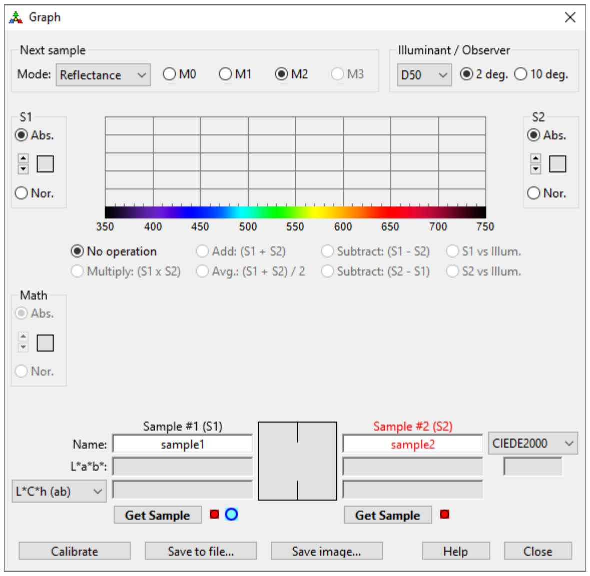
- It is assumed that your instrument is properly connected and detected, as discussed in the beginning of this section, and that the "Calibrate" and "Get x" buttons are enabled. Please note that some data entry buttons and controls will remain disabled if the program is not activated.
- Setup-1: If you are using an i1Pro 3 with an “i1Pro 3” driver, or an i1Pro 2 with the "i1Pro / i1Pro 2 (XRGA)" driver, you can select the "Measurement Conditions": M0 (Ill-A), M1 (D50), M2 (UV-cut). In addition, for the i1Pro 3 Plus, the M3 (Pol., i.e. Polarized) Measurement Conditions are available. If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument.
- Setup-2: Select a "Measurement type": Reflection density, Dot Area, Print Contrast, Hue error - Grayness - Saturation. Data is kept independently for each measurement type.
- Setup-3: Select a "Density standard" defined as per ISO 5-3: Status A, Status E (DIN), Status I (DIN NB, SPI), Status T. You can change the density standard at any time; all previous measurements will be recomputed according to the selected standard.
- Setup-4: If required, select a "Formula" (for Dot Area and Apparent Trap) and set the "*n Factor*" (for Dot Area/Yule-Nielson).
- Setup-5: If available, select a "White base" (for Reflection density, Print Contrast, Hue error - Grayness - Saturation).
- Setup-6: If available, select the "Filter" mode (for Reflection density, Dot Area, Print Contrast).
- Setup-7: Calibrate the instrument by clicking the "Calibrate" button.
- If "Paper" is selected for the "White base", click on the "Get" button and follow the instructions.
- Up to five sets of measurements can be done for each Density tool. Select the measurement set by clicking on a radio button in the "Measurement control" group. You should also see the selected number (#1, #2, etc.) in the upper-left cell of the data table.
- To automatically change the measurement number in the "Measurement control" group, simply check the "Auto-select" box.
- Once a measurement is completed, you can grab it as the reference using the "Grab (Ref.)" button.
- Once there is at least two complete measurements, you can display the average by checking the "Show avg." box. You can grab the average as the reference.
- Click on "Save to file..." to save the data of the selected "Measurement type". You can also save the data acquired in all Density tools.
- **Note**: The measurements made with the M3 Measurement Conditions are separate from those made with the M0/M1/M2 Measurement Conditions which are recorded at the same time.

FluoCheck Tools



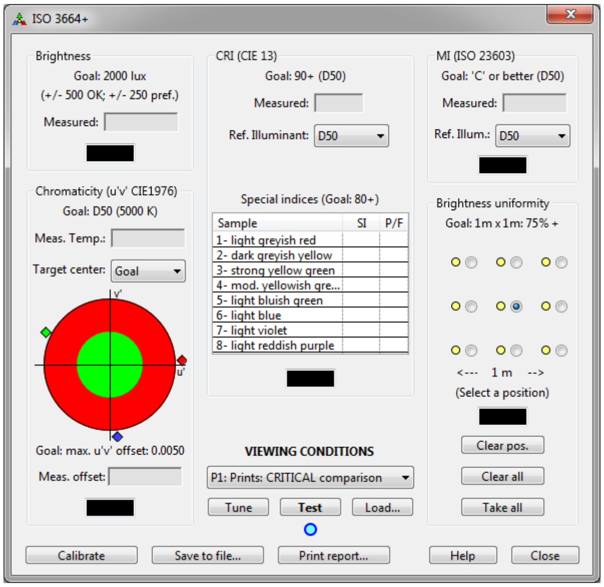
- **Important:** An **i1Pro 2** which supports the **M0** (Ill-A), **M1** (D50), and **M2** (UV-cut) Measurement Conditions is **required** to use these tools (an i1Pro cannot be used!).
- Setup-1: In the toolbar window, you must select the "**i1Pro / i1Pro 2 (XRGA)**" driver.
- It is assumed that your i1Pro 2 is properly connected and detected, as discussed in the beginning of this section, and that the "Calibrate", "Get Ref.", and "Get Sample" buttons are enabled. Please note that some controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated.
- Setup-2: Select an "Observer"; data will be updated if it is changed after a measurement is done.
- Setup-3: Select the "FI formula", a Color difference formula, for the "Fluorescence Index" (FI); data will be updated if it is changed after a measurement is done. This setting does not affect the "Fluorescence Metamerism Index" (FMI) value which is always computed using the CIELAB color-difference formula.
- Setup-4: Calibrate the instrument by clicking the "Calibrate" button.
- To erase a measurement, first press the **Alt** key, in Windows, or the **Option** key on a Mac. Whenever the mouse cursor is within the tool window, the "Get Ref." or "Get Sample" buttons will change their caption to "Clear" (if there is a measurement).
- The Fluorescence Metamerism Index (FMI) is computed when there is a Reference and a Sample. The FMI is obtained by using the M2 measurements of the two colors, and either the M0 or M1 measurements (a different FMI is computed relative to M0 and M1). There is no need for a perfect match under one Illuminant.
- Click on "Save to file..." to save a "Fluorescence report".

Graph Tools



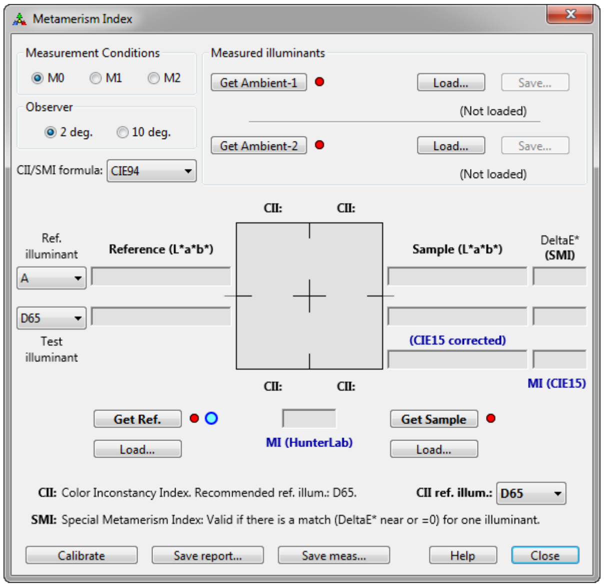
- It is assumed that your instrument is properly connected and detected, as discussed in the beginning of this section, and that the "Calibrate" and "Get Sample" buttons are enabled. Please note that some controls will remain disabled if the program is not activated.
- Setup-1: Select a measurement "Mode" in the "Next sample" group: Emission, Ambient, Reflectance, Flash. Different modes can be used for each sample. For reflectance measurements, and if you are using an i1Pro 3 with an “i1Pro 3” driver, or an i1Pro 2 with the "i1Pro / i1Pro 2 (XRGA)" driver, you can select the "Measurement Conditions": M0 (Ill-A), M1 (D50), M2 (UV-cut). In addition, for the i1Pro 3 Plus, the M3 (Pol., i.e. Polarized) Measurement Conditions are available. If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument.
- Setup-2: Select the "Illuminant" and "Observer" that will be used to compute the colorimetric data (L*C*h, xyY, etc.); data will be updated if they are changed after a measurement is done.
- Setup-3: Select the data type (L*C*h, xyY, etc.) and the color difference formula that will be computed with the acquired data; data will be updated if they are changed after a measurement is done.
- Setup-4: Calibrate the measurement mode shown in the "Next sample" group by clicking the "Calibrate" button.
- When a measurement is made in "Emission", "Ambient" or "Flash" mode, the photometric quantity, cd/m^2, lux, or lux-sec is shown for this sample.
- When a measurement is made in "Ambient" or "Flash" mode, the Correlated Color Temperature (CCT, in kelvin) and Color Rendering Index (CRI) of the sample are shown. You can compare such spectrums against an ideal illuminant by selecting the "S1 vs Illum." or "S2 vs Illum." radio button.
- You can see the numerical coordinates of the spectrums by moving the mouse over the graphs.
- To erase a measurement, first press the **Alt** key, in Windows, or the **Option** key on a Mac. Whenever the mouse cursor is within the tool window, the "Get Sample" buttons will change their caption to "Clear" (if there is a measurement).
- Mathematical operations can be performed with the spectrums. The operations are enabled according to the measurement modes of both samples.
- Click on "Save to file..." to save the spectral data or on "Save image..." to save an image of the display.

ISO 3664+ Tools



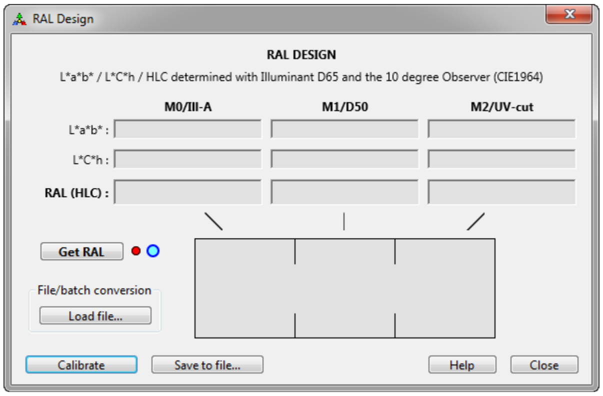
- The ISO 3664+ tools can accept input from a file or from a supported instrument. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use these tools.
- Please note that some data entry buttons and controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated.
- For instrument input, it is assumed that your instrument is properly connected and detected, as discussed in the beginning of this section, and that the "Calibrate", "Tune", "Test" and "Take all" buttons are enabled.
- Setup-1: Select the "VIEWING CONDITIONS". If "Color monitors" is selected, the Color Rendering Index (CRI) and Metamerism Index (MI) tests are not required, and not shown in the dialog.
- Setup-2: Select the chromaticity "Target center"; selecting "Goal" will show the tolerance required by ISO 3664. Data will be updated if the target center is changed after a measurement is done.
- Setup-3: Select the "Ref. Illuminant" for the Color Rendering Index (CRI); D50 is required by ISO 3664. Selecting "Auto" will compute the CRI based on the measured temperature, in kelvin; a D-series illuminant will be selected for color temperatures ≥ 5000 K, and a blackbody will be selected for color temperatures below 5000 K. Data will be updated if the reference illuminant is changed after a measurement is done.
- Setup-4: Select the "Ref. Illum." for the Metamerism Index (MI) determined as per ISO 23603/CIE S 012; D50 is required by ISO 3664. Data will be updated if the reference illuminant is changed after a measurement is done. This test gives a Quality Grade, from "A" to "E", with "A" being the best grade, to the measured illumination relative to the selected ideal illuminant.
- Select one of the positions. There are either 9 or 25 positions depending on the selected Viewing Condition and ISO 12646 version (for color monitors). A complete set of measurements can be taken for each position.
- Setup-5: Calibrate the instrument by clicking the "Calibrate" button.
- File input: At any time, when not tuning, you can use a data file as input in place of a measurement. A file must contain only one (1) spectrum. Acceptable file formats are described in the input file requirements section. There are two methods to open/load a file:.
    - 1st method: Click on the "**Load...**" button and select the file to open with the file input dialog.
    - 2nd method: Drag-and-drop one (1) file on the "**Load...**" button.
- A test result will be shown as **PASS** or **FAIL**. A green colored **PASS** indicates that the test meets the requirements of ISO 3664. A yellow colored **PASS** indicates that the test meets the selected goal but this goal is not the one recommended by ISO 3664.
- When a measurement is made in more than one position, the relative brightness of each position is shown in the "Brightness uniformity" group.
- To rapidly take a measurement at each position, select the "Take all" button. The input position will automatically change after each click on the "Test" button or press of the instrument button. If the "Color monitors" viewing condition is selected, the program can automatically draw either White, Grey, or Dark-Grey targets at the prescribed screen positions.
- Click on "Save to file..." to save the measured data and all derived results.
- Click on "Print report..." to print a well-formatted one-page report which contains information dedicated to compliance-type reports.

Metamerism Index (MI) Tools



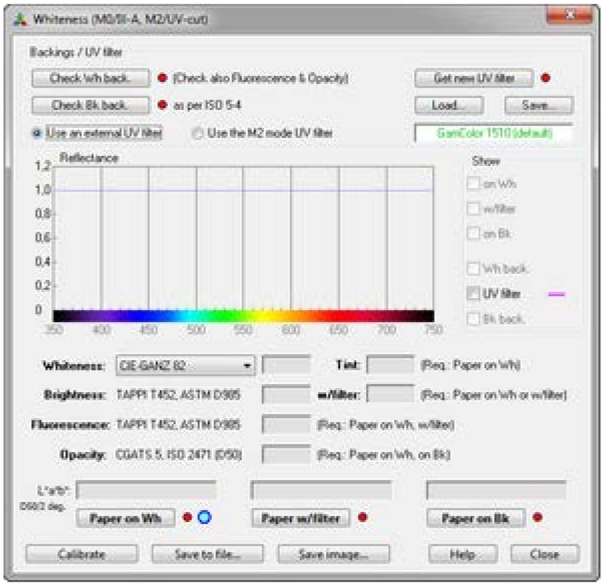
- The Metamerism Index tools can accept input from a file or from a supported instrument. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use these tools.
- Please note that some controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated.
- For instrument input, it is assumed that your instrument is properly connected and detected, as discussed in the beginning of this section, and that the "Calibrate", "Get Ref.", and "Get Sample" buttons are enabled.
- Setup-1: Select the "Measurement Conditions": If you are using an i1Pro 2 with the "i1Pro / i1Pro 2 (XRGA)" driver, an i1Pro 3, or an i1Pro 3 Plus, you can select M0 (Ill-A), M1 (D50), or M2 (UV-cut). If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement condition supported by the instrument. For file input, select a colorimeter in the toolbar; this will disable instrument input for all spectral tools but will enable all measurement conditions in this dialog.
- Setup-2: Select an "Observer"; data will be updated if it is changed after a measurement is done.
- Setup-3: Select the "CII/SMI formula", a color difference formula used for the Color Inconstancy Index (CII), the Special Metamerism Index (SMI), and the CIE15 Metamerism Index (MI). Data will be updated if it is changed after a measurement is done. This color difference formula does not affect the HunterLab MI value which is based on the CIELAB color-difference formula.
- Setup-4: If required, click the "Get Ambient-1" or "Get Ambient-2" button to acquire an ambient illumination (follow the on-screen instructions). Once acquired, you can save the spectrum in a standard CGATS file format. You can also load an ambient spectrum from file (ambient file requirements).
- Setup-5: In the middle-left of the window, select the *Reference illuminant* and *Test illuminant* that will be used for metamerism evaluation; data will be updated if either is changed after a measurement is done.
- Setup-6: Select the reference illuminant for CII computation ("CII ref. illum."). Recommended illuminant: D65.
- Setup-7: If using an instrument, calibrate it by clicking on the "Calibrate" button.
- File input: At any time, you can use a data file as input in place of a measurement. A file may contain one or more spectrums. Acceptable file formats are described in the MI input file requirements section.
- To erase an instrument measurement, first press the **Alt** key, in Windows, or the **Option** key on a Mac. Whenever the mouse cursor is within the tool window, the "Get Ref." or "Get Sample" buttons will change their caption to "Clear" (if there is a measurement).
- A Color Inconstancy Index (CII) is computed independently for both the *Reference* and the *Sample*, and for each selected illuminant. The CII is computed relative to the CII reference illuminant as selected in "Setup-6". For example, if D65 is selected as the CII reference, the CII will be zero if D65 was also selected in "Setup-5".
- A color difference (DeltaE*) is computed between the *Reference* and the *Sample* for both illuminants of "Setup-5" above. If the *Reference* and *Sample* match, or nearly match, under one Illuminant, the color difference obtained for the Illuminant which does not match is called the Special Metamerism Index (SMI).
- The CIE15 and HunterLab Metamerism Indices (MI) are computed when there is a *Reference* and a *Sample*. There is no need for a perfect match under one Illuminant.
- Click on "Save report..." to save a "Metamerism Index report", with all the results and the measurements data or on "Save meas..." to save the *Reference* and *Sample* patches spectrums in a CGATS format text file.

RAL DESIGN Tool



- The RAL DESIGN tool can accept input from a file or from a supported instrument. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use this tool.
- Please note that some data fields will not be available (shown as "N.A. in demo") if the program is not activated.
- For instrument input, it is assumed that your instrument is properly connected and detected, as discussed in the beginning of this section, and that all buttons are enabled.
- If you are using an i1Pro 2 with the "i1Pro / i1Pro 2 (XRGA)" driver, an i1Pro 3, or an i1Pro 3 Plus, all measurements will be taken with the three "Measurement Conditions", M0 (Ill-A), M1 (D50), and M2 (UV-cut). If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument and data will not be shown for the other measurement conditions (Note: RAL DESIGN coordinates are provided only in reflectance mode).
- Setup-1: If using an instrument, calibrate it by clicking on the "Calibrate" button.
- File input: At any time, you can convert spectral data in a file to RAL DESIGN values in place of a measurement. A file may contain one or more spectrums. Acceptable file formats are described in the RAL DESIGN input file requirements section. The input data is immediately converted and saved in a CGATS format text file. There are two methods to open/load a file:
    - 1st method: Click on the "**Load file...**" button and select the file to open with the file input dialog.
    - 2nd method: Drag-and-drop the file to open on the "**Load file...**" button. You can also drag-and-drop multiple files at a time.
- Click on "Save to file..." to save a "RAL DESIGN report" based on **instrument measurements**, i.e. not from file input.

Whiteness Tools



- **Important:** If using an i1Pro, fluorescence measurements require a thin, transparent, UV filter, which is not provided and must be purchased separately; in addition, the i1Pro must NOT be UV-cut. If using an i1Pro 2 or i1Pro 3 which supports the M0 and M2 Measurement Conditions, a separate filter is not required. If your i1Pro 2 only supports the M2 (UV-cut) measurement condition, it cannot be used with this tool. The whiteness measurements require compliant white or black backings, which are also not provided; however, you can easily check white and black backings compliance with the provided tools.
- It is assumed that your instrument is properly connected and detected, as discussed in the beginning of this section, and that the "Calibrate" as well as all the data entry buttons are enabled. Please note that some data entry buttons and controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated.
- Setup-1: If you have an i1Pro 2 or i1Pro 3 which supports the M0 and M2 Measurement Conditions, you can select to use either an external UV filter or the internal filter associated to M2 measurements.
- Setup-2: Select the "Whiteness" formula; a common choice is "CIE-GANZ 82".
- Setup-3: Calibrate the instrument by clicking the "Calibrate" button.
- For a full measurement sequence when using an external filter, first place a blank sheet of paper on a compliant white backing and press on the "Paper on Wh" button. This will give you the paper *Whiteness* and *Tint*, and its *Brightness*. Then place the UV filter on the paper and press on the "Paper w/filter" button. This will give you the *Brightness w/filter*, and the *Fluorescence*. Finally, remove the UV filter and place the paper on a compliant black backing and press on the "Paper on Bk" button. This will give you the *Opacity*.
- For a full measurement sequence when using an i1Pro 2 or i1Pro 3 with the M2 mode, first place a blank sheet of paper on a compliant white backing and press on the "Paper on Wh" button. This will give you the paper *Whiteness* and *Tint*, its *Brightness*, the *Brightness w/filter*, and the *Fluorescence*. Secondly, place the paper on a compliant black backing and press on the "Paper on Bk" button. This will give you the *Opacity*.
- To check a backing compliance, place your instrument on the backing and click on the relevant "Check..." button. A short message with data will be shown against the button.
- When making measurements with an external filter, this tool requires the transmission spectrum of the UV filter to process the "Paper w/filter" measurement. The program comes with filter data obtained from a commercial filter which may be different from the filter you use, even if of the same brand. We **strongly** recommend that you characterize your own filter. This is done by first measuring a white backing (using the "Check Wh back." button, and then measuring the transmission of the filter on this same backing with the "Get new UV filter" button; the two measurements are processed to extract the filter transmission properties. The measured filter becomes the default filter afterwards, even if you do not save it in a file; you can export the filter spectrum in a separate file if you wish, or load a filter spectrum from file (this is useful to restore the default filter if required; the file is provided in the "UV-filters files" folder located within the CT&A application folder). Please consult the Whiteness tools section for more info on UV filter measurement.
- To see the spectrum of one of the inputs, check the corresponding box in the "Show" group.
- Click on "Save to file..." to save the spectral data and all the derived data, or on "Save image..." to save an image of the display.

For more information on the **spectral tools** features, go to the following sections:

- CRI tools
- Density tools
- FluoCheck tools
- Metamerism Index (MI) tools
- RAL DESIGN tool
- Graph tools
- ISO 3664+ tools
- Whiteness tools

Click here for **technical data, definitions, and theory**.

Click here for **tutorials**.

1.2 Purchasing, Upgrades, Legal info

Click on a link to go directly to the sub-section:

- Purchasing
- Upgrades
- License Agreement / Legal notice
- Copyrights and Trademarks
- Credits

1.2.1 Purchasing

Important:

- You need to purchase a license in order to receive a **Product Key** which enables all of the program's features.
- The software will remain in a limited-features mode as long as it is not activated with the **Product Key**.

If you decide to purchase this program, please go to our Web site and look for the link to our "Store" page. This page will provide detailed instructions, and a link to our secure third party payment processor.

Click on the following link to go to our Web site:

- https://www.babelcolor.com .

If you have a problem with the Web purchasing process or if you have special requirements, click on the following link to send us an e-mail:

- info@babelcolor.com .

1.2.2 Upgrades

A **Product Key** remains valid for fractional changes in the software version. For example, it will be possible to use the same key for versions 6.0 up to, but not equal to, 7.0. For this reason, you should keep the e-mail containing your **Product Key** in a secure place; you will also need this information if you install the program on another computer. Please note that no other **Product Key** will be sent if you lose it or if it gets stolen.

You can check the program version and the activation status in the “About CT&A” dialog.

Upgrading from version 6.x to version 7.x may require additional purchasing.

1.2.3 License Agreement / Legal notice

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You MAY:

a) install and use the Software in evaluation mode with limited features as long as you wish;
b) after purchasing a License and receiving a **Product Key** (also called a License Code), activate the software with the Product Key and use the activated Software, with all features, on a single (one) computer per purchased License (a single Product Key may correspond to one or more Licenses);
c) for a Product Key valid for one License, activate your Product Key on another computer as long as you first deactivate the computer on which the program is currently activated;
d) for a Product Key valid for two or more Licenses, activate and deactivate computers **from the same Company** as long as the number of activated computers does not exceed the number of purchased licenses.

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d) cause or permit reverse engineering, disassembly, decompilation or alteration of this Software;
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f) copy the documentation accompanying the Software;
g) extract the data contained in the Color Decks database and publicly distribute it, or offer it for resale, or use it within another product, without a written agreement with BabelColor.

DATA EXCHANGE

In the activation process, the Software generates a "fingerprint" from hardware components to uniquely and anonymously identify the computer. The Product Key and the “fingerprint” are sent to an activation server which sends back an activation certificate. The activation server will also record network related data from where the request comes from.

INTERNET CONNECTION REQUIREMENTS

You may activate and deactivate a Product Key any number of times for free (i.e. at no cost for you) as long as the computer on which the activation or deactivation is performed is connected to the Internet. If an Internet connection is not available or not possible, the Software can still be activated and deactivated offline but a service fee may be required for each offline activation; in addition, you should allow a few working days for the offline process. An Internet connection is not required once the Software is activated.

TERM

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- "SWOP" is a registered trademark of SWOP, Inc. Since 2005, SWOP is a Program within Idealliance.
- "Windows" is a registered trademark of Microsoft Corporation.
- "X-Rite" is a registered trademark of X-Rite Incorporated.

1.2.5 Credits

DEVELOPED BY

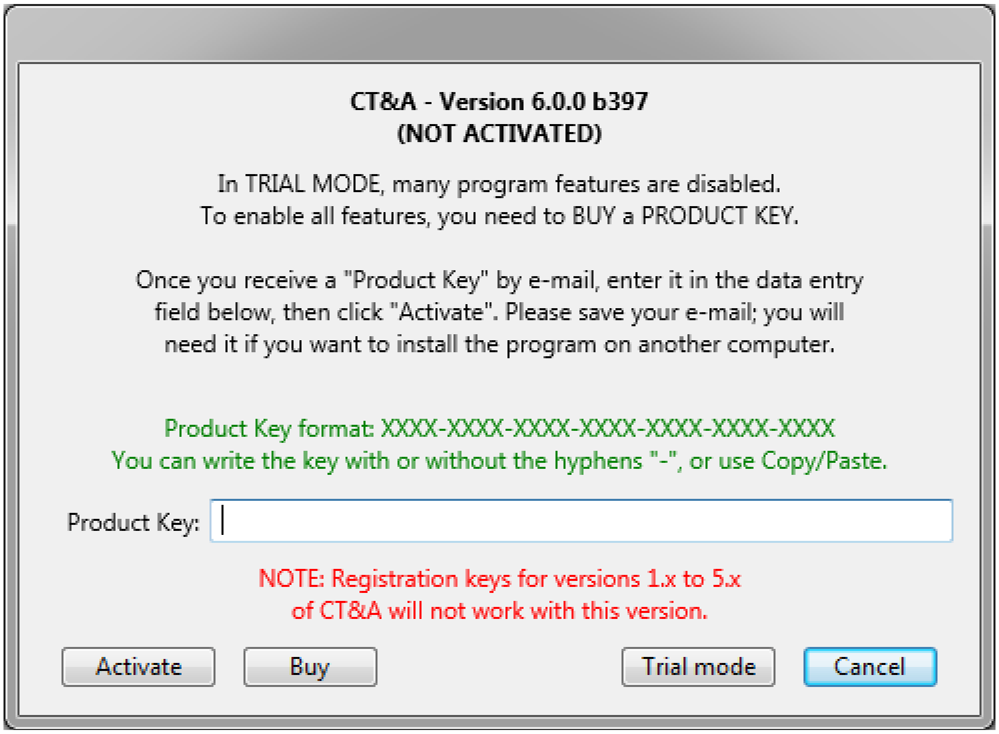
- **Danny Pascale**, programming, documentation, etc.

SPECIAL THANKS TO

- **Sylvie**, for her support and understanding.
- **Marti Maria,** for his free lcms (Little Color Management System, or LittleCMS) color software libraries (https://www.littlecms.com/).
- **Jordan Russell,** for Inno Setup, a free, and really good, installer for Windows applications (https://www.jrsoftware.org/).
- **All friends and customers** who helped improve this product by their comments, questions, bug reports and request for enhancements.

1.3 Activation-Deactivation

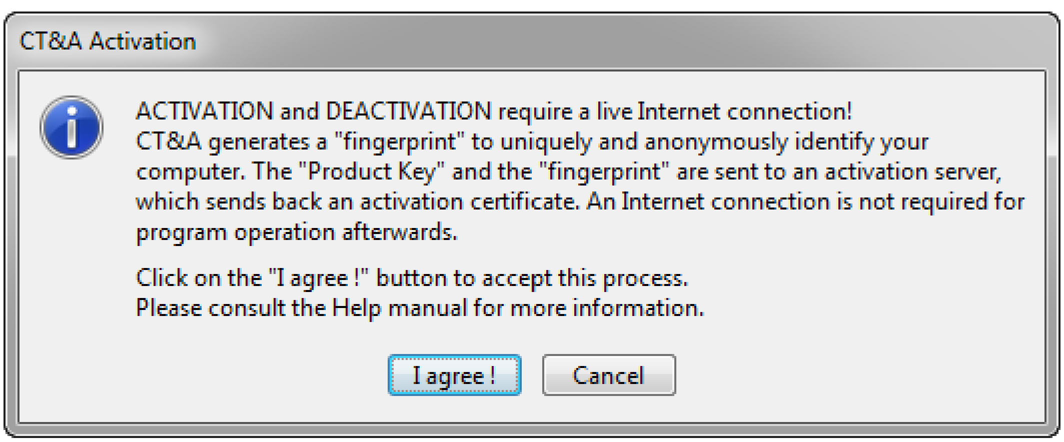
Following your purchase of CT&A, you will receive an e-mail confirming the transaction; this e-mail also contains your **Product Key**. This key is **valid for both the Mac AND Windows** versions! When the program is not activated, the following dialog is shown each time the program is started; please copy the Product Key you received in this dialog. This dialog can also be opened with the "Help/Activate…" menu command.



Copy/Paste shortcuts:

- **Windows:** To copy, press the **Ctrl + C** keys; to paste, press the **Ctrl + V** keys.
- **Mac:** To copy, press the **Command (⌘) + C** keys; to paste, press the **Command (⌘) + V** keys.

When you click on the "Activate" button, the following **activation agreement** dialog opens:



If you know that you DO NOT have an Internet connection, you should still click on the "**I agree !**" button; the program will try to communicate with the activation server and will open an offline activation dialog if the communication fails. Offline activation and deactivation is discussed later in this section.

You can check if your program is properly activated with the "About CT&A…" menu.

Note: No personal data is used to generate the fingerprint. The activation server will also record network related data from where the request comes from. The activation server is managed by a third-party provider.

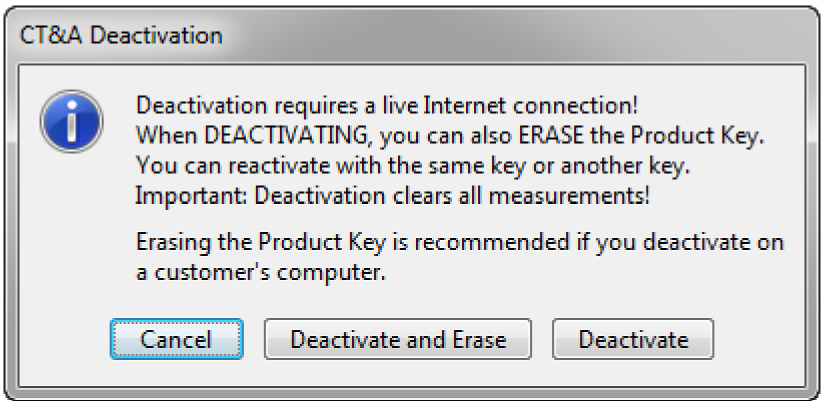
Note: If you have an Internet connection and activation fails, you may need to unblock some specific communications ports used by the program. Activation requires that **ports 80 and 443** be open. Please consult your company's network specialist for help.

Here are shortcuts to sub-sections discussing specific dialogs used to manage your Product Key:

- Deactivation / Transfer
- Reactivation
- Offline activation
- Offline deactivation

Deactivation / Transfer

If you wish to use the program on another computer, you must first deactivate the computer on which your key is being used. To deactivate, select the "Help/Deactivate…" menu command; you will get the following dialog.

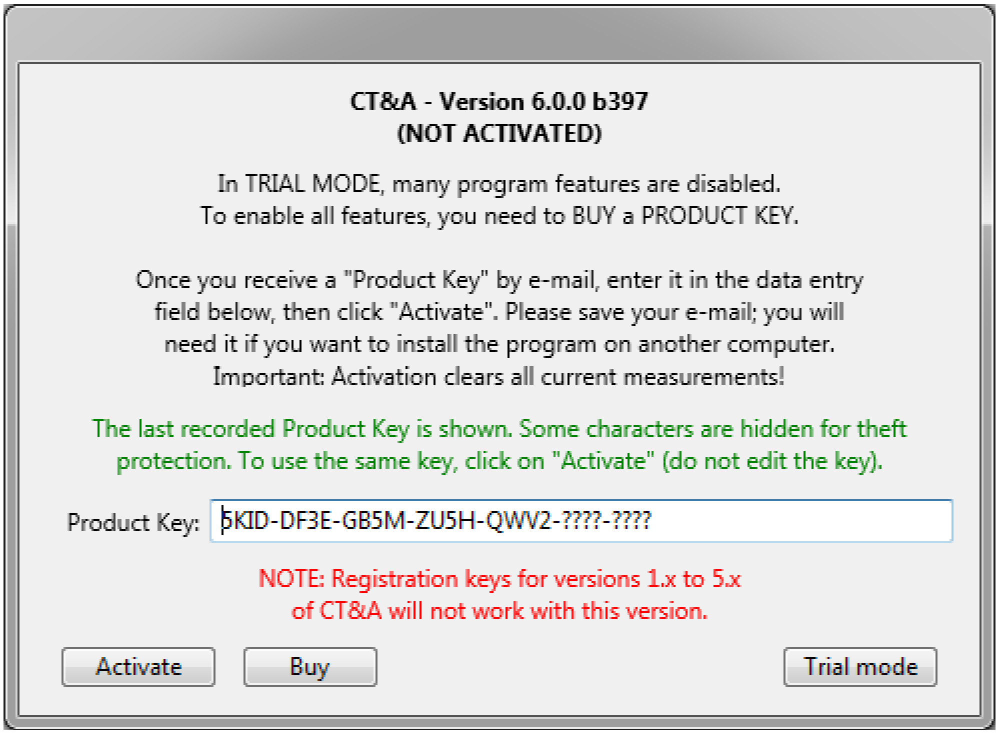


When deactivating, you have the choice to erase or not the Product Key. As indicated in the dialog, erasing the key is recommended if you temporarily installed the program on a customer's computer. You would similarly erase the key if the program was installed on a computer which will foreseeably not be used with CT&A in the future. On the other hand, if you intend to reuse CT&A on this computer soon or on a regular basis, you should just deactivate without erasing the key.

If you know that you DO NOT have an Internet connection, you should still click on either the "Deactivate and Erase" button or the "Deactivate" button; the program will try to communicate with the activation server and will open an offline deactivation dialog if the communication fails. Offline activation and deactivation is discussed later in this section.

Important: If your Product Key is valid for one (1) license, it is your responsibility to deactivate a computer before activating another one with the same key. BabelColor cannot remotely deactivate a computer, so make sure your first computer is deactivated before moving to the second computer.

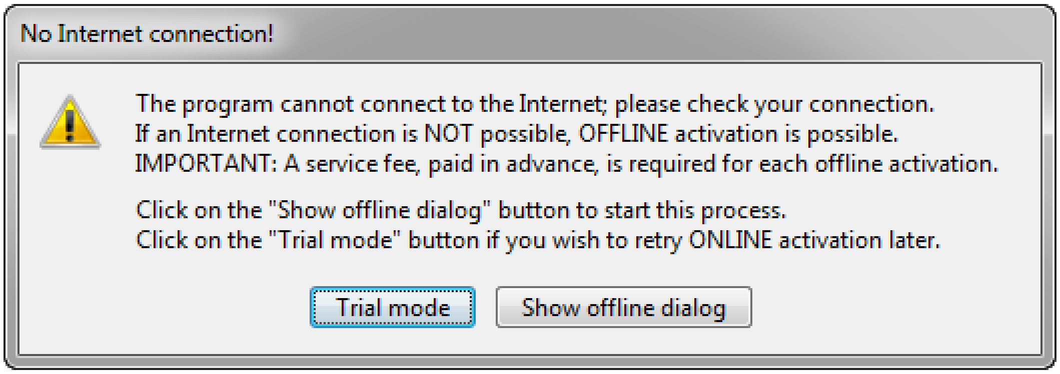
Reactivation
When you re-activate a computer on which the key was not erased, you get the following activation dialog.



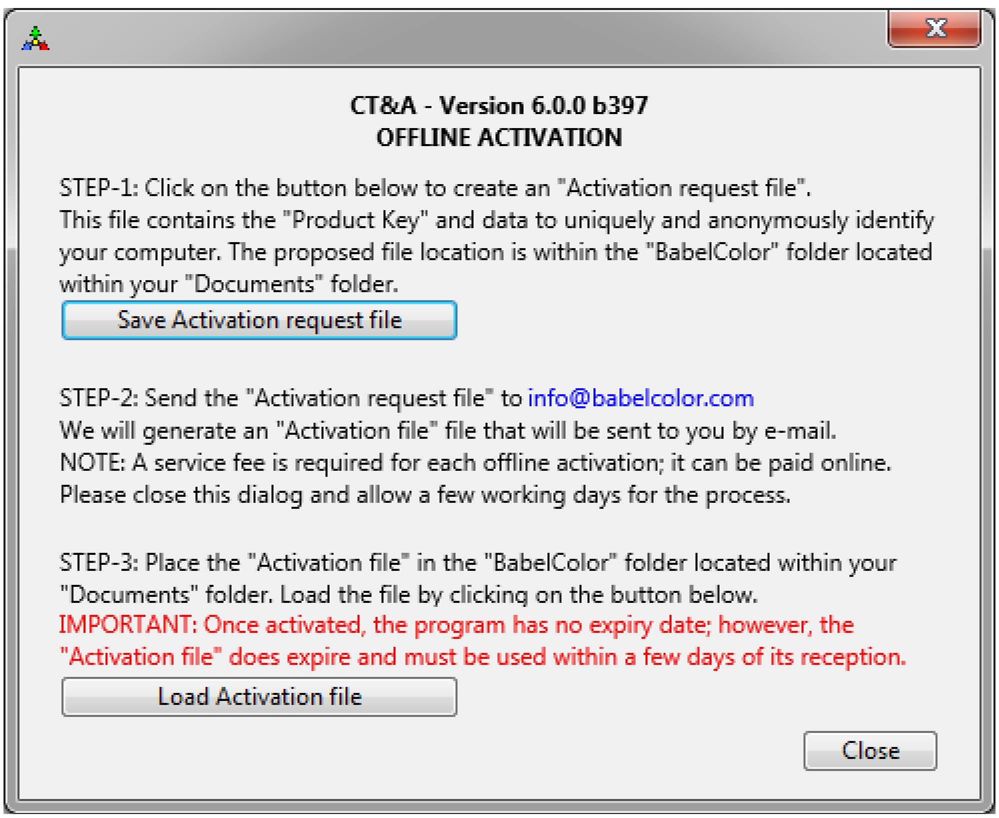
This dialog is the same which appeared when the program was installed and not activated, except that the first characters of the Product Key are now shown, with the last characters hidden. The last characters are hidden for theft protection, to prevent a casual user from copying the key. However, you do not need to replace the interrogation points (?) with the correct values to reactivate; just click on the “Activate” button. As you see, you can use the same key to activate the program on many computers. Please note that you can only simultaneously activate a number of computers corresponding to the number of licenses assigned to the key; if you purchased one license, then you can activate one computer at a time.

Important: If your Product Key is valid for one (1) license, it is your responsibility to deactivate a computer before reactivating another one with the same key. BabelColor cannot remotely deactivate a computer, so make sure your first computer is deactivated before moving to the second computer.

Offline activation
If you do not have an Internet connection and you want to activate the program, you should still click on the "**I agree !**" button of the activation agreement dialog. Following a communication check, if the absence of Internet connection is confirmed, you will see this dialog:



As mentioned in the dialog, a service fee is required for each offline activation. This fee covers the time to manually process the request and set the activation server. The activation fee can be purchased online on the BabelColor Web Store page. The fee is not required to view the offline dialog, which is shown below and which appears when you click on the "Show offline dialog" button.



The first step is to save an "Activation request file". The default location proposed by the program is the "BabelColor" folder located within your "Documents" folder. The file name will start with "**ActivationRequest-CTA6_**" followed by the first characters of your Product Key.

As indicated in STEP-2, you must send the file to BabelColor. We will verify that you purchased the activation service fee and we will generate an "Activation file" by e-mail. You can now close this dialog; the program will start in evaluation mode, with limited features. Please allow a few working days to complete the process.

Hint: When you receive the "Activation file" which is simply named "**ActivationResponse.xml**" (Note: The file name may also contain additional information to better identify its targeted Key), place the file in the "BabelColor" folder located within your "Documents" folder. This is the default location the program will use when opening it.

To perform STEP-3, you should redo the activation process from the beginning, either by starting the program or with the "Help/Activate…" menu command. When you get to the offline activation dialog, load the "Activation file" by first clicking on the corresponding button. You will get a confirmation message once the "Activation file" is processed; you can also check if your program is properly activated with the "About CT&A…" menu.

Important: When you receive the "Activation file" you should use it promptly since this file is valid for a few days only. However, please note that the activated program has no expiry date.

Transferring a license from an offline computer
Transferring a license requires **deactivating the first** computer and **activating the second** computer. To deactivate a computer activated offline, you have two options:

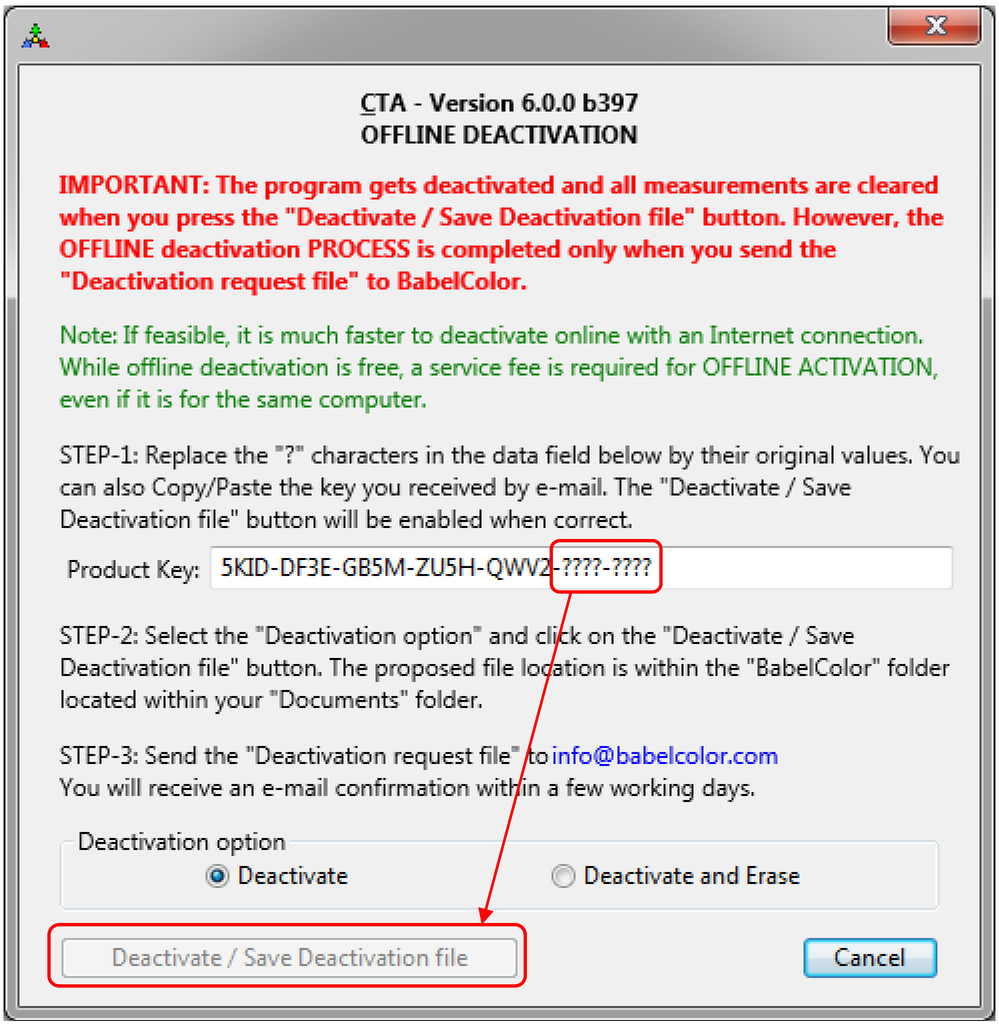
- If the **first** computer is still not connected to the Internet, you must do an offline deactivation.
- If the **first** computer now has access to the Internet, you can deactivate online.

To activate the second computer you also have two options:

- If the **second** computer is not connected to the Internet, you must do another offline activation.
- If the **second** computer has access to the Internet, you can activate online.

Offline deactivation
If you try to deactivate using the "Help/Deactivate…" menu command and there is no Internet connection, you get the following message:

The offline deactivation dialog is shown below:



The "**Deactivate/Save Deactivation file**" button will be enabled when the missing characters of the Product Key are replaced by their correct values. You will find the complete key in the e-mail you received when you purchased the software. This procedure insures that a casual user will not deactivate the program by mistake.

Important: In fact, the program gets deactivated when you SAVE the "Deactivation request file" after pressing the "Deactivate/Save Deactivation file" button; this gives you one last chance to cancel deactivation. However, even if the program is deactivated, the deactivation process is not completed until you send the "**Deactivation request file**" to BabelColor.

Note: While there is no fee required to perform the offline deactivation, we strongly recommend performing the deactivation online if you can temporarily connect the computer to the Internet, since this could save you time.

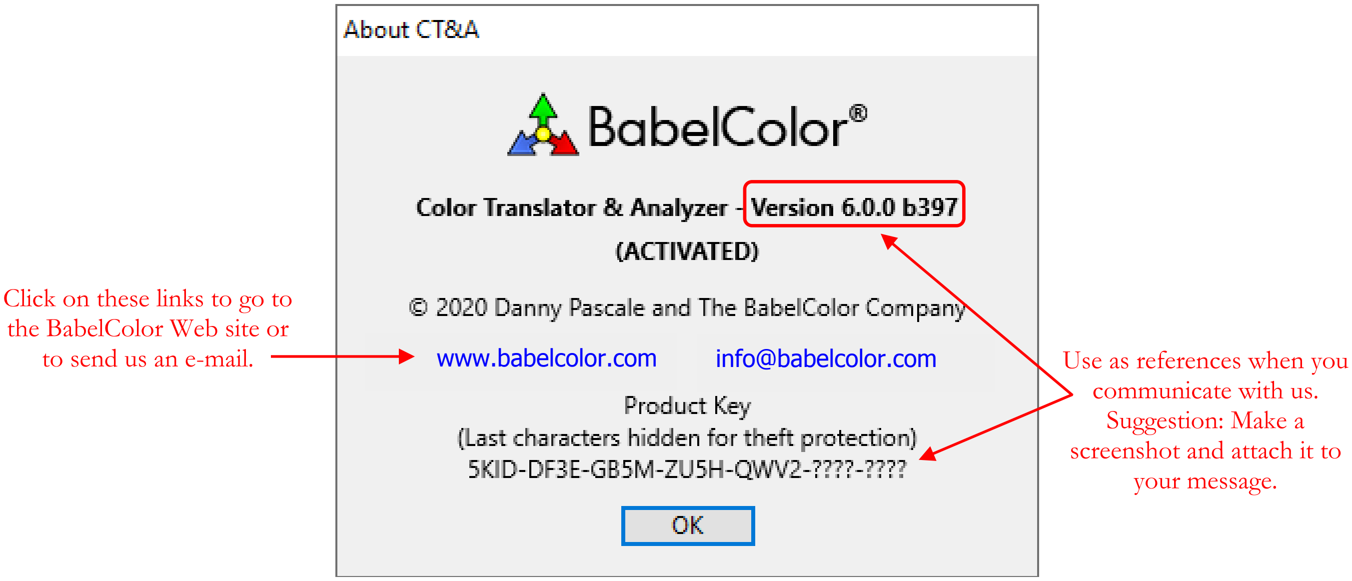
The deactivation options are the same as those available when you deactivate with a live Internet connection. Erasing the key is recommended if you temporarily installed the program on a customer's computer. You would similarly erase the key if the program was installed on a computer which will foreseeably not be used with CT&A in the future. On the other hand, if you intend to reuse CT&A on this computer soon or on a regular basis, you should just deactivate without erasing the key.

The "Deactivation request file" file name will start with "**DeactivationRequest-CTA6_**" followed by the first characters of your Product Key. Once the "Deactivation request file" is saved, you get a message confirming deactivation; the message will also specifically mention that the Product Key was erased if you selected this option. You should now send the deactivation request file to BabelColor to complete the offline deactivation process.

Important: It is mandatory to send the "Deactivation request file" to BabelColor if you intend to ACTIVATE another computer OFFLINE with the same Product Key. We will not issue a new offline "Activation file" for the same Product Key if we do not receive first the "Deactivation request file" from the previous computer. However, nothing prevents you from deactivating ONLINE if you can connect the computer to the Internet; this is equivalent to a complete offline deactivation procedure.

1.3.1 Checking activation and program version

In Windows, you can check the activation status with the "Help/About CT&A..."; on a Mac, use the "CT&A/About CT&A..." menu. The following dialog will open:



The dialog also shows the current program version. Clicking on the Web link will launch your default Web browser and open the BabelColor home page. Clicking on the e-mail address will open your default e-mail application.

You will notice that only part of the Product Key is shown; its last characters are hidden to prevent a casual user from steeling your license. However, the remaining numbers are still sufficient to identify who purchased the product in case you require product support. As discussed in more details in the Activation-Deactivation section, you can deactivate CT&A on a computer and activate the software on another computer with the same Product Key. When deactivating, you can decide to erase or not the product key. If the product key is not erased on a given computer, you can reactivate this computer without entering the Product Key (and assuming that the Product Key is not activated over its prescribed limit on other computers). If the Product Key is erased, you will need to re-enter the COMPLETE Product Key in the Activation dialog. It is thus essential to keep a copy of the e-mail that contains the Product Key, an e-mail which you received when you purchased the software.

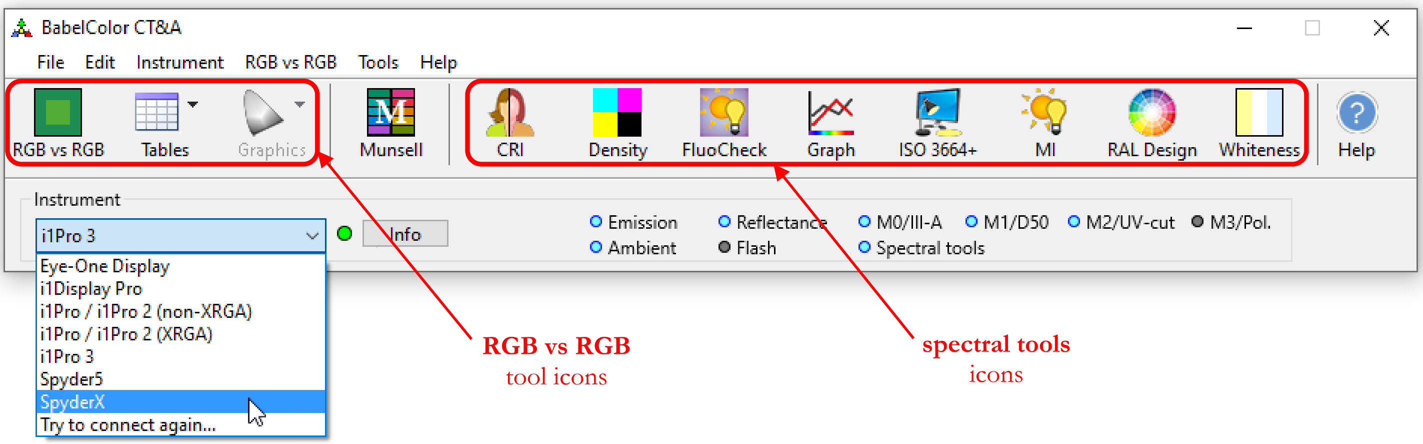
2. Toolbar window

CT&A's top window contains a toolbar with icons that open each set of tools in separate windows. The icons are separated in four groups. The first group, with three icons, is associated to the RGB vs RGB tool, a tool which accepts tristimulus type color space inputs such as L*a*b* and RGB. The second group, with one icon, opens the Munsell tools where you can convert FROM and TO Munsell notation. The third group, with eight icons, is associated to tools which require spectral data in order to provide a measurement; these tools are collectively called spectral tools. The last group has one icon, which opens the Help documentation, this document. Opening and closing windows can be done with the toolbar icons or with the "Tools" menu, which contains additional window management functions.

Important: The program automatically records the user-selectable setups of each tool as well as the windows' positions when the program is closed. Whenever feasible, the windows reopen to the last saved configuration.

The toolbar window also contains controls to select a measuring instrument (purchased separately), and status lights for the features supported by the connected instrument (measurement modes, measurement conditions, spectral tools compatibility). Additional information on the supported instruments is presented here.

The following screenshot shows the toolbar window with the "Instrument" menu opened:



A green light beside the instrument selection menu indicates that the instrument is recognized and ready to use; a red light indicates that it is not available. Clicking on the "Info" button opens the "Instrument info" dialog which shows information relative to the instrument and enables you to change its settings. If your instrument is connected but shown as not available, you should first attempt a reconnect by selecting "Try to connect again…" in the "Instrument" menu. If the instrument is still not connected, clicking on the "Info" button may provide information on the source of the problem.

Note: If the above fails, physically disconnect and reconnect the instrument, then select "Try to connect again…" in the "Instrument" menu. If you have an Eye-One Display or i1Pro and the problem persists, read **Note 4** in the Supported instruments section. For instance, we noticed that it is sometimes not possible to reconnect the instrument just by using the Instrument menu when the instrument was previously recognized but the computer was put in "Sleep" mode.

You will also notice that the instrument menu does not offer "i1Pro" and "i1Pro 2" as separate menu items. Instead, "**i1Pro / i1Pro 2 (non-XRGA)**" and "**i1Pro / i1Pro 2 (XRGA)**" are shown; these descriptions correspond respectively to the old i1Pro driver and the new i1Pro 2 driver. Both the i1Pro and i1Pro 2 instruments can be used with either driver. The i1Pro driver is NOT XRGA compliant and the i1Pro 2 driver is XRGA compliant. You can thus make measurements with your instruments with or without XRGA calibration.

Note: The "**Eye One Display**" and "**i1Pro / i1Pro 2 (non-XRGA)**" menu items are NOT available in 64 bit packages.

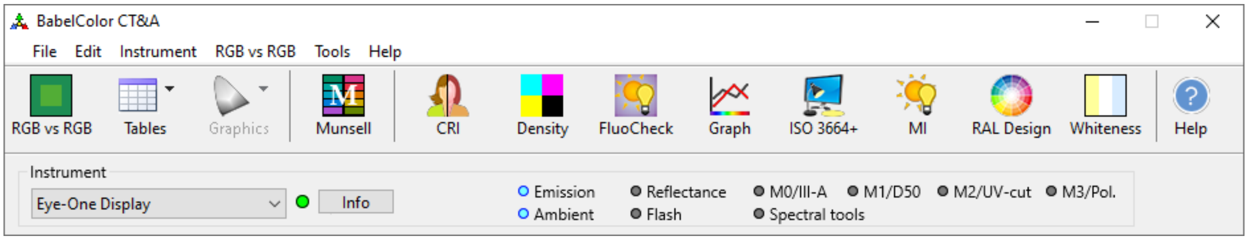
Click on a link in the Table of Contents below for more information.

Toolbar window - Table of Contents

2.1 Toolbar status lights

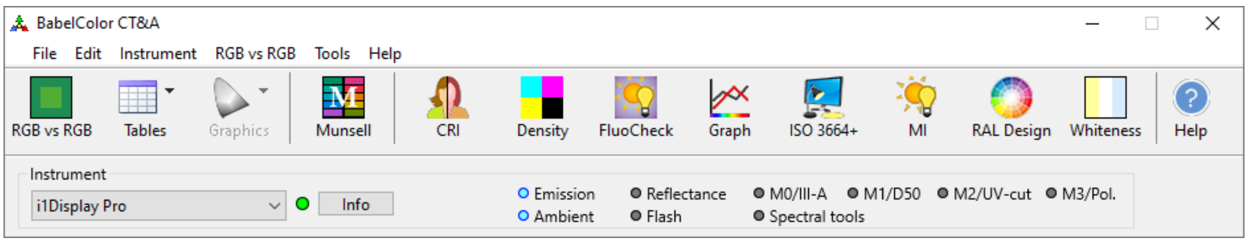
The screenshots in this section show the toolbar window status lights as they appear for each instrument and, in the case of the i1Pro and i1Pro 2, depending on the selected driver. The status lights are blue (ON) when the feature is supported and grey (OFF) when it is not.

Eye-One Display 2

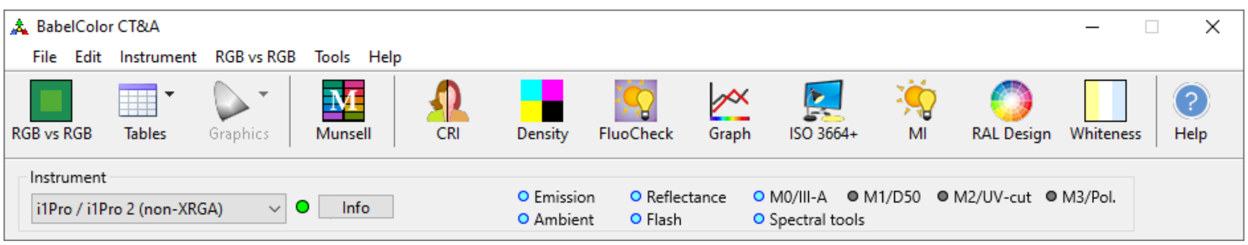


Note: The "Ambient" status light will be OFF for an older Eye-One Display with no ambient adapter.
Note: This instrument is NOT supported in 64 bit packages.

i1Display Pro

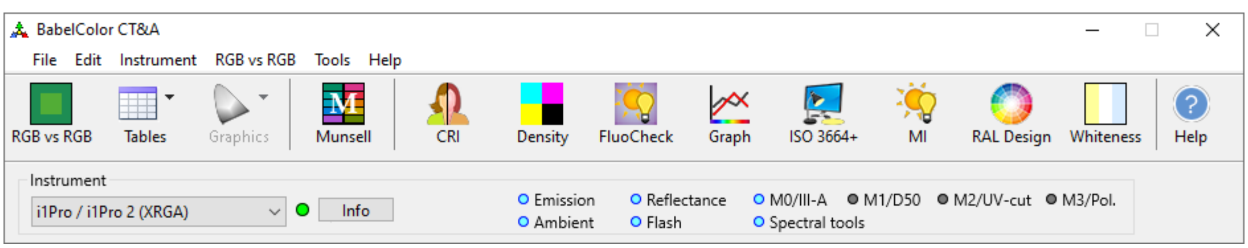


i1Pro or **i1Pro 2** with the "**i1Pro / i1Pro 2 (non-XRGA)**" driver



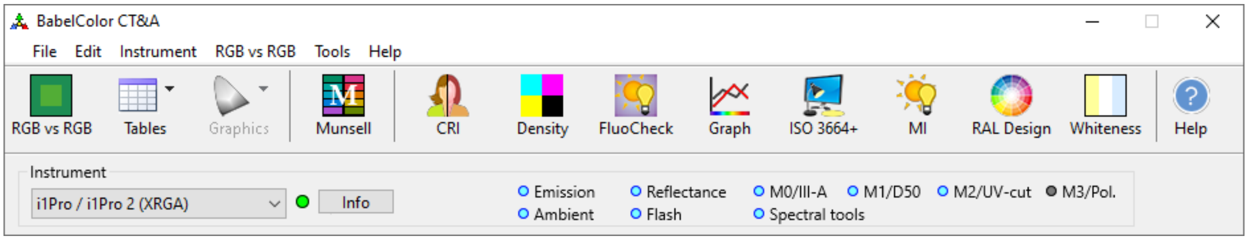
Note: The "Ambient" and "Flash" status will be OFF for an i1Pro without ambient measurement capabilities.
Note: An **i1Pro 2** can only be used in its default mode (M0 or M2 depending on model) with this driver.
Note: This driver is NOT supported in 64 bit packages.

i1Pro with the "**i1Pro / i1Pro 2 (XRGA)**" driver

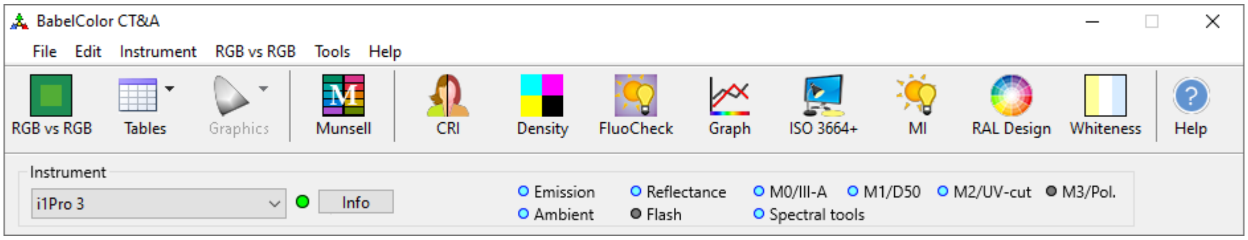


Note: An **i1Pro** can only be used in its default mode (M0 or M2 depending on model) with this driver.

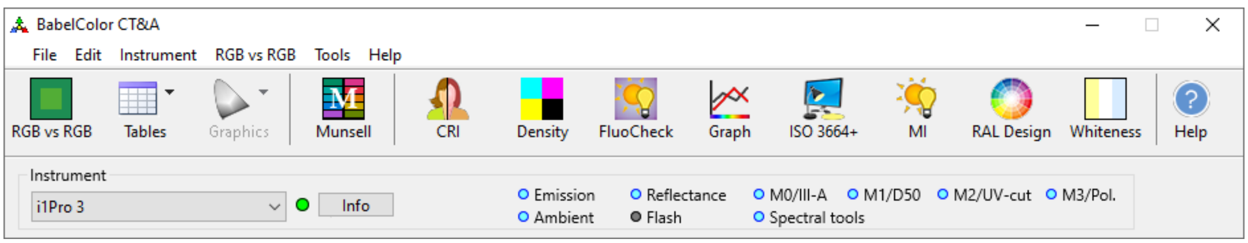
i1Pro 2 with the "**i1Pro / i1Pro 2 (XRGA)**" driver



I1Pro 3

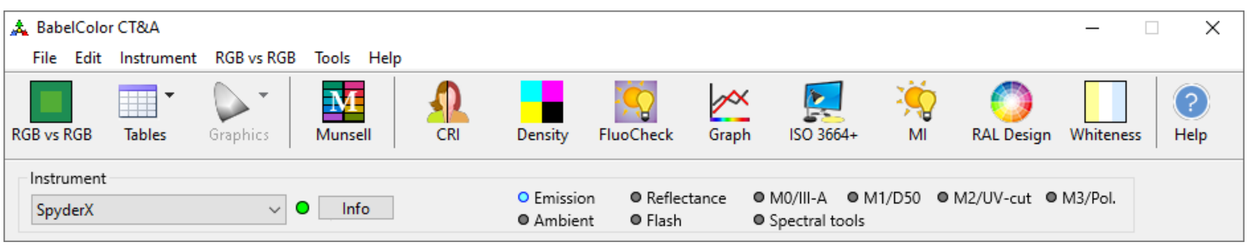


I1Pro 3 Plus



Note: The only instrument which supports the M0, M1, M2, and M3 Measurement Conditions.

Spyder5 and **SpyderX**



2.2 Supported instruments

The supported instruments (purchased separately) are:

Instrument	CT&A 32 bit (Windows)	CT&A-Mac 64 bit (Mac)	Notes	Type	Manufacturer
Eye-One Display **Eye-One Display 2**	✔	✘	1 to 5	colorimeter	X-Rite www.xrite.com
i1Display Pro	✔	✔	6, 7, 8	colorimeter	
i1Pro, i1Pro 2	✔	✔	3, 4	spectrophotometer	
i1Pro 3, i1Pro 3 Plus	✔	✔	3, 4	spectrophotometer	
Spyder5	✔	✔	9	colorimeter	Datacolor www.datacolor.com
SpyderX	✔	✔	9	colorimeter	

Important: The CT&A 32 bit executable for Windows can run on 32 bit and 64 bit Windows systems. For the macOS, the program is provided in a 64 bit package. See the System requirements section for OS compatibility.

Note (64 bit packages): The "i1Pro / i1Pro 2 (non-XRGA)" driver/menu selection is not available.

Important (Windows OS only): If you need USB drivers for an instrument, consult the "CT&A_Readme.txt" file located within the main CT&A application folder for driver install instructions. The i1Display Pro uses the default OS USB drivers and no separate driver installation should be required. The SpyderX also uses default OS USB drivers but they may not be installed if you use Windows 7; please consult the "CT&A_Readme.txt" file for more information.

Note 1 (Eye-One Display 2): The Eye-One Display 2 offered or bundled with many wide gamut monitors sold by **NEC**, such as the PA271W model, can be used with CT&A. The Eye-One Display 2 is often bundled with monitors sold by other companies; it is usually a standard model which is only "re-branded", but it can also be a custom version tuned to a company's product. This special version of the NEC Eye-One Display 2 is identified as **Custom calibrated color sensor (MDSVSENSOR2)** and is available in the SVII-PRO-KIT. This custom instrument is tuned to the primaries of NEC's wide gamut monitors. For such monitors, it is not recommended to use a standard Eye-One Display 2 because the filters used in these instruments were optimized for standard gamut monitors, and measurements done on wide gamut monitors are less accurate. According to NEC, the MDSVSENSOR2 provides accurate colors for both wide gamut and standard gamut displays; all color corrections are performed internally (in the colorimeter), and the instrument provides color values which do not require further corrections when read by a program such as CT&A. With BabelColor's PatchTool program, we have performed an Idealliance certification procedure on an iMac using both a standard Eye-One Display 2 and the special NEC version, and the results are identical within the inter-instrument tolerance of the instruments.

Note 2 (Eye-One Display 2): If an Eye-One Display 2 is properly recognized after you click on "Info" button, then it should work with CT&A. If it is not recognized, i.e. if there is a message that the instrument is not connected, then there are good chances that it cannot be used with CT&A. For instance, CT&A cannot be used with the special version of the Eye-One Display 2 provided with HP DreamColor monitors. IMPORTANT: Make sure that instrument connection is not blocked by another program such as "X-Rite Device Services" (see **Note 4**).

Note 3 (Eye-One Display, Eye-One Display 2, i1Pro – All models): CT&A should be used with only one Eye-One/i1Pro/i1Pro 2 connected at a time and only one i1Pro 3 at a time. You can however connect one Eye-One/i1Pro/i1Pro 2 in addition to one i1Pro 3 and one i1Display Pro since these instruments use different drivers.

Note 4 (Eye-One Display, Eye-One Display 2, i1Pro – All models): If you installed software from X-Rite, such as **i1Profiler**, which comprises the "X-Rite Device Services" program, you may receive a message to the effect that the instrument is not connected when you click on the "Info" button. Assuming that your instrument is indeed connected, first check if the i1Profiler program from X-Rite is opened, and, if opened, close it, since CT&A cannot be used at the same time. Early versions of i1Profiler provide a control panel named "X-Rite Device Services", which is used to assign/unassign instruments to X-Rite software. On a Mac, the "X-Rite Device Services" control panel is located in the System Preferences dialog. The latest versions of i1Profiler still include "X-Rite Device Services" but do not include a control panel, and instrument assignment is performed dynamically when opening an X-Rite program. If using an early version of i1Profiler, you should DESELECT the i1 (Eye-One) in the "X-Rite Device Services" control panel; this will make the instrument available for CT&A. Please note that changes in the X-Rite control panel can be done while CT&A is opened. You should then be able to connect the instrument by selecting "Try to connect again…" in the "Instrument" menu. The early versions of i1Profiler may also open one or more dialogs asking if you want CT&A to take ownership of the i1 peripherals; please answer "Yes" to the question(s). "X-Rite Device Services" is dedicated to X-Rite programs and is not under CT&A's control; any problem related to its use should be directed to X-Rite.

Note 5 (Eye-One Display, Eye-One Display 2): To properly calibrate these instruments, you must specify, before calibration, if your monitor is a CRT or a LCD. This selection is done in the "Instrument" tab of the Preferences dialog. Whenever this setting is changed, you should re-calibrate the instrument.

Note 6 (i1Display Pro): "i1Display Pro" is the name of the package that contains the "i1Display", the actual device's name, **plus** the i1Profiler software. However, the device is most often referred to as the "i1Display Pro" in the many reviews found on the Web, a name that differentiates it from the previous Eye-One Display models.

Note 7 (i1Display Pro): The i1Display Pro measurement time is adjustable by software. When making tests with this instrument we verified that we get less noise when increasing the measurement time, as expected, but the difference is most often not significant (in particular, the noise is low for dark patches even with short measurement times). We offer two options: a FAST setting which takes a measurement about every 0,5 second, and a SLOW setting which takes a measurement about every 1,2 seconds. Select the FAST setting to start with; use the SLOW setting if you see large differences between two series of measurements done back-to-back, or when the display refresh rate is lower than 50 Hz. Always use the SLOW setting when making measurements on a CRT.

Note 8 (i1Display Pro): In order to make measurements with the i1Display Pro, it is required to stop the "**i1ProfilerTray**" application that may be running in the background. The i1ProfilerTray utility is part of the i1Profiler software provided by X-Rite in the i1Display Pro package; it will automatically launch each time you boot your computer. i1ProfilerTray can show reminders when a calibration is due and can monitor the ambient lighting conditions to see if the display profile should be tweaked; it can also automatically adjust the display profile following ambient illumination changes. Stopping this utility will not change your display calibration. CT&A will display a message if i1ProfilerTray is running when you select the i1Display Pro and can stop it for you.

Note 9 (Spyder5 and SpyderX): In order to make measurements with these instruments, it is required to stop the "SpyderUtility" application that may be running in the background. SpyderUtility is part of the software provided by Datacolor for these instruments; it will automatically launch each time you boot your computer. This program checks the display settings and monitors the ambient lighting conditions to see if they are still within tolerance relative to the settings and conditions present when the display was last calibrated. Stopping this utility will not change your display calibration. CT&A will display a message if SpyderUtility is running when you select these instruments.

2.3 Instrument info

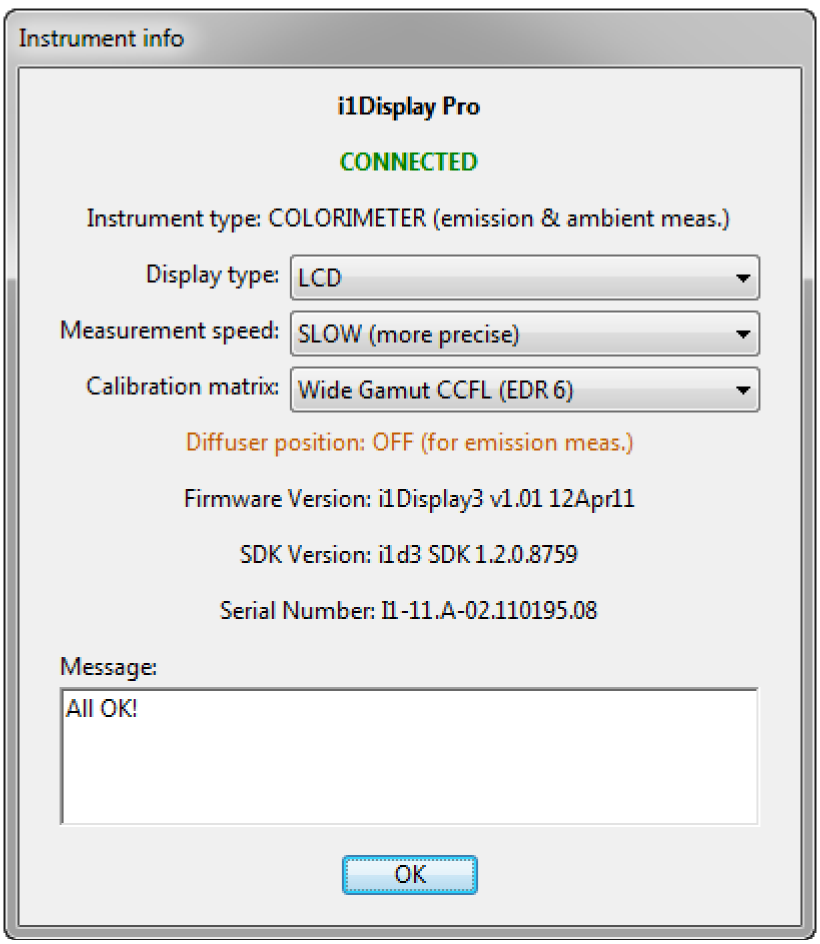
The "Instrument info" dialog provides information relative to the selected instrument, its driver, its current status, and can be used to select or assign various instrument and measurement modes. The dialog is opened by clicking the "Info" button in the toolbar window or with the "Instrument" menu.

If your instrument is connected but shown as not connected in this window, first close this dialog, then physically disconnect and reconnect the instrument, and finally select "Try to connect again…" in the toolbar "Instrument" menu. If you have an Eye-One Display or i1Pro and the problem persists, read **Note 4** in the Supported instruments section. For instance, we noticed that it is sometimes not possible to reconnect the instrument just by using the Instrument menu when the instrument was previously recognized but the computer was put in "Sleep" mode.

The dialog content is customized for each instrument since not all instruments support all features or provide the same information. Also, it is important to note that CT&A changes instrument settings only when making a measurement, and not when selecting a different measurement mode. It may thus be preferable to open the "Instrument info" dialog AFTER making a measurement, unless you want to see the current instrument settings before doing a measurement.

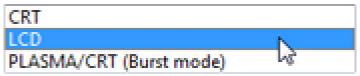
The following screenshots show a few examples of the dialog with different combinations of instrument, measurement mode and driver.

i1Display Pro

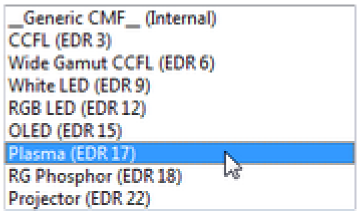


From this dialog you can select or assign: the **display type**, the **measurement speed**, and a **calibration matrix**. The display type and measurement speed can also be selected in the Preferences dialog. The calibration matrix setting is only available in this dialog when the instrument is connected and ready. The **diffuser position** is a feature specific to the i1Display Pro; the field is updated continuously so you can change the diffuser position and see if it is detected.

The current display types for the i1Display Pro are:



The current calibrations matrices for the i1Display Pro are:



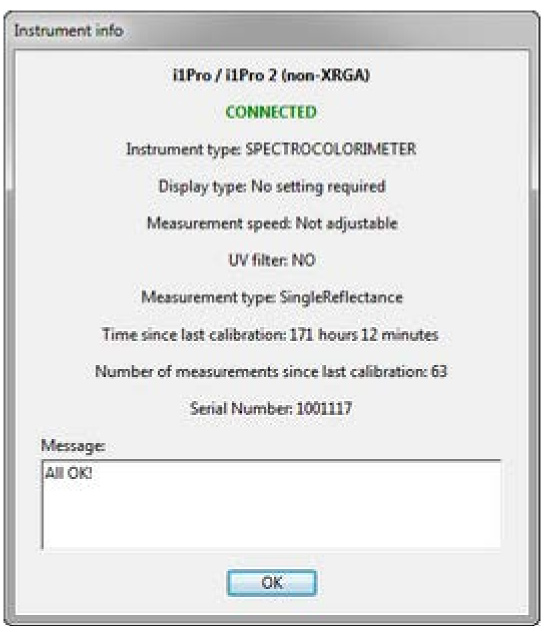
Note 1: The calibration matrices list could be updated in the future just by replacing the content of the "i1d3 Support Files" folder located in the main CT&A folder.

Note 2: Select the "PLASMA/CRT (Burst mode)" display type and the "Plasma (EDR 17) calibration matrix when doing measurements with a plasma display.

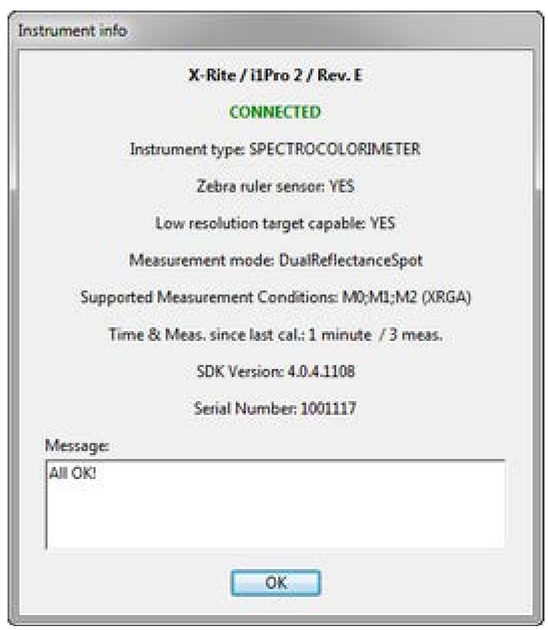
Note 3: When measuring a CRT, the "PLASMA/CRT (Burst mode)" display type is said to provide more accurate results than the standard CRT display type, especially for darker colors.

Here are four screenshots obtained with the same **i1Pro 2**, with either the old i1Pro driver (**i1Pro/i1Pro 2 (non-XRGA)**) or the new i1Pro 2 driver (**i1Pro/i1Pro 2 (XRGA)**). The two top screenshots were obtained after making **reflectance** measurements; the two bottom screenshots were obtained after making **flash** measurements.

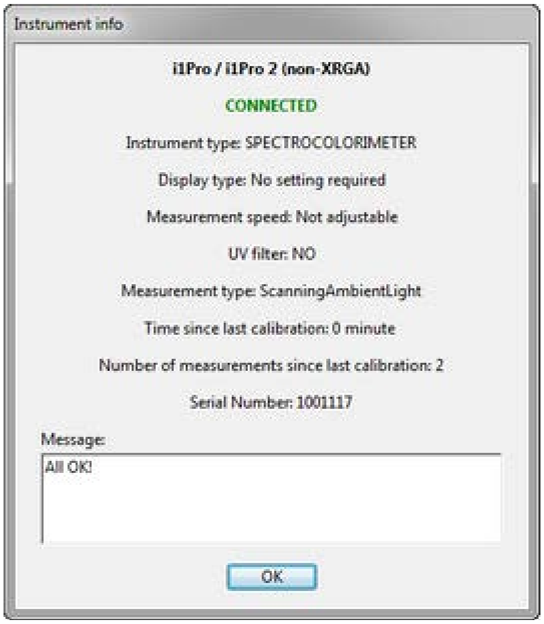
i1Pro 2 (**reflectance**) with **i1Pro/i1Pro 2 (non-XRGA)** driver



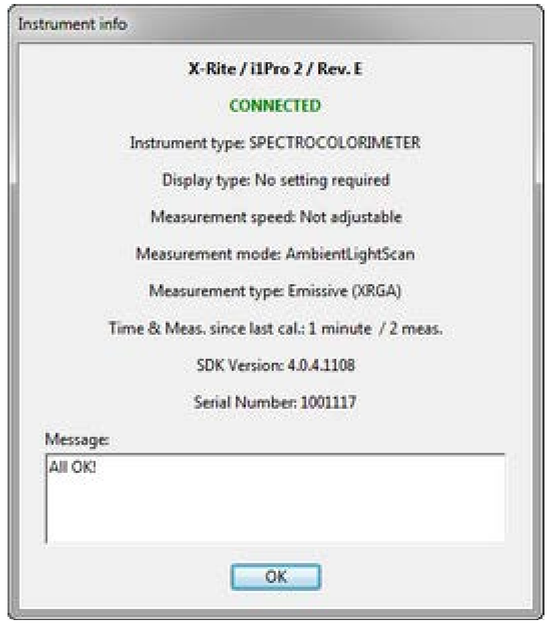
i1Pro 2 (**reflectance**) with **i1Pro/i1Pro 2 (XRGA)** driver



i1Pro 2 (**flash**) with **i1Pro/i1Pro 2 (non-XRGA)** driver



i1Pro 2 (**flash**) with **i1Pro/i1Pro 2 (XRGA)** driver



Note 4: The i1Pro driver (**i1Pro/i1Pro 2 (non-XRGA)**) cannot differentiate between the i1Pro and i1Pro2; both are seen as an i1Pro. The i1Pro 2 driver (**i1Pro/i1Pro 2 (XRGA)**) can identify the instrument and provide the Rev. level.

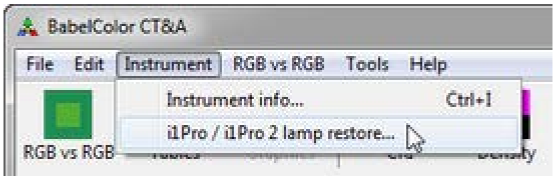
Note 5: The i1Pro 2 driver resets the time since the last measurement and the number of measurements quite aggressively compared to the i1Pro driver. This information is often not available.

Note 6: In reflectance mode, with the i1Pro driver, the i1Pro 2 used for the above screenshots can support only the M0 measurement condition (incandescent illumination with no UV filter). With the i1Pro 2 driver, M0, M1, and M2 are supported.

Note 7: The **i1Pro/i1Pro 2 (non-XRGA)** driver is NOT supported in 64 bit packages.

2.4 Lamp restore

Starting with Version 4.2, CT&A includes updated i1Pro / i1Pro 2 software libraries (DLL, for Windows, or Framework, for Mac) from the i1Pro Software Development Kit (SDK) Version 4.2.0. These libraries are used **exclusively** with the "**i1Pro / i1Pro 2 (XRGA)**" instrument selection and provide a new function to test tungsten lamp drift and restore it if required. Lamp restore is possible with both the i1Pro and i1Pro 2 instruments. According to X-Rite, restoring a lamp is infrequently necessary. However, if you suspect that your lamp has drifted, then select the "i1Pro / i1Pro 2 lamp restore..." menu item of the "Instrument" menu and follow the instructions.



Important: Before initiating the lamp restore procedure, please do the following checks:

- Make sure that you are using the correct calibration tile/base for your instrument. The tile is matched to the instrument and identified with the same serial number.
- Calibrate your instrument before doing a lamp restore check; this is a good indication that your USB connection is in proper working order. When there is a USB problem, you should get specific error messages to this effect when calibrating, particularly in reflectance, and typically more often with the i1Pro 2 than with the i1Pro. A more complete check-list to go through in case of calibration failure is presented on the next page.

Once the restore check procedure is started, the lamp will be restored automatically if a lamp drift is detected. Restoring the standard lamp condition takes about **2 minutes** and you will get a confirmation message when it is completed. If you get a message in less than 10 seconds, then restoration was not required.

Warning: Leave the instrument on the calibration plate until you get a confirmation message that the check or restore is completed.

Note: If lamp restore is required for an **i1Pro 2**, you will see a series of yellow-green flashes on the instrument at the beginning and end of the 2 minutes procedure. Because the **i1Pro** has no such lights, you should simply wait until you get a confirmation message. For both instruments, you will also see a waiting cursor while the check and restore is performed; however, please note that this cursor is visible only when the mouse cursor is over one of CT&A's windows.

i1Pro/i1Pro 2 calibration failure check-list

Calibration failure more often occurs when calibrating in reflectance mode. This can happen even if the instrument is properly detected and identified in the "Instrument info" dialog. Here are potential causes to look for:

1. The instrument is not properly seated on the calibration tile. This may seem obvious but it is worth checking!
2. The calibration tile is dirty. Clean it gently with a soft tissue lightly dabbed in isopropyl alcohol.
3. You are using the wrong calibration tile for the instrument. The i1Pro calibration tile is matched to the instrument at the factory. You should be aware that using a tile from another instrument will very likely provide inaccurate measurements, even if you do not get an error message!
4. There is a bad or degraded contact between the instrument and the USB cable or between the cable and the computer USB port. If a connection is loose, you can sometimes improve it by pushing, holding, or reinserting the connector. Try another USB cable or another USB port to see if you get better results. In some extreme cases your computer USB port or your instrument connector may need to be replaced.
5. The overall USB cable resistance is too high. This can be due to a poor quality cable, a damaged cable, a cable which is too long, or a cable with dirty connectors.
6. The computer USB port cannot provide enough current for calibration. This is more often a problem with external USB hubs. Try a USB port which is not used (i.e. connected and disconnected) often.
7. If all of the above is non-conclusive, your instrument may be due for a factory calibration or repair.

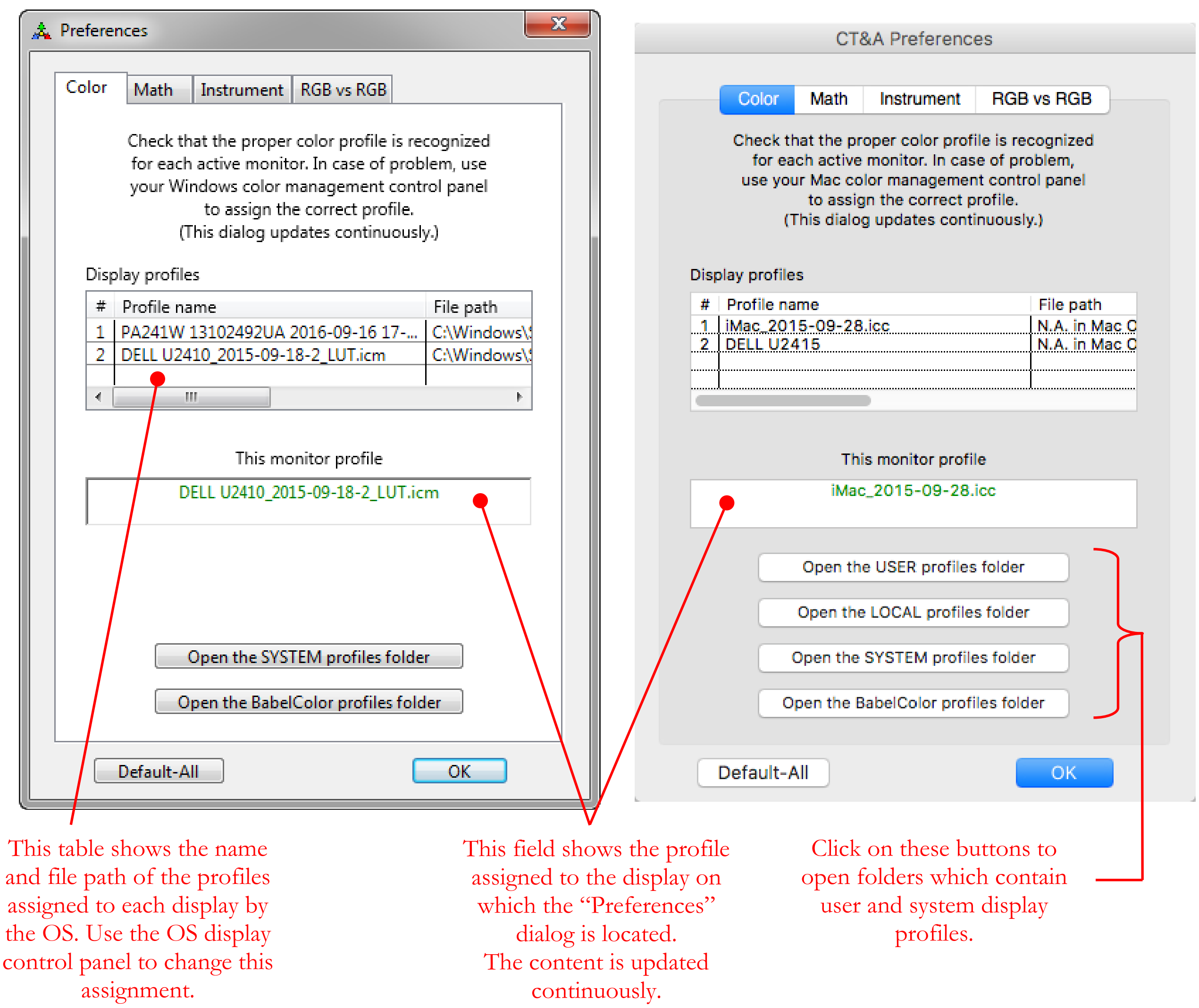
3. Preferences dialog

In Windows, the **Preferences dialog** is opened with the "Edit/Preferences" menu; on a Mac, the dialog is opened with the "CT&A/Preferences..." menu.

The dialog has four tabs: "Color", "Math", "Instrument", and "RGB vs RGB". The “Math”, “Instrument” and “RGB vs RGB” tabs have a "**Default**" button that can be used to reset factory settings for the tab. Also, you can click on the "**Default-All**" button, located below the tab zone, to reset the content of all tabs in one click. The settings are saved when you leave the dialog, and are loaded at the program start.

COLOR TAB

CT&A is color-managed and the display profile is used to compute the appearance of all color patches. The program uses the profile assigned to the display corresponding to the window position. If the window is moved to another display, the patches are rendered with the new display profile; there is no need to manually select a profile in multi-display systems. The tools in which a display profile is used for rendering color patches are: RGB vs RGB, CRI, Density, FluoCheck, Graph, Metamerism Index, and RAL DESIGN.



The “Color” tab of the “Preferences” dialog cannot be used to assign or select a profile but is used to check if the profiles assigned to each display are the correct ones. Please consult the Display calibration section for short procedures to test display contrast and highlight saturation.

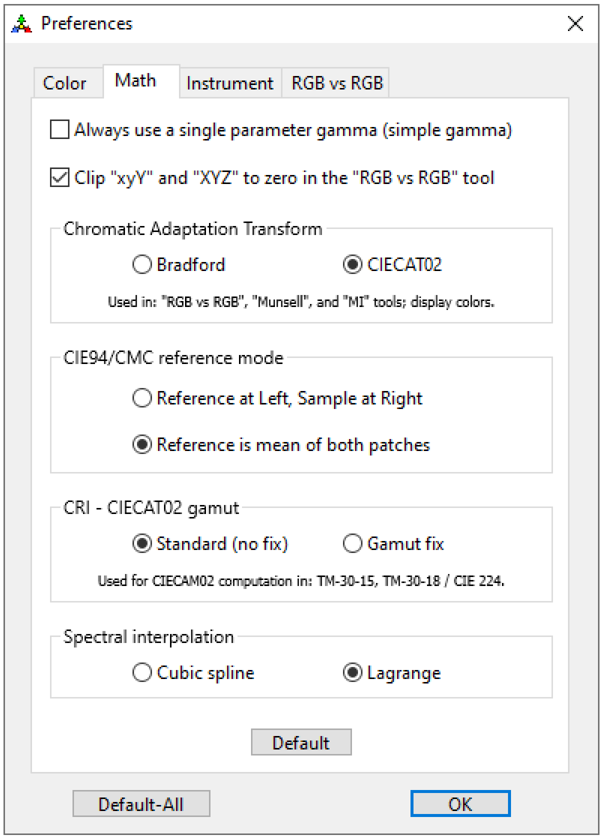
Note: The profile file path is not shown on the Mac OS.

Important: Please be careful when you change a display profile using the OS display control panel because a display profile is generally matched to its hardware settings. When you make a display profile, you are often asked to set a White Point and brightness level. This adjustment is made automatically on high end systems but remains a manual task in many calibration workflows. In any case, these hardware adjustments are linked to the resulting profile as well as to the graphic card Look-Up-Table (LUT), and sometimes also to the display LUTs if so equipped. This means that if you assign a different profile to a display, you should make sure that the hardware settings correspond to this other profile. Since these settings are often manually adjusted and not recorded, there is little chance of getting the system back to the correct state. On the plus side, we often make many profiles with the same White Point and brightness values, changing only software settings between each profile.

Important: Make sure the LUTs corresponding to the selected profile are loaded. In particular, for Windows computers, the LUTs are NOT updated when the display profile is changed using the display properties dialog. A dedicated LUT loading application, or a reboot, is required.

Important: The display profile has **NO EFFECT** on the accuracy of the computations; it simply affects the appearance of the color patches.

MATH TAB



☐ **Always use a single parameter gamma (simple gamma)**

Unselected by default. A definition of gamma can be found here. To view the gamma parameters for a given space, use the "RGB vs RGB/Table data/Space data..." menu or the "Space data..." menu of the toolbar "**Tables**" icon. This setting may affect the results associated to the RGB spaces available in the RGB vs RGB and the Munsell tools.

☑ **Clip "xyY" and "XYZ" to zero in the "RGB vs RGB" tool**

Selected/clipped by default. Negative "xyY" and "XYZ" values do not represent visible colors and are traditionally clipped to zero. However, it can be useful to get the negative values when working with RGB spaces which have negative primaries, such as ACES AP0.

When this preference is selected, the RGB vs RGB tool will clip "xyY" and "XYZ" values to zero and the corresponding data point on the chromaticity diagram will stay on the "x" or "y" axis (or stay at zero). "L*" of L*a*b* and L*C*h will also be clipped to zero instead of being negative.

When this preference is NOT selected, "xyY" and "XYZ" values can go below zero and the corresponding data point on the chromaticity diagram will go into the negative "x" and "y" regions. "L*" of L*a*b* and L*C*h are allowed to be negative.

Chromatic Adaptation Transform (CAT)

The CAT matrix is used for illuminant/space conversion in the RGB vs RGB, Munsell, and Metamerism Index (MI) tools; it is also used to compute display colors. **CIECAT02** is the default, and is recommended to compute the Color Inconstancy Index (CII) in the MI tools.

Note: The CIECAT02 matrix is sometimes referred to as MCAT02.

CIE94/CMC reference mode

This checkbox has an effect on the equations used in the CIE94 and CMC(l:c) Δ*E* color-difference formulas. The two options are:

- **Reference at Left, Sample at Right**
  To be used when doing a Quality Control (QC) check. Here are the *Reference* and *Sample* for the various tools:
  - RGB vs RGB tool: In Compare mode, the LEFT side is the *Reference* and the RIGHT side is the *Sample*. In Convert mode, the side being converted FROM is always the *Reference*, and the side being converted TO, the *Sample*. This setting will also affect the selection of the L*C*h pad patches.
  - FluoCheck tools: For the FI, the *Reference* is M2 and the *Sample* either M0 or M1.
  - Graph tools: The LEFT side is the *Reference* and the RIGHT side is the *Sample*.
  - Metamerism Index tools: For the SMI, the *Reference* and *Sample* correspond to the button labels. For the CII, the *Reference* is the data computed with the illuminant selected in the "CII ref. illum." menu and the *Sample* is the data computed with one of the two illuminant menus on the left of the window.

- **Reference is mean of both patches**
  The default. It should be used when comparing two colors where none of the color has more importance than the other.
  - RGB vs RGB tool: In Compare mode, the reference is the mean of both patches. In Convert mode, this option is overridden and the side being converted FROM is always the *Reference*, and the side being converted TO, the *Sample*. This setting will also affect the selection of the L*C*h pad patches

CRI - CIECAT02 gamut

The CRI2012, TM-30-15, TM-30-20, and CIE 224 methods all use the CIECAT02 Chromatic Adaptation Transform (CAT). However, we have noticed that CRI2012 uses a “gamut-fixed” matrix (Ref. 56) while the others use the “standard” matrix, which is the default setting. You can select either one with this option, which applies to TM-30-15, TM-30-20, and CIE 224 only. The differences between the results obtained with the two matrices are generally small.

Note: The CIECAT02 matrix is sometimes referred to as MCAT02.

Spectral interpolation

The method used to interpolate spectrums at 5 nm intervals when the original data is available at 10 nm intervals. The 10 nm bandwidth data may originate from measurements, from an i1Pro series spectrophotometer for instance, or from files. Interpolated 5 nm data is used for improved accuracy in the following tools:

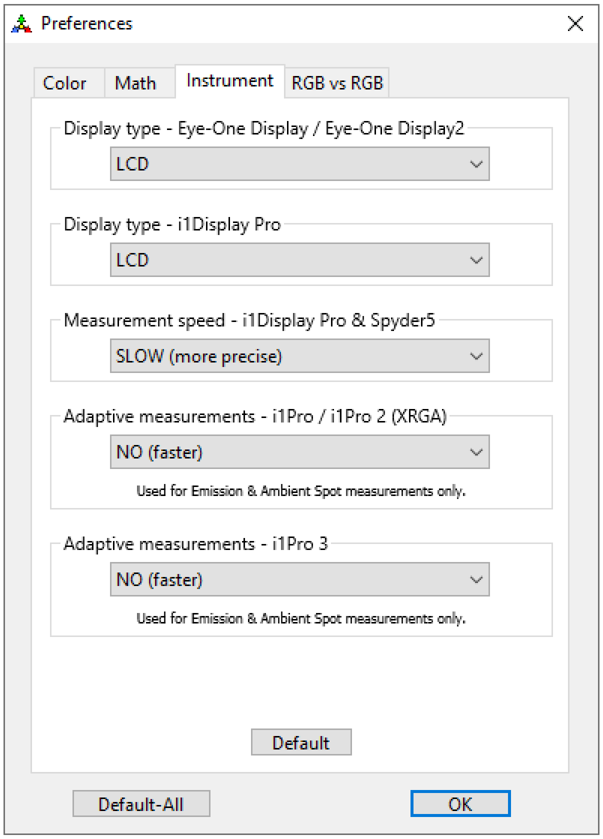
- CRI tools: Used for all computations.
- ISO 3664+ tools: Used for the CRI and the Visible Metamerism Index (MI, ISO 23603).
- Graph and MI tools: Used for the CRI of Ambient data.

Note: For the CRI tools, a newly selected interpolation setting will apply only to **new** measurements and **new** files with a 10 nm bandwidth! If you wish to re-interpolate the currently opened spectrums, you should export them in CGATS format with a 10 nm bandwidth and reopen them with the new setting. You can thus see the effect of the interpolation method by opening the same file twice and changing the interpolation setting in between.

Note: Only “Lagrange” interpolation was used prior to V-5.3.0 and is thus the default for this setting.

Note: The “Cubic spline” method used here is also called “Natural Cubic Spline”. It is not constrained and will typically show undershoot and overshoot where there are sharp transitions. It was found to be the best interpolation method, when the input data is uniformly sampled, among the following methods: linear, third order polynomial (Lagrange), cubic spline, fifth order polynomial, and Sprague (Ref. 66).

INSTRUMENT TAB



Display type – Eye-One Display / Eye-One Display2

"CRT" or "LCD"; "LCD" by default. To properly calibrate these instruments, you must specify the type of monitor on which they will be used. This option is also available in the Instrument info dialog.

Display type – i1Display Pro

"CRT", "LCD", or "PLASMA/CRT (Burst mode)"; "LCD" by default. To properly calibrate this instrument, you must select the type of monitor on which it will be used. This option is also available in the Instrument info dialog.

Note: When measuring a CRT, the "PLASMA/CRT (Burst mode)" display type is said to provide more accurate results than the standard "CRT" display type, especially for darker colors.

Measurement speed – i1Display Pro & Spyder5

"SLOW (more precise)" or "FAST"; "SLOW" by default. The "SLOW" setting is less sensitive to instabilities, i.e. noise, when measuring darker colors and thus provides more precise values. This option is also available in the Instrument info dialog.

Important: Always use a "SLOW" setting when making measurements on a CRT with an i1Display Pro.

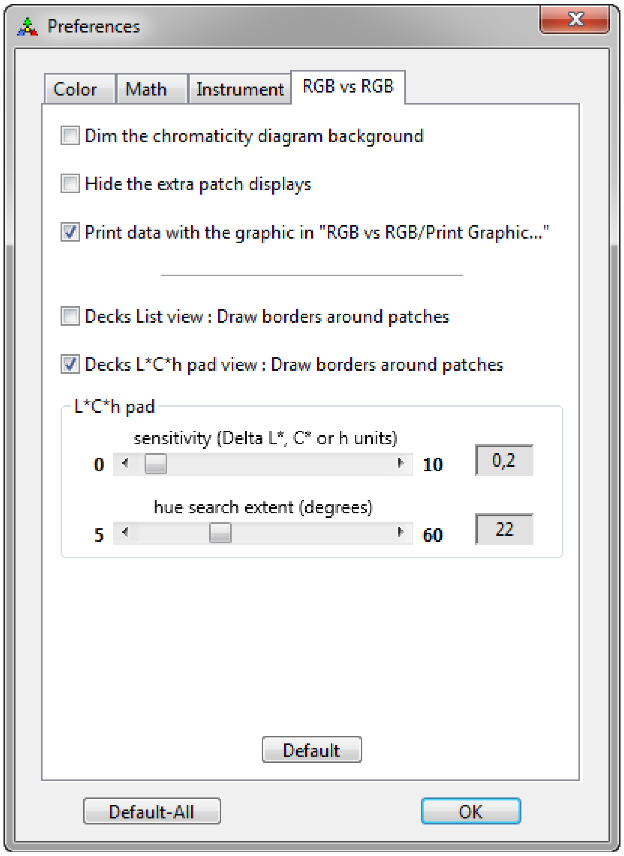
Adaptive measurements – i1Pro / i1Pro 2 (XRGA)

"YES (more precise)" or "NO (faster)"; "NO" by default. If selected, the measurement time is automatically adapted to the patch luminance by the instrument, with longer times allocated for darker patches. If not selected, the same time is used for all patches. Used with the i1Pro and i1Pro 2 when the "i1Pro / i1Pro 2 (XRGA)" instrument/driver is selected. This setting applies only to the "Emission" and "Ambient Spot" modes (and not for the "Flash" mode).

Adaptive measurements – i1Pro 3

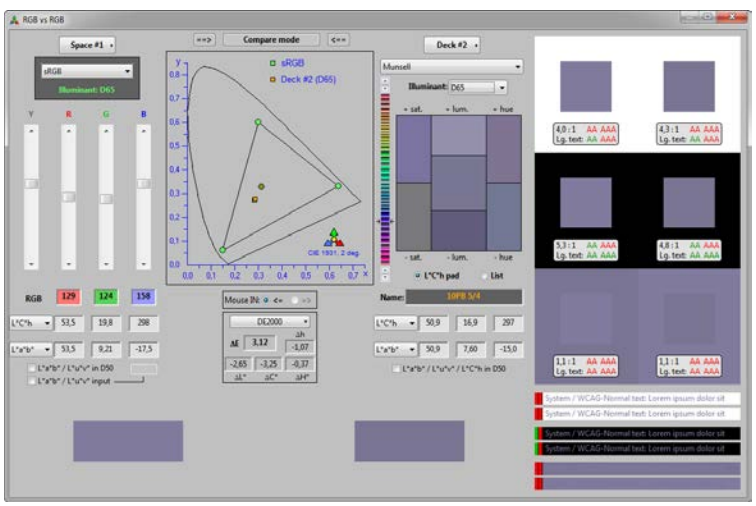
"YES (more precise)" or "NO (faster)"; "NO" by default. If selected, the measurement time is automatically adapted to the patch luminance by the instrument, with longer times allocated for darker patches. If not selected, the same time is used for all patches. This setting applies only to the "Emission" and "Ambient Spot" modes.

RGB vs RGB TAB



☐ Dim the chromaticity diagram background

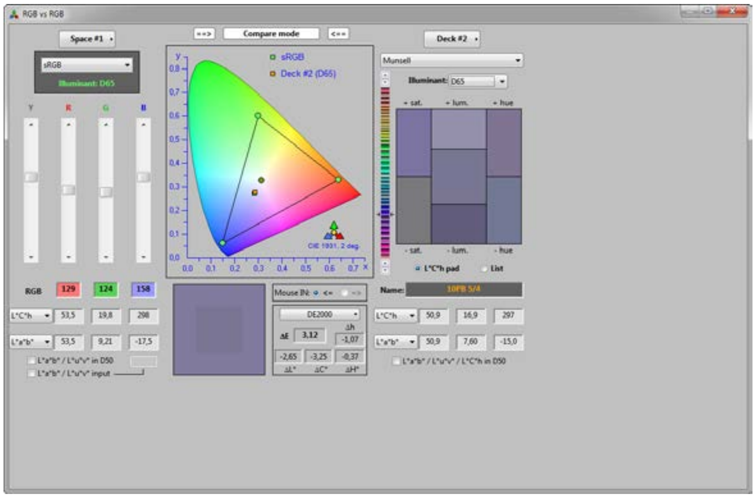
Unselected by default. When selected, the chromaticity diagram background color is changed to light gray.



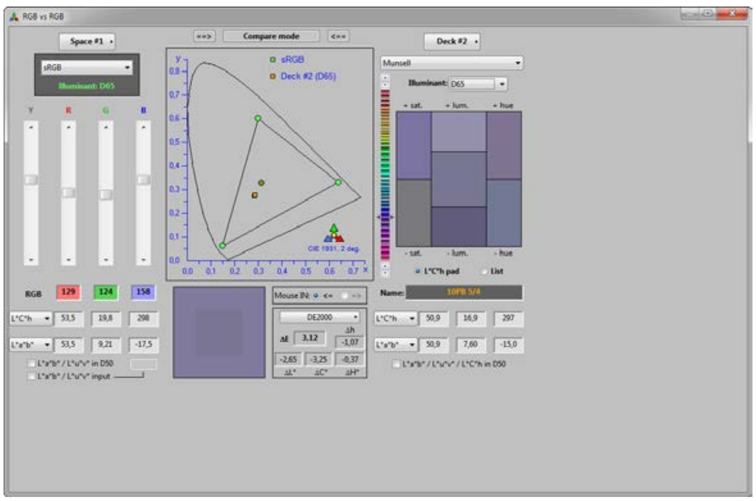
This configuration facilitates the comparison of similar colors by minimizing the interference caused by the large colored surface of the diagram.

☐ Hide the extra patch displays

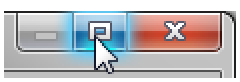
Unselected by default. When selected, the additional patch layouts, normally seen when the window is enlarged, are not shown.



You can dim the chromaticity diagram to minimize the screen clutter even more:

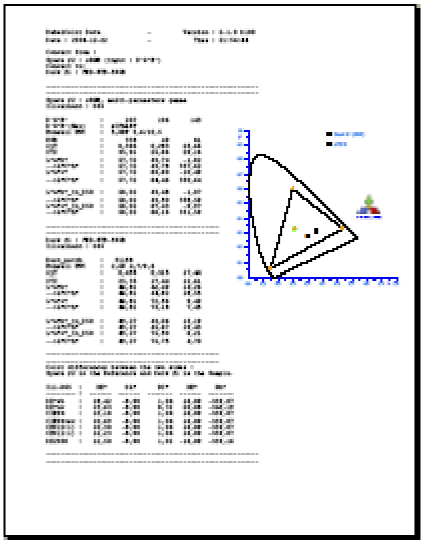


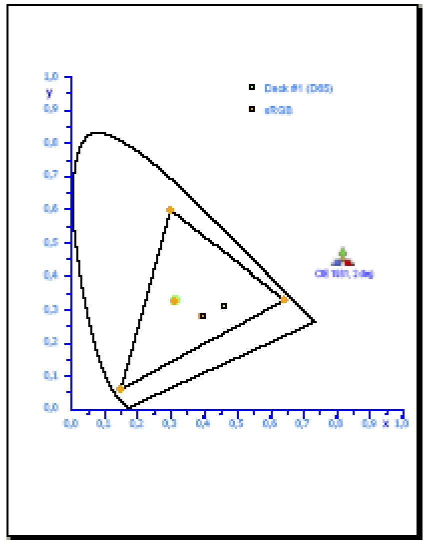
In addition, the interference caused by other opened windows on the desktop can be removed by maximizing the RGB vs RGB window so that it fills the screen:

 in Windows,

 in Mac OS X.

☑ **Print data with the graphic in "File/Print Graphic..."**
Selected by default. Prints the current screen data and mode settings beside the chromaticity diagram when the "RGB vs RGB/Print Graphic..." menu command is selected. Here are reduced views of the printed graphic **with** and **without** data:





☐ **Decks List view: Draw borders around patches**
Unselected by default. Draws a thin black outline around each patch of the List view (Color Deck).

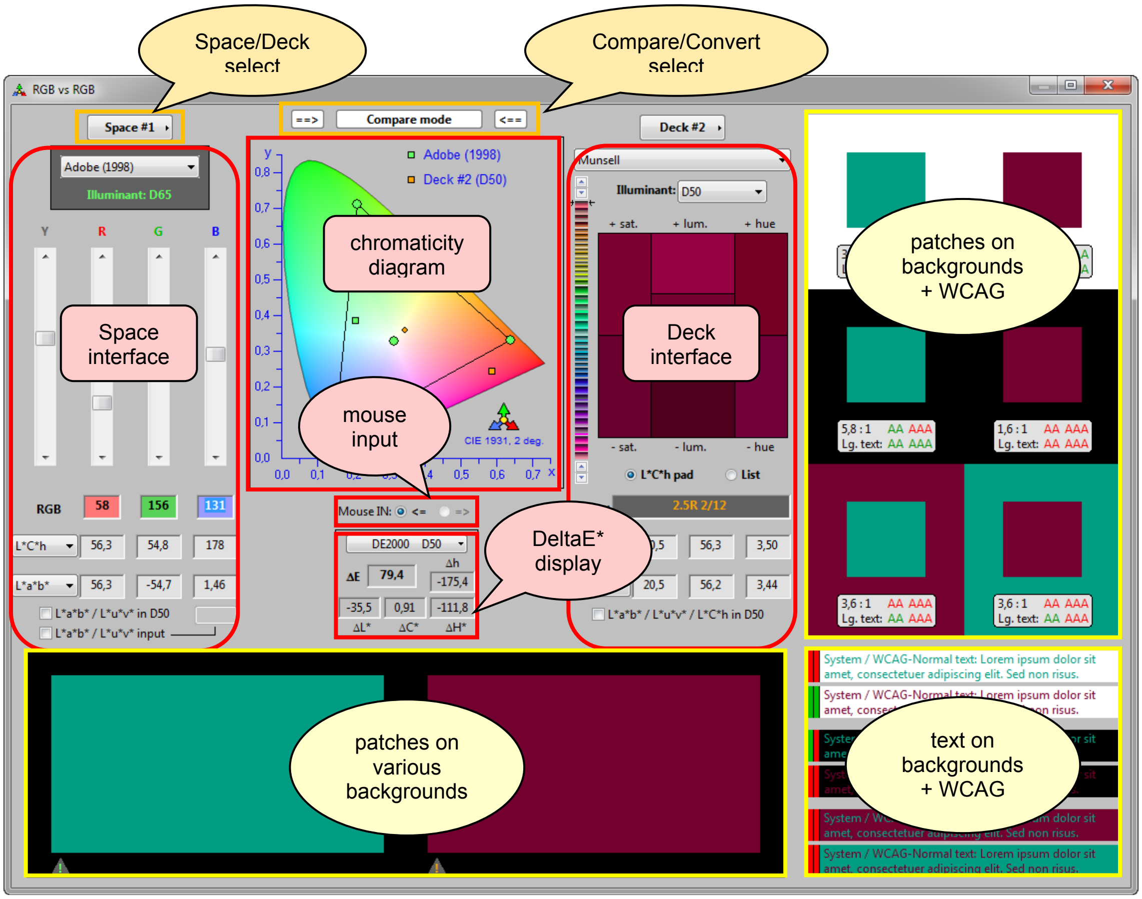
☑ **Decks L*C*h pad view: Draw borders around patches**
Selected by default. Draws a thin black outline around each patch of the L*C*h pad (Color Deck).

L*C*h pad "sensitivity" and "hue search extent"

- **Sensitivity:** Because the searching algorithm used for the L*C*h pad looks for the closest chip which minimizes the other two parameters, for example the lightness and the hue when searching for the chroma (saturation), it may find a chip which is almost the same as the one represented in the center patch. This may happen, for example, if the deck contains chips of the same hue but with different surface finishes (i.e. mat, glossy, etc.). To filter out these chips, we impose a threshold, or **sensitivity**, on the search algorithm. The default sensitivity value is 0,2 units of L*, C*, or h; it can be set between 0 and 10 units with 0,1 units steps.
- **Hue search extent:** For chips located very near the illuminant, it does happen that the best candidates for **+hue** and **-hue**—which are chips which minimize the lightness and chroma differences with the center patch—have a large angular difference with the center patch. To prevent this situation, the **hue search extent** is limited to an angle which can be set by the user. The default angular extent is 22 degrees; it can be set between 5 and 60 degrees with 1 degree steps.

Important: To prevent odd program behavior, a message will appear if you set the **sensitivity** setting too close, or higher, than the **hue search extent** value, and when you set the hue search extent too close, or lower, than the sensitivity. The program will then assign the nearest valid number to the parameter being set.

4. RGB vs RGB tool



The **RGB vs RGB tool** window is opened either by clicking on the corresponding icon on the toolbar window, by selecting the "RGB vs RGB/Show window" menu, or by selecting the "Tools/RGB vs RGB" menu. This tool window can be resized to show or hide additional text and patch layouts.

Two colors can be selected either **within an RGB space** or **within a catalogue of color chips**, herein called "**Color Decks**." The two colors can be compared on various backgrounds (white, gray, black), against each other or superimposed on one another. You can also see how text of the two selected colors will look on white and black, and on a background of the other color; with an analysis of each color pair Contrast Ratio as defined by the Web Content Accessibility Guidelines (WCAG).

There are 20 predefined RGB spaces, plus one user-defined space (Custom RGB space dialog). You can thus compare your custom space against any of the predefined RGB spaces; you can also export the matrix parameters used for XYZ to RGB conversion and get the Chromatic Adaptation Transform (CAT) matrices, either Bradford or CIECAT02, between a custom illuminant and many standard illuminants. Input in a given RGB space is done either by selecting RGB values, by clicking on the chromaticity diagram, or by entering L*a*b* or L*u*v* values; the L*a*b*/L*u*v* values can be either manually entered or they can be measured using one of the supported instruments.

First, let's say a few words about "RGB" (in reality R'G'B', i.e. RGB with primes beside each letter), the most used but least understood of these color languages. For most people, "RGB is RGB" is like "A rose is a rose", where the same word describes the same "thing." Alas, RGB spaces are most often very different. The graphic designer is well aware of the difference between the look of an image created on a wide gamut display whose device space is close to Adobe (1998) RGB and its appearance on a Windows compatible PC (with a default sRGB space), where both the colors and the brightness (luminance) are affected. Similarly, the serious amateur or professional photographer will be confronted with a choice of RGB spaces which are all presented as the best choice for manipulating his images, but which produce vastly different results.

High-end graphic processing software can easily navigate between several RGB spaces and change an image color according to desired output intent. They can also perform translations between the color spaces of the numerous input and output devices. This conversion is often done via ICC based color management software.

The process, performed in the background, even if controlled by the user, is usually complex and does not provide direct information on how a specific color was translated: What are the RGB coordinates of a particular color in the new space? Was that color clipped? By how much? These answers can be found with the RGB vs RGB tool.

Within CT&A, a color in an RGB space can also be described by multiple other color spaces, which could be though of as different "color languages." The other color spaces include the principal color characterization and description standards used in the graphic and colorimetric trades: "xyY", "XYZ", "L*a*b*", "L*u*v*", "Hex #", "HSB", "Munsell HVC", in various illuminant settings.

The "Hex #" color representation is simply a conversion of RGB values from the decimal base (base-10) to the hexadecimal base (base-16). Previously used mainly by programmers, it is now often required for assigning colors when designing Web pages. Both "HSB" (Hue-Saturation-Brightness) and the "Munsell HVC" (Hue-Value-Chroma) color systems describe color using a code structure which attempts to simplify the relation between the perceived color and its description. The simpler HSB notation is used by many graphic applications in color pickers, whereas the Munsell notation, a perceptively uniform system and an International Standard, is used for accurate and critical color assessment.

Important: When inputting L*a*b* or L*u*v* data in the RGB space interface, you should remember that all RGB spaces have a limited gamut (i.e.they do not represent all visible colors), and that if you enter a color value which is outside of the RGB space, this color will be clipped to fit within the space.

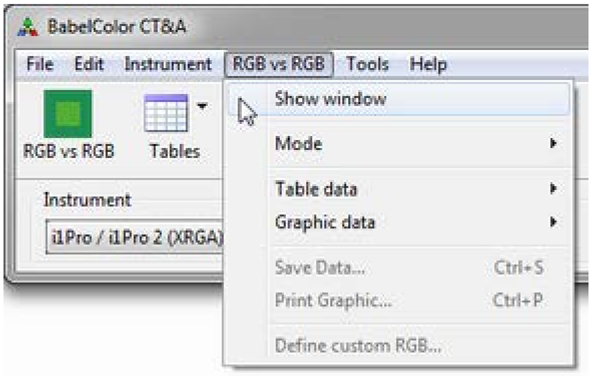
Important: Some settings, tools and functions may not be available when the program is not activated.

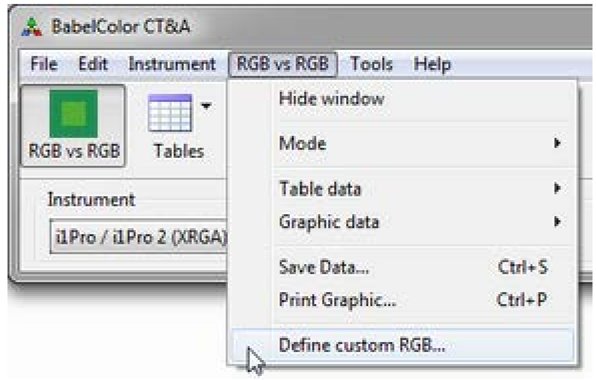
Click on a link in the Table of Contents below for more information.

RGB vs RGB tool - Table of Contents

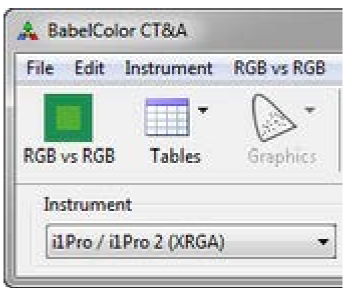
4.1 RGB vs RGB menu

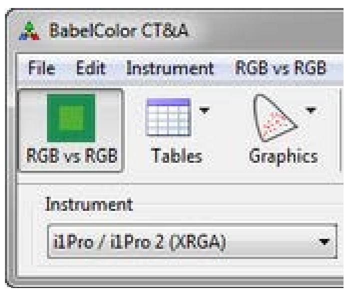
Because of its large number of options, three icons and a separate menu are dedicated to the RGB vs RGB tool. While some menu items are always enabled, other menu items are enabled only when the RGB vs RGB window is opened.





The three icons are grouped at the left of the toolbar. The "Tables" icon is equivalent to the "Table data" menu item while the "Graphics" icon is equivalent to the "Graphic data" menu item. The "Tables" icon is always enabled while the "Graphics" icon is enabled only when the RGB vs RGB tool window is opened.

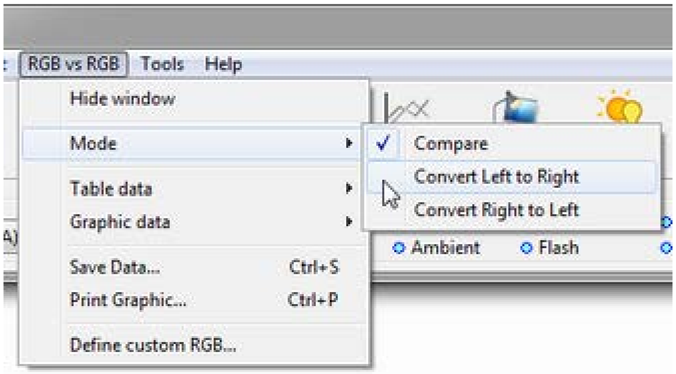




The following pages present a short description of each menu item.

- **Show window / Hide window:** Opens and closes the RGB vs RGB window. This can also be done by clicking on the "RGB vs RGB" icon or with the "Tools/RGB vs RGB" menu.

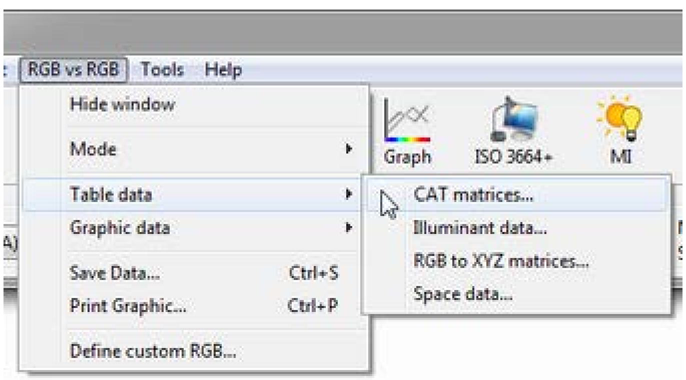
- **Mode:** Three modes are available. These modes affect how the data is compared or converted in the RGB vs RGB window.

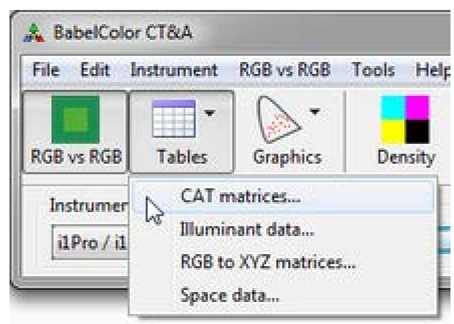


  - **Compare:** Sets the program in [Compare mode] if it was in Convert mode (either Left to Right or Right to Left). It has no effect if the program is already in Compare mode.
  - **Convert / Left to Right:** Sets the program in [Convert mode] Left to Right (Space #1 to Space #2). It has no effect if the program is already in Convert mode Left to Right.
  - **Convert / Right to Left:** Sets the program in Convert mode Right to Left (Space #2 to Space #1). It has no effect if the program is already in Convert mode Right to Left.

  These modes can also be set directly from the tool window. Please consult the RGB vs RGB [Mode Settings] section.

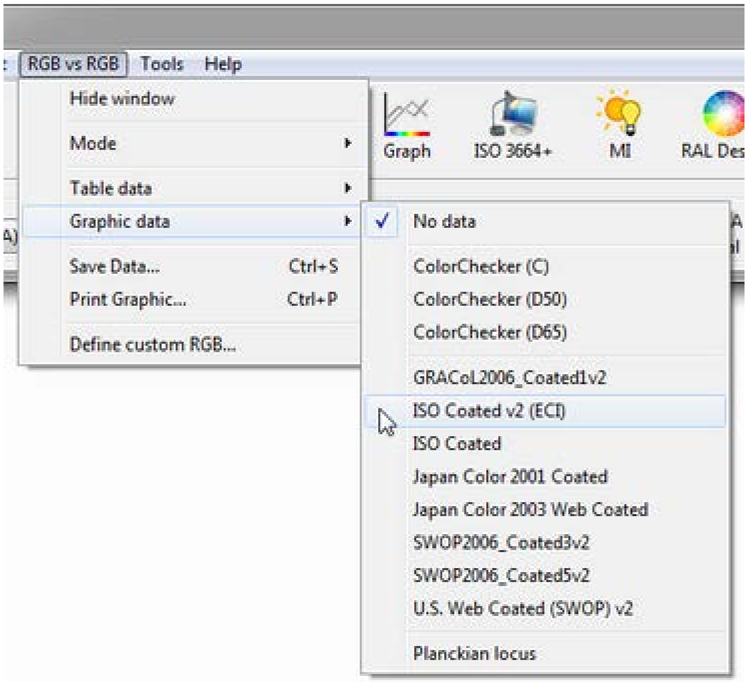
- **Table data:** These menu items are available even when the RGB vs RGB window is closed; they open stand-alone dialogs.

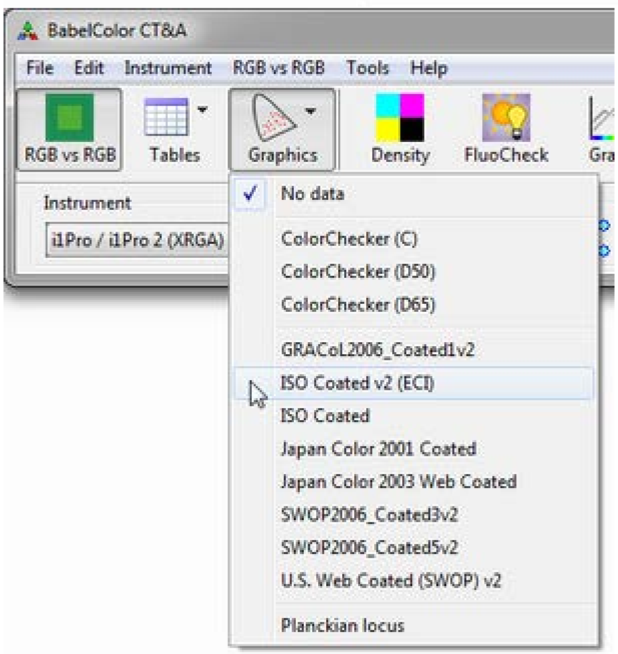




  - **CAT matrices...:** Opens the [CAT matrices dialog] which can display the [Bradford] and [CIECAT02] Chromatic Adaptation Transform (CAT) matrices that correspond to user selectable source and destination illuminants.
  - **Illuminant data...:** Opens the [Illuminant data dialog] that displays the [xyz] and [XYZ] coordinates of a user selectable illuminant.
  - **RGB to XYZ matrices...:** Opens the [RGB to XYZ matrices dialog] that displays the "RGB to XYZ" and "XYZ to RGB" matrices of a user selectable space.
  - **Space data...:** Opens the [Space data dialog] that displays the illuminant, the primaries, and the [gamma] parameters of a user selectable space.

- **Graphic data:** These menu items are available only when the RGB vs RGB window is opened; they control additional data that is shown in the chromaticity diagram.





The ColorChecker coordinates for all three illuminants are presented in this section. The CMYK data corresponds to the C, M, and Y primaries, plus the CM, MY, and YC overprints. The Planckian locus is the locus of blackbody illuminants between 1,000 K and 25,000 K.

- **Save Data...:** Opens a standard dialog to write, or select, the name of the file to save. The data and the Mode Settings of the current screen are saved in plain ASCII text (*.txt) format that can be opened with text editor application. The *.txt extension is added automatically. Saving in an existing file will overwrite it. An alternate means of opening this dialog is to press the **Control + S** keys, in Windows, or the **Command (⌘) + S** keys on a Mac.

  Hint: You can open the saved file in Microsoft Excel as well as other spreadsheet applications. In Excel, first select to open all files, then select the report file (its default name is BabelData.txt), then use the input Wizard. Select the "Delimited" and "Space separation" options. Some of the file content will be awkwardly formatted but, most importantly, the coordinates data and the data columns titles should be aligned. You can then copy and paste the data to another spreadsheet.

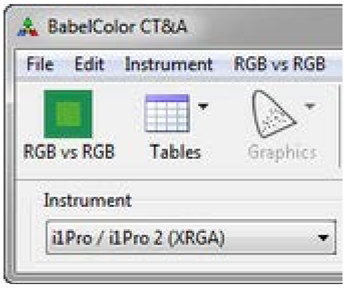
- **Print Graphic...:** Opens a standard dialog to select a printer, if more than one is available, and prints the chromaticity diagram. In addition, if enabled in the "RGB vs RGB" tab of the Preferences dialog, all the corresponding data and mode settings will be printed beside the diagram. The print size is adjusted to fill the default printable width. An alternate means of opening this dialog is to press the **Control + P** keys, in Windows, or the **Command (⌘) + P** keys on a Mac.

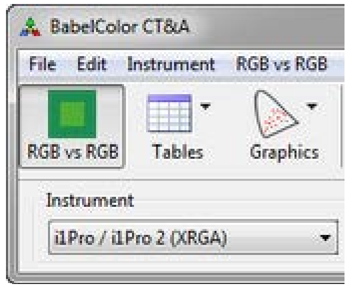
  Note: The page setup dialog ("**File/Page Setup...**") will be called before printing for the first time after a program start. This dialog is used to select the paper size, its orientation, and the print margins and, depending on the operating system version, you may also be able to change the printer from it.

- **Define custom RGB...:** Opens the Custom RGB space dialog where you can edit the Illuminant, primaries and gamma parameters of a custom RGB space; this space can then be selected, in a RGB Space space selection list. The illuminant of the custom space also defines the Custom illuminant in a Color Deck illuminant selection list.

4.2 RGB vs RGB Tables & Graphics

The "Tables" and "Graphics" icons of the toolbar window are associated to the RGB vs RGB tool window. The "Tables" icon is always enabled while the "Graphics" icon is enabled only when the RGB vs RGB tool window is opened. The "Tables" icon is equivalent to the "RGB vs RGB/Table data" menu item while the "Graphics" icon is equivalent to the "RGB vs RGB/Graphic data" menu item.





Here is a description of the "Tables" and "Graphics" menu items, with links to a description of each dialog and additional information.

TABLES / TABLE DATA

The data presented in the tables is used internally by the program to perform its color conversion routines.

- **CAT matrices...:** Opens the CAT matrices dialog which can display the Bradford and CIECAT02 Chromatic Adaptation Transform (CAT) matrices that correspond to user selectable source and destination illuminants.
- **Illuminant data...:** Opens the Illuminant data dialog that displays the xyz and XYZ coordinates of a user selectable illuminant.
- **RGB to XYZ matrices...:** Opens the RGB to XYZ matrices dialog that displays the "RGB to XYZ" and "XYZ to RGB" matrices of a user selectable space.
- **Space data...:** Opens the Space data dialog that displays the illuminant, the primaries, and the gamma parameters of a user selectable space.

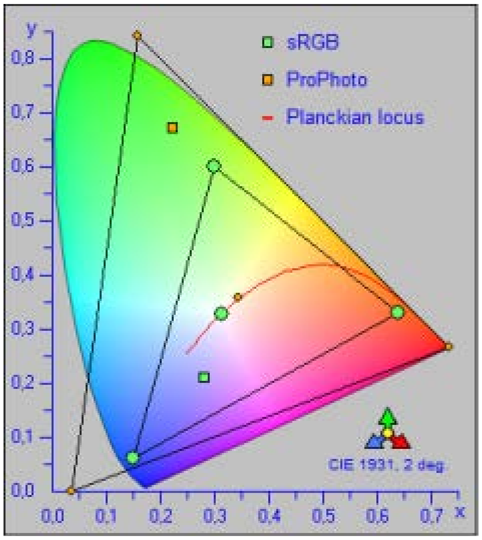
GRAPHICS / GRAPHIC DATA

When selected, the graphic data is shown on the "xy" chromaticity diagram (CIE 1931) and the diagram legend is updated. Only one data set can be seen at one time.

- **ColorChecker (C):**
  ColorChecker (D50):
  ColorChecker (D65):
  Displays the xy coordinates of the X-Rite/GretagMacbeth Colorchecker chart produced by the Munsell Color Lab. The chart has 24 color patches. Six of the patches are neutral gray, with identical coordinates corresponding to the illuminant. Thus, 19 data points are shown, 18 for the color patches and one for the illuminant. You can select to view the patch locations as computed with three different illuminants: "C", "D50" or "D65"; the coordinates are presented in this section.

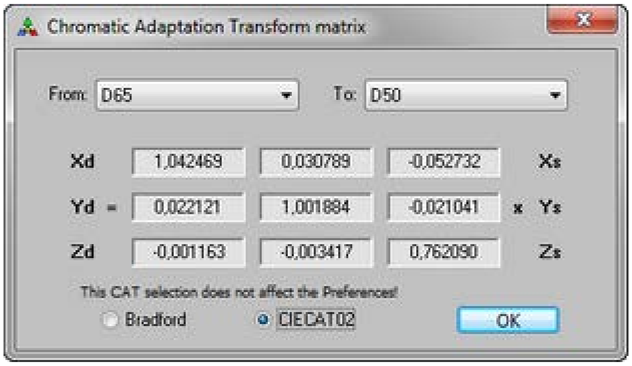
- **CMYK spaces:** Displays the C, M, and Y primaries and CM, MY, and YC overprints of eight common CMYK spaces. The coordinates are computed for the D50 illuminant.

- **Planckian locus:** Displays the chromaticity coordinates locus of blackbodies with temperatures between 1 000 K and 25 000 K, as shown below.



Note: Any graphic data selected with these menus will also be visible in the chromaticity diagram of the [Custom RGB space dialog](#).

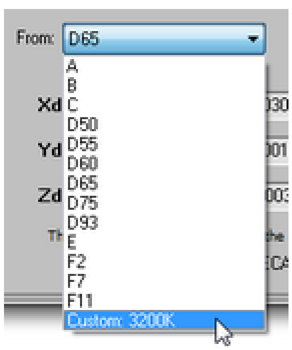
4.2.1 CAT matrices



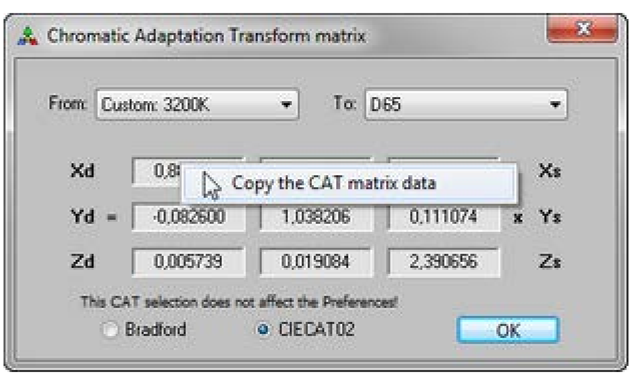
This dialog displays the 3 x 3 (Rows x Columns) **Bradford** or **CIECAT02** Chromatic Adaptation Transform (CAT) matrix that corresponds to user selectable source (**From**) and destination (**To**) illuminants. Source data is $X_sY_sZ_s$ and destination data is $X_dY_dZ_d$; both are column vectors.

By default, in Compare mode, the source is the illuminant of the LEFT side (Space #1 or Deck #1), and the destination is the illuminant of the RIGHT side (Space #2 or Deck #2). By default, in Convert mode, the source is the illuminant of the Space or Deck being converted "FROM", and the destination is the illuminant of the Space or Deck being converted "TO".

Additional standard illuminants plus any custom illuminant defined in the Custom RGB space dialog are provided in the illuminant selection menus:

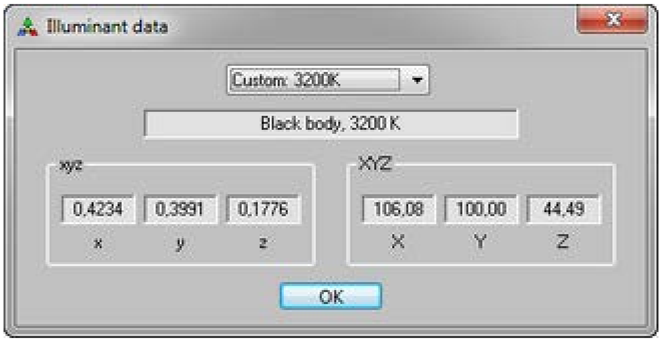


You can copy matrix data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on any data field. When copied, the data is transferred into the clipboard. Please note that matrix values are separated by Tabs, on three lines; you can then easily paste the values in a spreadsheet or document table, where they will be distributed in individual cells.



This dialog is called with the "RGB vs RGB/Table data/CAT matrices..." menu or with the "CAT matrices..." menu of the toolbar "**Tables**" icon.

4.2.2 Illuminant data



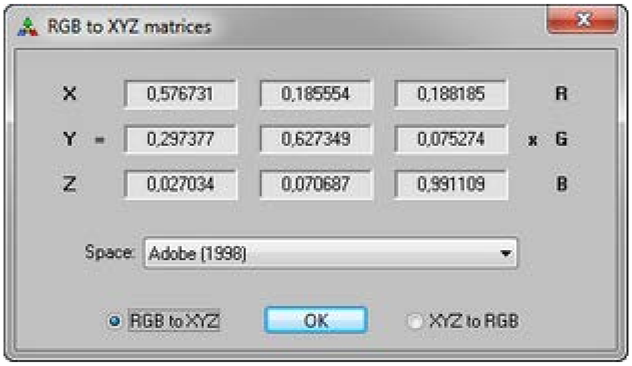
This dialog displays the xyz and XYZ coordinates of a user selectable illuminant.

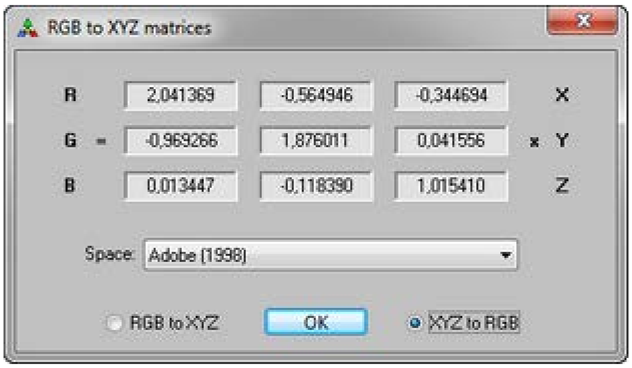
The "Y" coordinate is, by definition, equal to 100.

By default, the dialog selects the illuminant of the LEFT side (Space #1 or Deck #1). Any custom illuminant defined in the Custom RGB space dialog is also provided in the illuminant selection menu.

This dialog is called with the "RGB vs RGB/Table data/Illuminant data..." menu or with the "Illuminant data..." menu of the toolbar "**Tables**" icon.

4.2.3 RGB to XYZ data





This dialog displays either the 3 x 3 (Rows x Columns) RGB to XYZ matrix, or its inverse, the XYZ to RGB matrix, of a user selectable space. Input and output data are assumed to be column vectors.

Selecting "RGB to XYZ" or "XYZ to RGB" is done by clicking the corresponding radio button.

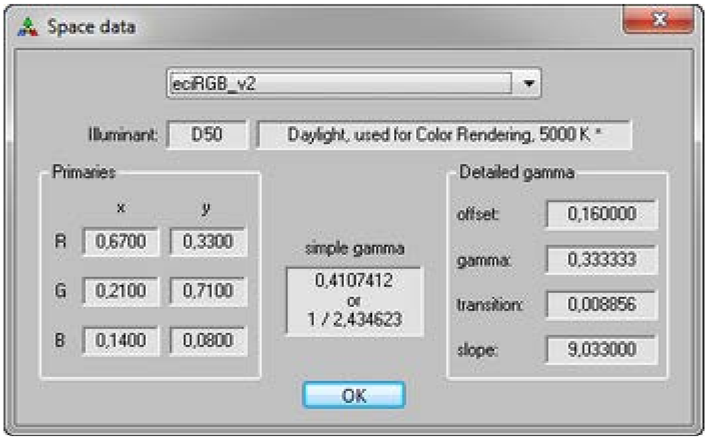
By default, the dialog presents the RGB to XYZ matrix of **Space #1** if the LEFT side is in Space mode, or when both sides are in Deck mode.

By default, the dialog will present the RGB to XYZ matrix of **Space #2** if the LEFT side is in Deck mode AND the RIGHT side is in Space mode.

Hint: You can save the two matrices data in a file by using the "Export to file..." button in the Custom RGB space dialog.

This dialog is called with the "RGB vs RGB/Table data/RGB to XYZ matrices..." menu or with the "RGB to XYZ matrices..." menu of the toolbar "**Tables**" icon.

4.2.4 RGB Space data



This dialog displays the illuminant, the primaries, and the gamma parameters of a user selectable RGB space.

The primaries coordinates are presented in the xyz form. Only "x" and "y" are shown since, by definition, z = 1 - x - y.

The "Detailed gamma" parameters are filled with zeros when the space is not defined with a detailed gamma function. For spaces defined with a detailed gamma function, we also provide a "simple gamma", a single parameter, which is often used by graphic editing programs.

The "simple gamma" is presented in two equivalent forms, with the second form showing the inverse value of the first one. However, the second form may look more familiar as it is the number used to characterize gamma in many programs.

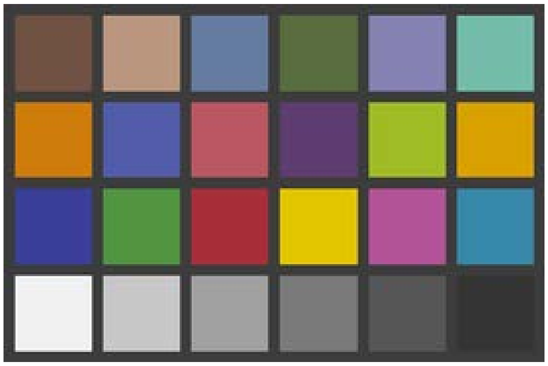
By default, the dialog presents data for Space #1 if the LEFT side is in Space mode, or when both sides are in Deck mode.

By default, the dialog will present data for Space #2 if the LEFT side is in Deck mode AND the RIGHT side is in Space mode.

Hint: You can get this data in a file by using the "Export to file..." button in the Custom RGB space dialog.

This dialog is called with the "RGB vs RGB/Table data/Space data..." menu or with the "Space data..." menu of the toolbar "**Tables**" icon.

4.2.5 ColorChecker data



Important: The above image is a **simulation** of the X-Rite/GretagMacbeth ColorChecker chart produced by the Munsell Color Lab. The colors are not calibrated and the image should not be used as a reference.

The ColorChecker card is ubiquitous in the photographic and video fields. Its main application is for obtaining a rapid assessment of an imaging devices' color rendering accuracy, although it can be used for calibration purposes. The ColorChecker consists of a series of six gray patches, plus typical additive (Red-Green-Blue) and subtractive (Cyan-Magenta-Yellow) primaries, plus other "natural" colors such as light and dark skin, sky-blue, foliage, etc. The color pigments were selected for optimum color constancy when comparing pictures of the chart with pictures of the natural colors... as reproduced on color film! Optimizing the human visual match was thus not the first priority; still, it was shown, by the chart designers, that the degree of metamerism was also very small when directly comparing the chart to the natural colors. Expressed otherwise, the perceived colors of the ColorChecker vary in the same way as the natural colors they represent when the light source changes, either when imaged on film or compared directly. Please consult Ref. 6 for a detailed description of the chart by the persons who designed it

Note: The technical term for a change in a single perceived color with various illuminants is Color Inconstancy, which is related to, but not the same as, metamerism, the term used when two colors matching under one illuminant do not match under another illuminant.

The coordinates of the patches under the "C", "D50" and "D65" illuminants are shown in the table below; in relation with the image above, the patch numbers start in the upper left corner and increase from left to right, and from top to bottom. The table values were derived from the measured spectral data of thirty (30) ColorChecker or Mini ColorChecker charts. The spectrums were first averaged, then converted to XYZ using the procedure and the weights of ASTM E308 (Ref. 16), and finally converted to xyY. You will find much more information and data on the ColorChecker, including "synthetic" images of the chart in numerous color spaces, on the ColorChecker page of the BabelColor Web site.

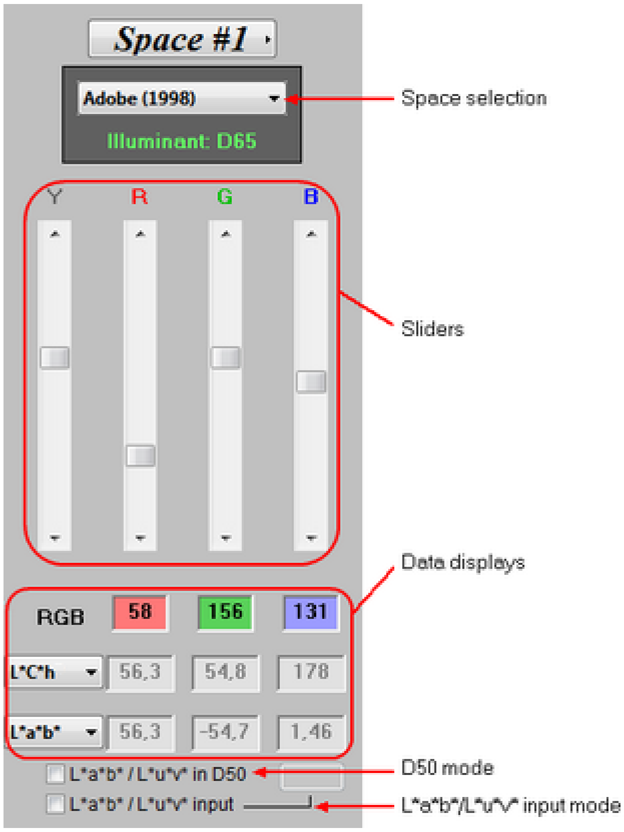
		C			D50			D65		
#	description	x	y	Y	x	y	Y	x	y	Y
1	dark skin	0,396	0,350	10,1	0,433	0,379	10,3	0,398	0,360	10,1
2	light skin	0,381	0,346	34,6	0,419	0,375	35,3	0,383	0,356	34,6
3	blue sky	0,246	0,252	18,8	0,276	0,300	18,5	0,249	0,266	18,9
4	foliage	0,343	0,419	13,3	0,370	0,450	13,3	0,343	0,432	13,3
5	blue flower	0,266	0,242	23,5	0,302	0,288	23,2	0,269	0,254	23,5
6	bluish green	0,260	0,345	42,4	0,286	0,391	41,7	0,261	0,360	42,7
7	orange	0,508	0,401	30,0	0,529	0,408	31,2	0,508	0,406	29,7
8	purplish blue	0,210	0,173	11,8	0,234	0,216	11,4	0,212	0,184	11,8
9	moderate red	0,458	0,305	18,9	0,501	0,329	19,8	0,462	0,312	18,7
10	purple	0,288	0,210	6,42	0,333	0,256	6,44	0,292	0,222	6,37
11	yellow green	0,380	0,487	44,0	0,399	0,500	44,3	0,377	0,496	44,2
12	orange yellow	0,476	0,437	42,4	0,496	0,443	43,6	0,476	0,442	42,1
13	blue	0,187	0,135	6,16	0,204	0,170	5,79	0,188	0,144	6,11
14	green	0,307	0,477	23,2	0,327	0,503	23,1	0,306	0,489	23,4
15	red	0,537	0,316	11,9	0,571	0,330	12,7	0,539	0,322	11,7
16	yellow	0,452	0,471	59,5	0,469	0,473	60,8	0,449	0,476	59,4
17	magenta	0,364	0,232	19,5	0,418	0,270	20,1	0,369	0,241	19,2
18	cyan	0,197	0,255	19,7	0,215	0,304	19,0	0,198	0,270	20,0
19	white (0.05 D)	0,313	0,322	91,3	0,349	0,363	91,3	0,316	0,334	91,2
20	neutral (0.23 D)	0,310	0,317	58,9	0,345	0,360	58,9	0,312	0,330	58,9
21	neutral (0.44 D)	0,309	0,317	36,0	0,345	0,359	36,0	0,312	0,330	36,0
22	neutral (0.70 D)	0,309	0,317	19,1	0,344	0,359	19,1	0,311	0,329	19,1
23	neutral (1.05 D)	0,307	0,315	8,94	0,342	0,358	8,93	0,310	0,328	8,94
24	black (1.5 D)	0,308	0,314	3,20	0,344	0,356	3,20	0,311	0,327	3,20

The locations of the ColorChecker chart patches for these three illuminants can be viewed on the chromaticity diagram by selecting one of the three "RGB vs RGB/Graphic data/ColorChecker ( )" menus or one of the three "ColorChecker ( )" menus of the toolbar "**Graphics**" icon.

Note: The numbers between parentheses in the neutral patches descriptions are optical densities.

A procedure to simulate a ColorChecker color patch is given in the Tutorials section.

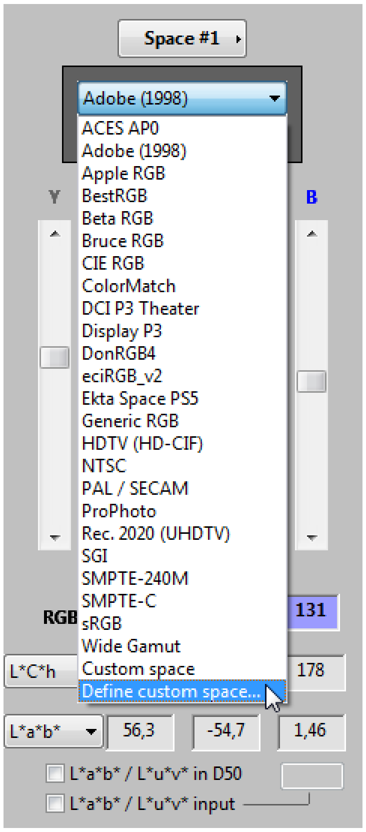
4.3 RGB Space interface



The interface is identical for Space #1 (LEFT side) and Space #2 (RIGHT side).
For more information, use the links in the Table of Contents below.

RGB Space interface - Table of Contents

4.3.1 Space selection



You can select any of twenty-four (24) pre-defined spaces or one custom space by clicking in the menu below the "Space #1" or "Space #2" labels. The selection list is the same for Space #1 and Space #2. A custom space can be defined in terms of "illuminant", "primaries", and "gamma"; the Custom RGB space dialog can be opened either by selecting the last menu item in the space selection menu, as shown on the left, or with the "RGB vs RGB/Define custom RGB..." menu.

The illuminant corresponding to the selected space will automatically be shown below the space name.

Space selection change effect in Compare mode

After a space selection, if the Input mode for the Space is R'G'B', the system uses the displayed R'G'B' values to recompute all other data fields (xyY, XYZ, L*a*b*, L*u*v*, L*a*b* (D50), L*u*v* (D50), DeltaE*...).

If the input mode for the Space is L*a*b* / L*u*v* (see L*a*b* / L*u*v* input), and the  button (click here for information on this button) is NOT active at the change request, the system uses the displayed values of either L*a*b*, L*u*v*, L*a*b* (D50), or L*u*v* (D50), depending on the selected modes, and updates all the others, including R'G'B'.

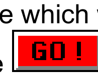
If the  button is active at the change request, then the following sequence is performed:

1. The L*a*b* / L*u*v* display boxes are reloaded with the last computed values.
2. The "GO !" button is de-activated.
3. Recomputing is performed with the new space parameters.

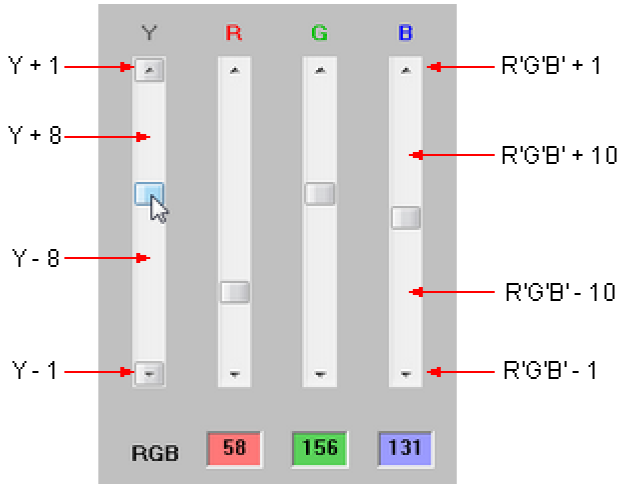
In Compare mode, the spaces and decks are independent and only the Space for which the space selection was changed will be updated.

Space selection change effect in Convert mode

If the change is in a Space which is the source of the data (i.e. being converted "FROM"), then the selection change has the same effect as if in Compare mode. However, the other Space or Deck (i.e. being converted "TO"), is updated thereafter.

If the change is in a Space which is being converted "TO", then the selection change first triggers an update on the **other** side, Space or Deck, which then updates the Space which was changed. If that other side (i.e. being converted "FROM") is in "L*a*b* / L*u*v* input" mode and the  button is active at the change request, the L*a*b* / L*u*v* display boxes are reloaded and the "GO !" button is de-activated before updating both sides.

4.3.2 Sliders



R'G'B' SLIDERS

The **R**, **G** and **B** sliders control the R'G'B' inputs. Their minimum value is zero and their maximum is 255; all values in between are integer numbers. The actual values are shown in the R'G'B' display boxes under the sliders.

"Y" SLIDER

The Y slider is a luminance control related to the "Y" in the xyY or XYZ color representations. Its minimum value is zero but its maximum is controlled by a combination of the R'G'B' values and the selected space characteristics. The "Y" value is not linearly related to the slider position. Moving the Y slider affects the **R**, **G** and **B** sliders and displays, as well as the "Y" display, but it does not affect the "xy" coordinates, as it can be verified by looking at the xyY data display or the position of the space's color on the chromaticity diagram.

The Y slider has the following characteristics:

- It is always positioned at the level of the maximum value of the current R'G'B' data set.
- Increasing and decreasing it will maintain the color content (chroma, i.e. "xy" coordinates) irrelevant of luminance.
- In order to maintain the accuracy of the "xy" coordinates when moving the "Y" slider, the slider will generate fractional values of R', G' and B'. The R'G'B' data displays show rounded values in this case. See the data integrity section for more information.
- Moving the Y slider to the top will give you the brightest R'G'B' coordinates (with maximum "Y" and maximum "L*"), in the selected RGB space, for the current "xy" data set.
- "Y" acts like the Brightness variable in the HSB (Hue-Saturation-Brightness) color model. Calling it "Y" prevents confusion with the **B** of **RGB**. But, more importantly, by not providing a fixed scale value display and associating it, instead, to a variable with a physical significance, "Y", it gives a better assessment of the real luminance of a color; in comparison, the "B" in HSB is the relative brightness of a Hue and Saturation combination, with a maximum of 100 for all combinations.

Note: "Y" is proportional to the luminance of the color (measured in cd/m^2) as it would be measured with a photometric detector. Doubling its value doubles the amount of flux emitted by the color patch. However, since the human eye is not a linear detector, the perceived brightness is less than doubled. The "L*" of the L*a*b* and L*u*v* color representations are designed to closely mimic the human eye in terms of brightness response and can, as well, be mentally associated with the Y slider. Please note, however, that increasing or decreasing the Y slider not only changes "L*" but the "a*" and "b*" coordinates as well.

SLIDERS' CONTROL

All four sliders in each space can be positioned by either:

- Moving the elevator box directly with the mouse.
- Clicking between the elevator and the arrows at the extremities.
- Clicking the arrows at the extremities (Not available on Mac OS X 10.7, i.e. Mac Lion).
- Moving the elevator box using the mouse wheel (or a sliding gesture on a Mac Magic Mouse).

The R'G'B' values will change by the amounts showed in the above illustration. The "Y" slider will affect the maximum value of the R'G'B' data set by the amount shown. The actual value change for "Y" is relative to the maximum emitted flux of each specific color, and is thus different for each color and space.
Note: Starting with "Y" at the top of its slider, clicking repeatedly between the elevator box and the bottom arrow will give 32 color patches of uniformly decreasing brightness, plus a patch of black at the last click.

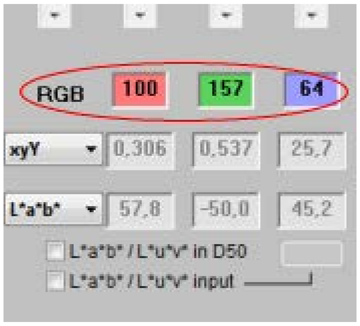
4.3.3 Data displays

Within the RGB Space interface, data can be inserted in R'G'B', L*a*b*, or L*u*v* coordinates, depending on the input mode. Data fields with a grayish background do not accept input.

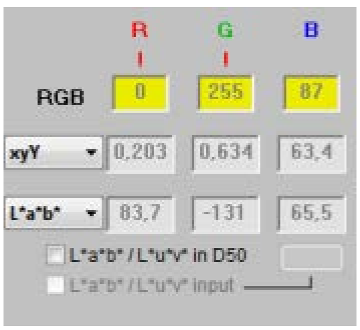
Click or double-click in the data display boxes to change the values. Use the **Tab** key to move between all the enabled boxes of both spaces, either R'G'B' or L*a*b* / L*u*v*.

Data is presented in the following formats:

- **RGB** (in reality: R'G'B')



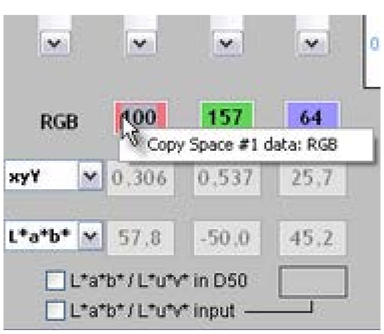
The red, green and blue background colors of the RGB data displays shown above indicate that this space input mode is R'G'B', i.e. color data for this space is entered either directly in these boxes, or via the sliders. If data in this space was converted from the other space, the RGB display would be seen as follow:

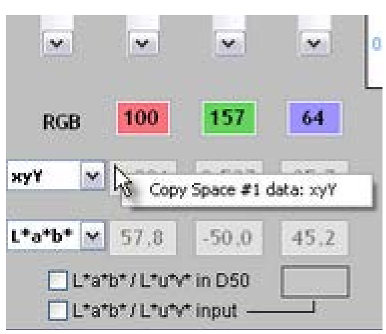


In the display just above, the background color of the R'G'B' display boxes is yellowish and input is disabled. The sliders are also disabled.

When this display is visible, you will notice, from time to time, the appearance and disappearance of red exclamation points (**!**) between the display boxes and the sliders; these **clipping indicators** which inform the user that the color from the originating space is out of the converted space gamut, and it had to be clipped; see the Mode settings section for more information on the Convert mode.

You can copy numerical data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on a data field. Shown below is the contextual menu which appears with a right-click on an RGB field or on a xyY field; selecting the menu will transfer the three coordinates into the clipboard, separated by Tabs. You can then easily paste the values in a spreadsheet or document table, where they will be distributed in three columns.





- **Hex #** (Hexadecimal equivalent of R'G'B')
- **HSB** (Hue-Saturation-Brightness)
- **Munsell HVC** (Hue-Value-Chroma)
- **L*C*h** based on either L*a*b* or L*u*v* and the D50 checkbox
- **xyY** referenced to the illuminant of the selected space
- **XYZ** referenced to the illuminant of the selected space

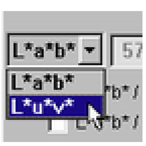
Use the menu located below the "**RGB**" label to select among the following color spaces: Hex #, HSB, Munsell HVC, L*C*h, xyY or XYZ.

The Munsell HVC values are not simply the ones corresponding to the closest sample in the Munsell deck catalogue, but are INTERPOLATED values that closely match the selected Space color.

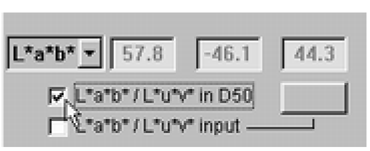
The L*C*h values are automatically updated, even if there is no color change, when you change the L*a*b* / L*u*v* display and when you click in the "L*a*b* / L*u*v* in D50" checkbox described below. The displayed values are:

1. $\boldsymbol{L^*C^*_{ab}h_{ab}}$ referenced to the **space illuminant** when **L*a*b*** is selected and the "L*a*b* / L*u*v* in D50" checkbox is **NOT** selected
2. $\boldsymbol{L^*C^*_{uv}h_{uv}}$ referenced to the **space illuminant** when **L*u*v*** is selected and the "L*a*b* / L*u*v* in D50" checkbox is **NOT** selected
3. $\boldsymbol{L^*C^*_{ab}h_{ab}}$ referenced to **D50** when **L*a*b*** is selected and the "L*a*b* / L*u*v* in D50" checkbox **IS** selected
4. $\boldsymbol{L^*C^*_{uv}h_{uv}}$ referenced to **D50** when **L*u*v*** is selected and the "L*a*b* / L*u*v* in D50" checkbox **IS** selected

- **L*a*b*** referenced to the illuminant of the selected space
- **L*a*b*** referenced to illuminant D50
- **L*u*v*** referenced to the illuminant of the selected space
- **L*u*v*** referenced to illuminant D50



Use the bottom menu to select either the L*a*b* or L*u*v* color space.



Checking the "L*a*b* / L*u*v* in D50" checkbox instructs the program to show L*a*b*, L*u*v* and L*C*h values converted to illuminant D50, irrelevant of the illuminant of the selected space. Of course, if the space illuminant is D50, no change will be seen in the displays. When the "L*a*b* / L*u*v* in D50" checkbox is unchecked, the L*a*b*, L*u*v* and L*C*h displays show values corresponding to the illuminant of the selected space.

Changing the L*a*b* / L*u*v* selection or changing the "L*a*b* / L*u*v* in D50" checkbox status will automatically update the L*C*h display, whether it is visible or not. Please refer to the additional information on the L*C*h display above.

Checking the "L*a*b* / L*u*v* input" checkbox instructs the program to use L*a*b* or L*u*v* as input values; this selection is also required for instrument input. Click here for more information on the "L*a*b* / L*u*v* input" interface.

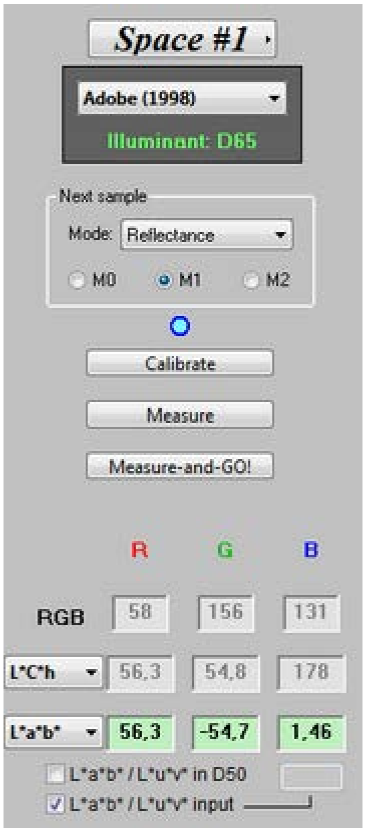
When in "L*a*b* / L*u*v* input" mode, and when the 

button is active, changing the L*a*b* / L*u*v* selection or the "L*a*b* / L*u*v* in D50" checkbox status will reset the display to the previously calculated values, and disable the "GO !" button.

Note: Be cautious, the L*a*b* values shown in Adobe Photoshop are always in D50, irrelevant of the illuminant of the selected space.

For more information on the program modes, go to the Mode Settings section.

4.3.4 L*a*b* / L*u*v* input



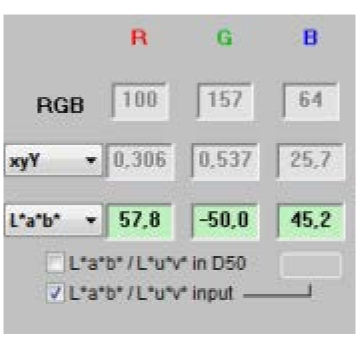
The above display is obtained by checking the "L*a*b / L*u*v* input" checkbox (RGB space: Adobe (1998)).

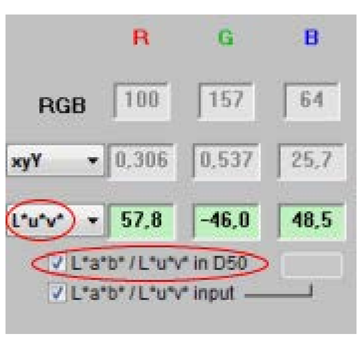
The light green background color of the L*a*b* data displays indicate that this space input mode is L*a*b*; the R'G'B' sliders and RGB data boxes are disabled and replaced by controls dedicated to instrument input. Color data for this space can be entered directly in the light green data fields, either manually or by making a measurement with one of the supported instruments. There is no setting to select between manual or instrument input; you just enter data or take a measurement.

Note: We see a blue indicator in the screenshot above. This indicator appears when an i1Pro series spectrophotometer is connected and recognized by the program (the RGB vs RGB window must also be selected, i.e. brought to the front). In this case we know it is an i1Pro 2 since the M0, M1, M2 measurement conditions can be selected.

ALTERNATE INPUT MODES

Beside L*a*b*, alternate input modes are L*u*v*, L*a*b* (D50), or L*u*v* (D50); they are selected with a combination of the L*a*b* / L*u*v* menu and the "L*a*b* / L*u*v* in D50" checkbox. For the screenshot below on the left, we first assigned RGB = (100, 157, 64) in the Adobe (1998) space and then selected the "L*a*b* / L*u*v*" checkbox. For the screenshot below on the right, we selected "L*u*v*" in the L*a*b* / L*u*v* menu and we checked 'L*a*b* / L*u*v* in D50".

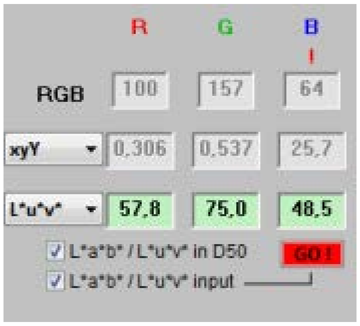




Note: In order to match the L*u*v* in D50 values of the screenshot, you should select "Bradford" as the Chromatic Adaptation Transform (CAT) used to convert XYZ coordinates between different illuminants (in this case between D65 and D50) in the "Math" tab of the Preferences dialog.

MANUAL DATA INPUT

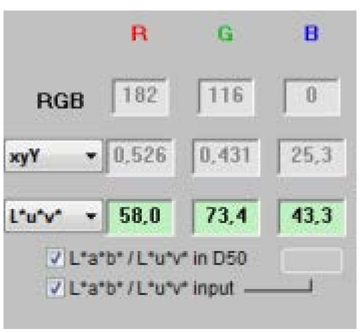
Click or double-click in the data display boxes to change the values. Press the **Tab** key to move between the boxes. Whenever a display content is changed, here "75.0" was entered for the u* coordinate, a button with a red background and "**GO !**" written on it appears:



You will notice, when entering data, that all other displays are **NOT** automatically updated. To update the other data displays, you should first enter all L*a*b* or L*u*v* values and then click on the 

button (alternately, press the **Return** or the **Enter** key).

This manual refresh procedure was devised because the L*a*b* and L*u*v* spaces can describe all the visible spectrum while the R'G'B' spaces only represent a subset of it. When entering data, it is very likely that the color described by the input data is outside of the R'G'B' space gamut, and clipping will occur; in such a case, clipping will be flagged by one or more red exclamation points (**!**) located below the "R", "G", and "B" labels. These clipping indicators provide **advanced warning**; they identify the R'G'B' coordinate(s) that **will be** clipped by the data present in the input boxes. The three data input fields can be modified at will, until the "GO !" button is pressed, to see how and if other data values will be clipped. If you press the "GO!" button when clipping is flagged, the software will select the closest color corresponding to the input data within the RGB space, as shown below.



By comparing the display just above with the previous display, we see that the requested L*u*v* (D50) input of (57.8, 75.0, 48.5) requires an out of bound B' (blue) value (a negative value in this case). The nearest valid R'G'B' color computed by the software has a B' value of zero, indicative of the clipping process. Also, the program recomputed the L*u*v* (D50) value (and all other color representations) to match the R'G'B' data.

The clipping indicators disappear once the "GO !" button is pressed.

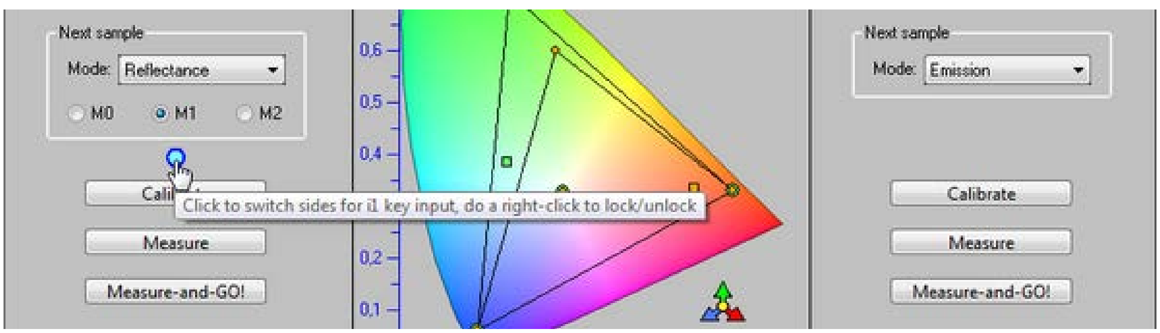
DATA INPUT WITH AN INSTRUMENT

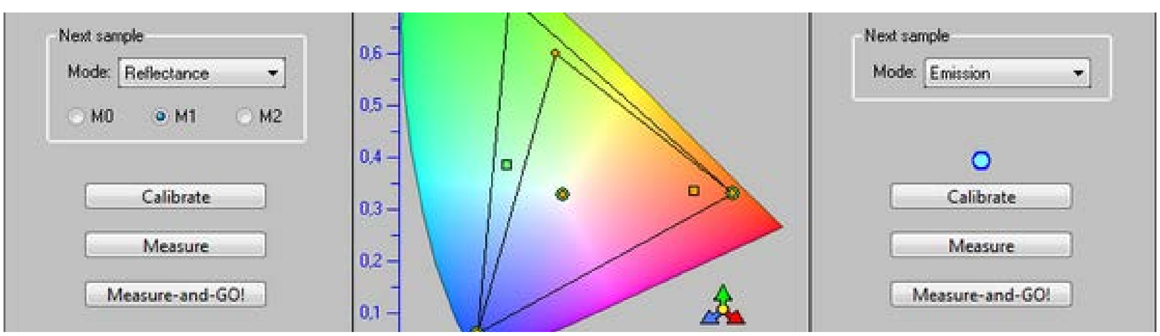
If you have one of the supported instruments, you can input data by clicking on the "Measure" or "Measure-and-GO!" buttons or, if you have an i1Pro series spectrophotometer, simply by pressing the instrument button. When you click the "Measure" button, the data measured by the instrument is entered in each data field as if it was entered manually; the GO! button appears and you will know that your measurement is outside the RGB space gamut if clipping indicators are visible. Like for manually entered values, you need to press the GO! button to complete the measurement. When you click the "Measure-and-GO!" button, the data is entered and the GO! button is pressed automatically; this procedure is faster and is recommended when you know that your measured values are within the selected RGB space. If using an i1Pro series spectrophotometer, pressing the instrument button is equivalent to click the "Measure-and-GO!" button.

Hint: If you just want to measure and compare colors in L*a*b*, with no need for this color to be associated with an RGB space, you can select a very large space, ProPhoto RGB for instance, to perform your measurements. Selecting a larger space minimizes the chances of measuring a color which will be clipped. You can also define your own space or edit an existing one; for example you could create a space with ProPhoto RGB primaries and a D65 illuminant, instead of D50, if D65 is the illuminant for which you want specific L*a*b* data.

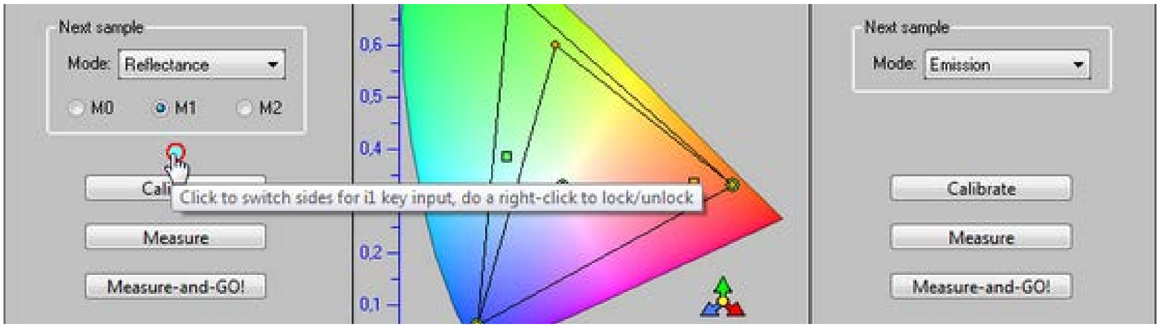
If an instrument is properly connected and detected by the program, as it can be easily confirmed by a green instrument status light in the toolbar window, the "Calibrate", "Measure", and "Measure-and-GO!" buttons of the RGB vs RGB window will be enabled; also, the measurement mode menu in the "Next sample" controls group will offer only the modes supported by the connected instrument. In addition, if using an i1Pro series spectrophotometer, a large blue indicator will appear above a "Calibrate" button when the RGB vs RGB window is selected (brought to the front). The blue indicator identifies the space for which a measurement will be done if you press the instrument button. If both spaces can accept input by measurement, the blue indicator automatically changes location after making a measurement.

You can click (left-click) on the indicator to move it to the other side if required; this is shown below in the next two screenshots.





You can also do a right-click on the blue indicator to lock it on a given side; a locked indicator is surrounded by a red circle, as shown below. If you do a left-click on a locked indicator; the indicator will change side and the new position will be locked.



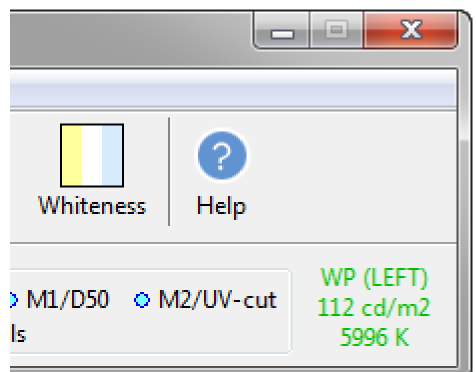
In the above screenshots, you will notice that the measurement mode was set differently in each space, to **Reflectance/M1** for Space #1, on the left, and **Emission** for Space #2, on the right. The measurement modes available in the "Mode" menu of the "Next sample" group depend on the capabilities of the connected instrument; the "Emission", "Ambient", "Reflectance", and "Flash" modes are supported. For reflectance measurements, and if you are using an **i1Pro 2** with the "**i1Pro / i1Pro 2 (XRGA)**" driver, an i1Pro 3, or an i1Pro 3 Plus, you can select the "Measurement Conditions": M0 (Ill-A), M1 (D50), M2 (UV-cut). If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument.

The "Illuminant" used to process the measurement will be the one assigned to the RGB space. For reflectance measurements, and if this illuminant is not one of the standard illuminants supported by the program (A, C, D50, D65, or E), the measurement will have to be done by first selecting the "L*a*b* /L*u*v* in D50" checkbox; the measurement will then be converted internally to the illuminant of the RGB space.

The "Observer" is 2 degree, by default, in all RGB spaces.

Before making your first measurement, you should calibrate the instrument by clicking the "Calibrate" button. The program will calibrate the instrument in the mode selected in the "Next sample" controls group located just above the calibration button.

Note: In CT&A, emission calibration requires the measurement of a white patch, preferably located on the display or emissive surface on which subsequent measurements will be performed; this procedure sets the *White Point* (WP). The WP characteristics (display location, luminance and CCT) are shown in the toolbar window, as seen in green text in the screenshot on the right.



When a measurement is made in "Emission", "Ambient" or "Flash" mode, the photometric quantity, cd/m^2, lux, or lux-sec, and the Correlated Color Temperature (CCT, in kelvin) is shown just above the "RGB" label. Please note that the CCT may not be provided if the measured coordinates are too far from the central "Illuminant" zone of the chromaticity diagram.

The *L** (of L*a*b*) and *Y* (of XYZ) values of the **AMBIENT color coordinates** are always maximized relative to their *xy* (chromaticity coordinates) position in the selected RGB space (in other words, at least one of the R, G, or B coordinates will have a value of 255). *L** and *Y* values of 100 can only be assigned to the chromaticity coordinates of the illuminant. (Note: this is different than what is done in the Graph tools where *L** and *Y* are 100 for all ambient measurements).

Important: The *L** and *Y* values of the **EMISSION color coordinates** are computed relative to the display *White Point*, as discussed above. Accordingly, the display white is assigned *L** and *Y* values of 100. Nothing prevents you of using another monitor or another emissive surface to set this reference value, and all subsequent emission measurements will then be referenced to this new white point. However, be aware that the L*a*b* and "Y" values, as well as the appearance of the patches of all **previous** emission measurements will NOT be updated. On the positive side, in emission measurements, the only absolute parameters are the chromaticity coordinates (xy), and these parameters should **not** be affected by an emission calibration change.

Here is a table which describes the difference between the RGB vs RGB tool and the Graph tools relative to **EMISSION** and **AMBIENT** measurements:

Mode	RGB vs RGB tool	Graph tools
Emission	• Y and L* are relative (0-100) to the calibration white Luminance (Yabs) • Y is limited by the maximum xyY values of the selected RGB space (i.e. the input may be clipped) • Patches with chromaticities outside of the RGB space will be clipped	• Y and L* are relative (0-100) to the calibration white Luminance (Yabs) • The input is NOT clipped
Ambient	• Y is the maximum value, for the RGB space, of the input xy coordinates (i.e. one or more RGB coordinate will always be 255) • Patches with chromaticities outside of the RGB space will be clipped	• Y and L* are always equal to 100 • The input is NOT clipped

Note: Only x and y are absolute coordinates. While the absolute luminance and illuminance are provided in cd/m^2 or lux, Y is normalized when shown in the xyY and XYZ data fields.

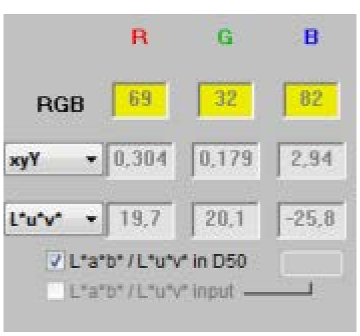
Important: Many displays (usually CRTs, but sometimes LCDs) will change their brightness depending on what is displayed on the rest of the screen. This is why a single small white square over a black background is used for emission calibration. As a consequence, in some displays, you may find that, thereafter, white is measured with an *L** value of less than 100 in many situations. Also, most displays are not uniform, with the center portion "usually" at a higher luminance than the rest of the display; however, it is also possible that the display center is not the area with the highest luminance.

Note: You may be curious to know why a *White Level* calibration is required in this program and not in X-Rite/GretagMacbeth MeasureTool? In effect, MeasureTool also uses a *White Level* reference value, very likely coming from a screen profile saved on your computer. The only difference is that, with CT&A, you can set the reference to other displays.

Measured data can be saved by using the "Save data..." and "Print Graphic..." commands of the "RGB vs RGB" menu. You should also consult the "RGB vs RGB" tab of the Preferences dialog for additional options.

APPEARANCE IN CONVERT MODE

By default, the "L*a*b* / L*u*v* input" checkbox is disabled if the user selects to Convert "TO" a space set for "L*a*b* / L*u*v* input". The display then looks as follow (data content is irrelevant in the following image):

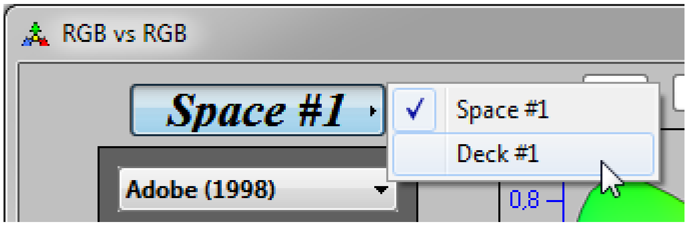


The display appearance is the same whether the input was R'G'B' or "L*a*b* / L*u*v* input" before the requested Convert "TO" mode change. The background color of the R'G'B' display boxes is yellowish and input is disabled. The sliders are also disabled.

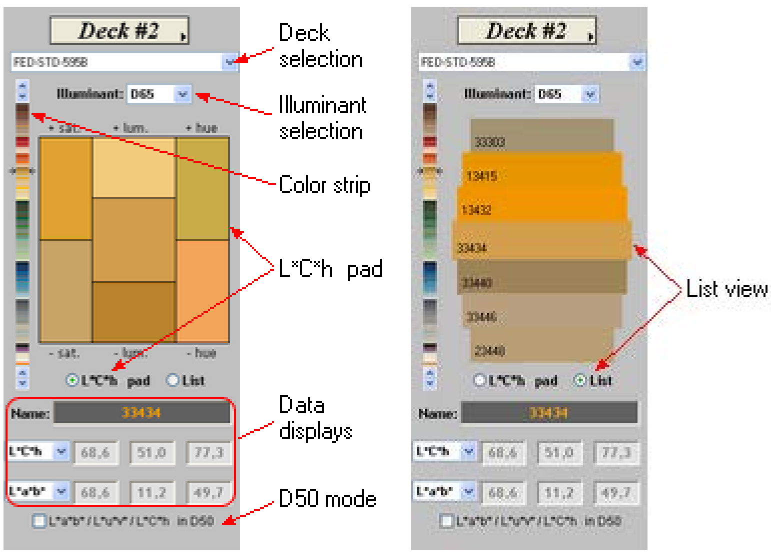
If the system is set in Compare mode afterwards, input mode becomes R'G'B', by default.

4.4 Color Deck interface

Catalogues of color chips, herein called **Color Decks**, can be opened in lieu of an RGB space. To access the Deck mode, click on the Space #1 or Space #2 label in the RGB vs RGB window and select the Deck menu. To come back to the RGB space mode, just select the Space menu when you click on the Deck label.



The interface is identical for Deck #1 (LEFT side) and Deck #2 (RIGHT side). Two deck navigating modes are available, one using the L*C*h pad, and the other a List view. They are selected with the radio buttons located below the color patches.



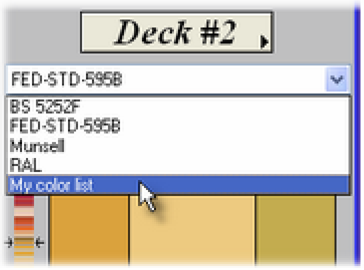
The following Color Decks are provided: British Standard 5252F (BS 5252F), the framework for many British color standards; FEDERAL STANDARD 595 (FED-STD-595), a set of colors used in the United States of America for government procurement; the Munsell collection, which are samples based on the Munsell color system and manufactured at uniform Hue, Value, and Chroma intervals; and the RAL CLASSIC colors, a set of colors used in Europe since 1927. User-defined color lists can also be imported and added as Color Decks.

Click on a specific zone of the interface image for more information, or in the Table of Contents below.

Deck interface - Table of Contents

4.4.1 Deck selection

SELECTION CHANGE EFFECT IN COMPARE MODE



Use the menu below the "Deck #1" or "Deck #2" label to select a Color Deck. The selection list is the same for Deck #1 and Deck #2.

The default D65 illuminant will automatically be shown below the deck name. Another illuminant can be assigned using the Illuminant selection menu; click here for more information on illuminant selection.

After a deck selection, the system loads the deck information from the database. The sequence of events is as follow:

1. The color strip is regenerated according to the Color Deck database content.
2. The data corresponding to the first color chip in the database is computed in relation to the selected illuminant.
3. The L*C*h pad or the List view is updated.

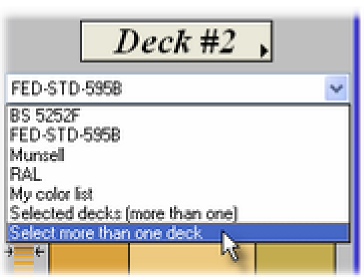
In Compare mode, the spaces and decks are independent and only the Deck for which the deck selection was changed will be updated.

SELECTION CHANGE EFFECT IN CONVERT MODE

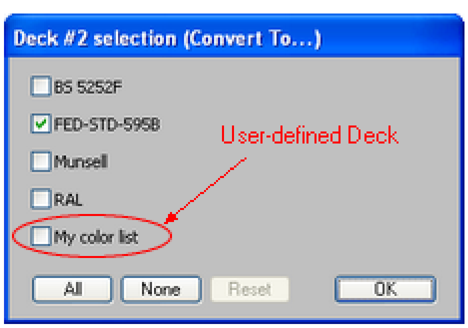
If the change is in a Deck which is the source of the data (i.e. being converted "FROM"), then the selection change has the same effect as if in Compare mode. However, the other Space or Deck (i.e. being converted "TO"), is updated thereafter.

If a Deck is being converted "TO", then two new menu items appear at the bottom of the deck selection list:

- "Selected decks (more than one)"
- "Select more than one deck"



Selecting the last item, "Select more than one deck", opens a Deck Select dialog, shown below, that is used to select one or more decks as destinations for converting "TO":



In the Deck Select dialog, the "Reset" button is enabled whenever a change is done in the selection. Clicking on this button will reselect the initial configuration.

At least one deck has to be selected when leaving the dialog; if not, a window with a warning message will pop up. Once the dialog is closed, the color strip is regenerated according to the dialog selection and will show a snapshot of ALL selected decks. When two or more decks are selected, the next to last menu item, "Selected decks (more than one)", is displayed instead of a single Deck name.

When making changes to a Deck(s) which is/are being converted "TO", then the selection change first triggers an update on the other side (i.e. being converted "FROM"), Space or Deck, which then updates the Deck(s) which was/were changed. If that other side is in "L*a*b* / L*u*v* input" mode and the 

button (click here for information on this button) is active at the change request then:

1. The L*a*b* / L*u*v* display boxes are reloaded with the last computed values.
2. The "GO !" button is de-activated.
3. An update is performed for both sides.

ADDING A USER-DEFINED DECK

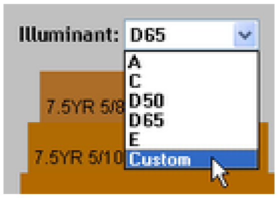
User-defined color lists can be added as Color Decks; one such list, named "My color list", is shown in the screenshots above. Adding a Deck is performed using the BabelColor CT&A Export tool of the PatchTool program (an external program), which converts color lists saved in CGATS, CXF, ASE (Adobe Swatch Exchange file format), or plain text format to the Color Decks database format. PatchTool can also remove a Deck from the database.

PatchTool's "BabelColor CT&A Export" tool is accessible even when PatchTool is not purchased (or not activated); however, accessing all of PatchTool's features requires purchasing a separate license. Please consult the PatchTool Help manual in the section dedicated to the "BabelColor CT&A Export" tool for more information on how to edit the Color Decks database.

IMPORTANT: Starting with CT&A version 3.1, the Color Decks database file name is *ColorDecks_R2.bbd*; the database file name in previous versions was *ColorDecks.bbd*. Users who have customized their Color Decks in previous versions will need to regenerate them starting with the *ColorDecks_R2.bbd* file. DO NOT CHANGE THE OLD DATABASE NAME TO THE NEW NAME! If you do so, the Munsell Deck, as well as conversions to the Munsell space, will be less precise.

4.4.2 Illuminant selection

The default illuminant used to show deck data is D65. This illuminant can be changed using the illuminant selection list:



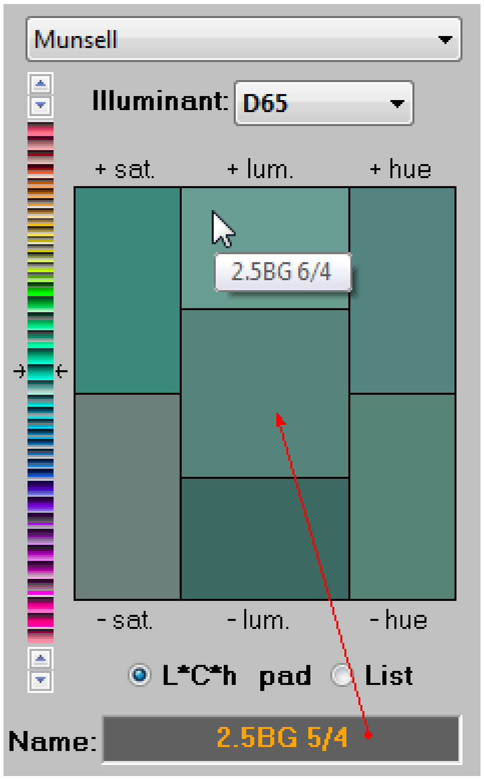
The selection will affect the deck data, the data displays, as well as the chromaticity diagram. The "Custom" illuminant is the one selected for the custom space; it can be changed by first selecting the "RGB vs RGB/Define custom RGB..." menu command and editing the illuminant section of the Custom RGB space dialog.

Important: The data displays will not show any change if the "L*a*b* / L*u*v* / L*C*h in D50" checkbox is selected when you change a deck illuminant. This checkbox forces the display to show data converted to illuminant D50, irrelevant of the illuminant of the selected deck. However, if you uncheck this box, you will notice that the data has indeed changed according to the selected illuminant.

Note: The Munsell HVC values shown in the data displays are, by design, referenced to Illuminant C and will remain unchanged following a change in the deck illuminant selection.

4.4.3 L*C*h pad

The L*C*h pad is one of the two deck navigating modes available in Compare mode (the other is List view). It is selected by clicking the corresponding radio button located below the color patches.



L*C*h INTERFACE

The center square patch is the selected patch (Munsell 2.5BG 5/4 in the screenshot above) . This patch name and coordinates are shown in the data displays. The selected patch is also shown in the color patches displays. The name of the other patches can be seen by resting the mouse cursor over a patch for a moment; a pop-up tag with the patch name will then appear.

The patches surrounding the center patch show the nearest patches in the deck(s) corresponding to the following criteria:

- **+sat and -sat:** These labels respectively identify the patches which display more and less saturated colors than the center patch while being the closest to the center patch in terms of luminosity and hue.
- **+lum and -lum:** These labels respectively identify the patches which are more and less luminous than the center patch while being the closest to the center patch in terms of color saturation and hue. In the screenshot above, the center square represents the Munsell 2.5BG 5/4 patch. The mouse is over the "+ lum." patch, and 2.5BG **6**/4 is shown in the popup help text; this patch has the same Munsell Hue (2.5BG) and the same Munsell Chroma (i.e. saturation, =4) as the center patch, but its Munsell Value (i.e. brightness, luminosity) is higher (6 instead of 5).
- **+hue and -hue:** These labels respectively identify the patches which have a hue angle which is bigger and smaller than the center patch hue angle while being the closest to the center patch in terms of saturation and luminosity.

All computations are based on the chips L*C*h values, as determined with the selected illuminant. The **+sat** and **-sat** patches are based on the chroma (i.e. *C**), the **+lum** and **-lum** patches are based on the lightness (i.e. *L**), and the **+hue** and **-hue** patches are based on the hue angle (i.e. *h*).

The L*C*h pad search algorithm uses the current DeltaE* formula, as selected in the DeltaE* display, for some of its calculations; accordingly, changing the DeltaE* formula may result in a different L*C*h pad layout. In Compare mode, the CIE94 and CMC(l:c) formulas are further impacted by the state of the "**CIE94/CMC**

reference mode" option located in the "Math" tab of the Preferences dialog. Please note that the search is always performed for the deck illuminant even if the D50 version of a DeltaE* formula is selected.

When the algorithm cannot find a valid chip, a neutral color is used for the patch (same color as the tool background) and "N.A." can be seen in the pop-up tag.

Clicking on any patch beside the center one will bring that patch to the center and all other patches will be recomputed. You can thus navigate within the deck using the three *L**, *C** and *h* dimensions. You can also select a chip by clicking directly in the color strip or on the arrows at both ends of the strip. You can also go back and forth between the L*C*h pad and the List view.

Repeatedly clicking on **+hue** will move the selection in an anti-clockwise direction. Similarly, repeatedly clicking on **-hue** will move the selection in a clockwise direction.

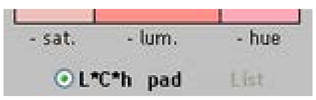
Important: Not all decks have dense and uniform distributions across the visible spectrum and you may find, for example, that the nearest chip for increased luminance shows a significant hue and saturation difference. This is less frequent in large uniformly distributed decks such as Munsell.

Note: The L*C*h space is more uniform than the xyY space. When navigating by clicking on the **+hue** and **-hue** patches, you will follow a somewhat elliptical path around the illuminant, instead of the expected circular path. This is more obvious when using a large uniformly distributed deck such as Munsell.

Note: The coordinates of all the patches as well as the color differences between the center patch and the other patches are presented in the report saved using the "RGB vs RGB/Save Data..." menu.

CONVERTING "TO" A DECK

The L*C*h display mode is the only mode available when a deck is being converted "TO" (see Convert mode):



In such instance, the L*C*h pad is disabled (i.e. it cannot be used to select patches).

When converting "TO" a deck, the center patch is the best match relative to the reference on the other side. THE OTHER PATCHES ARE THEN DETERMINED RELATIVE TO THE REFERENCE, NOT THE CENTER PATCH. As mentioned in the "L*C*h interface" section above, you can change the DeltaE* formula to see how it affects the match.

Note: The coordinates of all the patches as well as the color differences between the reference patch and all the L*C*h patches, including the center one, are presented in the report saved using the "RGB vs RGB/Save Data..." menu.

L*C*h PAD OPTIONS

The L*C*h pad options can be set in the "RGB vs RGB" tab of the Preferences dialog. In Windows, this dialog is opened with the "Edit/Preferences" menu. On a Mac, this dialog is opened with the "CT&A/Preferences" menu.

- **Sensitivity:** Because the searching algorithm looks for the closest chip which minimizes the other two parameters, for example the lightness and the hue when searching for the chroma (saturation), it may find a chip which is almost the same as the one represented in the center patch. This may happen, for example, if the deck contains chips of the same hue but with different surface finishes (i.e. mat, glossy, etc.). To filter out these chips, we impose a threshold, or **sensitivity**, on the search algorithm. The default sensitivity value is 0,2 units of L*, C*, or h; it can be set between 0 and 10 units with 0,1 units steps.

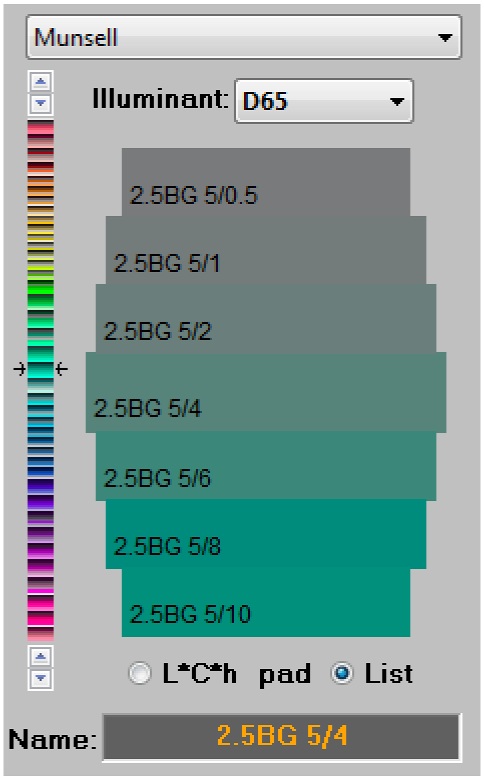
- **Hue search extent:** For chips located very near the illuminant, it does happen that the best candidates for **+hue** and **-hue**—which are chips which minimize the lightness and chroma differences with the center patch—have a large angular difference with the center patch. To prevent this situation, the **hue search extent** has to be limited. The default angular extent is 22 degrees; it can be set between 5 and 60 degrees with 1 degree steps.

- **Patches outline:** By default, the patches are surrounded by a thin black border. This border can be removed by unselecting the "Decks L*C*h pad view: Draw borders around patches" checkbox.

Important: To prevent odd program behavior, a message will appear if you set the **sensitivity** setting too close, or higher, than the **hue search extent** value, and when you set the hue search extent too close, or lower, than the sensitivity. The program will then assign the nearest valid number to the parameter being set.

4.4.4 List view

The List view is one of the two deck navigating modes available in Compare mode (the other is the L*C*h pad). It is selected by clicking the corresponding radio button located below the color patches.



LIST VIEW INTERFACE

The name of all the patches is shown in their lower-left corner. The largest rectangular patch in the middle of the patches is the selected patch. The selected patch is also shown in the color patches displays; its name and coordinates are shown in the data displays.

The patches surrounding the center patch show the nearest chips in the order they are catalogued. Although there is a logic in how the catalogues are built, you may find the chips grouped by hue, saturation, or any other criteria.

Clicking on any patch beside the center one will bring that patch to the center, and the other patches will shift accordingly.You can also select a chip by clicking directly in the color strip or on the arrows at both ends of the strip. You can also go back and forth between the List view and the L*C*h pad.

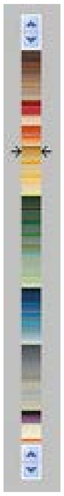
Note: Only the L*C*h display mode is available when the deck(s) is/are being converted "TO".

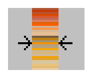
LIST VIEW OPTIONS

By default, the patches are NOT surrounded by a thin black border. A border can be added by selecting the "Decks List view: Draw borders around patches" checkbox located in the "RGB vs RGB" tab of the Preferences dialog.

4.4.5 Color strip

The color strip shows a snapshot of all the "chips" in a color catalogue (Color Deck) as if you looked at the edge of a fan deck:



Two small black arrows on each side of the strip  indicate the position of the selected chip. These chips are shown as color patches in the L*C*h pad and List view.

When in Compare mode, the color strip can be used to select a chip by clicking either in the color strip itself or on the arrows at both ends of the strip. Clicking on the arrows will move the selected chip by 6 positions in the deck database. When in List view, clicking on the "upward" arrows will bring the top patch at the bottom of the view, as if we were moving towards the top of the strip; similarly, clicking on the "downward" arrows will bring the bottom patch at the top of the view, as if we were moving towards the bottom of the strip. Clicking on the arrows in L*C*h pad view also moves the selected chip by 6 positions in the strip, but the overall pad view change is not as obvious as with the List view.

Chip selection is also possible by clicking the L*C*h pad and List view patches.

In Convert mode, it is possible to select more than one deck as a destination (see Deck selection). In such a case, the color strip shows a snapshot of ALL selected decks.

Note: The color strip cannot be used to select chips when a deck is being converted "TO".

4.4.6 Data displays

The data display boxes in the deck interface are for display only and do not accept input from the user. You can copy numerical data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on a data field. Shown below is the contextual menu which appears with a right-click on one of the L*C*h fields; selecting the menu will transfer the three coordinates into the clipboard, separated by Tabs. You will note that the contextual menu indicates that the L*C*h data is derived from L*a*b* (i.e. the "ab" in parenthesis), and for Illuminant D50, which is expected since the "L*a*b* / L*u*v* / L*C*h in D50" checkbox is selected. You can then easily paste the values in a spreadsheet or document table, where they will be distributed in three columns.

Data is presented in the following formats:

- **Name**

  The chip name is the usual reference number or name used in the color catalogue. In Convert mode, more than one deck can be selected as a destination (see Deck selection); to prevent confusion when in this mode, the deck name is also shown beside the selected chip ID in the name field:

- **Munsell HVC** (Hue-Value-Chroma)
- **L*C*h** based on either L*a*b* or L*u*v* and the D50 checkbox
- **xyY** referenced to the illuminant of the selected space
- **XYZ** referenced to the illuminant of the selected space

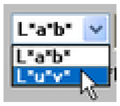
Use the menu located below the "**Name**" field to select among the following color spaces: Munsell HVC, L*C*h, xyY or XYZ.

The Munsell HVC values are not simply the ones corresponding to the closest sample in the Munsell deck catalogue, but are INTERPOLATED values that closely match the selected deck color.

The L*C*h values are automatically updated, even if there is no color change, when you change the L*a*b* / L*u*v* display and when you click in the "L*a*b* / L*u*v* / L*C*h in D50" checkbox described below. The displayed values are:

1. $L^*C^*_{ab}h_{ab}$ referenced to the **space illuminant** when **L*a*b*** is selected and the "L*a*b* / L*u*v* / L*C*h in D50" checkbox is **NOT** selected
2. $L^*C^*_{uv}h_{uv}$ referenced to the **space illuminant** when **L*u*v*** is selected and the "L*a*b* / L*u*v* / L*C*h in D50" checkbox is **NOT** selected
3. $L^*C^*_{ab}h_{ab}$ referenced to **D50** when **L*a*b*** is selected and the "L*a*b* / L*u*v* / L*C*h in D50" checkbox **IS** selected
4. $L^*C^*_{uv}h_{uv}$ referenced to **D50** when **L*u*v*** is selected and the "L*a*b* / L*u*v* / L*C*h in D50" checkbox **IS** selected

- **L*a*b*** referenced to the illuminant of the selected space
- **L*a*b*** referenced to illuminant D50
- **L*u*v*** referenced to the illuminant of the selected space
- **L*u*v*** referenced to illuminant D50



Use the bottom menu to select either the L*a*b* or L*u*v* color space.

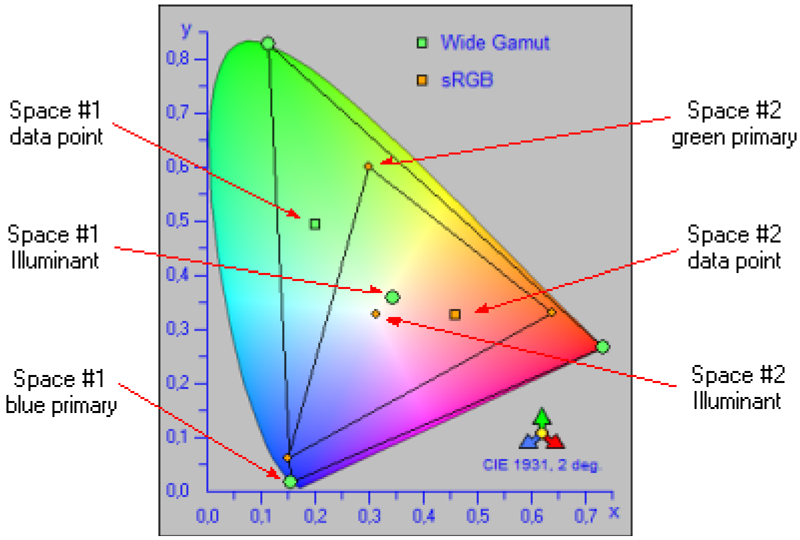
Checking the "L*a*b* / L*u*v* / L*C*h in D50" checkbox instructs the program to show L*a*b*, L*u*v* and L*C*h values converted to illuminant D50, irrelevant of the illuminant of the selected deck. Of course, if the space illuminant is D50, no change will be seen in the displays.

When the "L*a*b* / L*u*v* / L*C*h in D50" checkbox is unchecked, the L*a*b*, L*u*v* and L*C*h displays show values corresponding to the illuminant of the selected space.

Changing the L*a*b* / L*u*v* selection or changing the "L*a*b* / L*u*v* / L*C*h in D50" checkbox status will automatically update the L*C*h display, whether it is visible or not. Please refer to the additional information on the L*C*h display above.

Note: Be cautious, the L*a*b* values shown in Adobe Photoshop are always in D50, irrelevant of the illuminant of the selected space.

4.5 Chromaticity diagram



This diagram represents the chromaticity coordinates ("xy") of the Space or Deck colors selected on each side of the RGB vs RGB tool window. This coordinates system was defined by the Commission Internationale de l'Éclairage (CIE) in a standard published in 1931. It is based on the observation of color patches subtending a 2 degrees Field-of-View. The diagram is often referred to by the simpler "CIE1931, 2 degree" description. Please see the xyY and XYZ section for a description of how the "xy" data is obtained.

In a nutshell, the "horseshoe" shape represents the gamut of colors perceived by the human eye. On the contour are located pure (or fully saturated) colors typically generated by lasers. The "reddest" red is located at the extreme right and the deepest blue at the bottom (x=0.175, y=0). Following the contour, clockwise from the deepest blue, all other "rainbow" colors will be found (blue, cyan, green (toward the top), yellow, orange and red). The straight line between red and blue represents a mix of the two colors located at the extremes of the visible spectrum (red + blue = magenta).

The colors within the horseshoe are less saturated variants of the pure colors. Typical "whitish" illuminants have colors located towards the center of the horseshoe.

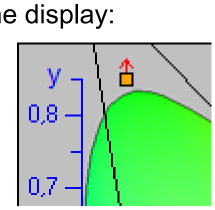
Hint: The BabelColor logo can be used as a reminder of the locations of the red, green and blue zones.

The colors used to draw data in the diagram match the colors used to print the illuminant description in the space interface and the chip name in the deck interface:

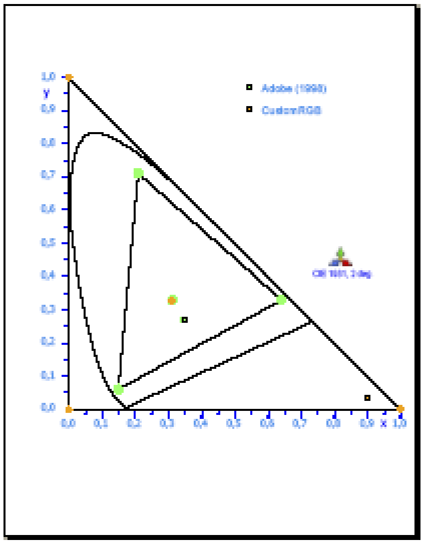
- **Light green** for Space #1 and Deck #1
- **Orange** for Space #2 and Deck #2

Additional data such as the chromaticities of the X-Rite/GretagMacbeth ColorChecker patches, the limits of many standard CMYK spaces, or the locus of blackbody illuminants (i.e. the Planckian locus), can be superimposed on the diagram by using either the menu from the "Graphics" icon in the toolbar window or the "RGB vs RGB/Graphic data" menu.

In order to maximize the area of the display dedicated to the visible gamut, the "x" and "y" axis are clipped to values less than one. Because it is possible to define a space, using the Custom RGB space dialog, which extends past the displayed limits, a little arrow will appear next to the data point when its location is outside of the display:

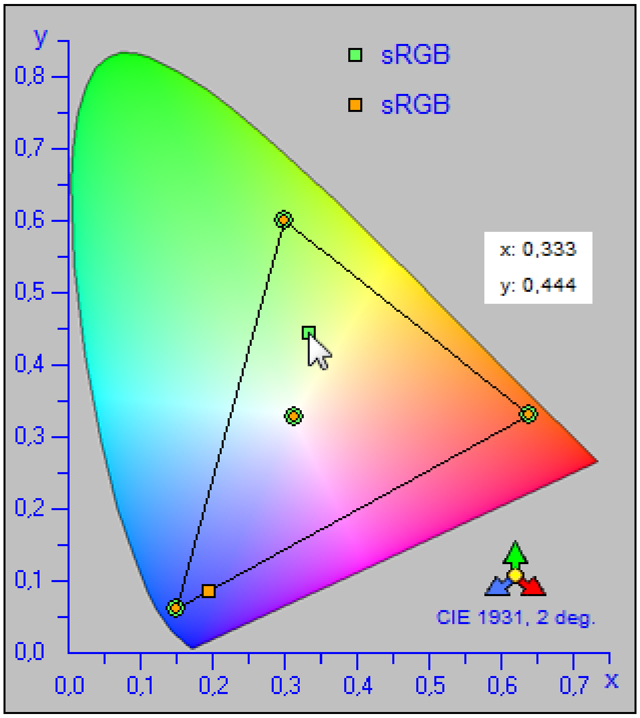


The values shown in the [data displays]() are not affected and the full extent of the chromaticity diagram is represented, with both axis up to one, when printing using the "[RGB vs RGB/Print Graphic...]()" menu command:

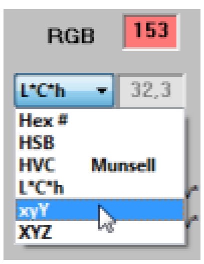


“xy” MOUSE INPUT

Data can be entered by clicking directly in the chromaticity diagram window. As a guide, a small window will open in the chromaticity diagram, showing the coordinates over which the mouse is located:



You may not be able to select any coordinates with a precision of 0,001; however, you can always tweak the input with the R'G'B' and Y sliders afterwards. We suggest you select the xyY data display to see the input coordinates in the selected space:



Selecting to which space the mouse click will input the data is done by selecting the proper radio button in the "xy" mouse input display:

A mouse click (a left-click on a multi-buttons mouse) will direct the input to the space selected in the mouse input control window. A mouse right-click (or ctrl + click on a one-button Mac mouse) will direct the input to the other space. This mode can be used simultaneously with the R'G'B' input mode.

Note: The mouse input controls must be enabled to enter data via this method.

When clicking outside of a space perimeter, the triangle defined by the space primaries, the software finds the closest valid color on the perimeter. By default, the program sets the Y coordinate (of XYZ) at the highest permissible value for the selected "xy" data set (i.e. it sets the maximum value of the R'G'B' triad to 255). xyY data is then converted in R'G'B', XYZ, L*a*b*, L*u*v*, L*a*b* (D50), L*u*v* (D50), Hex, HSB, and Munsell HVC, and can also be used as input for the other side.

Mouse input is disabled when in L*a*b* / L*u*v* input mode, when the space is being converted "TO", or when the side is in Deck mode. The various displays are shown in the Mouse input interface section.

4.6 Mouse input interface

An alternate means of entering data for a given space is to do a mouse click (a left-click on a multi-buttons mouse) or a mouse **right-click** (or **ctrl + click** on a one-button Mac mouse) directly on the chromaticity diagram, within the horseshoe. A mouse click will direct the input to the space selected in the mouse input control window; a mouse right-click will direct the input to the other space.

Note: The mouse input controls must be enabled to enter data via this method.

See the chromaticity diagram section for more information on how the data is processed.

INPUT SELECTION

To select the space to which the input will be directed with a mouse click, click on the radio button with the arrow pointing toward the chosen side:

The arrow of the radio button selected just above points towards the RIGHT side, or Space #2.

DISPLAY VARIATIONS

One or both buttons are automatically disabled when the program is set in specific modes. The various displays are:

- Display seen in Compare mode when both sides are in RGB Space mode; both buttons are enabled:

  When you select the LEFT side, as shown above, a mouse click will enter data in the LEFT side (Space #1), and a mouse right-click will enter data in the RIGHT side (Space #2). When you select the RIGHT side, a mouse click will enter data in the RIGHT side (Space #2), and a mouse right-click will enter data in the LEFT side (Space #1)

- Display seen in Convert mode Right-to-Left (Space #2 to Space #1) **OR** Compare mode with Space #1 in L*a*b* / L*u*v* input mode **OR** Compare mode with Deck #1 selected:

  A mouse click will enter data in the RIGHT side and a mouse right-click will do nothing since mouse input is disabled for the LEFT side.

- Display seen in Convert mode Left-to-Right (Space #1 to Space #2) **OR** Compare mode with Space #2 in L*a*b* / L*u*v* input mode **OR** Compare mode with Deck #2 selected:

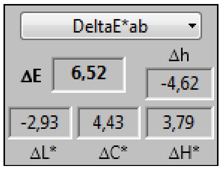
  A mouse click will enter data in the LEFT side and a mouse right-click will do nothing since mouse input is disabled for the RIGHT side.

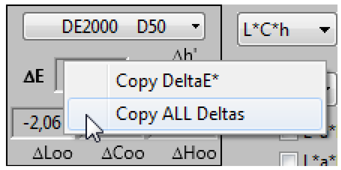
- Display seen in Convert mode with the input space in L*a*b* / L*u*v* input mode **OR** Compare mode with both spaces in L*a*b* / L*u*v* input mode **OR** Compare mode with both decks selected; both buttons are disabled:

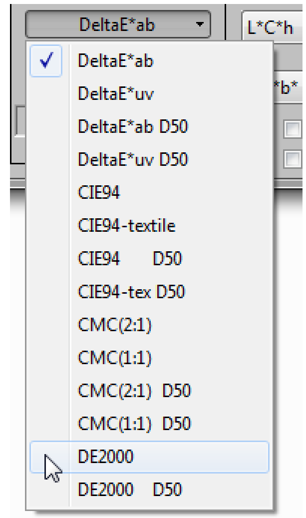
  

4.7 DeltaE* display

The color-difference between the two sides — space or deck — is shown in the DeltaE display (ΔE in abridged form). The difference is shown at all times, irrelevant of the Mode Settings. You can copy this data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on a data field. Shown below in the center screenshot is the contextual menu which appears with a right-click on the DeltaE* field; you can copy either the DeltaE* value or all Deltas in one operation. When selecting "Copy ALL Deltas", the values are separated by Tabs into the clipboard, and will be separated in different columns when pasting them in a spreadsheet or document table.







FORMULA SELECTION

Fourteen DeltaE formulas and variants are available:

- **ΔE^*_{ab}**
  "CIELAB color-difference", referenced to the selected space or deck illuminant (shown only if same illuminant for both sides)
- **ΔE^*_{uv}**
  "CIELUV color-difference", referenced to the selected space or deck illuminant (shown only if same illuminant for both sides)
- **ΔE^*_{ab} D50**
  "CIELAB color-difference", referenced to D50 illuminant
- **ΔE^*_{uv} D50**
  "CIELUV color-difference", referenced to D50 illuminant
- **ΔE^*_{94}**
  ΔE^*_{94}-textile
  "CIE94 color-difference", referenced to the selected space or deck illuminant (shown only if same illuminant for both sides). The **ΔE^*_{94}-textile** version has its k_L factor equal to 2; k_L equals one for the standard version.
- **ΔE^*_{94} D50**
  ΔE^*_{94}-textile D50
  "CIE94 color-difference", referenced to D50 illuminant
- **$\Delta E^*_{CMC(2:1)}$**
  $\Delta E^*_{CMC(1:1)}$
  "CMC(ℓ:c) color-difference", referenced to the selected space or deck illuminant (shown only if same illuminant for both sides). CMC(2:1) is used for acceptability (pass/fail) measurements while CMC(1:1) is used for perceptibility measurements.
- **$\Delta E^*_{CMC(2:1)}$ D50**
  $\Delta E^*_{CMC(1:1)}$ D50
  "CMC(ℓ:c) color-difference", referenced to D50 illuminant
- **ΔE_{00}**
  "CIEDE2000 color-difference", referenced to the selected space or deck illuminant (shown only if same illuminant for both sides).
- **ΔE_{00} D50**
  "CIEDE2000 color-difference", referenced to D50 illuminant

DISPLAY DATA

In addition to ΔE, the following information is presented in the DeltaE* display:

- **ΔL^*:** The *lightness* difference between the two sides.
- **ΔC^*:** The *chroma* difference between the two sides.
- **ΔH^*:** The *hue* difference between the two sides.
- **Δh**: The *hue angle* difference between the two sides.

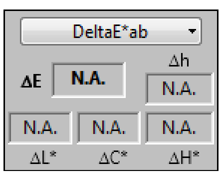
The ΔL^*, ΔC^*, and ΔH^* parameters are defined in the CIELAB & CIELUV section; they represent the individual contributions of lightness, chroma and hue to the global ΔE color difference. Δh, defined in the L*C*h section, is also shown because this angular difference is readily associated with a 360 degrees hue circle whereas ΔH^* is an indirectly derived value.

Since ΔL^*, ΔC^*, and Δh can be positive OR negative, it is important to identify a reference and a sample. In Compare mode, the reference is always on the LEFT side and the sample on the RIGHT side. In Convert mode, the reference is always on the side being converted "FROM" while the sample is the side being converted "TO".

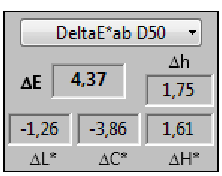
Important: For the CIEDE2000 formula, the display shows the weigthed ΔL_{00}, ΔC_{00}, and ΔH_{00} values (and $\Delta h'$), instead of the unweighted ΔL^*, ΔC^*, and ΔH^* values (and Δh).

DISPLAY VARIATIONS

As mentioned above, all color-differences referenced to the selected space or deck illuminants are shown only if the illuminants on both sides are the same (Ex.: Apple RGB and sRGB, where both spaces are defined with illuminant D65). If not, the following display will be seen (Ex.: Apple RGB, with illuminant D65, and ColorMatch, with illuminant D50):



You are still able to get a color-difference by selecting the corresponding **D50** color-difference formula; for DeltaE*ab it is **DeltaE*ab D50**:



where the L*a*b* coordinates of both spaces, translated in D50, are used to compute the numbers. All color-difference formulas have an equivalent D50 selection.

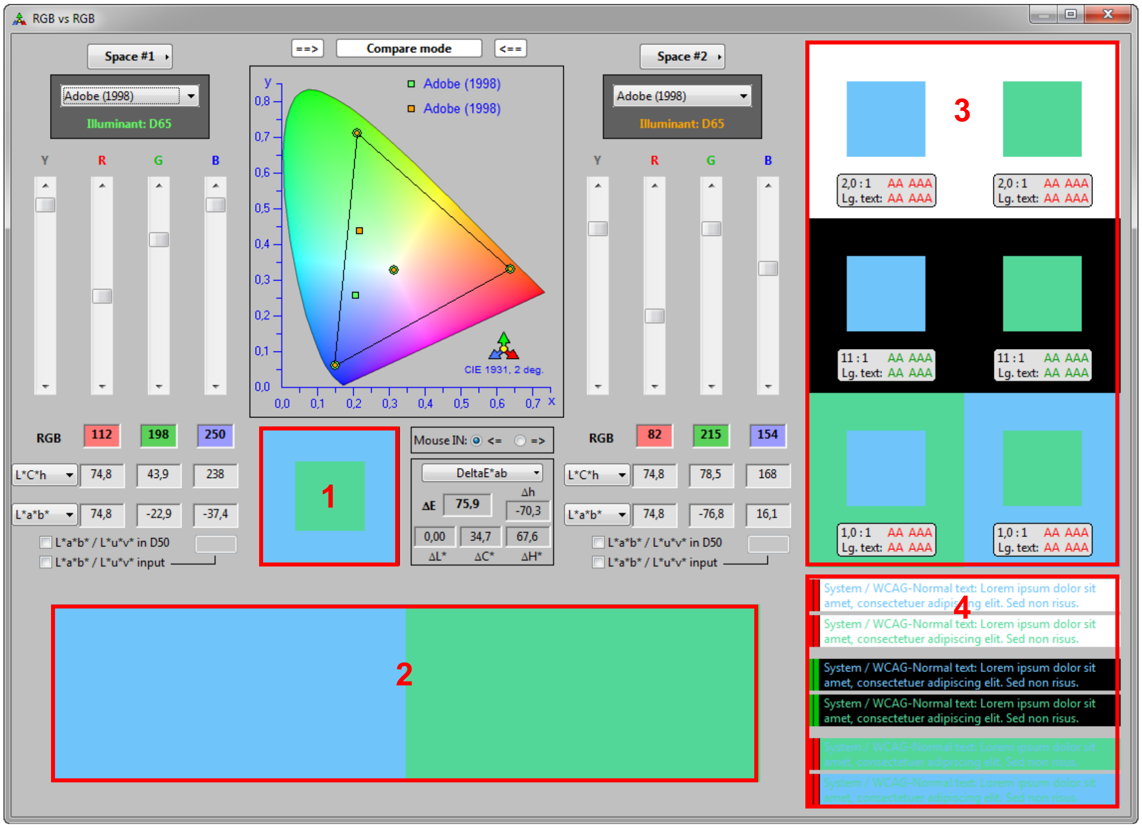
Hint: If you want to see the L*a*b* D50 values used to compute the D50 color-difference, select the "L*a*b* / L*u*v* in D50" checkbox appearing under the data displays of the corresponding space, or the "L*a*b* / L*u*v* / L*C*h in D50" checkbox of the corresponding deck.

Hint: Although the results for only one color difference formula are displayed at a time, all formulas are computed. The data for all formulas can be seen by saving or printing data.

Important: As per their definition, the CIE94 and CMC(ℓ:c) color-differences will be different depending on which of the two color sides is defined as the reference, or if none of the sides can be considered a reference. The software will automatically adjust the formula according to the definitions; as a result, variations in the displayed values will be seen when going from Compare mode to Convert mode, or vice-versa. See the DeltaE* section for detailed formula information.

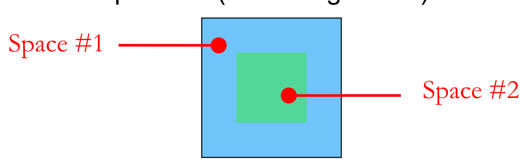
4.8 Color patches displays

A color patch of each space or deck is shown under the chromaticity diagram, and in the additional patch layouts which can be seen when enlarging the RGB vs RGB window dimensions. In the screenshot below we see two colors selected in the Adobe (1998) RGB space, where we have tweaked the "Y" slider of Space #2, located at the left of the RGB sliders, in order to get the same Lightness (L^* = 74.8) on each side.



There are four zones in which the colors of each Space (or Deck) can be compared. Please refer to the screenshot above for the zone locations.

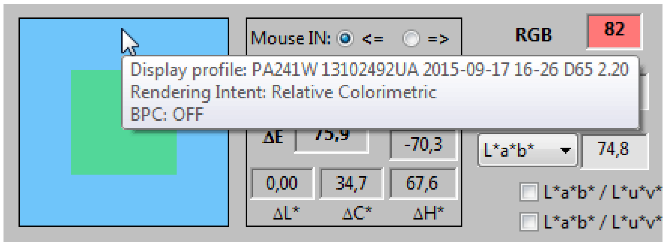
- Zone 1 – below the chromaticity diagram: The two selected colors are shown on two superimposed squares. The larger square corresponds to Space #1 (or the Left side), and the smaller square corresponds to Space #2 (or the Right side).



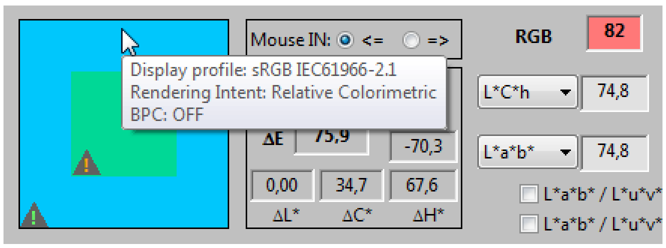
- Zone 2 – bottom-left: This part of the window is dedicated to patches seen side-by-side. Clicking on these patches will change the size and background of the patches. The Zone 2 layouts are presented later in this section.
- Zone 3 – upper-right: This zone is dedicated to patches of the selected colors super-imposed on standard white and black backgrounds, and on a background of the other color. These color combinations are also used to compute a Contrast Ratio defined by the Web Content Accessibility Guidelines (WCAG), a ratio helpful in analyzing the legibility of colored text, with corresponding examples shown in the bottom-right zone (Zone 4). The WCAG requirements are presented in the next section, which is dedicated to the text layout zone.
- Zone 4 – bottom-right: This zone is dedicated to text of the selected colors shown on white, black, and the other color backgrounds. Red and green bars indicate if these samples meet the WCAG requirements; the text layout and the WCAG requirements are further described in the next section.

DISPLAY PROFILE

All colors in CT&A are converted, *for viewing purposes only*, to the color space of the display profile corresponding to the window location. To see the profile, position your mouse cursor over the patches and wait for a second; a popup help message should appear with the profile settings, as we see below. This display profile, for a NEC PA-241W, is very close to Adobe (1998) RGB and we expect colors to be represented accurately.



The next screenshot shows how the patches appear when the display corresponds to the more limited sRGB space. Because the patches are located outside of the sRGB display profile range (*gamut*), with one or more coordinates clipped at either zero or 255, **clip indicators** (**!**) are shown in the bottom-left corner of the patches.



The colors used to draw the clip indicators in the patches match the colors used to print the illuminant description in the space interface and the chip name in the deck interface:

- **Light green** for Space #1 and Deck #1
- **Orange** for Space #2 and Deck #2

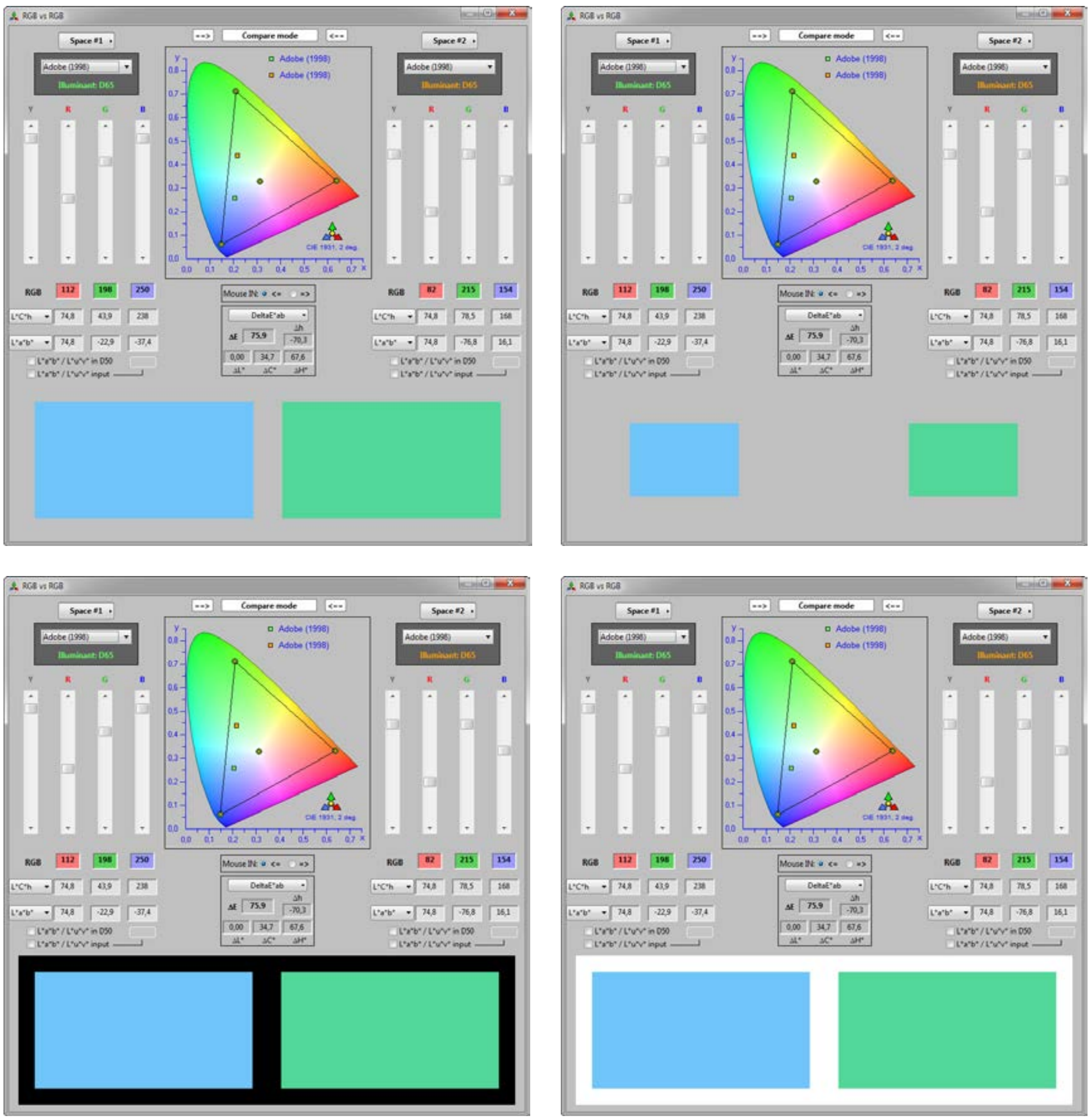
Important: Please note that the clipping indicators in the **color patches displays** are **NOT** indicative of any clipping resulting from the conversion from one space to the other (ex.: from Space #1 to Space #2), or between a deck and a space, or from L*a*b* / L*u*v* input. See the L*a*b* / L*u*v* input interface and data displays sections for more information on these other clipping indicators.

In a multi-monitor setup, the display profile used for display purposes will be automatically updated when you move the RGB vs RGB window across monitors. You can see the profile assigned to each monitor in the "Color" tab of the Preferences dialog.

ZONE2 – BOTTOM-LEFT: LAYOUT OPTIONS

Depending on the window size, the patches on the bottom-left of the enlarged window can be much bigger than the two superimposed patches shown under the chromaticity diagram. The patches in this window zone are shown side-by-side instead of one over the other. If you click on these patches, the layout background and the patches size will cycle through five combinations, the first of which is shown at the beginning of this section, and the four others below. You will notice that we have reduced the window dimensions to hide the patches and text on the right side.

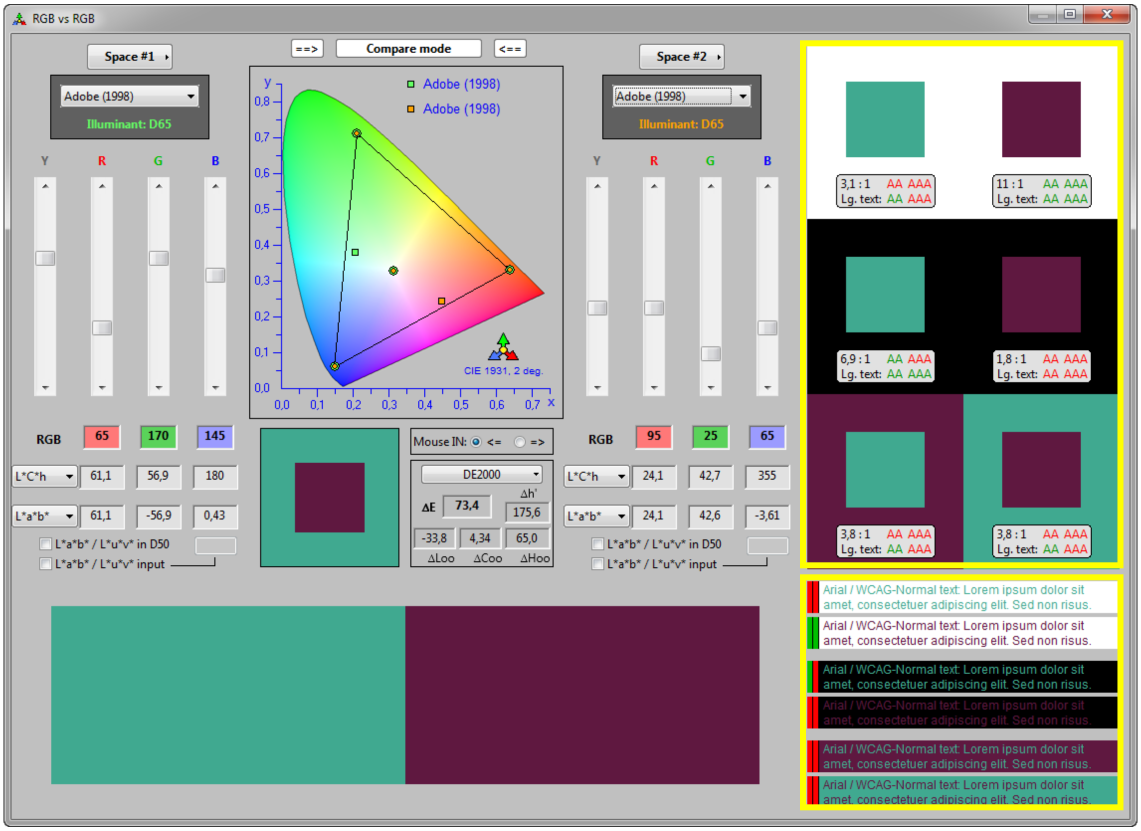
These layouts can be useful when comparing colors which may be displayed on grey, white or black backgrounds, or when checking if two nearly identical colors will be seen as identical when viewed separated by a distance.



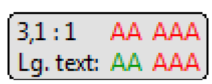
Of course, you can adjust the window dimension so that the patches become one pixel high lines, as shown below at full scale. This is useful for judging the visibility and contrast of such lines on black or white backgrounds, and how they differ.

4.9 Text on backgrounds - WCAG Contrast Ratio

Additional patch layouts appear when you enlarge the RGB vs RGB tool window. This is shown below. We see on the right side of the window two zones, identified by a yellow border. The top zone presents patches of the two selected colors, defined in the Space #1 and Space #2 sections of the window, on white and black backgrounds, as well as on a background of the other color. The bottom zone presents text with the same color combinations appearing in the upper zone.



These two zones can thus be used to rapidly assess how the selected colors visually appear against various backgrounds in both graphic and text form. You will also notice, in the top zone, labels with text and data, with a label for each color on background combination. A label example is shown below; it corresponds to the Space #1 color on white:



The numbers on the first line indicate the Contrast Ratio for the two colors (one selected color on a given background), as defined in the Web Content Accessibility Guidelines (WCAG). The “AA” and “AAA” symbols of the first line respectively indicate if this contrast meets or not the **Minimum** and **Enhanced** contrast requirements for *Normal text*. The symbols of the second line indicate similar compliance for *Large text*. The WCAG Contrast Ratio definition and the compliance thresholds are presented later in this section, but even without this knowledge, the above label tells us that:

- the Contrast Ratio is 3,1 to 1;
- this color pair does not meet the Minimum and Enhanced contrast requirements for *Normal text* (“AA” and “AAA” are red);
- this color pair meets the Minimum requirements for *Large text* (“AA” is green) and fails the Enhanced requirements for *Large text* (“AAA” is red).

Note: Depending on the number of vertical pixels on your display, you will be able to see more or less lines of each text combination. At least one line of each combination should be visible with a display size of 768 pixels vertically. Also, you may need to hide the tool or task bar in your desktop to see the entire text layout.

Note: The labels with WCAG data will appear only if the window is enlarge wide enough.

WCAG CONTRAST RATIO AND REQUIREMENTS

The Web Content Accessibility Guidelines (WCAG) contains recommendations for making Web content more accessible. The recommendations are designed to facilitate access to people with disabilities. The guidelines apply not only to text but to all media accessible from of a Website, including illustrations, video, and audio. The Contrast Ratio and compliance results provided in CT&A apply to text and images of text as described in Sections 1.4.3 and 1.4.6 of the guidelines (Version 2.0), available online with this link:

- https://www.w3.org/TR/WCAG20/

The Contrast Ratio is defined as:

$$\text{Contrast Ratio} = (L1 + 0.05) / (L2 + 0.05)$$

where

- *L1* is the relative luminance of the lighter of the colors, and
- *L2* is the relative luminance of the darker of the colors.

The relative luminance is simply the "*Y*" of the XYZ color space where *Y* is normalized, for the purpose of this equation, between zero and one, i.e. 0 and 1. The "0.05" constant added to each luminance is an estimate of the typical viewing flare (reflection from ambient light) which will affect each color seen on a monitor. From the Contrast Ratio definition, we see that the ratio can range between 1 and 21, which is commonly written as 1:1 to 21:1.

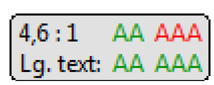
The ratio requirements are:

Contrast Ratio	**Minimum contrast** (Level AA)	**Enhanced contrast** (Level AAA)
Normal text	4.5 : 1	7 : 1
Large text	3 : 1	4.5 : 1

Large text is defined as:

- regular text, 18 points or larger, or
- **bold** text, 14 points or larger.

Please note that we have presented the contrast requirements in the table in the same order as they appear in the WCAG labels of the RGB vs RGB window, as seen with this example:



When a requirement is met, the symbol is shown in green; when the requirement fails, the symbol is shown in red. In addition, you will note that the requirement for **Normal text/Level AA** is the same as **for Large text/Level AAA** (the required contrast is 4.5:1 in both cases), which means that when the contrast ratio is 4.5 or larger, the two corresponding symbols ("AA" on the first line, and "AAA" on the second line) become green, as shown in th example above.

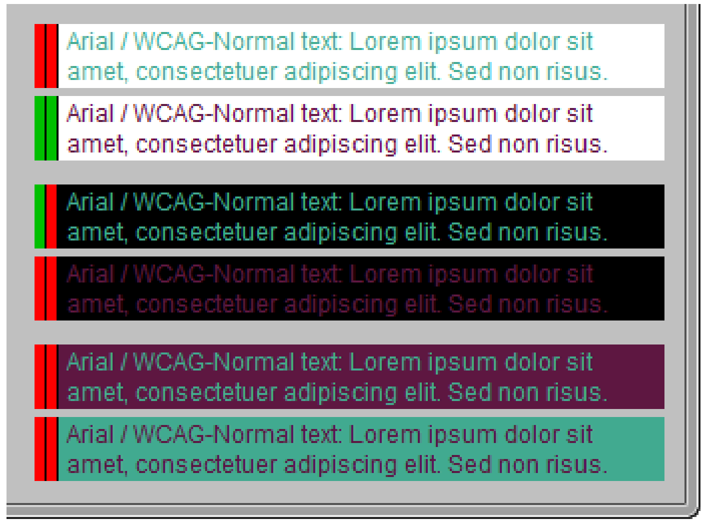
Note: In the additional notes provided to understand WCAG 2.0 (Understanding WCAG 2,0, Understanding Success Criterion 1.4.3 - Contrast (Minimum)), it is acknowledged that a contrast ratio of 3:1 is the minimum level recommended by ISO-9241-3 and ANSI-HFES-100-1988 for standard text and vision (i.e. 20/20 vision). The higher value recommended for Minimum contrast and *Normal text* (4.5:1) takes into account a lower visual acuity of 20/40. Similarly, the Enhanced contrast requirement for *Normal text* (7:1) is designed to account for users with a 20/80 visual acuity.

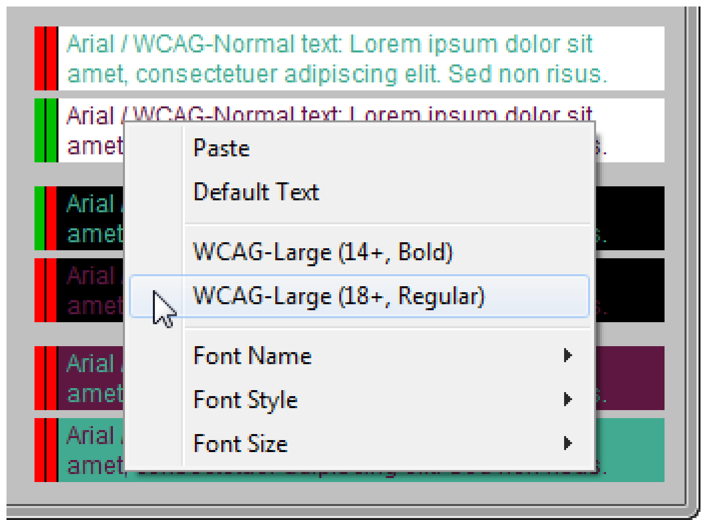
Important: While you can select any RGB space, even different spaces for each sample, we recommend that you use the same color space on each side, and, as well, the color space that you will use in your final application. If you select a Space and a Deck, make sure you use the same Illuminant.

TEXT ZONE

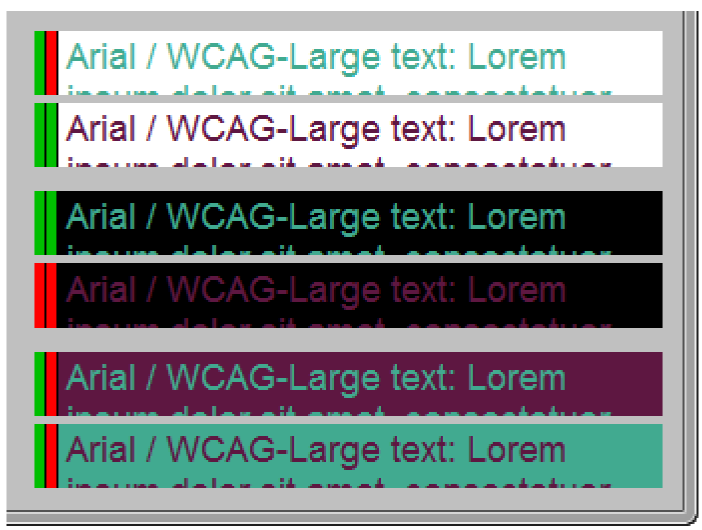
The text zone comprises six boxes, where text of the two selected colors is shown on three backgrounds (white, black, and a background of the other selected color). These color combinations correspond to those used for the patches above the text.

The text is the same in each box. The beginning of the first line shows the name of the selected font and indicates if the combined font size and font style correspond to either *Normal text* or *Large text* as defined in the WCAG (see the requirements on the preceding page). This text is followed by dummy Latin text ("Lorem ipsum…"). This dummy text can be replaced by your own text; first copy your text in the clipboard then do a mouse right-click in any text box of the RGB vs RGB window. In the popup menu that opens, select "Paste" (the menu is shown in the middle screenshot on the right); the text change in one box will be replicated in the other boxes. To reset the dummy text, just select "Default text" in the same menu.



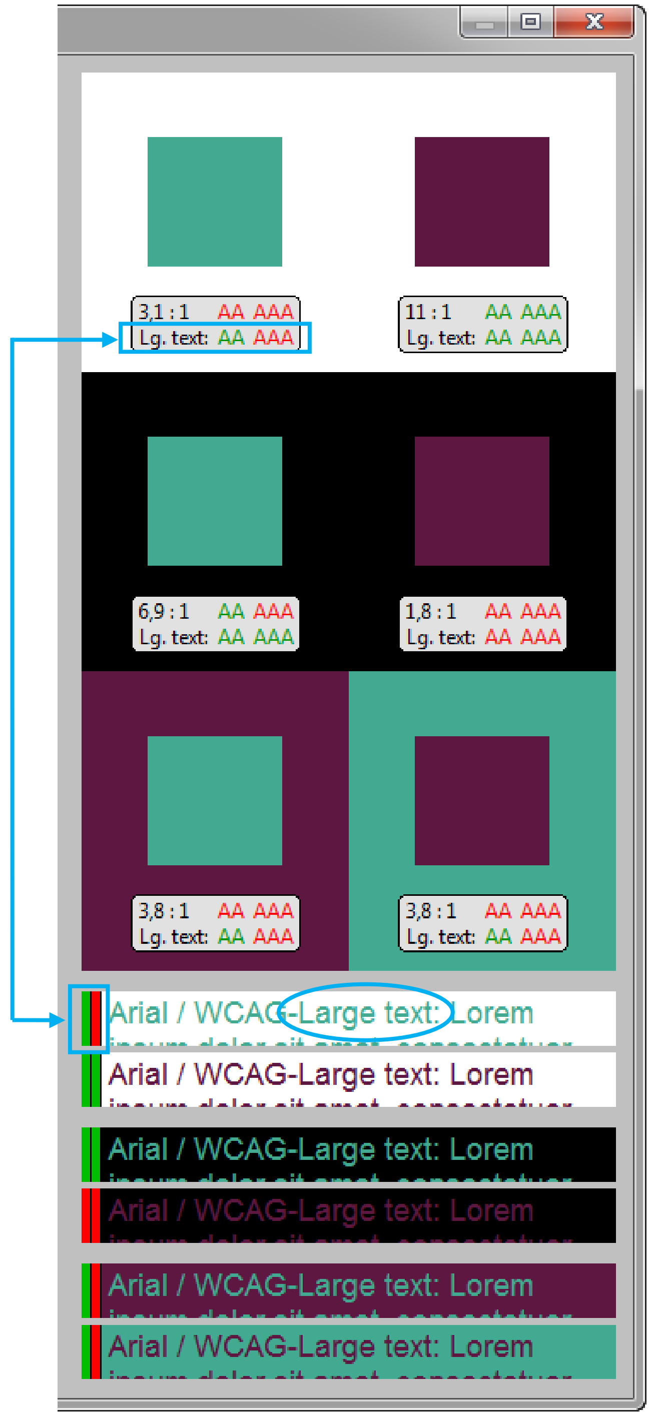


With the same popup menu you can change the font name, the font style, and the font size for the entire text. You can also use the menu to change the font size and font style to meet one of the two minimal requirements of WCAG *Large text* (either 14+ and bold, or 18+ and regular). The screenshot below-right shows the resulting display with a regular 18 points font size.



The two red or green vertical bars on the left of each text box indicate if the text as shown meets the WCAG requirements. The first bar corresponds to the **Minimum contrast (Level AA)**, and the second bar corresponds to **Enhanced contrast (Level AAA)**. Since the text can be either "Normal" or "Large", as written in the text first line, only two bars need to be shown at any given time. This is further illustrated by the screenshots on the next page.

The two screenshots below illustrate the correspondence between the “AA” and “AAA” symbols and the two vertical bars located at the left of each text box. For the screenshot on the left, the text boxes contain *Normal text*, so the two red bars correspond to the symbols of the first line, with “AA” and “AAA” in red. For the screenshot on the right, the text boxes contain *Large text*, so the green and red bars correspond to the symbols of the second line, with “AA” in green and “AAA” in red.

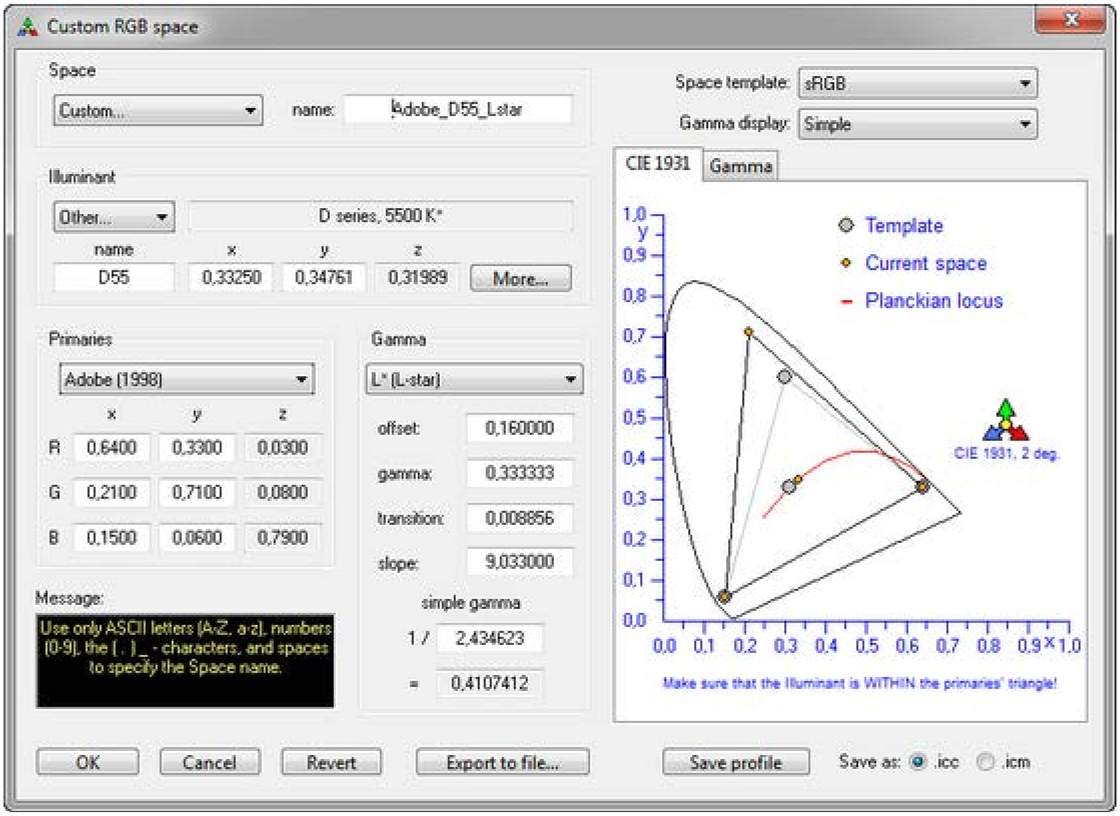


Hint: EXAMPLE 3 of Tutorial #4 proposes a method on how to optimize two colors to maximize text contrast.

SAVING THE WCAG RESULTS

The WCAG Contrast Ratios and the contrast compliance results for all text color combinations are included in the report obtained with the “**Save Data…**” menu item of the RGB vs RGB menu.

4.10 Custom RGB space dialog



This dialog is called with the "RGB vs RGB/Define custom RGB..." menu or by selecting the last menu item in a RGB vs RGB window space selection menu.

Any change in a user-modifiable data value — with a white background — will take effect as you enter the data, updating the other fields, the chromaticity diagram, and the gamma diagram.

SPACE SELECTION

Selecting any of the preset RGB spaces will automatically fill the "Illuminant", "Primaries" and "Gamma" input fields with the values corresponding to this space. Modifying any field will automatically change the space selection list to "Custom...", and the Space "name" field will allow user input (default name: "CustomRGB").

MESSAGE WINDOW

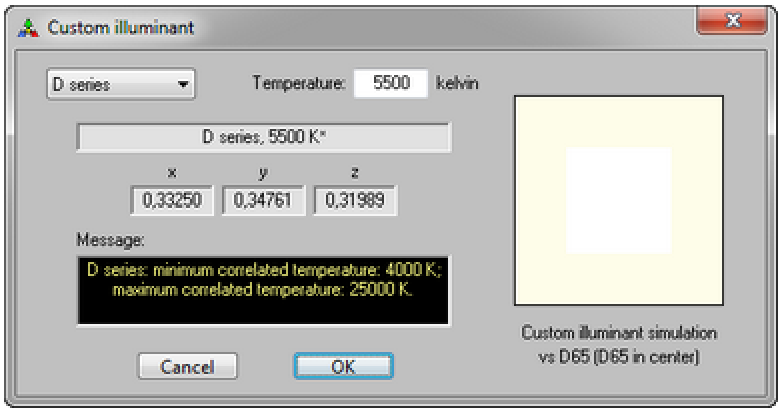
This window is used to indicate the various characteristics and limitations of the input fields.

ILLUMINANT SELECTION

Selecting any of the standard illuminants will fill the corresponding fields. Modifying the illuminant coordinates will automatically change the illuminant selection list to "Other...", and the "Illuminant name" field will allow user input (default name: "Custom").

When a new value is assigned by the user to the "x" coordinate, the system makes sure that the "x + y + z" total remains equal to one. The "z" value will first be adjusted to fill the difference; if "z" reaches zero or one, then the "y" value is adjusted. Similarly, when the user assigns a new value to "y", the "z" value will first be adjusted to fill the difference; if "z" reaches zero or one, then the "x" value is adjusted.

Additional pre-calculated illuminants are available by pressing the "More..." button, which opens the **Custom illuminant dialog**:



The selection list of this dialog offers additional standard illuminant presets, such as B, F2, F7, and F11, and will automatically calculate the coordinates of either D-series illuminants or blackbodies as per a user specified temperature (in kelvin). The equations of the D-series illuminants are presented in the Illuminants section.

A simulated representation of the illuminant "whiteness" relative to D65 is shown in concentric color patches; these patches are to be used as a guide only.

Pressing "OK" will transfer the coordinates shown in the **Custom illuminant dialog** into the **Custom RGB space dialog**.

The Bradford and CIECAT02 Chromatic Adaptation Transform (CAT) matrices between the Custom illuminant and many standard illuminants (i.e. A, C, D50, D65, E, etc.) can be seen in the CAT matrices dialog opened with the "RGB vs RGB/Table data/CAT matrices..." menu or with the "CAT matrices..." menu of the "Tables" icon in the toolbar window.

Important: The illuminant has to be located within the triangle formed by the primaries. If the illuminant is outside or on the periphery of this triangle, the program will not accept the Custom space when pressing "OK".

Note: The illuminant defined for the Custom space is also available in the illuminant selection list of a Color Deck.

Note: The CAT matrix will map all custom illuminants to white in the color patches display (i.e. converted to D65 for either sRGB or Apple RGB), even if the custom illuminant cannot be adapted (i.e. it has a definite color tint).

PRIMARIES SELECTION

Selecting any of the standard primaries sets will fill the data fields with the corresponding chromaticity coordinates. Modifying a coordinate in a field will automatically change the primaries selection list to "Custom..."

When a new value is assigned by the user to any "x" or “y” chromaticity coordinate, the program makes sure that the "x + y + z" total remains equal to one (1) by adjusting the "z" value. The coordinates can be either positive or negative. Please be aware that coordinates which are outside of the chromaticity diagram spectral locus (the horseshoe) will correspond to non-visible or non-real colors.

The coordinates shown in the input fields are displayed in the "CIE1931" diagram of the dialog. They are identified by the "Current space" legend.

Note: Assigning negative chromaticity coordinates may result in negative “xyY”, “XYZ”, and “L*” values. In the past (before CT&A V-5.2), when chromaticity coordinates were always positive, negative XYZ values happened only because of rounding errors, and they were clipped to zero; this was the default (and only) processing. Now, in order to get negative (i.e. non-clipped) XYZ values for a space with negative chromaticities, you must first deselect the

☑ Clip “xyY” and “XYZ” to zero in the “RGB vs RGB” tool

checkbox in the “Math” tab of the Preferences dialog.

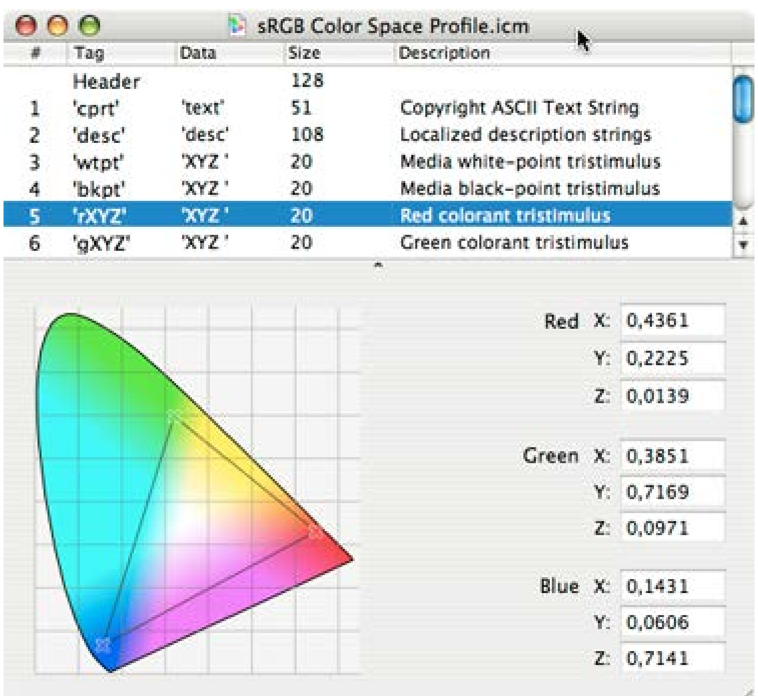
Important: The primaries have to be positioned to form a triangle which encompasses the illuminant. If the illuminant is outside or on the periphery of this triangle, the program will not accept the Custom space when pressing "OK".

Important: Make sure the primary coordinates you enter are x, y, and z chromaticities, which are always shown in lowercase. For instance, you cannot use the XYZ coordinates presented by Apple's **ColorSync Utility**, as shown below. You first need to derive xyz from XYZ with the following equations (see this section for more info):

$x = X / (X+Y+Z)$

$y = Y / (X+Y+Z)$

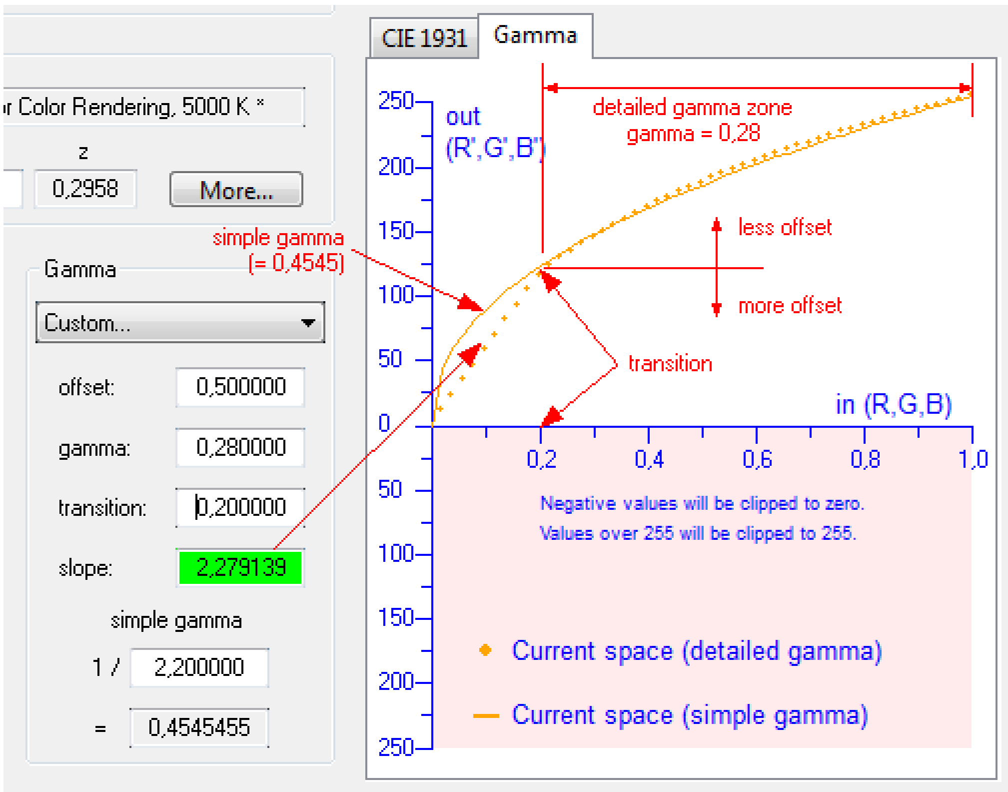
$z = Z / (X+Y+Z)$.



GAMMA SELECTION

Selecting any of the standard gamma sets will fill the corresponding fields. Modifying a value in a field will automatically change the gamma selection list to "Custom...".

The values shown in the input fields are used to compute the simple and detailed gamma functions shown in the "Gamma" diagram of the dialog. The functions are identified by the "Current space" legend. The equations for gamma are shown in the RGB to R'G'B', and gamma section. Here is an example that illustrates how the detailed gamma parameters affect the function:



To ease the design of the detailed gamma, the software will automatically compute the *slope* value that matches the *offset*, *gamma* and *transition* values; the *slope* characterizes the linear portion of the gamma function located below the *transition*. If a change is required to the current *slope* value, the new value will be displayed with either a green or a red background. As a design rule, you should not define a detailed gamma which results in a red (negative) *slope*. Here is what can happen:

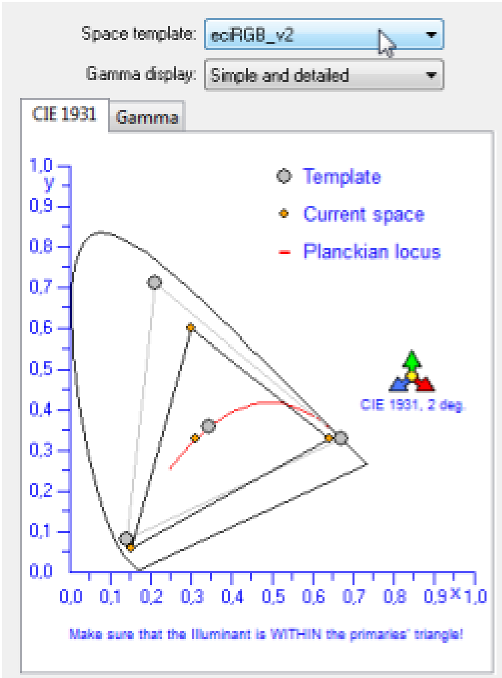
- If the *slope* field is red or green, editing the field or pressing the "Tab" key while the cursor is in the field will change the color of the *slope* background back to white. However, if the edited value is negative, it will be clipped to zero.
- If the *slope* field is green and you do not edit it, the program will assign the displayed value as the new *slope*.
- If the *slope* field is red and you do not edit it, a slope of zero will be nonetheless assigned when you click "OK" in the dialog.

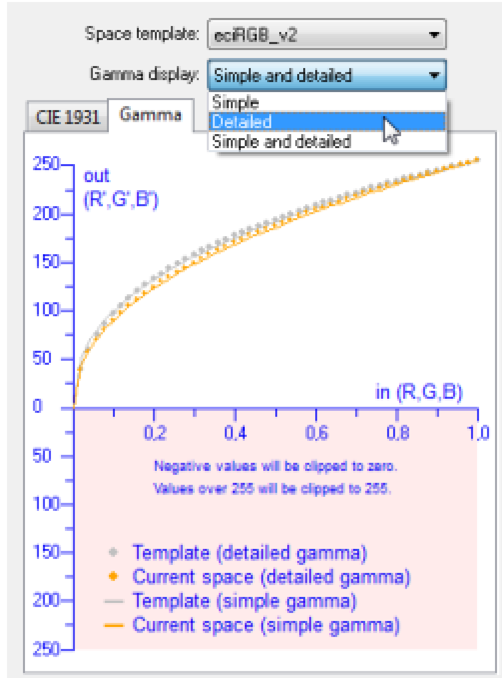
You can always select a different *slope* than the one suggested, as long as it is positive, and that you do not further change the *offset*, *gamma* or *transition*; if this is the case, a new *slope* value will be suggested.

Important: If you set the *detailed gamma* to zero, the program will reset to zero all other detailed gamma fields (*offset*, *transition*, and *slope*).

DISPLAY SETTINGS

These settings affect what is seen in the graphics window:





The "Space template" selection menu affects both the "CIE1931" and "Gamma" diagrams. Using this menu, you can overlay a gray colored template corresponding to any of the preset RGB spaces or to the last saved Custom space; you can also select to not display any template using the "**(none)**" selection. These templates are to be used as design guides. The current space data is always shown in orange.

The "Gamma display" selection menu affects only the "Gamma" diagram. Using the menu enables you to see either the simple or the detailed gamma function, or both. If the detailed gamma function is not defined for a given space, a red **X** will be shown over the legend symbol.

Hint: To see the Planckian locus, or any other graphic data, you should select it using either the "RGB vs RGB/Graphic data" menu or the menu of the "Graphics" icon in the toolbar window **before** opening the custom RGB space dialog.

EXPORT TO FILE

At any time while you are editing the custom RGB space, you can export a file which contains the following information:

1. the illuminant description and coordinates;
2. the primaries coordinates;
3. the gamma parameters;
4. the RGB to XYZ matrix coefficients;
5. the XYZ to RGB matrix coefficients.

This file can be opened by any text editor. It can also be imported in any spreadsheet that supports space delimited tables.

Important: No check of the validity of the current RGB space is made before exporting the space data.

Note: A Custom space is not saved for use within the program RGB vs RGB tool until the "OK" button is pressed.

SAVE PROFILE

At any time while you are editing the custom RGB space, you can export it as an ICC profile. This profile can be assigned to an image using image editing programs that support profile embedding, such as Photoshop. It can also be assigned to a color list in BabelColor's PatchTool, or used to convert a color list using PatchTool's Gamut Tools.

You can save the profile with either the "*.icc" extension, the standard ICC profile extension, which is standard on Mac but also common on Windows, or the "*.icm" extension usually found on Windows computers. While the file extensions are different, the content of "*.icc" and "*.icm" profiles are the same.

Note: If you enter parameters for both a detailed gamma and a simple gamma, the ICC profile's gamma will be built using the detailed gamma information.

Important: No check of the validity of the current RGB space is made before creating the profile.

Note: A Custom space is not saved for use within the RGB vs RGB tool until the "OK" button is pressed.

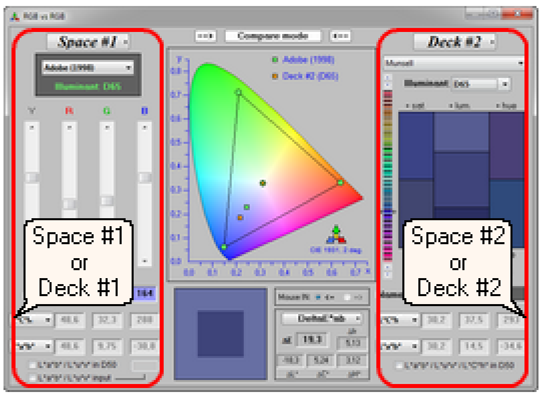
4.11 Mode Settings

CT&A's "RGB vs RGB" tool has numerous operational modes. These modes are related to operations between the selected RGB spaces and Color decks, to inputs and outputs, and to how data is processed. These modes are:

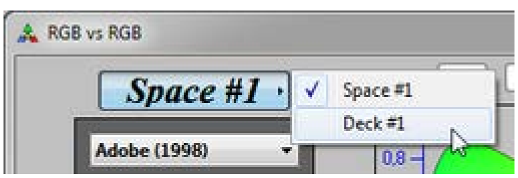
- RGB Space / Color Deck select
- Compare mode
- Convert mode
- Input modes
- Gamma modes
- Chromatic Adaptation Transform matrix

RGB SPACE / COLOR DECK SELECT

When the RGB vs RGB tool is first opened, both sides show a RGB space, Space #1 on the LEFT, and Space #2 on the RIGHT. Either side can then be changed to display a color catalogue, also called a Color Deck (Deck #1 on the LEFT, and Deck #2 on the RIGHT).



To change a side into Deck mode, click on the label identified "Space #1" or "Space #2" and slide the cursor to the Deck selection:

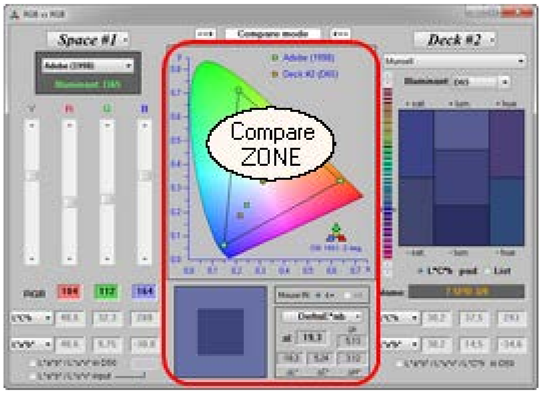


To change a side back into Space mode, click on the label identified "Deck #1" or "Deck #2" and slide the cursor to the Space selection:

For more information on the interface of each mode, look in the RGB Space interface and Color Deck interface sections.

COMPARE MODE

Set by default when the tool is first opened, the Compare mode enables independent input for each side, Space or Deck. The "Compare ZONE" identified in the following illustration comprises the chromaticity diagram where the "xy" coordinates of each side are shown, color patches of each side converted to the user-selected display space, and color difference data between the two sides.



The Compare mode is readily identified by the following three buttons located on top of the chromaticity diagram:

The buttons have the following appearance if the "Dim the chromaticity..." option is enabled:

To get back to the Compare mode when in either of the Convert modes, simply click on the central Convert mode button:

when in Convert Left-to-Right,

when in Convert Right-to-Left,

OR

select the "RGB vs RGB/Mode/Compare" menu.

For an RGB space in Compare mode, input is done either by assigning R'G'B' values, shown below on the left, or by entering L*a*b* / L*u*v* data, shown below on the right (L*a*b*/L*u*v* data can be entered manually or directly with one of the supported instruments).

For a Color deck in Compare mode, two deck navigating modes are available, one using the L*C*h pad, shown below on the left, and the other using the List view, shown on the right.

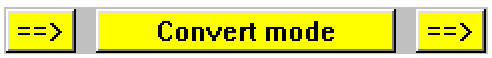
 

CONVERT MODE

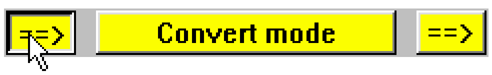
In this mode, the color from one side, RGB space or Color deck, is converted to the other side, space or deck. If converting to a RGB space, the reference color is converted to the exact equivalent color on the other side, unless there is clipping, in which case, the closest value is computed. If converting to a Color deck, the system finds the color chip that most closely matches the reference color. Color-difference data is shown.

When in Compare mode, you can go in **Convert mode Left to Right** by clicking the central Compare mode button:

By **default**, clicking the Compare mode button will select the Convert **Left-to-Right** mode and the button label will change to "Convert mode". Also, the button color as well as the color of the arrows on each side will become yellow, as shown in the illustration just below.



To alternate between the Left-to-Right and Right-to-Left modes, simply click on one of the arrows:



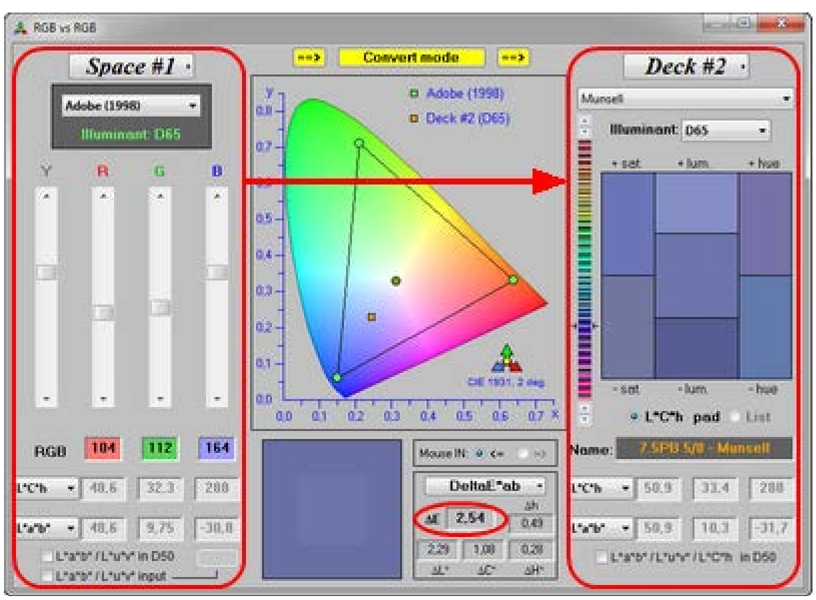
OR

OR

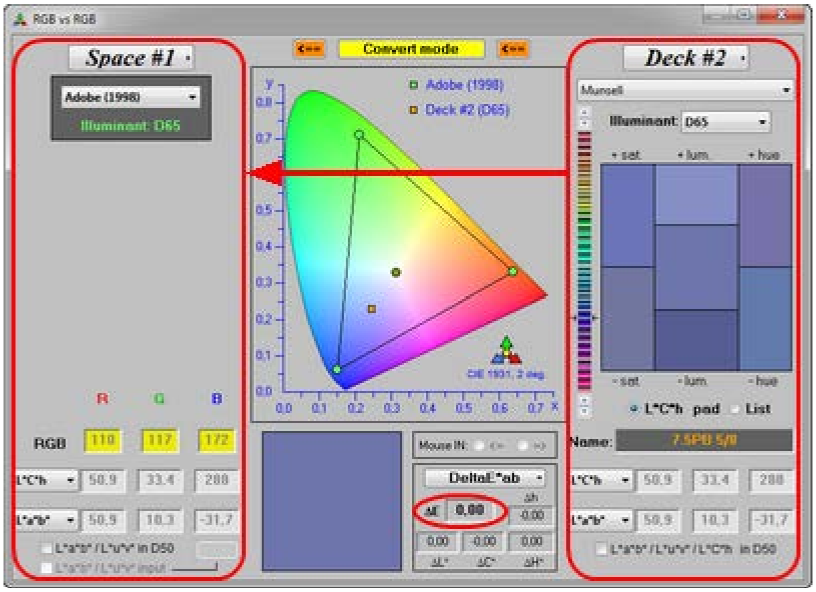
use the "RGB vs RGB/Mode/Convert Left to Right" and "RGB vs RGB/Mode/Convert Right to Left" menus.

Note: There is NO action when clicking on the arrows while in Compare mode.

In **Convert Left-to-Right** mode, you can perform a conversion **from** (Space #1 or Deck #1) **to** (Space #2 or Deck #2):



In **Convert Right-to-Left** mode, you can perform a conversion **from** (Space #2 or Deck #2) **to** (Space #1 or Deck #1):



You will notice in the just-above illustration (Convert Right-to-Left) that all local inputs of the RGB space on the LEFT, including the sliders and the "xy" mouse input, are disabled, and that the R'G'B' displays' backgrounds are yellow.

When converting to a RGB space, the converted coordinates are high precision, non-integer, **fractional** numbers which are rounded only for R'G'B' display purposes. This is why the color-difference, DeltaE*, when there is no clipping, is exactly zero. When going back to Compare mode, this RGB space is injected **rounded** integer values as R'G'B' inputs, and all other data values are updated. As a result, a small color difference value may then appear in the DeltaE* display. For more information on integers and rounding, go to the data integrity section.

Note: L*a*b*/L*u*v* input is not available in a RGB space when a space is being converted "TO".

Note: The Color deck List view is not available when a deck is being converted "TO".

Important: As part of the conversion process, the software determines, using a Chromatic Adaptation Transform matrix, the coordinates that would be obtained if the color was measured using the illuminant of the destination space or deck. When converting to a RGB space, colors which fall outside the new space gamut are clipped to the nearest in-gamut color. This is the method used when converting color profiles with "**Relative Colorimetric**" intent in Photoshop and other graphic editing programs that use this terminology. When converting to a deck, the system finds the best match based on the current DeltaE* formula, as selected in the DeltaE* display. Accordingly, changing the DeltaE* formula may result in a different match. Please note that the match is always performed using the deck illuminant even if the D50 version of a DeltaE* formula is selected.

INPUT MODES

In Compare mode, a RGB Space input can be done with R'G'B' data, L*a*b* or L*u*v* data entered manually or with a measuring instrument, or with a mouse by clicking on the chromaticity diagram ("xy" mouse input). When converting "TO" a RGB space, its input only comes from the other side, RGB space or Color deck.

In Compare mode, a Color deck input is performed by clicking in the color strip or by clicking on one of the L*C*h pad or List view patches. When converting "TO" a Color deck, its input only comes from the other side, RGB space or Color deck.

Click on one of the input modes listed below for more information:

- **R'G'B' space input modes**
  - R'G'B' data
  - R'G'B' sliders
  - L*a*b*/L*u*v* data entered manually
  - L*a*b*/L*u*v* data entered with one of the supported instruments
  - "xy" mouse input in the chromaticity diagram
  - From another RGB space or Color deck, in Convert mode

  The **R'G'B' data** and **R'G'B' sliders** input modes are disabled when the L*a*b* / L*u*v* input mode is active **OR** when the input is from another RGB space or Color deck, in Convert mode. To go back to R'G'B' input if the space is in L*a*b* / L*u*v* input mode, uncheck the L*a*b* / L*u*v* input checkbox. To go back to R'G'B' input if input is from another RGB space or Color deck, change from Convert to Compare mode.

  The **L*a*b* / L*u*v* input** input mode is disabled when the input is from another RGB space or Color deck (i.e. when the space is being converted "TO").

  The **"xy" mouse input** mode is disabled when in L*a*b* / L*u*v* input mode **OR** when the input is from another RGB space or Color deck.

- **Color deck input modes**
  - Color strip
  - L*C*h pad
  - List view
  - From another RGB space or Color deck, in Convert mode

  The **Color strip**, **L*C*h pad**, and **List view** input modes are disabled when the input is from another RGB space or Color deck (i.e. when the deck is being converted "TO"); if you want to go back to the other deck input modes, change from Convert to Compare mode.

GAMMA MODES

The conversion between linear RGB and non-linear R'G'B', the RGB values used in all graphic applications, is done with a formula called a gamma function (sometimes also referred to as a Tone Response Curve, or TRC). A gamma function can be defined in many ways:

- by a single parameter function (simple gamma);
- by a multiple parameters function (detailed gamma, with two segments and the following parameters: offset, gamma, transition, slope);
- with curves defined by multiple data points.

The single and multiple parameters functions are the most common methods, and the single parameter gamma is the most common overall. Not all spaces are defined with detailed gamma parameters, but all spaces have a simple gamma value assigned. A single parameter function (simple gamma) is often used even if the space has been defined by a multiple parameters function (detailed gamma); however, the detailed gamma will provide more accurate colorimetric transforms.

By **default**, CT&A uses a **detailed gamma**, if defined, but it can be set to use a simple gamma via the Preferences dialog. Please note that the Custom RGB dialog also supports both types of gamma functions.

To view the gamma parameters for a given space, use the "RGB vs RGB/Table data/Space data..." menu or the "Space data..." menu of the "Tables" icon in the toolbar window.

CHROMATIC ADAPTATION TRANSFORM MATRIX

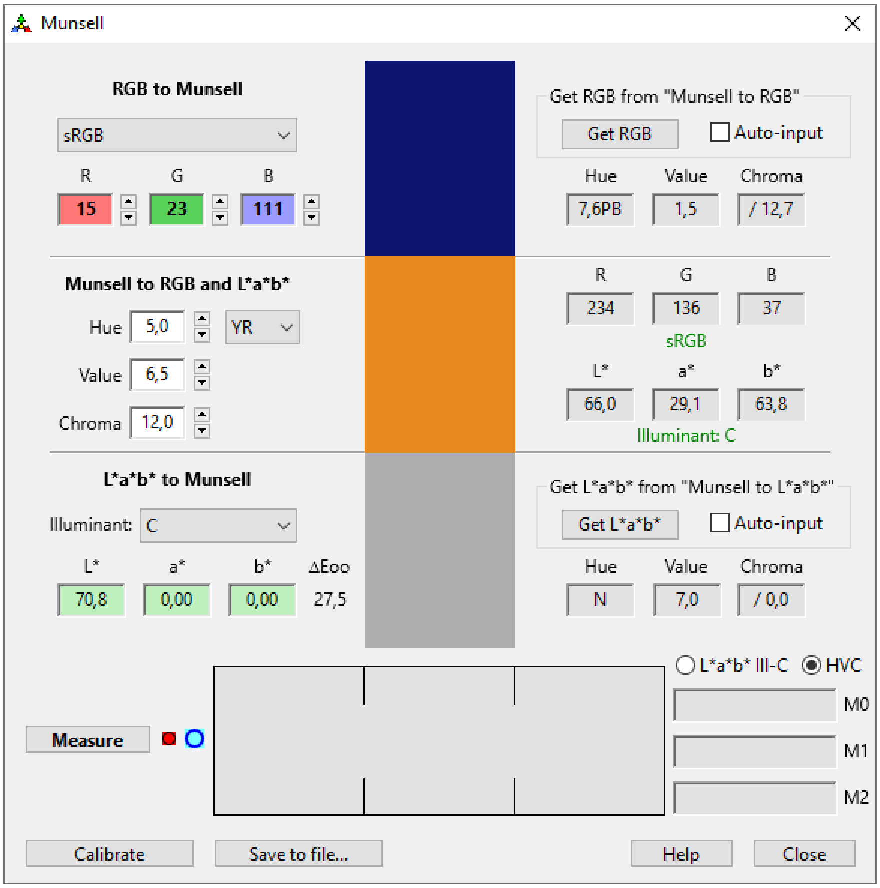
When converting color coordinates from one RGB space to another, it is often required to transform colors referenced to one illuminant into colors referenced to another illuminant. Sometimes, spectral data is available and we can recompute the color for the new illuminant, but most often, when dealing with tristimulus data, such as XYZ, spectral data is not available. In such cases, we can use a Chromatic Adaptation Transform (CAT) matrix whose purpose is to convert XYZ coordinates computed for one illuminant to XYZ coordinates that correspond to the same perceived color for another illuminant. Through time, many CATs were devised and two of them are supported in CT&A:

- a simplified matrix representation of the Bradford transform used in the development of the sRGB standard, and often found in ICC profiles;
- the CIECAT02 matrix, a more recent development, which is recommended to derive the Color Inconstancy Index (CII).

In CT&A, a CAT is used to for space conversion in the RGB vs RGB and Metamerism Index (MI) tools, and used to compute display colors in all tools. The CAT can be set in the Preferences dialog. Please note that it should be set to "CIECAT02" in order to obtain the prescribed CII values in the Metamerism Index tool.

Note: In older versions of CT&A, before Version 4.x, CIECAT02 was used only to compute the CII in the MI tool, and all other CAT functions were done with a Bradford CAT. Starting with CT&A Version 4.x, the CAT can be selected and CIECAT02 is the default.

5. Munsell tools



The **Munsell tools** window is opened either by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/Munsell" menu.

The Munsell tools enable you to:

- input RGB associated with a specific RGB space and convert it to Munsell Hue Value/Chroma (HVC);
- input Munsell HVC and convert it to both RGB and L*a*b* outputs;
- input L*a*b* and convert it Munsell HVC;
- measure a sample, in reflectance, with one of the supported spectrophotometers and get the Munsell coordinates for the M0, M1, and M2 Measurement Conditions (when supported by the instrument);
- save a report of the tools data, including the measured spectral data if applicable.

Click on a link in the Table of Contents below to jump to a specific section.

5.1 Munsell tools interface

The window is separated in four sections, with the first three dedicated to user-typed input and the fourth dedicated to instrument measurements. From top to bottom we have:

- typed **input RGB** to Munsell **Hue Value/Chroma** (HVC) output;
- typed **input Munsell HVC** to both RGB and L*a*b* outputs;
- typed **input L*a*b*** to Munsell HVC output;
- from an i1Pro series spectrophotometer to L*a*b* (always Illuminant C) and Munsell HVC.

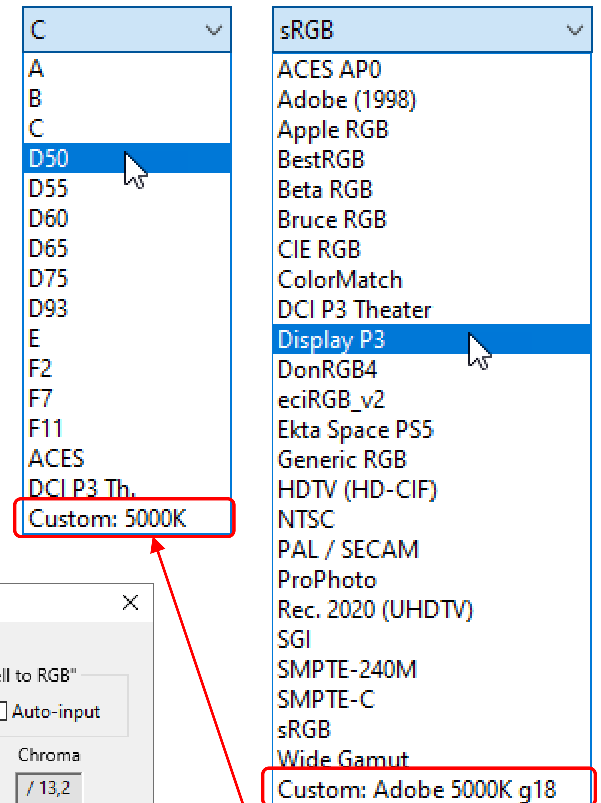
RGB SPACE AND ILLUMINANT SELECTION

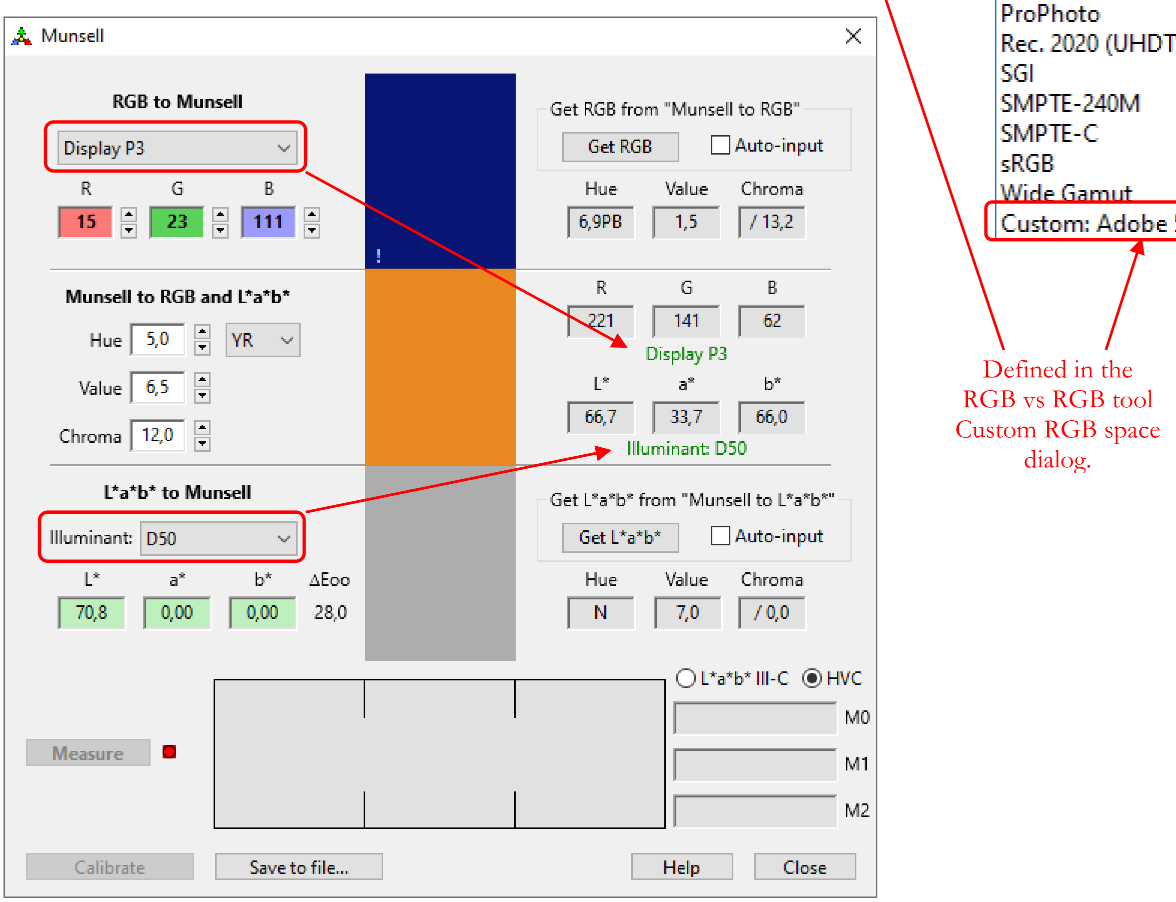
The list of RGB spaces is the same as the one available in the RGB vs RGB tool, including the Custom RGB space. You can thus define a Custom RGB space in the RGB vs RGB tool and use it in the Munsell tools.

The list of illuminants comprises many standard Illuminants, including the **Custom illuminant** assigned to the Custom RGB space in the RGB vs RGB tool.

The RGB space and illuminant selected in the input zones are also assigned as the destination space and illuminant for the "**Munsell to RGB and L*a*b***" conversions.

Important: The "**gamma**" and "**Chromatic Adaptation Transform**" settings in the Preferences dialog will affect the conversions of the Munsell tools dialog.



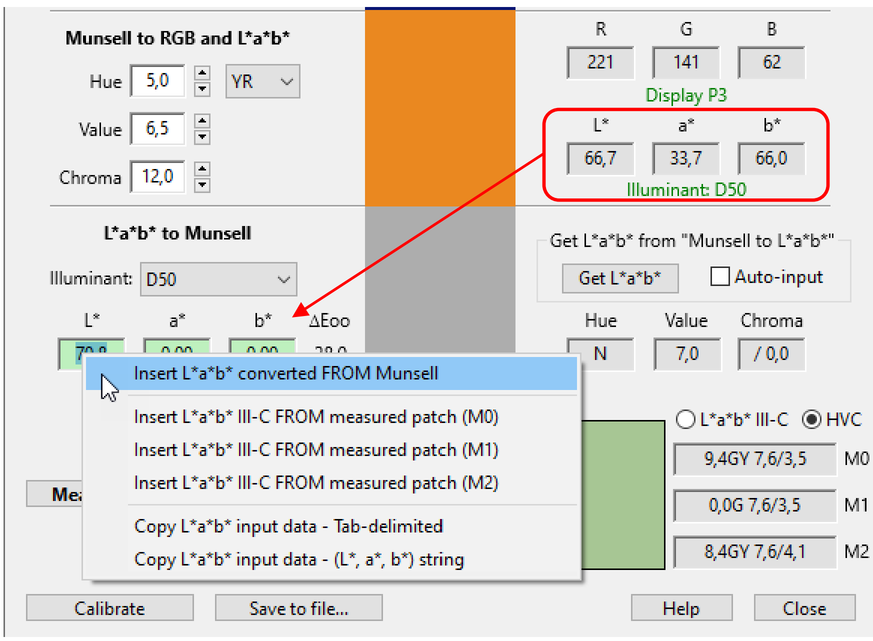


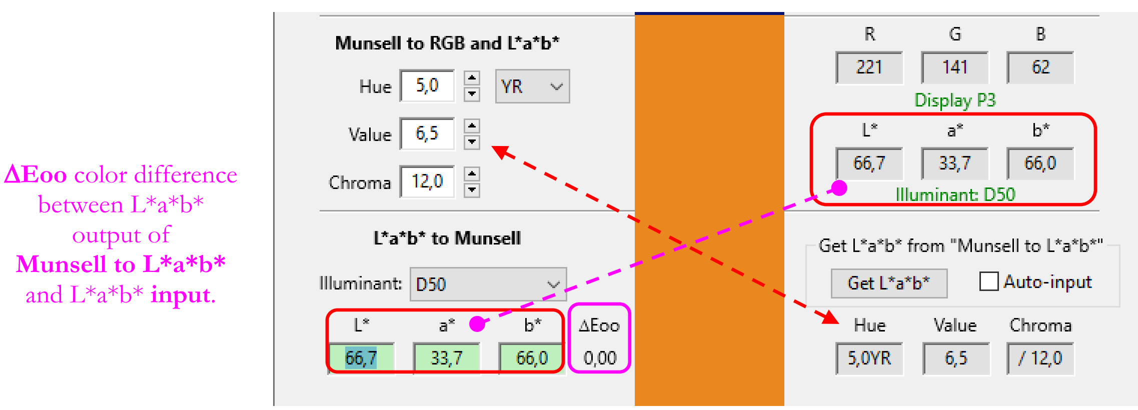
CONVERSIONS AND "ROUNDTRIP" CONVERSIONS

Conversion TO and FROM the Munsell Color System involves tridimensional data interpolation to which is associated a small error. The error will be higher when the reference data, the Munsell "table", has relatively sparse data. Rounding of RGB and L*a*b* input and output will also have an effect. One way of evaluating this error is to use the conversion output as input and do the reverse conversion. This can be done in several ways:

- Do a mouse right-click on an **input field** and assign the output from another conversion with the popup menu.
- Do a mouse right-click on an **output field** and assign the output to another input with the popup menu.
- Click on the "**Get RGB**" button to use the "**Munsell to RGB**" output as input to the "**RGB to Munsell**" converter. You can select the "Auto-input" box to automatically convert the "**Munsell to RGB**" output back to Munsell HVC.
- Click on the "**Get L*a*b***" button to use the "**Munsell to L*a*b***" output as input to the "**L*a*b* to Munsell**" converter. You can select the "Auto-input" box to automatically convert the "**Munsell to L*a*b***" output back to Munsell HVC.

Here is an example where we use the L*a*b* output converted from Munsell as input to the **L*a*b* to Munsell** conversion:

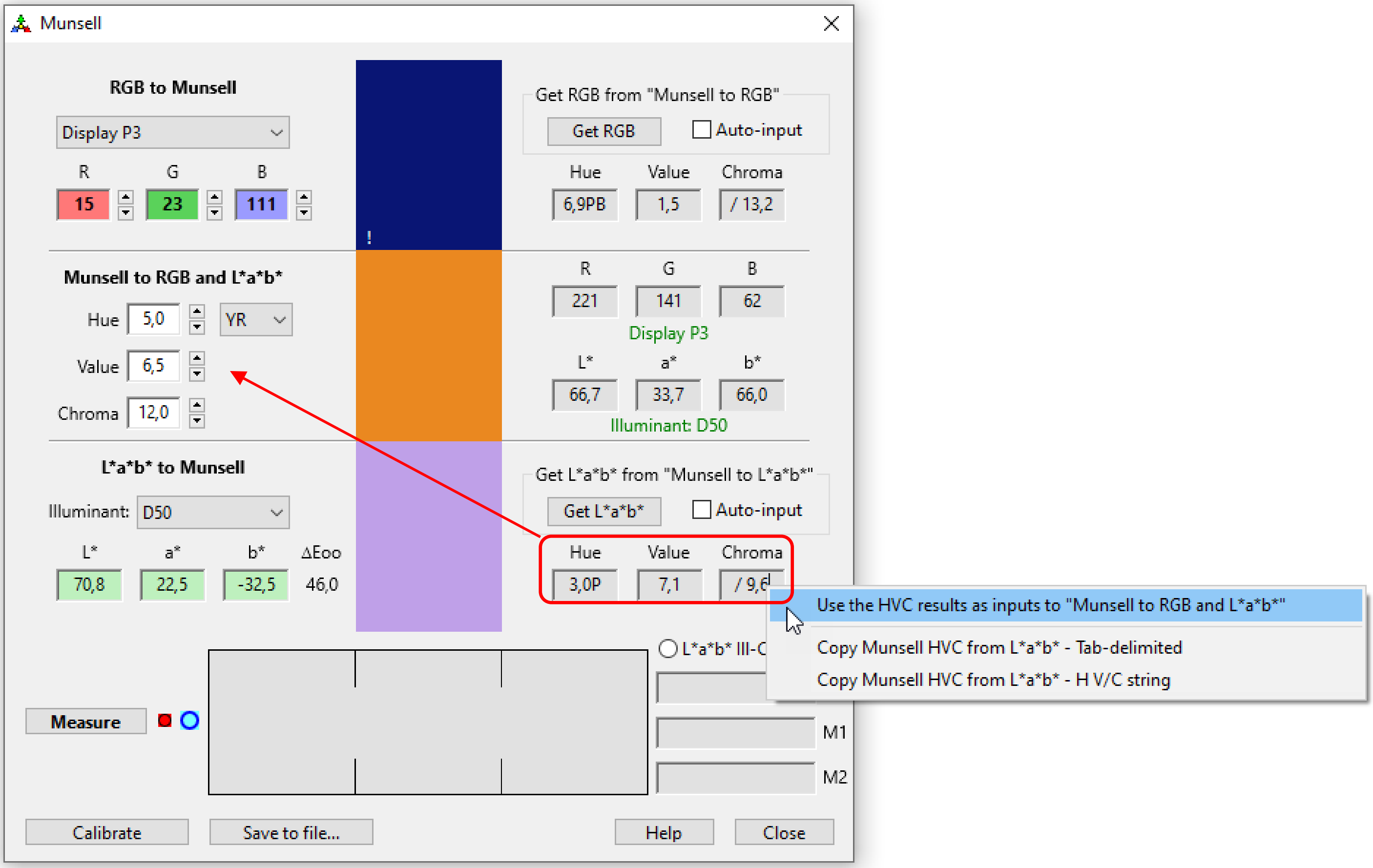


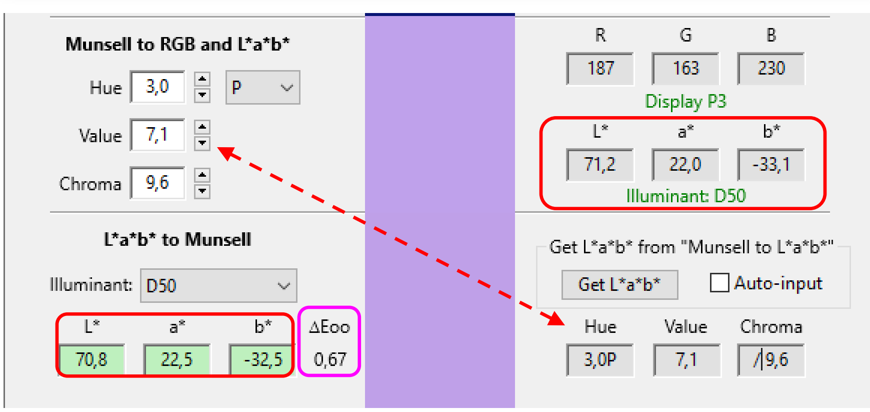


The ΔEoo (CIEDE2000) color difference data field shows the difference computed between the L*a*b* **output** from the **Munsell to RGB and L*a*b*** conversion and the L*a*b* **input** of the **L*a*b* to Munsell** converter. Of course, in this example, we just assigned the **output as input** and the color difference is zero! More interesting here is the Munsell output from the **L*a*b* to Munsell** conversion (= **5.0YR 6.5/12.0**) which is exactly the same

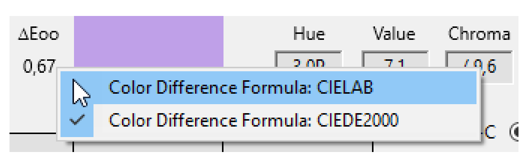
as the input of the **Munsell to RGB and L*a*b*** conversion, so we have a perfect roundtrip, from **Munsell-to-L*a*b*-to-Munsell**. While a perfect roundtrip is expected, it is not unusual to see small differences.

In this second example we use the Munsell HVC **output** from the **L*a*b* to Munsell*** conversion as **input** to the **Munsell to RGB and L*a*b*** conversion.





Do a mouse right-click on the color difference data fields to select the color difference formula.



We see a small color difference (CIEDE2000=0,67) in the L*a*b*-to-Munsell-to-L*a*b* roundtrip; this difference gives us an idea of the overall conversion precision. A similar analysis can be performed using RGB inputs and outputs.

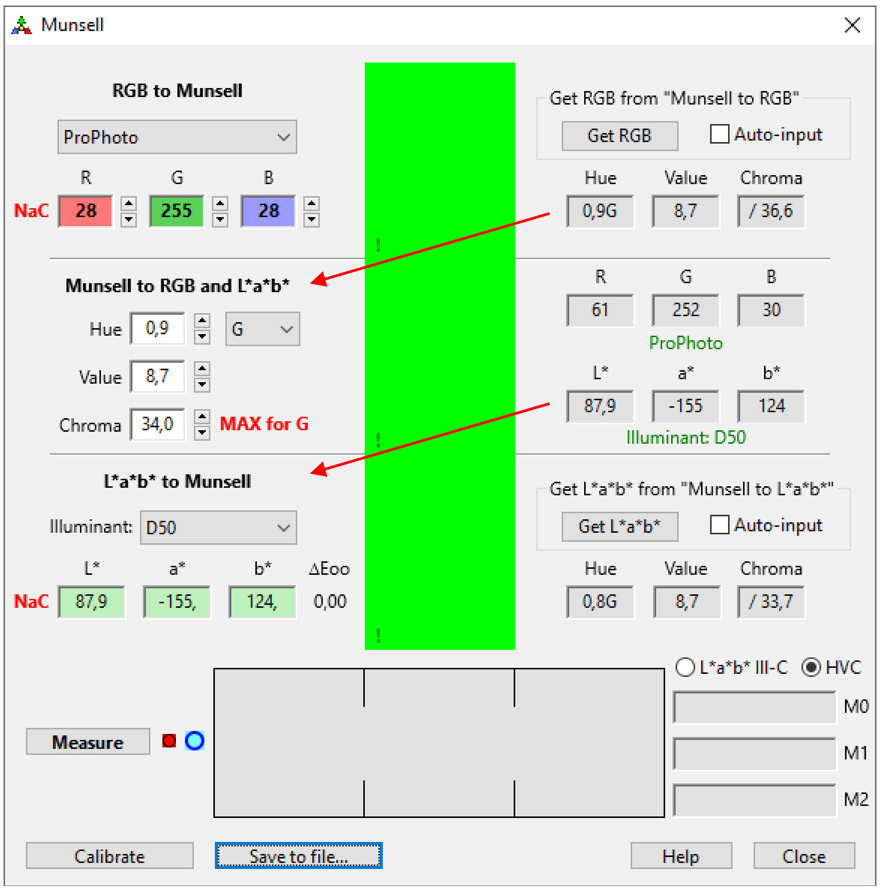
Hint: As shown on the screenshots of the preceding pages, you can copy input and output data by making a mouse right-click on a data field. When copied, the data is transferred into the clipboard. Depending on the selected menu item, the data may or may not be separated by Tabs; Tab separated data can easily be pasted in a spreadsheet or document table.

CLIPPED / OUT-OF-RANGE INPUT / OUTPUT

In an RGB space, not all coordinates may correspond to “visible” (or “real”) colors. This is the case for instance with the ProPhoto RGB space with its green and blue primaries defined outside of the “visible colors” chromaticity diagram, and even more so for the ACES AP0 RGB space. This does not mean that you cannot type these coordinates in a color picker, most software allow this and may even show a (very saturated) color, but the color represented on your monitor should not be considered valid.

For L*a*b* input, there is an additional constraint since there is no precise minimum or maximum limit on the a* and b* coordinates. Yet, for L*a*b* we can still check if the corresponding chromaticity is within the chromaticity diagram; in this case, the limits vary depending on the selected illuminant.

In the Munsell tools, chromaticity validity checks are performed on RGB and L*a*b* inputs. For Munsell HVC inputs, the Chroma is limited by the Munsell Color System data tables. The following screenshot shows a variety of flags that you will see when colors are off-limit. For the screenshot, we first typed the ProPhoto RGB coordinates in the **RGB to Munsell** section. We then assigned the Munsell output (from RGB) as an input to the **Munsell to RGB and L*a*b***. We finally assigned the L*a*b* output of the **Munsell to RGB and L*a*b*** conversion as an input to the **L*a*b* to Munsell** conversion.



The “**NaC**” flag before the RGB and L*a*b* inputs stands for “**Not a Color**”, indicating that the corresponding chromaticity coordinates are outside of the chromaticity diagram. You can verify this with the RGB vs RGB tool.

The “**MAX for G**” flag indicates that the assigned input, from the RGB to Munsell conversion, is larger than the maximum Chroma used in the Munsell Color System database; this is a program limitation. Please note that the maximum Chroma is different for each Hue.

Finally, you will also notice exclamation points (**!**) in the green color patches. This symbol indicates that the patch color is outside of the display color profile, i.e. that it is clipped.

5.2 Munsell tools instrument input

Important: To **measure** a sample, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate" and "Measure" buttons of the Munsell window being enabled (some controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Note: In Windows, if the i1Pro/i1Pro 2 or i1Pro3 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Instrument button support: When the Munsell tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears next to a "Measure" button. This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button.

SETUP

- **There is no user setup for this tool.** The program will set itself in **reflectance mode** and the data will be computed for illuminant **C** and the **2 degree Observer**. However, it is assumed that your instrument is properly connected and detected, as discussed above.

  Note: If you are using an **i1Pro 2** with the "**i1Pro / i1Pro 2 (XRGA)**" driver, an i1Pro 3, or an i1Pro 3 Plus, all measurements will be taken with the three "Measurement Conditions", M0 (Ill-A), M1 (D50), and M2 (UV-cut), as defined in ISO 13655 (Ref. 42). A description of the M0/M1/M2 measurement conditions can also be found in the FluoCheck tools. If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument and data will not be shown for the other measurement conditions.

- If not already done, calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions.

INSTRUMENT MEASUREMENT

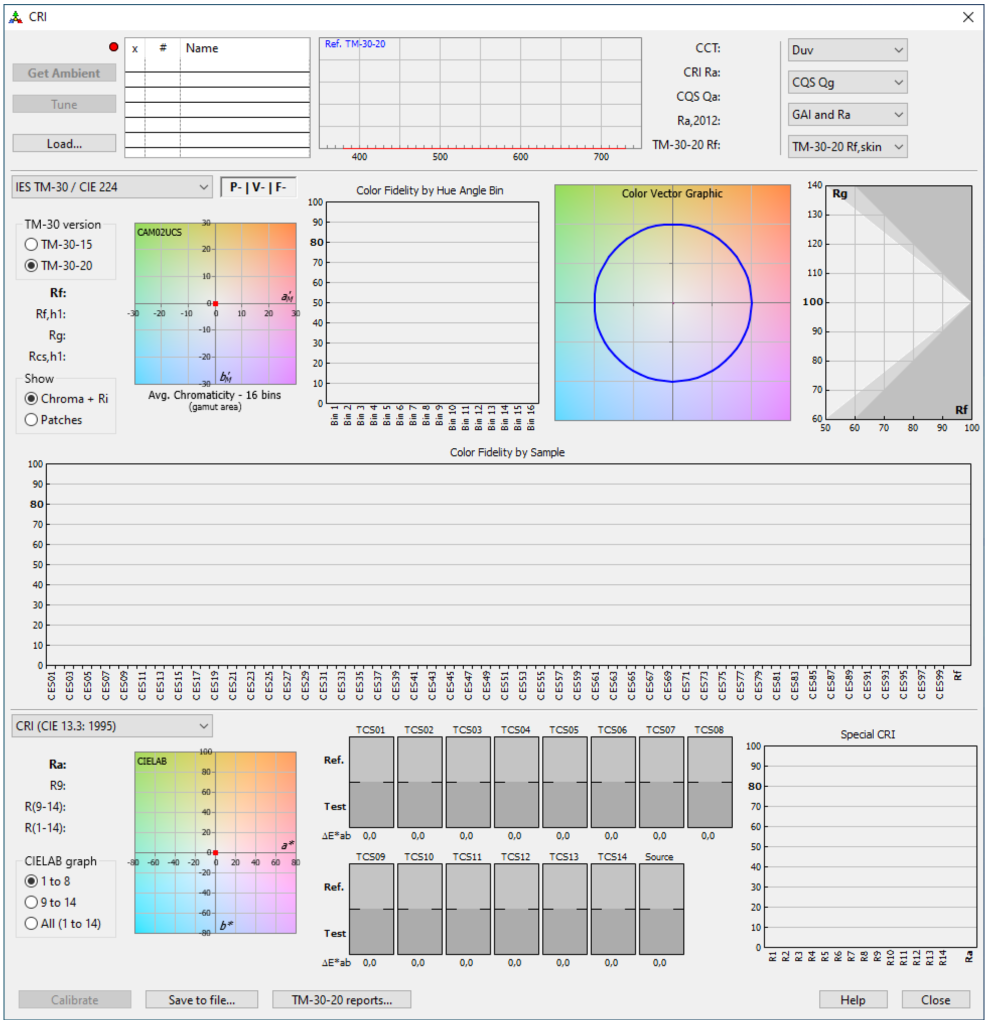
To make a measurement, just click on the "Measure" button or press the instrument button. Apart from the measurement in Munsell **Hue Value/Chroma** notation, the window can also show the L*a*b* values relative to Illuminant C.

If you take a measurement of a color patch, with non-florescent inks, printed on a non-fluorescent substrate, the M0, M1, and M2 values should be identical. However, if the ink or substrate is fluorescent, you will likely obtain three different values.

Note: A clipping indicator appears in the bottom left corner of the color patch when the color of the sample it represents is outside of the RGB space gamut of the monitor.

Click on "Save to file..." to save a Munsell report which will also include the user-typed conversions. The report has tab-delimited data that can be directly imported in a spreadsheet program and opened in many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting). The report spectral measurements can also be read by software, such as BabelColor PatchTool, which can open CGATS compatible files.

6. CRI tools



The **CRI tools** window is opened either by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/CRI, CQS, CRI2012, TM-30" menu.

The tools comprise the current Color Rendering Index (CRI) method as well as proposed replacement metrics, and new metrics for gamut area and memory colors. A short description of the metrics is presented below; a more complete description of each metric is presented in this section.

- **CRI** (CIE 13.3:1995): The only agreed method for computing the CRI. It comprises 14 individual indices of which the first 8 are used to compute ***Ra***, the general index usually presented as the "CRI" by lamp manufacturers. The ninth index (***R9***), computed from a saturated red sample, is often negative; while it is not used to compute the general index, ***R9*** is sometimes used in conjunction with ***Ra*** when assessing a light source. The remaining indices are also based on more saturated samples and, except for ***R14***, their values are generally lower than the first 8 indices.
- **CQS** (Color Quality Scale, NIST Version 9.0.3): A proposed CRI replacement developed by the USA National Institute of Standards and Technology (NIST). It addresses specific complaints against the standard CRI by using 15 saturated samples, by not penalizing chroma increase, and by using RMS averaging instead of arithmetic mean to compute the general index (***Qa***). It also includes a color fidelity metric (***Qf***), where saturation effects are not applied, and a relative gamut area metric (***Qg***). Many versions of this metric were developed; the one used in CT&A is the recommended version to be used at publication time.

- **CRI2012** (nCRI Version 2012): Another proposed CRI replacement, identified as ***Ra,2012***. This version is based on 17 mathematically defined samples which were shown to be representative of one thousand "hybrid" samples obtained by mixing real samples with "idealized" samples. As with the CQS metric, many versions were developed and it it is still being actively worked on, but this is the most recent officially published version.
- **TM-30-15** (IES, 2015): Published by the Illuminating Engineering Society (IES) as a *Method* (NOT a standard!), it was developed by an international team in response to issues with the CQS and CRI2012 metrics. Interestingly, the team comprised members of the groups who had developed CQS and CRI2012. This metric proposes a dual index approach, a Fidelity Index (***Rf***) associated to a Gamut Index (***Rg***), which explicitly demonstrates the tradeoff between fidelity and gamut. The computation is based on 99 Color Evaluation Samples (CES) representing real objects which were mathematically down-selected from an original bank of about 105,000 spectral samples.
- **TM-30-20** (ANSI/IES 2020) **/ TM-30-18** (ANSI/IES 2018) and **CIE 224:2017**: TM-30-20 integrates Annex E and Annex F of TM-30-18 which were published separately after TM-30-18 was issued; it also has a new page layout. The computation methods and the technical content are the same in TM-30-20 and TM-30-18. TM-30-18 was a revision of TM-30-15; it was approved as an ANSI standard (as is TM-30-20). The changes from TM-30-15 affect mostly how the Fidelity Index (***Rf***) is computed, with the Gamut Index (***Rg***) and other derived parameters such as the Local (bin-average) Hue and Chroma shifts remaining unchanged. TM-30-20 / TM-30-18 also contain more precise recommendations on data presentation. The TM-30-18 revision was done in parallel with the CIE 224 Fidelity Index development in an effort to harmonize both methods (more details in the TM-30-20 description). The CIE 224 and TM-30-20 / TM-30-18 Fidelity Indices are thus the same.
- **GAI** (Gamut Area Index): The ***GAI*** uses the same eight Munsell samples which provide the CRI *Ra*. The gamut computation is based on the area encompassed by the samples in the CIE 1976 (*u', v'*) plane. The *GAI* is the ratio of the test source area on the reference source area, where the reference source is the equal energy stimulus (i.e. Illuminant E). This index is generally used in conjunction with *Ra*, and it has been shown that it can even be averaged with *Ra* (defined in this software as "***GAI and Ra***"). *GAI* is normalized to 100, with 100 meaning that the test source matches the reference source.
- **MCRI** (Memory Color Rendering Index): The general degree of similarity (***Sa***) evaluates the degree of similarity between the color appearance of ten familiar objects under the test light source and the memory of those colors. The reference Illuminant is D65. This index is scaled between 0 and 1, with 1 meaning that all familiar objects look as we expect them. When *Sa* is rescaled between 0 and 100 with a sigmoid function; we obtain ***Rm***, the general memory quality index.

Important: The CRI tools can accept input from a file or from a supported instrument. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use these tools. A file may contain one or more spectrums. The file may be either in CGATS format, or a plain text file; the specific requirements for each file formats are presented in the CRI input file requirements section. There are two methods to open/load a file:

- 1st method: Click on the "**Load...**" button and select the file to open with the file input dialog.
- 2nd method: Drag-and-drop the file to open on the "**Load...**" button OR on the **table** located beside the input buttons. You can also drag-and-drop multiple files at a time.

Important: To measure a light source with the CRI tools, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate", "Get Ambient", and "Tune" buttons of the CRI window being enabled (all selection menus will be disabled and most data fields will not be available if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Important: Please make sure that your instrument supports the use of an ambient adapter as some versions of the i1Pro and i1Pro 2 are sold without this capability.

Note: In Windows, if the i1Pro/i1Pro 2 or i1Pro 3 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Note: All computations for the CRI tools are performed with 5 nm reference data tables. You should be aware that using 10 nm source data may not provide results as precise as using 5 nm data, especially with sources which exhibit narrow spectral peaks. For 10 nm data files and measurement data from an i1Pro series spectrophotometer, the data is first interpolated to 5 nm with a user-selected spectral interpolation method, a process which mitigates the effects of the larger bandwidth.

Instrument button support: When the CRI tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears above the "Get Ambient" button. This indicator confirms that the next instrument key press will be assigned to this button; of course, you can also do a mouse click on the button.

Click on a link in the Table of Contents below to jump to a specific section.

CRI tools - Table of Contents

6.1 CRI tools description

6.1.1 Introduction

The goal of the Color Rendering Index (CRI) is to provide an assessment of how a white light "Test source" will make reflectance color samples appear relative to a "Reference source". If the samples appear exactly the same under the Test and Reference sources, then the CRI has a perfect 100 score. Behind this apparent simplicity lies a chasm of variables. First, we need to define this “white light”, then select representative colored samples, and then define a method to compare how the samples appear when viewed with the two sources.

Because the human visual system is very adaptive, it automatically adjust itself to a vast array of light sources and accept as "white" sources whose dominant wavelength varies from the yellowish to the bluish. Of course, if the source's tint is too strong, our brain will then consider that the source is "colored" and process all viewed samples accordingly. The acceptable "white light" zone is defined by a line in the CIE1960 (*u, v*) coordinates plane computed with the chromaticity of Planckian radiators (i.e. blackbodies) of varying temperature, between 1000 and 100,000 kelvin in CT&A, to which is added a certain tolerance expressed as a distance (*Duv*, ±0.05 in CT&A) from the Planckian locus (Ref. 52). The Color Temperature of the blackbody which corresponds the most with the Test source is called the Correlated Color Temperature (CCT).

A low temperature blackbody can easily be simulated by a candle, and a tungsten or halogen-tungsten lamp is very close to a blackbody with a temperature of 2856 K (i.e. Illuminant A). As a blackbody temperature goes higher, so does the proportion of blue light that it emits, with a corresponding shift in its perceived dominant wavelength. For temperatures higher than 5000 K it was customary until recently to use a phase of daylight corresponding to this temperature (CIE 15: 2004, Table T.2; herein called the D-series illuminants) instead of the blackbody spectrum. The difference between a blackbody and a D-series illuminant is that the D-Series illuminant, while based on a ubiquitous blackbody, the Sun, also take into consideration atmospheric absorption and sky illumination, which vary according to time of day, time of year, latitude, cloud cover, etc.

Note: While the computed CCT of a light source is **valid** if its coordinates are within ±0.05 chromaticity units from the Planckian locus, **acceptable** *Duv* values are usually much lower, with a maximum of ±0.0054 being specified in the CRI standard (CIE 13.3: 1995), and ±0.006 specified in ANSI C78.377-2008 (Ref. 53). However, it is important to note that in ANSI C78.377-2008, for CCTs of 4000 K and higher, the center of the *Duv* tolerance zone is not on the Planckian locus in order to take into consideration the locus of the D-series illuminants which is slightly offsetted relative to the Planckian locus.

CRI Reference sources

The first step in determining the color rendition of a light source is to determine its CCT. Once the CCT of the Test source is determined, we can define a Reference source.

For the "standard" **CRI**, the **CQS** (Color Quality Scale), and **CRI2012** methods, the Reference source is:

- a Planckian radiator (i.e. a blackbody) if the CCT is less than 5000 K;
- a D-series (i.e. a phase of CIE Daylight) illuminant if the CCT is equal to or larger than 5000 K.

For the **TM-30-15** Method, the Reference source is:

- a Planckian radiator if the CCT is less than or equal to 4500 K;
- a proportional mix of a Planckian radiator and D-series illuminant if the CCT is larger than 4500 K and less than 5500 K. The proportion of the Planckian radiator goes from 100% at 4500 K to zero (0) at 5500 K;
- a D-series illuminant if the CCT is equal to or larger than 5500 K.

For the **TM-30-20** Method, the Reference source is:

- a Planckian radiator if the CCT is less than or equal to 4000 K;
- a proportional mix of a Planckian radiator and D-series illuminant if the CCT is larger than 4000 K and less than 5000 K. The proportion of the Planckian radiator goes from 100% at 4000 K to zero (0) at 5000 K;
- a D-series illuminant if the CCT is equal to or larger than 5000 K.

Once the Reference source is defined, the samples definition and how they are processed relative to this source is different with each metric.

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6.1.2 Color Rendering Index (CRI, CIE 13.3: 1995)

First published in 1965, with major updates in 1974 and 1995 (Ref. 33), the Color Rendering Index (CRI) measuring and computing method defines 14 reflectance color samples. Of these samples, only the first eight are used to compute the general index, called ***Ra*** and usually referred to as "the CRI". The individual indices of the 14 samples (***Ri***), called "special indices" are determined the same way:

- The (*u, v*) coordinates (CIE 1960 UCS) of the Reference and Test sources, as well as the (*u, v*) coordinates of each sample illuminated by the Reference and Test source are computed.
- Because the Test source usually has different (*u, v*) coordinates than the Reference source, even though they have the same CCT, the (*u, v*) coordinates of the samples illuminated by the Test source are converted (i.e. chromatically adapted) to the coordinates of the Reference source. This is done using a Von Kries chromatic adaptation procedure.
- The color difference between the samples is computed in the CIE 1964 (U*, V*, W*) color space. A simple scaling and offset is then applied to each color difference in order to get the individual indices. A zero color difference corresponds to an index of 100 and the index goes down as the color difference increases; however, for large color differences, the index can be negative and there is no specified lower limit.
- The **arithmetic mean** of the indices of the first 8 samples (*R1* to *R8*) is the general index (*Ra*).
- For additional information, the L*a*b* coordinates of the samples as perceived with the Reference and Test sources are also computed. The (*u, v*) coordinates are first converted to (*x, y*), then *XYZ*, and finally *L*a*b**, with the Reference source used as the White Point for all samples. In CT&A, this data is used in the CIELAB (*a*, b**) graph, to compute the display patches, and to compute the DeltaE*ab color differences shown below the patches.

While the indices of samples 9 to 14 are not taken into consideration when computing the general index, *R9* is a case in itself. Because it is a markedly more saturated red, it is not uncommon to get negative *R9* values which could seriously affect the general index if averaged with the differences of the first eight samples. Samples 10 to 12, although also more saturated, would similarly affect the average. The potential impact of *R9* on a global CRI index, and of the more saturated colors in general, was recognized early on and it was decided to base the CRI on the first eight samples, while keeping *R9* to *R14* as special indices only.

Of course, not all light sources are such that *R9* is dramatically bad, but since only *Ra* is typically provided by lamp manufacturers, it is easy to see how a lamp with an acceptable CRI can give poor results when illuminating a saturated red. This said, it is generally admitted that a "CRI" number alone is not enough to guarantee the quality of a light source and other measurements need to be done in parallel. This is why the Metamerism Index (MI) measurements described in ISO 23603/CIE S 012 was defined (see the ISO 3664+ tools section). By measuring both the CRI and the MI, one can get a very precise evaluation of a light source. Unfortunately, the MI is specifically targeted to the light sources used in the graphic arts field: D50, D55, D65, and D75. For other CCTs, one is left only with the CRI, yet, by also considering *R9* as an associated metric, as some lamp manufacturers are said to be contemplating, one could get a better fidelity metric, without the need to define a new standard.

Ever since the CRI computing method was adopted, there were proposals to improve it but none of them could be agreed upon as an international standard. It is interesting to note that the method is described in a **Technical Report** (CIE 13.3: 1995), and is not presented as a **Standard**, although it is used as such because it was at least agreed upon! With the advent of Solid-State Lighting (SSL), there was renewed interest in revamping the CRI and a new CIE Technical Committee (TC1-69) was formed in 2006. While the CRI was designed mostly for smooth and continuous light sources with the relatively small number phosphor peaks of standard fluorescent lamps, the essentially unlimited combinations of narrow bandwidths Light Emitting Diodes (LED) did not mesh well with the CRI method.

6.1.3 Color Quality Scale (CQS, NIST Version 9.0.3)

The CQS ***Qa*** (Ref. 46) and its additional color quality metrics, ***Qf*** and ***Qg***, were developed over many years by researchers of the USA National Institute of Standards and Technology (NIST). Many versions were devised and while work is ongoing, the spreadsheet of Version 9.0.3 is considered the latest "official" version. The following aspects were specifically developed to address CRI shortcomings:

- The metric is based on 15 saturated samples instead of 8 non-saturated samples of the standard CRI.
- Von Kries adaptation is replaced by the CMCCAT2000 chromatic adaptation model.
- Indices computation is performed in the CIE 1976 L*a*b* (i.e. CIELAB) color space.
- The individual indices and the global indices are scaled between 0 and 100.
- The **RMS average** of the 15 individual score is performed instead of the arithmetic mean. This minimizes the effect of extreme samples while still taking them into consideration. In addition, the individual CQS indices are scaled so that the average *Qa* of CIE sources F1 through F12 (CIE 15.2) is the same as that of CRI *Ra*.
- A slight chroma increase under the test source does not penalize the index since it was found that viewers will generally favor such an effect. Because chroma increase improves the computed index, *Qa* is sometimes labeled a "Color Preference" metric instead of a "Color Fidelity" one.

In addition, the two following parameters are defined:

- *Qf*: A Color Fidelity index, similar to *Qa*, but where the saturation factor is not applied.
- *Qg*: The ratio of the gamut area of the Test source samples relative to the area covered by the Reference source samples; the ratio is further normalized to 100. The areas are computed in the *a*b** plane of the L*a*b* color space, with the Test source coordinates adapted to the Reference source White Point; *Qg* values above and below 100 are thus possible. In general, a larger gamut is associated with better color discrimination.

In 2010, the CQS was almost voted by the TC1-69 CIE Technical Committee as the replacement standard for the CRI. In a dramatic finale, it was rejected and it was suggested that two metrics be recommended, in two new committees. These committees were formed in 2012:

- TC1-90 Colour Fidelity Index: *To evaluate available indices based on colour fidelity for assessing the colour quality of white-light sources with a goal of recommending a single* ***colour fidelity*** *index for industrial use.*
- TC1-91 New Methods for Evaluating the Colour Quality of White-Light Sources: *To evaluate available new methods for evaluating the colour quality of white-light sources with a goal of recommending methods for industrial use. (Methods based on colour fidelity shall not be included: see TC1-90.)*

The two committees were to write a report to propose the new metrics in 2015 but progress was slower than expected. The TC1-90 committee issued its report, CIE 224, in 2017. The *CIE 2017 Colour Fidelity Index* (***Rf***) is based on IES TM-30-15 to which a few changes were applied; these changes were simultaneously accepted by the group responsible for the TM-30 method and incorporated in the TM-30-18 version (now TM-30-20).

Note: According to a CIE Division 1 presentation, the *CIE 224:2017 Colour Fidelity Index* is **not** a replacement for the general color rendering index (***Ra*** of CIE 13.3:1995).

The TC1-91 committee is still working on the *Colour Quality* methods. However, do not expect a final answer on this subject since the committee will only evaluate various methods and will **not** provide a recommendation on which method to use.

6.1.4 CRI2012 (nCRI Version 12.0)

This CRI2012 index is known with various names, "***Ra,2012***", "*nCRI*", "*Ra12*", which also correspond to different versions of the algorithm. CRI2012 is an update to the metric previously known as "CRI-CAM02UCS" and it is proposed as a "Color Fidelity" index. The metric computed in CT&A corresponds to Ref. 47 and Version 12.0 of the spreadsheet used by the authors. Here are some of CRI2012 features:

- The metric is based on 17 mathematically defined samples. These samples exhibit smoothly varying spectrums while still representing saturated colors. The 17 samples are said to be representative of a larger set of 1000 samples which was obtained by stitching real spectrums in such a a way that, while appearing natural, the resulting colors uniformly cover L*a*b* space and the resulting spectrums do not statistically appear to come from a small mix of dyes.
- Von Kries adaptation is replaced by the CIECAT02 chromatic adaptation model.
- The color differences (DeltaE') are computed in the CAM02-UCS color space using the $J'a'_M b'_M$ coordinates.
- The **RMS average** of the 17 DeltaE' values is performed instead of the arithmetic mean. There is also a non-linear transformation between the averaged DeltaE' and the general color fidelity index (*Ra,2012*) as well as between each sample color difference and the corresponding specific color fidelity indices (***Ri,2012***). This transform is done with a sigmoid-type function which is said to better reflect human perceptual response, which tend to saturate at both extremes of an intensity range; the function output is scaled between 0 and 100. All indices are further scaled so that the average *Ra,2012* of CIE sources F1 through F12 (CIE 15.2) is the same as that of CRI *Ra*.

Note: One of the complaints against CRI2012 is that many samples cannot be accurately represented on most computer displays. In the CRI tool you may notice that some of the CRI2012 patches exhibit an exclamation point in the bottom-left corner. This is a flag to indicate that the patch color is outside of the display gamut, with at least one RGB coordinate clipped to zero or 255. The number of clipped colors will be less for displays which support larger gamut spaces, such as Adobe (1998) RGB. Of course, the computed values are not affected by the display gamut. Yet, a revised version of CRI2012 (referred to as CRI2014 in some texts) may use different samples for this reason.

6.1.5 TM-30-15 (IES, 2015)

The TM-30-15 method, "*IES Method for Evaluating Light Source Color Rendition*" (Ref. 54-55), was devised by an international team of experts in the lighting field, many of which were involved in developing the CQS and CRI2012 metrics. In developing the metric, they specifically addressed issues and shortcomings associated to previous work and retained many innovative concepts. Here are some of the design features:

- A Fidelity Index (***Rf***), which is similar in scaling to the current CIE CRI (*Ra*), but more robust in terms of sensitivity to test source variations.
- A Gamut Index (***Rg***), which is said to be an improved version of the Gamut Area Index (*GAI*).
- The Fidelity and Gamut indices are to be used in combination to better assess the overall rendition, as it was previously shown by combining "*GAI and Ra*".
- Use of 99 Color Evaluation Samples (**CES**) which, on average, cover the visible spectrum uniformly. This concept was introduced in CRI2012. The 99 CES were obtained from an original set of approximately 105,000 real spectral measurements which was first restricted to the gamut of the Natural Color System (NCS), which left about 65,000 samples. The 65,000 samples were then reduced to 99 by comparing them to a set of 4,900 NCS samples approximately uniformly distributed in the CAM02-UCS. The predictions of the 99 CES are typically within ±1 point for *Rf* and *Rg* when compared to the 4900 NCS samples.
- Use of high chroma samples, as proposed in the CQS and CRI2012 metrics, but not too high, so that the 99 CES fit within the Adobe (1998) RGB gamut, a now common extended gamut color space used in many higher-end monitors. This issue was particularly sensitive with the CRI2012 metric.
- For the Reference source, the transition between a Planckian radiator and a D-series illuminant is not abrupt, as it is in the CRI, CQS, and CRI2012. There is a **smooth transition between 4500 K and 5500 K** where we use a linear mix of a Planckian radiator and D-series illuminant. The proportion of the Planckian radiator goes from 100% at 4500 K to zero (0) at 5500 K; the proportion is reversed for the D-series illuminant.
- Computation based on the state-of-the-art uniform color space CAM02-UCS, as was done in CRI2012.
- Use of visualization tools to better evaluate color saturation and desaturation: the Color Vector Graphic and the similarly designed color distortion icon (originally proposed for the CQS).

Once we determine the CCT of the Test source and define the Reference source, we can compute the chromaticity coordinates ($J'a'_M b'_M$) of each CES with both the Test and Reference sources. From this point, the data is processed in two separate paths:

- We compute the color difference for each CES, which provides the Color Fidelity for each sample (*Rf,ces*), and the overall Fidelity Index (*Rf*). We also compute the average fidelity index for skin (*Rf,skin*), which is simply the average of the individual indices (*Rf,ces*) of samples CES15 and CES18.
- We group the samples in 16 bins covering 22.5 degrees each in the $a'_M b'_M$ chromaticity plane (herein called **Hue Angle Bins**) and we compute the average chromaticity for each bin. The average chromaticity data is processed to obtain:
    - The so called **"Local" data**: The color difference, Local Color Fidelity (*Rf,h*), Local Chroma Shift (*Rcs,h*), and Local Hue Shift (*Rhs,h*) for each Hue Angle Bin.
    - The **Gamut Area**: The areas enclosed by the average chromaticity coordinates of the Reference and Test sources represent their respective gamut. The area covered by the Reference source defines the 100% gamut reference; the ratio of the two areas gives us the Gamut Index (*Rg*).
    - The **Color Vector Graphic** (CVG): We normalize the Hue Angle Bin chromaticity coordinates of the Reference source so that they are represented by a perfect circle. The Hue Angle Bin coordinates of the Test source are then shown in relation with the reference circle; an increase in saturation (i.e. chroma) is shown as a point outside of the circle and a desaturation as a point within the circle. Any hue shift is immediately visible if the shift direction is not aligned to a radius of the reference circle.

We finally display the Fidelity Index (*Rf*) and the Gamut Index (*Rg*) on a graph of ***Rg* vs *Rf***.

Note: While the maximum value for *Rf* is the same as for the CIE CRI, with a value of 100 meaning that the Test source is equivalent to the Reference source, there is no official value assigned to a non-acceptable index. In the TM-30-15 interface, the value of "80" on the fidelity index axis is shown in bold simply as a reminder of the CIE CRI index threshold.

Note: The CRI2012, TM-30-15, TM-30-18, TM-30-20, and CIE 224 methods all use the CIECAT02 Chromatic Adaptation Transform (CAT). However, we have noticed that CRI2012 uses a "gamut-fixed" matrix (Ref. 56) while the others use the "standard" matrix. The differences between the results obtained with the two matrices are generally small, but we provide the option to select one or the other nonetheless. The option is set in the "Math" tab of the Preferences dialog (The CIECAT02 matrix is sometimes referred to as MCAT02).

Note: In CT&A, all data is processed at 5nm intervals between 380 nm and 730 nm while the CES spectral data is provided between 380 and 780 nm. Our tests done with the 300+ spectrums provided with the TM-30-15 documentation show that the effect of limiting the processing to 730 nm on the *Rf* and *Rg* indices is negligible.

Note: The CES are not distributed uniformly in each Hue Angle Bin and the number of samples per bin will vary with different test sources. The number of samples per bin is automatically provided in the report file whenever Hue Angle Bin data is selected for export (Hue Angle Bins data fields: *Rf,h*, *Rcs,h*, and *Rhs,h*).

Note: The ***Rg* vs *Rf*** graph has a dark grey zone in which you should never see a test point. The graph also has a light grey zone in which you may sometimes see a test point; if this happens, check this test source position relative to the Planckian locus since it may have a large *Duv* value.

Current recommendations for TM-30-15 data usage

There are no official thresholds or ranges associated with the various indices and characterization data derived with the TM-30-15 method. However, there are guidelines that were established from experimental data (Ref. 63-64) and which are summarized in the following table (see also CRI data ranges). The table also shows somewhat equivalent guidelines for the old CRI metric (CIE 13.3). Please note that such guidelines may vary with metric usage.

Fidelity	CRI (CIE 13.3)	TM-30-15
Best	N.A.	*Rf* ≥ 76 -1% ≤ *Rcs,h1* ≤ 9% *Rg* ≥ 100
Better	CRI ≥ 90 (*R9* ≥ 50)	*Rf* ≥ 76 -7% ≤ *Rcs,h1* ≤ 15% *Rg* ≥ 98
Good	CRI ≥ 80 (*R9* ≥ 0)	*Rf* ≥ 68 -12% ≤ *Rcs,h1* ≤ 18% *Rg* ≥ 88

These guidelines are not associated with a single parameter, *Rf* for instance, but consider a combination of parameters. For example, the "Best" fidelity criteria combines a Color Fidelity (*Rf*) of 76 or higher with a Chroma Shift of the first Hue Bin (*Rcs,h1*) between -1% and +9%, and a Gamut Index (*Rg*) of 100 or higher.

Note: The chroma shift of the first Hue Bin (*Rcs,h1*), corresponding to red patches, was selected in the guidelines because it *is the strongest single predictor of subjective evaluations* (Ref. 64), i.e. it correlates well with the overall visual assessment of the test subjects. It is interesting to note the similarity in the importance of Hue Bin #1 and patch *R9* of CIE 13.3, with the difference that this Hue Bin is always included when computing the overall fidelity whereas *R9* was often discarded.

Important: Be careful when comparing TM-30-15 results with those of TM-30-20 (or TM-30-18). While most numbers are the same, the *Rf* values of TM-30-15 are lower than the ones computed in TM-30-20. This is particularly important if you intend to use the guidelines of TM-30-20 Annex E for TM-30-15 data, an idea which we do not recommend.

6.1.6 TM-30-20 (ANSI/IES, 2020) / CIE 224:2017

The TM-30-20 standard, "*IES Method for Evaluating Light Source Color Rendition*" (Ref. 57), integrates Annex E and Annex F of TM-30-18 (Ref. 67-68) which were published separately after TM-30-18 was issued; it also has a new page layout. The computation methods and the technical content are the same in TM-30-20 and TM-30-18. TM-30-18, published in 2018, was a revision of the TM-30-15 method published in 2015; it was approved as an ANSI standard (as is TM-30-20). The TM-30 method was devised by an international team of experts in the lighting field, many of which were involved in developing the CQS and CRI2012 metrics. In developing the metric, they specifically addressed issues and shortcomings associated to previous work and retained many innovative concepts. Here are some of the design features:

- A Fidelity Index (***Rf***), which is similar in scaling to the current CIE CRI (*Ra*), but more robust in terms of sensitivity to test source variations.
- A Gamut Index (***Rg***), which is said to be an improved version of the Gamut Area Index (*GAI*).
- The Fidelity and Gamut indices are to be used in combination to better assess the overall rendition, as it was previously shown by combining "*GAI and Ra*".
- Use of 99 Color Evaluation Samples (**CES**) which, on average, cover the visible spectrum uniformly. This concept was introduced in CRI2012. The 99 CES were obtained from an original set of approximately 105,000 real spectral measurements which was first restricted to the gamut of the Natural Color System (NCS), which left about 65,000 samples. The 65,000 samples were then reduced to 99 by comparing them to a set of 4,900 NCS samples approximately uniformly distributed in the CAM02-UCS. The predictions of the 99 CES are typically within ±1 point for *Rf* and *Rg* when compared to the 4900 NCS samples.
- Use of high chroma samples, as proposed in the CQS and CRI2012 metrics, but not too high, so that the 99 CES fit within the Adobe (1998) RGB gamut, a now common extended gamut color space used in many higher-end monitors. This issue was particularly sensitive with the CRI2012 metric.
- For the Reference source, the transition between a Planckian radiator and a D-series illuminant is not abrupt, as it is in the CRI, CQS, and CRI2012. There is a **smooth transition between 4000 K and 5000 K** where we use a linear mix of a Planckian radiator and D-series illuminant. The proportion of the Planckian radiator goes from 100% at 4000 K to zero (0) at 5000 K; the proportion is reversed for the D-series illuminant.
- Computation based on the state-of-the-art uniform color space CAM02-UCS, as was done in CRI2012.
- Use of visualization tools to better evaluate color saturation and desaturation: the Color Vector Graphic and the similarly designed color distortion icon (originally proposed for the CQS).

Once we determine the CCT of the Test source and define the Reference source, we can compute the chromaticity coordinates ($J'a'_M b'_M$) of each CES with both the Test and Reference sources. From this point, the data is processed in two separate paths:

- We compute the color difference for each CES, which provides the Color Fidelity for each sample (*Rf,ces*), and the overall Fidelity Index (*Rf*). We also compute the average fidelity index for skin (*Rf,skin*), which is simply the average of the individual indices (*Rf,ces*) of samples CES15 and CES18.
- We group the samples in 16 bins covering 22.5 degrees each in the $a'_M b'_M$ chromaticity plane (herein called **Hue Angle Bins**) and we compute the average chromaticity for each bin. The average chromaticity data is processed to obtain:
  - The so called **"Local" data**: The color difference, Local Color Fidelity (*Rf,h*), Local Chroma Shift (*Rcs,h*), and Local Hue Shift (*Rhs,h*) for each Hue Angle Bin.
  - The **Gamut Area**: The areas enclosed by the average chromaticity coordinates of the Reference and Test sources represent their respective gamut. The area covered by the Reference source defines the 100% gamut reference; the ratio of the two areas gives us the Gamut Index (*Rg*).

- The **Color Vector Graphic** (CVG): We normalize the Hue Angle Bin chromaticity coordinates of the Reference source so that they are represented by a perfect circle. The Hue Angle Bin coordinates of the Test source are then shown in relation with the reference circle; an increase in saturation (i.e. chroma) is shown as a point outside of the circle and a desaturation as a point within the circle. Any hue shift is immediately visible if the shift direction is not aligned to a radius of the reference circle.

We finally display the Fidelity Index (*Rf*) and the Gamut Index (*Rg*) on a graph of ***Rg* vs *Rf***.

Note: While the maximum value for *Rf* is the same as for the CIE CRI, with a value of 100 meaning that the Test source is equivalent to the Reference source, the comparison stops here. The Illuminating Engineering Society (IES) has published guidelines, **TM-30-20 Annex E and F** (Ref. 57-67-68), to better relate the metric data with various color rendition intents, such as “Preference”, “Vividness”, and “Fidelity”. Table E2 from TM-30-20 Annex E is reproduced on the next page.

Note: The CRI2012, TM-30-15, TM-30-18, and CIE 224 methods all use the CIECAT02 Chromatic Adaptation Transform (CAT). However, we have noticed that CRI2012 uses a “gamut-fixed” matrix (Ref. 56) while the others use the “standard” matrix. The differences between the results obtained with the two matrices are generally small, but we provide the option to select one or the other nonetheless. The option is set in the "Math" tab of the Preferences dialog (The CIECAT02 matrix is sometimes referred to as MCAT02).

Note: In CT&A, all data is processed at 5nm intervals between 380 nm and 730 nm while the CES spectral data is provided between 380 and 780 nm. Our tests done with the 300+ spectrums provided with the TM-30-15 documentation show that the effect of limiting the processing to 730 nm on the *Rf* and *Rg* indices is negligible.

Note: The CES are not distributed uniformly in each Hue Angle Bin and the number of samples per bin will vary with different test sources. The number of samples per bin is automatically provided in the report file whenever Hue Angle Bin data is selected for export (Hue Angle Bins data fields: *Rf,h*, *Rcs,h*, and *Rhs,h*).

Note: The ***Rg* vs *Rf*** graph has a dark grey zone in which you should never see a test point. The graph also has a light grey zone in which you may sometimes see a test point; if this happens, check this test source position relative to the Planckian locus since it may have a large *Duv* value.

TM-30-20 vs TM-30-15

The three main differences between TM-30-20 and TM-30-15 are:

i- Some of the 99 Color Evaluation Samples (CES) are not defined outside of the 400 to 700 nm range. In TM-30-15 the data below and above this range was extrapolated using a derivative method. In TM-30-20, flat extrapolation using the 400 nm and 700 nm values is used. The effect on the computed indices is negligible.

ii- For the Reference source, the transition between a Planckian radiator and a D-series illuminant is now between 4000 K and 5000 K (instead of between 4500 K and 5500 K in TM-3015).

iii- The scaling factor used to compute the Color Fidelity (*Rf*) index is now 6.73 instead of 7.54. The overall effect is a noticeable increase in all Color Fidelity values (*Rf*, *Rf,skin*, *Rf,ces*, and *Rf,h*); there is no change to the Chroma Shift (*Rcs,h*) and Hue Shift (*Rhs,h*) values.

These changes were done to match the TM-30-20 Color Fidelity index (*Rf*) to the *CIE 224:2017 Colour Fidelity Index* (*Rf*) (Ref. 65) recommended by the CIE TC1-90 committee. Please note that CIE 224 is only concerned by *Rf* and not by the other indices derived in TM-30-20 (*Rg*, *Rf,skin*, *Rf,h*, *Rcs,h*, etc.).

Note: According to the CIE, the *CIE 224:2017 Colour Fidelity Index* is **not** a replacement for the general color rendering index (***Ra*** of CIE 13.3:1995) but only a step in its eventual replacement.

TM-30-20 also includes specifications on how the Color Vector Graphic (CVG) should be formatted in reports and proposes specific layouts for three report sizes. These reports can be generated using CT&A’s TM-30-20 report selector dialog.

Current recommendations for TM-30-20 data usage

The recommendations for specifying light source color rendition from TM-30-20 can be found in TM-30-20 Annex E (Ref. 57) of which **Table E2** is reproduced below. TM-30-20 Annex F provides additional background and evidence to support the recommendations. Reading of Annex E is strongly recommended for those who want to better understand the subtleties of color rendition analysis.

TM-30-20 Annex E – Table E-2 (used by permission)

		Design Intent (The desired effect of color rendition on the illuminated environment)		
Priority Level (The balance between allowing for tradeoffs and increasing the likelihood of meeting the design intent)		**Preference (P)**	**Vividness (V)**	**Fidelity (F)**
	1	**P1** $R_f \geq 78$ $R_g \geq 95$ $-1\% \leq R_{cs,h1} \leq 15\%$	**V1** $R_g \geq 118$ $R_{cs,h1} \geq 15\%$	**F1** $R_f \geq 95$
	2	**P2** $R_f \geq 75$ $R_g \geq 92$ $-7\% \leq R_{cs,h1} \leq 19\%$	**V2** $R_g \geq 110$ $R_{cs,h1} \geq 6\%$	**F2** $R_f \geq 90$ $R_{f,h1} \geq 90$
	3	**P3** $R_f \geq 70$ $R_g \geq 89$ $-12\% \leq R_{cs,h1} \leq 23\%$	**V3** $R_g \geq 100$ $R_{cs,h1} \geq 0\%$	**F3** $R_f \geq 85$ $R_{f,h1} \geq 85$

Table note: All criteria assume a polychromatic environment with average horizontal illuminance between 200 and 700 lux and uniform chromaticity.

The **Design Intents'** typical usage suggested in TM-30-20 Annex E are:

- **Preference (P)**: retail, office, hospitality, and residential lighting applications
- **Vividness (V)**: entertainment, display, and retail applications
- **Fidelity (F)**: manufacturing, medical, color matching, and color reproduction applications

Three **Priority Levels** are defined for each intent, with "**Level 1**" being the most stringent. Because of how the design constraints were defined and how the parameters are computed, it is not possible to find a light source which reaches a "Level 1" for all three intents. However, a **test** source which is **identical** to a **reference** source will exhibit a Level 1 for Preference (**P1**) and Fidelity (**F1**), and a Level 3 for Vividness (**V3**). These results are usually presented in the form "**P1 | V3 | F1**".

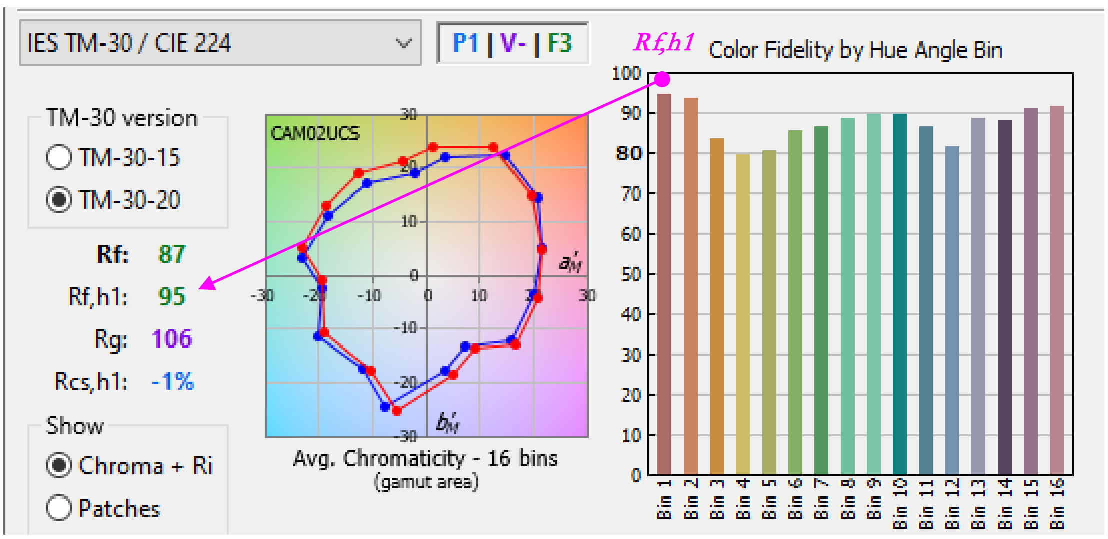
As we can see in the table, the guidelines are not associated with a single parameter, *Rf* for instance, but consider combinations of two or three of these parameters:

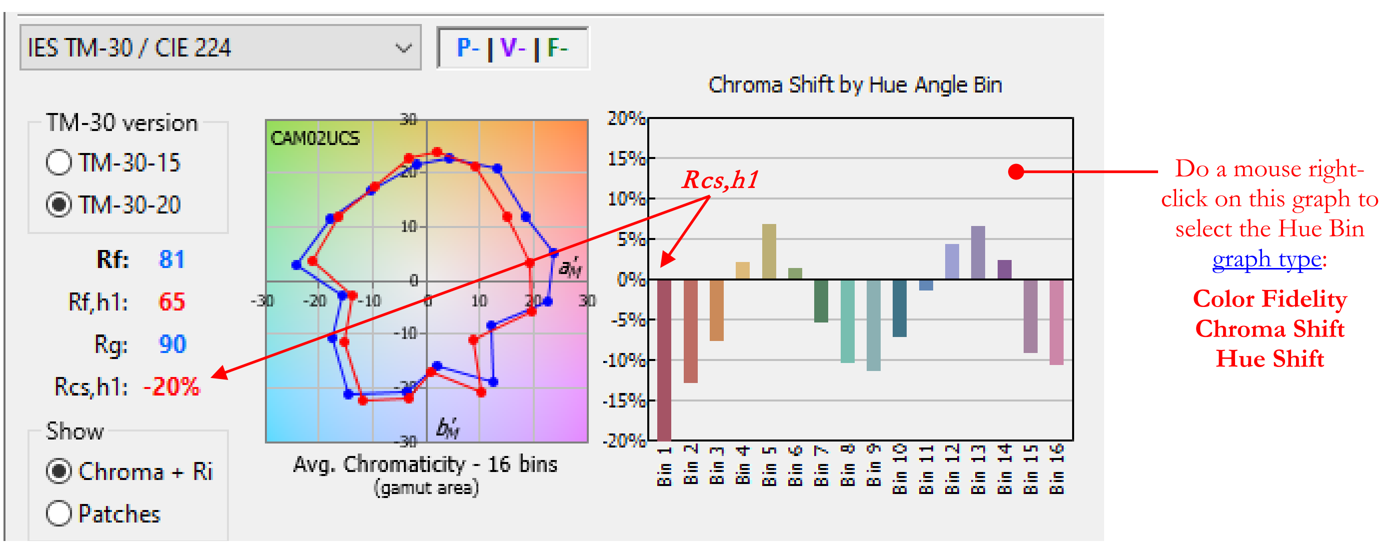
- the Fidelity Index (***Rf***);
- the Fidelity Index of the first hue bin (***Rf, h1***);
- the Gamut Index (***Rg***);
- the Chroma Shift of the first hue bin (***Rcs,h1***).

These parameters were selected because they have low correlation with each other and probe different aspects of color rendering quality (Ref. 64). In particular, red chroma which characterizes the patches of Hue Bins 1 and 16 (i.e. *h1* and *h16*), *is the strongest single predictor of subjective evaluations* i.e. it correlates well with the overall visual assessment of the test subjects. It is interesting to note the similarity in the importance of Hue Bin #1 and patch *R9* of CIE 13.3, with the difference that this Hue Bin is always included when computing the overall fidelity whereas *R9* was generally discarded.

Important: Be careful when comparing TM-30-20 results with those of TM-30-15. While most numbers are the same, the *Rf* values of TM-30-20 are higher than the ones computed in TM-30-15. This is particularly important if you intend to use the guidelines of TM-30-20 Annex E for TM-30-15 data, an idea which we do not recommend.

In the CRI tools window, the TM-30-20 Color Rendition Performance can be assessed with the values of the three parameters used for categorization analysis, ***Rf***, ***Rg***, and ***Rcs,h1*** and with the categorization results derived from these numbers. Two examples are shown below:





The categorization results are colored according to the colors used to illustrate the **Design Intent** of Table E2: **BLUE** for Preference, **VIOLET** for Vividness, and **GREEN** for Fidelity. A dash/hyphen (i.e. "-") is shown when the results are below **Level 3**. The four parameters used for analysis are also colored according to the Design Intent in which they are considered; when parameters are used in more than one intent, they are colored for the intent for which they achieve the highest score.

In the top example of the preceding page, both ***Rf*** and ***Rf,h1*** are green. ***Rf*** meets the **F3** level while ***Rf,h1*** exceeds the **F2** level (***Rf,h1*** is not used to define the F1 level). Overall, this sample meets the requirements of the **F3** level.

Please note that while a parameter may meet the requirements of one Design Intent level, this does not mean that the minimal level (i.e. 3) is achieved. For instance, in the top example, the gamut index (Rg=**106**) meets the **V3** level; however, ***Rcs,h1*** is just below the 0% requirement and the Vivid categorization is shown as" **V-**".

In the bottom example ***Rf*** exceed the **P1** level but does not meet the **F3** level; it is thus shown in **BLUE.** Rg meets the **P3** level but not the **P2** level. However, ***Rcs,h1*** is -20%, well below the **P3** level and is thus shown in **RED**. Overall, the minimum Preference level is not met and the Design Intent performance is shown as "**P-**".

6.1.7 Gamut Area Index (GAI)

This metric computation is based on the area encompassed by the CIE 1976 (*u', v'*) coordinates of eight color samples (Ref. 48); the samples are the same eight Munsell samples which provide the CRI *Ra*. The ***GAI*** is the ratio of the Test source area on the Reference source area, where the reference source is the equal energy stimulus (i.e. Illuminant E). *GAI* is normalized to 100, with 100 meaning that the test source matches the reference source; *GAI* values above and below 100 are possible. This index is generally used in conjunction with *Ra*. The metric authors consider that Test sources whose *Ra* and GAI are BOTH between 80 and 100 are to be favored in terms of color rendering properties.

In separate psychophysical analysis studies, Smet et al. (Ref. 49) have shown a good correlation of the number obtained by the arithmetic average of the *GAI* and *Ra* (= (*GAI* + *Ra*) / 2) is well correlated with the perception of "naturalness" (associated with Color Fidelity). This combined metric is identified as "***GAI and Ra***" in CT&A.

The GAI is very similar, in terms of computation method, to *Qg* of CQS. However, whereas the *GAI* reference area is a surface computed with Illuminant E, the reference area in *Qg* is computed with the Reference source White Point. This choice of the reference area has quite an effect on how these respective metrics are correlated with perceptual studies. While *GAI* is associated with "Color Discrimination", *Qg* is better associated with "Color Preference" (and "*GAI and Ra*" with naturalness/Color fidelity).

Note: It is shown in Ref. 51 that the CCT alone is moderately correlated with gamut size and Color Discrimination, with higher discrimination associated with higher CCTs. There is thus no surprise in *GAI* being well correlated with Color Discrimination since the GAI Reference area is associated to a fixed CCT and the Test area is associated with the measured CCT.

6.1.8 Memory Color Rendering Index (MCRI)

The MCRI (Ref. 50) is assessed by the general degree of similarity between the color appearance of a set of ten familiar objects under the Test source and the memory colors of those objects. The ten objects are:

- Apple
- Banana
- Orange
- Lavender
- Smurf
- Strawberry yoghurt
- Sliced cucumber
- Cauliflower
- Caucasian skin
- N4 Munsell grey

The individual indices (***Si***) describe the degree of similarity with each object's memory color. A general degree of similarity (***Sa***), is obtained with the **geometric mean** of the ten *Si* values. A *Sa* score of 1 means that the light source renders all familiar objects exactly as we expect them to look. *Sa* is then rescaled between 0 and 100 with a sigmoid function; the rescaled value is ***Rm***, the general memory quality index. Please note that, in practice, any *Sa* with a value of 0,5 or less is rescaled to *Rm*=0.

6.1.9 Conclusion

Selecting the best metric for a specific task is a difficult task, especially when the standardization bodies are hesitating. There were a lot of studies made to relate the various metric values to perceived color differences (see for ex. Ref. 49 and 51; and please note that these two studies were made before the TM-3015 Method was developed). With many tens of metrics developed over the years, they can be grouped into categories. Houser et al. (Ref. 51) have identified application clusters; these clusters are:

- Fidelity based measures: CRI (*Ra*, *R9*); CQS (*Qa*, *Qf*), nCRI Version 9 (*Ra12*)
- Preference based measures: CQS (*Qg*); MCRI (*Rm*)
- Discrimination (gamut based) measures: *GAI*

In the cluster list above, except for *Ra12* which is an older version of *Ra,2012*, we have indicated only the metrics which are computed in CT&A. In their analysis, the authors show that *Qg* is better correlated than *Qa* and *Qf* for discrimination, but not as good as *GAI*, yet they have found that *Qg* is more closely associated to the metrics of the "Preference" cluster than to the ones of the "Discrimination" cluster. They also suggest simultaneously using two metrics, such as *Qa* and *Qg*, which are computed using the same samples, for more accurate predictions; the reader should consult Ref. 51 for a complete analysis. In another study, Smet et al. (Ref. 49, Table 2) have categorized 13 metrics in two categories. Here is how the metrics supported by CT&A are categorized:

- Naturalness: CRI (*Ra*), CQS (*Qa*, *Qf*); "*GAI and Ra*"
- Preference / Attractiveness: *GAI*, MCRI (*Sa*)

You will note that *Ra*, *Qa* and *Qf* are considered better for Fidelity measurements in one study and better for Naturalness measurements in the other. There is no issue here, the terms “Fidelity”, “Quality” and “Naturalness” are often used interchangeably when categorizing illumination.

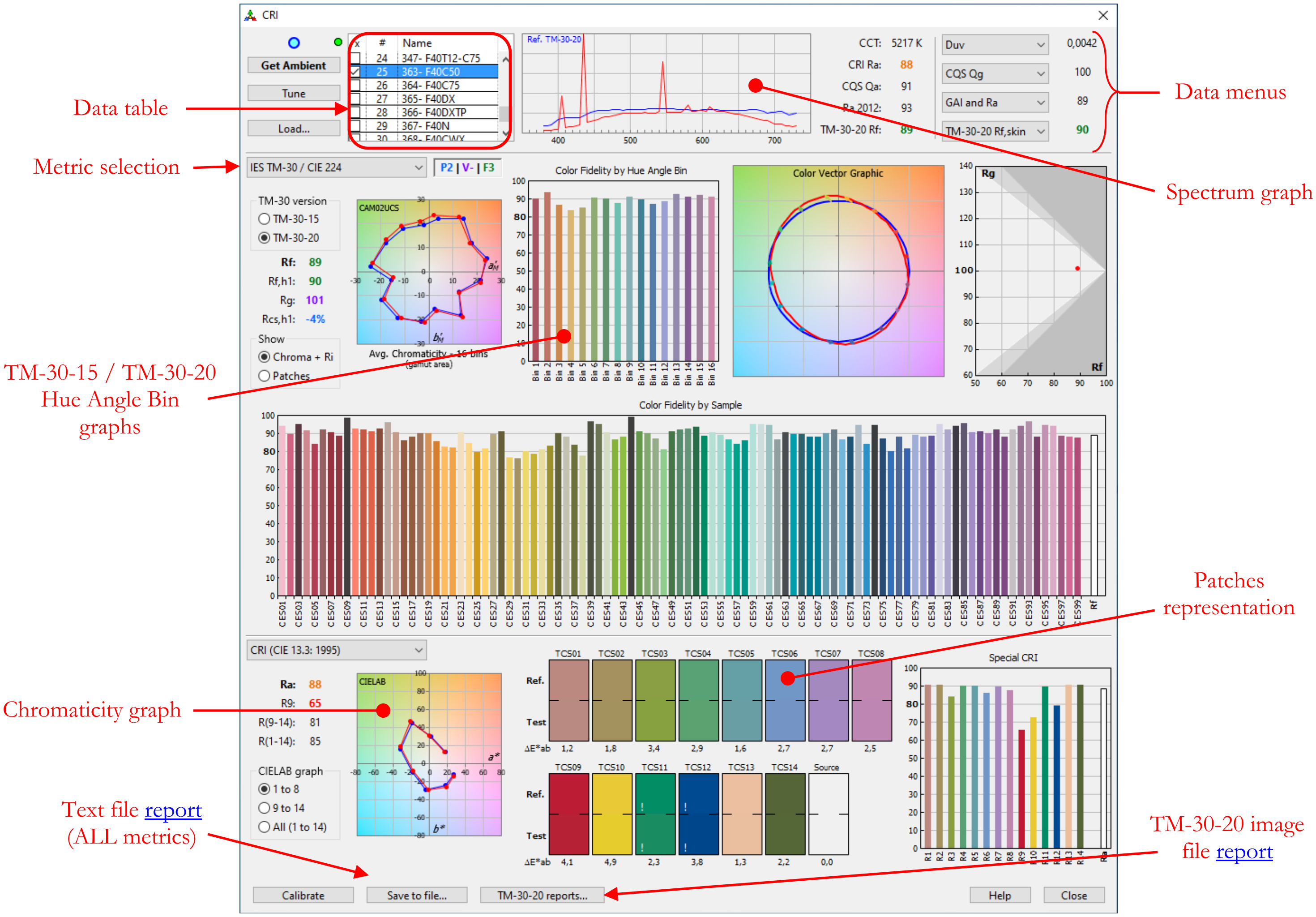
So with all these possibilities you may not be at ease to make a choice. Of course it depends on your design intent; the illumination requirements for a press room are not the same as those for a candy store. One thing is sure; we do not recommend using *Ra* alone for “Fidelity” assessment! You should as a minimum also consider *R9* in combination with *Ra* but you may find that very few light sources will qualify. This is where a modern multi-metrics method such as TM-30-20 can be helpful.

Preliminary experiments with TM-30-15 and TM-30-18 (Ref. 64) had shown that simultaneously taking into consideration *Rf*, *Rg*, and the Chroma Shift of the first Hue Bin (*Rcs,h1*) could provide a good match to subjective qualities of the sources such as “Preference” and “Naturalness.” Additional experiments with TM-30-18 have been compiled since and used to define guidelines for the “Preference” “Vividness” and “Fidelity” intents. These guidelines were published as **TM-30-18 Annex E** and additional background and evidence to support the recommendations were published in **TM-30-18 Annex F** (Ref. 67-68); these annexes are now integrated in the TM-30-20 main document (Ref. 57). The guidelines are summarized in the TM-30-20 description section.

The CRI data ranges section presents the nominal ranges for the CRI tools metrics (except TM-30-20 numbers which can be found here), the *CCT/Duv* acceptability ranges, and some results obtained with standard CIE illuminants.

The metrics selected in CT&A’s CRI tools hopefully provide an overview of the current state of knowledge. Time will tell if TM-30-20 will replace the old CRI, i.e. CIE 13.3:1995, or if this is yet another step towards this goal. Nonetheless, the newer metrics are backed with significant validation experiments which, at the very least, show that we cannot go back to a single-number-fits-all metric to describe the rendering quality of a light source.

6.2 CRI tools interface

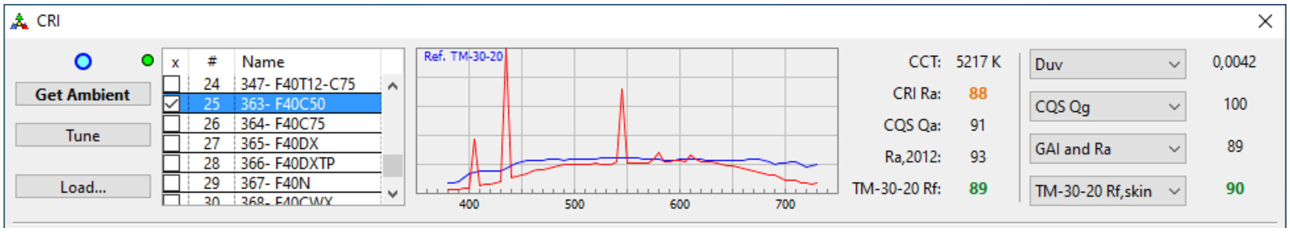


Click on a link in the Table of Contents below to jump to a specific sub-section.

CRI tools interface - Table of Contents

6.2.1 Data input and results overview

The top part of the CRI tools window is dedicated to Test source input and Test source characteristics. It also shows a snapshot of the results obtained with the various metrics. You will see a large blue indicator over the "Get Ambient" button if a compatible instrument is connected and recognized by the program, and if the CRI window is selected (i.e. on top of your display). To make a measurement, either click on the "Get Ambient" button or on the instrument button.



In the screenshot above we see that measurement #26 is selected in the table. Some of the metrics results are shown in black while others are shown in red or orange. You will find a description of all the supported metrics in the CRI tools description section; the expected ranges for each metric are discussed in the CRI metrics and Duv ranges section.

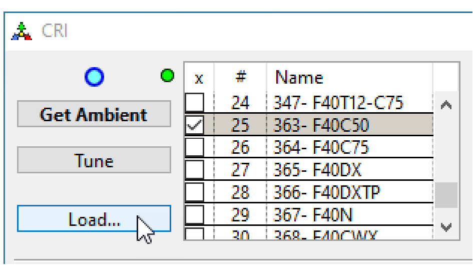
The instrument should be calibrated before making any measurements. Click on the "Calibrate" button of the CRI window and follow the indications to perform an "Ambient" mode calibration. You will be prompted to perform the calibration if you attempt to make a measurement without prior calibration.

Note: While the CRI tools accept 5 nm bandwidth data files (see CRI input files requirements) which are processed with a 5 nm workflow, 10 nm input data from measurements or from files are also processed internally with a 5 nm workflow. 10 nm data is interpolated to 5 nm with the user-selected spectral interpolation method (cubic spline / Lagrange).

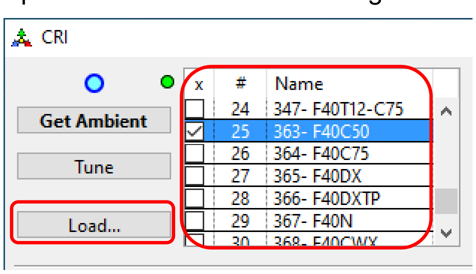
6.2.2 Input from a file

At any time, you can use a data file as input in place of a measurement; a connected instrument is NOT required for file input. A file may contain one or more spectrums; the file requirements are described in the CRI input files requirements section. There are two methods to open/load a file:

- 1st method: Click on the "**Load...**" button and select the file to open with the file input dialog.



- 2nd method: Drag-and-drop the file to open on the "**Load...**" button OR on the **table** located beside the input buttons. You can also drag-and-drop multiple files at a time.



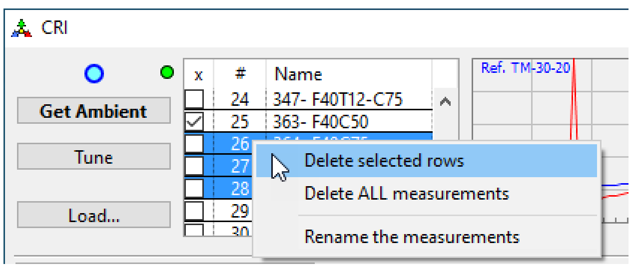
6.2.3 Data table

The measurements and inputted files appear in the data table in the order they were entered. A name will be automatically assigned for instrument measurements. For files, the file name will be used as "Name" if there is only one spectrum in the file; for files with multiple spectrums, the spectrum name will be used for each entry, if the “Name” tag is present. You can always edit the name once assigned but please note that this name may be used as a file name when exporting the data, so you will note that characters used for file paths in various Operating Systems will be rejected when entered.

When the table contains multiple measurements, select the measurement for which you want to see the processed data by clicking in one of the first two columns of the selected measurement/row. You can navigate in the measurement table with the UP and DOWN arrow keys.

To edit a measurement name, first click on the "Name" column; this will select the current name. You can use the LEFT and RIGHT arrow keys to position the cursor or the UP and DOWN arrow keys to edit the previous or next measurement name.

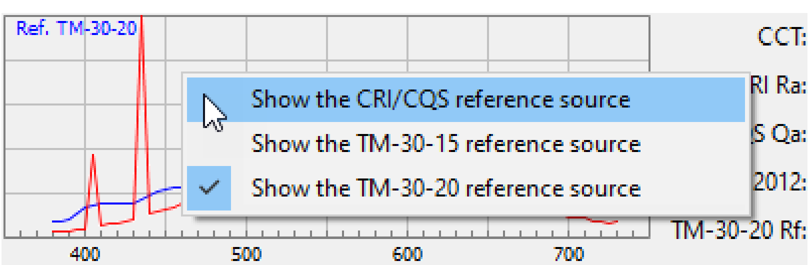
In Windows, you can select any number of measurements using the "Ctrl" and "Shift" keys in association with a mouse click; on a Mac, use the "Option" and "Shift" keys instead. Even if multiple measurements are selected, only the one with a check mark in the first column will be used for display. The selected measurements can be deleted using the menu which appears when you do a right-click on the table.



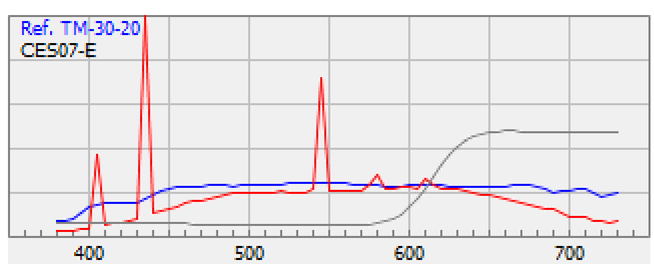
Being able to select specific measurements is also useful when you want to export only some of the current measurements.

6.2.4 Spectrum graph

The spectrum graph shows the Reference source spectrum in **BLUE** and the Test source spectrum in **RED**; the two spectrums are at the **same scale** and are normalized to a single maximum value determined from both spectrums. The Reference source can be a blackbody, a D-series illuminant, or a mix of a blackbody and D-series illuminant depending on the CCT and the metric. The TM-30-15 metric will use a mixed reference for a CCT between 4500 K and 5500 K while the TM-30-20 will use a mixed reference for a CCT between 4000 K and 5000 K. You can switch the displayed Reference with a menu which opens with a right-click over the graph.

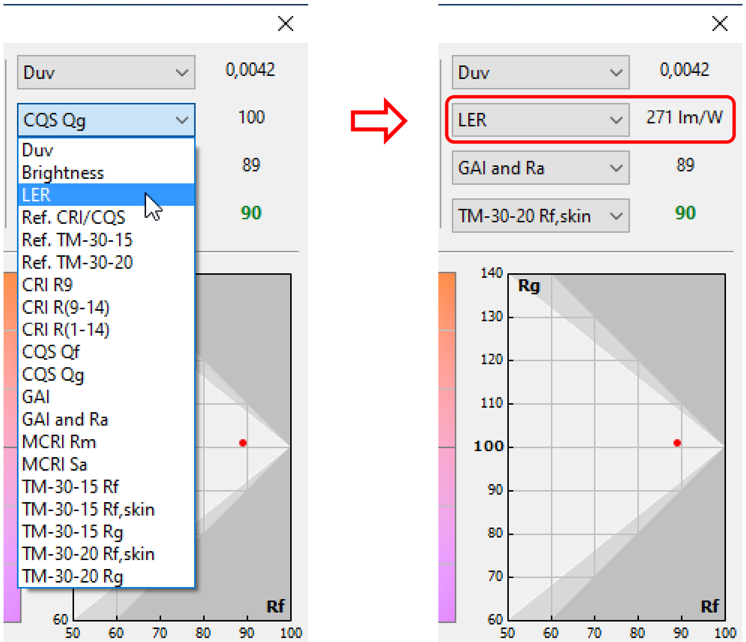


If there is at least one measurement, clicking on any [sample patch](#) used by a metric will display this sample spectrum in addition to the Reference and Test source. The sample spectrum is scaled so that the full height of the graph corresponds to 100% reflection. The screenshot on the right shows the CES07-E patch of the TM-30-20 metric, in black, superimposed on the Reference and Test sources spectrums.



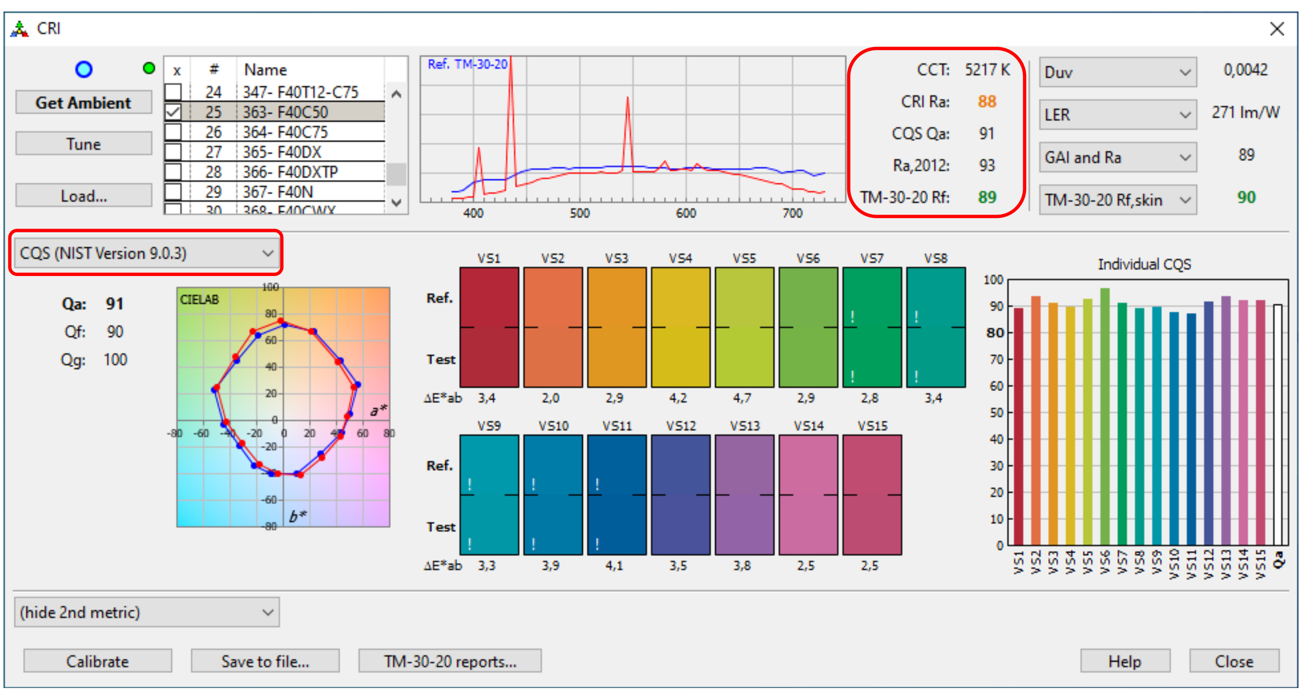
6.2.5 Data menus

On the top-right of the window, you will find four identical popup menus which you can use to customize the displayed data.



6.2.6 Metric selection

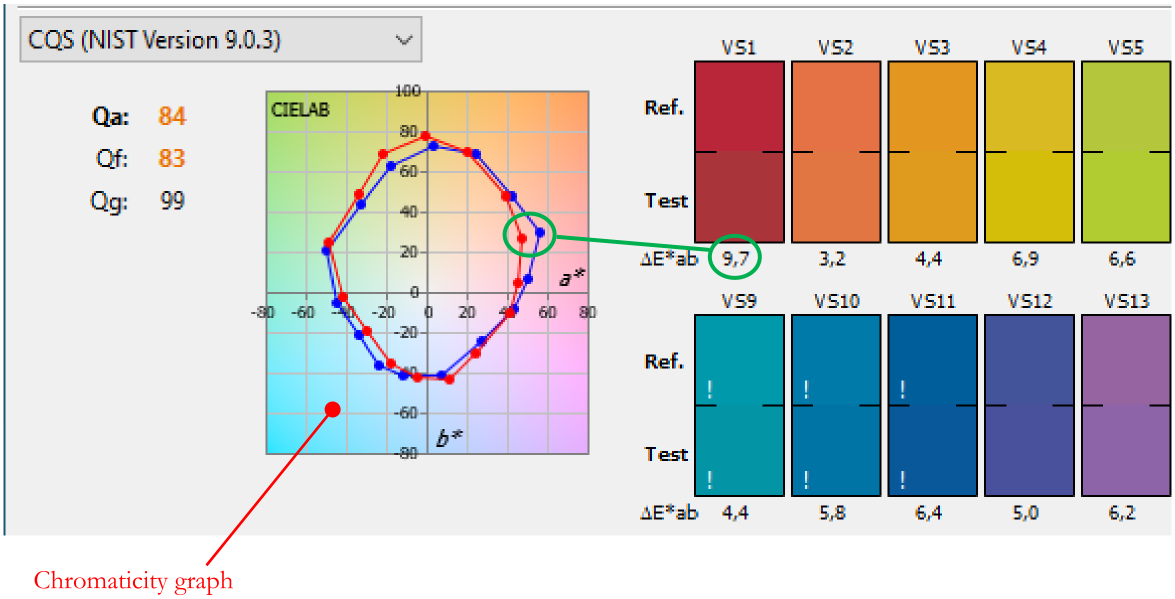
You can simultaneously display the graphs and patches for one or two of the following metrics: CRI, CQS, CRI2012, and TM-30-15 or TM-30-20. The screenshot below shows the CRI tools window with only the CQS (NIST Version 9.0.3) metric selected. The hidden metrics data is always computed and their principal indices are always shown on the top portion of the window (i.e. *Ra*, *Qa*, *Ra,2012*, TM-30-20 *Rf*).



Note: Only the standard CRI data (CIE 13.3: 1995) is shown when the program is not activated.

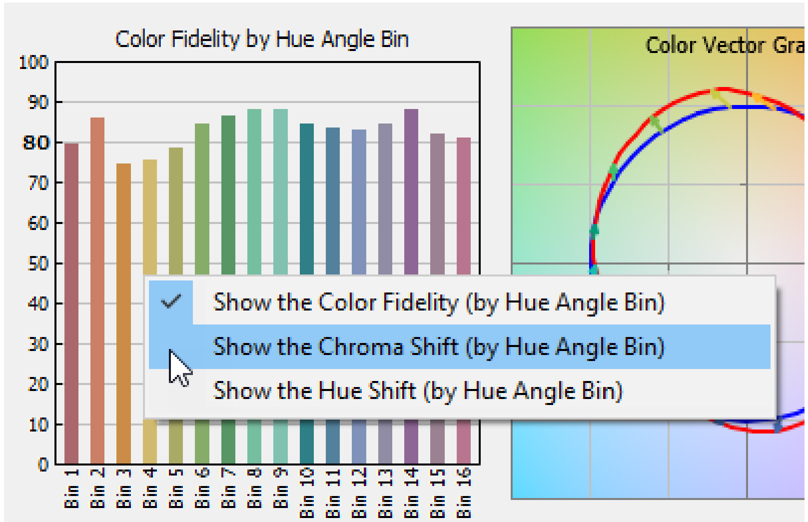
6.2.7 Chromaticity graphs

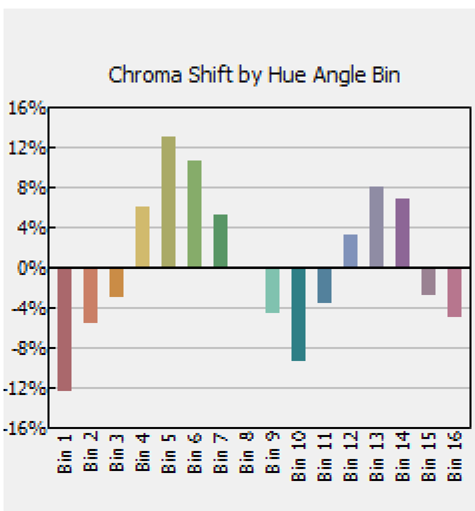
The CIELAB and CAM02UCS chromaticity graphs show the coordinates of the samples as processed by the Reference (in **BLUE**) and Test sources (in **RED**), but with the coordinates of the Test source adapted to the White Point of the Reference. The color difference between each sample coordinates are shown below the patches representing the samples.

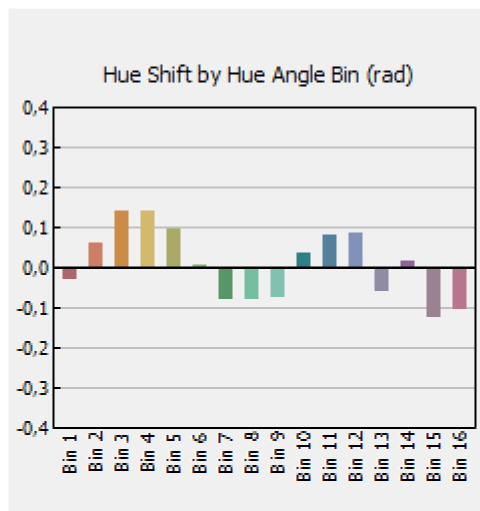


6.2.8 TM-30-15 / TM-30-20 Hue Angle Bin graphs

The 99 Color Evaluation Samples (CES) of the TM-30-15 and TM-30-20 metrics are grouped in 16 bins covering 22.5 degrees each in the $a'_M b'_M$ chromaticity plane. The average value in each bin is used to compute the "Local Color Fidelity", i.e. the color fidelity of a Hue Bin, as well as the "Local Chroma Shift", and "Local Hue Shift". You can switch between the graph for each of these computed values with a mouse right-click on top of the graph. For the Chroma Shift and Hue Shift there is also a sub-menu to set the graph scale.







All three graphs are include in the TM-30-20 "Full" report while only the Chroma Shift and Hue Shift graphs are included in the TM-30-20 "Intermediate" report.

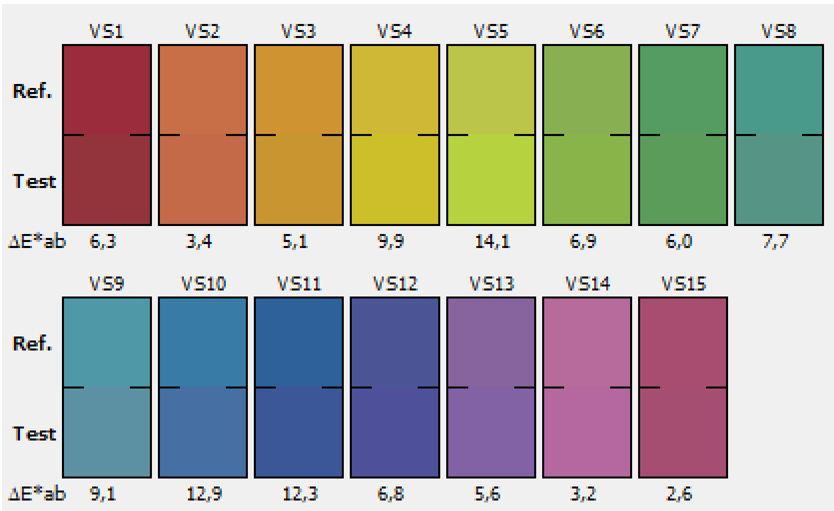
Note: The CES are not distributed uniformly in each Hue Angle Bin and the number of samples per bin will vary with different test sources. The number of samples per bin is automatically provided in the report file whenever Hue Angle Bin data is selected for export (Hue Angle Bins data fields: *Rf,h*, *Rcs,h*, and *Rhs,h*).

Note: According to current research (Ref. 63-64-67-68), the Color Fidelity (*Rf,h1*) and Chroma Shift (*Rcs,h1*) of the first Hue Bin, is of particular importance when assessing the fidelity of a light source. The first Hue Bin (*h1*, identified as "Bin 1" in the screenshots) represents the average of samples in the red part of the spectrum.

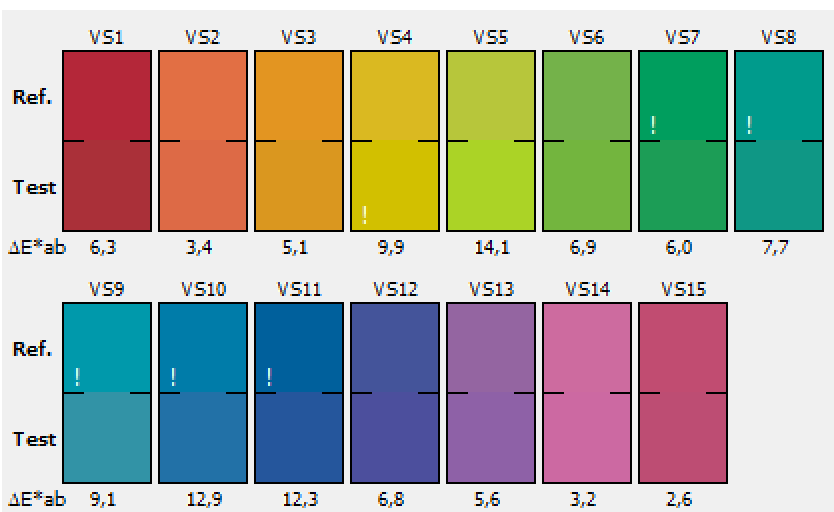
6.2.9 Patches representation

Since the samples colors may not be within the gamut of your display, clipped colors are flagged with an exclamation mark within the patch area. The two screenshots below show the patches used by the CQS metric. The top screenshot was obtained with a display profiled to a space very close in characteristics to the "Adobe (1998) RGB" space profile; there is no exclamation mark in the patches and one would assume that they are accurately displayed.

The second screenshot was obtained with a display which was assigned the sRGB profile (using the OS control panel). We see that five reference patches and one test patch are clipped. Please note that while the clipped colors may not be visibly accurate, all computed values remain accurate.



No patch color is clipped by the display.



The color of patches with an exclamation point (!) is clipped by the display.

6.3 CRI input files requirements

The CRI tools can accept input from a file even if there is no connected instrument. This file **MUST** contain spectral data. This file may come from an ambient measurement made in the Graph, ISO3664+, or MI tools, or from another application. Acceptable file formats are **CGATS** or **plain text**, with the following requirements.

Requirements for spectrum files in CGATS format:

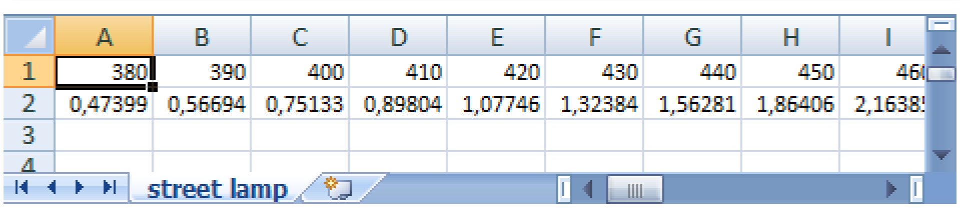
- The file may contain **one** or **more** spectrums.
- The file **MUST** conform to the "CGATS.17" format standard. As examples, you can use one of the files that you will find in the "Illuminants" folder located within the CT&A application folder.
- The illuminant name **MUST** be specified as either "Emission" or "Unknown." It **MUST NOT** be specified as "D50" or any other standard illuminant used to process reflection measurements.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **5 nm OR 10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength tags **MUST** be in one of the following formats: "nm450", "SPECTRAL_NM450", SPECTRAL_NM_450, or "SPECTRAL_450".
- The decimal separator for data can be a period (.) or a comma (,).
- The data delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all the data in the file.

Requirements for spectrum files in plain text format:

- The file may contain **one** or **more** spectrums.
- The first line **MUST** contain wavelength labels/tags.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **5 nm OR 10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength labels/tags may be simple numbers or contain other letters, such as "nm380", "380_nm", or "380NM", but no spaces.
- The first line may contain other tags such as "ID" or "Name". Tags **MUST NOT** contain spaces. These tags may be written in uppercase or lowercase. If additional tags are used in the first line, you **MUST** fill the second line with the corresponding information or number, with no spaces in the tag content.
- The second line **MUST** contain the spectral values (and the content of the additional tags if used) for the first sample. Data for other samples may be added on the following lines, one line per sample.
- The decimal separator for data can be a period (.) or a comma (,).
- The wavelength labels and the spectral values **MUST** be separated by data delimiters. The delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all lines.

A plain text file can easily be created with a word processor or a spreadsheet application, as shown below. When saving the file, do not use the often complex native application file formats (for ex.: *.xls); instead, select a tab-delimited or Comma-Separated-Value (CSV) **text** format.

```
380, 390, 400, 410, 420, 430, 440, 450, 460, 470, 480, 490, 500, 51
0.47399, 0.56694, 0.75133, 0.89804, 1.07746, 1.32384, 1.56281, 1.86
```



Note: You will find separate 5 nm and 10 nm data files for several CIE illuminants in the "Illuminants" folder located within the CT&A application folder. You can use these files as templates for your own CGATS file.

Important: Measurements performed with the CRI tools can be exported in separate files with a single spectrum per file or in a single file report containing many spectrums. If you intend to reopen an exported file in the CRI tool, we strongly suggest that you select the "CGATS" "File type" option in the CRI file options dialog since "Plain text" files will also contain extra information that will make the file unreadable by the CRI tool. Nonetheless, if required, files exported in "Plain text" format can easily be edited with a simple text editor to comply with the requirements detailed above.

Hint: If you are not sure of your file format, simply load it and export it under another name; then compare the original file with the exported file to see if the data is the same.

6.4 CRI data ranges

This section presents the nominal ranges for the CRI tools metrics and for *CCT/Duv* as well as some results obtained with standard CIE illuminants. In the CRI tools window, the numerical values of the various metrics are color coded in respect to the goals described below. The metrics are shown in **BLACK** if the goal is met and in **ORANGE** or **RED** if the goal is not met.

Note: The TM-30-20 metrics data ranges and color codes are presented in the TM-30-20 tool description section.

The CRI computing method (CIE 13.3: 1995) does not mention specific goals for a test source. It only mentions that the CRI was scaled so that a standard warm white fluorescent lamp (of the 1990s!) had a **General Colour Rendering Index** (*Ra*) of about 50. However, the ISO 3664:2009 standard (Ref. 32) recommends a goal of **90+** for *Ra* and a goal of **80+** for the separate **Special Colour Rendering Indices** (*Ri*).

While the authors of the CQS and CRI2012 metrics do not mention specific goals, they scaled their computation so that the average *Qa* and *Ra,2012* would be 50 for the twelve standard fluorescent lamps (FL1 to FL12; data files are provided in the "Illuminants" folder located within the CT&A application folder), therefore matching the average *Ra* for the same lamps. We thus extended the ISO 3664 goals for *Ra* to *Qa* and *Ra,2012*, and *Ri* to *Qi* and *Ri,2012*.

There is no generally approved goals associated with the TM-30-15 Method. You will find guidelines for Fidelity Index (*Rf*) and Gamut Index (*Rg*) ranges in slides from various seminars (see Ref. 63-64 for examples) but you should be aware that they have a tendency to change slightly because of ongoing experimentation and specific design intent. CT&A will highlight *Rf*, and *Rf,skin* if they are less than 76; *Rg* will be highlighted if less than 98 and more than 110.

The authors of the GAI metric (Ref. 48) mention that "a minimum CRI (i.e. *Ra*) of 80 and a GAI between 80 and 100 will provide good color discrimination and make objects in the scene appear both "vivid" and "natural," given sufficient illuminance is provided...". In CT&A, the goals of "*GAI and Ra*," a metric proposed by Smet et al. (Ref. 49), are borrowed from those of the *GAI* metric.

The authors of the MCRI metrics (Ref. 50) have shown a high correlation between *Ra* and *Rm*. They have scaled *Rm* so that CIE illuminant FL4 and D65 have values of 50 and 90 respectively but they do not recommend formal goals. We will nonetheless highlight *Rm* if its value goes below 80, by analogy with the CRI *Ri* goal of ISO 3664; we will also highlight the corresponding *Sa* value (*Rm* is a rescale of *Sa*) when *Sa* is less than 0.7268.

Metric		Min.	Max.	Goal	Off-goal colors
CRI	*Ra*	-X (Note 1)	100	90+	**< 90 : ORANGE** **< 80 : RED**
	Ri, R9	-X (Note 1)	100	80+	**< 80 : RED**
	R(9-14), R(1-14)	-X (Note 1)	100	80+	**< 80 : RED**
CQS	*Qa, Qf*	0	100	90+ (Note 2)	**< 90 : ORANGE** **< 80 : RED**
	Qi	0	100	80+ (Note 3)	**< 80 : RED**
	Qg	0	100+	80+ (Note 4)	**< 80 : RED**
CRI2012	*Ra,2012*	0	100	90+ (Note 2)	**< 90 : ORANGE** **< 80 : RED**
	Ri,2012	0	100	80+ (Note 3)	**< 80 : RED**
TM-30-15	*Rf, Rf,skin, Rf,ces, Rf,h*	0	100	76+ (Note 5)	**< 76 : ORANGE** **< 68 : RED**
	Rg	0	200	98 to 110 (Note 5)	**< 98 or > 110 : ORANGE** **< 88 : RED**
	$R_{CS,h1}$ (Notes 5-6)	-1% ≤ $R_{CS,h1}$ ≤ 9% (Best) -7% ≤ $R_{CS,h1}$ ≤ 15% (Better) -12% ≤ $R_{CS,h1}$ ≤ 18% (Good)		0%	
TM-30-20	*Rf, Rf,skin, Rf,ces, Rf,h*	0	100	(Note 8)	(Note 8)
	Rg	0	200		
	$R_{f,h1}$ (Note 7)	0	100		
	$R_{CS,h1}$ (Note 6)	(Note 8)			
GAI	*GAI*	0	100+	80 to 100	**< 80 or > 100 : ORANGE** **< 10 or > 130 : RED**
	GAI and Ra	-X (Note 9)	100+	80 to 100	
MCRI	*Rm*	0	100	80+ (Note 3)	**< 80 : RED**
	Sa	0	1	0.7268+ (Note 10)	**< 0.7268 : RED**

Note 1: Negative limit not specified in CIE 13.3: 1995.
Note 2: By analogy with the CRI *Ra* goal.
Note 3: By analogy with the CRI *Ri* goal.
Note 4: A maximum goal threshold is not considered but very large *Qg* may not be advantageous.
Note 5: Adapted from Ref. 63-64.and subject to change because of ongoing experimentation.
See also the TM-30-15 data usage recommendations.
Note 6: $R_{CS,h1}$: Chroma Shift of the first hue bin (i.e. red).
Note 7: $R_{f,h1}$: Color Fidelity of the first hue bin (i.e. red).
Note 8: See the TM-30-20 data usage section for data ranges and color codes.
Note 9: Small probability that it could be negative if *Ra* is negative.
Note 10: This goal corresponds to *Rm*=80+.

Note: Numerical values for *Ri*, *Qi*, *Ri,2012*, *Rf,ces* and *Rf,h* are not shown in the CRI window. However, the bar graphs with the individual indices show "**80**" in bold in their vertical scale, corresponding to the "Goals" in the table above.

CCT/*Duv* acceptability ranges

The Correlated Color Temperature (CCT) of a Test source is the temperature of a blackbody, in kelvin, whose chromaticity is the nearest to the chromaticity of the Test source (Ref. 52). Blackbodies of varying temperatures define a curved line on the chromaticity diagram; this line is called the "Planckian locus." In CT&A, the acceptable range for the CCT of Test sources extends between 1000 K and 100,000 K. Test sources with a CCT lower than 1000 K are shown as **OOR-** (Out-Of-Range Minus) and Test sources with a CCT higher than 100,000 K are shown as **OOR+** (Out-Of-Range Plus).

Duv is the distance in the CIE1960 (*u, v*) chromaticity plane between the coordinates of the Test source and the coordinates of the Planckian radiator. The CRI method (CIE 13.3: 1995) mentions that if the chromaticity difference is greater than ±0.0054 "...the resulting Colour Rendering Indices may be expected to become less accurate." This threshold is thus used abundantly in all test procedures designed to verify lamp conformance.

In the CRI tools, any *Duv* larger than ±0.0054 will be shown in **ORANGE**. Also, any *Duv* larger than ±0.05, or about ten times the acceptable threshold, will be shown as **OOR** (Out-Of-Range).

Note: A maximum *Duv* of ±0.006 is specified in ANSI C78.377-2008 (Ref. 53). However, it is important to note that in ANSI C78.377-2008, for CCTs of 4000 K and higher, the center of the *Duv* tolerance is not on the Planckian locus. This is simply because the locus of the D-series illuminants has a slight offset relative to the Planckian locus.

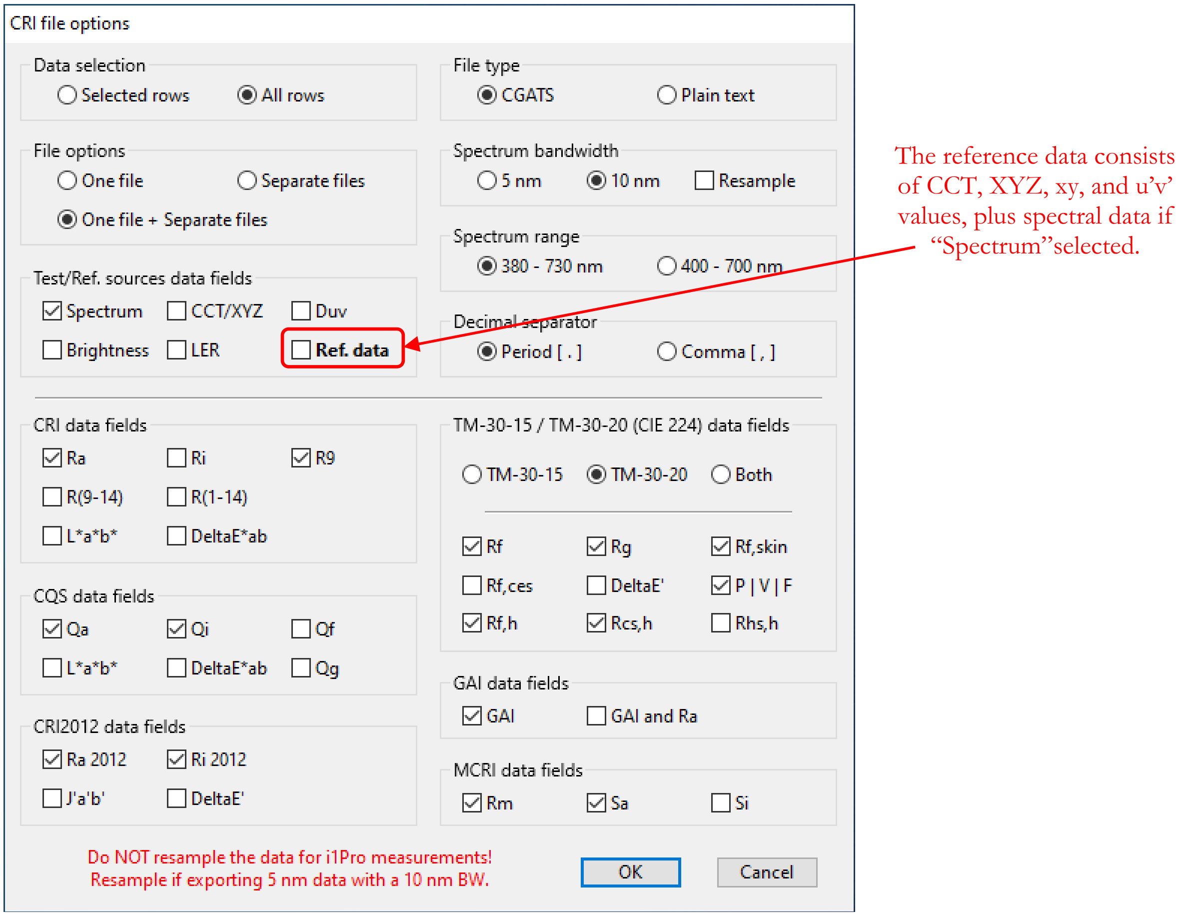
Examples

Here are some results obtained with standard CIE illuminants. Files for these illuminants can be found in the "Illuminants" folder (5nm-BW) located within the CT&A application folder.

			CRI		CQS			CRI2012	TM-30-15		TM-30-20	
Illuminant	**CCT**	***Duv***	***Ra***	***R9***	***Qa***	***Qf***	***Qg***	***Ra,2012***	***Rf***	***Rg***	***Rf***	***Rg***
CIE 15-A	2857	0	100	100	100	100	100	100	100	100	**100**	**100**
CIE 15-FL4	2938	-0.0008	**51**	**-111**	**53**	**54**	**79**	**51**	**52**	**84**	**57**	**84**
CIE 15-D50	5003	0.0032	100	100	100	100	100	100	98	99	**100**	**100**
CIE 15-E	5457	-0.0044	95	82	97	95	104	97	94	104	**95**	**104**
CIE 15-D65	6505	0.0032	100	100	100	100	100	100	100	100	**100**	**100**

			GAI		MCRI	
Illuminant	**CCT**	***Duv***	***GAI***	***GAI and Ra***	***Rm***	***Sa***
CIE 15-A	2857	0	**53**	**77**	90	0.763
CIE 15-FL4	2938	-0.0008	**45**	**48**	**50**	**0.664**
CIE 15-D50	5003	0.0032	88	94	90	0.767
CIE 15-E	5457	-0.0044	100	98	92	0.775
CIE 15-D65	6505	0.0032	98	99	90	0.765

6.5 CRI file export options



The **CRI file options** dialog is opened by clicking on the "Save to file..." button of the CRI window.

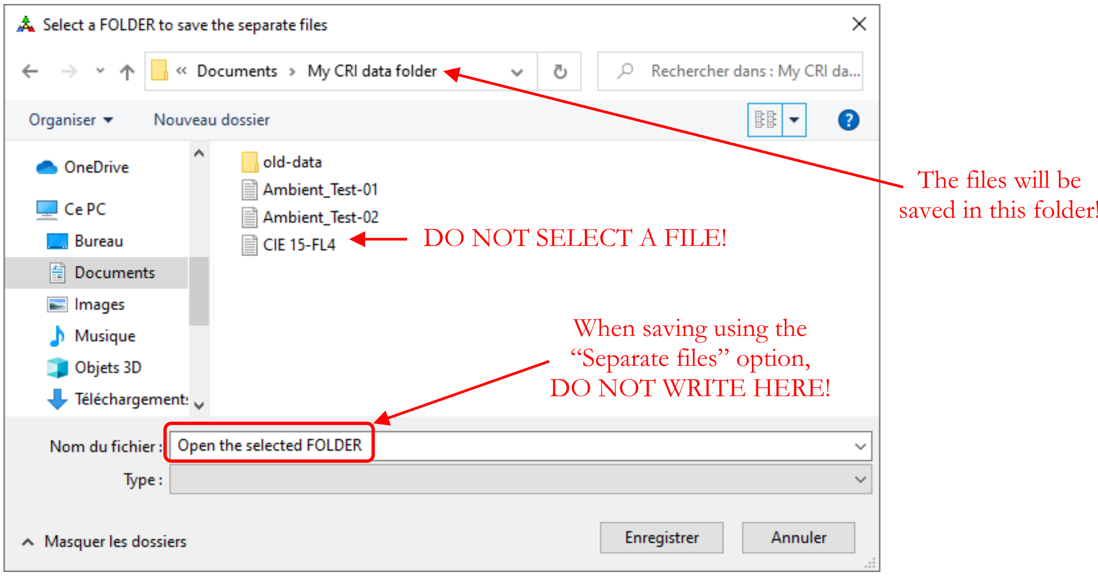
If you specifically selected some measurements rows in the data table of the CRI tools window before opening the dialog, you can save the data for only these measurements. You can also save the data for all rows/measurements. When you have multiple measurements, it can be advantageous to save the data in a single report file; this report corresponds to the "**One file**" radio button in the "File options" section of the dialog. This file can be opened in any word processor; because the data is tab-delimited, you can also open the report in a spreadsheet application, such as Microsoft Excel. The file type can be either "CGATS" or "Plain text"; you should select the "CGATS" type if you intend to reopen the file in the CRI tool. If you select the "One file" option you will be proposed a file name, which you can change if you wish.

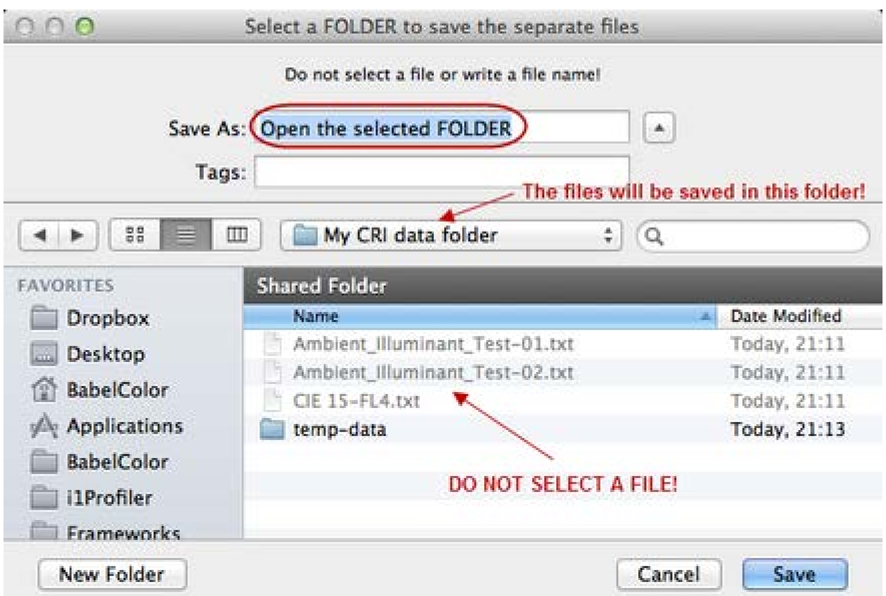
The data corresponding to each measurement can also be saved in its own file by selecting the "Separate files" file option, for which the file type can also be either "CGATS" or "Plain text". Again, if you intend to reopen the file in the CRI tool, select the "CGATS" option. Since the only CRI tools data which is compatible with the base "CGATS.17" file format is the measured spectral data, we strongly suggest that you at least select the "Spectrum" data field. All other (derived or computed) data will also be present in the file but it will be included in the form of commented lines (i.e. lines which start with the "#" character).

The "Plain text" file type results in a file very similar to the CGATS file but without the header and specific tags required by the CGATS format and without a special character at the beginning of each commented lines. This file format is more compact and easily readable.

Hint: If you saved your data using the "Plain text" file type, you can still use this file as input in the CRI tool (Obviously, the file must at least contain spectral data!). You should edit the file in a simple word processor to just keep the lines containing the wavelength labels and the spectral data. You will find additional information in the "CRI input file requirements" section.

When you select the "**Separate files**" option, you will **not be asked for a name** for each measurement and the measurement name defined in the data table of the CRI tools window will be used as file name. However, a file-save dialog will nonetheless be presented in order to **select a folder** in which the separate files will be located. Screenshots of the file save dialogs in Windows and Mac are shown below. Just open a folder without selecting a file or changing the proposed file name which is shown as "Open the selected FOLDER". In the screenshots, the separate files will be saved in the "My CRI data folder". You can of course create a new folder within the save dialog, and then open this new folder to save the files within.

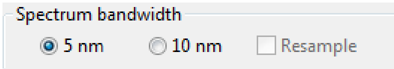




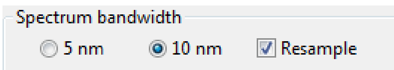
If you select the "**One file + Separate files**" option, you will first be asked to confirm the name and location of the "One file" report (you can change the report name!) and then be asked to select a folder into which the separate files will be saved. You can accept the proposed folder, define another folder, or save the files elsewhere.

Because the CRI tool processes all spectral data in 5 nm increments, interpolating 10 nm data if required, it is possible to export data with either 5 nm or 10 nm bandwidths. Here are a few things that you should consider before selecting the bandwidth options:

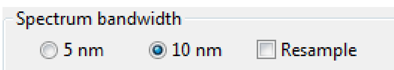
- Select the **5 nm** bandwidth if your input data had a 5 nm bandwidth. This will prevent information loss.



- Select the **10 nm** bandwidth if you intend to export spectral data to be used with other CT&A tools, the ISO3664+ and MI tools to be more specific, which only accept 10 nm ambient data.
- **Select** the "**Resample**" option (available for the 10 nm bandwidth only) if the input data had a 5 nm bandwidth. When this option is selected, the 5 nm data is **down-sampled** to 10 nm data using a triangular function. Resampling affects ALL spectral values.

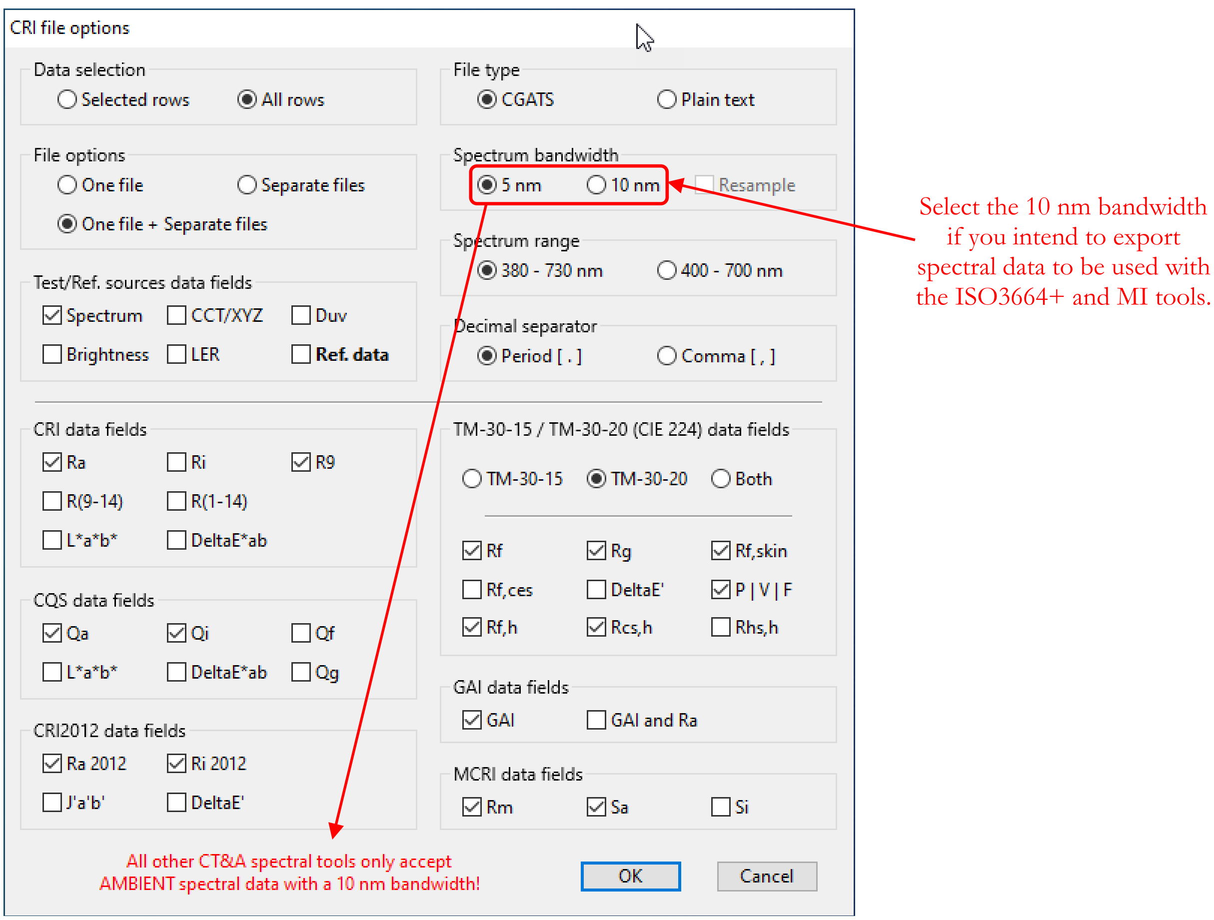


- **Do not select** the "**Resample**" option if your input data had a 10 nm bandwidth (for i1Pro measurements for instance). In this case, the output file will have the same spectral values as the input file, i.e. data for all wavelengths ending with a 5 will simply be discarded.

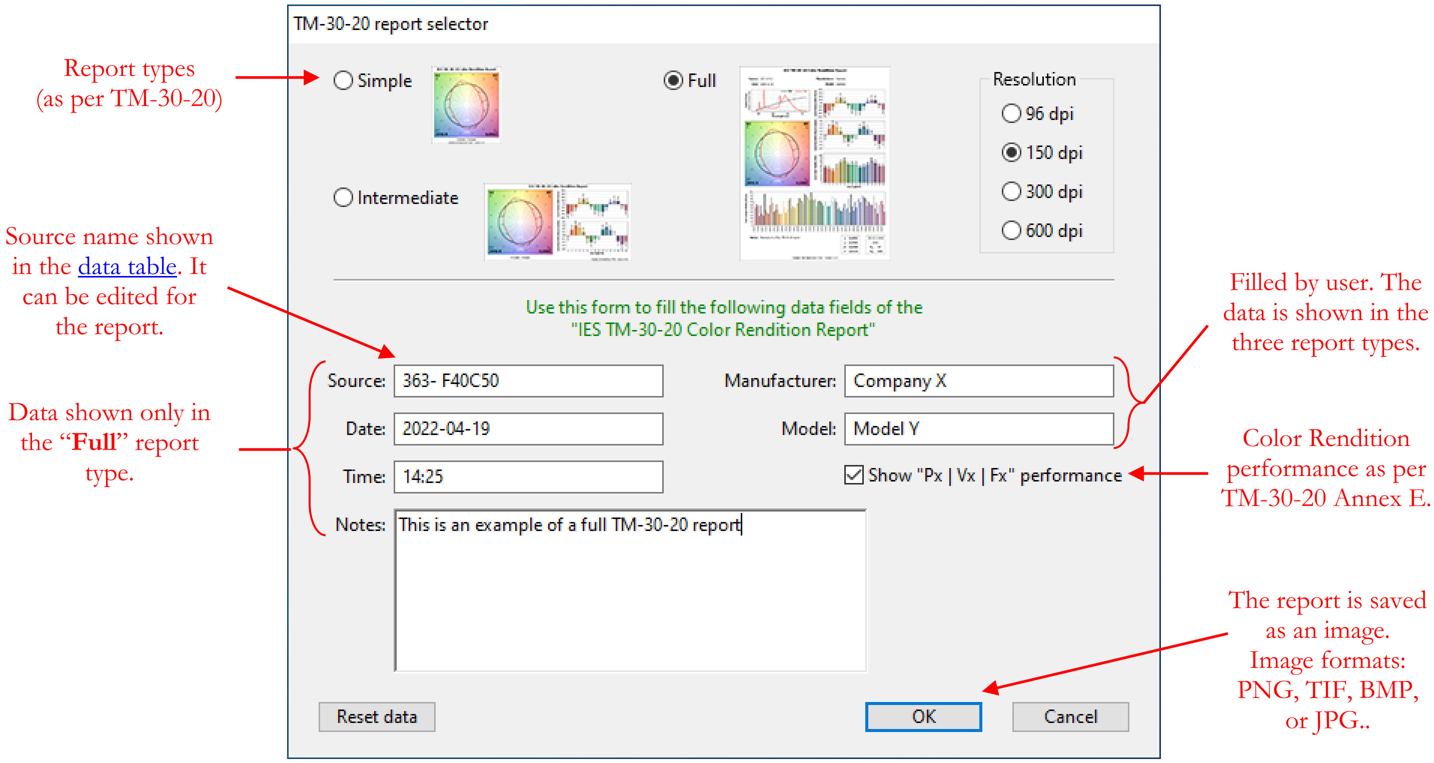


Warning: If your input data had a 10 nm bandwidth and you resample it when you save, this affects all spectral values and reopening such a file will show different results!

Note: If your input data had a 10 nm bandwidth, there will be no difference when you reopen exported data saved in either 5 nm or (10 nm bandwidth **without resampling**) since the 10 nm data will be re-interpolated. However, you may still want to save with a 5 nm bandwidth in order to get the interpolated values.



6.6 TM-30-20 report selector dialog



The **TM-30-20 report selector** dialog is opened by clicking on the "TM-30-20 reports..." button of the CRI window.

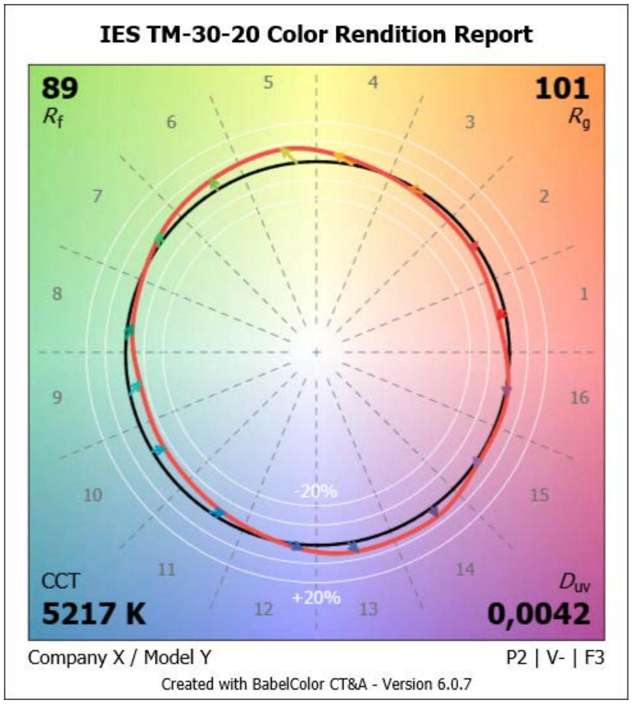
Three report types are offered. They are defined according to the TM-30-20 guidelines (Ref. 57).

- **Simple**: Contains the CVG graph with the numerical values of *Rf*, *Rg*, *CCT*, and *Duv*. The "Manufacturer" and "Model" data fields of the report selector dialog are shown. The nominal image size is about 3.25 x 3.6 in (8,25 x 9,2 cm).
- **Intermediate**: Contains the CVG graph with its additional data as well as the Chroma Shift and Hue Shift graphs. The "Manufacturer" and "Model" data fields of the report selector dialog are shown. The nominal image size is about 6.9 x 3.6 in (17,5 x 9,2 cm).
- **Full**: Contains the CVG graph with its additional data as well as the spectrum graph, the Chroma Shift graph, the Hue Shift graph, the Local Color Fidelity (Hue Bin) graph, and a graph with the fidelity of each CES. In addition to the "Manufacturer" and "Model" data fields, the Full report includes the content of the "Source", "Date" and "Notes" data fields of the report selector dialog. The report also presents *Ra* and *R9* of CIE 13.3, and the *xy* and *u'v'* coordinates of the Test source. The nominal image size is about 7 x 9 in (17,8 x 22,9 cm).

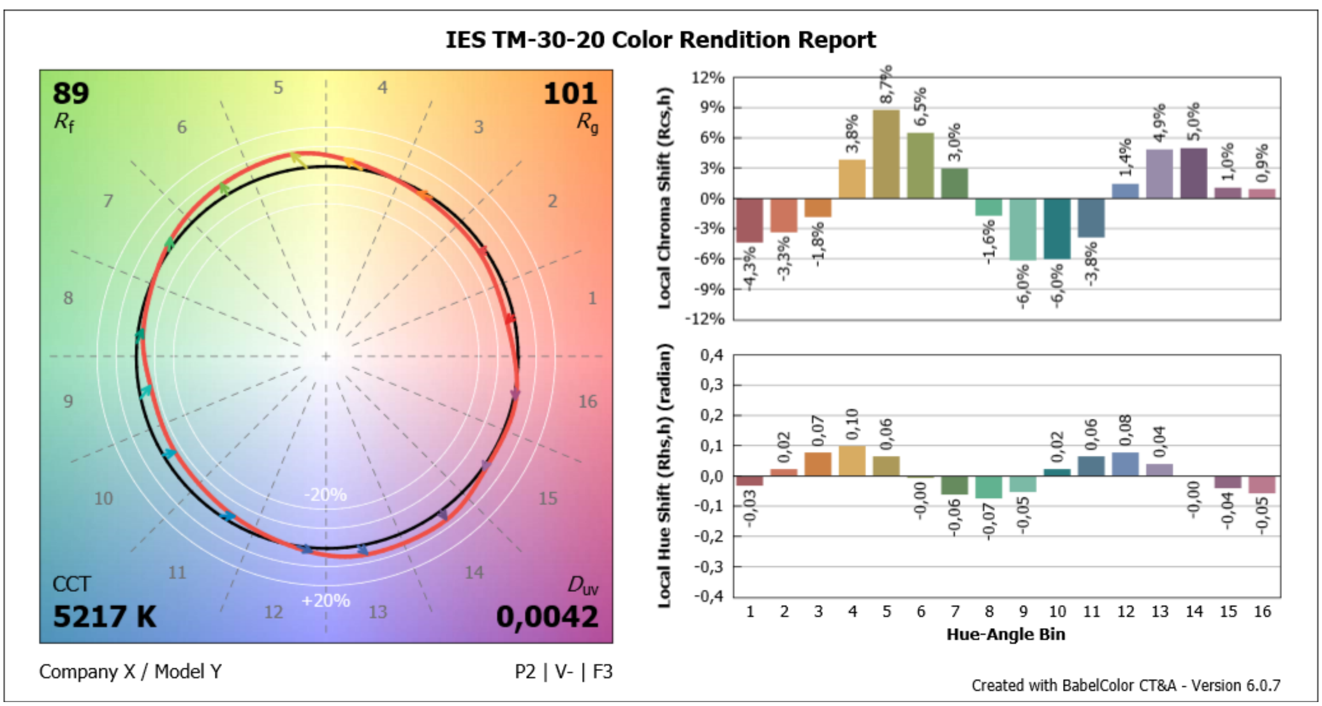
All report types can optionally show the **Color Rendition performance** as defined in Table E2 of TM-30-20 Annex E. The performance is expressed in the form "**Px | Vx | Fx**" where "**P**" corresponds to the "**Preference**" design intent, "**V**" corresponds to the "**Vividness**" design intent, and "**F**" to the "**Fidelity**" design intent. "**x**" is a placeholder for a number (**1**, **2**, or **3**) which indicates the priority level, with "**1**" being the highest; if level 3 is not met, a hyphen (**-**) is written.

Examples of the three report types are shown on the next pages.

Simple TM-30-20 report
3.25 x 3.6 in (8,25 x 9,2 cm)



Intermediate TM-30-20 report
6.9 x 3.6 in (17,5 x 9,2 cm)

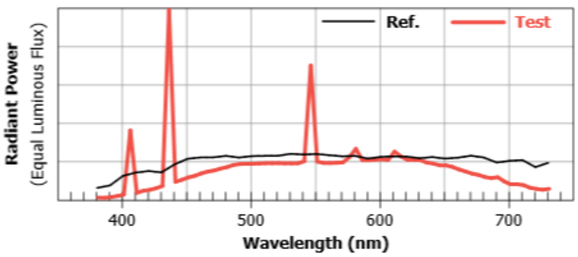


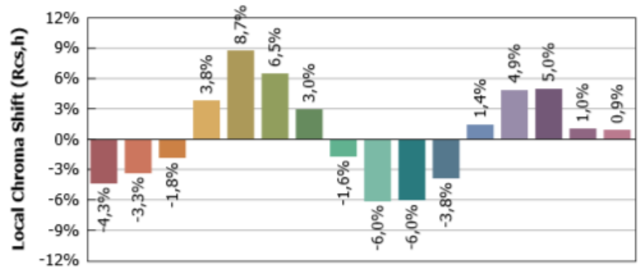
Full TM-30-20 report
7 x 9 in (17,8 x 22,9 cm)

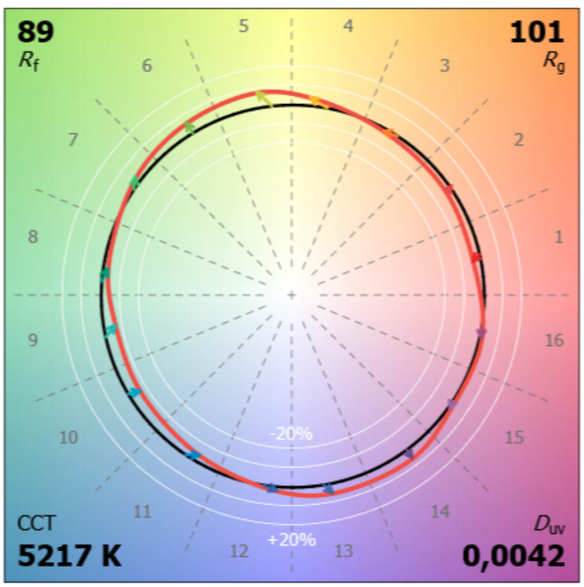
IES TM-30-20 Color Rendition Report

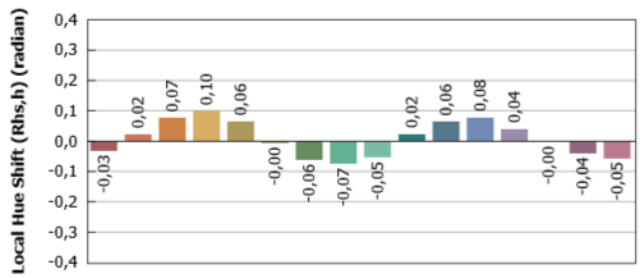
Source: 363- F40C50
Date: 2022-04-19
Time: 15:17

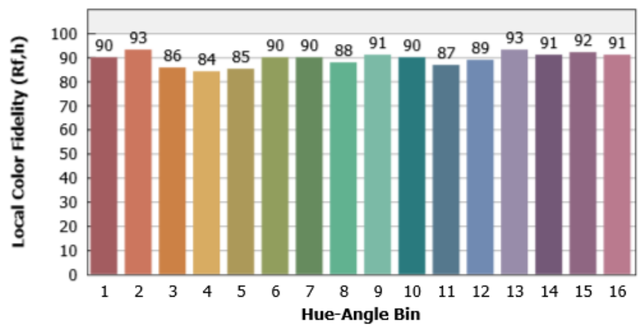
Manufacturer: Company X
Model: Model Y
Performance: **P2 | V- | F3**

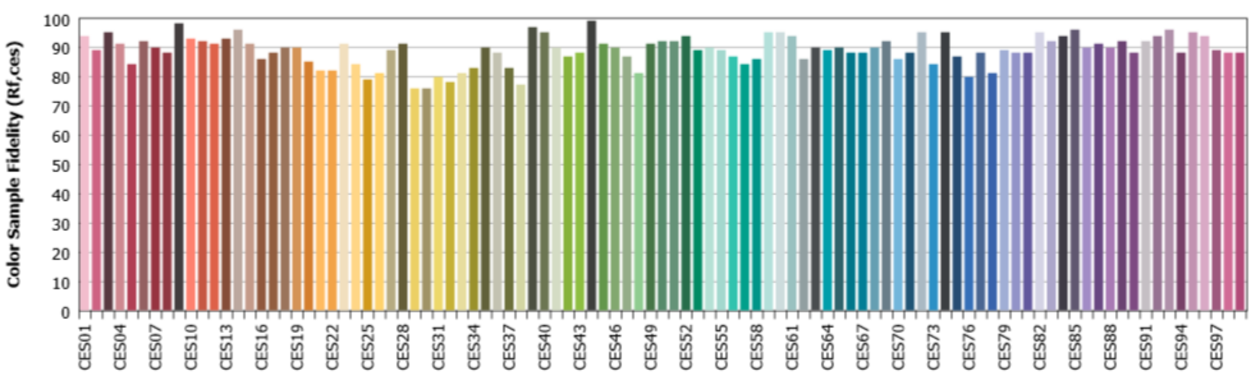












Notes: This is an example of a full TM-30-20 report

x	0,3397
y	0,3556
u'	0,2063
v'	0,4858

CIE 13.3-1995 (CRI)	
R_a	88
R_9	65

Created with BabelColor CT&A - Version 6.0.7

7. Density tools

A common tool in the pressroom, the densitometer is intimately associated to the half-tone (most often CMYK) color reproduction process. Most printing presses require manual adjustments which stem from the variables in the parameters of the CMYK plates separation software, the CMYK films process, plate engraving, ink composition, paper selection, and the presses' own adjustment parameters. Some modern high-end presses measure density parameters on-line and make continuous adjustments from them, a feature most useful for large production runs, but you still need a reference, hence the usage of a press-proof.

The press-proof, either "real" or "soft" (i.e. simulated on a calibrated monitor or printer), should be representative of the final product. Apart from the printed image, which is a "qualitative" proof, many individual color patches of the primary inks are added on the printed sheet outside of the main subject area. These patches are used for "quantitative" assessment of the reproduction quality.

Many different patch designs and patterns have been devised (Plate Control Targets or Color Bars) and their selection is a matter of preferences, expected print quality, and project cost. For more information, please consult the Web site and the publications of the Printing Industries of America (PIA) association (PIA joined forces with the Graphic Arts Technical Foundation (GATF) in 1999):

- https://www.printing.org/
- PIA Quality and Process Controls Catalog and Guide .

The **Density tools** window is opened either by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/Density" menu.

Important: To use these tools, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate" and data entry buttons of the Density window being enabled (some data entry buttons and controls will remain disabled and some data fields will not be available if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

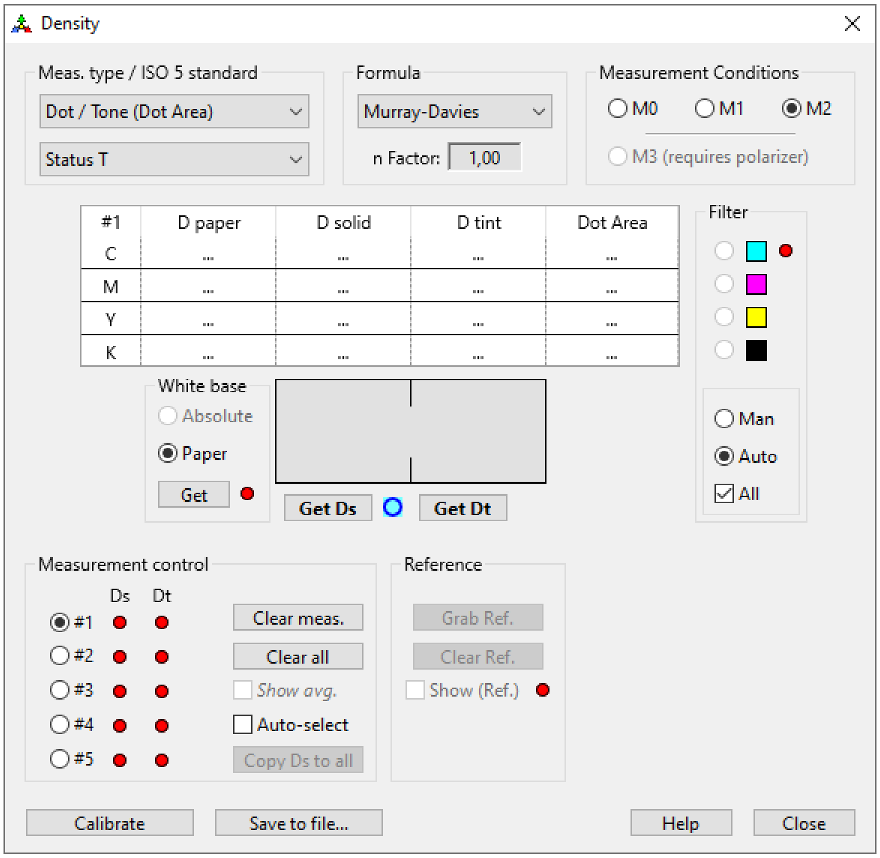
Note: In Windows, if the i1Pro/i1Pro 2 or i1Pro 3 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Instrument button support: When the Density tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears next to a data entry button ("Get D", "Get Ds", "Get OP", etc.). This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button. If the tool requires or supports more than one data entry field, the indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the previous measurement if required, or do a right-click to lock it on a given measurement. You can also do a left-click on a locked indicator; the new position will be locked.

Click on a link in the Table of Contents below for information on the tools' interface and for **specific tools descriptions** and **equations.**

Density tools - Table of Contents

7.1 Density tools interface



The section describes how to set up the interface and make measurements with the Density tools. For **specific tools descriptions** and **equations**, please select the tool in this Table of Contents.

Note: A clipping indicator will appear in the bottom left corner of a color patch when the color of the sample it represents is outside of the RGB space gamut of the monitor.

SETUP

- It is assumed that your instrument is properly connected and detected, as discussed in the Density tools introduction, and that the "Calibrate" and "Get x" buttons are enabled. Please note that some data entry buttons and controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated.

- Select a "Measurement Conditions". If you are using an **i1Pro 2** with the "**i1Pro / i1Pro 2 (XRGA)**" driver or an i1Pro 3, you can select the "Measurement Conditions": M0 (Ill-A), M1 (D50), M2 (UV-cut). If you are using an i1Pro 3 Plus, the M3 (Pol.) Measurement Conditions will also be available. If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument.

  Note: If multiple Measurement Conditions are supported by your instrument, the M0/M1/M2 measurements will be taken when any one of these conditions is selected. You can thus change this setting at any time.

  Note: Because M3 requires an accessory polarizer, and because M0/M1/M2 measurements are performed separately, the M3 density measurements are processed independently from M0/M1/M2 measurements, with their own “Measurement control” for instance, and are presented in a distinct report section.

- Select a "Measurement type": Reflection density, Dot Area, Print Contrast, Hue error - Grayness - Saturation. Data is kept independently for each measurement type.

- Select a "Density standard". The available density standards are the ones defined in ISO 5-3:
  - ANSI Status A: Should be used for measuring densities of photographic color prints.
  - ANSI Status E: Used mostly in Europe to measure printed material. It has a wide-band color response. Equivalent to the DIN status.
  - ANSI Status I: Has a narrow-band or interference-type filter response. Equivalent to the DIN NB and SPI statuses.
  - ANSI Status T: The equivalent of ANSI Status E in North America. The difference with Status E is how the yellow filter is weighted.

  Note: You can change this setting at any time; all previous measurements will be recomputed according to the selected standard.

- If required, select a "Formula" (for Dot Area and Apparent Trap). If required, set the "*n* Factor" for the Yule-Nielson formula of the Dot Area measurement. A *n* factor of 1,70 is shown by default when the Yule-Nielson formula is first selected; it can then be changed by the user by typing a new value in the field where it appears. Please consult the Dot Area and Apparent Trap sections for more information on these formulas.

- If not already done, calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions.

WHITE BASE

A "Paper" "White base" is automatically selected and "Absolute" is disabled if "Dot / Tone (Dot Area)" or "Apparent Trap" is selected. Both options are enabled for "Reflection density", "Print Contrast", and "Hue error - Grayness - Saturation".

If "Paper" is selected for the "White base", it is strongly suggested to measure the paper first by clicking on the "Get" button located in the "White base" group.

Important: The same paper data is used for all density measurements types. When "Paper" and "Absolute" are both available, selecting one or the other will update ALL the measurements sets of ALL measurement types.

FILTER

An "Auto" "Filter" is automatically selected and "Man" (i.e. Manual) is disabled if "Apparent Trap" or "Hue error - Grayness - Saturation" is selected. Both options are enabled for "Reflection density", "Dot / Tone (Dot Area)", and "Print Contrast".

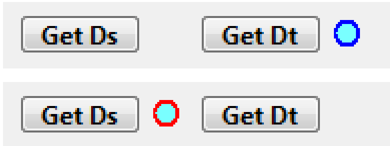
If available, selecting the "Man" radio button will enable the individual CMYK filters. Selecting any of these filters will instruct the program to show only the data — in the data table — corresponding to this filter.

MEASUREMENT CONTROL

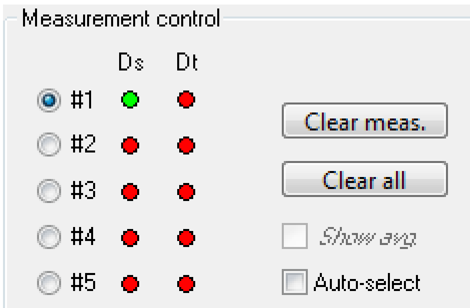
Up to five sets of measurements can be done for each density tool. Select the measurement set by clicking on a radio button in the "Measurement control" group (they are labeled #1, #2, etc.). You should see the measurement number in the upper-left cell of the data table.

To make a measurement, either click on the "Get x" button under the square patches, where "x" represents the measured variable (D, Ds, OP, etc.) which changes according to the selected measurement type, or press the instrument button. A large blue indicator is located beside the "Get x" button that will be selected if you press the instrument button:

This indicator automatically changes location when multiple inputs are required for a measurement set. Do a left-click on an indicator to move it to its previous position or a right-click to lock it (a locked indicator has a red border: ). You can also do a left-click on a locked indicator; the new position will be locked.



Once a measurement is done, its status light is changed to green:

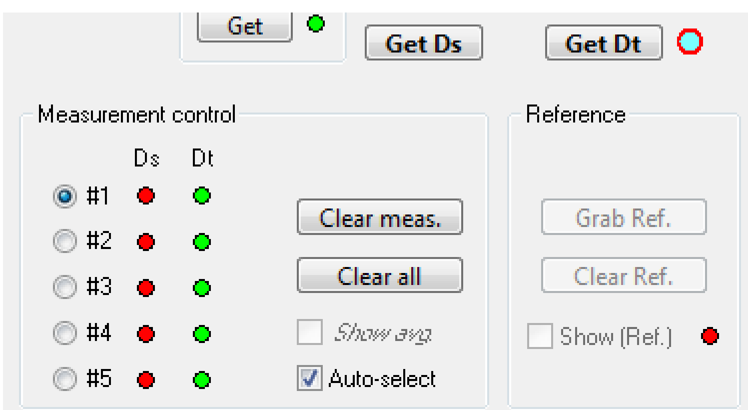


To automatically change/increment the measurement number in the "Measurement control" group, simply check the "Auto-select" box. Once all inputs for a measurement set are done (i.e. all inputs are green), the system selects the next measurement set. For example, if "D solid" and "D tint" for "Print Contrast" are measured for measurement set #3, then #4 is then selected.

The "*Show avg.*" box is enabled when there are at least two complete measurements. To display the average, check the "*Show avg.*" box. The values will appear in the data table with an *Italic* font and the word "Avg." will be displayed in the upper-left cell.

You can clear the selected measurement set or all sets by clicking on either the "Clear meas." or "Clear all" buttons. The "Clear all" button erases only the data of the current measurement type.

Hint: You can easily measure the same parameter for all measurements by locking the parameter. For example, in the "Dot / Tone (Dot Area)" tool, first check the "Auto-select" box and then lock the blue indicator on the "Get Dt" button; each press of the instrument button will then get Dt and assign it to a different measurement. This is shown in the screenshot below:



REFERENCE

The "Grab Ref." button is enabled when a measurement is completed and selected. To display the reference, check the "Show (Ref.)" box. The values will appear between parentheses in the data table. A green status light will appear next to the "Show (Ref.)" box when a reference is in memory.

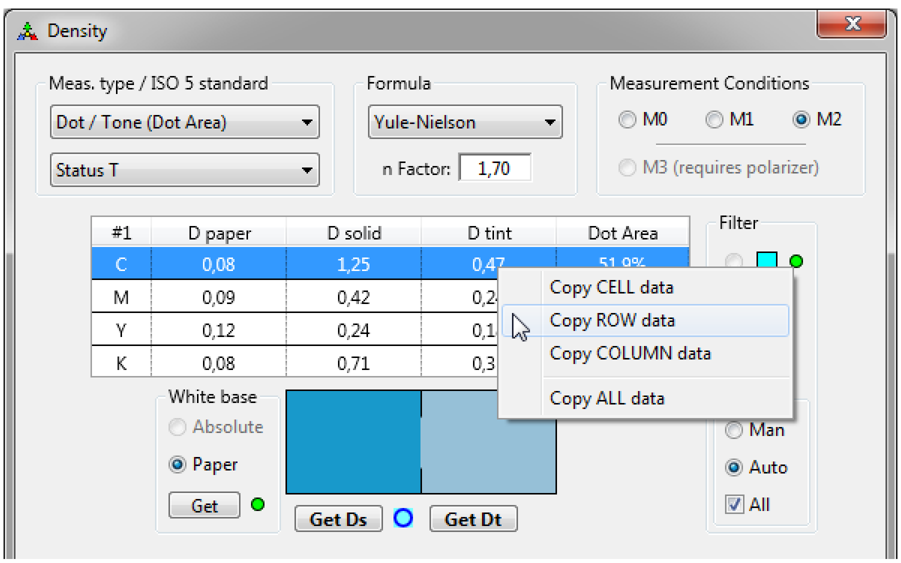
Hint: You can grab the average as the reference by first selecting the "*Show avg.*" box and then clicking the "Grab Ref." button.

OTHER TOOL FUNCTIONS

At all times, you can calibrate the instrument by clicking the "Calibrate" button. The measurement mode for all density tools is "Reflectance", by default, and cannot be changed.

Click on "Save to file..." to save a report of the selected "Measurement type". You will be prompted to save only the current measurement type or all the data acquired in all Density tools. The report has tab-delimited data that can be directly imported in a spreadsheet program, and opened in many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting).

You can copy numerical data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on any table cell or data field (such as the **Apparent Trap** and **Hue-Grayness-Saturation** results). Shown below is the contextual menu which appears with a right-click on the fourth column of the first row (Cyan, D tint); you can copy either the cell content, the complete row or column of this cell, or the entire table. When copied, the data is transferred into the clipboard, separated by Tabs. You can then easily paste the values in a spreadsheet or document table, where they will be distributed in individual cells.



Note 1: *Copy ROW data*: When copying a row, the filter label (*C*, *M*, *Y* or *K*) is also copied.

Note 2: *Copy COLUMN data*: When copying a column, the header (*D paper*, etc.) is also copied. The data will be pasted in a single line (i.e. ROW).

Note 3: *Copy ALL data*: When copying the entire table, the headers are also copied. The data will be pasted using the same number of rows and columns as in the copied table.

7.2 Reflection density

Mathematically, the density is expressed as:

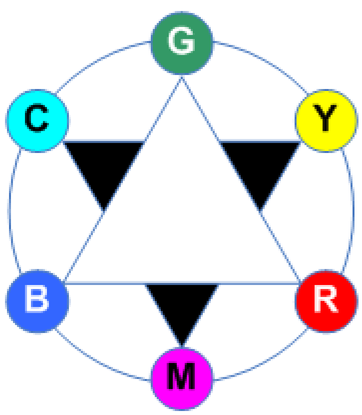
$$D = \log_{10}\left(\frac{1}{R}\right)$$

which is equal to zero (0,0 D) for 100% reflectance, 1,0 D for 10% reflectance, 2,0 D for 1% reflectance, 3,0 D for 0,1% reflectance, etc. The lower the reflection, the higher is the density. A similar equation can be defined for transmission, with "*T*" replacing "*R*".

Taking the logarithm effectively compresses the tonal difference and assigns the same significance, a 1,0 D difference, to a change between 1% and 10% compared to a change between 10% and 100%. This is representative of the non-linear sensitivity of the human eye, and of the similar characteristics of the photographic films used to make the printing plates.

A density is not a spectral characteristic per se, since it is a measure of reflection — or transmission — only. By associating the density to a color filter, we are able to characterize the densities of specific color ranges, the ones corresponding to the various inks of the color printing process for instance.

When an image is photographically reproduced, black and white separation films are exposed through Red, Green, and Blue filters. These films are negatives, where the brightest areas are recorded as black and the dimmest areas as white. The white areas of the red filtered image correspond to the complementary color of red, which is cyan. Similarly, the complementary color of the green filter is magenta and the complementary color of the blue filter is yellow.



The separation films are then used to expose the printing plates. Ink will be deposited proportionally to the clear areas of the film. Accordingly, inks of the complementary colors of the filters, Cyan, Magenta and Yellow (CMY), have to be used to properly reproduce the colors. Although the separation plates can be generated directly by software, the final reproduction steps are the same, and the same filters are assumed when measuring a hardcopy.

In densitometric instruments, the filters are most often referenced by their complementary colors; the red filter is referred as cyan, etc. For example, if you measure two cyan color patches, with the first patch being less saturated than the second patch, the measured density using the cyan filter is smaller for the first patch than for the second patch. This is simply an indication that the second patch has less red content — red is darker, with a corresponding higher density value — and the red separation negative is more "white", hence more cyan ink is printed. Using this "inverse logic" makes sense since we expect higher numbers for more saturated tints.

Different filter curves are used. Called "Status X", with "X" a letter such as "A", "E", "I" or "T", they are selected according to the reproduction process, print or film, and to agreed standards.

As single density measurement always combines the effect of the ink AND the paper on which it is printed; the measurement is thus an absolute value (*Dabs*). If you first measure the density of the paper (*Dpaper*), also called "White base" or substrate, you can subtract this value from the absolute measurement and obtain a relative density (*Drel*) representative of the ink deposition only:

$$D_{rel} = D_{abs} - D_{paper}$$

One of the simpler measurements that can be done is to measure the density of solid patches of each of the primary printing inks. By solid, it is meant that no half-tone is used and that the ink is uniformly covering the color patch (i.e. 100% coverage). It is important to specify if the densities are to be measured on wet or dry inks, since this has an impact on the values. A typical tolerance for densities is plus or minus 0,05 D. Typical values — these are NOT standards — as measured on **three coated papers** and **one uncoated paper**, and using a **black backing**, are:

	Reflection Density Status T / dry ink / Absolute	
	coated	uncoated
C	1,15 - 1,25	0,92
M	1,30 - 1,40	0,97
Y	0,95 - 1,05	0,80
K	1,50 - 1,70	1,10

The densities corresponding to the various filters can be combined to provide additional information on the printing process, such as Dot Area, Apparent Trap, Print Contrast, and Hue error, Grayness, and Saturation. These are defined in the following sections. Many of the equations used for density characterization use the relative values instead of the absolute ones.

7.3 Dot / Tone (Dot Area)

In the printing process, the various shades are obtained by adjusting the dot coverage; the higher the tint number (i.e. the tone), the higher the dot coverage. However, ink deposition is influenced by the interaction of the paper with the ink, as it can be absorbed more or less, which affects the dot size. *Dot Area* is thus an important part of the print quality assessment process.

In CT&A, three formulas can be used to obtain *Dot Area* values: **Murray-Davies**, **Yule-Nielson**, and **SCTV** (Spot Color Tone Value). The first two are used to evaluate tone values obtained with the four-color CMYK printing process; the third formula, **SCTV**, is a new formula designed specifically to measure the tone of spot colors (Ref. 59).

MURRAY-DAVIES AND YULE-NIELSON FORMULAS

Their equations are:

Murray-Davies:

$$DotArea = \frac{1-10^{-(Dtint-Dpaper)}}{1-10^{-(Dsolid-Dpaper)}} \times 100$$

Yule-Nielson:

$$DotArea = \frac{1-10^{-(Dtint-Dpaper)/n}}{1-10^{-(Dsolid-Dpaper)/n}} \times 100$$

where *Dsolid* is the solid density, *Dtint* the tint density, and *Dpaper* the paper density. The only difference between the two equations is the presence of the "*n* Factor" in the Yule/Nielson formula, an empirically determined value based on the printing substrate. By setting the *n* factor to one, the Yule-Nielson equation becomes identical to the Murray-Davies equation.

The *n* factor is typically set to values between 0,5 and 9,9. **Approximate** values for various materials are:

- 1,60 to 1,70 for coated paper;
- 2,70 for uncoated paper;
- 2,50 for newsprint.

In this tool, a default value of 1,70 appears for the *n* factor when the Yule-Nielson formula is first selected; this value can then be changed by the user.

The *Dot Area* on the separation film can also be measured; this measurement requires a transmission densitometer (Note: this measure cannot be done with an i1Pro series spectrophotometer). By comparing the dot areas of both the film and the print, one can obtain the *Dot Gain*, which is the increase in dot size between the film and print. One can also assume that the *Dot Area* of the film is equal to the percentage tint specified in the original data file (in Photoshop for example), and measure the *Dot Gain* as the difference between the *Dot Area* of the print and the file value.

Dot Area and *Dot Gain* are typically measured for 25% (highlights), 50% (mid-tones), and 75% (shadows) tints. Excessive dot gain in the shadows will result in "plugging" with a loss of contrast and detail. Excessive dot gain in highlights will make light, "washed-out", colors difficult to reproduce. As well, gray balance will be affected by inconsistent dot gains across the four printed colors.

Typical *Dot Area* and *Dot Gain* values — these are NOT standards — as measured on **three coated papers** and **one uncoated paper**, and using a **black backing**, are:

	Dot Area Status T / Murray-Davies / 50% tint	
	coated	uncoated
C	60%-70%	75%
M	65%-75%	79%
Y	70%-80%	76%
K	60%-70%	84%

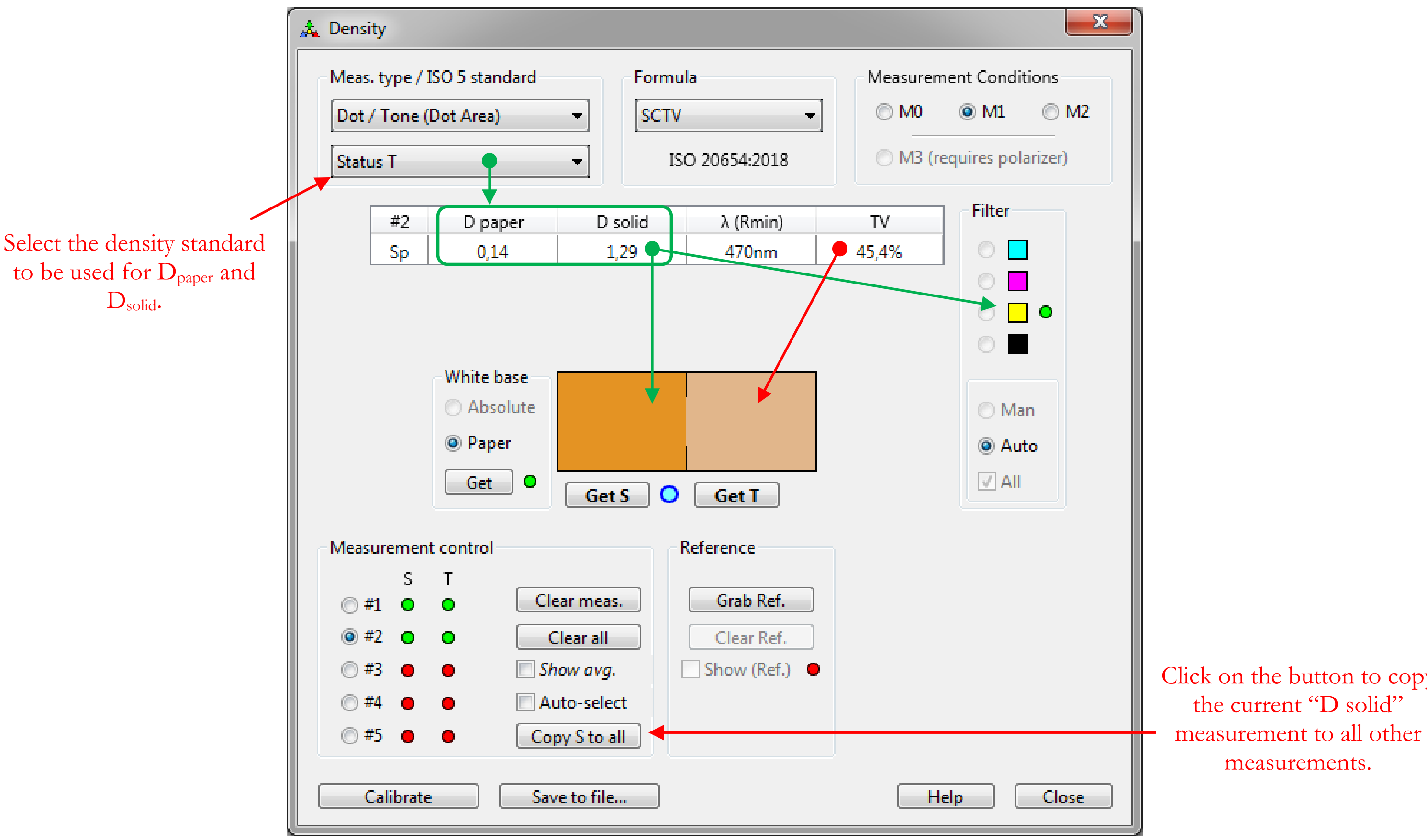
	Dot Gain Status T / Murray-Davies / 50% tint	
	coated	uncoated
C	10% - 20%	25%
M	15% - 25%	29%
Y	20% - 30%	26%
K	10% - 20%	34%

In the table above, the *Dot Gain* is determined relative to a 50% tint, as specified in the original data file. For example, for Magenta uncoated: *Dot Gain* = (*Dot Area* of print) - 50% = 79% - 50% = 29% .

SCTV FORMULA

The Tone Value (TV) is derived from the XYZ values of the spot ink solid, the substrate, and the spot ink tone. It is NOT derived from densities obtained from predefined Red, Green, and Blue filters. The Tone Value is normalized between substrate (TV=0%) and spot ink solid (TV=100%).

Below is a screenshot of a typical measurement. In addition to the Tone Value, you also get the paper and solid densities, and the wavelength corresponding to the lowest reflectance, λ (R_{min}). Here we get a TV of 45,4%, with a D_{paper} of 0,14Y and a D_{solid} of 1.29Y (both densities Status T), and a minimum reflectance at 470 nm.



Hint: For a given set of measurements, you can switch between the three formulas without having to re-measure the patches.

7.4 Apparent Trap

Apparent Trap is the evaluation of the covering properties of a solid ink printed over another solid ink. However, ink coverage is not perfect; it depends on a multitude of factors, which include: ink viscosity, adherence (i.e. tack), thickness, paper characteristics, press adjustments (roller pressure, print speed, etc.), temperature, etc. Poor trapping will be particularly noticeable where there are large areas of similar colors, such as a blue sky, a combination of cyan and magenta.

The two following formulas can be used to obtain *Apparent Trap* values:

Preucil (GATF), defined as the ratio of the difference between the density of the over-print and the density of the first ink printed (first-down ink) to the density of the second ink printed (second-down ink):

$$Trap = \frac{(Dop - Dpaper) - (D1 - Dpaper)}{(D2 - Dpaper)} \times 100$$

Brunner, which evaluates trapping as the apparent dot area of the second color as if it was printed as a tint instead of solid:

$$Trap = \frac{1 - 10^{-(Dop - Dpaper)}}{1 - 10^{-((D1 - Dpaper) + (D2 - Dpaper))}} \times 100$$

where *Dop* is the density of the over-print, *D1* is the density of the first-down ink, *D2* is the density of the second-down ink, and *Dpaper* is the density of the paper.

The computation is based on the filter corresponding to the dominant hue, usually from D2, which is the filter with the highest density. For example, if yellow is printed over cyan, the trap value will be computed using the "Y" filter values of all the samples (paper, 1st ink and 2nd ink). The trap value is reported in the following format:

trap% Y/C green

where **Y**ellow is printed over **C**yan and **green** is the color of the over-print.

Typical *Apparent Trap* values — these are NOT standards — as measured on **three coated papers** and **one uncoated paper**, and using a **black backing**, are:

	Apparent Trap Status T / Preucil	
	coated	uncoated
R	70% - 80%	51%
G	80% - 90%	85%
B	65% - 80%	69%

7.5 Print Contrast

Print Contrast is a good indicator of the overall print quality. It is usually computed for a 75% tint since shadows often carry much of the image information. It is computed using the following equation:

$$PrintContrast = \frac{Dsolid - Dtint}{Dsolid} \times 100$$

where *Dsolid* is the solid density and *Dtint* the tint density. The above formula shows only absolute inputs; if desired, the print contrast can be determined with relative density values, where the contribution of the paper density, *Dpaper*, is removed from both *Dsolid* and *Dtint*.

Typical *Print Contrast* values — these are NOT standards — that can apply for **coated paper** and **newspaper**:

	Print Contrast Status T / 75% tint	
	coated	newspaper
C	38% - 45%	13%
M	35% - 38%	12%
Y	30% - 33%	15%
K	38% - 43%	16%

7.6 Hue Error - Grayness - Saturation

In comparison with the other density measurement types, the *Hue error*, *Grayness*, and *Saturation* measurements are computed by combining the densities of two or three filters from the same sample, whereas the other measurement types always use values from a single filter.

The measurements are performed on solid patches (100% tint) of either cyan, magenta or yellow. The individual CMY values are first ranked as *Dlow*, *Dmid*, and *Dhigh*, where *Dlow* is the lowest density of the CMY values, *Dhigh* is the highest density, and *Dmid* is the middle density.

Hue error is a misnomer; it is not an error per se, but the variation from an ideal cyan, magenta or yellow:

$$HueError = \frac{Dmid - Dlow}{Dhigh - Dlow} \times 100$$

The *Hue error* is presented in the form:

22,5% C -> Y

The above example shows that the measured patch is **C**yan (the filter with *Dhigh*) with a tendency towards **Y**ellow (the *Dmid* filter). In the example, the hue error is the ratio of the yellow ink density over the cyan ink density once gray is removed by subtracting *Dlow* from each of them; the yellow-with-gray-removed density is **22,5%** of the cyan-with-gray-removed density.

Grayness, expressed as a percentage, indicates the level of gray in a color:

$$Grayness = \frac{Dlow}{Dhigh} \times 100$$

which you can visualize by the fact that there is at least a value of *Dlow* in each ink, creating a gray background.

Saturation is the difference between the highest density filter value and the lowest one:

$$Saturation = Dhigh - Dlow$$

which can be looked at as *Dhigh* without the gray. *Saturation* is expressed in **density units**, not in percentage.

The above formulas show only absolute inputs; if desired, they can be determined with relative density values, where the contribution of the paper density, *Dpaper*, is removed from the absolute values (*Dlow*, *Dmid*, and *Dhigh*).

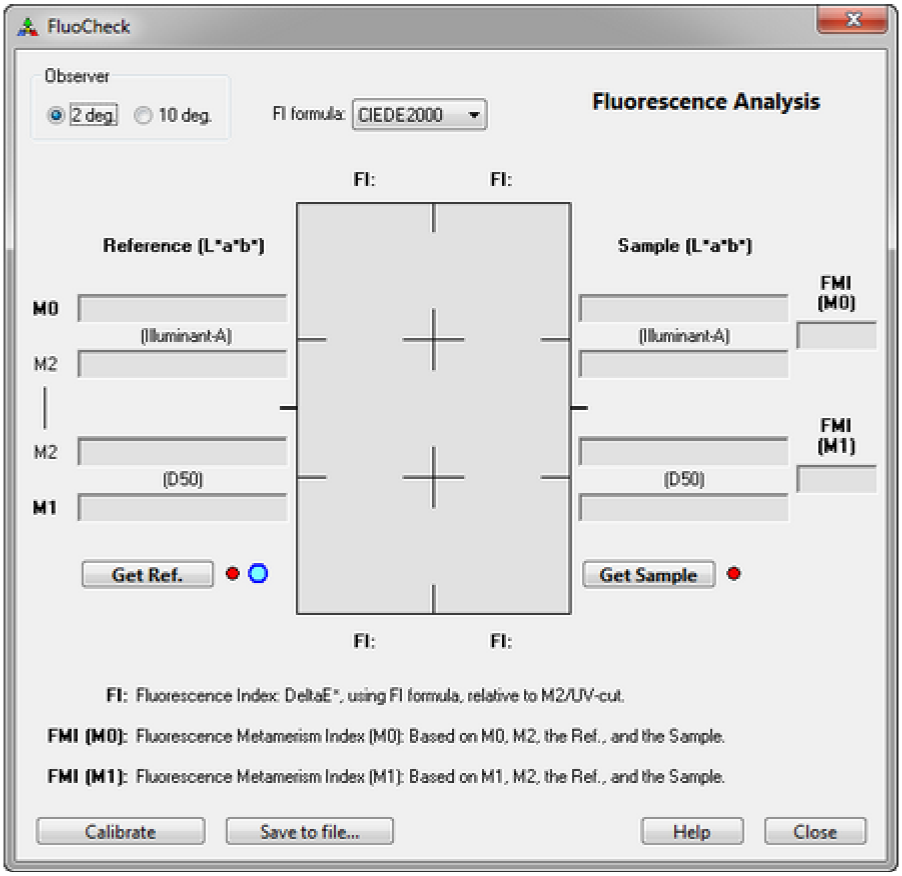
Typical *Hue error*, *Grayness*, and *Saturation* values — these are NOT standards — as measured on **three coated papers** and **one uncoated paper**, and using a **black backing**, are:

	Hue Error Status T / Paper included	
	coated	uncoated
C	16% - 20%	24%
M	40% - 44%	55%
Y	6% - 8%	9%

	Grayness Status T / Paper included	
	coated	uncoated
C	14% - 19%	24%
M	19% - 23%	28%
Y	8% - 11%	11%

	Saturation Status T / Paper included	
	coated	uncoated
C	0,95 - 1,05	0,70
M	1,00 - 1,20	0,70
Y	0,90 - 1,05	0,70

8. FluoCheck tools



INTRODUCTION

The **FluoCheck tools** are made possible by the capabilities of X-Rite's i1Pro 2 and i1Pro 3 spectrophotometers which supports the M0, M1, and M2 Measurement Conditions as defined in ISO 13655 (Ref. 42). The FluoCheck tools were devised by BabelColor to rapidly evaluate if a color sample is susceptible to fluorescence and if two samples that match without fluorescence still match when fluorescence is taken under consideration. The FluoCheck window is opened either by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/FluoCheck" menu.

The FluoCheck tools enable you to:

- characterize the Fluorescence Index (**FI**) of a **single printed sample** by computing the color difference between a measurement done under the M2 (UV-cut) measurement condition, and either M0 (Illuminant A) or M1 (D50);
- evaluate if the combined appearance of **two printed samples** varies between a reference Measurement Condition (M2, UV-cut) and a UV-inducing illuminant (either M0 or M1) using a Fluorescence Metamerism Index (**FMI**);
- judge how samples look under the M0, M1, and M2 measurement conditions and, for M2 (UV-cut), judge how they look under Illuminant A and D50 (virtual light box).

Important: An **i1Pro 2** or **i1Pro 3** which supports the **M0** (Ill-A), **M1** (D50), and **M2** (UV-cut) measurement conditions is **required** to use these tools (an i1Pro cannot be used!). Also, for the i1Pro 2, you must select the "**i1Pro / i1Pro 2 (XRGA)**" driver in the toolbar window and the instrument must be properly recognized by the program. Instrument recognition is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate", "Get Ref.", and "Get Sample" buttons being enabled in the FluoCheck window (some controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to

connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Note: In Windows, if the i1Pro 2 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Instrument button support: When the FluoCheck tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is recognized, a large blue indicator appears next to the "Get Ref." or "Get Sample" button. This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button. The indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the previous measurement if required, or do a right-click to lock it on a given measurement. You can also do a left-click on a locked indicator; the new position will be locked.

The remainder of this section describes how to set up the interface and make measurements. For additional information on the FluoCheck FI and FMI indices and for the FMI equation, click here.

SETUP

- It is assumed that your instrument is properly connected and detected, as discussed in the introduction just above.

- Select an "Observer"; data will be updated if it is changed after a measurement is done.

- Select a "FI formula"; data will be updated if it is changed after a measurement is done.

  The available color difference formulas are:

  - CIELAB
  - CIE94 (i.e. the common formula, CIE94 (1:1))
  - CIE94 tex. (i.e. CIE94 for textile, CIE94 (2:1))
  - CIE94 (2:2)
  - CMC (2:1)
  - CMC (1:1)
  - CIEDE2000

  This selection is used to compute only the Fluorescence Index (FI).

  Note: CIE94 (2:2), where k_L=2 and k_C=2, puts more weight on the hue (with k_H=1) than on the lightness and chroma. This formula is recommended by Berns (Ref. 25, p. 129) to determine the CII and is also a very good choice for the FI.

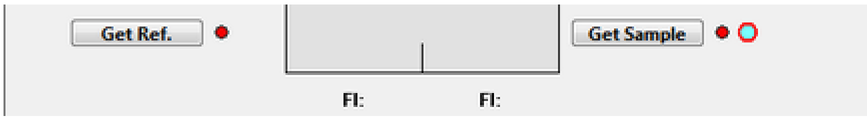
  Note: The FMI values are always computed using CIELAB color differences.

- If not already done, calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions.

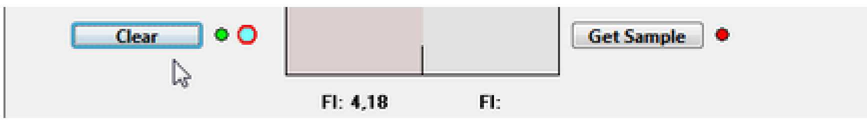
MEASUREMENTS

To make a measurement, either click on the "Get Ref." or "Get Sample" button or press the instrument button. A large blue indicator is located beside the input that will be selected if you press the instrument button:

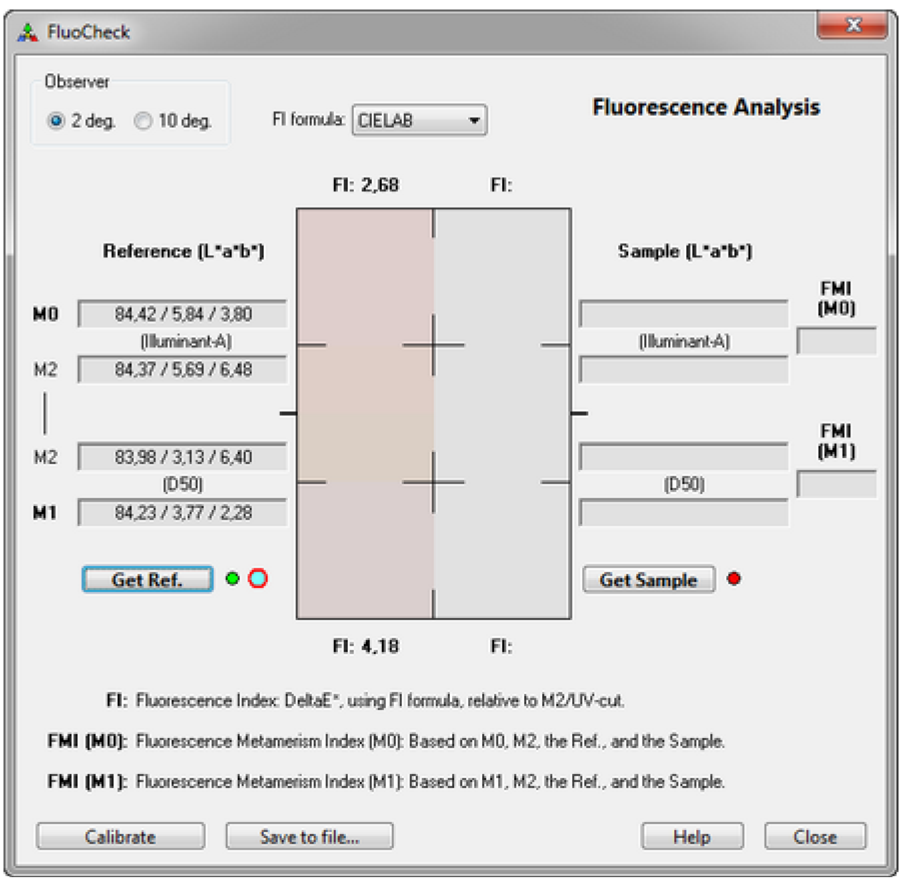
This indicator automatically changes location when an input is done at one position. Do a left-click on an indicator to change its position or a right-click to lock it (a locked indicator has a red border:). You can also do a left-click on a locked indicator; the new position will be locked.



To **erase** a measurement, first press the **Alt** key, in Windows, or the **Option** key on a Mac. Whenever the mouse cursor is within the tool window, the "Get Ref." and "Get Sample" buttons will change their caption to "**Clear**" (if there is a measurement). To clear the sample, click the button with the mouse while keeping the **Alt** or **Option** key pressed:

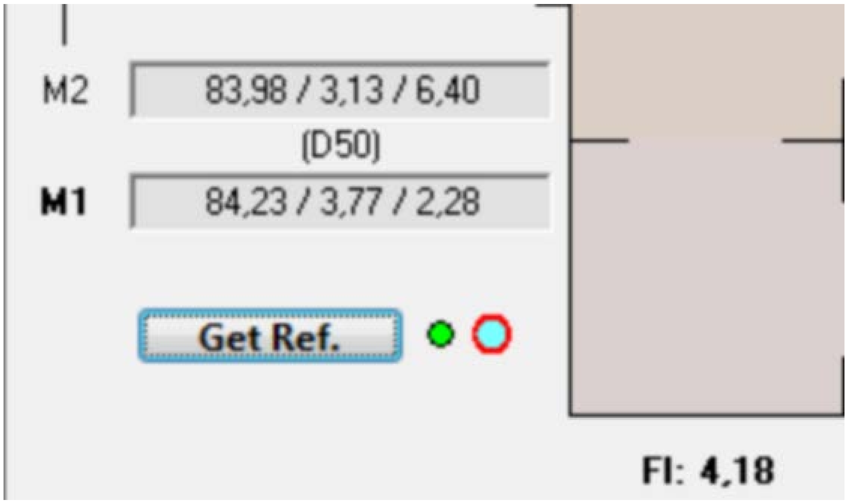


Here is a first example where only the Reference is measured; the measured patch is a skin color from a glossy magazine (you should enlarge the screenshot and wait a few seconds for your eyes to adapt in order to better differentiate the color differences):



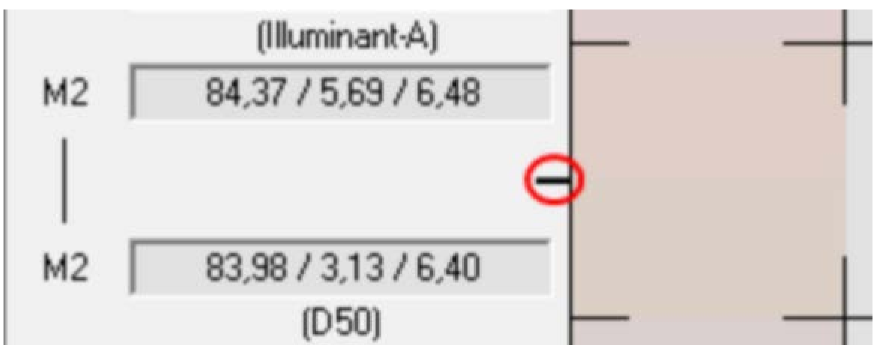
The displayed colors are computed to show how the patch would look like under the illuminants corresponding to each measurement condition. Illuminant A is used for the M0 condition and Illuminant-D50 is used for M2. At first sight, we see that the patch color obtained under M0 measurement condition is redder and the one obtained under the M1 measurement condition is bluer, in line with the respective spectral content of the illuminant associated with each measurement condition.

The Fluorescence Index (FI) for the patch measured under M1 relative to M2 is 4,18, i.e. this is the color difference between M1 and M2 as computed with the selected FI formula, in this case CIELAB. If we visually compare the patches, shown enlarged in the next screenshot, we see that the M2 color is more yellow and M1 is more neutral (i.e. bluer).



The effect is similar, but less intense, when we compare M2 and M0 computed for Illuminant A, with a FI of 2,68. The higher FI for M1-vs-M2 is expected since a D50 light source contains more UV than an Illuminant A light source.

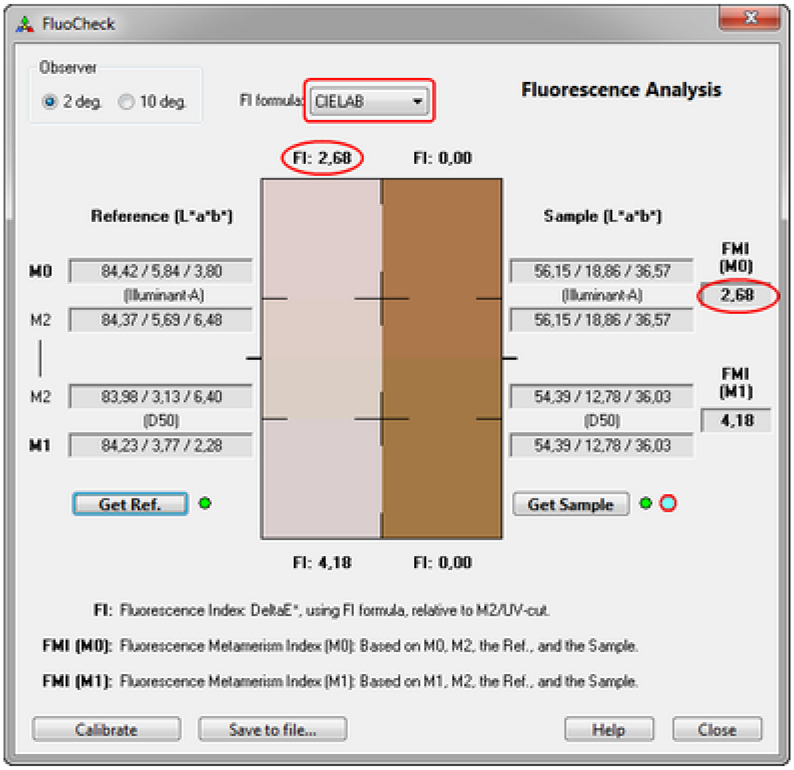
You will notice that the zone where the M2 color is represented can be distinctly separated in two; there is a black mark "–" outside of the patch layout which identifies where the two colors join:

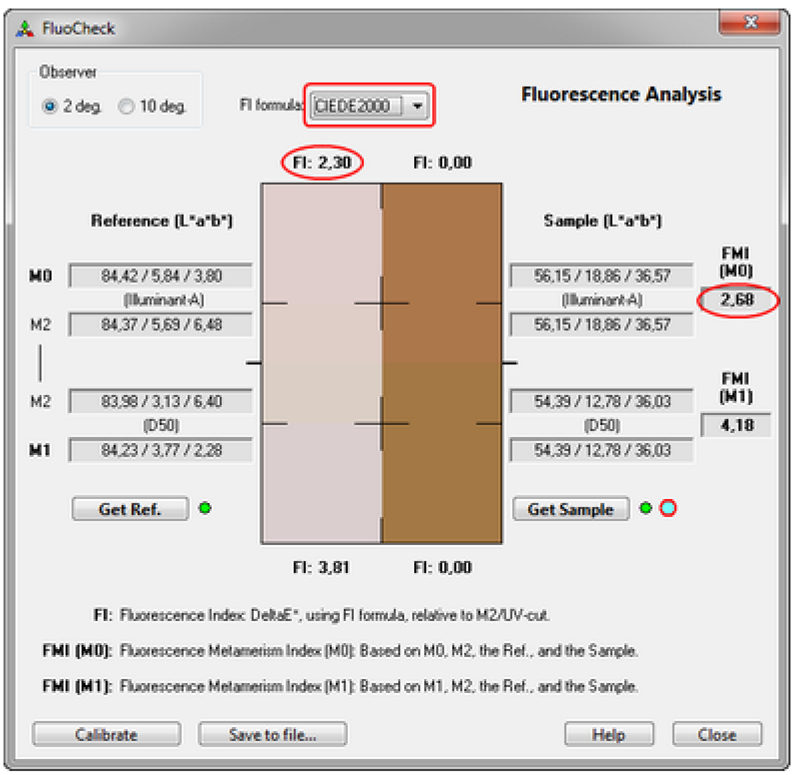


There are two reasons for this. Firstly, because M2 is UV-cut, there is no predetermined illuminant associated to this measurement condition. Secondly, in order to better compare M2 with M0 and M2 with M1, we compute M2 using the illuminant associated respectively to M0 (Ill-A) and M1 (D50). The two M2 colors are thus a representation of the patch as seen under two illuminants; the color difference is, in effect, color inconstancy, a phenomenon which can be better quantified using the Metamerism Tool (MI) tools. It is important to note that not all measured colors will display this inconstancy, and that this effect is distinct from fluorescence.

Note: The MI tool is best used to analyse non-fluorescent colors, or colors as they appear under non-fluorescent inducing sources, i.e. M2. If you see color inconstancy in the FluoCheck tool, this is merely a suggestion that further analysis may be required relatively to color inconstancy.

For the second example we measured another patch as the "Sample". The next two screenshots show the same measurements with different "FI formulas", CIELAB and CIEDE2000 respectively:



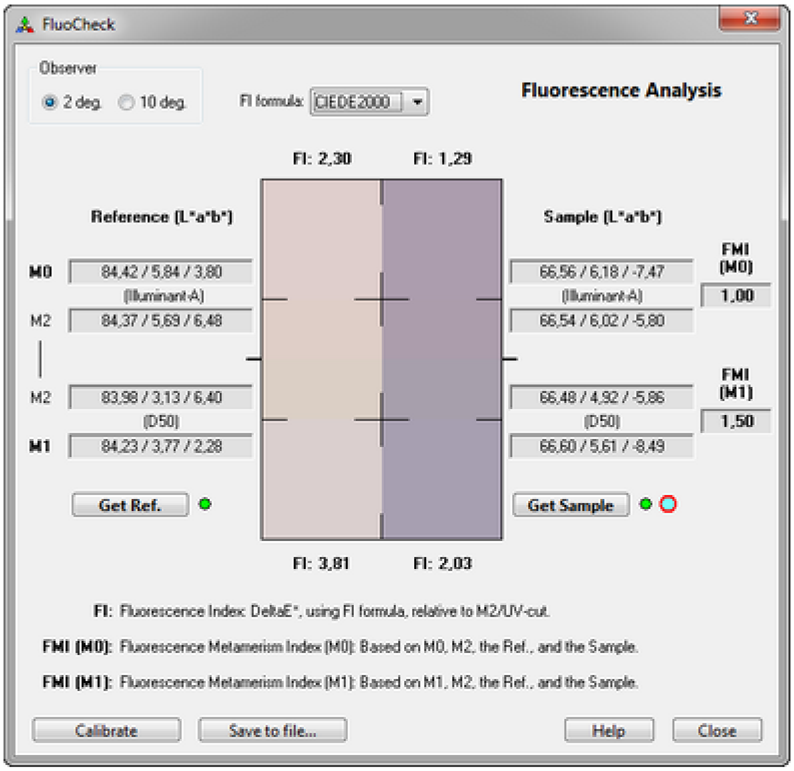


We want to bring your attention on five points in regards to this second example:

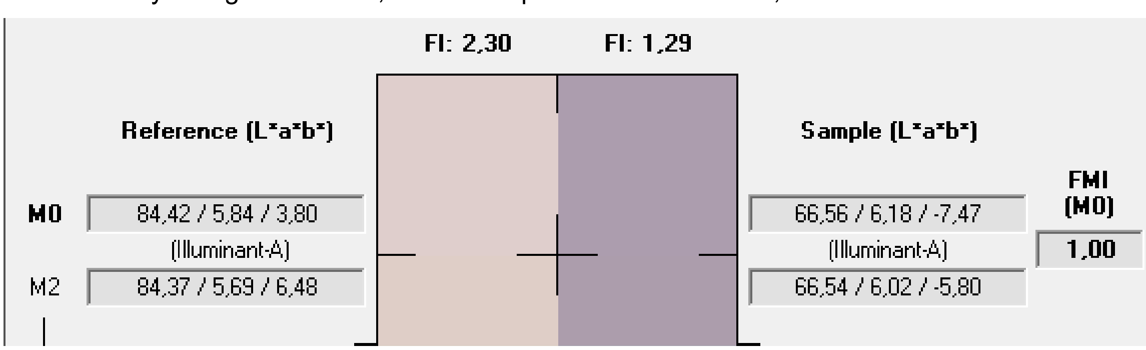
1. It is not required that the "Ref." and "Sample" be the same color as a goal since we can use this tool to evaluate how our patches jointly react to measurement conditions.
2. The FI values of the "Ref." change according to the FI formula, as expected.
3. The FI of the "Sample" is zero in both screenshots; this simply means that the sample is NOT fluorescent!
4. Two Fluorescence Metamerism Indices (FMI) were computed, one relative to M0 and the other relative to M1.
5. You will notice that the FMI is equal to the FI of the "Ref." for the screenshot on the top; this is a consequence of two factors: CIELAB was selected for the FI formula (the FMI is always computed with CIELAB), and the "Sample" is not fluorescent. In other words, if the sample was fluorescent, the FI and FMI would be different, even for a CIELAB FI formula.

Note: Because the FI and FMI are color differences, the same criteria and thresholds used in evaluating color differences should apply when assessing these numbers.

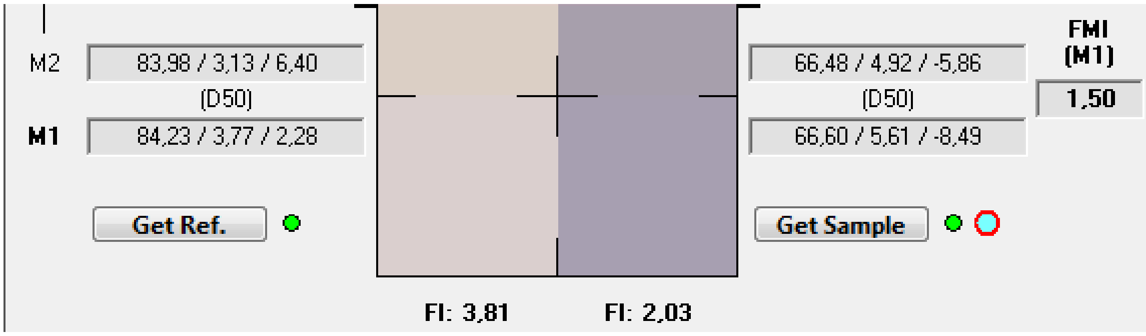
In this third example we kept the "Ref." of the previous two examples and measured another "Sample".



The FIs of the sample are not zero, indicating fluorescence, but they are not as high as the FIs of the reference. The FMI computed relative to M0, FMI(M0), is 1,00 and the FMI computed relative to M1, FMI(M1), is 1,50. Since the FMI values are lower than the FI, especially when the FI is computed with CIEDE2000 and the FMI with CIELAB, these results indicate that the two samples will somewhat change in the same fashion when subject to a fluorescent source. The lower FMI(M0) value (=1,0) also indicates that the color fluctuations for Illuminant A may well go unnoticed; this is not quite the case for D50, as we see below:



While there is fluorescence in both cases, M2-vs-M0 and M2-vs-M1, the variations are less noticeable in the screenshot above (M2-vs-M0) than in the screenshot below (M2-vs-M1).



In practice, this measurement could mean that the change between these two colors will be more noticeable under daylight (D50) than under tungsten illumination (Illuminant A) as the paper's Fluorescent Whitening Agents (FWA) degrade and there is less fluorescence. This degradation could also happen if looking at the colors in daylight but behind a window which cuts most of the UV content.

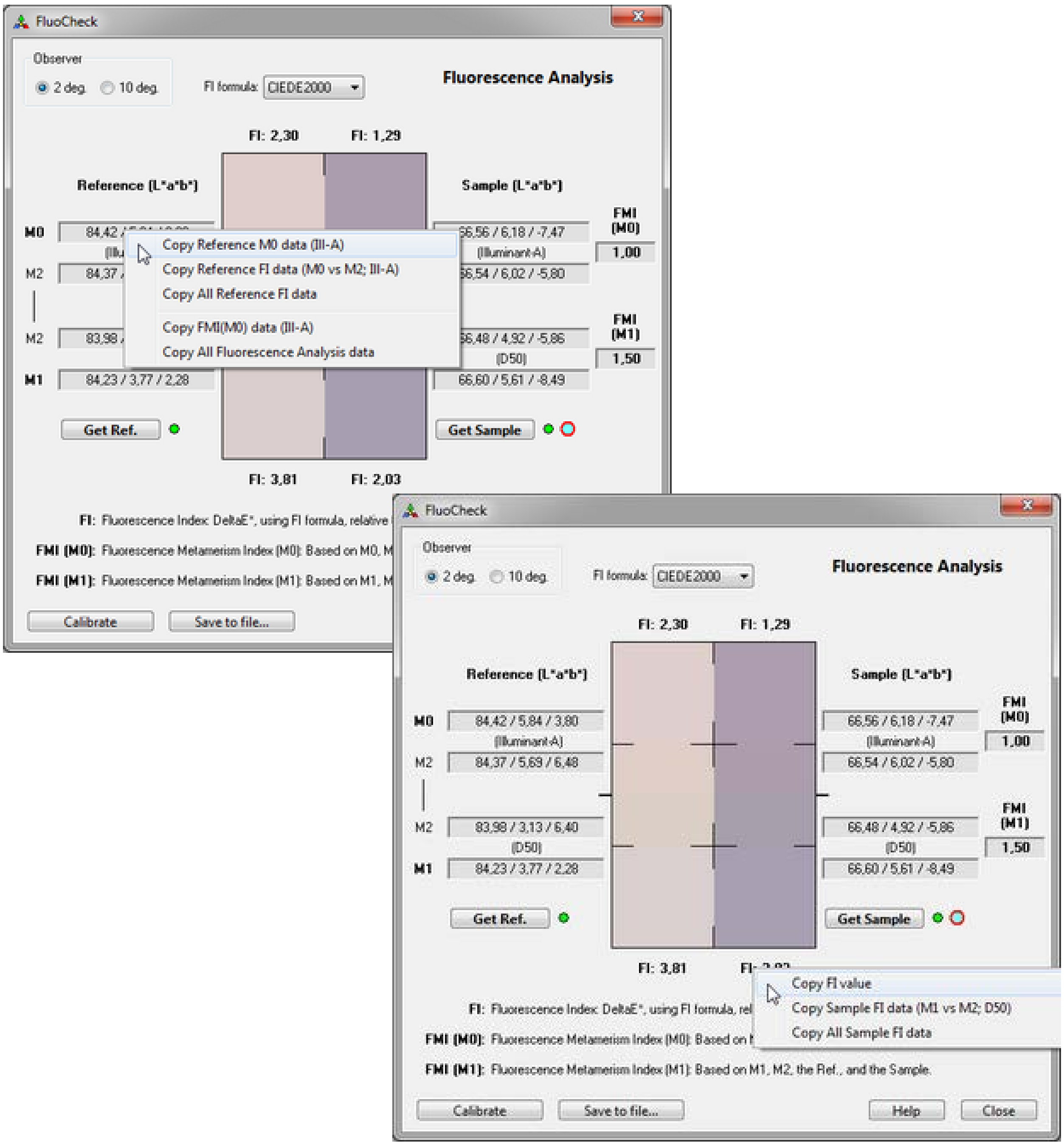
Note: A clipping indicator appears in the bottom left corner of a color patch when the color of the sample it represents is outside of the RGB space gamut of the monitor.

OTHER TOOL FUNCTIONS

At all times, you can calibrate the instrument by clicking the "Calibrate" button. The measurement mode for all FluoCheck tools is "Reflectance", by default, and cannot be changed.

Click on "Save to file..." to save a Fluorescence report. The report has tab-delimited data that can be directly imported in a spreadsheet program, and opened in many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting).

You can copy numerical data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on any data field (L*a*b*, FI, FMI)). Shown below is the contextual menus which appear with a right-click in the reference M0 L*a*b* data field and on the bottom-right FI. When copied, the data is transferred into the clipboard. Please note that L*a*b* values are separated by Tabs; you can then easily paste the values in a spreadsheet or document table, where they will be distributed in individual cells.



8.1 FluoCheck tools description

The FluoCheck tools are dedicated to the analysis of colored patches printed on fluorescent substrates, typically paper. With these tools you can evaluate how a printed color or a set of two colors will be perceived when illuminated by a light source with no UV content, a source with low UV content (Illuminant A), and a source with definite UV content (D50). These tools are made possible by the capabilities of X-Rite's i1Pro 2 and i1Pro 3 spectrophotometers which supports the **M0**, **M1**, and **M2** Measurement Conditions as defined in ISO 13655 (Ref. 42). Here is a short description of each condition:

- **M0:** The spectral power distribution of the light incident on the measured patch should conform to CIE Illuminant A, with a color temperature of 2856 K ± 100 K. Such a light source can be found in many colorimetric instruments, such as the i1Pro and i1Pro 2. It also closely corresponds to the spectrum of many halogen desk lamps. While a 2856 K blackbody does emit UV, the UV content for M0 is often not controlled and may vary between instrument models. M0 has traditionally been used for density measurements.
- **M1:** The spectral power distribution of the light incident on the measured patch should match CIE illuminant D50. This condition is specifically defined to study fluorescence by optical brighteners in the paper and /or in the printing inks. According to ISO 13655, conformance to M1 can be achieved by two methods. The first method is by providing a source which exactly matches illuminant D50 in both the UV and visible regions of the spectrum, with the UV requirement more precisely defined by ISO 3664. The second method is providing a separate UV source which replicates the effect of UV light on the optical brighteners of the paper; this is the method used in the i1Pro 2 (and apparently also by the i1Pro 3).
- **M2:** The measurement shall contain no contribution from optical brightening agents in the paper. While the spectral distribution is not explicitly defined, it shall be continuous in the wavelength range from 420 nm to at least 700 nm. The standard does not specify if the source should be filtered or if the measurement can be deduced from measurements with and without UV content. The i1Pro 2 uses the second method; it does not have a physical UV filter, and M2 data is obtained by processing the M0 and UV light measurements. If a paper is not fluorescent, then M0, M1 and M2 should be equal.

Note: ISO 13655 also describes the **M3** Measurement Conditions which covers instruments fitted with a polarizing filter; these conditions are not supported by the i1Pro 2 and the standard aperture i1Pro 3. M3 is supported with the large aperture i1Pro 3 Plus which does have an accessory polarizer head. Please note that M3 measurements are not required in the FluoCheck tools.

Important: Because the i1Pro 2 uses a separate UV source tuned for the optical brighteners typically found in paper, this UV source may not create fluorescence in the printing inks. For instance, some fluorescent inks are also excited by violet, blue, and even green light, with a re-emission in the yellow, orange or red portions of the spectrum. In such a case, a measurement made with an i1Pro 2, which is based on a M0 lamp, will show less ink fluorescence than an instrument base on a Xenon lamp which has relatively more violet and blue content. As for the i1Pro 3 and i1Pro 3 Plus, which use a LED-only based light source, they react the same way as an i1Pro 2 when measuring a sample printed with fluorescent ink and are likely similarly optimized to measure the effect of UV light on the substrate. Thus, it is not recommended to use the FluoCheck tool to analyze ink fluorescence.

The **Fluorescence Index** (**FI**) and the **Fluorescence Metamerism Index** (**FMI**) described on the next page were devised by BabelColor. The FI and FMI are not described in a standard but they are based on the standard-defined M0, M1, and M2 measurement conditions.

FLUORESCENCE INDEX (FI)

This index is obtained by computing the color difference between a measurement made with the M2 (UV-cut) measurement condition and a measurement made with either M0 (Illuminant A) or M1 (D50). The formula used to compute the color difference can be any of the standard color difference equations; it is selected using the "FI formula" menu in the FluoCheck window. However, if we consider that the FI can be somewhat associated in purpose to the Color Inconstancy Index (CII) measured in the Metamerism Index (MI) tools, we can recommend the CIE94 (2:2) formula, where k_L=2 and k_C=2 puts more weight on the hue (with k_H=1) than on the lightness and chroma, as did Berns for the CII (Ref. 25, p. 129).

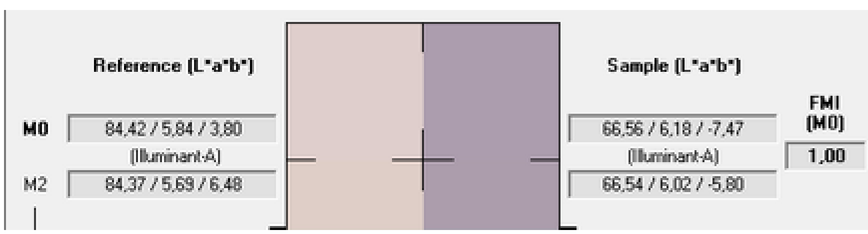
Please note that the FI could as well be measured using the Graph tools, by first making a reflectance measurement in M2, on the left side of the Graph tool, and then a measurement in M0 or M1 on the right side. The color difference obtained in the Graph tool would be identical to the FI of the FluoCheck tools. The advantage of using the FluoCheck tools is that you obtain the color difference, i.e. the FI, simultaneously for M2-vs-M0 and M2-vs-M1 while being able to visualize the patches in all three measurement conditions.

In addition, the FluoCheck tools enable you to compare a "Ref." against a "Sample", or two samples.

FLUORESCENCE METAMERISM INDEX (FMI)

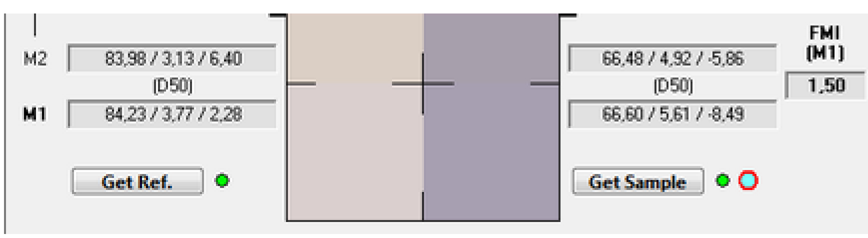
In the FluoCheck window, once you get the data that enables you to measure the FI for two samples, identified as"Reference" and "Sample" in the window, you can use this data to evaluate how the combined appearance of these two samples varies between a reference Measurement Condition (M2, UV-cut) and a UV-inducing condition (either M0 or M1). This overall appearance change is analogous to the HunterLab Metamerism Index (MI) of the Metamerism Index tools and we define the Fluorescence Metamerism Index (**FMI**) with the same equation, which is referred to as the *HunterLab Metamerism Index* equation (Ref. 44). However, because we have two UV-inducing conditions, M0 and M1, we effectively get two FMI equations, with the first one identified as ***FMI(M0)***, corresponding to the top portion of the FluoCheck window:

$$FMI(M0) = \sqrt{(\Delta L^*_{M0} - \Delta L^*_{M2})^2 + (\Delta a^*_{M0} - \Delta a^*_{M2})^2 + (\Delta b^*_{M0} - \Delta b^*_{M2})^2}$$



and the second one identified as ***FMI(M1)***, corresponding to the bottom portion:

$$FMI(M1) = \sqrt{(\Delta L^*_{M1} - \Delta L^*_{M2})^2 + (\Delta a^*_{M1} - \Delta a^*_{M2})^2 + (\Delta b^*_{M1} - \Delta b^*_{M2})^2}$$

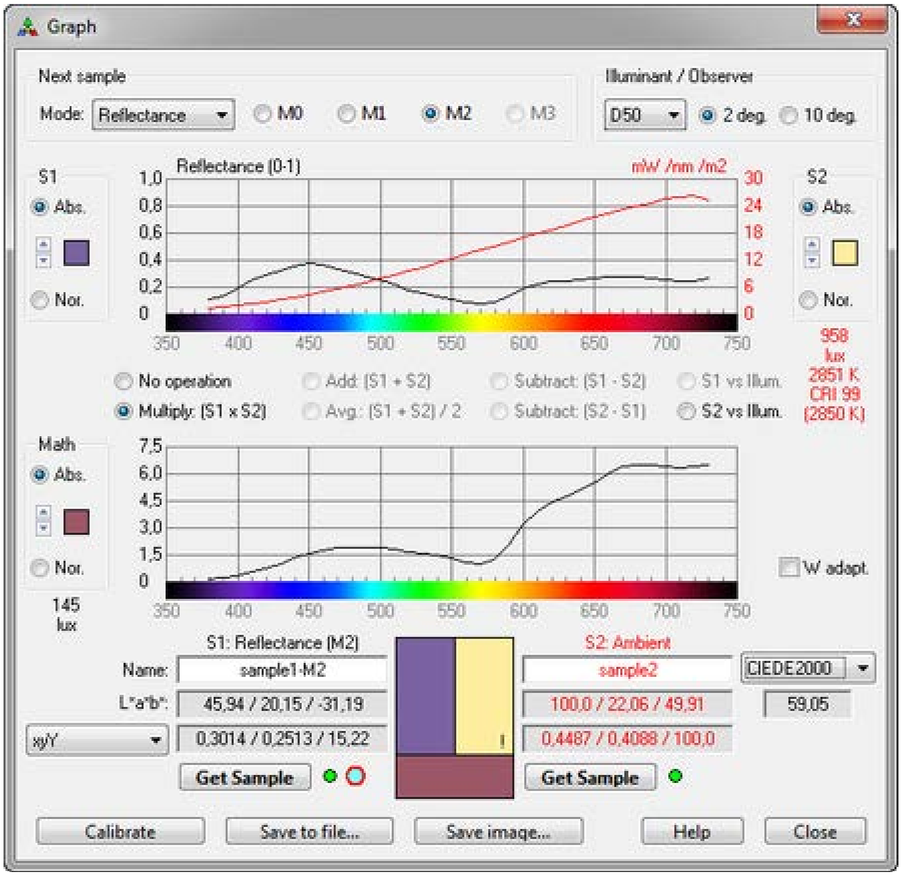


where M0, M1, and M2 refer to the measurement conditions, and where

$$\Delta L^* = L^*_{sample} - L^*_{ref}$$
$$\Delta a^* = a^*_{sample} - a^*_{ref}$$
$$\Delta b^* = b^*_{sample} - b^*_{ref}$$

are computed with the data of the measurement condition referred to in the FMI equation. As we can see by inspecting the equations, the FMI is based on CIELAB.

9. Graph tools



INTRODUCTION

The **Graph tools** window is opened either by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/Graph" menu.

The Graph tools enable you to:

- acquire, evaluate and compare two spectrums in relative or absolute radiometric units;
- perform basic mathematical operations on the spectrums;
- compare the spectrum of an ambient or flash source with the spectrum of an ideal blackbody or D-series illuminant;
- obtain the luminance or illuminance of sources (displays, ambient lights, photo-flashes);
- obtain the Correlated Color Temperature (CCT) and Color Rendering Index (CRI) of ambient and flash sources;
- obtain colorimetric coordinates (L*a*b*, xyY, etc.) of the spectrums for various illuminants and Standard Observer combinations;
- get the color difference between the two spectrums in many standard color difference formulas;
- export numeric data and spectrum images in bitmap (.bmp), JPEG (.jpg), or PNG (.png) format.

Important: To use these tools, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate" and "Get Sample" buttons of the Graph window being enabled (some controls will remain disabled if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Note: In Windows, if the i1Pro/i1Pro 2 or i1Pro3 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Instrument button support: When the Graph tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears next to a "Get Sample" button. This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button. The indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the previous measurement if required, or do a right-click to lock it on a given measurement. You can also do a left-click on a locked indicator; the new position will be locked.

SETUP

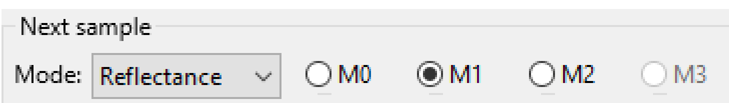
- It is assumed that your instrument is properly connected and detected, as discussed in the introduction just above.

- Select a measurement "Mode" in the "Next sample" group.

  The available measurement modes are:

  - Emission
  - Ambient (with the diffuser cap installed on the instrument)
  - Reflectance
  - Flash (with the diffuser cap installed on the instrument)

  For reflectance measurements, and if you are using an **i1Pro 2** with the "**i1Pro / i1Pro 2 (XRGA)**" driver or an i1Pro 3, you can select the "Measurement Conditions" M0 (Ill-A), M1 (D50), or M2 (UV-cut), as defined in ISO 13655 (Ref. 42). If you are using an i1Pro 3 Plus, the M3 (Pol.) Measurement Conditions will also be available. A description of the M0/M1/M2 measurement conditions can also be found in the FluoCheck tools.



  If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument.

  The photometric and radiometric units for emission, ambient and flash modes are:

Mode	photometric units name	photometric units	radiometric units (for spectrums)
Emission	luminance	cd / m^2	mW /nm /m^2 /sr
Ambient	illuminance	lux	mW /nm /m^2
Flash	integrated illuminance	lux-sec	mJ /nm /m^2

  Important: The "Ambient" and "Flash" modes are not available for older i1Pros which were sold without the diffuser cap accessory. These instruments can be factory refurbished; please contact X-Rite for additional information.

- Select the "Illuminant" and "Observer" that will be used to compute the tristimulus data.

  The available illuminants are:

  - A (Tungsten or Incandescent, 2856 K)
  - B (Direct sunlight at noon, 4874 K*, obsolete)
  - C (North sky daylight, 6774 K*)
  - D50 (Daylight, used for color rendering, 5000 K*)

- D55 (Daylight, used for photography, 5500 K*)
- D60 (Daylight, 6000 K*)
- D65 (New version of North sky daylight, 6504 K*)
- D75 (Daylight, 7500 K*)
- D93 (Daylight, 9300 K*)
- E (Uniform energy illuminant, 5400K*)
- F2 (Cool White Fluorescent (CWF), 4200 K*)
- F7 (Broad-band Daylight Fluorescent, 6500 K*)
- F11 (Narrow-band White Fluorescent, 4000 K*)

The colorimetric coordinates will be updated if these settings are changed after a measurement is done.

Important: The "Illuminant" and "Observer" settings have no effect on the spectrums' shapes and the spectrums' data values.

- Select the data type, or color space, that will be computed with the acquired data. L*a*b* is always computed in addition to the user-selected color space. Data will be updated if the color space is changed after a measurement is done.

  The available color spaces are:

  - L*C*h (ab) (i.e. L*C*h from L*a*b*)
  - L*u*v*
  - L*C*h (uv) (i.e. L*C*h from L*u*v*)
  - XYZ
  - xyY (recommended for **ambient** and **flash** measurements)

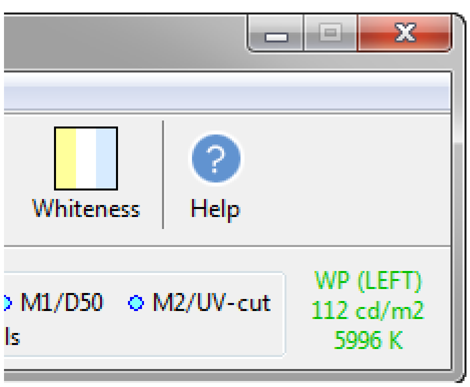
- Select the color difference formula that will be used with the acquired L*a*b* data; the difference will be updated if the formula is changed after a measurement is done.

  The available color difference formulas are:

  - CIELAB
  - CIE94 (i.e. the common formula, CIE94 (1:1))
  - CIE94 tex. (i.e. CIE94 for textile, CIE94 (2:1))
  - CMC (2:1)
  - CMC (1:1)
  - CIEDE2000

- If not already done, calibrate the selected measurement mode by clicking on the "Calibrate" button and following the on-screen instructions.

Note: In CT&A, emission calibration requires the measurement of a white patch, preferably located on the display or emissive surface on which subsequent measurements will be performed; this procedure sets the *White Point* (WP). The WP characteristics (display location, luminance and CCT) are shown in the toolbar window, as seen in green text in the next screenshot.



Important: The *L** (of L*a*b*) and *Y* (of XYZ) values of the **AMBIENT and FLASH color coordinates** are always 100 since they are considered as **sources**. As an example, look at the L*a*b* and xyY coordinates of **S2** on the bottom-right of the screenshot at the beginning of this section. (Note: this is different than what is done in the "L*a*b*/L*u*v* input" mode of the RGB vs RGB tool where *L** and *Y* are maximized relative to their *xy* (chromaticity coordinates) position in the selected RGB space, and where *L** and *Y* values of 100 can only be assigned to the chromaticity coordinates of the illuminant).

Important: The *L** and *Y* values of the **EMISSION color coordinates** are computed relative to the display *White Point*, as discussed above. Accordingly, the display white is assigned *L** and *Y* values of 100. Nothing prevents you of using another monitor or another emissive surface to set this reference value, and all subsequent emission measurements will then be referenced to this new white point. However, be aware that the L*a*b* and "Y" values, as well as the appearance of the patches of all previous emission measurements will NOT be updated. On the positive side, in emission measurements, the only absolute parameters are the chromaticity coordinates (xy), and these parameters should **not** be affected by an emission calibration change.

Here is a table which describes the difference between the RGB vs RGB tool and the Graph tools relative to **EMISSION** and **AMBIENT** measurements:

Mode	RGB vs RGB tool	Graph tools
Emission	• Y and L* are relative (0-100) to the calibration white Luminance (Yabs) • Y is limited by the maximum xyY values of the selected RGB space (i.e. the input may be clipped) • Patches with chromaticities outside of the RGB space will be clipped	• Y and L* are relative (0-100) to the calibration white Luminance (Yabs) • The input is NOT clipped
Ambient	• Y is the maximum value, for the RGB space, of the input xy coordinates (i.e. one or more RGB coordinate will always be 255) • Patches with chromaticities outside of the RGB space will be clipped	• Y and L* are always equal to 100 • The input is NOT clipped

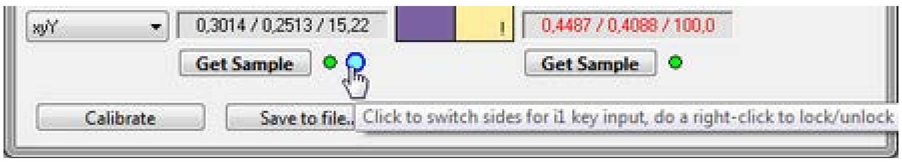
Note: Only x and y are absolute coordinates. While the absolute luminance and illuminance are provided in cd/m^2 or lux, Y is normalized when shown in the xyY and XYZ data fields.

Important: Many displays (usually CRTs, but sometimes LCDs) will change their brightness depending on what is displayed on the rest of the screen. This is why a single small white square over a black background is used for emission calibration. As a consequence, in some displays, you may find that, thereafter, white is measured with an *L** value of less than 100 in many situations. Also, most displays are not uniform, with the center portion "usually" at a higher luminance than the rest of the display; however, it is also possible that the display center is not the area with the highest luminance.

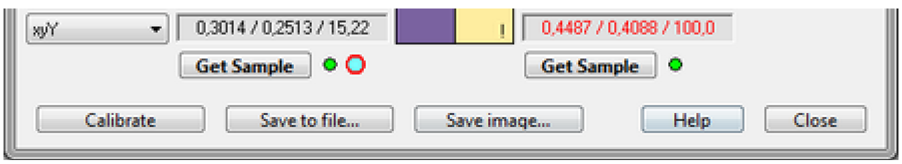
MEASUREMENTS

- **Emission, ambient and reflectance modes:** Before making any measurement, you should calibrate the instrument for the selected mode by clicking on the "Calibrate" button and following the instructions. Please note that the calibration process is not the same for all modes; however, calibrating for the ambient mode will also do the calibration for the flash mode. If you try to do a measurement and the calibrations was not done, or is outdated, you will automatically be directed through the calibration sequence before doing the measurement.

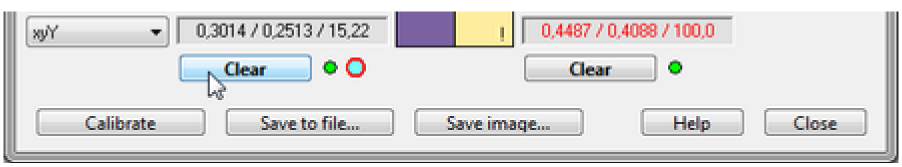
  To make a measurement, click on one of the "Get Sample" buttons or press the instrument button. A large blue indicator is located beside the input that will be selected if you press the instrument button:



  This indicator automatically changes location when an input is done at one position. Do a left-click on an indicator to change its position or a right-click to lock it (a locked indicator has a red border:). You can also do a left-click on a locked indicator; the new position will be locked.



  To **erase** a measurement, first press the **Alt** key, in Windows, or the **Option** key on a Mac. Whenever the mouse cursor is within the tool window, the "Get Sample" buttons will change their caption to "**Clear**" (if there is a measurement). To clear the sample, click the button with the mouse while keeping the **Alt** or **Option** key pressed:

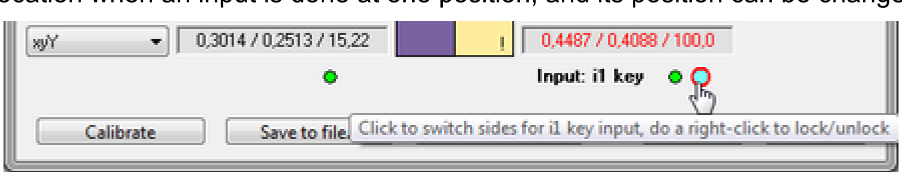


- **Flash mode:** Before making any measurement, you should calibrate the instrument by clicking on the "Calibrate" button and following the instructions. Please note that calibrating for the flash mode will also do the calibration for the ambient mode. If you try to do a measurement and the calibrations was not done, or is outdated, you will automatically be directed through the calibration sequence before doing the measurement.

  To make a flash measurement:

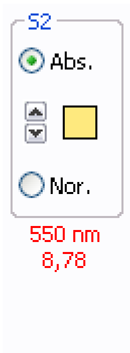
  1. press and **hold** the instrument button (you should hear a short beep; your computer must be connected to a speaker and the sound volume should not be muted!);
  2. trigger the flash;
  3. release the instrument button (you should hear a second short beep).

  Because of the above sequence, where it is required to press and hold the instrument button, it is not possible to start a flash measurement from the program window; accordingly, **the "Get Sample" buttons are hidden**. The sample to which the next instrument key press will be assigned is identified by the "**Input: i1 key**" text and by the blue indicator. As discussed above in this section, the indicator automatically changes location when an input is done at one position, and its position can be changed or locked using the mouse.

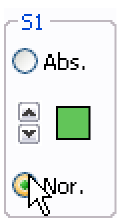


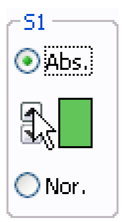
INTERFACE FEATURES

When a measurement is made in **emission**, **ambient** or **flash** mode, the photometric quantity, in cd/m^2, lux, or lux-sec respectively, and the *Correlated Color Temperature* (CCT), in kelvin, is shown under the scale adjustment groups (labeled S1, S2 and Math). In addition, in **ambient** or **flash** mode, the *Color Rendering Index* (CRI) is provided (the reference Illuminant used to determine the CRI is displayed between parentheses); this is shown just below, on the left. You can also see the individual coordinates of the spectrums by moving the mouse over the graphs; again, this information is displayed under the scale adjustment group, as shown below, on the right.

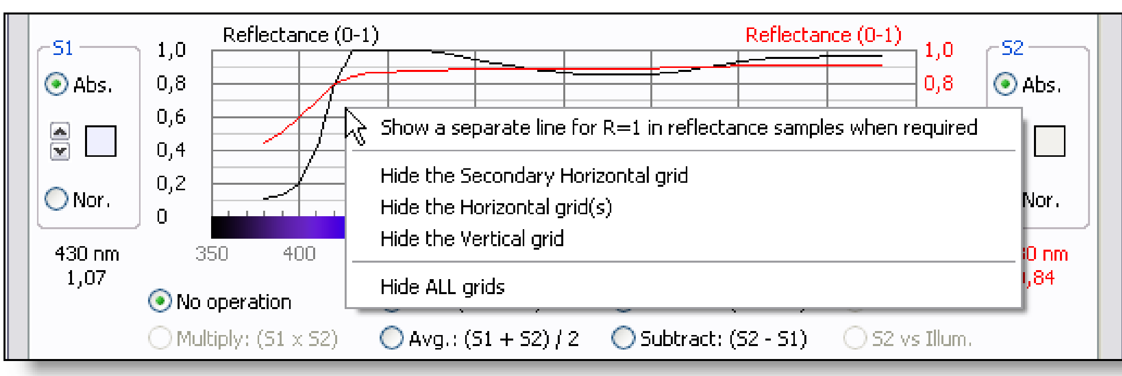


You will notice that, by default, the coordinates for emission, ambient and flash measurements are **absolute** values ("Abs."). If desired, you can **normalize** a graph by selecting the "Nor." radio button in the scale adjustment groups, as shown below on the left; this action will set the maximum of a spectrum to one (1). The normalization is for viewing purposes only; internally, the data is still saved in absolute coordinates. You can also zoom-in and zoom-out a graph by clicking the small arrows in the scale adjustment zones, as shown below on the right.

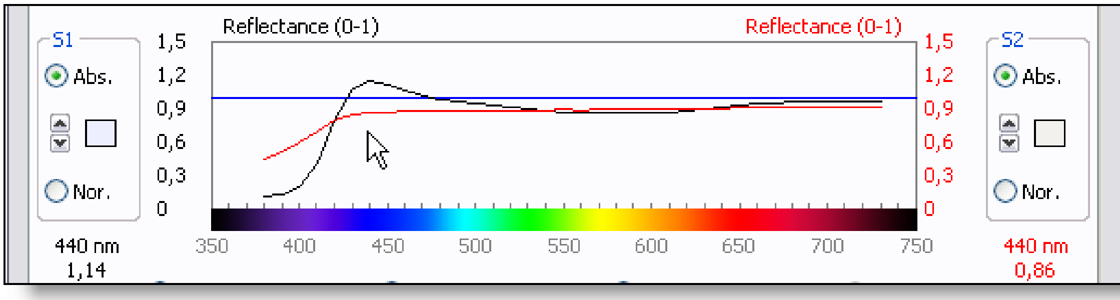




To change the graph grids appearance, use your mouse right-click (or **ctrl + click** on a one-button Mac mouse) and select an option.



By first hiding all grids then selecting to show a separate line for R=1, you can easily view the reflectance of a fluorescent paper, as shown in the example below, which is compared with a very neutral but grayish paper. At 440 nm, corresponding to the mouse cursor position, the reflectance of this fluorescent paper is 114% (R=1,14) compared to 86% for the more neutral paper.



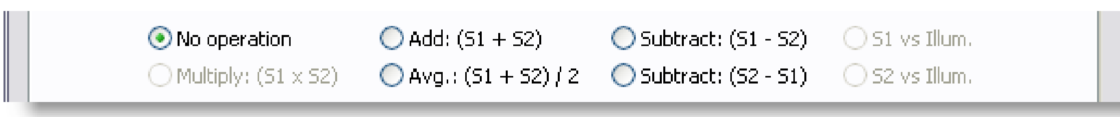
Note: A clipping indicator appears in the bottom left or right corner of a color patch when the color of the sample it represents is outside of the RGB space gamut of the monitor.

SPECTRUM MATH OPERATIONS AND FUNCTIONS

Mathematical operations can be performed between two samples; some functions require only one sample. The operations are enabled according to the measurement modes of the samples. All operations are performed on absolute values even if the display is normalized. The enabling logic is the following:

SPECTRUM OPERATIONS		**S2**			
		Emission	**Ambient**	**Flash**	**Reflectance**
S1	**Emission**	Add, Avg, Sub	S2 vs	S2 vs	Mult
	Ambient	S1 vs	Add, Avg, Sub S1 vs, S2 vs	S1 vs, S2 vs	Mult, S1 vs
	Flash	S1 vs	S1 vs, S2 vs	Add, Avg, Sub S1 vs, S2 vs	Mult, S1 vs
	Reflectance	Mult	Mult, S2 vs	Mult, S2 vs	Add, Avg, Sub

Here is what the middle section of the dialog looks like when two reflectance samples are measured:



- **Multiply**: This is always done with a **reflectance** spectrum **and either** an **ambient**, **flash**, or **emission** spectrum.

  There are two ways to consider the resulting spectrum:

  a- As a source whose spectrum is the light reflected from the color patch.
  b- As the reflectance of a color patch under an Illuminant (ambient, flash or emission) under which you are *white adapted*.

  You should select "b-", and check the "W adapt." box located to the right of the Math spectrum, when the emission or ambient spectrum is close to "white", and "a-" (which corresponds to "W adapt." unchecked) in all other cases (the "b-" option has no sense for a deeply colored light source).

  In the screenshot shown at the start of this section, Sample #1 (S1) is a reflectance measurement of a purple color patch done with the M2 measurement condition whereas Sample #2 (S2) is an ambient measurement of a typical halogen desk lamp, with a color temperature and a spectrum close to Illuminant A. The illuminance is 958 lux and the color temperature is 2850 K; please note that this light source is represented as a light-yellow patch because the selected reference illuminant is D50 and a 2850 K source looks yellower when compared to a D50 source (even though a 2850 K source is perceived as "white" when our eyes are adapted to it, after a few seconds).

In the same screenshot, the "Multiply (S1 x S2)" operation is selected and a third graph is shown. We clearly see the effect of the multiplication. Also shown below the scale adjustment group, labeled "Math", is an illuminance value of 145 lux; the difference from the original 958 lux value is from the absorption in the reflectance sample. 145 lux is the effective luminance of the light that would result from the sample reflection, as if filtered by it (case "a-" above); apart from being dimmer, the resulting patch is also redder, a consequence of the original source spectrum having much more red content than blue content.

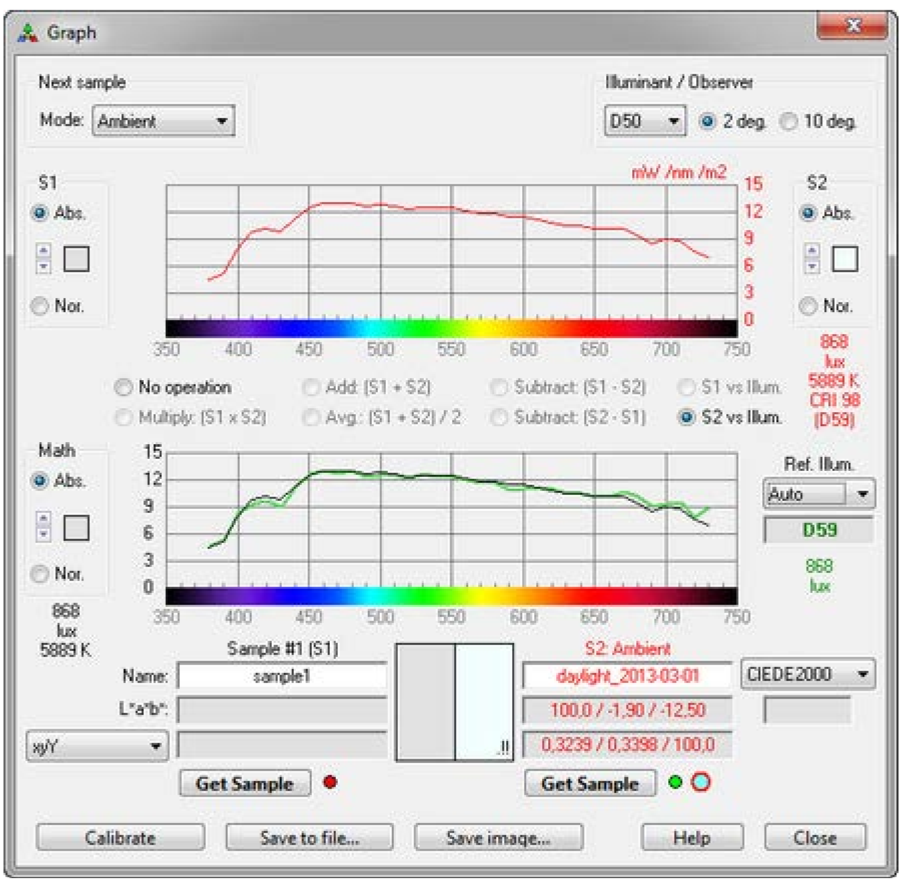
If you assume that you are "illuminant adapted" to the source and that the sample is basically lit by white light (case "b-" above), the resulting perceived color is closer to the one of the original sample. As mentioned, this can be simulated by clicking the "W adapt" box (not shown in the screenshot).

- **Add**: Adding two reflectance spectrums will simulate an additive RGB process. However, adding reflectance and emission spectrums may result in *L** and *Y* values superior to 100. When adding ambient spectrums, the resulting coordinates will always be normalized to *L** and *Y* values of 100.

- **Average**: The resulting spectrum has the same shape as the one obtained with the "Add" function, but its brightness is half the one of the "Add" function.

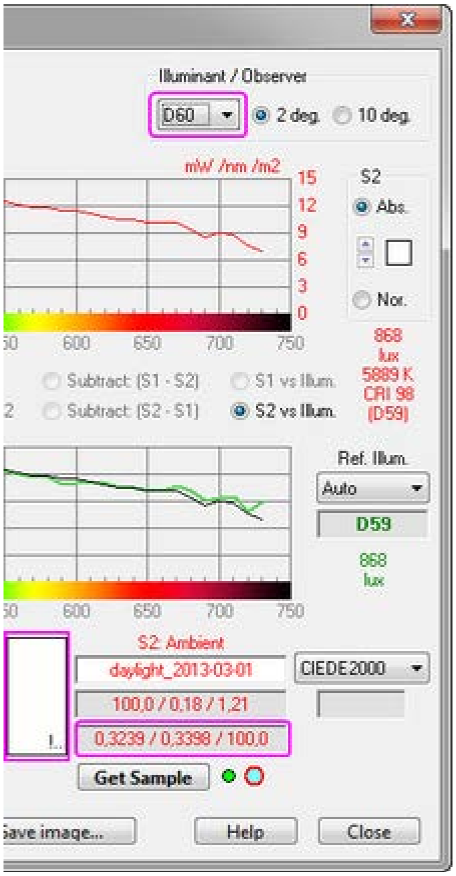
- **Subtract**: You can select to subtract either spectrum from the other. Negative values, while displayed, are clipped to zero — for all measurements types — when computing tristimulus data, for color patch representation, and for data export.

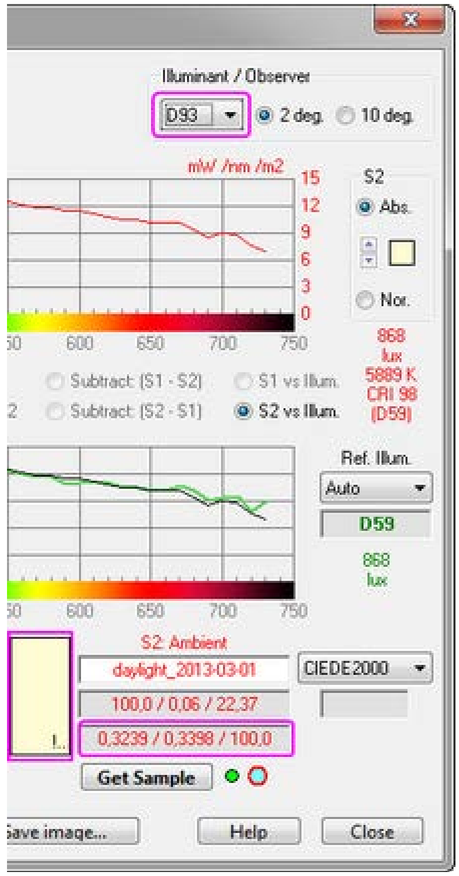
- **S1 vs Illum. or S2 vs Illum.:** These functions appear whenever you measure a sample in "Ambient" or "Flash" mode. In the screenshot below, "S2: Ambient" is the measurement, in ambient mode, of daylight measured through a window (in winter, around noon, with a heavy cloud cover and snow on the ground); accordingly, the "S2 vs Illum." radio button is enabled. When this button is selected, the spectrum of the sample is reproduced in the bottom graph, in black, along with a spectrum, in green, of an "ideal" reference illuminant corresponding to a rounded value of the measured sample's CCT. The reference illuminant type, a blackbody or a D-series Illuminant, is based on the CCT value; in addition, ten commonly used illuminants can be manually selected (there is more information on CCT selection further down):



In this case, the sample CCT is 5889 K and the automatically selected reference illuminant used for comparison is a D-series Illuminant at 5900 K (i.e. D59). We see that the measured light has essentially the same spectral distribution as the reference daylight illuminant.

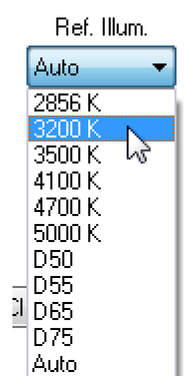
You will notice that the color of the patch representing the measured daylight has a slight blue tint. This is because its CCT, D59, is higher than the selected reference illuminant, D50, and thus corresponds to a bluer chromaticity. Here is what happens if we select D60 and D93 as the reference illuminant:





When we select D60, the patch color is almost pure white; this is expected since D60 is very close to the source CTT (=D59). When we select D93, the patch color now has a definite yellow tint; this is because the chromaticity of D93 is bluer than the one for D59, and the measured source does appear relatively yellower in comparison. You will also notice that, in all three screenshots, the chromaticity coordinates of the measured light (0,3239 / 0,3398 / 100,0) remains unchanged but the L*a*b* value, computed using the reference illuminant, does change (with the most neutral value obtained for a D60 reference illuminant).

Important: When selecting "S1 vs Illum." or "S2 vs Illum.", the reference illuminant is ALWAYS generated for the SAME ILLUMINANCE/LUMINANCE as the selected sample (868 lux in this example) so that you can better compare them with an absolute ("Abs.") scale.



You can also manually select other illuminants with the "Ref. Illum." Listbox shown on the right. The selection comprises a 2856 K blackbody, which is Illuminant A, a 3200 K blackbody generally used for TV Studio lighting, as well as four blackbodies corresponding to many **SoLux** lamps, and four commonly used Daylight series (D-series) illuminants. Selecting "Auto" will compute the ideal spectrum based on the measured CCT, in kelvin. A D-series illuminant will be selected for color temperatures over 4000 K, and a blackbody will be selected for color temperatures below 4000 K. The temperature is assigned in steps of 100 K for D-series illuminants and 50 K for blackbodies. The spectral data of the reference illuminant is scaled to match the measured illuminance; it can be exported to a file (see below).

OTHER TOOL FUNCTIONS

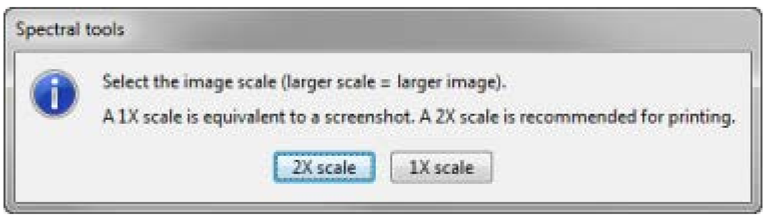
At all times, you can calibrate the instrument by clicking the "Calibrate" button. The calibration will be done for the measurement mode selected in the "Next sample" group. Please read the **SETUP** section above for important information on emission calibration.

Click on "Save to file..." to save the spectrums of the measured samples and of the mathematical operations, if selected. You can use the text entry fields to assign a custom name to each sample. The report has tab-delimited data that can be directly imported in a spreadsheet program as well as many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting). The file is also CGATS compliant and can be opened by many color-management software, including BabelColor's PatchTool and X-Rite/GretagMacbeth MeasureTool.

Important: Although the ambient, emission, and flash spectrums are saved in a CGATS compatible file format, these spectrums are not normalized to 1 or 100, like a reflectance spectrum. The appearance of the patch and the computed color coordinates will thus not be correct in programs that can read these files.

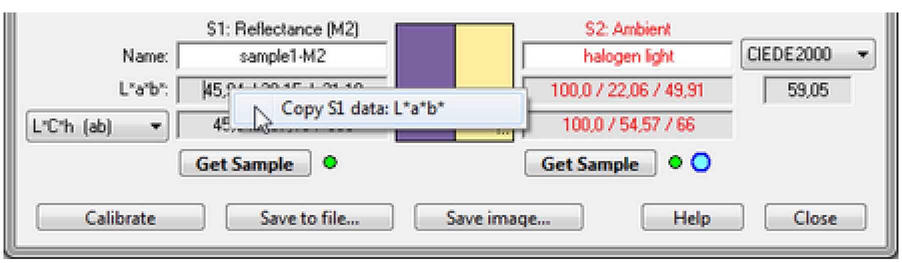
Hint: An ambient spectrum saved in the Graph tools can be loaded in the MI tools as a "Measured illuminant" using the "Load.." button. Such a spectrum can also be loaded as a measurement in the ISO 3664+ tools (look for the section on how to load an ambient spectrum from a file). In both cases, it is important to save only one spectrum in the file, erasing the second spectrum with the method described in the **MEASUREMENTS** section above if required.

Click on "Save image..." to save an image of the display. You will be shown a dialog where you are asked to select a printing scale:

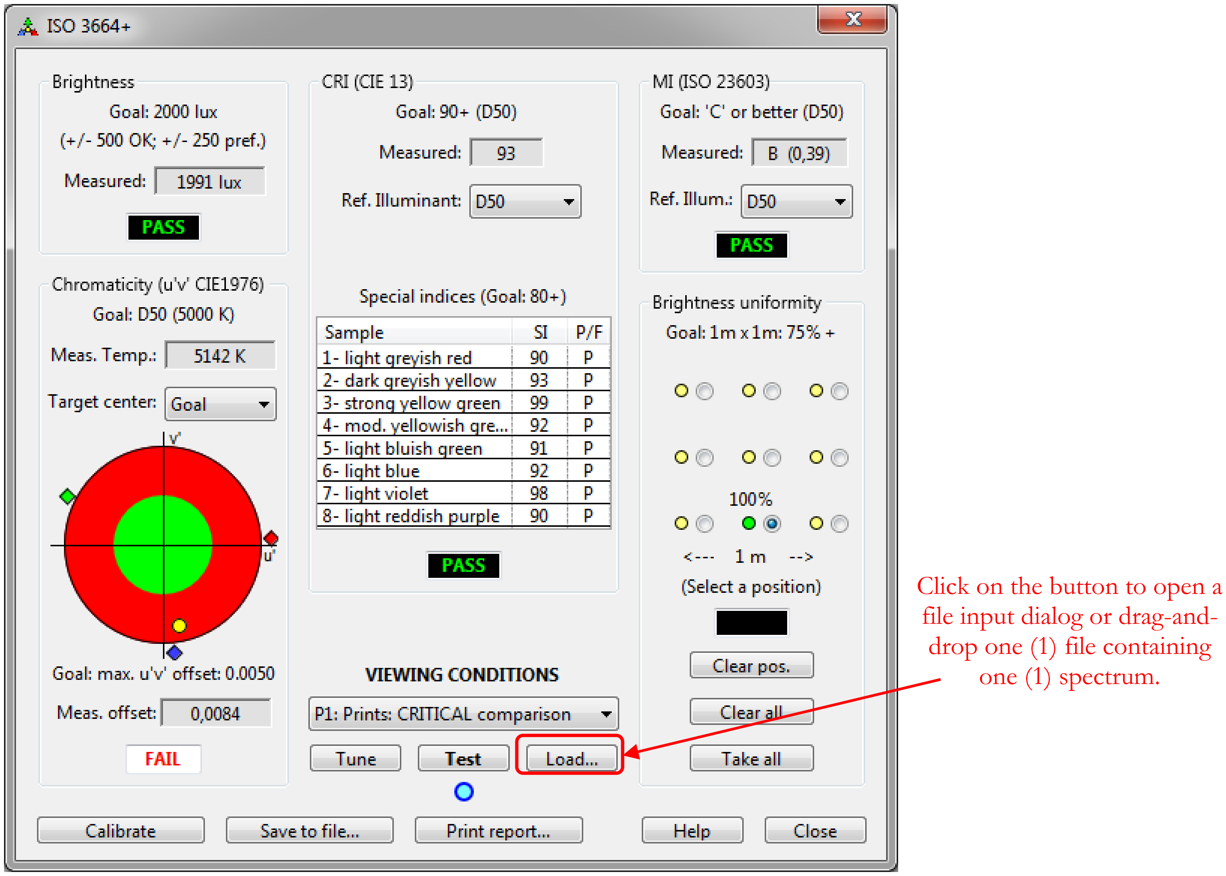


The 1X scale is equivalent to a screenshot. The 2X scale draws everything twice the size; this is the same as doubling the resolution for the same image size. The 2X scale is recommended if you want to use the image in a printed report.

You can copy numerical data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on any data field. Shown below is the contextual menu which appears with a right-click on the **L*a*b*** data field of **Sample #1 (S1)**; selecting the menu will transfer the three coordinates into the clipboard, separated by Tabs. You can then easily paste the values in a spreadsheet or document table, where they will be distributed in three columns.



10. ISO 3664+ tools



INTRODUCTION

The **ISO 3664+ tools** help in measuring if a viewing system meets selected requirements of ISO 3664 ("*Viewing conditions - for Graphic Technology and Photography*") and other standards referred by it, with additional custom goals for increased flexibility in characterizing your environment. The ISO 3664+ window is opened either by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/ISO 3664+" menu.

Important: While a measurement may meet a requirement, such as the brightness level, the CRI, the Metamerism Index (MI), etc., overall compliance to a standard requires that all tests in the standard be passed as measured by equipment which exactly meets the specified characteristics. For instance, the i1Pro and i1Pro 2 provide spectral data at 10 nm increments between 380 and 730 nm while the data tables of many standards referred to by ISO 3664, including ISO 23603, CIE S 012, and CIE 13, are defined for wider wavelength ranges and for 5 nm bandwidth instruments. Obviously, since an i1Pro cannot provide data below 380 nm, the Ultra-Violet (UV) Metamerism Index of ISO 23603 / CIE S 012 cannot be measured. On the other hand, in the great majority of cases, with appropriate data processing, the effects of its larger instrumental bandwidth are small or negligible, and provide results comparable to the ones obtained with a 5 nm bandwidth instrument, with more apparent differences sometimes seen with light sources which exhibit very narrow spectral peaks. As with any instrument, you should also take into account the instrument accuracy provided by the manufacturer when assessing its measurements.

The ISO 3664+ tools are:

- **Brightness:** Measure ambient illuminance or display luminance.
- **Chromaticity:** Measure the Correlated Color Temperature (CCT, in kelvin) of your ambient illumination or display. Measure the offset from ideal chromaticity coordinates (*u' and v'* defined in CIE1976 and measured with the 10 degree CIE1964 Observer).
- **Color Rendering Index (CRI):** Based on CIE 13.3: 1995, the CRI is computed using eight pre-defined color patches whose coordinates are compared with a reference daylight illuminant of prescribed temperature (D50 in the case of ISO 3664). You have the choice of using either the prescribed Illuminant, other common illuminants, or have the program automatically select the corresponding blackbody or D-series Illuminant.
- **Metamerism Index (MI):** This test assigns a Quality Grade to the measured illumination relative to a selected "ideal" daylight illuminant. This grade is expressed by a letter from "A" to "E", with "A" being the best grade. The grade is based on the average color difference between L*a*b* data obtained with a set of virtual metamers (i.e. theoretical reflection samples) and the measured ambient light, which is compared to the data obtained with the ideal illuminant (D50 for ISO 3664). Both a visible and UV MI are specified in ISO 3664 but only the visible MI can be computed with an i1Pro.
- **Brightness uniformity (for ambient measurements, transparency viewer):** Measurements can be performed for up to nine positions identified by radio buttons in the "Brightness uniformity" group. When a measurement is done, the relative brightness at this position is shown above the radio button. The reference brightness is the measurement done in the center position, if measured; if the center position is not measured, then the reference brightness is the maximum value measured at any position. Please note that it is not only the brightness which is measured at each position, but the **CCT**, the **chromaticity**, the **CRI** and the **MI** data as well.
- **Brightness uniformity as per ISO 12646:2008, Section 4.4 (for color monitors):** Measurements can be performed for up to nine positions located on a **non-uniform** 3 x 3 grid which favors the monitor's center area. Measurements can be done on WHITE, GREY, and DARK-GREY targets for each position. When a measurement is done, the **relative brightness** is shown for this position. The reference brightness is the measurement done in the center position, if measured; if the center position is not measured, then the reference brightness is the maximum value measured at any position. Please note that, for the white targets, it is not only the brightness which is measured at each position, but the **CCT** and **chromaticity** as well.
- **Tone uniformity, i.e. Color uniformity, as per ISO 12646:2014-Final Draft, Section 4.2.2 (for color monitors):** This test is identified as "**Color**" in CT&A's interface since this is what is being compared. Measurements can be performed for up to twenty-five positions located on a **uniform** 5 x 5 grid. Measurements can be done on WHITE, GREY, and DARK-GREY targets for each position. When a measurement is done, the **Color difference** is shown relative to the center position, if measured; if the center position is not measured, then the reference is the position corresponding to the brightest target of this color. Please note that, for the white targets, the **CCT** and the **chromaticity** are measured as well.
- **Tonality Evaluation, i.e. Grey/White Tone ratio uniformity, as per ISO 12646:2014-Final Draft, Section 4.2.3 (for color monitors):** This test is identified as "**Tone**" in CT&A's interface since we are comparing tone ratios. Measurements can be performed for up to twenty-five positions located on a uniform 5 x 5 grid. Measurements need to be done with both WHITE and GREY patches for a given position. When a tone ratio can be computed, the deviation of this ratio is shown relative to the center position, if measured; if the center position is not measured, then the reference is the position with the brightest WHITE patch for which tonality was computed. Please note that, for the white targets, the **CCT** and the **chromaticity** are measured as well.

Important: Although it is identified with the same name, the Metamerism Index referenced to in ISO 3664 is not the same as the MI determined in the MI Tools. The MI test specifically called for in ISO 3664 is ISO 23603. This is the same test defined in CIE S 012 /E:2004, which is an evolution of the CIE 51 test. The metamers of CIE S 012 are basically identical to the ones of CIE 51; however, their spectrums are now defined between 380 and 780 nm instead of between 400 and 700 nm in CIE 51. The grade categories for CIE 51 and CIE S 012 are the same and are computed in the same manner.

Important: The ISO3664+ tools can accept input from a file or from a supported instrument. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use these tools. A file must contain only one (1) spectrum. The file may be either in CGATS format, or a plain text file; the specific requirements for each file formats are presented in the input file requirements section. There are two methods to open/load a file:

- 1st method: Click on the "**Load...**" button and select the file to open with the file input dialog.
- 2nd method: Drag-and-drop one (1) file on the "**Load...**" button.

Important: To measure a light source with the ISO3664+ tools, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate", "Tune", "Test" and "Take all" buttons of the ISO3664+ window being enabled (some data entry buttons and controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Note: In Windows, if the i1Pro/i1Pro 2 or i1Pro 3 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Instrument button support: When the ISO 3664+ tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears between the "Tune" and "Test" buttons. This indicator confirms that the next instrument key press will be assigned to this window's "Test" button; of course, you can also do a mouse click on any data entry button.

Click on a link in the Table of Contents below to jump to a specific section.

ISO 3664+ tools - Table of Contents

See also:

- Tutorial 8: Measure your display characteristics with the ISO 3664+ tools.

10.1 ISO 3664+ tools description

The **ISO 3664** standard, *Viewing conditions - Graphic Technology and Photography* (Ref. 32), is mostly a collection of other standards and accepted procedures to which it makes reference, and from which it selects particular conditions in regards to its specific target audience. To these, CT&A adds some options and additional related measurements, thus the "+" after ISO 3664 (click here for information on the ISO 3664+ user interface).

See the end of this section, or click on the references numbers, for contact and purchasing information on the publications and standards mentioned herein.

The principal standards and procedures referred to by ISO 3664 are:

- **CIE 13.3-1995**: *Method of Measuring and Specifying Colour Rendering Properties of Light Sources* (Ref. 33). This procedure is used to determine the *Color Rendering Index* (**CRI**).

  The CRI is a number between 0 and 100, with 100 being the best value, which defines how well colors are rendered by a light source in comparison with a reference illuminant, or standard. This standard can be either a thermal radiator (blackbody) or a D-series (daylight) illuminant.

  The first step in obtaining the CRI is to compute the color difference (*Ei*) of eight pre-defined color patches whose coordinates are determined using both the test source and the reference illuminant. Subtracting the scaled color differences to 100 provides eight numbers which are called *Special Color Rendering Indices* (*Ri*):

  $$R_i = 100 - 4{,}6\Delta E_i$$

  The CRI is the average of the eight special indices:

  $$CRI = \frac{1}{8}\sum_{i=1}^{8} R_i$$

  The reference illuminant is D50 in ISO 3664, but in this tool, you have the choice of using either the prescribed illuminant, other common illuminants, or let the program automatically select it. In "Auto" mode, a D-series illuminant will be selected for color temperatures equal to or larger than 5000 K, and a blackbody will be selected for color temperatures below 5000 K.

  The color patches are "real" patches (compared to CIE 51; see below) with the following descriptions and references:

No.	Color appearance under daylight	Munsell notation (approx.)
TC S01	light grayish red	7,5R 6/4
TC S02	dark grayish yellow	5Y 6/4
TC S03	strong yellow green	5GY 6/8
TC S04	mod. yellowish green	2,5G 6/6
TC S05	light bluish green	10BG 6/4
TC S06	light blue	5PB 6/8
TC S07	light violet	2,5P 6/8
TC S08	light reddish purple	10P 6/8

  The CRI, even though relied on by many, and often quoted as a measure of quality by lamp companies in particular, should not be considered simply at its face value. With the possibility of selecting a reference in a large array of illuminants, it is not too difficult to find an illuminant for which the computed CRI is over 90. To prevent any abuse, the reference illuminant should always be given in association with the CRI. Also, even though the color rendering properties of illuminants as different as a blackbody at 2856 K (Illuminant A) and D65 (daylight, 6500 K) are not the same, they will both result in a CRI of 100 if the test source matches the reference.

Because of its limitations, many feel that a good CRI alone is not enough (some critics are even harsher!). However, it can be shown (Ref. 30) that by combining a CRI value to a *Quality Grade*, as obtained with ISO 23603 / CIE S 012, described below, one can obtain a more accurate assessment of its viewing environment.

Note: This index is computed for ambient type illumination only, not for color monitors.

- **ISO 23603 / CIE S 012/E**: *Standard method of assessing the spectral quality of daylight simulators for visual appraisal and measurement of colour* (Ref. 32). This procedure is used to determine a *Metamerism Index* (**MI**) and a *Quality Grade*. This index is not the same as the one computed in the MI Tool although it is similarly based on measuring metameric differences using the CIELAB color difference formula.

ISO 23603 and CIE S 012 /E:2004 are identical; they are an evolution of the CIE 51 test:

CIE 51.2-1999 *A Method for Assessing the Quality of Daylight Simulators for Colorimetry* (Ref .33).

The metamers of ISO 23603 / CIE S 012 are basically identical to the ones of CIE 51; however, their spectrums are now defined between 380 and 780 nm instead of between 400 and 700 nm in CIE 51 (see Ref. 31 which contains tabular data on the metamers used for the visual index of CIE S 012). The MI is computed in the same manner for CIE 51 and ISO 23603 / CIE S 012, and the quality grade categories are the same.

The computation of this MI is based on the average color difference of five pairs of virtual metamers (i.e. theoretical, or mathematically defined). These metamers have been defined in such a way that the computed color difference is zero for all pairs if the illuminant under test has the same spectrum as the ideal illuminants; computations are done with the 10 degree Observer (CIE1964). This ideal illuminant is D50 for ISO 3664 but ISO 23603 also covers the use of D55, D65, and D75. A different pair of metamers is assigned by the standard for each reference illuminant. Any of these reference illuminants can be selected within the tool; click here for information on this interface.

The difference between ISO 23603 and CIE 13, used to compute the CRI, is that CIE 13 compares the same patches with two illuminants while ISO 23603 compares two metamers with the test illuminant.

The five virtual metamers have the following L*a*b* and L*C*h coordinates:

No.	2 degree Observer (CIE 1931)										
	D50					D65					C
	L*	a*	b*	C*	h	L*	a*	b*	C*	h	Munsell notation
1	59,0	31,2	59,5	67,2	62,3	57,9	27,5	58,0	64,1	64,6	5,7YR 5,7/10
2	25,5	21,7	-9,27	23,6	337	25,2	21,6	-10,33	23,9	334	1,5RP 2,5/5,2
3	36,6	-2,79	24,2	24,3	96,6	36,4	-4,90	24,1	24,6	101,5	9,7Y 3,6/3,7
4	57,2	5,63	-16,7	17,6	289	57,4	5,99	-16,2	17,3	290	9,1PB 5,6/4,4
5	46,9	29,3	-2,25	29,4	356	46,3	27,5	-2,97	27,6	354	5,0RP 4,6/6,4

No.	10 degree Observer (CIE 1964)									
	D50					D65				
	L*	a*	b*	C*	h	L*	a*	b*	C*	h
1	57,9	32,2	58,5	66,8	61,1	56,5	29,3	56,4	63,6	62,5
2	25,7	18,3	-9,68	20,7	332	25,4	18,1	-10,59	21,0	330
3	36,0	-0,56	23,6	23,6	91,3	35,7	-2,13	23,2	23,3	95,2
4	57,9	1,26	-15,3	15,4	275	58,2	1,26	-14,6	14,6	275
5	47,1	24,4	-1,64	24,4	356	46,6	22,4	-2,17	22,5	354

The coordinates in the "**10 degree**" table above are the **same for both metamers** of a given pair, by definition. The coordinates in the "**2 degree**" table correspond to the reference metamers of each pair; the coordinates for the metamers assigned to each illuminant (not shown) are very slightly different, simply because the metamers were optimized for the 10 degree Observer.

The average color difference from the five pairs, the MI, is used to assign the Quality Grade, a letter between "A" and "E". Grade "A", the best grade, is quite challenging to achieve and any illumination environment compliant with grade "B" is excellent, while grade "C" is still acceptable. The assignation table is:

Quality grade	MI (CIE S 012)
A	≤ 0,25
B	> 0,25 to 0,50
C	> 0,50 to 1,00
D	> 1,00 to 2,00
E	> 2,00

Note: This index is computed for ambient type illumination only, not for color monitors.

Note: ISO 23603 / CIE S 012 and CIE 51 not only describe how to measure a visible metamerism index, but an Ultra-Violet (UV) index as well. In practice, the i1Pro and i1Pro 2 cannot do measurements in the range required for the UV index, and thus, only the visible index is computed.

Warning: The chromaticity tolerance called for in ISO 23603, CIE S 012 and CIE 51 is a 0,015 radius centered on the reference illuminant whereas ISO 3664 specifies a 0,005 tolerance. This tolerance is expressed in *u'v'* coordinates determined with the Uniform Chromaticity Scale (UCS, CIE1976), and the 10 degree Observer (CIE1964).

- **ISO 12646:2008**: *Graphic technology -- Displays for colour proofing -- Characteristics and viewing conditions* (Ref. 32). ISO 12646 is referred to but not specified in ISO 3664. To see the interface corresponding to the 2008 version of ISO 12646, first select the "Color monitors" Viewing Condition, then the **3x3 "Monitor grid"**. This version contains, among other tests, a Brightness uniformity specification (Section 4.4) which we have adapted for this tool because of its usefulness. Brightness uniformity is performed on nine positions defined by a 3 x 3 grid; the grid is non-uniform as it favors the monitor's center area. The test is performed separately for the White, Grey, and Dark-Grey patches; the brightness of the white patch at the selected position is shown in the upper-left of the tool window, if measured. The positions can be selected manually or automatically; see the ISO 3664+ user interface section for more information.

- **ISO 12646:2014-Final Draft**: *Graphic technology -- Displays for colour proofing -- Characteristics* (Ref. 32). ISO 12646 is referred to but not specified in ISO 3664. To see the interface corresponding to the 2014 version of ISO 12646, first select the "Color monitors" Viewing Condition, then the **5x5 "Monitor grid"**. This version contains, among other tests, a Tone uniformity specification (Section 4.2.2) which is in effect a Color uniformity test; this test is selected by the "**Color**" radio button in the tool interface. The standard also contains a Tonality Evaluation (Uniformity) specification (Section 4.2.3) which is based on the ratio of the luminances of the GREY and WHITE patches; this test is selected by the "**Tone**" radio-button in the tool interface. Both tests are performed on twenty-five positions defined by a uniform 5 x 5 grid. The positions can be selected manually or automatically; see the ISO 3664+ user interface section for more information.

Color: The reference white illuminant for Color uniformity is the center patch XYZ coordinates. The "color" of the other patches is compared with the center using the CIEDE2000 color difference equation. Thus, a color difference from the center patch is shown for all non-center positions; by definition, when measured, the center patch shows a color difference of zero. The color difference is performed separately for the White, Grey, and Dark-Grey patches. Please note that only the **color difference** is shown in the interface representing the 5 x 5 grid; the XYZ and L*a*b* coordinates used to compute the color difference are not required to be shown by the standard.

Tone: The deviation from uniform tonality (T_i) for a non-center position (with index i = 1 to 24) is expressed by the following equation:

$$T_i = abs(R_i / R_c - 1)$$

where R_c is the Grey/White luminance ratio measured in the center, and R_i is the ratio for the non-center position. The maximum deviation seen when all positions are measured shall be less than 0.1 (or 10%, which is the number format used in CT&A). By definition, when measured, the center patch shows a tonality deviation of zero. Please note that only the **tonality deviation** is shown in the interface representing the 5 x 5

grid. The luminance (i.e. brightness) of the white patch at the selected position is shown in the upper-left of the tool window, if measured.

Important: the reference display illuminant for **color monitors** is **D50 in ISO 12646** while it is **D65 in ISO 3664**. The difference stems from the different target applications. ISO 3664 is dedicated to applications where the display and the hardcopy are viewed independently, and ISO 12646 is dedicated to applications where direct comparison is made between the monitor and the hard copy. Either illuminant (or others) can be selected as the reference in CT&A.

Warning: If you elect to use the specifications of ISO 12646:2008 for your **color monitors**, you should be aware that the chromaticity tolerance for the D50 illuminant is 0,010, not 0,025 as in ISO 3664 (both expressed in *u'v'* coordinates, UCS, CIE1976 and the 10 degree Observer).

ISO 3664 VIEWING CONDITIONS

ISO 3664 identifies five viewing conditions:

- (P1) Critical comparison of PRINTS;
- (P2) Practical appraisal of PRINTS;
- (T1) Direct viewing of TRANSPARENCIES;
- (T2) Projection viewing of TRANSPARENCIES;
- Color monitors.

The following table shows a snapshot of the requirements for each condition:

<table>
<tr><th>Viewing condition</th><th>Ref. Illuminant</th><th>u'v' tolerance (note 1)</th><th>Illuminance / Luminance</th><th>CRI (CIE 13)</th><th>MI (ISO 23603)</th><th>Illuminance uniformity</th><th>Surround luminous refl./ lum./ illumin.</th></tr>
<tr><td>P1</td><td rowspan="4">D50</td><td rowspan="4">0,005</td><td>2000 lux
± 500 lux
(should be
± 250 lux)</td><td rowspan="4">Gen. index ≥ 90
Special indices ≥ 80</td><td rowspan="2">Visual: C or better
(should be B or better)
UV: < 1,5 (should be < 1)</td><td rowspan="2">up to 1 m x 1 m ≥ 75%
for larger surfaces ≥ 60%</td><td rowspan="2">< 60% (neutral and matte)</td></tr>
<tr><td>P2</td><td>500 lux
± 125 lux</td></tr>
<tr><td>T1</td><td>1270 cd/m^2
± 320 cd/m^2
(should be
± 160 cd/m^2)</td><td rowspan="2">Visual: C or better
(should be B or better)</td><td rowspan="2">≥ 75%</td><td rowspan="2">5-10% of the luminance level
(neutral and extend at least 50mm on all sides</td></tr>
<tr><td>T2 (note 4)</td><td>1270 cd/m^2
± 320 cd/m^2</td></tr>
<tr><td>Color monitors</td><td>D65 (note 2)</td><td>0,025 (note 2)</td><td>> 80 cd/m^2
(should be
> 160 cd/m^2)</td><td>N.A.</td><td>N.A.</td><td>N.A. (note 3)</td><td>neutral and dark gray or black
(should be ≤ 32 lux)
(shall be ≤ 64 lux)</td></tr>
</table>

Note 1: The chromaticity coordinates, *u'* and *v'*, are determined using the CIE1976 Uniform Chromaticity Scale (UCS) equations and a 10 degree Observer (CIE1964); the tolerance is a radius with its center on the reference illuminant.

Note 2: In ISO 12646:2008, the reference illuminant for the monitor is D50 and the chromaticity tolerance is a 0,010 radius.

Note 3: There are no specific requirements for luminance uniformity on color monitors in ISO 3664. Nonetheless, CT&A can perform uniformity measurements based on ISO 12646:2008 (Brightness, 9 positions) and ISO 12646:2014 (Color and Grey/White tone ratio, 25 positions).

Note 4: Projection viewing of TRANSPARENCIES not supported in CT&A.

Purchasing **ISO** and **CIE** publications can be done through the following sources:

- https://www.iso.org/
- http://www.cie.co.at (CIE International headquarter)
- http://www.cie-usnc.org (CIE U.S.A. branch)

10.2 ISO 3664+ tools interface

SETUP

- For instrument input, it is assumed that your instrument is properly connected and detected, as discussed in the last page of the introduction.

- Select the "**VIEWING CONDITIONS**":
    - (P1) Critical comparison of PRINTS
    - (P2) Practical appraisal of PRINTS
    - (T1) Direct viewing of TRANSPARENCIES
    - Color monitors

The Color Rendering Index (CRI) and Metamerism Index (MI) tests are not required when the "Color monitors" viewing condition is selected, and these tools are not shown for this selection.

Important: The "P1" and "P2" viewing conditions are not available for an i1Pro sold without ambient measurement capabilities, and thus without the diffuser cap accessory. This can be confirmed by looking at the Toolbar status lights or by opening the Instrument info dialog. Some of the older models can be factory refurbished; please contact X-Rite for additional information.

- Select the "Target center":
    - 2856 K (Illuminant A)
    - 3200 K (TV Studio lighting)
    - 3500 K (SoLux lamp)
    - 4100 K (SoLux lamp)
    - 4700 K (SoLux lamp)
    - 5000 K (SoLux lamp)
    - D50
    - D55
    - D60
    - D65
    - D75
    - D93
    - **Goal**

Selecting "Goal" will show the tolerance required by ISO 3664, which varies according to the viewing conditions. You can also select targets corresponding to many ambient viewing conditions and popular display color temperatures. Data will be updated if the target center is changed after a measurement is done. Data will be updated if it is changed after a measurement is done.

- Select the "Ref. Illuminant" for the Color Rendering Index (CRI):
    - 2856 K (Illuminant A)
    - 3200 K (TV Studio lighting)
    - 3500 K (SoLux lamp)
    - 4100 K (SoLux lamp)
    - 4700 K (SoLux lamp)
    - 5000 K (SoLux lamp)
    - **D50**
    - D55
    - D65
    - D75
    - Auto

D50 is required by ISO 3664. Selecting "Auto" will compute the CRI based on the measured temperature, in kelvin. A D-series illuminant will be selected for color temperatures equal to or larger than 5000 K, and a blackbody will be selected for color temperatures below 5000 K. Data will be updated if the reference illuminant is changed after a measurement is done.

- Select the "Ref. Illum." for the Metamerism Index (MI)/Quality Grade determined as per CIE S 012:
  - **D50**
  - D55
  - D65
  - D75

D50 is required by ISO 3664. Data will be updated if the reference illuminant is changed after a measurement is done.

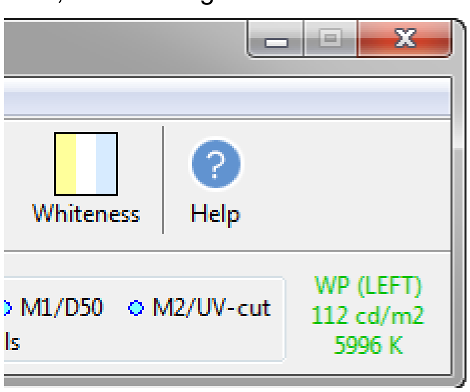
- For the **P1, P2, and T1** "Viewing Conditions", select a position in the "Brightness uniformity" group by clicking on one of the nine radio buttons.

- For the **Color monitors** "Viewing condition", first select the "Monitor grid", either **3x3** corresponding to the "Brightness uniformity" measurements of ISO 12646:2008, or the **5x5** grid corresponding to the "Color and Tone uniformity" measurements of ISO 12646:2014. Select the target color and one of the positions. The target colors and their corresponding RGB 8-bit values are:
  - White: R=G=B= 255
  - Grey: R=G=B= 127
  - Dark-Grey: R=G=B= 63

  When the targets are generated and displayed by CT&A, the display profile is NOT used. However, the displayed color should be the same as if a display profile was used, the reason being that color profiling programs first correct the display *White Point* (WP) and the neutral axis by modifying the graphics card Look-Up-Tables (LUT) **before** computing an ICC profile. By doing this, the WP and neutral axis are corrected even when a program is not ICC-aware (Note: CT&A is ICC-aware but displaying the targets with profile correction is not a requirement here). Yet, if you wish, you could display the targets with an ICC-aware program; for this task, you need target images, with one image per target color. Such images can be generated with the provided target creation dialog illustrated later in this section. In your ICC-aware imaging program you should then associate the display profile to the image data, which should also be displayed using the display profile; since the input and output profile are the same, this is equivalent to using no ICC profile! What is most important here is to make sure the proper graphics card's LUTs corresponding to the display profile are loaded; on Windows this usually happens at reboot and requires a dedicated LUT application provided by the profiling program manufacturer, while on a Mac simply selecting a profile is usually sufficient.

- If not already done, calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions. Please note that the P1 and P2 viewing conditions require calibrating the instrument in "Ambient" mode, with the diffuser adapter mounted, while the T1 and Color monitors' conditions require a calibration in "Emission" mode, without the diffuser.

Note: In CT&A, emission calibration requires the measurement of a white patch, preferably located on the display or emissive surface on which subsequent measurements will be performed; this procedure sets the *White Point* (WP). The WP characteristics (display location, luminance and CCT) are shown in the toolbar window, as seen in green text in the next screenshot.



MEASUREMENTS

To make a measurement, you can click on the "Test" button, press the instrument button, click on the “Load…” button and open a file, or drag-and-drop a file on the “Load…” button.

A test result will be shown as **PASS** or **FAIL**. A green colored **PASS** over a black background indicates that the test meets the requirements of ISO 3664. A yellow colored **PASS** over a black background indicates that the test meets the selected goal but this goal is not the one recommended by ISO 3664.

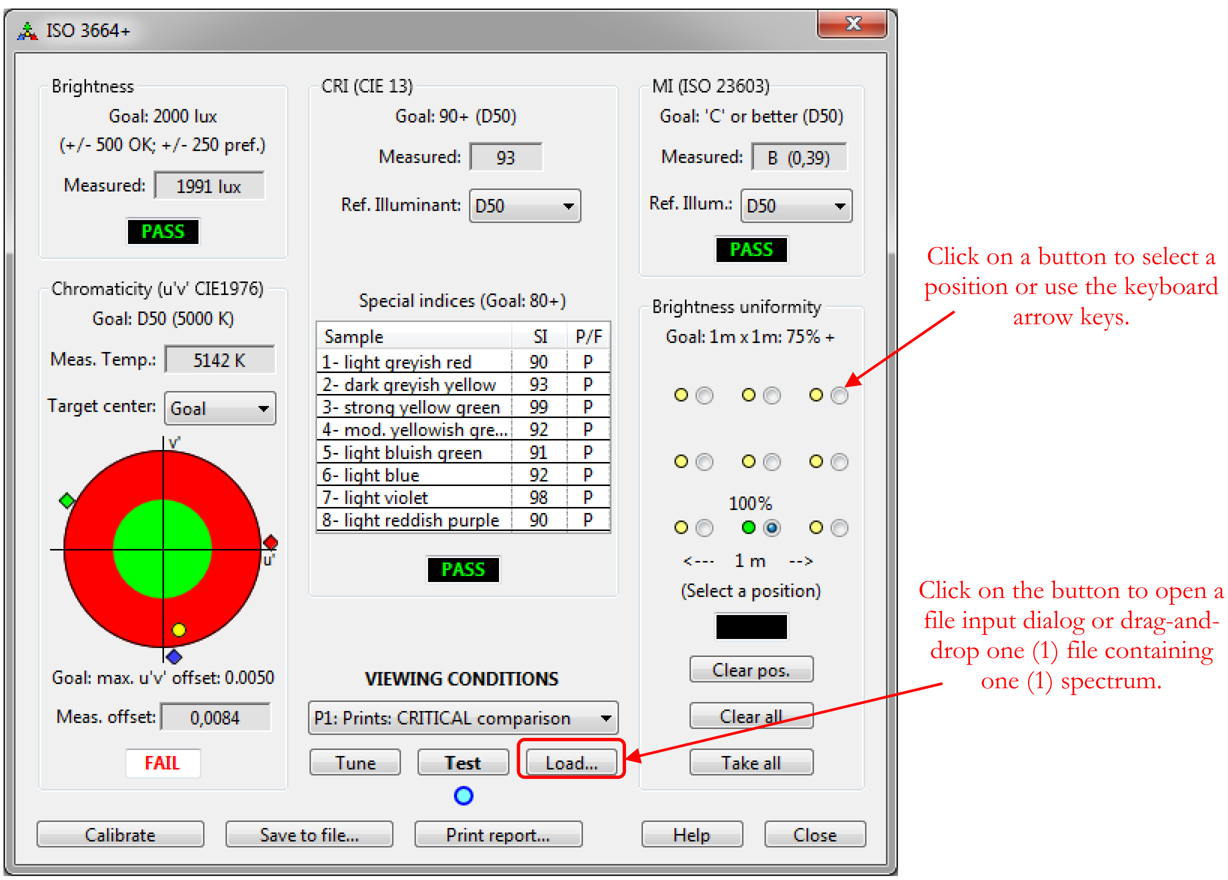
No measurement for this position, or not enough measurements (Brightness uniformity)

PASS Requirement met as per viewing condition goal

PASS Non-standard requirement met

FAIL Requirement NOT met

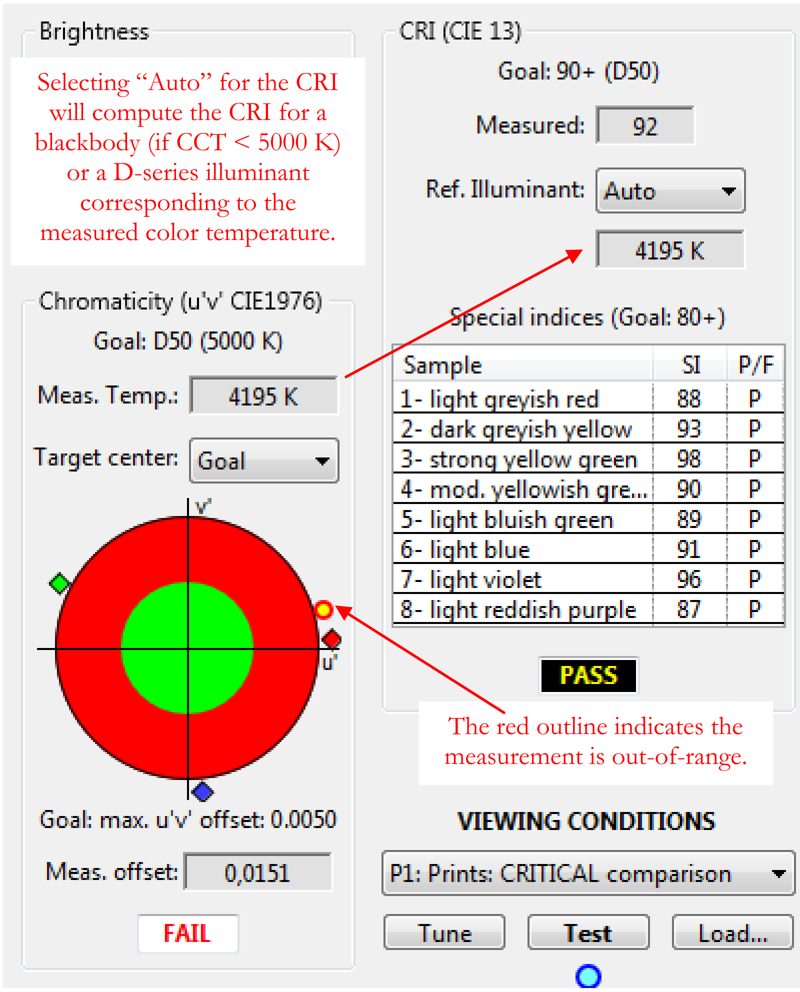
Let's go back to the first screenshot shown in the ISO 3664+ tools introduction, which is reproduced below. The measured brightness (1991 lux) meets the requirement of the P1 Viewing Condition (for critical comparison of prints), which is 2000 lux. The location where the measurement was taken, in the bottom-center of the viewing zone, is shown in the "Brightness uniformity" section (there is not enough data to show a Pass/Fail result). The green central zone of the chromaticity target represents the maximum acceptable *u'v'* offset (the vector obtained by combining the *u'* and *v'* offsets). In our example, the target center has been selected as "Goal", which corresponds to D50 for this viewing condition; the measured offset (illustrated by a yellow dot) is 0,0084, outside of the acceptable zone (A "passed" chromaticity measurement would be illustrated by a white dot).



The CRI results are presented as an index between 0 and 100, with 100 being the best result. The index of each sample used in the CRI computation is presented in a data table; these values are called the "Special indices". The data table can be sorted by clicking on a column heading: "Sample", "SI", or "P/F" (i.e. "Pass/Fail"). The CRI is the average of these indices. For the above screenshot, the goals for the special indices as well as the one for the CRI are met. Finally, we see that we meet the MI requirements.

When measuring an unknown source, you should select "Auto" as the reference illuminant for CRI computation. A D-series or blackbody illuminant corresponding to the measured color temperature, shown in the "Chromaticity" test, will be selected for CRI computation. A D-series illuminant will be selected for color temperatures equal to or larger than 5000 K, and a blackbody will be selected for color temperatures below 5000 K.

In **another example** shown in the screenshot below, we see that a 4195 K blackbody was selected to compute the CRI of a D50 light source. The measured chromaticity, the yellow dot just outside of the target, is shown with a red circle to indicate it is out-of-range (Note: Measurements located outside of the target are always shown on the target periphery even if located farther away).

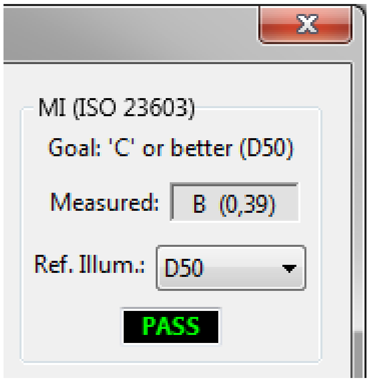


The three colored diamonds around the chromaticity target are used to identify primary colors that need to be removed or added in order to approach the target center. When a measurement is close to a diamond, then we should remove this diamond's color. In the above screenshot we see that the measurement is too red, which is not surprising since the measured dource is at a lower temperature than our goal (D50 target center), and thus with a more reddish appearance. If the measurement had been midway between the green and red diamonds, then we would have had too much yellow (green + red, in additive fashion), or not enough blue, as we can use the opposite diamond to see what color needs to be added.

Note: The "diamonds" are positioned on the target edge at locations which are a projection of the primaries (R=830 nm, G=515 nm, B=360 nm) relative to the selected target center (i.e. the Illuminant). Because the Illuminants are not located at the same place in the u'v' chromaticity diagram (CIE1976, 10 degree Observer), the locations of the primaries' projections are adjusted for each case.

In order to make multiple measurements at a fast rate, just click on the "**Tune**" button to start the tuning mode; the tuning mode can be used for all viewing conditions. A small dialog will open, asking you to set the interval between the measurements which will be done continuously until the tuning mode is stopped. Use the colored diamonds as a guide when tuning.

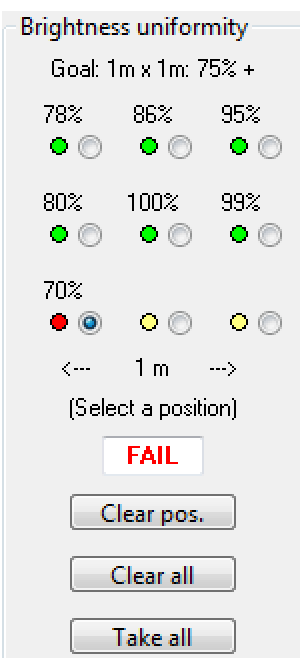
Metamerism Index (MI, ISO 23603): Let's go back one last time to the tool **introduction screenshot** where we now look at the MI result, shown below. The measured source has a MI Quality Grade of "B", an excellent results which exceeds the minimal requirements of ISO 3664. The average color difference of the five metamers pairs is 0,39, well within the “B” grade range. You will find that natural light measurements will often give acceptable to excellent results for this test, which is more severe than the CRI test, whereas it will often fail for artificial lights not specially designed for daylight simulation.

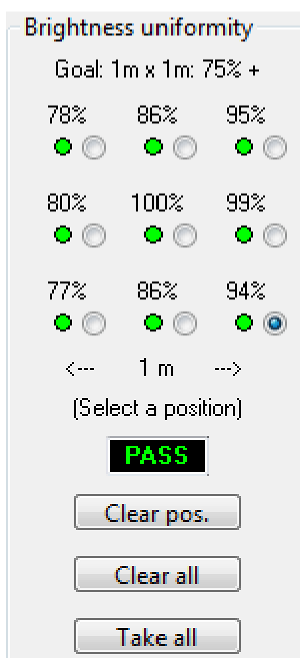


Hint: The color differences of the five metamers used to determine the MI Quality Grade, not shown in the tool interface, is contained in the report generated by clicking the "Save to file..." button. You will also find in this file all the other data presented in the tool window. In addition, you can print a well-formatted one-page report which contains information dedicated to compliance-type reports by clicking the "Print report..." button.

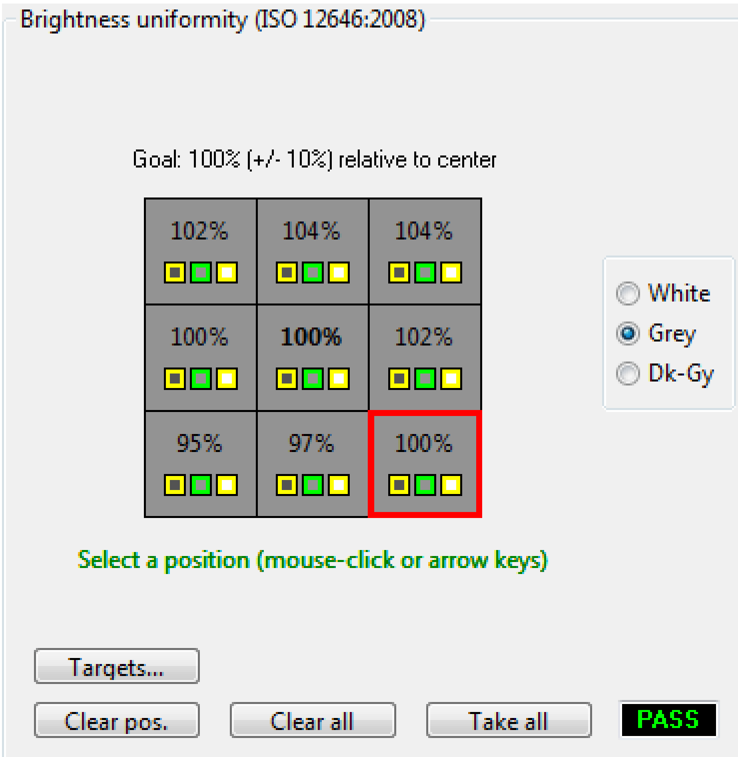
We will see next the various uniformity tests which can be performed with the tool.

Brightness uniformity (for ambient measurements, transparency viewer): The two screenshots below show brightness uniformity results obtained with measurements done for the **P1** Viewing Condition (Note: The P2 interface is identical, and the transparencies interface is nearly identical). The image on the left shows measurements done at seven of the nine positions; the non-measured positions are shown in yellow. The positions which meet the requirement of 75%+ relative to the center position are shown in green, and the one which does not meet it is shown in red; the brightness uniformity thus fails because of this single position where the brightness is 70% of the center value. The image on the right shows a similar set of measurements where the brightness uniformity is within requirement, even if we notice a brightness decrease towards the left side of the monitor. The data from the image on the right can also be seen in the Example-1 screenshot of the printed reports section; please note that the report includes other measurements not shown here.



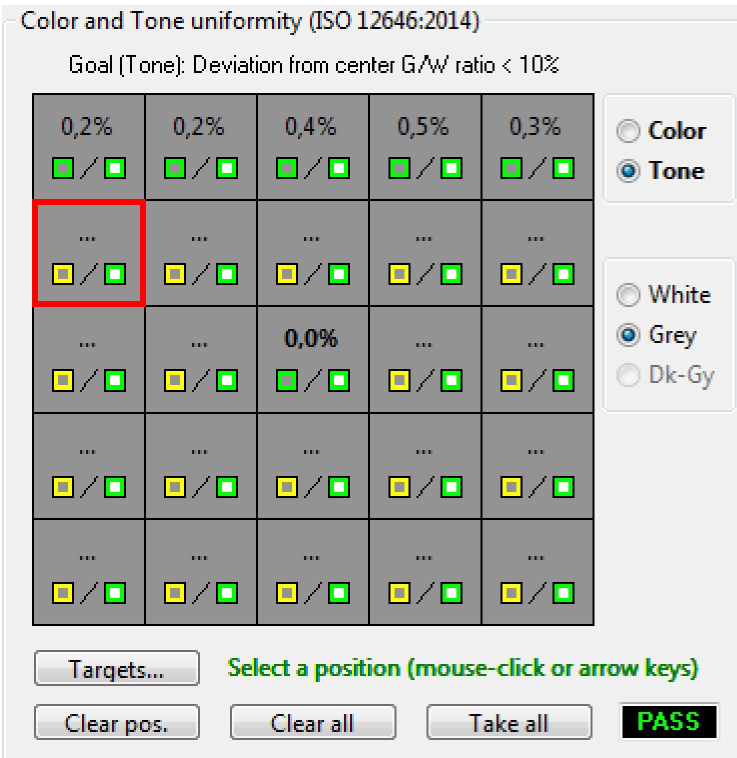


Brightness uniformity as per ISO 12646:2008, Section 4.4 (for color monitors): The screenshot below shows brightness uniformity results obtained with Grey patches on a **color monitor**. The three small squares located at each position indicate if a measurement was done with a Dark-Grey (i.e. Dk-Gy), Grey, or White target respectively. Non-measured targets are shown with a yellow border while measured targets are shown with a green border. Here we see that all the Grey targets were measured, which is confirmed by the uniformity result shown at each position. To make measurements with the White and Dark-Grey patches, you would first need to select the corresponding radio button on the right side of the Brightness uniformity group. You do not need to perform measurements with all target colors in order to generate a printed report; a screenshot of the report corresponding to this data can be seen as Example-2 in the printed reports section.



Tone uniformity, i.e. Color uniformity, as per ISO 12646:2014-Final Draft, Section 4.2.2 (for color monitors): The screenshot below shows the Color uniformity results obtained with White patches on a **color monitor**. All positions were measured for the White target while only the center plus the top row were measured with Grey patches, as we can see from the small Grey squares surrounded by a green border. To see the uniformity results for the Grey patches you would just select the Grey radio button on the right side of the Color and Tone uniformity group. Since there are positions where both the Grey and White patches were measured, we can expect to also get Tone ratio uniformity results. These results can be seen by selecting the "**Tone**" radio button, as shown in the next screenshot. A screenshot of the report containing the results of the Color uniformity as well as the Tone ratio uniformity (shown next in this section) can be seen as Example-3 in the printed reports section.

Tonality Evaluation, i.e. Grey/White Tone ratio uniformity, as per ISO 12646:2014-Final Draft, Section 4.2.3 (for color monitors): The screenshot below shows the Tone ratio uniformity results obtained for all positions where both the Grey and White patches were measured. When the Tone test is selected, the small squares indicating if the Dark-Grey patches were measured are not shown since they are not required for this test. You should select the White or Grey radio button depending on the target color you want to measure. Here we see that the measurements are completed for the center position and the top row. Please note that the deviation values are the same wether you select the White or Grey radio button since the Tone deviation is derived from a ratio of the Grey on White luminances. A screenshot of the report containing the results of the Tone ratio uniformity as well as the Color uniformity (shown just before in this section) can be seen as Example-3 in the printed reports section.



All the measurements and results (Brightness, Chromaticity, CCT, uniformity, as well as CRI and MI when applicable) for a given position, and for a selected target color if applicable, can be erased by first selecting the position for which you want to erase the data, and then clicking on the "**Clear pos.**" button.

All the data for all positions of a given viewing condition, and for a selected target color if applicable, can be erased by clicking the "**Clear all**" button.

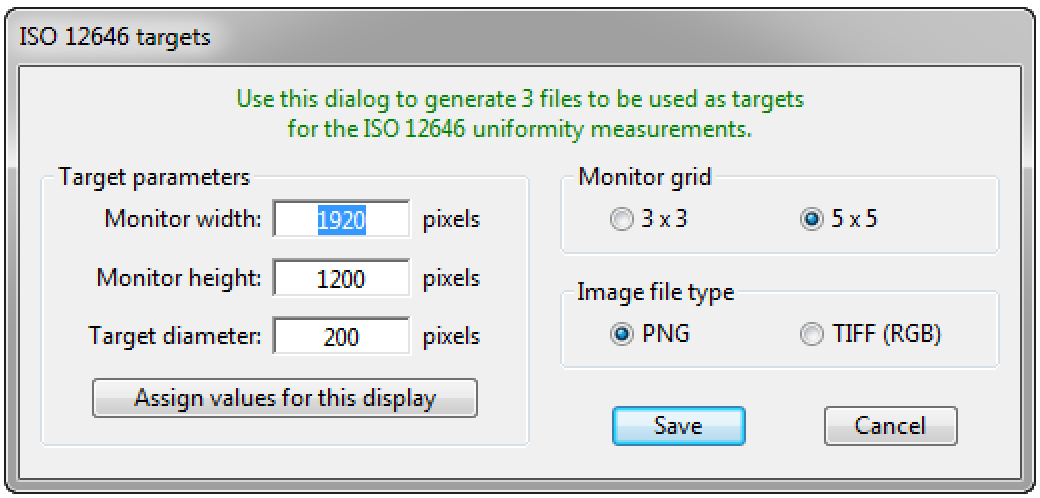
Take all

To rapidly take a series of measurement at all positions, click the "**Take all**" button. The input position will automatically change after each click of the "Test" button or press of the instrument button. The positioning sequence always starts at the center, followed by the upper-left position. The position then moves from left to right, then to the row below, and so on. A small message indicating the selected position will appear in the tool window (Note: The tool window may not be visible when measuring targets on a one-monitor computer but the target will move to the proper location!). Move the instrument between each measurement so that its position corresponds to the target drawn on the display or the location shown in the tool window.

If required, you can select any other position and continue the sequence from this point. In the P1, P2, and T1 Viewing Conditions, and when measuring an external monitor, do a mouse click to select the position in the tool window. When measuring a monitor connected to your computer, use the arrow buttons on the keyboard to change the target position. Changing the target position while doing a "Take all" sequence is useful if you are not sure of a measurement or if you pressed on the instrument button inadvertently.

If the "Color monitors" viewing condition is selected, clicking the "Take all" button will open a small dialog which asks if you want to do the measurements on the display used for White Point calibration; if not, we suggest you redo the emission calibration. If you select a display attached to the same computer on which the CT&A program resides, the program can automatically draw the targets at the prescribed screen positions for this monitor (one or two monitors supported). If you want to perform these measurements manually, or on a third display, or on the display of another computer, we suggest that you use dedicated target images instead of a simple large patch that fills the screen.

You can define target images for any monitor size by clicking on the "**Targets...**" button; this will open the following dialog:



If you need targets for the computer on which CT&A is running, just position the dialog within the monitor for which you want the targets and click on the "**Assign values for this display**" button; this action will fill the target parameters fields. The target parameters can also be manually set to the values of your choice. Select the monitor grid for which you want the targets as well as the file type and click the "Save" button when ready. A file name will be proposed; edit the name if you wish but please note that a suffix identifying the target color will be added for each of the three image files that will be generated. You can then open the images using the graphic editing program of your choice; we recommend using a program which offers a "Full screen" viewing mode.

Note: The 3x3 grid defined in ISO 12646:2008 favors the monitor's center area, and the targets are thus non-uniformly distributed on the monitor, while the 5x5 grid defined in ISO 12646:2014 is uniform.

OTHER TOOL FUNCTIONS

At all times, you can calibrate the instrument by clicking the "Calibrate" button. The measurement mode will be set to "Ambient" or "Emission" depending on the selected viewing condition.

Click on "Save to file..." to save an ISO 3664 report. The report has tab-delimited data that can be directly imported in a spreadsheet program, and opened in many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting).

MEASUREMENTS ON LCD DISPLAYS (i1Pro polarization sensitivity)

While making emission measurements with an i1Pro on an LCD display, it was noticed that different *Luminance* and *Color Temperature* measurements were obtained, depending on the spectrophotometer position on the display. Luminance variations by as much as 10% were measured for the same display area when rotating the spectrophotometer by 90 degrees. This problem affects i1Pro units with manufacturing revisions A, B, and C (shown as REV A, REV B, REV C on the instruments). According to our own measurements on a REV D unit and on an i1Pro 2 (REV E), this problem has essentially disappeared; this has been confirmed by other owners of REV D i1Pros.

The problem with earlier units is related to the polarization of the light emitted from the display. In an LCD display, the intensity of each pixel is controlled by rotating the light's polarization state between crossed polarizers, and the light coming out is linearly polarized (often at a 45 degrees angle). To check this, look at your display using a photographic polarizing filter (or polarizing sunglasses), and rotate it slowly; you should see maximum and minimum transmission for angular positions separated by 90 degrees. The display light is not seen differently by the human eye whether it is polarized or not, since we only perceive the light intensity; however, polarization can affect an instrument reading.

In order to obtain reproducible and valid measurements, we recommend making all measurements with the instrument placed at the same angle that was used for calibration. If calibration is done with the instrument suspended in its cradle, as shown in the following illustrations, all subsequent measurements should be done with the i1Pro placed vertically. It is acceptable to make measurements with the instrument turned 180 degrees from its calibration position, so that it is still vertical, as shown in the illustration on the left. Accordingly, in such a case, measurements should not be done with the instrument positioned horizontally, or at an angle, as shown in the illustration on the right.

Note: "Older" CRT displays do not emit polarized light and are thus not susceptible to errors due to instrument orientation.

Note: Colorimeters, such as the Eye-One Display or i1Display Pro, are usually not affected by this effect.

10.3 ISO 3664+ input file requirements

The ISO 3664+ tools can accept input from a file even if there is no connected instrument. This file **MUST** contain spectral data. This file may come from an ambient measurement made in the CRI, Graph, or MI tools, or from another application. Acceptable file formats are **CGATS** or **plain text**, with the following requirements.

Requirements for spectrum files in CGATS format:

- The file **MUST** contain only **one** (1) spectrum.
- The file **MUST** conform to the "CGATS.17" format standard. As an example, you can use a 10 nm bandwidth file that you will find in the "Illuminants" folder located within the CT&A application folder.
- The illuminant name **MUST** be specified as either "Emission" or "Unknown." It **MUST NOT** be specified as "D50" or any other standard illuminant used to process reflection measurements.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength tags **MUST** be in one of the following formats: "nm450", "SPECTRAL_NM450", SPECTRAL_NM_450, or "SPECTRAL_450".
- The decimal separator for data can be a period (.) or a comma (,).
- The data delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all the data in the file.

Requirements for spectrum files in plain text format:

- The file **MUST** contain only **one** (1) spectrum.
- The first line **MUST** contain wavelength labels/tags.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength labels/tags may be simple numbers or contain other letters, such as "nm380", "380_nm", or "380NM", but no spaces.
- The first line may contain other tags such as "ID" or "Name". Tags **MUST NOT** contain spaces. These tags may be written in uppercase or lowercase. If additional tags are used in the first line, you **MUST** fill the second line with the corresponding information or number, with no spaces in the tag content.
- The second line **MUST** contain the spectral values (and the content of the additional tags if used).
- The decimal separator for data can be a period (.) or a comma (,).
- The wavelength labels and the spectral values **MUST** be separated by data delimiters. The delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all lines.

A plain text file can easily be created with a word processor or a spreadsheet application, as shown below. When saving the file, do not use the often complex native application file formats (for ex.: *.xls); instead, select a tab-delimited or Comma-Separated-Value (CSV) **text** format.

```
380, 390, 400, 410, 420, 430, 440, 450, 460, 470, 480, 490, 500, 51
0.47399, 0.56694, 0.75133, 0.89804, 1.07746, 1.32384, 1.56281, 1.86
```

	A	B	C	D	E	F	G	H	I
1	380	390	400	410	420	430	440	450	46
2	0,47399	0,56694	0,75133	0,89804	1,07746	1,32384	1,56281	1,86406	2,1638
3									
4									

street lamp

Important: You should make sure that the file data corresponds to the selected viewing condition, i.e. **ambient** measurements for **P1** and **P2**, and **emission** measurements for **T1** and **color monitors**.

Note: You can load a spectrum in any of the nine (9) positions shown in the "Brightness uniformity" group (P1, P2, T1, and 3x3 Color monitors viewing conditions) or in any of the twenty-five (25) positions of the "Color and Tone uniformity" group (5x5 Color monitors). File input is also possible after you click the "Take all" button.

10.4 ISO 3664+ printed reports

Click on the "**Print report...**" button to print a well-formatted one-page report which contains information dedicated to compliance-type reports. Such a report is available for all viewing conditions. While these reports do not contain all the data provided in the document obtained with the "Save file..." button, the data is color-coded and formatted to rapidly assess the main evaluation parameters. Reduced size screenshots of one "P1" and two "Color monitors" reports are presented in this section.

Data entry forms appear in a dialog box when you press the 'Print report…' button. These forms are to be used to fill the data fields which appear in the bottom of the report (highlighted below). Two forms are presented, one for the P1, P2, and T1 Viewing Conditions, and another for the Color monitors Viewing Condition.

Example 1 (P1): The first screenshot corresponds to the P1 brightness uniformity results shown in the ISO 3664+ tools interface section; while the brightness uniformity passes, as well as the CRI and MI, the absolute illuminance levels is too high in the center and the chromaticity fails at all positions.

BabelColor®

ISO 3664 Test Report: Prints - Critical Comparison (P1)

Illuminance (lux)

1962	2151	2383
1999	2508	2475
1935	2166	2362

FAIL

Goal: 2000 lux
Tolerance: +/- 500 OK; +/- 250 pref.

Brightness uniformity

78%	86%	95%
80%	100%	99%
77%	86%	94%

PASS

Goal: Up to 1m x 1m: 75% +, relative to center
For larger areas: 60% +, relative to center

CCT (kelvin) / u'v' error

4784 K 0.0066	4847 K 0.0060	4834 K 0.0060
4477 K 0.0118	4874 K 0.0058	4840 K 0.0060
4603 K 0.0094	4733 K 0.0074	4838 K 0.0061

FAIL

u'v': Chromaticity in CIE 1976 UCS units
CCT ref.: D50
u'v' ref.: D50
u'v' tolerance: 0.0050 radius

CRI / Special Indices

96 SI min: 95	96 SI min: 93	96 SI min: 93
95 SI min: 91	95 SI min: 92	96 SI min: 93
97 SI min: 93	97 SI min: 95	96 SI min: 93

PASS

CRI as per CIE 13
Ref.: D50
CRI goal: 90+
Special Indices (SI) goal: 80+

MI Quality Grade / Value

"B" 0.35	"B" 0.38	"B" 0.37
"B" 0.37	"B" 0.40	"B" 0.37
"B" 0.32	"B" 0.34	"B" 0.38

PASS

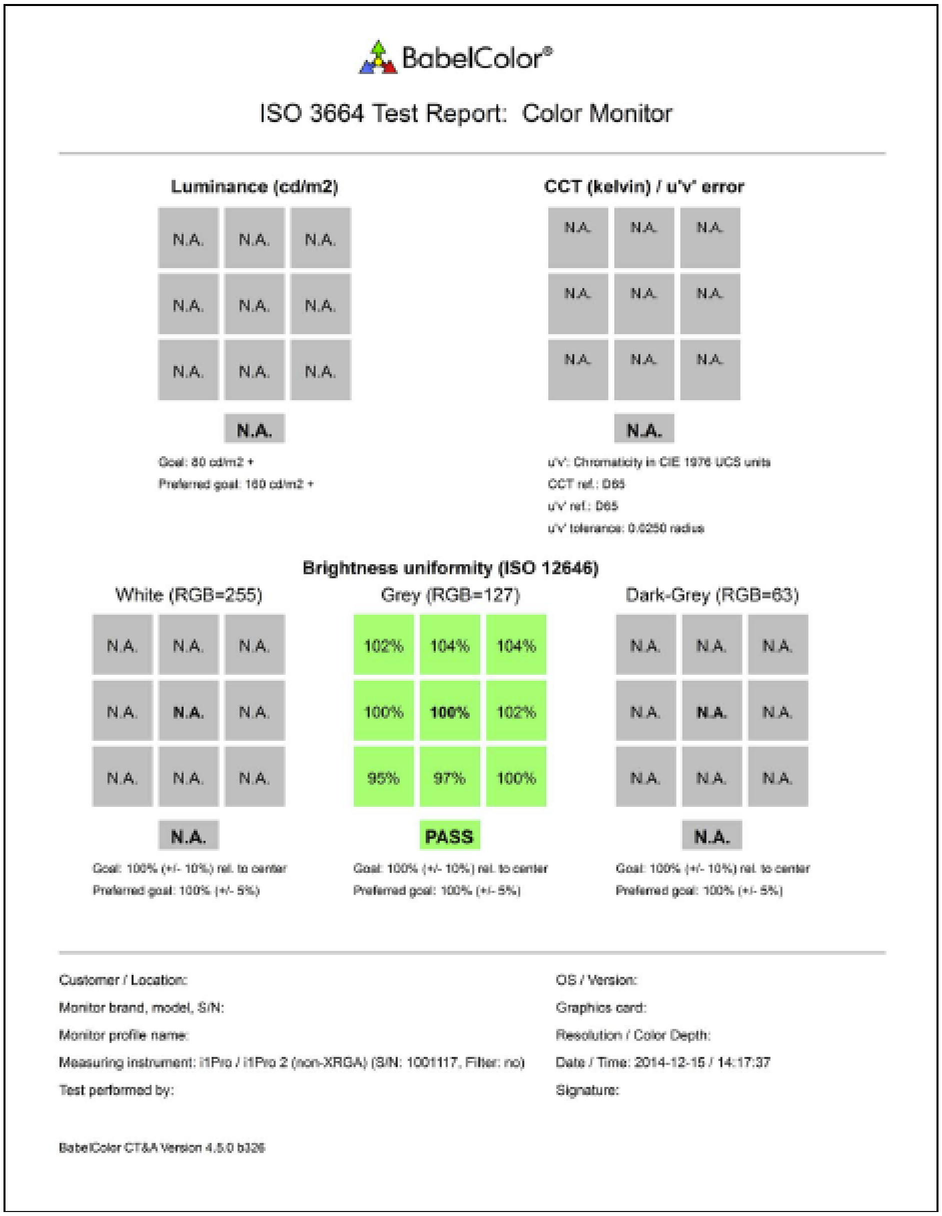
MI (Visible) as per ISO 23603 / CIE S 012
MI ref.: D50
QG goal: 'C' or better (MI ≤ 1)
Preferred goal: 'B' or better (MI ≤ 0.5)

Customer:
Lightbooth brand, model, S/N:
Lamp brand, type:
Measuring instrument: i1Pro / i1Pro 2 (non-XRGA) (S/N: 1001117, Filter: no)
Test performed by:

Test location:
Nominal White Point:
Lamps usage (hours):
Date / Time: 2014-12-15 / 15:23:13
Signature:

BabelColor CT&A Version 4.5.0 b326

Example-2 (Color monitors ISO 12646:2008): The next screenshot corresponds to the Brightness uniformity for color monitors specified by ISO 12646:2008 shown in the ISO 3664+ tools interface section. In the example, only the Grey targets were measured and the report accordingly shows only these results. The luminance, CCT, and chromaticity are shown only when a White target is measured.



BabelColor®

ISO 3664 Test Report: Color Monitor

Luminance (cd/m2)

N.A.	N.A.	N.A.
N.A.	N.A.	N.A.
N.A.	N.A.	N.A.

N.A.

Goal: 80 cd/m2 +
Preferred goal: 160 cd/m2 +

CCT (kelvin) / u'v' error

N.A.	N.A.	N.A.
N.A.	N.A.	N.A.
N.A.	N.A.	N.A.

N.A.

u'v': Chromaticity in CIE 1976 UCS units
CCT ref.: D65
u'v' ref.: D65
u'v' tolerance: 0.0250 radius

Brightness uniformity (ISO 12646)

White (RGB=255)

N.A.	N.A.	N.A.
N.A.	**N.A.**	N.A.
N.A.	N.A.	N.A.

N.A.

Goal: 100% (+/- 10%) rel. to center
Preferred goal: 100% (+/- 5%)

Grey (RGB=127)

102%	104%	104%
100%	**100%**	102%
95%	97%	100%

PASS

Goal: 100% (+/- 10%) rel. to center
Preferred goal: 100% (+/- 5%)

Dark-Grey (RGB=63)

N.A.	N.A.	N.A.
N.A.	**N.A.**	N.A.
N.A.	N.A.	N.A.

N.A.

Goal: 100% (+/- 10%) rel. to center
Preferred goal: 100% (+/- 5%)

Customer / Location:
Monitor brand, model, S/N:
Monitor profile name:
Measuring instrument: i1Pro / i1Pro 2 (non-XRGA) (S/N: 1001117, Filter: no)
Test performed by:

OS / Version:
Graphics card:
Resolution / Color Depth:
Date / Time: 2014-12-15 / 14:17:37
Signature:

BabelColor CT&A Version 4.5.0 b326

Example-3 (Color monitors ISO 12646:2014): This last report screenshot shows the results associated with color monitor measurements made according to ISO 12646:2014. The data in this report corresponds to the Color and Tone uniformity results shown in the ISO 3664+ tools interface section. We clearly see that the Tone uniformity is computed only for the positions where both the White and Grey targets were measured. Because the White targets were measured for all positions, we also get the luminance, CCT and chromaticity data for all positions.

BabelColor®

ISO 3664 Test Report: Color Monitor

Luminance (cd/m2)

113	113	115	113	118
108	105	109	110	112
105	106	107	111	110
101	100	103	104	105
101	101	104	105	107

PASS

Goal: 80 cd/m2 +
Preferred goal: 160 cd/m2 +

CCT (kelvin) / u'v' error

6270 K 0,0006	6404 K 0,0008	6382 K 0,0006	6346 K 0,0011	6231 K 0,0015
6300 K 0,0003	6384 K 0,0010	6408 K 0,0009	6344 K 0,0003	6374 K 0,0006
6320 K 0,0006	6477 K 0,0016	6416 K 0,0010	6444 K 0,0016	6530 K 0,0022
6441 K 0,0014	6650 K 0,0036	6736 K 0,0043	6649 K 0,0034	6586 K 0,0027
6505 K 0,0025	6584 K 0,0029	6573 K 0,0026	6668 K 0,0036	6599 K 0,0025

PASS

u'v': Chromaticity in CIE 1976 UCS units
CCT ref.: D65
u'v' ref.: D65
u'v' tolerance: 0.0250 radius

Tone uniformity (ISO 12646)

0,2%	0,2%	0,4%	0,5%	0,3%
N.A.	N.A.	N.A.	N.A.	N.A.
N.A.	N.A.	0,0%	N.A.	N.A.
N.A.	N.A.	N.A.	N.A.	N.A.
N.A.	N.A.	N.A.	N.A.	N.A.

PASS

Goal: Deviation from center G/W ratio < 10%
Computed if White & Grey measured

Color uniformity (ISO 12646)

White (RGB=255)

1,7	1,2	1,5	1,9	2,8
1,0	1,2	0,5	0,8	1,4
1,3	0,9	0,0	1,9	1,3
1,4	2,4	2,6	2,4	1,6
2,2	2,0	1,5	2,5	1,6

PASS

Goal: Color diff. rel. to center <= 4
Color difference formula: CIEDE2000

Grey (RGB=127)

2,4	2,0	2,0	2,6	2,9
N.A.	N.A.	N.A.	N.A.	N.A.
N.A.	N.A.	0,0	N.A.	N.A.
N.A.	N.A.	N.A.	N.A.	N.A.
N.A.	N.A.	N.A.	N.A.	N.A.

PASS

Goal: Color diff. rel. to center <= 4
Color difference formula: CIEDE2000

Dark-Grey (RGB=63)

N.A.	N.A.	N.A.	N.A.	N.A.
N.A.	N.A.	N.A.	N.A.	N.A.
N.A.	N.A.	N.A.	N.A.	N.A.
N.A.	N.A.	N.A.	N.A.	N.A.
N.A.	N.A.	N.A.	N.A.	N.A.

N.A.

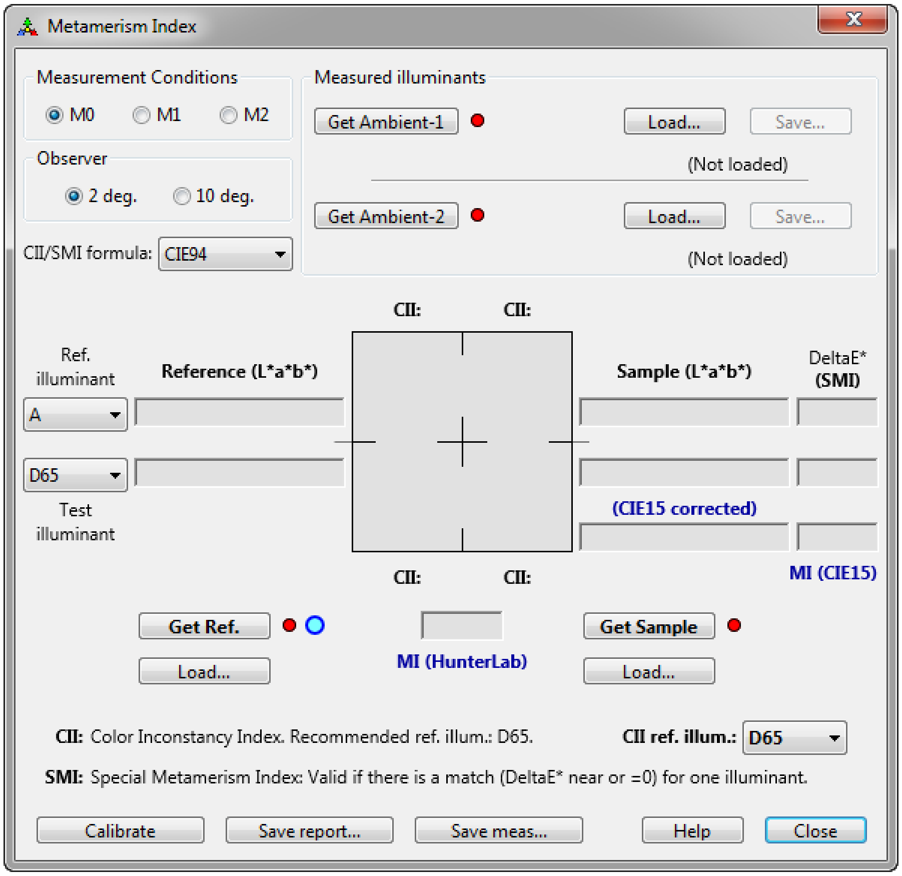
Goal: Color diff. rel. to center <= 4
Color difference formula: CIEDE2000

Customer / Location:
Monitor brand, model, S/N:
Monitor profile name:
Measuring instrument: i1Pro / i1Pro 2 (non-XRGA) (S/N: 1001117, Filter: no)
Test performed by:

OS / Version:
Graphics card:
Resolution / Color Depth:
Date / Time: 2014-12-15 / 14:18:10
Signature:

BabelColor CT&A Version 4.5.0 b326

11. Metamerism Index tools



INTRODUCTION

The **Metamerism Index tools** window is opened either by clicking on the MI icon on the toolbar window, or by selecting the "Tools/Metamerism Index" menu.

The Metamerism Index tools enable you to:

- characterize the color stability of a **single color patch** when changing the illuminant using a Color Inconstancy Index (**CII**);
- evaluate how **two color patches** which look the same under a *Reference illuminant* will match under a *Test illuminant* using the Special Metamerism Index (**SMI**; the color difference between the *Reference* and *Sample* patches under the *Reference illuminant* is assumed to be zero, as per CIE15:2004, Section 9.2);
- if the color difference obtained with the *Reference Illuminant* is NOT zero, compute a Metamerism Index (**MI**) by applying a Multiplicative Correction to the data of the *Sample* patch illuminated with the Test Illuminant (as per CIE15:2004, Section 9.2.2.3);
- evaluate how the relationship of **two color patches** under one illuminant is maintained under another illuminant using the HunterLab Metamerism Index;
- judge how color patches look under various illuminants (virtual light box), including two measured, or loaded from file, ambient lights.

Important: The Metamerism Index tools can accept inputs from a file or from a supported instrument. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use these tools. Files for the *Reference* and *Sample* patches may contain one or more reflectance spectrums while files for the *Measured illuminants* MUST contain only one ambient spectrum. A file may be either a text file complying with the CGATS format, or a plain text file. The specific requirements for each file formats are presented in the MI input file requirements (reflectance) and MI input file requirements (custom illuminant) sections.

Important: To **measure** the *Reference* and *Sample* patches with the Metamerism Index tools, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate", "Get Ref.", and "Get Sample" buttons being enabled in the Metamerism Index window (some controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Note: In Windows, if the i1Pro 2 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Instrument button support: When the MI tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears next to the "Get Ref." or "Get Sample" button. This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button. The indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the previous measurement if required, or do a right-click to lock it on a given measurement. You can also do a left-click on a locked indicator; the new position will be locked.

Click on a link in the Table of Contents below to jump to a specific section.

Metamerism Index tools - Table of Contents

11.1 MI tools description

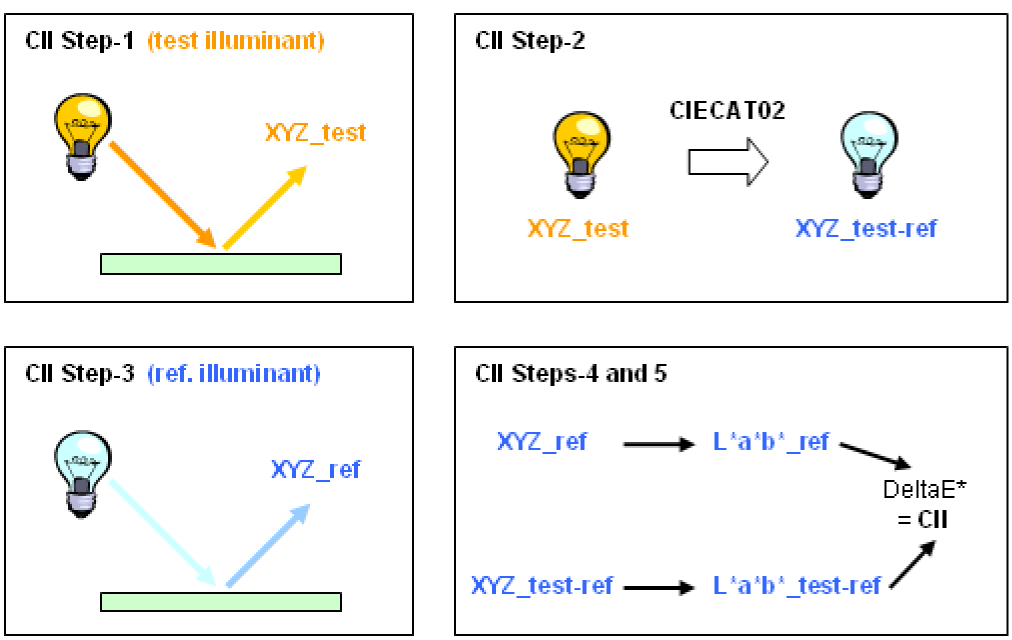
Metamerism is not a well-known word but its effect is experienced by anyone using a computer display. Any given color shown on a computer display is derived by adding various proportions of the three display primaries. The resulting spectrum of that color is likely very different from the spectrum of the original color, but is perceived as same; these two colors are then said to be a *metameric pair*.

Matching inks to textile colors is a similar process. The ink pigments and the textile dyes usually have different spectrums but a color match can still be obtained. However, because the spectrums are different, the match is usually dependent on the illuminant. For instance, an ink patch matched with a textile color under a halogen lamp may not match under daylight or fluorescent illumination.

There are basically two aspects to look at when we want to match two colors under different lights. The first is how each color will be perceived under these lights, or how "constant" the color is, and the second comes into play when you compare the two colors simultaneously. For the first aspect, an index which characterizes the stability of a single color under different light sources has been defined: the *Color Inconstancy Index* (**CII**). Computing the CII requires a *Chromatic Adaptation Transform* (CAT) matrix, which exists in many variants. The CAT recommended for the CII is **CIECAT02**, used in the CIECAM02 color appearance model (Ref. 26-28). The CIECAT02 matrix is a variant of a simplified Bradford CAT, where some non-linear parameters are omitted, and which is further optimized in regards to many experimental data sets.

Computing the CII involves the following steps:

1. Determine the XYZ coordinates of the sample under the **test illuminant**. This is done by using the **spectral data** of the sample and the test illuminant, for a given Observer. This is how the color is actually perceived under the test illuminant.
2. From the XYZ coordinates determined in step 1, and using **CIECAT02**, determine the equivalent coordinates of the sample color under a **daylight reference illuminant** (no spectral data is used). These are what the coordinates should be for the sample to be perceived as the same color under the reference illuminant.
3. Determine the XYZ coordinates of the sample using the **spectral data** of the sample, the **daylight reference illuminant**, and the Observer. This is how the color is actually perceived under the reference illuminant.
4. Convert both XYZ data sets, computed in steps 2 and 3, to L*a*b*.
5. Compute the color difference using any color difference formula.



The recommended **daylight reference illuminant** is D65. This is consistent with the use of L*a*b* as the color difference space, since it is often considered that the L*a*b* space is most uniform for D65. However, in CT&A, the user has the option to select any one of 12 preset illuminants, or one of two measured ambient sources.

From the procedure described above, we can see that if the test illuminant and the daylight reference illuminant are the same, the CII will always be zero.

Now let's see what happens if we compare two colors simultaneously. If the pigments or dyes are of the same type and origin, the two patches should remain quite similar under various illuminations. If not, which is quite common in the real world, the match will generally hold only for a limited set of illumination conditions (if well done!).

There are two sub-cases here:

1. You are able to obtain a perfect match (i.e. no color difference) under a *Reference illuminant* but no match under a *Test illuminant*. The color difference under the *Test illuminant* is called the *Special Metamerism Index* (**SMI**). Note: This SMI is often simply referred to as a *Metamerism Index* (**MI**).
2. There is a color difference under both illuminants. This case can be extended to color pairs which are quite different, beige and light gray samples for example, but for which you want to keep the color difference relation across various illuminants. Here we cannot use the SMI value directly and we need a method to derive a more general *Metamerism Index* (**MI**).

Important: The REFERENCE and TEST illuminants may not be the same for the CII and SMI.

Because the SMI is simply the color difference between two samples under a single illuminant, it can be determined using any color difference formula (CIELAB, CIE94, CMC, etc.). However, as mentioned above, if we do not have a perfect match under the *Reference illuminant*, we cannot use this number as the MI.

Computing a general MI is more complex because each sample spectrum interacts with each illuminant spectrum, for a total of four sample-illuminant combinations. Many formulas were proposed and tested, some which use residual differences of a wavelength by wavelength comparison between the two samples (Ex.: Bridgeman's, and Nimeroff and Yurow's metameric indices), and some which are simply based on the L*a*b* coordinates of the samples. While the spectral math approach may seem more accurate, it was found that the L*a*b* based methods, which take into consideration the illuminant, showed better correlation with the perceived difference (Ref. 29).

Two MI computing methods are proposed in CT&A:

- A Multiplicative Correction to the data of the *Sample* patch illuminated with the *Test Illuminant* (as per CIE15:2004, Section 9.2.2.3, Ref. 58).
- The *HunterLab Metamerism Index* formula (Ref. 44).

MI (CIE15)
When the *Reference* and *Sample* patches are not exactly metameric under the *Reference illuminant*, this means that:

$$XYZ_{Ref.,\ Ref.ill.} \neq XYZ_{Sample,\ Ref.ill.} \quad .$$

In such a case, we apply a Multiplicative Correction to the *Sample* XYZ values obtained with the *Test illuminant*. The correction is the ratio of the *Reference* and *Sample* XYZ values obtained with the *Reference illuminant*:

$$XYZ_{Sample\ corr.,\ Test\ ill.} = XYZ_{Sample,\ Test\ ill.}\left(XYZ_{Ref.,\ Ref.ill.} / XYZ_{Sample,\ Ref.ill.}\right) .$$

In the Metamerism Index tools dialog, the **(CIE15 corrected)** data field represents the corrected *Sample* L*a*b* values derived from the corrected XYZ values.

The color difference between the *Reference* patch L*a*b* value obtained with the *Test illuminant* and the corrected *Sample* patch L*a*b* is the **MI (CIE15)** value.

MI (HunterLab)
The *HunterLab Metamerism Index* is determined using the individual values of L*, a* and b* for the *Reference* AND *Sample* under EACH Illuminant. The color difference computation for this MI is always based on CIELAB. The MI equation is:

$$MI = \sqrt{\left(\Delta L^*_{n1} - \Delta L^*_{n2}\right)^2 + \left(\Delta a^*_{n1} - \Delta a^*_{n2}\right)^2 + \left(\Delta b^*_{n1} - \Delta b^*_{n2}\right)^2}$$

where n1 refers to the first illuminant and n2 refers to the second illuminant, and where

$$\Delta L^* = L^*_{sample} - L^*_{ref}$$
$$\Delta a^* = a^*_{sample} - a^*_{ref}$$
$$\Delta b^* = b^*_{sample} - b^*_{ref}$$

are computed with the data of the illuminant referred to in the MI equation.

Note: In a HunterLab Application Note (Ref. 44), the following guidelines are mentioned in regards to the above equation when matching textile colors with dyes:

- Acceptable match: MI < 0,5
- Doubtful match: 0,5 ≤ MI < 1,0
- Not acceptable: 1,0 ≤ MI (the application note uses the term "reformulation")
- Be less stringent when matching with a fluorescent-tube illuminant (such as F2, F7, F11, etc.)

Note: You will obtain the same value for the SMI and both MI if the *Reference* and *Sample* patches match for one Illuminant (ΔL^*, Δa^*, and Δb^* are zero for the matching illuminant), AND if you select CIELAB as the color difference formula for the SMI.

Note: In addition to the Metamerism Index tools, CAT matrices are used in CT&A for space conversion in the RGB vs RGB tool, and to compute all display colors. Two CAT matrices are available, "CIECAT02" and "Bradford"; it can be selected in the "Math" tab of the Preferences dialog.

11.2 MI tools interface

SETUP

- For instrument input, it is assumed that your instrument is properly connected and detected, as discussed in the last page of the introduction.

- Select the Measurement Conditions: If you are using an **i1Pro 2** with the "**i1Pro / i1Pro 2 (XRGA)**" driver, an I1Pro 3, or an i1Pro 3 Plus, you can select the "Measurement Conditions" M0 (Ill-A), M1 (D50), or M2 (UV-cut), as defined in ISO 13655 (Ref. 42). A description of the M0/M1/M2 measurement conditions can also be found in the FluoCheck tools. If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument.

  Hint: For file input, if you want to enter data in all measurement conditions and the instrument is not compatible, you can either unconnect the instrument or select a colorimeter in the instrument menu.

  Important: Although the Metamerism Index tools can provide data when measuring color patches printed on a fluorescent substrate, the MI tools are better used for non-fluorescent substrates and non-fluorescing inks. If you have an i1Pro 2 connected using the the "i1Pro / i1Pro 2 (XRGA)" driver, all measurements are made with the three measurement conditions and you can switch the condition to see if the CII, SMI, and MI indices are affected. For fluorescent substrates, we recommend using the FluoCheck tools; however, even in such a case, you can use the MI tools with the M2 measurement condition to evaluate the color stability when there is no substrate fluorescence (assuming your instrument supports M2). If you have an i1Pro which is not UV-cut, you can check substrate fluorescence using the Whiteness tools and a UV filter (not provided).

- Select an "Observer"; data will be updated if it is changed after a measurement is done.

- Select the "CII/SMI formula", a color difference formula, used to compute the CII and SMI values. Data will be updated if it is changed after a measurement is done. The available color difference formulas are:
  - CIELAB
  - CIE94 (i.e. the common formula, CIE94 (1:1))
  - CIE94 tex. (i.e. CIE94 for textile, CIE94 (2:1))
  - CIE94 (2:2)
  - CMC (2:1)
  - CMC (1:1)
  - CIEDE2000

  Note: CIE94 (2:2), where k_L=2 and k_C=2, is recommended by Berns (Ref. 25, p. 129) to determine the CII as it puts more weight on the hue (with k_H=1) than on the lightness and chroma, which is the intent of the CII measurement.

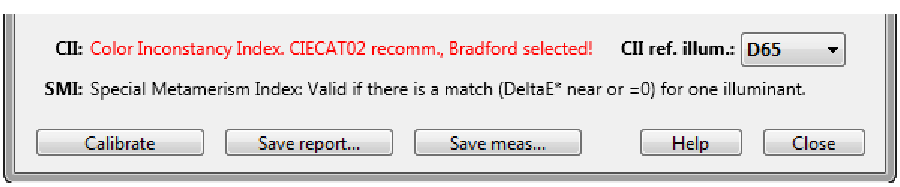
  Note: Because the CII, SMI, and MI are color differences, the same criteria and thresholds used in evaluating color differences should apply when assessing these numbers.

  Note: The HunterLab MI values are always computed using CIELAB color differences.

- Select the reference illuminant for CII computation. D65 is recommended but any other is valid.

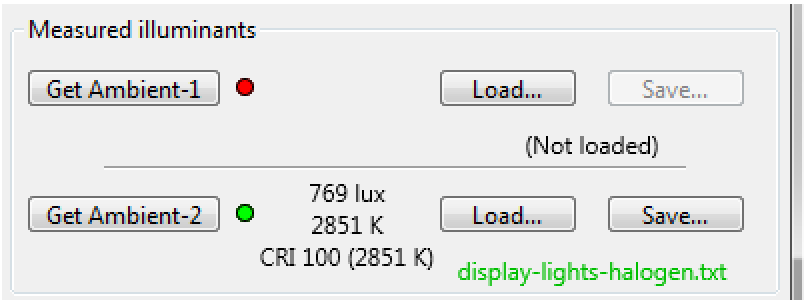
- If not already done, calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions.

Note: Computing the CII requires processing the measured data with a Chromatic Adaptation Transform (CAT) matrix. CT&A supports the "CIECAT02" and "Bradford" matrices but CIECAT02 is recommended for the CII. If "Bradford" is currently selected, you will see a warning message, in red, in the MI window, as shown below. You can select the CAT matrix in the Preferences dialog.



MEASURED ILLUMINANTS

If desired, click the "Get Ambient-1" or "Get Ambient-2" button to acquire the spectrum of an ambient light source or load a spectrum from a file (Measured illuminants input file requirements). When making a measurement, you are prompted to install the ambient diffuser; you may also be prompted to calibrate the instrument for this mode, if not already done.



The illuminance (lux), the Correlated Color Temperature (CCT, in kelvin), the Color Rendering Index (CRI, see the CIE 13.3 section in the ISO3664+ tools description), and the CCT used for CRI computation will be shown at the right of the "Get Ambient" button. Once measured, you can save the spectrum in a file for reference, or for use at a later time.

Hint: If there is a problem during the ambient calibration procedure, for example, if you forget to place the black cap on the diffuser, then the calibration should be redone. However, if you click on the "Calibrate" button while in the MI tools, the default procedure is to calibrate in Reflectance, and not in Ambient mode. To redo a calibration in Ambient mode, open the Graph tools, select the "Ambient" mode, and then click on the "Calibrate" button. Once the calibration is completed, you can go back in the MI tools and measure an ambient source.

Hint: We recommend saving your ambient light source measurements since, apart from the spectrum, the file contains: the illuminance, the CCT, the CRI with the CRI reference CCT, the chromaticity coordinates (xyY), and the tristimulus values (XYZ). This file can be opened in any word processor or spreadsheet application.

Hint: An ambient spectrum saved in the MI tools can be used as input in the CRI and ISO 3664+ tools.

Important: Although the ambient spectrum is saved is a CGATS compatible file format, which can be opened by most color processing software, it contains a spectrum which is not normalized to 1 or 100, like a reflectance spectrum. The appearance of the patch and the computed color coordinates will thus not be correct in such programs.

You will find files of many standard illuminants in the "Illuminants" folder located within the main CT&A application folder. In Windows, this folder can be opened directly with the "Start menu/BabelColor/Illuminant files" shortcut.

ILLUMINANT SELECTION

Select the "Illuminants" that will be used for SMI and MI metamerism evaluation, and as the CII reference.

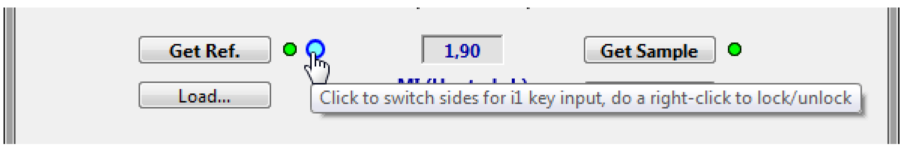
The available illuminants are (an asterisk indicates that a correlated color temperature is shown):

- A (Tungsten or Incandescent, 2856 K)
- B (Direct sunlight at noon, 4874 K*, obsolete)
- C (North sky daylight, 6774 K*)
- D50 (Daylight, used for color rendering, 5000 K*)
- D55 (Daylight, used for photography, 5500 K*)
- D60 (Daylight, 6000 K*)
- D65 (New version of North sky daylight, 6504 K*)
- D75 (Daylight, 7500 K*)
- E (Uniform energy illuminant, 5400K*)
- F2 (Cool White Fluorescent (CWF), 4200 K*)
- F7 (Broad-band Daylight Fluorescent, 6500 K*)
- F11 (Narrow-band White Fluorescent, 4000 K*)
- Amb-1 (i.e. Ambient-1)
- Amb-2 (i.e. Ambient-2)

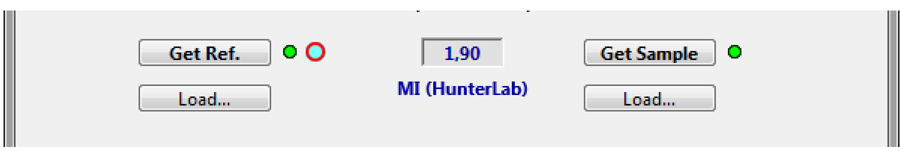
If Ambient-1 or Ambient-2 is selected but not already measured, or loaded from file, when measuring the Reference or Sample, you will get a message asking you to acquire the ambient spectrum. Once a Reference or Sample is measured, the window data will be updated whenever you change an illuminant.

INSTRUMENT MEASUREMENTS

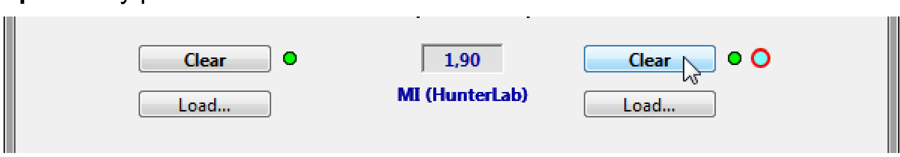
To make a measurement, either click on the "Get Ref." or "Get Sample" button or press the instrument button. A large blue indicator is located beside the input that will be selected if you press the instrument button:



This indicator automatically changes location when an input is done at one position. Do a left-click on an indicator to change its position or a right-click to lock it (a locked indicator has a red border:). You can also do a left-click on a locked indicator; the new position will be locked.

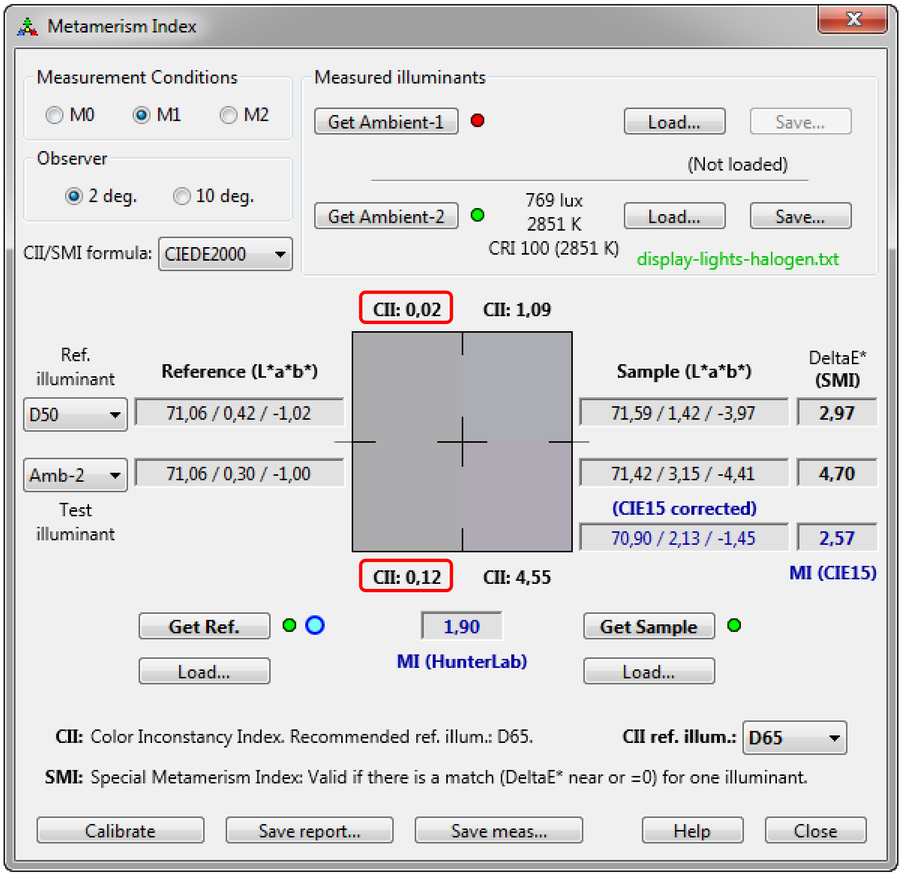


To **erase** a measurement, first press the **Alt** key, in Windows, or the **Option** key on a Mac. Whenever the mouse cursor is within the tool window, the "Get Ref." and "Get Sample" buttons will change their caption to "**Clear**" (if there is a measurement). To clear the sample, click the button with the mouse while keeping the **Alt** or **Option** key pressed:



MI EXAMPLE-1

In this example, the *Reference* is a neutral patch printed with black ink only and the *Sample* the same patch printed with CMY inks (and no K). The displayed patch colors show how the *Reference* and *Sample* would look like under the selected illuminants, D50 and "Amb-2" (Ambient-2), a measured light source:



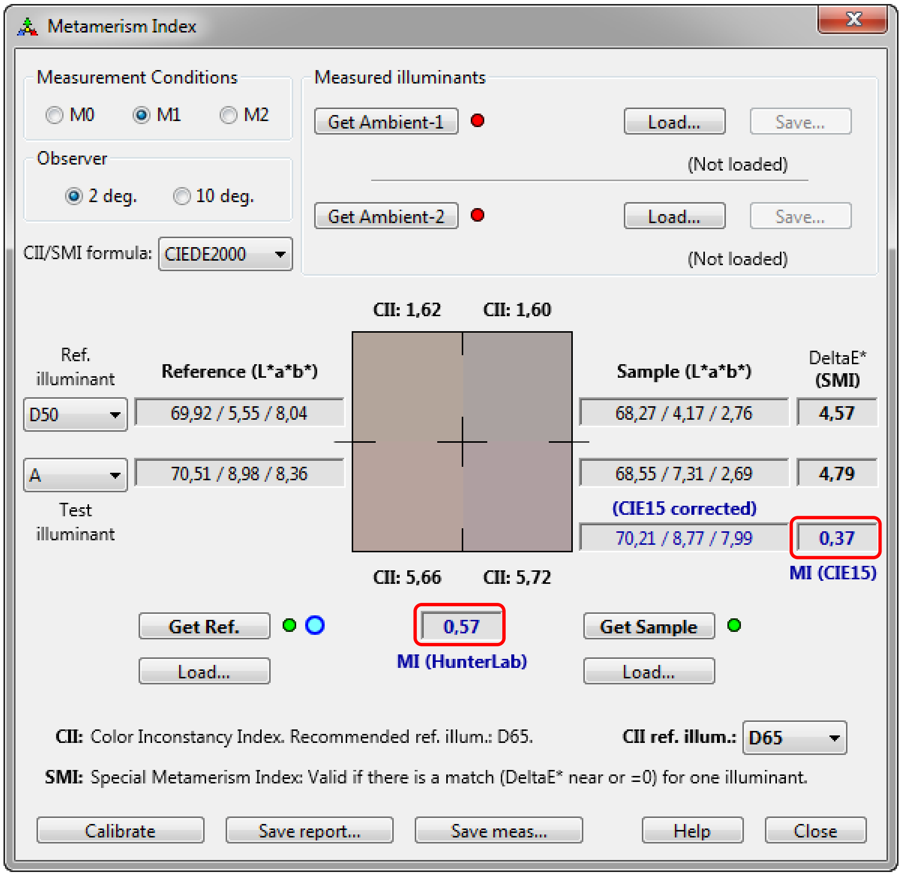
Here is a short analysis of the screenshot:

- We note that the *Reference* patch looks almost identical under D50 and the Ambient-2 illuminant, a color constancy which is confirmed with the low Color Inconstancy Index (**CII**) values computed relative to D65 (CII=0.02 between D50 and D65; CII=0.12 between Amb-2 and D65). You will recall that the CII is computed independently for both the *Reference* and the *Sample*, and for each selected illuminant. The CII is computed relative to a user-specified reference illuminant (D65 by default).
- There is a smaller difference between the *Reference* and *Sample* patches under D50 (SMI=2.97) than between the *Reference* and *Sample* patches under Ambient-2 (SMI=4.70). The *Sample* is quite reddish under the *Test illuminant*, which is not surprising since Ambient-2, an halogen lamp with a CCT of 2851 K, close to Illuminant A, has a strong red content.
- The CII values for the *Sample* patch are much higher than those for the *Reference* patch. The maximum inconstancy is obtained between the *Test illuminant* and the CII reference illuminant (CII=4.55).
- The **DeltaE* (SMI)** color difference between the *Reference* and the *Sample* for the *Reference illuminant* is not zero (SMI=2,97), as it often happens in real life. In this case, the *Sample* L*a*b* coordinates obtained with the Ambient-2 *Test illuminant* were corrected and are shown in the **(CIE15 corrected)** data field; the corrected color difference, and MI, is 2.57, as shown in the **MI (CIE15)** data field.
- The HunterLab MI, determined from CIELAB coordinates, is 1.90.

The analysis clearly shows that the *Reference* and *Sample* patches are not matched. This is not to say that a high CII is synonymous with high MI, since the color shift could be in the same direction for the two colors and could possibly result in a near-zero MI, as we will see with the second example on the next page.

MI EXAMPLE-2

In this second example, we compare two very different colors:



Here is a short analysis of the screenshot:

- We note that the *Reference* and Sample patches looks quite different under each illuminant (D50 and A). The CII between the *Reference illuminant* (D50) and the CII reference illuminant (D65) is moderately high for both the Reference and Sample patches (CII=1.62 and 1.60) but quite high between the Test illuminant (A) and the CII reference illuminant (D65) (CII=5.66 and 5.72). We also have very similar CII values for the *Reference* and *Sample* for a given illuminant (D50 or A).
- Even with high CII numbers, the corrected MI (CIE 15) value is very low, at 0.37. We see a similarly low value for the HunterLab MI at 0.57.
- Looking at the patches, we see that both the *Reference* and the *Sample* get reddish under the *Test illuminant*. In effect, the color shifts are in the same direction, and we could add of the same magnitude since the CII numbers are almost equal. In other words, the color relationship between these colors is maintained when changing the light source, and the resulting Metamerism index is small.

If these were pieces of clothes, their color relationship would be the same under tungsten halogen lamps (i.e. Illuminant A) in a room, or outside in daylight.

Note: A clipping indicator appears in the bottom left corner of a color patch when the color of the sample it represents is outside of the RGB space gamut of the monitor.

OTHER TOOL FUNCTIONS

At all times, you can calibrate the instrument by clicking the "Calibrate" button. The measurement mode for all MI tools is "Reflectance", by default, and cannot be changed.

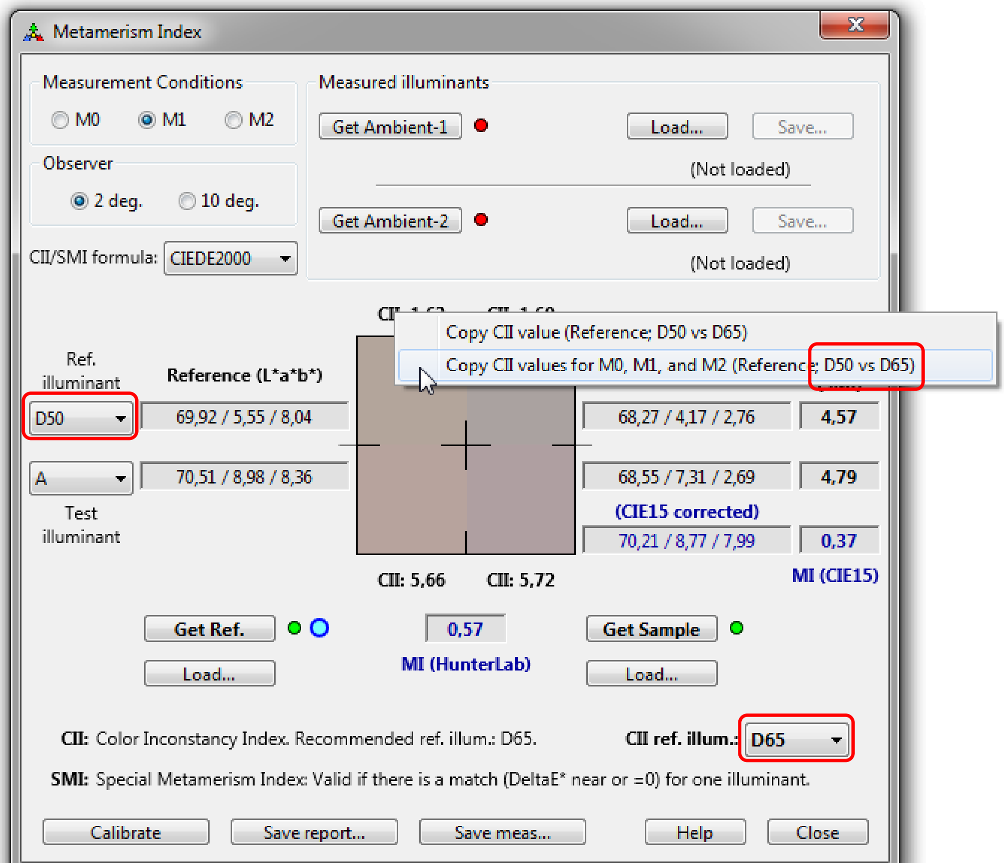
Click on "Save report..." to save a Metamerism Index report. The report contains:

- The L*a*b* values for the *Reference* and *Sample* patches.
- All CII, SMI, and MI data.
- The *Reference* and *Sample* patches spectrums.

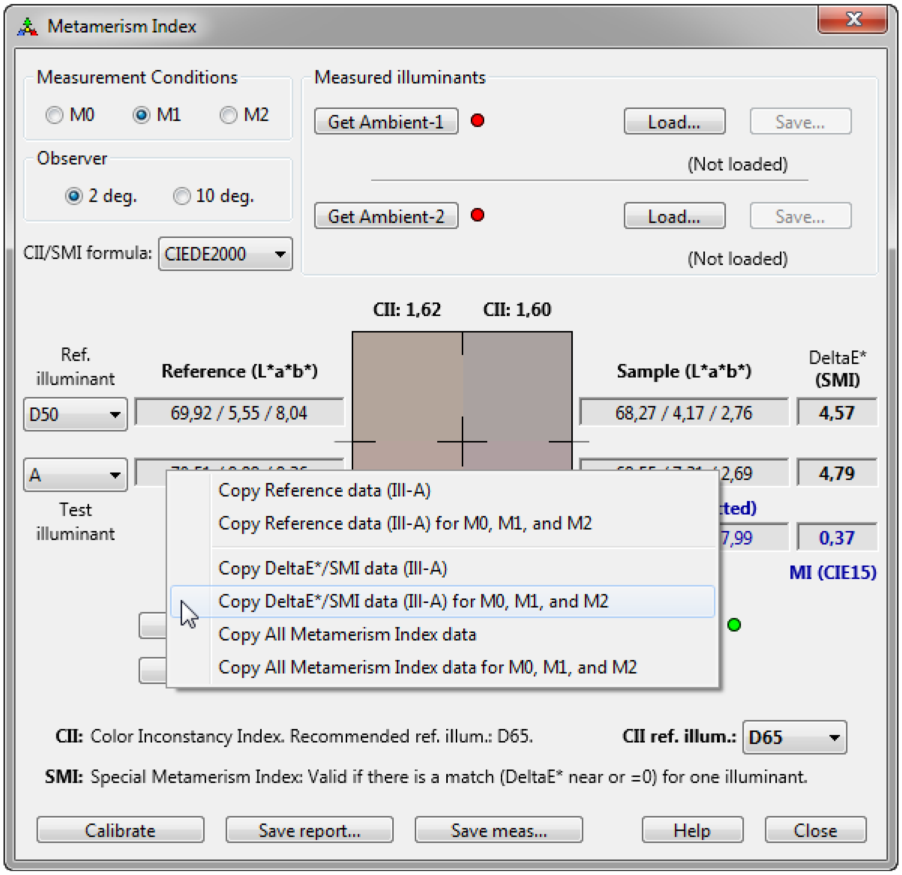
The report is tab-delimited; it can be directly imported in a spreadsheet program and opened in many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting). Data is saved for all applicable Measurement Conditions.

Click on “Save meas…” to save the *Reference* and *Sample* patches spectrums in a CGATS format text file, which can easily be used for file input afterwards.

You can copy numerical data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on any data field (L*a*b*, CII, SMI, MI)). Shown below is the contextual menu which appears with a right-click on the upper-left CII, which quantifies the color inconstancy for the *Reference* between "D50" and "D65". When copied, the data is transferred into the clipboard. Please note that L*a*b* values are separated by Tabs; you can then easily paste the values in a spreadsheet or document table, where they will be distributed in individual cells.



The screenshot below shows the menu which appears with a right-click on the L*a*b* *Reference* data obtained with the *Test illuminant* (Illuminant A in this example).



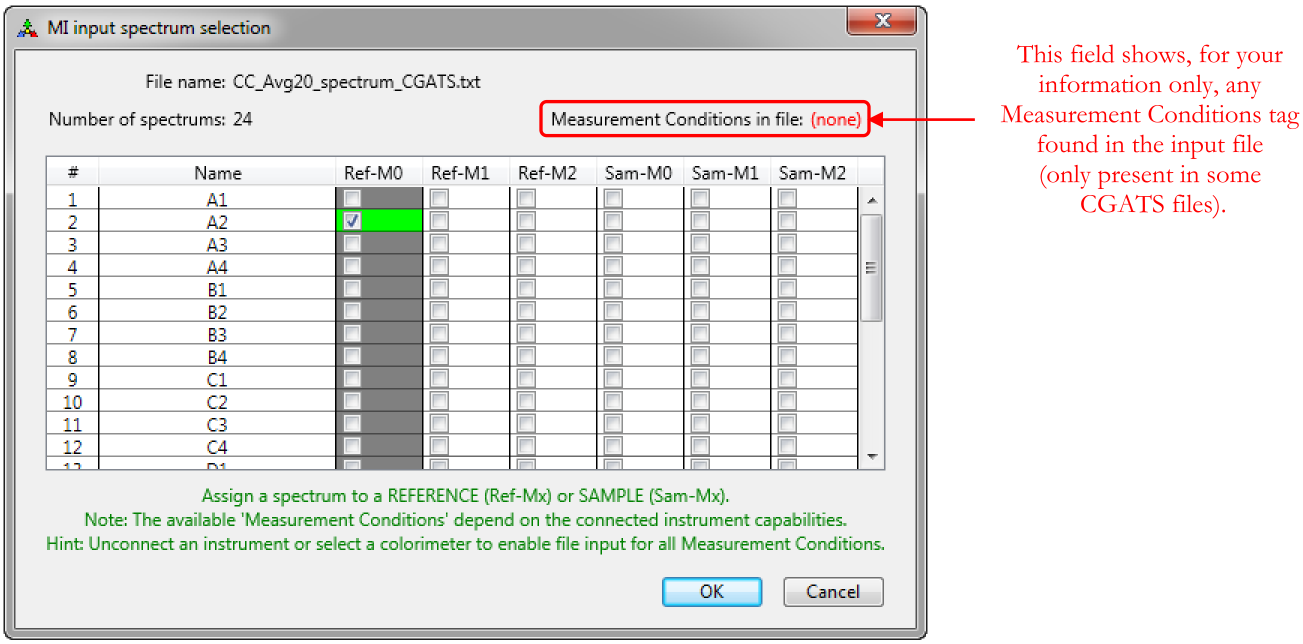
11.3 MI input file spectrum selection dialog

There are two methods to open/load a file:

- 1st method: Click on one of the "**Load...**" buttons located below the “Get Ref.” or “Get Sample” buttons. These two buttons can be used interchangeably, i.e. they are not uniquely assigned to the *Reference* or *Sample* input. Select the file to open with the file input dialog shown in this section.
- 2nd method: Drag-and-drop one or more files on a "**Load...**" button. You can also drag-and-drop multiple files at a time..

Note: At any time, you can use a data file as input in place of a measurement; a connected instrument is NOT required for file input. A file may contain one or more spectrums.

The input spectrum selection dialog appears once a file is opened:



In this dialog, the available Measurement Conditions depend on the connected instrument capabilities. Here are a few examples:

- An i1Pro may be capable of providing only M0 or M2 data, depending on the instrument model.
- An i1Pro 2 with M0/M1/M2 capabilities will provide only M0 data if connected with the “i1Pro / i1Pro 2 (non-XRGA)” instrument driver.
- An i1Pro 2 with M0/M1/M2 capabilities can provide measurements in all measurement conditions (M0/M1/M2) if connected with the “i1Pro / i1Pro 2 (XRGA)” instrument driver.

If you want to enter data in all measurement conditions and the instrument is not compatible, you can either unconnect the instrument or select a colorimeter (an instrument which cannot provide spectral data) in the instrument menu. This will disable instrument input for all spectral tools but will enable all measurement conditions in this dialog

Here is what you can do with the dialog:

- You can assign one input per measurement condition for either the *Reference* patch or the *Sample* patch.
- If you assign an input to only one or two measurement conditions of a patch, the spectrum(s) for the unassigned condition(s) will be erased.
- If you do not assign an input to the *Reference* or the *Sample*, the current inputs, if present, will remain unchanged.

The file requirements are described in the MI input file requirements (reflectance) section.

11.4 MI input file requirements (reflectance)

The MI tools can accept input from a file even if there is no connected instrument. This file **MUST** contain spectral data. This file may come from a reflectance measurement made in the Graph or MI tools, or from another application. Acceptable file formats are **CGATS** or **plain text**, with the following requirements.

Important: You should make sure that the file data represents **reflectance** measurements. The reflectance values shall be defined between zero and one, with one representing full (100%) reflectance or between 0 and 100.

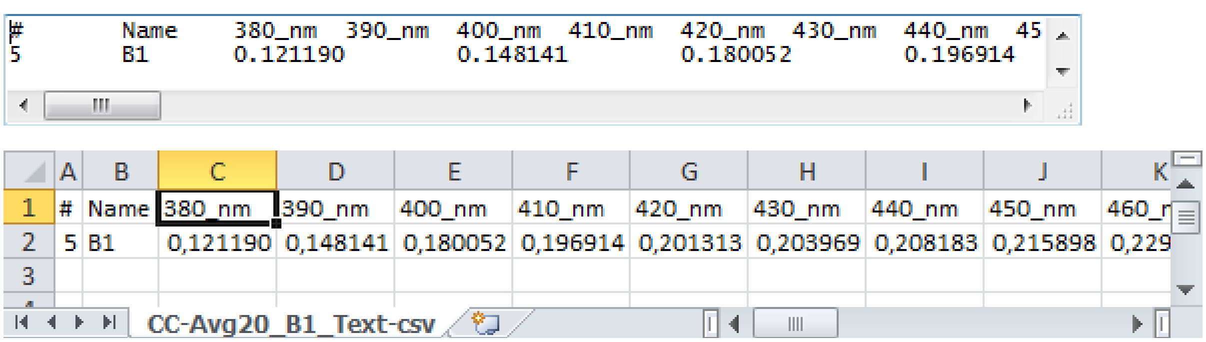
Requirements for spectrum files in CGATS format:

- The file may contain **one** or **more** spectrums.
- The file **MUST** conform to the "CGATS.17" format standard. As an example, you can use a 10 nm bandwidth file that you will find in the "Illuminants" folder located within the CT&A application folder.
- There is no need to specify an illuminant and an observer since the tool uses spectral data.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength tags **MUST** be in one of the following formats: "nm450", "SPECTRAL_NM450", SPECTRAL_NM_450, or "SPECTRAL_450".
- The decimal separator for data can be a period (.) or a comma (,).
- The data delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all the data in the file.

Requirements for spectrum files in plain text format:

- The file may contain **one** or **more** spectrums.
- The first line **MUST** contain wavelength labels/tags.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength labels/tags may be simple numbers or contain other letters, such as "nm380", "380_nm", or "380NM", but no spaces.
- The first line may contain other tags such as "ID" or "Name". Tags **MUST NOT** contain spaces. These tags may be written in uppercase or lowercase. If additional tags are used in the first line, you **MUST** fill the second line with the corresponding information or number, with no spaces in the tag content.
- The second line **MUST** contain the spectral values (and the content of the additional tags if used) for the first sample. Data for other samples may be added on the following lines, one line per sample.
- The decimal separator for data can be a period (.) or a comma (,).
- The wavelength labels and the spectral values **MUST** be separated by data delimiters. The delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all lines.

A plain text file can easily be created with a word processor or a spreadsheet application, as shown below. When saving the file, do not use the often complex native application file formats (for ex.: *.xls); instead, select a tab-delimited or Comma-Separated-Value (CSV) **text** format.



11.5 MI input file requirements (custom illuminant)

The MI tools can accept input from a file in order to define a custom illuminant even if there is no connected instrument. This file **MUST** contain spectral data. This file may come from an ambient measurement made in the CRI, Graph, ISO3664+, or MI tools, or from another application. Acceptable file formats are **CGATS** or **plain text**, with the following requirements.

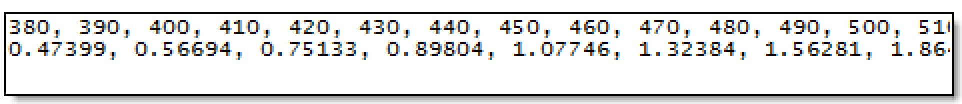
Requirements for spectrum files in CGATS format:

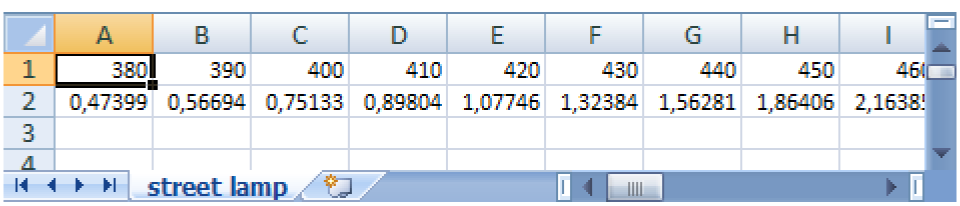
- The file **MUST** contain only **one** (1) spectrum.
- The file **MUST** conform to the "CGATS.17" format standard. As an example, you can use a 10 nm bandwidth file that you will find in the "Illuminants" folder located within the CT&A application folder.
- There is no need to specify an illuminant and an observer since the tool uses spectral data.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength tags **MUST** be in one of the following formats: "nm450", "SPECTRAL_NM450", SPECTRAL_NM_450, or "SPECTRAL_450".
- The decimal separator for data can be a period (.) or a comma (,).
- The data delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all the data in the file.

Requirements for spectrum files in plain text format:

- The file **MUST** contain only **one** (1) spectrum.
- The first line **MUST** contain wavelength labels/tags.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength labels/tags may be simple numbers or contain other letters, such as "nm380", "380_nm", or "380NM", but no spaces.
- The first line may contain other tags such as "ID" or "Name". Tags **MUST NOT** contain spaces. These tags may be written in uppercase or lowercase. If additional tags are used in the first line, you **MUST** fill the second line with the corresponding information or number, with no spaces in the tag content.
- The second line **MUST** contain the spectral values (and the content of the additional tags if used).
- The decimal separator can be a period (.) or a comma (,).
- The wavelength labels and the spectral values **MUST** be separated by data delimiters. The delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all lines.

A plain text file can easily be created with a word processor or a spreadsheet application, as shown below. When saving the file, do not use the often complex native application file formats (for ex.: *.xls); instead, select a tab-delimited or Comma-Separated-Value (CSV) **text** format.

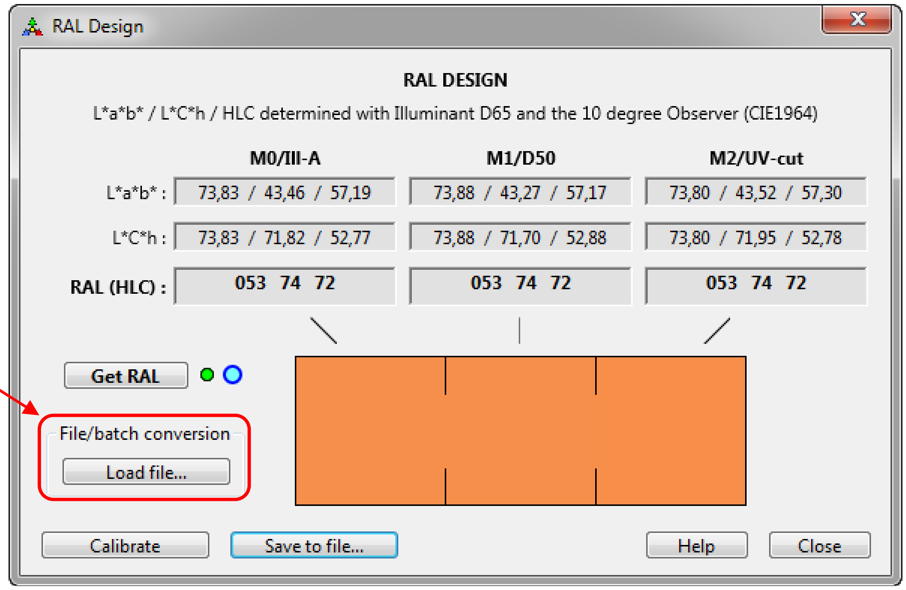




Hint: If you are not sure of your file format, simply load it and save it under another name; then compare the two files to see if the data is the same.

12. RAL DESIGN tool

Click on the button to open a file input dialog or drag-and-drop one or more files containing one or more spectrums.



INTRODUCTION

The **RAL DESIGN tool** window is opened either by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/RAL DESIGN" menu. The RAL DESIGN tool is a straightforward measurement and conversion tool that presents the measured data as per the RAL DESIGN HLC convention:

- H: Hue angle (from 0, written as “000”, to 360 degrees)
- L: Lightness (apparent brightness, from 0, written as “00”, to 100)
- C: Chroma (saturation, from 0, written as “00”, to 100)

The RAL DESIGN notation is based on L*C*h data computed from illuminant D65 and the 10 degree Standard Observer (CIE1964). HLC data is simply a reordering of the L*C*h values, with "h" becoming "H" and being shifted as the first coordinate. The values are also rounded to the nearest integer. For additional information on the RAL DESIGN notation, Measurement Conditions, and where you can purchase reference chips, click here.

Important: The RAL DESIGN tool can accept inputs from a file or from a supported instrument. **A CONNECTED INSTRUMENT IS NOT REQUIRED** in order to use this tool. A file may contain one or more spectrums; multiple files can be inputted with drag-and-drop on the "Load file…" button. The input data is immediately converted and saved in a CGATS format text file. A file may be either a text file complying with the CGATS format, or a plain text file. The specific requirements for the file formats are presented in the RAL DESIGN input file requirements section.

Important: To measure a color with the RAL tool, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate" and "Get RAL" buttons of the RAL DESIGN window being enabled (some data fields will not be available (shown as "N.A. in demo") if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Note: In Windows, if the i1Pro/i1Pro 2 or i1Pro 3 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

Instrument button support: When the RAL DESIGN tool window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears beside the "Get RAL" button. This indicator confirms that the next instrument key press will be assigned to this button; of course, you can also do a mouse click on the button.

SETUP

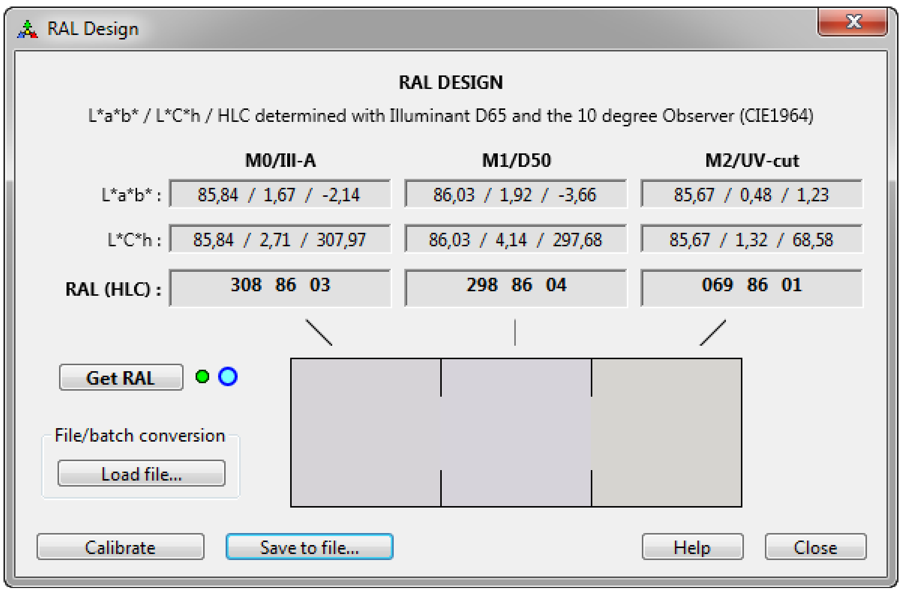
- **There is no user setup for this tool.** The program will set itself in **reflectance mode** and the data will be computed for illuminant **D65** and the **10 degree Observer**. However, for input with an instrument, it is assumed that your instrument is properly connected and detected, as discussed in the introduction.

  Note: If you are using an **i1Pro 2** with the "**i1Pro / i1Pro 2 (XRGA)**" driver, an i1Pro 3, or an i1Pro 3 Plus, all measurements will be taken with the three "Measurement Conditions", M0 (Ill-A), M1 (D50), and M2 (UV-cut), as defined in ISO 13655 (Ref. 42). A description of the M0/M1/M2 measurement conditions can also be found in the FluoCheck tools. If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument and data will not be shown for the other measurement conditions.

- If not already done, calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions.

INSTRUMENT MEASUREMENT

To make a measurement, just click on the "Get RAL" button or press the instrument button. Apart from the measurement in RAL DESIGN notation, the display also shows the L*a*b* and L*C*h values. If you take a measurement of a color patch printed on a non-fluorescent substrate, the M0, M1, and M2 values should be identical, as shown in the screenshot at the beginning of this section. However, if the substrate is fluorescent, you may obtain three different values, as shown below:

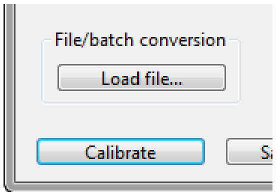


HINT: Even though all colors can be represented in RAL DESIGN notation, not all colors are available in "real" inked or painted color chips. The standard RAL DESIGN patches are typically offered in increments of five for each coordinate. For communicating the RAL DESIGN value, we suggest you give the exact measurement as well as the closest available printed patches.

Note: A clipping indicator appears in the bottom left corner of the color patch when the color of the sample it represents is outside of the RGB space gamut of the monitor.

FILE / BATCH CONVERSION

At any time, you can convert spectral data in a file to RAL DESIGN values; a connected instrument is NOT required for file input. You can either click on the "Load file..." button or drag-and-drop one or more files on the button. The files may contain one or more spectrums.



The input data is immediately converted and saved in a CGATS format text file. The output data comprises:

- the color in RAL DESIGN notation (defined as the SAMPLE_NAME);
- the individual RAL Hue, Lightness, and Chroma (HLC) components;
- L*a*b* computed with Illuminant D65 and the 10 degree Observer;
- the original file sample ID, if present, or a sequential ID, if not;
- the original sample NAME if detected, and redefined as SAMPLE_REF.

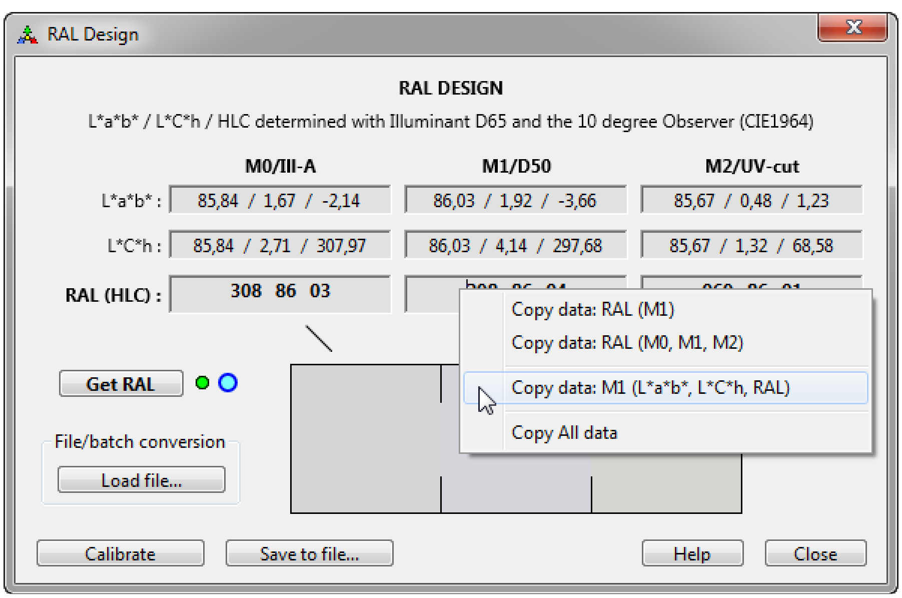
The input file requirements are described in the RAL DESIGN input file requirements section.

OTHER TOOL FUNCTIONS

At all times, you can calibrate the instrument by clicking the "Calibrate" button. The measurement mode for the RAL DESIGN tool is "Reflectance", by default, and cannot be changed.

Click on "Save to file..." to save a RAL DESIGN report based on instrument measurements, i.e. not from file input. The report has tab-delimited data that can be directly imported in a spreadsheet program, and opened in many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting).

You can copy numerical data by making a mouse right-click (or **ctrl + click** on a one-button Mac mouse) on a data field. Shown below is the contextual menu which appears with a right-click on the RAL (HLC) data field of the M1 measurement condition. Right-clicking in any data field will give you the choice of copying only the field, or the data of the entire row or column in which the cell is located, or even all measured data. When copied, the data is transferred into the clipboard. Please note that L*a*b*, L*C*h, and RAL values are separated by Tabs; you can then easily paste the values in a spreadsheet or document table.



12.1 RAL DESIGN System description

A very common standard in Europe, the first RAL color standard was devised in Germany in 1927. Now known as RAL CLASSIC, this older standard comprises 213 shades, which are grouped according to broad categories and identified with numbers which have no relation to colorimetric quantities, as is the case with the FED-STD-595 system. Nonetheless, like the FED-STD-595 system, it has found wide usage and many specifications still use these numbers as references.

However, apart from its limited size, RAL CLASSIC has a major drawback: it cannot describe "any" color. To solve that issue, a new RAL system was devised, this time based on modern colorimetric criteria. Called **RAL DESIGN**, the system numbering scheme is a simple re-ordering and rounding of the L*C*h color space values which is presented as **HLC**, for *Hue*, *Lightness*, and *Chroma*, with the hue being placed as the first coordinate.

For example, L*C*h coordinates such as:

75,87 / 11,93 / 62,13

would be presented as:

062 76 12

in RAL DESIGN notation.

While any color can be represented in the RAL DESIGN notation, not all colors can be reproduced physically on printed patches. In practice, 1625 patches are offered in fixed spaced increments of 5 to 10 units for each parameter. The nearest physical patch of the above example is:

060 80 10 .

If the match is critical, it may be advisable to identify two or three nearest patches and visually interpolate between them. For the example above, for which a patch with close enough **Lightness** is not available, these would be:

060 **70** 10 and 060 **80** 10 .

In order to obtain RAL DESIGN data, the original requirements were as follow:

RAL DESIGN requirements	
Instrument	Datacolor DC 3890
Geometry	d / 8°
Observer	10 degrees (CIE 1964)
Illuminant	D65 (6504 K)

Note: The required instrument, model DC 3890 from the Datacolor company, is not available anymore and support has been discontinued in September 2002. Since then, we have seen the Datacolor SF 600X mentioned as a reference instrument; however, other instruments of the same geometry are easily available from various manufacturers.

Important: As per RAL DESIGN requirements, CT&A uses the 10 degree Observer (CIE1964) and the D65 illuminant for its calculations. These requirements correspond to the needs of the paint and textile markets. Unfortunately, this also means that RAL DESIGN data cannot easily be converted to, or compared with, typical data available in the printing and graphic fields, since these fields are essentially based on the 2 degree (CIE1931) Observer.

Important: As indicated above, RAL DESIGN data should be derived from a spectrophotometer configured with a d / 8° geometry, where the color sample is subjected to a diffuse illumination and measurement is done 8 degrees away from the sample normal. Since the i1Pro and i1Pro 2 spectrophotometer are 45° / 0° instrument with a circular illumination at 45 degrees incidence and measurement at 0 degree (i.e. on the sample normal), the RAL DESIGN values obtained with these instruments will not be accurate for glossy samples. The reason is that, for glossy samples, the reflection coefficients are slightly higher with a d / 8° instrument compared to the values measured with a 45° / 0° instrument. However, good measurement correlation can be obtained with semi-gloss and matte samples.

Please consult the following Web site for more information on the RAL DESIGN system and how to purchase color patches:

- https://shop.ral-farben.de
- https://www.ral.de/ (Main Web page of RAL site).

12.2 RAL DESIGN input file requirements

The RAL DESIGN tool can accept input from a file even if there is no connected instrument. This file **MUST** contain spectral data. This file may come from a reflectance measurement made in the Graph or MI tools, or from another application. Acceptable file formats are **CGATS** or **plain text**, with the following requirements.

Important: You should make sure that the file data represents **reflectance** measurements. The reflectance values shall be defined between zero and one, with one representing full (100%) reflectance or between 0 and 100.

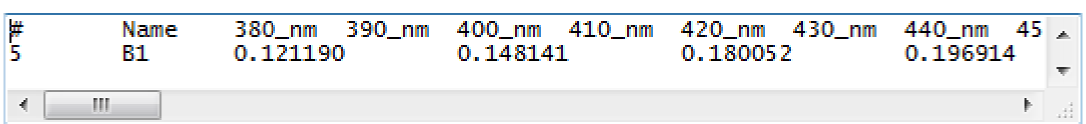
Requirements for spectrum files in CGATS format:

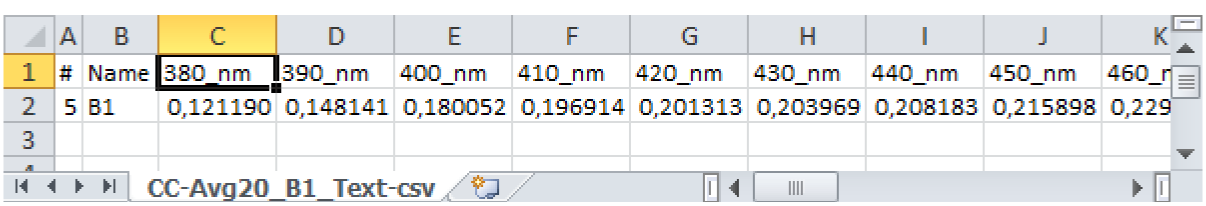
- The file may contain **one** or **more** spectrums.
- The file **MUST** conform to the "CGATS.17" format standard. As an example, you can use a 10 nm bandwidth file that you will find in the "Illuminants" folder located within the CT&A application folder.
- There is no need to specify an illuminant and an observer since the tool uses spectral data.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength tags **MUST** be in one of the following formats: "nm450", "SPECTRAL_NM450", SPECTRAL_NM_450, or "SPECTRAL_450".
- The decimal separator for data can be a period (.) or a comma (,).
- The data delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all the data in the file.

Requirements for spectrum files in plain text format:

- The file may contain **one** or **more** spectrums.
- The first line **MUST** contain wavelength labels/tags.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength labels/tags may be simple numbers or contain other letters, such as "nm380", "380_nm", or "380NM", but no spaces.
- The first line may contain other tags such as "ID" or "Name". Tags **MUST NOT** contain spaces. These tags may be written in uppercase or lowercase. If additional tags are used in the first line, you **MUST** fill the second line with the corresponding information or number, with no spaces in the tag content.
- The second line **MUST** contain the spectral values (and the content of the additional tags if used) for the first sample. Data for other samples may be added on the following lines, one line per sample.
- The decimal separator for data can be a period (.) or a comma (,).
- The wavelength labels and the spectral values **MUST** be separated by data delimiters. The delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all lines.

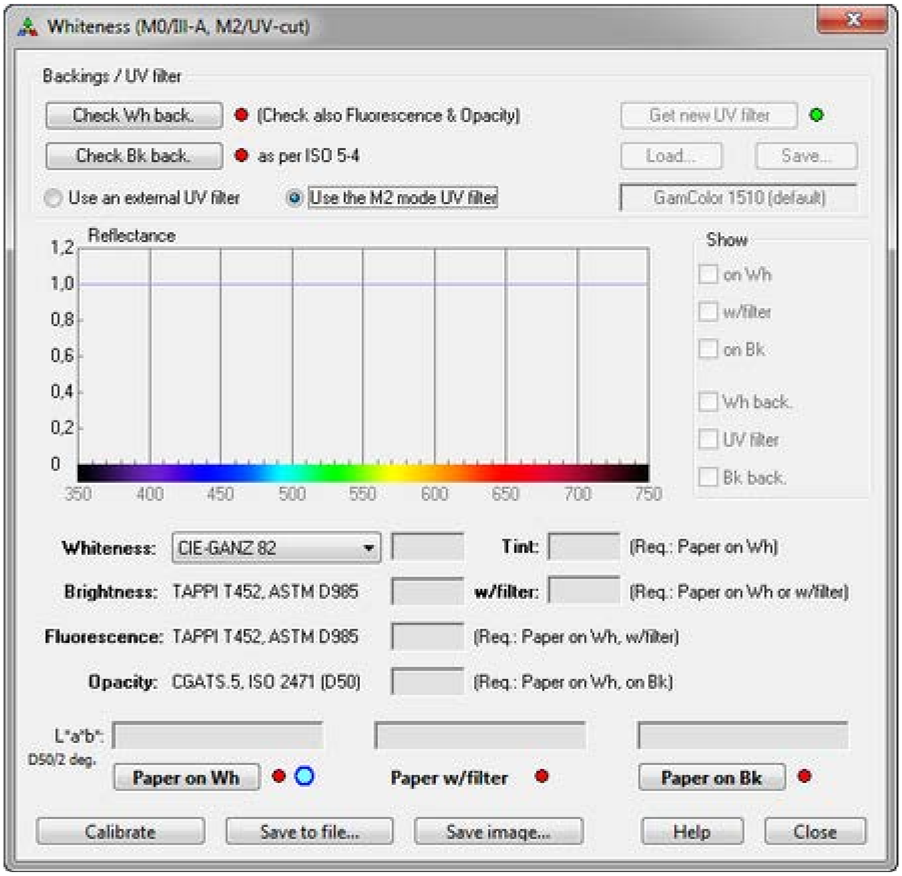
A plain text file can easily be created with a word processor or a spreadsheet application, as shown below. When saving the file, do not use the often complex native application file formats (for ex.: *.xls); instead, select a tab-delimited or Comma-Separated-Value (CSV) **text** format.





	A	B	C	D	E	F	G	H	I	J	K
1	#	Name	380_nm	390_nm	400_nm	410_nm	420_nm	430_nm	440_nm	450_nm	460_n
2	5	B1	0,121190	0,148141	0,180052	0,196914	0,201313	0,203969	0,208183	0,215898	0,229
3											

13. Whiteness tools



INTRODUCTION

The **Whiteness tools** window is opened either by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/Whiteness" menu.

The Whiteness tools can be used to measure:

- **Whiteness and Tint:** Measure a paper whiteness and tint according to three different formulas.
- **Brightness:** Measure a paper brightness according to TAPPI T452 / ASTM D985.
- **Fluorescence:** Measure a paper fluorescence according to TAPPI T452 / ASTM D985.
- **Opacity:** Measure a paper opacity according to CGATS.5 / ISO 2471.
- **White backing compliance:** Check the compliance of a white backing used to measure color patches as per ISO 13655 (Ref. 42).
- **Black backing compliance:** Check the compliance of a black backing used to measure color patches as per ISO 5-4 (Ref. 43).
- **Derive a UV filter spectrum:** Derive the spectral characteristics of an unknown UV filter to be used for fluorescence measurements.

Important: To use these tools, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate"and data entry buttons of the Whiteness window being enabled (some data entry buttons and controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

Additional Whiteness tools requirements:

1. For fluorescence measurements:
   - The instrument must not be UV-cut
   - You must use either a thin, transparent, UV filter (not provided) **or** an i1Pro 2 which supports the M0 and M2 measurement conditions.
2. For the other measurements:
   - Compliant white and black backings (not provided). Please note that you can easily check white and black backings compliance with this window's tools

Note: In Windows, if the i1Pro 2 USB drivers are not installed, please consult the "CT&A_Readme.txt" file located within the main CT&A application folder. This file can be opened directly with the "Start menu/BabelColor/CT&A Readme" shortcut.

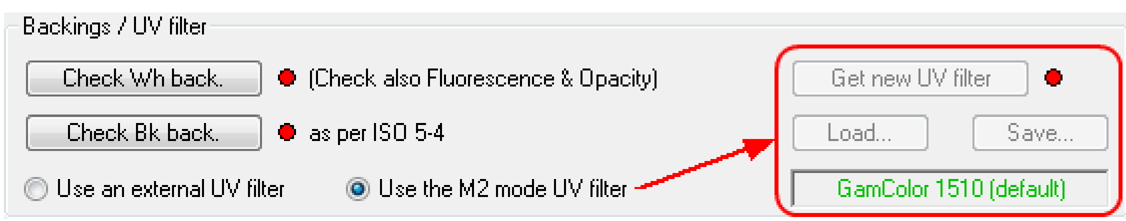
Instrument button support: When the Whiteness tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears next to the "Paper on Wh", "Paper w/filter", or "Paper on Bk" button. This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button. The indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the previous measurement if required, or do a right-click to lock it on a given measurement. You can also do a left-click on a locked indicator; the new position will be locked.

The remainder of this section describes how to set up the interface and make measurements. For a description of the standards and the Measurement Conditions, click here.

SETUP

- It is assumed that your instrument is properly connected and detected, as discussed in the introduction just above.

- If you have an i1Pro 2 which supports the M0 and M2 measurement conditions, you can select to use either an external UV filter or the internal filter associated to M2 measurements. When you select the "Use the M2 mode UV filter" radio button, the controls associated with the external filter are disabled, as shown below.



  Note: Even if you use an i1Pro 2, the M2 mode UV filter radio button is enabled only when you select the "**i1Pro / i1Pro 2 (XRGA)**" driver in the toolbar window.

  Note: If you use an external UV filter, you should characterize it before measuring the paper properties. A filter characterization procedure is presented later in this section. You can also load the **filter relative transmission** spectrum from a file (file requirements).

- Select the "**Whiteness**" formula.

  The available formulas are:

  - CIE-GANZ 82 (Ref. 35): The standard CIE formula. Based on XYZ measurements (D65, 2 degree Observer). This formula is also described in the ASTM E313 standard (Ref. 36), which also provides formulas for a few combinations of formulas and Observers.
  - CIE-Uchida (Ref. 37): This formula extends CIE-GANZ 82 by supporting a wider range of tints and purity over which whiteness can be evaluated. Based on XYZ measurements (D65, 2 degree Observer).
  - CIELAB-HE 2007 (Ref. 38): Based on CIELAB (D65, 10 degree Observer). Works over a wider range of tints and purity. It is said to be more uniform and to better match visual ranking.

- The following accessories are required to perform the specific measurements:
  - White backing: Required to measure the *brightness*, the *fluorescence*, and the *opacity*
  - Black backing: Required to measure the *opacity*
  - UV filter (if an external filter is selected): Required to measure the *brightness w/filter* (i.e. with a UV filter), and the *fluorescence*

  Note: These accessories can be characterized within the Whiteness tools' window, as we will see later in this section.

- If not already done, calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions.

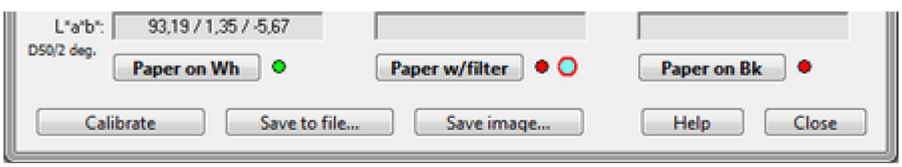
MEASUREMENTS

A typical measurement sequence goes as follow:

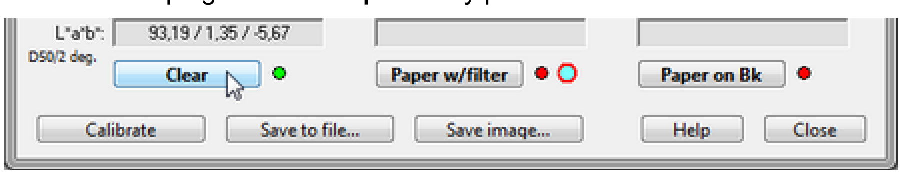
- **Paper on white** backing: Place the paper for which you want to determine the characteristics on the white backing and press on the "Paper on Wh" button.
- **Paper with filter** on white backing: With the paper still on the white backing, place the UV filter between the paper and the instrument and press on the "Paper w/filter" button.
  Note: If you selected the "Use the M2 mode UV filter" radio button, the "Paper w/filter" button is removed and this measurement is done automatically each time you do a "Paper on Wh" measurement.
- **Paper on black** backing: Remove the UV filter between the instrument and the paper. Place the paper on the black backing and press on the "Paper on Bk" button.

To make a measurement, click on one of the buttons or press the instrument button. A large blue indicator  is located beside the input that will be selected if you press the instrument button:

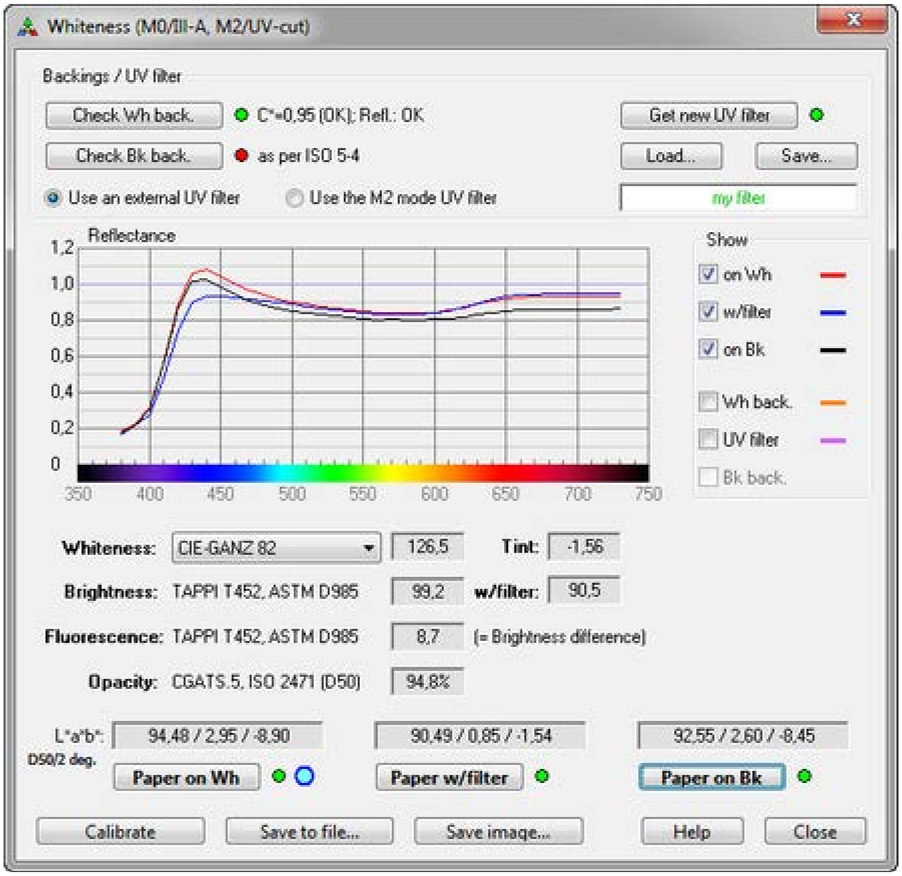
This indicator automatically changes location when an input is done at one position; in fact you can do the above measurement sequence simply by pressing the instrument button two or three times in a row. Do a left-click on an indicator to move it to its previous position or a right-click to lock it (a locked indicator has a red border: ). You can also do a left-click on a locked indicator; the new position will be locked.



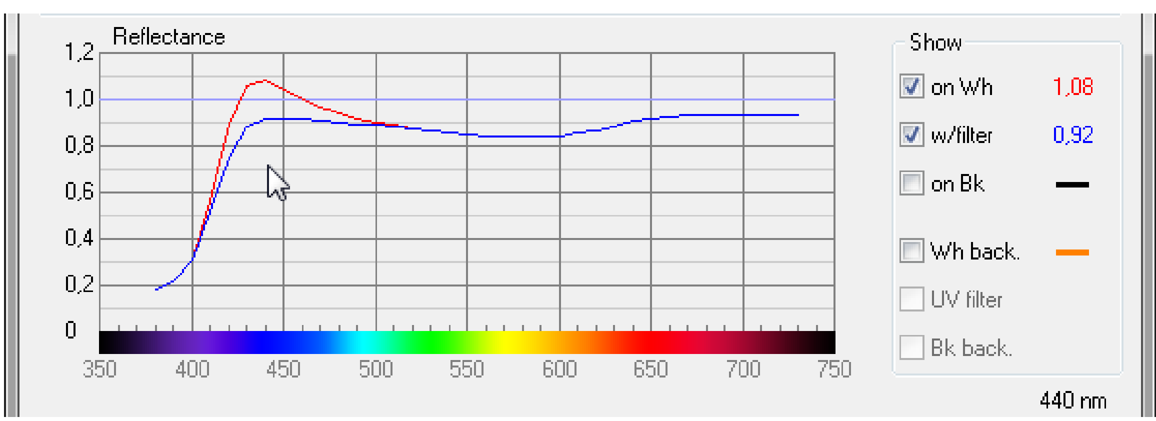
To **erase** a measurement, first press the **Alt** key, in Windows, or the **Option** key on a Mac. Whenever the mouse cursor is within the tool window, the "Paper on Wh", "Paper w/filter", and "Paper on Bk" buttons will change their caption to "**Clear**" (if there is a measurement). To clear the sample, click the button with the mouse while keeping the **Alt** or **Option** key pressed:



As a first example, here are measurements obtained with a common bright white paper designed for ink-jet printers:



This is a paper whose whiteness and brightness comes from fluorescence due to paper additives called Optical Whitening Agents (OWA), Fluorescent Whitening Agents (FWA), or Optical Brightening Agents (OBA). These additives convert the invisible ultra-violet wavelength of the light source to blue light, which makes the paper look whiter compared to the generally yellowish tint of standard paper fibers. We can see the reflectance going almost up to 1,1 (or 110%) at 440 nm for the measurement on the white backing (red curve), while the same paper measured with the UV filter (which cuts the UV) shows a maximum reflectance just over 90% at the same wavelength (blue curve). The red and blue curves essentially are the same for wavelengths over 520 nm. Precise numerical data can be obtained by moving the mouse over the graph; the wavelength at the location of the mouse cursor and the corresponding spectral reflectance for all selected spectrums appears in the "Show" group:



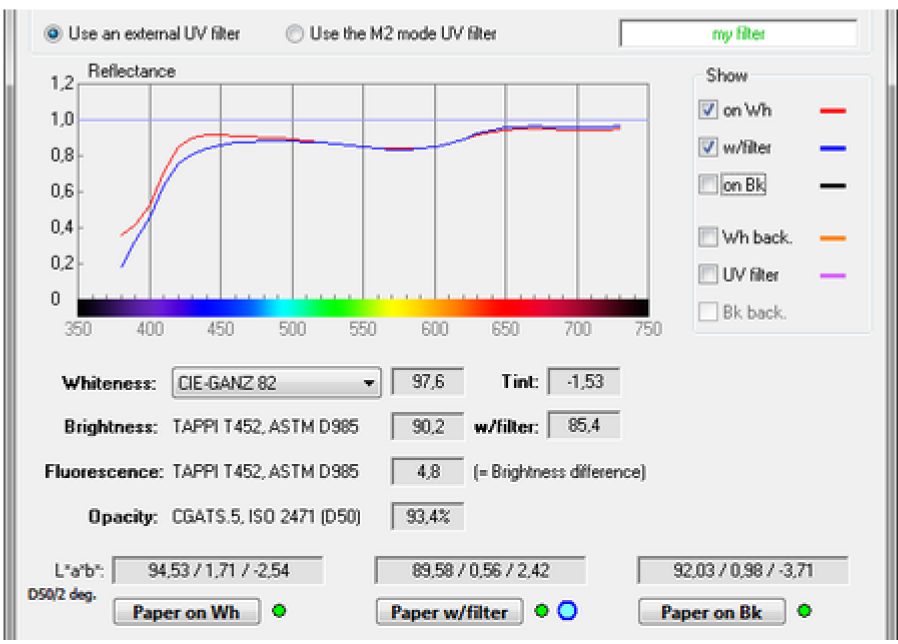
The fluorescence, which is the brightness difference between the measurement without the UV filter (=99,2) and the measurement with the UV filter (=90,5), on the white backing, is almost 9 (99,2 - 90,5 = 8,7).

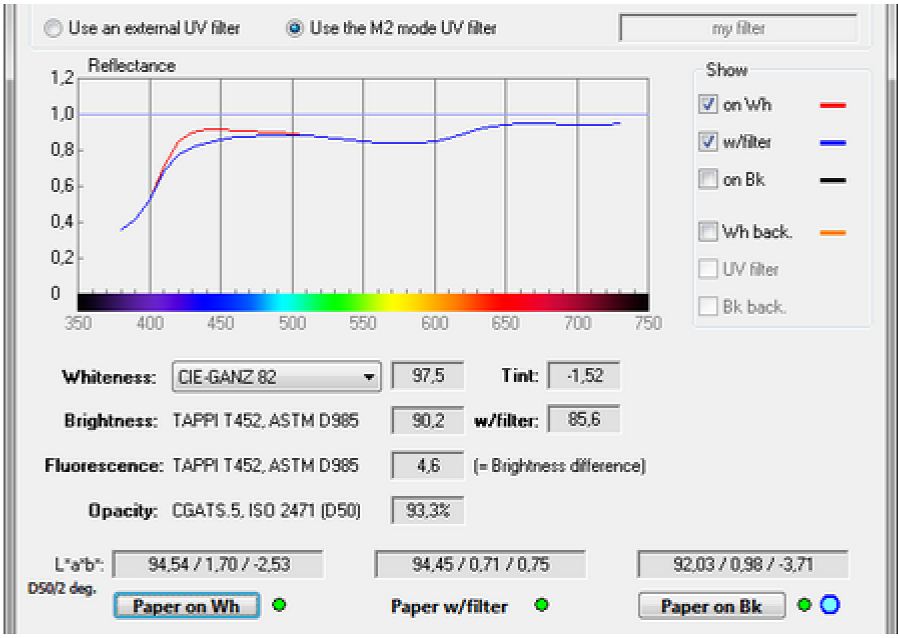
The opacity, which is the ratio of Y (of XYZ) measured on the black backing divided by Y on the white backing, is 94,8%. When we compare the spectrum measured on the white backing (in red), to the spectrum measured on the black backing (in black), in the second above screenshot, we see an almost constant gap for wavelengths over 430 nm.

Important: Here are essential steps to take in order to insure more accurate and repeatable fluorescence measurements. For a more detailed procedure, please consult the following Application Note: "AN-8 How to optimize the accuracy of fluorescence measurements with BabelColor CT&A" available on the BabelColor Tutorials Web page.

- If using an external filter, make sure you characterize it (characterization procedure) as presented further down in this section. In the example above, we used a GamColor 1510 filter whose data we saved in a file named "my filter" (Note: this filter data is also kept within the program's preferences and there is no need to keep this file, even though we suggest you do so).
- Use the plastic positioning guide, provided for the i1Pro, or the positioning base, provided for the i1Pro2, which are dedicated to spot measurements. This accessory insures proper spacing between the instrument and the sample.
- Wait 20 to 30 seconds between each measurement and after calibration. This delay provides time for the instrument to stabilize.
- Repeat the full measurement sequence a few times, always saving the results. You will be better able to reject a measurement sequence which contains marginal data (usually the "Paper w/filter" measurement made with an external filter).

In this second example we took fluorescence measurements of the same paper using an i1Pro 2 with an external filter, shown in the first screenshot below, then using the internal UV filter of the i1Pro 2 M2 mode, shown in the second screenshot. The paper is from a glossy magazine; it is not as bright as the paper used for the first example but does exhibit fluorescence.





We notice three things:

1. The spectrum measured with the external filter, the blue line in the first screenshot, is more filtered below 420 nm than the spectrum obtained using the M2 mode UV filter. Since the M2 spectrum is obtained by manipulating the data of the M0 and M1 measurements, and not from a physical filter, such a difference may or may not be seen in every case; it will depend on the actual fluorescent agents present in the paper and on the agents assumed to be present by the i1Pro 2 internal processing algorithms.
2. For wavelengths over 510 nm, the filtered spectrum is essentially the same as the unfiltered spectrum when using the M2 mode UV filter (second screenshot) while we see a good but not perfect match for the external filter (first screenshot). The less than perfect match of the external filter is a consequence of small contact variations in the **instrument+filter+paper** stack compared to the **white backing+filter** stack used for deriving the UV filter characteristics.
3. The "Paper w/filter" L*a*b* values are quite different but the fluorescence is quite similar (4,8 vs 4,6).

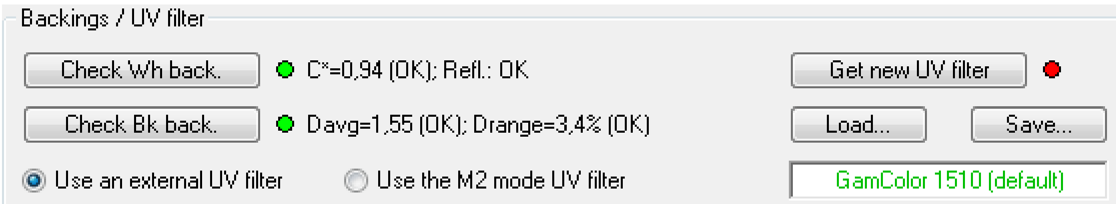
Note: In our experience, the fluorescence measured with an external filter can match well within 15% the fluorescence measured using the M2 mode filter.

Hint: Because a measurement made with a non-UV-cut instrument plus a separate UV-cut filter is equivalent to making measurements with an instrument fitted with a permanent UV-cut filter, you can use the Whiteness tools to rapidly make measurements with and without UV-cut. Such measurements can also be done on colored patches, and are thus not limited to white paper, although you should only look at the L*a*b* values in this case, and disregard the *Whiteness*, *Brightness*, *etc*. values. For measurements without a UV-cut filter, you have to use the "Paper on Wh" button, and for UV-cut measurements you need to place the UV filter between the instrument and the color patch, and press the "Paper w/filter" button.

Checking white and black backings compliance

You can check the compliance of your white and black backings by placing the instrument on the backing — using the plastic positioning guide — and clicking on the "Check Wh back." or "Check Bk back." button. For the white backing, the Chroma (the C* of L*C*h, D50, 2 degree Observer) shall not be more than 3,00, and the reflectance shall be equal or higher than the requirements at eight (8) specific wavelengths; however, the reflectance cannot be too high and shall not exceed an L* value of 97. For the black backing, the optical density shall be 1,50 ± 0,20 and the density range shall be less than 5% of the average density.

A message will appear beside the button after a measurement:



The message contains a short assessment of the measurement; the text is red when the backing is not compliant, and black when compliant. You can see the backings' spectrum by selecting the corresponding check box in the "Show" group. You can also export the backings' spectrums and get the measured reflectance vs requirements values at the eight control wavelengths for the white backing by clicking on the "Save to file" button (located in the bottom of the Whiteness window).

In addition to the Chroma and reflectance requirements, **the white backing shall not be fluorescent**; this is particularly important when using this backing to characterize a UV filter. Here are three methods to check for white backing fluorescence:

1. **Visual spectral check:** Place the instrument directly on the backing and click on the "Paper on Wh" button. Look for a bump in the spectrum in the blue region between 420 nm and 460 nm. In particular, if the spectral reflectance exceeds 1,0 (100%) at one wavelength, then you know for sure this backing is fluorescent.
2. **Measured with an external UV filter**: This method can be used to characterize an unknown backing and assumes that the UV filter characteristics were obtained with measurements on **another** non-fluorescent backing (Note: When properly characterized, you will never measure backing fluorescence on the same backing used to characterize the UV filter, even if this backing is fluorescent, and even if you can see a characteristic spectral bump). To measure a backing fluorescence, take the "Paper on Wh" and "Paper w/filter" measurements directly on the backing, without paper. In other words, first measure the backing by placing the instrument on the backing and press the "Paper on Wh" button, then place the filter between the instrument and the backing and press the "Paper w/filter" button. A fluorescent backing will result in a positive brightness difference, i.e fluorescence, in a similar manner as fluorescence in paper.
3. **Measured with the FluoCheck tools:** This method requires that you use an i1Pro 2. Open the FluoCheck tools window and measure the Fluorescence Index (FI) obtained when placing the instrument on the backing. The FI will be zero if the backing is not fluorescent.

How to acquire the transmission spectrum of a UV filter

For proper operation, the program must know the transmission characteristics of the UV filter used for the measurement done when clicking on the "Paper w/filter" button; this is why default values are required. The filters we recommend are:

Default UV filter: GamColor 1510

- https://us.rosco.com/en/products/catalog/gamcolor

Equivalent UV filter: Rosco 3114

- https://www.rosco.com

To our knowledge, a thin TAPPI T452 UV filter suitable for use under an i1Pro cannot be found off-the-shelf. The filters we recommend are equivalent to those recommended in the ISO 13655 standard (Ref. 42) for UV-cut and fluorescence measurements (Wratten 2B and the FujiFilm SC-41). All these filters have a sharper cut-off slope than the filters required by the TAPPI T452 standard, and their 50% transmission point is at lower wavelengths, i.e. more towards the violet. However their sharp cut-off effectively blocks the UV as efficiently. You will find files with the transmission characteristics of these filters in the "UV-filters" folder located within the main CT&A application folder. In Windows, this folder can be opened directly with the "Start menu/ BabelColor/UV-filters files" shortcut.

Important: In order to obtain more accurate measurements, we strongly recommend that you characterize your own UV filter, even if you have a sheet of one of the filters for which we provide a transmission characteristics file. We have noticed that the characteristics of sheet filters vary between batches and even within a single sheet. We suggest that you draw a 10 mm diameter circle (about half an inch), with a felt pen, on the filter sheet, identifying a zone that will be used to characterize the filter and make the measurements afterwards.

Obtaining a filter transmission is a three steps procedure, with the first two requiring a measurement. Firstly, you measure the **reflectance of a reference substrate**. Secondly, you measure the **filter reflectance** on this substrate. Thirdly, the **filter transmittance** is derived, by the program, from the two measurements. Two important requirements of the reference substrate are that it shall be opaque, and that it shall NOT be fluorescent. The substrate does not need to be perfectly white, and it does not need to be highly reflective (a light gray substrate could do), and it even does not need to be a compliant white backing. Still, a compliant white backing is a perfect reference substrate since it has all the required characteristics (see the **Checking white and black backings compliance** sub-section above for more information). Here is the procedure:

- Calibrate your instrument.
- Wait 30 seconds and measure the reference substrate, i.e. the white backing, by clicking the "Check Wh back." button; a compliant white backing is not absolutely required as discussed above.
- Place the filter between the instrument and the reference substrate. Wait 30 seconds and click on the "Get new UV filter" button. If successful, the new UV filter transmission data will be saved internally and will be used as the reference thereafter.

Note: There is no need to save filter data to an external file since it is kept internally by the program. However, you may want to save it separately for reference or comparison purposes. You can change the filter name by clicking in the text box below the "Load" and "Save" buttons.

Important: There are uncertainties in all measurements. Since the filter transmission is derived from two measurements, and since the transmission characteristics are applied to a third measurement, you may obtain, at certain wavelengths, a spectral reflectance of the measured paper with filter ("Paper w/filter") which is higher than the reflectance of the paper measured with no filter. The increase is typically between zero and two percent, and does not affect the measured parameters by a significant amount.

Note: You can also load the **filter relative transmission** spectrum from a file which contains data provided by a filter supplier or that you derived yourself (UV filter file requirements).

UV filter check procedure

In this procedure we measure the backing as if we measured fluorescence on paper.

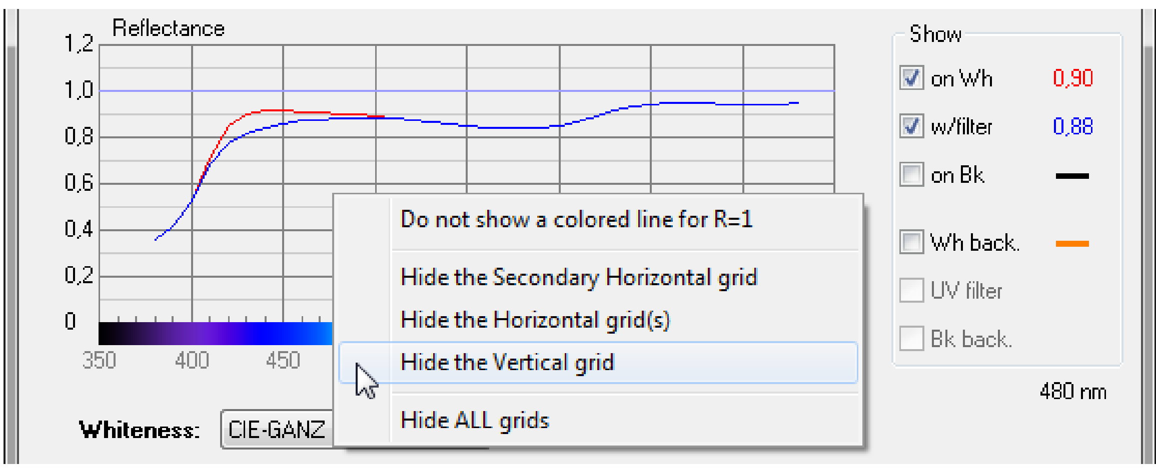
- Wait at least 30 seconds after the filter characteristics were measured. Place the instrument on the backing, without paper, and press the "Paper on Wh" button.
- Wait 30 seconds. Place the filter between the instrument and the backing and press the "Paper w/filter" button.

You should obtain two identical spectrums, the same L*a*b* coordinates, the same brightness without the filter and with the filter, and zero fluorescence. This happens because the filter transmission is compensated when using the "Paper w/filter" button. In practice, because there are uncertainties in the measurements, and because the filter characteristics were determined with other measurements which were also imperfect, the measured L*a*b* and brightness values will not be exactly equal, and the fluorescence will not be zero. Still, a fluorescence lower than ± 0,5 is expected, i.e. between + 0,5 and -0,5. As we have indicated before, it is particularly important to wait 30 seconds between each measurement in order to let the instrument stabilize.

Hint: Do not hesitate to redo the procedure if you are not satisfied. If the procedure fails, you can always reload the default filter from a file provided with the program; this file is located in the "UV-filters" folder located within the main CT&A application folder. In Windows, this folder can be opened directly with the "Start menu/BabelColor/UV-filters files" shortcut.

INTERFACE FEATURES

To change the graph grids appearance, use your mouse right-click (or **ctrl + click** on a one-button Mac mouse) and select an option.

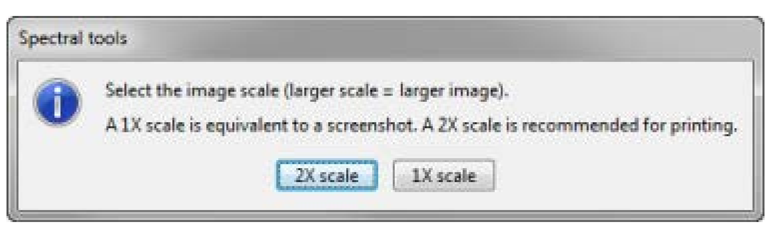


OTHER TOOL FUNCTIONS

At all times, you can calibrate the instrument by clicking the "Calibrate" button. The measurement mode for all Whiteness tools is "Reflectance", by default, and cannot be changed.

Click on "Save to file..." to save a Whiteness report. The report has tab-delimited data that can be directly imported in a spreadsheet program as well as many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting). The file is also CGATS compliant and can be opened by many color-management software, including BabelColor's PatchTool and X-Rite/GretagMacbeth MeasureTool.

Click on "Save image..." to save an image of the display. You will be asked to select a printing scale in a dialog. The 1X scale is equivalent to a screenshot and the 2X scale, recommended for printed reports, doubles the resolution for the same image size.



13.1 Whiteness tools description

The Whiteness tools are designed to measure the characteristics of white paper which influence how it is perceived. These measurements are:

- the *Whiteness and Tint*;
- the *Brightness*, with and without a UV-blocking filter;
- the *Fluorescence*;
- and the *Opacity*.

This section presents a description of each Whiteness tool. It also describes the requirements for black and white backings, and information on commercially available UV filters. For a presentation of the Whiteness tools' interface, go to this section.

Many standards were developed over time and many are still in use. Because whiteness is not just desirable for paper, similar standards have been developed for textiles, chemical powders and paper pulp. The main differences between the standards are:

- the instrument measurement geometry;
- the light source used for the measurement;
- the illuminant and Standard Observer used for computation;
- the use or not of wavelength selective filters;
- the backing on which the paper is measured;
- and the equations!

We have selected the standards which correspond to the measurement geometry and light source of the i1Pro and i1Pro 2, and which are relevant to the photographic and print fields.

Since backings are fundamental to reliable measurements, not only of white paper but also for colored targets, we provide tools to check the compliance of white and black backings. As well, because the precise characteristics of the UV filter must be used in the computations related to fluorescence, we provide a tool to characterize your own filter.

Here is a description of the standards and measurement conditions used in each tool.

- **Whiteness and Tint**
  - Instrument geometry: 0 deg./45 deg. or 45 deg./0 deg.
  - Three formulas are available:
    - CIE-GANZ 82 (Ref. 35): The standard CIE formula. Based on XYZ measurements (D65, 2 degree Observer). This formula is also described in the ASTM E313 standard (Ref. 36), which also provides formulas for a few combinations of formulas and Standard Observers.
    - CIE-Uchida (Ref. 37): This formula extends CIE-GANZ 82 by supporting a wider range of tints and purity over which whiteness can be evaluated. Based on XYZ measurements (D65, 2 degree Observer).
    - CIELAB-HE 2007 (Ref. 38): Based on CIELAB (D65, 10 degree Observer). Works over a wider range of tints and purity. It is said to be more uniform and to better match visual ranking.

  Of the three, the CIE-GANZ 82 is the most commonly used. Many more formulas and variants have been defined over time. We have retained these three because they are either well known or, in the case of CIELAB-HE 2007, could potentially provide better results. All these formulas are based on, or are compatible with, the 45 deg./0 deg. illumination/viewing geometry of the i1Pro and i1Pro 2.

  Note: The 45 deg./0 deg. illumination/viewing geometry is equivalent to the 0 deg./45 deg. geometry.

  Whiteness is measured by placing the paper to be analysed on a compliant white backing; the exact specifications are presented below in the BLACK AND WHITE BACKINGS sub-section.

  The whiteness is expressed with a number relative to a perfect diffuser. The tint characterizes the shift from neutrality, i.e. how much of a tint is perceived; a perfectly neutral white will have a zero tint. In practice, perfectly diffusing and neutral papers are never seen. We do find neutral papers which are not perfect

diffusers; this neutrality is usually obtained at the expense of brightness and these papers appear slightly gray when compared to whiter papers which are not as neutral.

The typical whiteness and tint ranges for which the CIE-GANZ 82 formula is valid are:

40 < *Whiteness* < (5Y - 280)

and

-3 < *Tint* < +3

where Y is the measured CIE Y (the luminance, the Y of XYZ). Higher whiteness values correspond to whiter samples. Positive values of *Tint* indicate a greenish tint, while negative values of *Tint* indicate a reddish tint; the tint is stronger as the absolute value increases. A perfect diffuse reflector will result in a *Whiteness* = 100 and a *Tint* = 0. A message is shown in the Whiteness tools window when the *Whiteness* or *Tint* are out-of-range.

These formulas are not linear, and equal differences in *Whiteness* or *Tint* may not represent equal perceptual differences. Also, the upper-limit for the validity of the whiteness range is a hard stop; any sample exceeding this limit is not considered white, and because of the way the limit is formulated (= 5Y - 280), lower-luminance samples (i.e. samples of lower Y values) are valid in smaller ranges than higher luminance samples. These drawbacks are the reasons why the CIE-Uchida equations were developed.

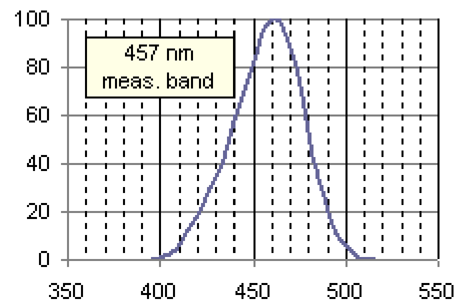
The CIE-Uchida equations are similar in structure to the CIE-GANZ 82 equations but the whiteness and tint numbers are not the same. Compensation factors are added to the equation parameters, for better linearity between the numbers and the perceptual differences, and the whiteness is no longer limited by an upper range (the lower range is still 40 whiteness units according to the CIE-GANZ 82 formula). In practice, the *Whiteness* and *Tint* obtained with the CIE-Uchida formula are close to the CIE-GANZ 82 numbers when the whiteness is within the limits of CIE-GANZ 82, but differ when the upper limit is exceeded. In fact, the CIE-Uchida numbers are valid when the upper whiteness limit of CIE-GANZ 82 is exceeded while the CIE-GANZ 82 numbers should be rejected. In addition, there is no limits proposed by Uchida for the tint; accordingly, we do not test if the measurement is within tint limits when this formula is selected.

The CIELAB-HE 2007 formula takes the same approach as the CIE-Uchida formula to improve the linearity and extend the whiteness range, but the goal was to improve it even more by selecting the visually uniform L*a*b* space instead of the XYZ space. Such an approach was looked at previously by Ganz (Ref. 39), but it lacked the extended range and uniformity that the Uchida formula provides. The CIELAB-HE 2007 was judged to be well correlated with visual estimation, and the formula's authors concluded that it does significantly improve the visual uniformity compared to the CIE-GANZ 82 and CIE-Uchida formulas (and other formulas as well). You will note that the *Whiteness* and *Tint* values obtained with this formula are quite different from the values obtained with the two other formulas (more generally, you cannot directly compare the numbers between formulas).

- **Brightness**
  - Standards: Defined in TAPPI T452 (Ref. 40), which is the same as ASTM D985 (Ref. 41)
  - Instrument geometry: 45 deg. illumination/0 deg. viewing geometry
  - The cone of light required by this method is wider than that specified for the CIE Standard 45 deg./0 deg. geometry.
  - Lamp source: 3000 K (TAPPI T452); 2800 ± 100 K (ASTM D985). This is equivalent to Illuminant A, i.e. a tungsten lamp. The relative spectral energy distribution of the light incident on the specimen, **E(λ)**, shall be:

wavelength	E(λ)
320 nm	0,0
330 nm	0,7
340 nm	3,0
360 nm	9,7
380 nm	17,1
400 nm	26,0
420 nm	37,2
440 nm	50,3
460 nm	64,1
480 nm	80,0
500 nm	100,0

  - The brightness scale is based on the reflectance of magnesium oxide, which defines a brightness of 100,0; other reference diffusers are accepted if characterized relative to magnesium oxide.
  - Other requirements: The measurement is done essentially in the blue part of the spectrum, in a band centered around 460 nm. In the context of this standard, *Brightness* is associated with *blue reflectance*. The effective wavelength of 457 nm, used in the brightness standard title, is obtained by the combination of illuminant, glass optics, filters, and photodetector for which the mathematical product of relative spectral power distribution, spectral transmittance, and spectral response is shown (in %) in the following graph.



Important: There are sufficient differences between an i1Pro and an instrument designed expressly for the requirements of TAPPI T452 or ASTM D985 that you should not expect to match the results obtained with qualified equipment. However, the instrument geometry is close, the lamp source is of the required type, the blue wavelength band is simulated in software, and the reference white can be derived from the i1Pro reflectance calibration.

Note: ISO 2470 is a standard often referred to for brightness assessment. While it is also dedicated to the measurement of blue reflectance (ISO brightness), it requires a **Diffuse illumination/0 deg. viewing geometry** instrument which is so different from the **45 deg. illumination/0 deg. viewing geometry** of the i1Pro, that any comparison between the numbers obtained with each standard is not recommended.

The measurement is done by placing the paper on a white backing. The brightness can be measured with or without a UV-blocking filter; the difference between the computed brightness is a measure of the paper fluorescence. This is discussed in the **Fluorescence** sub-section below.

Brightness values over 100 are common. This feat is possible by the use of additives, called Optical Whitening Agents (OWA), Fluorescent Whitening Agents (FWA), or Optical Brightening Agents (OBA), which increase the reflection coefficient and improve the neutrality of typically yellowish paper fibers. The increase in brightness comes from a fluorescence effect; in such an effect, Ultra-Violet (UV) light is absorbed by the additives and transformed into visible light, typically in the blue wavelengths range. The transformation of invisible light into visible light improves the brightness while the added blue compensates for the intrinsic yellowish color to make the paper look more neutral; this is the principle behind adding blue dyes in washing detergents.

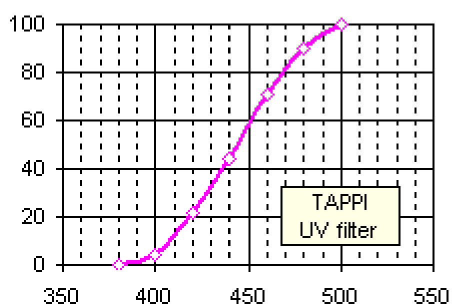
- **Fluorescence**
  - Standards: Defined in TAPPI T452 (Ref. 40), which is the same as ASTM D985 (Ref. 41)
  - Instrument geometry: 45 deg. illumination/0 deg. viewing geometry
  - Other requirement: UV-blocking filter. The filter transmission is not given; instead, the relative spectral energy distribution of the light incident on the paper with the UV filter present, **F(λ)**, shall be:

wavelength	F(λ)
380 nm	0,0
400 nm	1,0
420 nm	8,2
440 nm	22,4
460 nm	45,3
480 nm	71,7
500 nm	100,0

If we compare the spectral distribution with a filter with the one without a filter, presented above in the **Brightness** sub-section, we obtain the **ideal** TAPPI T452 filter transmission, where T = 100 * (F(λ) / E(λ)), where the maximum transmission is normalized to 100:

wavelength	filter T (%)
380 nm	0
400 nm	4
420 nm	22
440 nm	45
460 nm	71
480 nm	90
500 nm	100

and the corresponding graph:



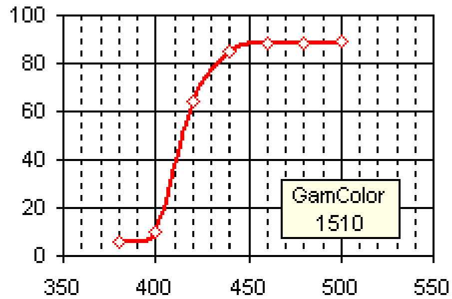
The fluorescence is obtained by the brightness difference without and with the UV-blocking filter:

$$Fluorescence = Brightness_{\text{without a filter}} - Brightness_{\text{w/filter}}$$

While fluorescence can brighten and whiten a paper appearance, the effect is affected by the UV content of the light source, with halogen lights having much less UV than outdoor daylight. This means that when you make an ICC profile of a paper which exhibits strong fluorescence, the colors will change depending on the lights under which the print is seen. Because of this, many printers and photographers favor papers which exhibit low fluorescence, or even no fluorescence at all.

Another drawback of fluorescent papers is that the additives lose their properties with time and exposure to light. So even if the print is calibrated properly for viewing under a specific light source, the colors will change with time.

Note: To our knowledge, a thin TAPPI T452 UV filter suitable for use under an i1Pro cannot be found off-the-shelf. The filter we recommend, as well as the many equivalents mentioned in the UV FILTER sub-section below, are available off-the-shelf, and are equivalent to those recommended in the ISO 13655 standard (Ref. 42) for UV-cut and fluorescence measurements. They have a sharp cut-off transmission curve which effectively blocks the UV as efficiently.



While the filter curve shown above does not reach 100% transmission, as in all real filters with no anti-reflection coatings, we need to compensate for the imperfect transmission. We also need to compensate for the visible radiation which is blocked below 450 nm. This is done by CT&A for all measurements done with the "Paper w/filter" button.

Important: Because the suggested UV filters have transmission characteristics which are not those required by the standards, you should not expect to reproduce the results obtained with the prescribed filter. However, you will be able to reliably detect papers which are fluorescent and be able to grade their susceptibility to fluorescence.

- **Opacity**
  - Standards: Defined in CGATS.5 and ISO 2471
  - Instrument geometry: 0 deg./45 deg. or 45 deg./0 deg.
  - D50, 2 degree Observer

The opacity is obtained by first measuring the paper on the white backing and then on the black backing. The opacity is defined by the ratio of CIE Y (the Y of XYZ) on the black backing divided by CIE Y on the white backing:

$$\textit{Opacity (\%)} = 100 * (Y_{black} / Y_{white})$$

For ISO 13655, a sample is considered opaque if its opacity is not less than 99%.

Note: One difference between CGATS.5 and ISO 2471 is that ISO 2471 calls for self-backing instead of a white backing. Self-backing, a backing made of a thick pile of the same paper, is obtained when you place under the paper sheet to be measured as many additional unprinted sheets as are necessary to ensure that no further change in measurement are seen when more are added.

BLACK AND WHITE BACKINGS

White backing requirements

According to ISO 13655 (Ref. 42):

- the backing shall be opaque, with a measured opacity of no less than 99%;
- the backing surface shall be diffuse-reflecting, with no perceptible specular reflection when viewed at any angle under typical office room illumination;
- the backing shall not be fluorescent when excited by the instrument source;
- the Chroma (the C* of L*C*h, D50, 2 deg. Observer) shall not be more than 3,0 and should not exceed 2,4;
- the reflectance shall be equal or higher than the requirements at these eight (8) specific wavelengths (this corresponds to a CIELAB L* value greater than 92; however, the CIELAB L* value shall not exceed 97):

wavelength	R_{min}
400 nm	0,30
410 nm	0,30
420 nm	0,75
450 nm	0,75
460 nm	0,80
670 nm	0,80
680 nm	0,75
700 nm	0,75

You can check the backing fluorescence in the same way that you would check paper fluorescence. Please see the Whiteness tools section for more information on the tools provided to check a white backing compliance (Chroma, reflectance, fluorescence).

Black backing requirements

According to ISO 5-4 (Ref. 43):

- the backing surface shall be diffuse-reflecting, with no perceptible specular reflection when viewed at any angle under typical office room illumination;
- the optical density (ISO visual reflection density) shall be 1,50 ± 0,20; this is approximately equivalent to a CIELAB L* value range of 15 to 27, or a reflectance range between 2% and 5%;
- the backing shall be spectrally non-selective, and the density range shall be less than 5% of the average density when measured in the wavelength interval between 400 nm and 700 nm.

Please see the Whiteness tools section for more information on the tools provided to check a black backing compliance (optical density, density range).

Should you use a WHITE or a BLACK backing for your measurements?

A BLACK backing is recommended for:

- making densitometric measurements as defined in ISO 5-4 and, more generally, computing density values from spectral data;
- standard viewing condition as defined in older versions of ISO 3664 (Ref. 32); however, more recent versions of the standard do not favor one backing over the other.

A WHITE backing is recommended for:

- measuring color patches when the paper opacity is below 95%;
- measuring data for visual correlation (!).

The least we can say is that the situation is not black or white!. Because the backing used for measurement can have an impact on the resulting data, especially if the opacity is on the low side, it is recommended to use the same backing for measurements and visual assessment. There used to be a preference for black backings, mainly because of ISO 5-4, but many now favor the white backing, because it is closer to self-backing, while being more stable. Self-backing is a backing made of a thick pile of the same paper, an approximation of what you find in books and magazines (with not too much ink per page though!).

UV FILTER

The purpose of this filter is to cut the Ultra-Violet (UV) from the instrument lamp, so that no fluorescence is generated. This is equivalent to an i1Pro or i1Pro 2 with a UV-cut filter; however, because the Whiteness tools also require measurements with an instrument which has NO UV-cut filter, a UV-cut i1Pro is not recommended for these tools.

Hint: Because a measurement made with a non-UV-cut instrument plus a separate UV-cut filter is equivalent to making measurements with an instrument fitted with a permanent UV-cut filter, you can use the Whiteness tools to rapidly make measurements with and without UV-cut. Such measurements can also be done on colored patches, and are thus not limited to white paper, although you should only look at the L*a*b* values in this case, and disregard the *Whiteness*, *Brightness*, *etc*. values. For measurements without a UV-cut filter, you have to use the "Paper on Wh" button, and for UV-cut measurements you need to place the UV filter between the instrument and the color patch, and press the "Paper w/filter" button.

As we mentioned previously in this section while describing the Fluorescence measurement, the TAPPI T452 UV filter cannot easily be found off-the-shelf. However, we have found two very similar types of plastic sheets designed to remove UV emissions from lamps (particularly fluorescent lamps) which effectively block UV wavelengths. The default values used in the program are those of the **GamColor 1510**; a very similar filter, **Rosco 3114**, can also be used. For purchasing information, please consult these web sites:

- GamColor 1510
  - https://us.rosco.com/en/products/catalog/gamcolor
- Rosco 3114
  - https://www.rosco.com

According to the ISO 13655 standard, other equivalent filters are the Wratten 2B and the FujiFilm SC-41. All these filters have a sharper cut-off slope than the filters required by the TAPPI T452 standard, and their 50% transmission point is at lower wavelengths, i.e. more towards the violet. However their sharp cut-off effectively blocks the UV as efficiently. You will find files with the transmission characteristics of these filters in the "UV-filters" folder located within the main CT&A application folder. In Windows, this folder can be opened directly with the "Start menu/BabelColor CT&A 6/CT&A UV-filters" shortcut.

When you do a measurement with the filter between the instrument and the paper, not only is the UV radiation prevented from hitting the paper, but the visible radiation (i.e. the white light from the instrument lamp) is also affected by the filter. In other words, this filter is not perfectly transparent and has a typical transmission of 90% in the visible. In fact, the filter transmission affects the instrument light twice, once as the light goes from the instrument to the paper, and another time when, reflected by the paper, it goes back in the instrument. We thus need to compensate any absorption by the filter in the **visible** range, as if it was perfectly transparent. This is why the filter characteristics, its transmission, is absolutely required by the program, and why we provide default values as well as a method to re-generate the transmission characteristics with your own filter.

Important: We have noticed that the characteristics of sheet filters vary between batches and even within a single sheet. In order to obtain more accurate measurements, we strongly recommend that you characterize your own UV filter, even if you have a sheet of one of the filters for which we provide a transmission characteristics file.

13.2 Whiteness UV filter file requirements

The UV filter characteristics can either be measured with a compatible instrument or loaded from a file. This file **MUST** contain spectral data. This file may come from a previously characterized filter made with the Whiteness tool or from another source. Acceptable file formats are **CGATS** or **plain text**, with the following requirements.

Important: You should make sure that the file data represents **relative transmittance** measurements. The transmittance values shall be defined between zero and one, with one representing full (100%) transmittance. Although such a file can be opened by other software, such as BabelColor PatchTool, it cannot be interpreted or used as reflectance data.

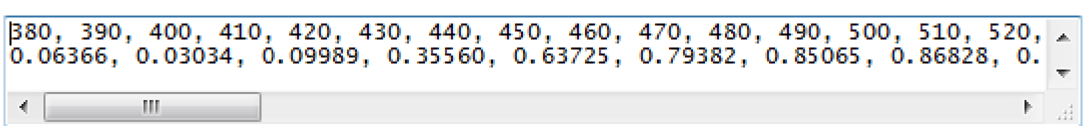
Requirements for spectrum files in CGATS format:

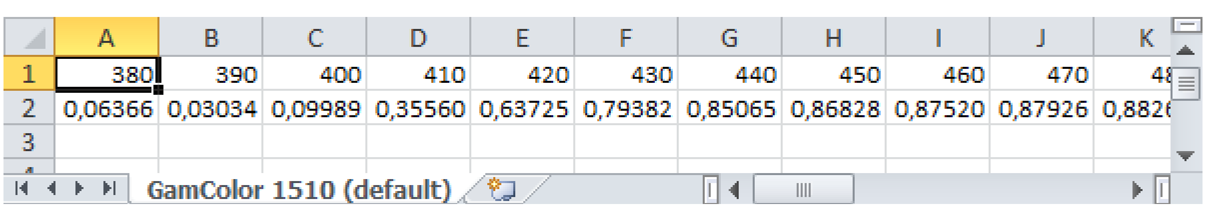
- The file **MUST** contain only **one** (1) spectrum.
- The file **MUST** conform to the "CGATS.17" format standard. As an example, you can use a 10 nm bandwith file that you will find in the "Illuminants" folder located within the CT&A application folder.
- The illuminant name **MUST** be specified as either "Emission" or "Unknown." It **MUST NOT** be specified as "D50" or any other standard illuminant used to process reflection measurements.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength tags **MUST** be in one of the following formats: "nm450", "SPECTRAL_NM450", SPECTRAL_NM_450, or "SPECTRAL_450".
- The decimal separator for data can be a period (.) or a comma (,).
- The data delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all the data in the file.

Requirements for spectrum files in plain text format:

- The file **MUST** contain only **one** (1) spectrum.
- The first line **MUST** contain wavelength labels/tags.
- Spectral data is **REQUIRED between 400 and 700 nm**, in **10 nm** steps. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
- The wavelength labels/tags may be simple numbers or contain other letters, such as "nm380", "380_nm", or "380NM", but no spaces.
- The first line may contain other tags such as "ID" or "Name". Tags **MUST NOT** contain spaces. These tags may be written in uppercase or lowercase. If additional tags are used in the first line, you **MUST** fill the second line with the corresponding information or number, with no spaces in the tag content.
- The second line **MUST** contain the spectral values (and the content of the additional tags if used).
- The decimal separator for data can be a period (.) or a comma (,).
- The wavelength labels and the spectral values **MUST** be separated by data delimiters. The delimiters may be "tabs", "commas", "semicolons", or "spaces". The same delimiter **MUST** be used for all lines.

A plain text file can easily be created with a word processor or a spreadsheet application, as shown below. When saving the file, do not use the often complex native application file formats (for ex.: *.xls); instead, select a tab-delimited or Comma-Separated-Value (CSV) **text** format.





14. Technical data

This section covers background technical information on CT&A's inner works as well as simple descriptions of the RGB spaces and color catalogues it supports.

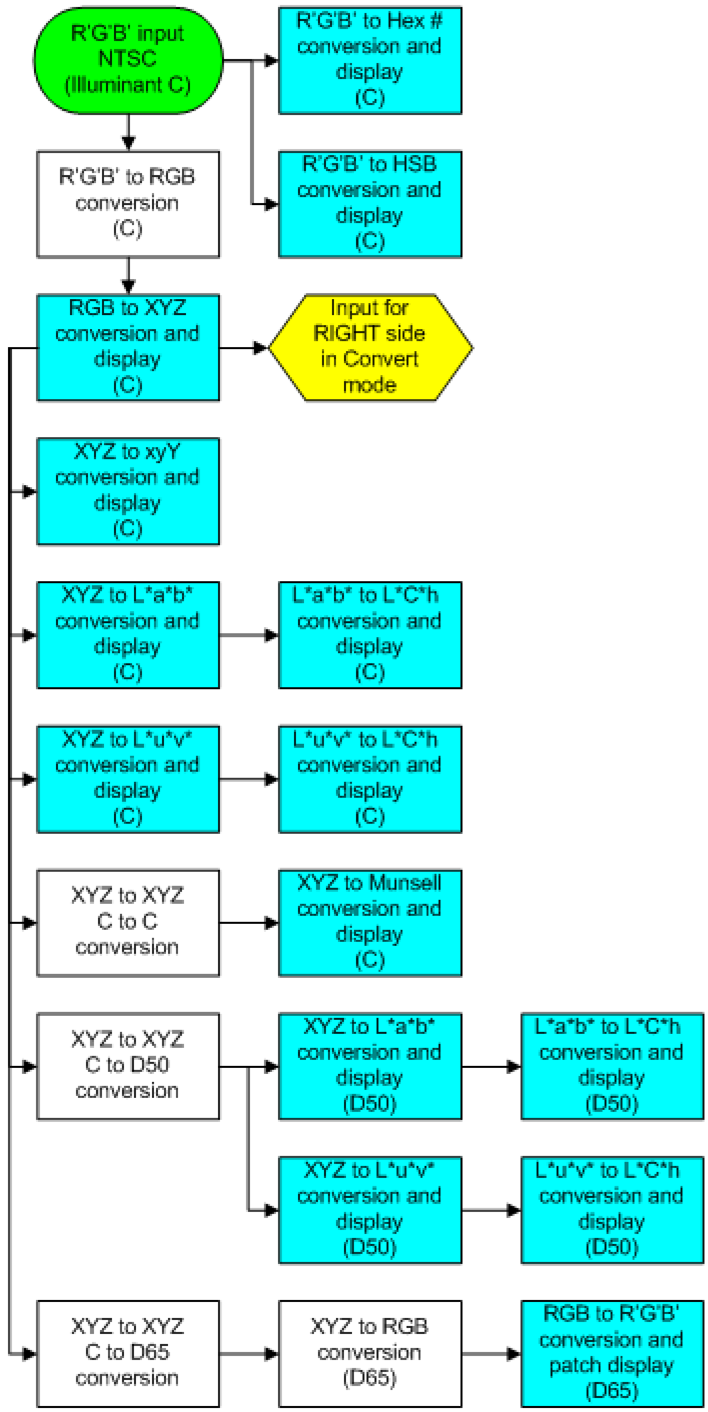
Although the "Definitions and theory" section is not required reading in order to be able to use the program, it contains a lot of information about RGB spaces and the mathematics of colorimetry. For more information on colorimetry, the reader can consult our References.

Technical data - Table of Contents

14.1 Data flow

The following diagram is an example of data flow within the software for the RGB vs RGB tool. It shows the conversions and processes **within a single RGB space**, Space #1 with NTSC selected (Illuminant C), in R'G'B' input mode.

From the input, in green, multiple conversions are performed to obtain the various displayed outputs, in light blue; the results of the steps with a white background are not displayed but used internally. If in Convert mode, the input for the other side, which can be either a Space or a Deck, is XYZ data; it is shown in yellow.



You will notice that the "XYZ to XYZ" conversion before the "XYZ to Munsell" conversion is from illuminant C to illuminant C ("C to C", as shown in the box); this is a one-to-one conversion and this step could have been eliminated. This is a particular case since Munsell HVC data is referenced to illuminant C, as is our input data. However, as we see further down in the diagram, a chromatic adaptation step is required for the same XYZ data in order to obtain the remaining D50 and D65 data.

The three boxes at the bottom of the illustration show the steps required to compute the color for the color patches display in the user-selected display space; these are steps typically performed with an ICC profile.

Click on a link below for more information on a specific conversion.

- R'G'B' to RGB
- RGB to XYZ
- R'G'B' to Hex #
- R'G'B' to HSB
- XYZ to xyY
- XYZ to L*a*b*
- XYZ to L*u*v*
- L*a*b* or L*u*v* to L*C*h
- XYZ to XYZ (CAT matrix)
- XYZ to Munsell
- XYZ to RGB
- RGB to R'G'B'

14.2 Data integrity

This section discusses data integrity in the context of the RGB vs RGB tool.

Color data within this tool is of two types: integer and real, i.e. with fractional precision. R'G'B' data is most often seen and used in integer form since this is how it is saved in images; however, nothing prevents someone of using real values for increased accuracy, especially when converting to higher bit number representations, such as 16 bit. Hex # data is, by definition, integer based while HSB data is rarely, if ever, seen in non-integer form. The xyY, XYZ, L*a*b*, L*u*v*, and L*C*h color data representations can have fractional values and usually benefit greatly from the added precision.

Integer input is in effect when using either the R', G' or B' sliders, or their corresponding data displays boxes. However, fractional input values for R'G'B' will happen when using the "Y" slider or "xy" mouse input; this is required in order to provide accurate and consistent results with these input controls.

Please note that all R'G'B' inputs will be rounded after one of the following actions, and when R'G'B' is the input mode after the change:

- a mode change (Compare to Convert, Convert to Compare, a direction change in Convert),
- an input mode change (L*a*b* / L*u*v* input **to** R'G'B' input),
- a different RGB space is selected,

If the input mode before and after the change is L*a*b* or L*u*v*, there is no rounding of the input variables.

When converting a color into a RGB space, i.e. in Convert mode, the converted coordinates are high precision, non-integer, **fractional** numbers. The R'G'B' values, thus also Hex # and HSB, are rounded to the nearest integer for display purposes but the other color spaces data correspond to the fractional R'G'B' values. This is why the color-difference, DeltaE*, when there is no clipping, is exactly zero. When going back to Compare mode, a small color difference value may appear in the DeltaE* display. What happens is that the space which was converted "TO" is now independent and in R'G'B' input mode. To be consistent with the integer logic of R'G'B', the software replaces the fractional R'G'B' values, which were previously rounded for display only, by their nearest integers, and re-computes all other color data.

This process logic was defined to maintain accuracy for users interested in color conversions not related to RGB spaces, while not affecting the integer conversion accuracy for users interested in RGB spaces computations.

14.3 Definitions and theory

The theory, definitions and equations presented in this section support and document the features of CT&A. Most standard equations for colorimetric transforms can be found. In particular, there is the complete set of equations required to compute the most recent, and complex, color difference formulas (i.e. CMC and CIEDE2000).

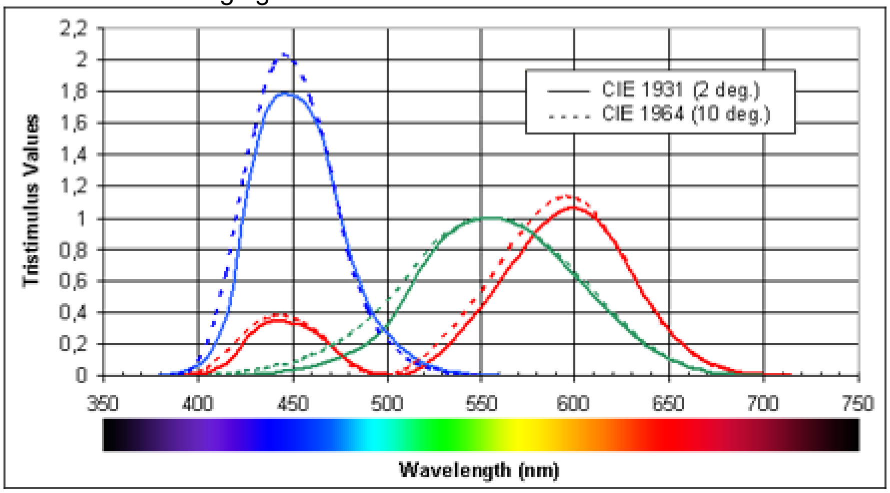
Definitions and theory - Table of Contents

For further reading, we recommend these two excellent books:

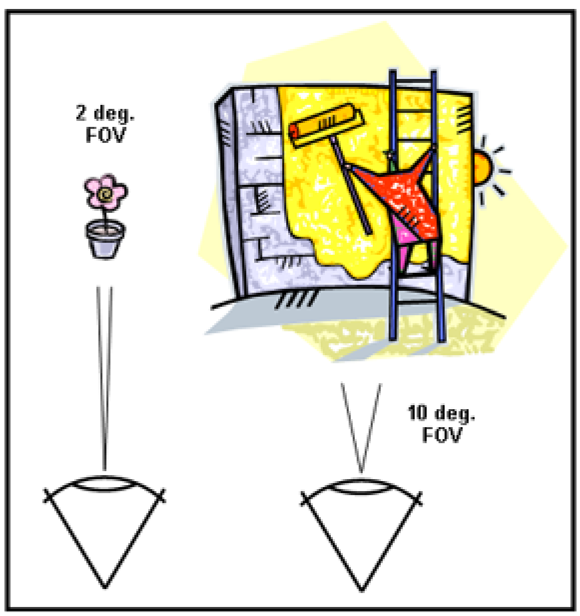
- *The reproduction of Colour*, by R.W.G. Hunt (Ref. 5)
- *Billmeyer and Saltzman's "Principles of Color Technology*, by Roy S. Berns (Ref. 25)

14.3.1 xyY and XYZ

In 1931, the **Commission Internationale de l'Éclairage (CIE)** established standards for color representation based on the physiological perception of light. They are built on a set of three *color-matching functions* whose individual values are called *tristimulus* values. These functions, collectively called the *Standard Observer*, are related to the red, green and blue cones in the eye (Ref. 14), and are the basis of essentially all modern color models; they are shown in the following figure:



The **CIE1931** representation was determined from color patches covering a two degrees Field Of View (FOV). This FOV is well within the angle subtended by the eye's fovea, the region of the retina near the eye's optical axis where the density of cones is the highest. Cone density falls rapidly to less than ten times the peak value at plus or minus five degrees from the fovea's center (Ref. 15) and, in practice, color patches subtending FOVs between one and four degrees can be treated using the CIE1931 data. For larger patches it was found that the eye has a somewhat different response. This resulted in a new set of measurements, called the **CIE1964** data set, which was done for patches subtending a FOV of ten degrees. Data corresponding to the CIE1964 data set is often presented as (X_{10}, Y_{10}, Z_{10}) or (x_{10}, y_{10}, Y_{10}) to distinguish it from the 1931 system.



Since most images are made of combinations of small color patches subtending small angles, the CIE1931 system remains a valid choice for many practical applications. In particular, it is the one used to define all RGB spaces. There is also no need to convert all legacy CIE1931 standards since, in most instances, the users just want to match a specification, and as long as that specification can be measured, there is no reason to change it! On the other hand, it can be seen that the 10 degree Observer is specified more often in recent standards, such as RAL DESIGN and ISO 3664.

FROM TRISTIMULUS TO XYZ

Color is not an intrinsic property of an object. It is the perception of the energy emitted or reflected from the object, once processed by the human visual system and the brain, which makes us assign colors to this energy. This psychophysical process is described by the color-matching functions shown above. The mathematical derivation of color coordinates from these functions first requires measuring the spectrum of the source. This spectrum is usually expressed in terms of a Spectral Power Density (SPD), in Watt/nm, and it can be determined by separating the visible spectrum in a number of wavelength bands, with 10 nm per band for example, and by measuring the power, in Watt, within each band.

For reflected light, the reflectance is measured for each wavelength band and a ratio is computed relative to a perfect white diffuser. For transmitted light, a ratio is computed relative to a perfect transmitter. In the case of self-luminous sources, a radiance factor, the ratio between actual output and maximum output, may be determined.

Then, for each wavelength band, the reflectance, transmittance, or radiance factor is multiplied by the source SPD and by the spectral tristimulus value of each color-matching function. Results are then added separately for each function. In other words, the reflected or transmitted spectrum is weighted by the color-matching functions and integrated to provide a single value, a scalar, also called the tristimulus value, for each function.

The scalar obtained with the red color-matching function is named *X*. Similarly, the scalars obtained with the green and blue functions are *Y* and *Z*.

The green color-matching function has an interesting characteristic. It was defined in such a way that it matches the overall Luminance response of the human eye (*X* and *Z* have no such easily attributed correspondence to a physiological phenomenon). All values represented by *Y* are therefore, by design, photometric quantities (lux, cd/m^2, etc.). Also, by definition, the color coordinates of the illuminant, the brightest color, are, when normalized, the ones for which *Y* equals 100 (i.e. maximum *Y* is 100 even if *X* or *Z* can be higher).

An excellent source of data, presented in tabular forms, on the SPD of all standard illuminants, such as C, D50, D65, F6 etc., and for the color-matching functions, is ASTM Standard E308-99 (Ref. 16) which describes a complete procedure to calculate XYZ with custom illuminants as well as a simplified procedure that can be used with standard sources.

FROM XYZ TO xyY

Another way of presenting the tristimulus data is to determine the proportion of each value relative to the sum of all three. These ratios are defined as:

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

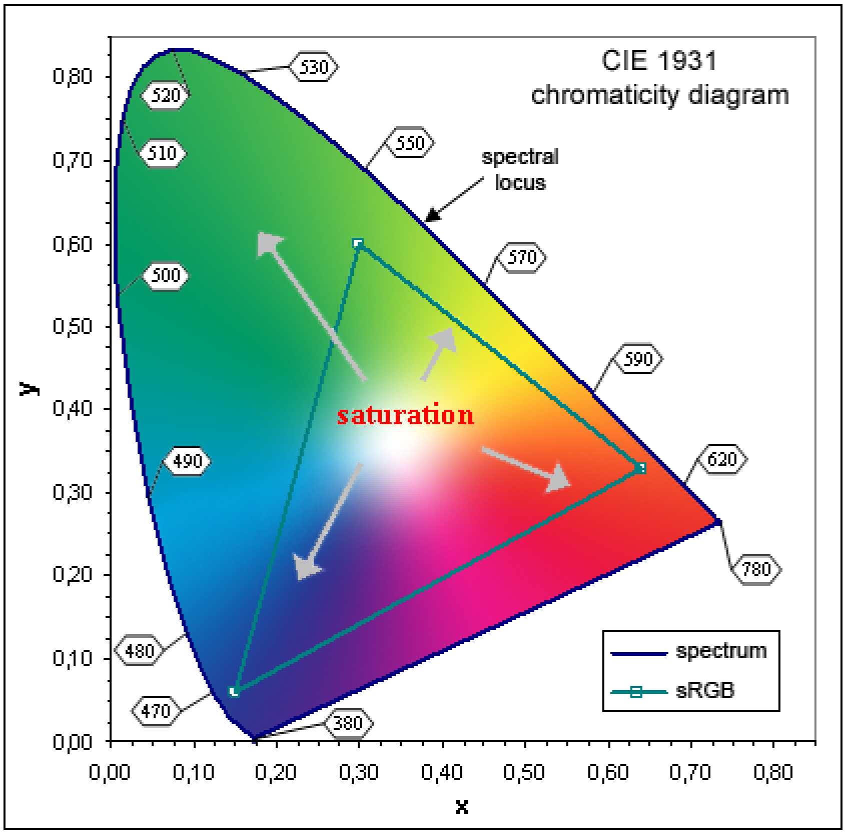
$$z = \frac{Z}{X+Y+Z}$$

with, as a complement, the relation

$$x + y + z = 1$$

In the xyz representation, because of the redundancy of the fourth equation above, only two coordinates are required, usually *x* and *y*, to convey the chromatic content of a sample. The representation of color is thus simplified from 3 dimensions to 2 dimensions. However, the absolute luminance information of *Y* is lost in the process. For these reasons, it is a common practice to present color data as xyY.

When the pure monochromatic colors of the spectrum are plotted in the "xy" plane, they form a line, the spectral locus, which has the shape of a horseshoe, officially named the CIE1931 chromaticity diagram (labels identify the positions of many specific wavelengths):

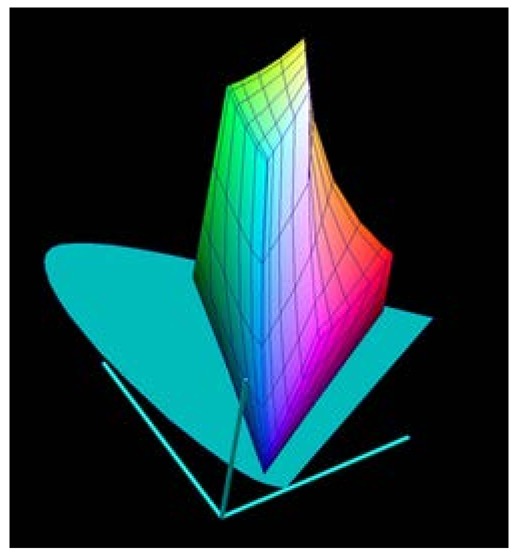


The straight line at the base of the horseshoe represents the mixture of red and blue light, two colors at the opposite of the spectrum. All other "impure", or non-monochromatic, or less saturated colors fall within the horseshoe. Only the colors inscribed within the horseshoe are possible. The colors outside the horseshoe are "imaginary" and result from the mathematical treatment behind the color-matching functions. The horse shoe is inscribed in a larger triangle, defined by the (x,y) = (0,0), (1,0), and (0,1) coordinates, which is called the Maxwell triangle, from the name of the Scottish physicist, James Clerk Maxwell (1831-1879), who used a

similar triangle to understand color, and which is considered the inventor of the trichromatic photographic process.

The more one goes away from the edges of the horseshoe, the more the color is de-saturated. The ideal white, also called the equal energy illuminant since all three reference functions are equal, has *x*, *y* and *z* equal to 0,33333… and is located somewhere in the center of the horseshoe. It is interesting to note that the ideal black is located at the same spot. This seemingly contradictory result is simply because the diagram does not represent intensity, thus its name chromaticity diagram, and the importance of the *Y* information in comparing measured color data.

A very useful feature of this diagram is that it can be used to determine the color resulting from the mix of two known emissive colors. The chromaticity of a color resulting from the mixture of two colored lights will simply be located on the straight line between the two. This is one of the characteristics of additive color mixture, also called Grassmann's laws. Adjusting the ratio between the two lights will make the resulting color move along the line. An interesting consequence is that mixing two colors located at such positions on the chromaticity diagram that a line between them goes through the white point region will result in "white" being perceived for certain ratios. This last example is just to contradict the often-heard statement that you need at least three colors to generate white, and is a direct consequence of the overlapping bandwidths of the cones.



Similarly to the color mix obtained with two sources, we can extend the concept to three sources. To be called primaries these sources have to be selected in such a way that it is not feasible to simulate one of them by mixing the two others. From this requirement we see that three sources will enclose a triangular shape. Mixing the primaries in various proportions will generate all the colors within the triangle, also called the color gamut. This property of the diagram makes it easy to understand how color TV and computer monitors use only three different phosphors, in a CRT or plasma display, or three different filters, in a LCD, to simulate a multitude of colors. The primaries of the sRGB space can be seen, in two dimensions, in the chromaticity diagram of the preceding page; the image on the right shows the same space in three dimensions, where we added the *Y* coordinate (i.e. xyY).

We see that the triangle defined by the primaries is fully used for low luminance colors only. As the luminance is increased, the color range becomes smaller.

Note: One of this program features is that when you select a color by clicking on its chromaticity diagram (see also "xy" mouse input), the selected color will always be the highest — i.e. brightest — possible color in the xyY representation.

One of the challenges in color display design is to select the best primaries to generate the maximum number of colors. Since it is impossible to generate all colors with three primaries, one can think of using four, five, or more, different basic colors to define a multi-facet polygon that would encompass most of the horseshoe shape. However, this is difficult in practice, firstly because of the limited availability of high-brightness long-life monochromatic phosphors, for CRTs, or the manufacturing cost of high purity filters, for LCDs, and secondly because of the complexity of controlling sources which are redundant for much of the gamut (many colors can be created by more than one mix of the basic colors). In short, the technology required to achieve these goals is not cost-effective and there has been few consumer level products so far (SHARP developed a 4-color LCD TV technology, named "Quattron Technology", which is sold under the AQUOS brand, and where the addition of yellow pixels is said to increase the color gamut by 10% and improve color gradation). Historically, the phosphors of the first color TVs were selected in most part for the two following reasons: they were available, and three phosphors are enough to get a very good job done.

14.3.2 Illuminants

Illuminants cannot be dissociated from the XYZ data they helped generate. When providing colorimetric data, information on the illuminant used for the measurements always has to be given in order to understand and further process the data. Various standard illuminants have been devised to satisfy the evolving needs. The following table shows the coordinates of the principal standard illuminants in the CIE system:

Illuminant	Description
A	Tungsten or Incandescent, 2856 K
B	Direct Sunlight at Noon, 4874 K * (obsolete)
C	North Sky Daylight, 6774 K *
D50	Daylight, used for Color Rendering, 5000 K *
D55	Daylight, used for Photography, 5500 K *
D65	New version of North Sky Daylight, 6504 K *
D75	Daylight, 7500 K *
9300 K	High eff. blue phosphor monitors, 9300 K
E	Uniform energy Illuminant, 5400 K *
F2	Cool White Fluorescent (CWF), 4200 K *
F7	Broad-band Daylight Fluorescent, 6500 K *
F11	Narrow-band White Fluorescent, 4000 K *

Chromaticity data for the A, C, D50, D65, E and a user-defined illuminant can be found in the dialog which is called with the "RGB vs RGB/Table data/Illuminant data..." menu or with the "Illuminant data..." menu of the toolbar "**Tables**" icon.

Bradford or CIECAT02 Chromatic Adaptation Transform (CAT) matrices used to convert XYZ data between two of these illuminants or between one of those illuminants and a user-defined illuminant can be found in the dialog which is called with the "RGB vs RGB/Table data/CAT matrices..." menu or with the "CAT matrices..." menu of the toolbar "**Tables**" icon.

It is common to associate a temperature with an illuminant. This temperature is related to the emission of a blackbody. A blackbody is by definition a material that has perfect emissivity and absorptivity at all wavelengths; it will therefore not reflect or scatter light. The light emitted from the blackbody has a spectral content with a dominant color that shifts from red to blue with increasing material temperature. Temperature is expressed in the kelvin scale, with zero kelvin defined as the absolute zero (-273 Celsius). The perceived color of a blackbody, its chromaticity coordinates, can easily be determined using the Custom illuminant dialog which can be accessed from within the Custom RGB space dialog.

Few illuminants are perfect blackbodies. However, when a source matches the chromaticity of a blackbody, we refer to the source temperature as the color temperature. If the chromaticity does not match, the blackbody temperature that most closely matches the spectral properties of the illuminant is given; this temperature is called the *Correlated Color Temperature* (CCT). These temperatures are identified with an asterisk in the table above, as well as in the program's illuminant table data.

The illuminant referred as D65, with a correlated temperature of 6504 K, emits light with a spectrum close to mid-day daylight illumination and can be considered a good "general use" white. D65 is part of the standard CIE D-series illuminants which cover the 4000 K to 10000 K plus range where the number following the "D" is an abbreviation of the correlated temperature—all D-series illuminant have chromaticities slightly different than same temperature blackbodies.

D50, with a correlated 5000 K temperature, has a spectrum with a strong orange content, typical of tungsten lights. D50 is the reference illuminant for the print industry and the only illuminant used to compute L*a*b* data in Adobe Photoshop. D50 is also, presently, the only illuminant in the Profile Connection Space (PCS), a color space used as the link between devices, in the International Color Consortium (ICC) profile definition (Ref. 17).

The chromaticities of the D-series illuminants can be obtained with the following equations:

$$x_D = \frac{-4{,}6070 \times 10^9}{T^3} + \frac{2{,}9678 \times 10^6}{T^2} + \frac{99{,}11}{T} + 0{,}244063$$

for 4000 K ≤ T ≤ 7000 K,

$$x_D = \frac{-2{,}0064 \times 10^9}{T^3} + \frac{1{,}9018 \times 10^6}{T^2} + \frac{247{,}48}{T} + 0{,}23704$$

for 7000 K < T ≤ 25000 K, and

$$y_D = -3{,}000 {x_D}^2 + 2{,}870 x_D - 0{,}275 .$$

Like for the blackbodies, the chromaticity coordinates of the D-series illuminants can be obtained with the Custom illuminant dialog.

14.3.3 CAT matrix

When converting color coordinates from one RGB space to another, it is often required to transform colors referenced to one illuminant into colors referenced to another illuminant. All modern color appearance models competing for international acceptance incorporate such a *Chromatic Adaptation Transform* (see Ref. 7), or **CAT** for short.

For many years, one contender that has withstood critical revue is called the **Bradford** CAT, or BFD, from the name of the city, in England, where the researchers who developed it came from. A simplified matrix representation of the Bradford transform was found to give excellent results during the work performed in the development of the sRGB standard (Ref. 8). In its simplified version, the only data required to derive a Bradford matrix, in addition to the predefined Bradford cone response and inverse cone response matrices, are the XYZ coordinates of the source and destination whites. The *source white* is the illuminant used to measure the original data, and the *destination white* is the illuminant to which the data has to be translated.

Once derived, the Bradford conversion matrix is used in the following way:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{destination} = \begin{bmatrix} Bradford \\ 3x3 \\ matrix \end{bmatrix} \bullet \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{source}$$

where XYZ_{source} is the data derived from the original illuminant, and $XYZ_{destination}$ is the data transformed in the destination space illuminant.

More recently, another CAT, named **CIECAT02**, was developed for use with the CIECAM02 color appearance model (Ref. 26-28). The CIECAT02 transform is a variant of the simplified Bradford CAT, where some non-linear parameters are omitted, and which is further optimized in regards to many experimental data sets. Like the simplified Bradford based CAT, a CIECAT02 based CAT is a 3x3 matrix, and it can be used in the same way as the equation above.

CT&A can use a Bradford or a CIECAT02 CAT; the selection is done in the "Math" tab of the Preferences dialog. The CAT matrices can be viewed in a dialog which is called with the "RGB vs RGB/Table data/CAT matrices..." menu or with the "CAT matrices..." menu of the toolbar "**Tables**" icon.

Although it is clear that more accurate XYZ values are obtained when using spectral data combined with the color-matching functions (see the **Important** note below), such spectral data is often not available; a CAT is then the only choice. The average error obtained in Ref. 8 when converting Pantone color chips from D50 to D65 using the Bradford transform was 1,4 ΔE^*_{ab} with a standard deviation of 0,9. A similar conversion study from D65 to D50, done by the BabelColor Company with the 611 FED-STD-595 chips (of Rev-B), resulted in a 0,71 ΔE^*_{ab} average error with a 0,65 standard deviation. Not surprisingly, the fluorescent samples show larger errors.

Note: In older versions of CT&A, before Version 4.x, CIECAT02 was used only to compute the Color Inconstancy Index (CII) in the Metamerism Index tools, and all other chromatic adaptations were done with a Bradford CAT. Starting with CT&A Version 4.x, the CAT can be selected and CIECAT02 is the default. However, CIECAT02 remains the recommended CAT when computing the CII.

Important: A chromatic adaptation transform gives us the coordinates of a color as seen under another illuminant; however, being based on tristimulus data, it cannot take into consideration the spectral content of a light source interacting with the spectral content of a sample measured in reflectance. In practice, such interactions do take place and the perceived color of a sample is often different when viewed under two light sources. The CAT computed color is the exact match for the color seen under the first illuminant, and the color computed with the spectral data is the color actually perceived; the difference is defined as color inconstancy, an effect measured with the MI tools.

14.3.4 XYZ to RGB

XYZ to RGB conversions require a 3 x 3 matrix that, in essence, maps a space defined by three primaries, expressed in XYZ coordinates, into a space defined by **relative ratios** of **R**ed, **G**reen and **B**lue. The matrix is derived using a recommended practice from the Society of Motion Picture and Television Engineers (Ref. 18). The matrices used by the program, including the ones assigned to the custom RGB space, can be viewed in a dialog which is called with the "RGB vs RGB/Table data/RGB to XYZ matrices..." menu or with the "RGB to XYZ matrices..." menu of the toolbar "**Tables**" icon.

FROM XYZ to RGB

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} & XYZ \rightarrow RGB & \\ & 3 \times 3 & \\ & matrix & \end{bmatrix} \bullet \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

After this operation, the RGB coordinates of the illuminant are (100, 100, 100) when normalized XYZ data with *Y* equal to 100 is used. Results over 100 or below zero are clipped at 100 and zero respectively.

FROM RGB TO XYZ

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} & RGB \rightarrow XYZ & \\ & 3 \times 3 & \\ & matrix & \end{bmatrix} \bullet \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

By the combined use of the **RGB to XYZ** and **XYZ to RGB** matrices, we can transform RGB data from one RGB space to another. If the illuminant is not the same for both spaces, we apply a Chromatic Adaptation Transform (CAT), Bradford or CIECAT02, in mid process. The RGB space-to-space conversion procedure is represented by the equation:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{space2} = \begin{bmatrix} XYZ \rightarrow RGB \\ 3 \times 3 \\ Illuminant\ 2 \end{bmatrix} \bullet \begin{bmatrix} Bradford \\ XYZ(ILL1) \rightarrow XYZ(ILL2) \\ 3 \times 3\ matrix \end{bmatrix} \bullet \begin{bmatrix} RGB \rightarrow XYZ \\ 3 \times 3 \\ Illuminant\ 1 \end{bmatrix} \bullet \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{space1}$$

The computation sequence is performed from right to left. If the illuminant is the same, the CAT transform (Bradford shown in the equation) is simply omitted. It is important to mention that converting from one space to another is often done in conjunction with an additional step, called *gamut mapping*, which is not represented in the preceding equation. Gamut mapping algorithms attempt to minimize the effects of clipping by distorting the values of either or both the clipped and non-clipped colors. Variants of the process, still a subject of active research (Ref. 19), have been devised for different requirements such as maintaining saturated colors in business graphics or achieving a balanced "realistic" look in pictures, even if none of the resulting colors are accurate.

Important: When converting colors to other spaces, the software adapts the new coordinates to the destination space illuminant by using a CAT. Colors which fall outside the new space are clipped to the nearest color. This is the method used when converting color profiles with "**Relative Colorimetric**" intent in Photoshop and other graphic editing programs that use this terminology.

Important: Many RGB to RGB conversion matrices found in the literature are simply the **RGB to XYZ** and **XYZ to RGB** matrices shown above, combined into one, as per ASTM RP 177-93 (also Ref. 18), with no CAT matrix or gamut mapping.

14.3.5 RGB to R'G'B', and gamma

We cannot talk about RGB and R'G'B' without first presenting **gamma**. The equations for **RGB to R'G'B'** and **R'G'B' to RGB** conversions are presented further down.

GAMMA

The eye is more sensitive to variations of luminance in low luminance levels than similar variations in high luminance levels. Compared to RGB, which is scaled linearly in luminance, R'G'B' values are scaled according to this non-linear perception of the eye, and more data triads are assigned to the lower luminance levels. As a result, the R'G'B' scale is close to a perceptively linear scale where doubling the values of a triad will result in a color whose brightness appears doubled.

The conversion equations shown here describe how two "flavors" of gamma are used to encode data from RGB to R'G'B' and vice-versa. This is just one aspect of gamma, the **software-encoding gamma**, amongst the other gamma parameters that define a complete vision chain.

The vision chain consists of:

- A **file gamma** that combines the **camera gamma** and the **software-encoding gamma** ($\gamma_{file} = \gamma_{camera} * \gamma_{encoding}$). In most photographic images, the camera gamma is already combined with the software-encoding gamma. However, this is less and less the case as many images from cameras and scanners now come with an embedded ICC profile. When the image is processed in a graphic editing program, the output file has a single gamma usually corresponding to the RGB space in which the file will be displayed.

  When the image is created on a computer, the file gamma is simply the software-encoding gamma. In most image archives, the software-encoding gamma is the only one remaining.

  The gamma used and displayed in this software, either simple or detailed, is the software-encoding gamma.

- A **decoding gamma**, which is defined as the gamma of any transformation performed by the software reading the image file. For example, this is the gamma used for display calibration by the operating system or an application which supports color management.
- A **display gamma**, which combines the **look-up table** (**LUT) gamma** and the **CRT gamma**: ($\gamma_{display} = \gamma_{LUT} / \gamma_{CRT}$). In most PCs there is no LUT correction and this gamma is equal to one. The CRT gamma is often equal to 0.40 (=1/2.5). Please note that different values of LUT gamma and CRT gamma are used for the Apple, ColorMatch and SGI displays.
- The **overall gamma** that combines all the preceding gammas.
- The **human eye gamma**.

For more information on the elements of a vision chain, see Ref. 9, Ref. 10, and Ref. 11.
For a detailed presentation on colorimetry and how images are perceived, see Ref. 5.

Important: All computer programs which display R'G'B' data, in color pickers for example, present R'G'B' data as **R**, **G** or **B**, or **RGB**, without the prime symbol after the letter. These programs **never** display linear RGB values as obtained in converting from XYZ to RGB. Still, this is an "industry standard" representation, and this is how this program user interface is done. However, in CT&A's documentation, the correct **R'**, **G'**, and **B'**, or **R'G'B'** form is used to minimize any confusion in the transformation equations.

Important: You should always verify how gamma is defined before making comparisons with other sources of information, and you should get used to the fact that any author's gamma value could be the reciprocal (= 1/*x*) of another author's definition.

FROM RGB TO R'G'B'

Going from RGB to R'G'B' can be done using either a single parameter ("simple") gamma function, or a multiple parameters ("detailed") function, a function which is sometimes referred to as a Tone Response Curve, or TRC.

The detailed gamma function is (for simplicity, only *R′* is shown; *G′* and *B′* are similar; *R*, *G*, and *B* are normalized between zero and one prior to this operation):

$$R' = round\left(255\left(\left(1+offset\right)R^{\gamma} - offset\right)\right)$$

for $1 \geq R \geq transition$, and

$$R' = round\left(255\left(slope \times R\right)\right)$$

for $transition > R \geq 0$.

The function is defined by two segments: a linear segment at low light levels, below the defined *transition* level, which makes the transform less susceptible to noise around zero luminance, and a power segment with a γ (gamma) exponent. The effect of that exponent is to compress the luminance signal by assigning a larger signal range to dim colors, where the eye is most sensitive, and a small signal range to bright colors.

The *offset* is related to what is generally identified in TVs and monitors as the *black level*, *intensity* or *brightness* control knob. The combination of (1 + *offset*) is related to the *picture*, *gain* or *contrast* knob. It may sound surprising to associate brightness to a DC level and contrast to a term which controls the maximum luminance level, but these terms were defined in relation to what is perceived, not the mathematical expression. In effect, the eye perceives as a brightness increase a change in the black level more than it does of a change in the gain.

The four parameters — *offset*, *gamma*, *transition*, and *slope* — collectively define the "**detailed gamma**."

The two above equations can be approximated by a simpler function of the form:

$$R' = round\left(255\,R^{\gamma}\right)$$

for $0 \leq R \leq 1$.

Here, a single parameter, the γ (gamma) exponent, with a value different than the gamma of the detailed function, defines what we call the "simple encoding gamma," or "**simple gamma**" for short. Not all spaces are defined with detailed gamma parameters, but all spaces have a simple gamma value assigned. The simple gamma is generally used by all graphic editing programs while the detailed gamma provides more accurate colorimetric transforms.

You can define and compare both simple and detailed gamma functions using the Custom RGB space dialog which opens with the "RGB vs RGB/Define custom RGB..." menu or with the last menu item in a RGB vs RGB window space selection menu.

Note: An average difference of 1.3 DeltaE*ab, with a 0.9 DeltaE*ab standard deviation, was measured when using a simple gamma instead of a detailed one in random sRGB to L*a*b* conversions.

FROM R'G'B' TO RGB

Going from R'G'B' to RGB can also be done using either a single parameter gamma ("simple gamma") function, or a multiple parameters function ("detailed gamma").

The detailed gamma equations are (*R′*, *G′*, and *B′* are normalized between zero and one prior to this operation):

$$R = 255\left(\left(R' + offset\right) / \left(1 + offset\right)\right)^{1/\gamma}$$

for $1 \geq R' \geq$ (*transition* x *slope*), and

$$R = 255\left(R' / slope\right)$$

for (*transition* x *slope*) > $R' \geq 0$.

Again, the two above equations can be approximated by a simpler function of the form:

$$R = 255\, R'^{\,1/\gamma}$$

for $0 \leq R' \leq 1$.

14.3.6 R'G'B' to Hex

R'G'B' to Hexadecimal (**hex** for short) "conversion" is often use in Web development environments.

The conversion is not from one color space to another but simply a change in the numerical base of the R', G' and B' numbers. Instead of being written in standard decimal way (base 10), a base 16 (hexadecimal) is used. Here is the decimal to hexadecimal conversion table:

decimal	hex
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	**A**
11	**B**
12	**C**
13	**D**
14	**E**
15	**F**
16	**10**
17	**11**
etc.	

For example, the R'G'B' =(255, 0, 16) triad is written as **#FF0010**, where "**FF**" is the hexadecimal equivalent of **255** (= (15 x 16) + 15), "**00**" is **zero**, and "**10**" hexadecimal is **16** (= (1 x 16) + 0).

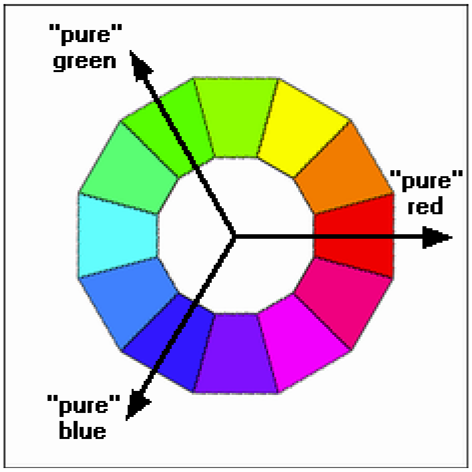
The numbers are presented side by side, with no separating spaces, in the traditional R'G'B' sequence: **#redgreenblue**. By convention, a number (**#**) sign precedes the hexadecimal color. This representation has the advantage that a single, fixed size, string of six characters can represent all colors.

To view this representation, select **Hex #** in the Hex # / HSB / xyY / XYZ display.

14.3.7 R'G'B' to HSB

The HSB (***H**ue-**S**aturation-**B**rightness*) color representation is used mainly in graphic design software. It is presented as a more intuitive color selection means than R'G'B'. Instead of selecting a color by adding primaries, a method which takes a long time to "visualize", HSB defines a color by its pure base color (its *Hue*), how pure or diluted it is (its *Saturation*), and its *Brightness*.

Hue is a value between zero and 360, in reference with the degrees of a circle where zero degrees is "pure" red, 120 degrees is "pure" green, and 240 degrees is "pure" blue. By "pure", we mean the maximum purity that can be obtained with an R'G'B' triad (Ex.: maximum red is R'G'B' = (255, 0, 0)). A simplified representation of the color variation with the angle is shown below (Note: the actual 3D shape of the HSB space is a six-sided cone, a hexcone):



The intent of HSB is good, but it has drawbacks. Firstly, its use is not standardized; there are many variants, such as HSL (***H**ue-**S**aturation-**L**ightness*), or HSV (***H**ue-**S**aturation-**V**alue*). The equations to derive these representations are similar, but not identical, and you will find various scales for each parameter.

Secondly, the conversion equations are not continuous, which does not make them mathematically, or computer, "friendly" (and fast!).

More importantly, because of the way it is derived, the HSB representation is **NOT** a **colorimetrically accurate** representation of color. The brightness parameter ("B") has no relation with the actual luminance (*Y*), or the relative brightness (i.e. *lightness*, *L**), of the color. In HSB, any hue can have a maximum "B" value of 100. As illustrated in the xyY and XYZ section, the maximum luminance of an RGB space is a very non-uniform function, where the maximum luminance is only achieved for pure white.

A more "scientifically correct" alternative is to use the **chroma** (C^*_{ab}) and **hue angle** (h_{ab}) of the L*a*b* representation, or their equivalent in the L*u*v* representation, but they are not as intuitive. Another more perceptually correct way of selecting colors is to use the Munsell Color System, which characterizes the spectrum in uniformly perceived ***H**ue*, ***V**alue* (an indicator of lightness), and ***C**hroma* (a counterpart of saturation) steps. Still another "scientifically correct" way of picking colors is to use the color picker capabilities of this program, as it is shown in Tutorial 4.

Nonetheless, when used for picking colors, HSB is a good alternative to R'G'B'.

FROM R'G'B' to HSB

The R'G'B' to HSB conversion equations used in CT&A are the same as the ones employed in Photoshop. Hue has a value between zero and 359; saturation and brightness are values between zero and 100.

Here are the steps used to derive the HSB values:

- **Normalize the data:**

  Normalize *R′*, *G′* and *B′* between zero and one:

  $$r = R'/255; \quad g = G'/255; \quad b = B'/255 .$$

  Determine the maximum (*MAX*) and minimum (*MIN*) value of the ***rgb*** triad (both are values between zero and one):

  $$MAX = maximum(r, g, b); \quad MIN = minimum(r, g, b) .$$

- **Calculate the Brightness ("B"):**

  $$B = 100\,MAX .$$

- **Calculate the Saturation ("S"):**

  $$S = 100\left(\frac{MAX - MIN}{MAX}\right) .$$

- **Calculate the Hue ("H"):**

  If ***r*** is the *MAX* value:

  $$H = 60\left(\frac{g - b}{MAX - MIN}\right) .$$

  If ***g*** is the *MAX* value:

  $$H = 60\left[2 + \left(\frac{b - r}{MAX - MIN}\right)\right] .$$

  If ***b*** is the *MAX* value:

  $$H = 60\left[4 + \left(\frac{r - g}{MAX - MIN}\right)\right] .$$

  Finally, if ***H*** is negative:

  $$H = H + 360 .$$

14.3.8 XYZ to L*a*b*

As good as it may be, the CIE1931 chromaticity diagram is not without faults. Soon after it was issued, it was found that it does not represent color gradations in a uniform manner. David L. MacAdam showed (Ref.12) in the early forties that the minimum distance between two discernible colors is smaller in the lower left portion of the horseshoe, and progressively bigger toward the top. It is also non-uniform; for any given point, tracing the coordinates of the minimally discernible colors around the point forms an ellipse, called a *MacAdam ellipse*.

Attempts to transform the original diagram into a more uniform representation have resulted, after much work and discussions, in a relatively recent industry wide "agreement" on **two** standards, the **L*a*b*** representation, called either **CIE1976 (L*a*b*)** or **CIELAB**, and the **L*u*v*** space, called either **CIE1976 (L*u*v*)** or **CIELUV**. Since both spaces have their proponents and preferred applications, it is up to the users to select the most appropriate model, at least until a better "universal" one is defined and accepted.

Note: The **L*** of L*a*b* and L*u*v* are identical.

XYZ to L*a*b*

L*a*b* is derived from XYZ data with the following equations:

$$L^* = 116\, f_y - 16 \qquad a^* = 500\left(f_x - f_y\right) \qquad b^* = 200\left(f_y - f_z\right)$$

where

$$f_x = \sqrt[3]{x} \qquad x > \varepsilon$$

$$f_x = \frac{\kappa x + 16}{116} \qquad x \le \varepsilon$$

$$f_y = \sqrt[3]{y} \qquad y > \varepsilon$$

$$f_y = \frac{\kappa y + 16}{116} \qquad y \le \varepsilon$$

$$f_z = \sqrt[3]{z} \qquad z > \varepsilon$$

$$f_z = \frac{\kappa z + 16}{116} \qquad z \le \varepsilon$$

with either

$$\varepsilon = 0.008856 \quad and \quad \kappa = 903.3$$

which are the values now in use by the CIE, or

$$\varepsilon = {}^{216}\!/_{24389} \quad and \quad \kappa = {}^{24389}\!/_{27}$$

which are values which provide a better continuity in the *f* functions around the "ε" threshold, and

$$x = \frac{X}{X_n} \qquad y = \frac{Y}{Y_n} \qquad z = \frac{Z}{Z_n}$$

where X_n, Y_n, Z_n, are the values of *X*, *Y*, *Z* for a specified *reference white*, i.e. illuminant.

Better uniformity is thus obtained with L*a*b* by normalizing the color coordinates with the illuminant coordinates, and by applying a 1/3 exponent to the ratios, which corresponds to the non-linear perception, i.e. dynamic range compression, of the eye subjected to increased luminance.

The exact name for *L** is *lightness*, to indicate it is the *relative brightness* of a color patch when compared to the brightness of a perfect "white" diffuser in the same illuminating conditions (or when compared to a "white" patch, with R'G'B' =(255, 255, 255), if the patch is seen on a computer monitor). In effect, the actual brightness can vary for a given lightness.

Increases in *a** values represent increases mainly in redness, while decreases in *a** values represent increases mainly in greenness. Increases in *b** values represent increases mainly in yellowness while decreases in *b** values represent increases mainly in blueness.

Note: In practice, selecting the "in use by the CIE" or "better continuity" ε and κ values will result in essentially no difference relatively to the precision of 8 bit RGB data.

L*a*b* to XYZ

The XYZ coordinates are derived from L*a*b* data with the following equations, starting with *y* and f_y:

$$X = xX_n \qquad Y = yY_n \qquad Z = zZ_n$$

where

$$x = f_x^3 \qquad f_x^3 > \varepsilon$$
$$x = (116 f_x - 16)/\kappa \qquad f_x^3 \le \varepsilon$$

$$y = ((L^* + 16)/116)^3 \qquad L^* > \kappa\varepsilon$$
$$y = L^*/\kappa \qquad L^* \le \kappa\varepsilon$$

$$z = f_z^3 \qquad f_z^3 > \varepsilon$$
$$z = (116 f_z - 16)/\kappa \qquad f_z^3 \le \varepsilon$$

and

$$f_x = \frac{a^*}{500} + f_y$$

$$f_y = \frac{L^* + 16}{116} \qquad y > \varepsilon$$
$$f_y = \frac{\kappa y + 16}{116} \qquad y \le \varepsilon$$

$$f_z = f_y - \frac{b^*}{200}$$

where X_n, Y_n, and Z_n are the illuminant coordinates, and ε and κ are defined as for XYZ to L*a*b*.

14.3.9 XYZ to L*u*v* (UCS)

As good as it may be, the CIE1931 chromaticity diagram is not without faults. Soon after it was issued, it was found that it does not represent color in a uniform manner. David L. MacAdam showed (Ref.12) in the early 1940s that the minimum distance between two discernible colors is smaller in the lower left portion of the horseshoe, and progressively bigger toward the top. It is also non-uniform; for any given point, tracing the coordinates of the minimally discernible colors around the point forms an ellipse, called a *MacAdam ellipse*.

Attempts to transform the original diagram into a more uniform representation have resulted, after much work and discussions, in a relatively recent industry wide "agreement" on **two** standards, the **L*a*b*** representation, called either **CIE1976 (L*a*b*)** or **CIELAB**, and the **L*u*v*** space, called either **CIE1976 (L*u*v*)** or **CIELUV**. Since both spaces have their proponents and preferred applications, it is up to the users to select the most appropriate model, at least until a better "universal" one is defined and accepted.

Note: The **L*** of L*a*b* and L*u*v* are identical.

XYZ to L*u*v*

L*u*v* is derived from XYZ data with the following equations. We start by computing u'_n and v'_n once (for a given illuminant):

$$u'_n = 4X_n / (X_n + 15Y_n + 3Z_n)$$
$$v'_n = 9Y_n / (X_n + 15Y_n + 3Z_n)$$

where X_n, Y_n, and Z_n are the illuminant coordinates. An equivalent set of equations using *x* and *y* is:

$$u'_n = 4x_n / (-2x_n + 12y_n + 3)$$
$$v'_n = 9y_n / (-2x_n + 12y_n + 3)$$

Then, for each data set, we calculate the intermediate variables *u'* and *v'*:

$$u' = 4X / (X + 15Y + 3Z)$$
$$v' = 9Y / (X + 15Y + 3Z)$$

The equivalent set of equations from *x* and *y* is:

$$u' = 4x / (-2x + 12y + 3)$$
$$v' = 9y / (-2x + 12y + 3)$$

The *u'* and *v'* coordinates are a projective transformation of the *xy* coordinates plane, and define a more uniform chromaticity diagram called the **Uniform Chromaticity Scale (UCS, CIE1976)**, which is often used as a replacement to the CIE1931 *xy* chromaticity diagram. Straight lines in the *xy* chromaticity diagram remain straight in the *u'v'* diagram.

u'v' chromaticity tolerances are specified in many Standards and Publications, such as ISO 12646, ISO 3664, CIE 51 and CIE S 012 (click here for more information on these standards). The L*a*b* space does not have such chromaticity units.

Finally, we calculate L*u*v*, starting with *L**:

$$L^* = 116\sqrt[3]{y} - 16 \qquad y > \varepsilon$$
$$L^* = \kappa y \qquad y \le \varepsilon$$

where

$$y = \frac{Y}{Y_n}$$

with either

$$\varepsilon = 0.008856 \quad and \quad \kappa = 903.3$$

which are the values now in use by the CIE, or

$$\varepsilon = 216/24389 \quad and \quad \kappa = 24389/27$$

which are values which provide a better continuity for the *L** functions around the "ε" threshold, and

$$u^* = 13L^*(u' - u'_n)$$
$$v^* = 13L^*(v' - v'_n)$$

The exact name for *L** is *lightness*, to indicate it is the *relative brightness* of a color patch when compared to the brightness of a perfect "white" diffuser in the same illuminating conditions (or when compared to a "white" patch, with R'G'B' =(255, 255, 255), if the patch is seen on a computer monitor). In effect, the actual brightness can vary for a given lightness. The difference between *u'v'* and *u*v** is that, as the equations show, the later form takes into account the variation in perception due to lightness.

L*u*v* to XYZ

The XYZ coordinates are derived from L*u*v* data with the following equations. We start by computing u'_n and v'_n once (for a given illuminant):

$$u'_n = 4X_n / (X_n + 15Y_n + 3Z_n)$$
$$v'_n = 9Y_n / (X_n + 15Y_n + 3Z_n)$$

where X_n, Y_n, and Z_n are the illuminant coordinates.

Then, for each data set, we calculate the intermediate variables *u'* and *v'*:

$$u' = (u^*/13L^*) + u'_n$$
$$v' = (v^*/13L^*) + v'_n$$

Finally, we calculate XYZ, starting with *Y*:

$$Y = Y_n((L^* + 16)/116)^3 \qquad L^* > \kappa\varepsilon$$
$$Y = Y_n(L^*/\kappa) \qquad L^* \le \kappa\varepsilon$$

where ε and κ are defined as for the XYZ to L*u*v* equations, and

$$X = (9Y/4v')\left[(u^*/13L^*) + u'_n\right]$$
$$Z = (1/3)\left[(4X/u') - X - 15Y\right]$$

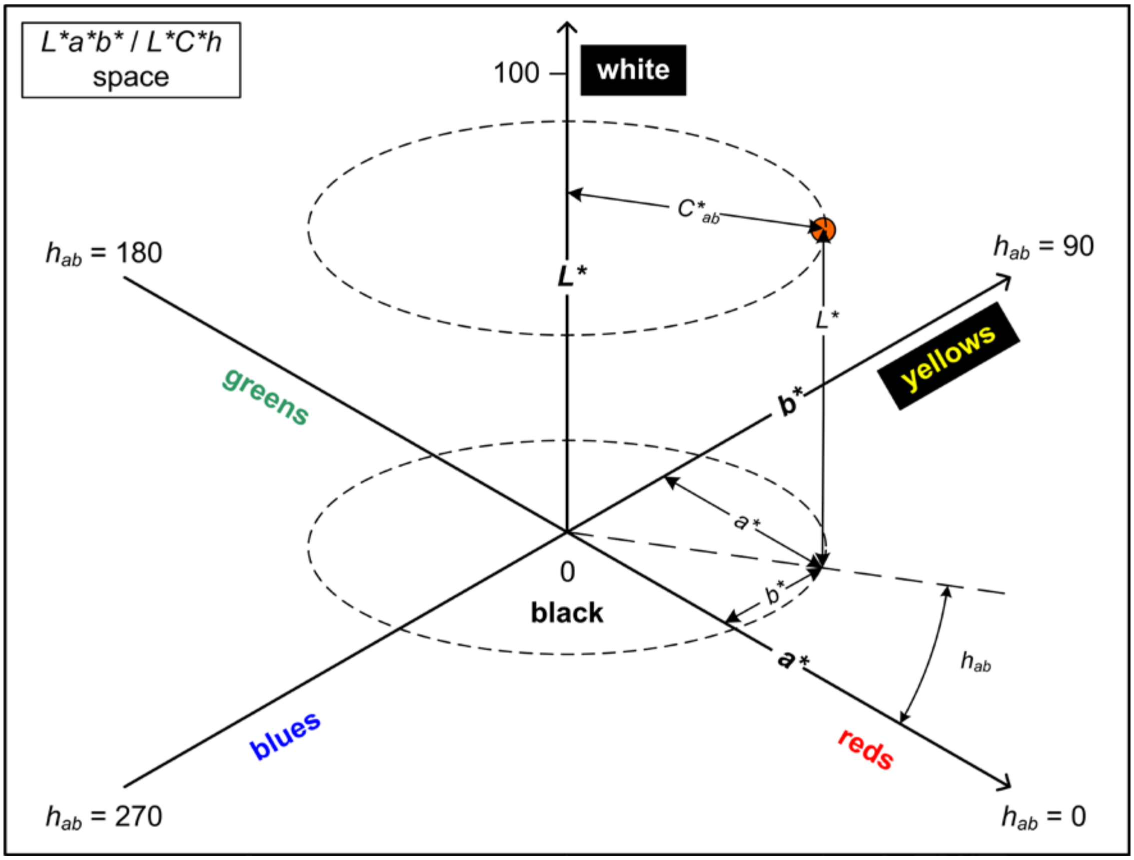
14.3.10 L*a*b* or L*u*v* to L*C*h

Because of the difficulty in navigating intuitively in the L*a*b* space using *a** and *b**, derived correlates of *chroma* (*C**), called **CIE1976 chroma**, and *hue* (*h*), called **CIE1976 hue angle**, were defined:

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

$$h_{ab} = \arctan(b^* / a^*) \quad .$$

The *C** and *h* variables are shown in relation with *L**, *a** and *b** in the following diagram:



Equivalent equations and a similar diagram for L*u*v* can be derived:

$$C^*_{uv} = (u^{*2} + v^{*2})^{1/2}$$

$$h_{uv} = \arctan(v^* / u^*) \quad .$$

It is important to note that the 3D shapes of the L*a*b* and L*C*h spaces, as well as the position of the data within them, and the value of *L**, are identical; it is simply that the data is represented using cylindrical coordinates instead of three orthogonal axes.

Chroma can be considered an approximate counterpart of perceived color saturation. The higher the chroma, the more monochromatic the color tends to be; the lower the chroma, the closer to neutral gray the color tends to be. A hue angle of zero degree, equivalent to 360 degrees, is red-purple, using the Munsell description lingo, or magenta-red, if you prefer using descriptions which are closer to the ones used in color printing. Increasing the hue angle will make you go through red, orange, yellow, green, cyan, blue, and then back to red-purple (magenta-red). This is very similar to what is seen when increasing the hue, going counter-clockwise, in the HSB space and the Munsell Color System, although you will notice that these representations are not similar in terms of the relative importance they allocate to each major hue.

With these alternate parameters, two color samples can be compared in terms of lightness (ΔL^*), chroma (ΔC^*_{ab}), and hue angle (Δh_{ab}) differences:

$$\Delta L^* = L^*_2 - L^*_1$$

$$\Delta C^*_{ab} = C^*_{ab_2} - C^*_{ab_1}$$

$$\Delta h_{ab} = h_{ab_2} - h_{ab_1} \quad .$$

The corresponding equations for L*u*v* are (ΔL^* is the same):

$$\Delta C^*_{uv} = C^*_{uv_2} - C^*_{uv_1}$$

$$\Delta h_{uv} = h_{uv_2} - h_{uv_1} \quad .$$

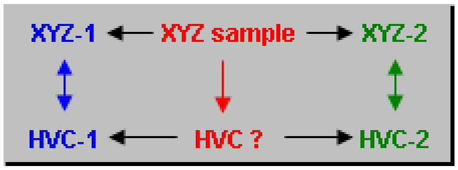
These differences are shown in the DeltaE* interface window. See the CIELAB & CIELUV section for more information on the difference between ΔH^*_{ab} and Δh_{ab}.

Note: The three variables, *L**, *C**, and *h* define a space which has the same representation goal as the HSB space, but is more colorimetrically correct.

14.3.11 XYZ to Munsell

Converting data between XYZ — or from any other CIE compliant color data representations — and the **Munsell Color System** cannot be done entirely using equations. The fact that this system is still not mathematically formalized more than a century after its introduction simply emphasizes the magnitude of the task, and is another illustration of the complexity of the human visual perception process.

One of the few methods left to convert data between the two color systems is interpolation. Traditionally done manually by using tables and graphics, such as the ones contained in the ASTM D1535 standard (see Ref. 23), it is now performed by computers. This task is facilitated by the inherent structure of the **Munsell Book of Color** which presents samples with uniform *Munsell* ***H****ue*, *Munsell* ***V****alue*, and *Munsell* ***C****hroma* (HVC) steps between them. By measuring the XYZ characteristics of all these samples, we obtain two matching three-dimensional tables, one with XYZ numbers and the other with HVC numbers, from which we can interpolate the HVC coordinates of any XYZ sample, or the reverse. A simplified illustration of interpolation is shown below:



The goal is to find the unknown Munsell coordinates (**HVC ?**) corresponding to the measured **XYZ sample**. In this simplified case, two nearest neighbors of the sample, **XYZ-1** and **XYZ-2**, are found from a search within the known XYZ database. The corresponding, and also known, Munsell coordinates in the HVC table are labeled **HVC-1** and **HVC-2**. The relative position of the **XYZ sample** between **XYZ-1** and **XYZ-2** is then used to deduce the HVC coordinates of the sample. In practice, this process is performed in three dimensions and the search routine looks for multiple neighbors located around the sample.

Alternately, the following equations can be used to determine *Munsell Value* from the CIE *Y* coordinate (from Ref. 23):

For $Y <= 0{,}9$:

$$\text{Munsell Value} = 0{,}87445 * Y^{0{,}9967} \quad .$$

For $Y > 0{,}9$:

$$\begin{aligned}\text{Munsell Value} = & (2{,}49268 * Y^{1/3}) - 1{,}5614 \\ & - \{ 0{,}985 / [(0{,}1073 * Y - 3{,}084)^2 + 7{,}54] \} \\ & + (0{,}0133 / Y^{2{,}3}) \\ & + [0{,}0084 * \sin(4{,}1 * Y^{1/3} + 1)] \\ & + \{ (0{,}0221 / Y) * \sin[0{,}39 * (Y - 2)] \} \\ & - \{ [0{,}0037 / (0{,}44 * Y)] * \sin[1{,}28 * (Y - 0{,}53)] \} \quad .\end{aligned}$$

Although it is quite an elaborate data fitting formula, implementing it in a conversion program is straightforward. Alas, there are no similar equations for the other two parameters, hue and chroma, and interpolation is the only solution.

Two particular problems arise from the interpolation method. The first one is that it is difficult to recognize true neutral samples (ex: "**N 2,3/**") and most converters show a "nearest best candidate", which can be of any hue; this condition is monitored and displayed correctly in CT&A. The second one is that the reference samples, the ones used for interpolation, for a color located near the illuminant, can be located all around the illuminant. In such a case, the interpolation routine must contain additional code to prevent large hue shifts; this is also considered in this program.

Even though the Munsell Book of Color, the original presentation method of the Munsell Color System, contains samples which cover a large part of the visible gamut, it is not exhaustive since it is impossible to reproduce on printed or painted chips all the colors humans can perceive. This is the case for high chroma colors, like the

ones generated by lasers. Also, it does not make commercial sense to provide many samples with very dark colors, with low values and chromas, since they are seldom used. Nonetheless, these colors were also characterized using the Munsell notation by extrapolating from available data. This extrapolation was even extended outside the visible gamut to facilitate the mapping between CIE based data, which covers the entire visible gamut by definition, and the Munsell representation. Thus, it is possible to convert back on forth between the notations of the CIE system and the Munsell system.

According to ASTM D1535 (again from Ref. 23), the estimated precision with which a color can be characterized visually is 0,5 hue step, 0,1 value step and 0,4 chroma step.

Important: The data tables built for the Munsell Color System were derived using Illuminant "C". Since the chromatic adaptation transforms (CAT matrix) do not take into account any potential color inconstancy effect, the conversion errors for samples subject to this effect may be higher than what is normally expected for these transforms (click here for typical values).

Note: They were other attempts at devising a formal uniform color system. The best known is the Optical Society of America (OSA) Uniform Color Scales (UCS) project which development spanned on over three decades. UCS development was ultimately "officially" abandoned; one of the reason being that it was still not perfectly uniform, but it could well resurface as it provides an original view into color space and a different approach in building color palettes (see Ref. 24).

14.3.12 L* (L-star)

L*, pronounced L-star, is a gamma function based on the CIELAB *L** (lightness). It is proposed as the Tone Response Curve (TRC) for the eciRGB_v2 space. *L** is derived from the CIE *Y* (of XYZ) with the following equation (the complete XYZ to L*a*b* equations are shown in this section):

$$L^* = 116\, f_y - 16$$

$$f_y = \sqrt[3]{y} \qquad y > \varepsilon$$

$$f_y = \frac{\kappa y + 16}{116} \qquad y \le \varepsilon$$

with

$$\varepsilon = 0.008856 \quad and \quad \kappa = 903.3$$

and

$$y = \frac{Y}{Y_n}.$$

By incorporating the f_y terms and the constants in *L**, we can simplify the above equations to:

$$L^* = (100 + 16)\sqrt[3]{y} - 16 \qquad y > 0.008856$$

$$L^* = 116\,\frac{\kappa y + 16}{116} - 16 = \kappa y = 903.3\, y \qquad y \le 0.008856$$

Since *y* is the normalized luminance (=Y/Y_n), and varies between zero and one. We can easily associate *y* to linear RGB (i.e. before gamma correction), and assume that R,G, and B are also normalized between zero and one (*y* = *R*/255). We can thus associate R'G'B' values to *L**. Because the maximum value of the *L** function is 100, we need to multiply the equation by 2,55 in order to obtain the proper R'G'B' maximums. The re-written equations are:

$$L^* = 2.55\left((100 + 16)\sqrt[3]{y} - 16\right) \qquad y > 0.008856$$

$$L^* = 2.55\,(903.3\, y) \qquad y \le 0.008856$$

Now, let's look at the equation we use for the detailed gamma function (for simplicity, only *R'* is shown; *G'* and *B'* are similar; *R*, *G*, and *B* are normalized between zero and one prior to this operation):

$$R' = round\left(255\left((1 + offset)R^{\gamma} - offset\right)\right)$$

for 1 ≥ *R* ≥ *transition*, and

$$R' = round\left(255\,(slope \times R)\right)$$

for *transition* > *R* ≥ 0 .

By comparing the equations of *L** and *R'*, we can see that they have the same structure or, in other words, that they are the same equation. We can deduce that the *L** *offset* is 16, that its gamma exponent (γ) is 1/3, and that the *slope* is 903,3.

Finally, if we adjust the normalizing factor in the *L** equations (=2,55) to the ones used in CT&A (=255), we get these equivalent equations:

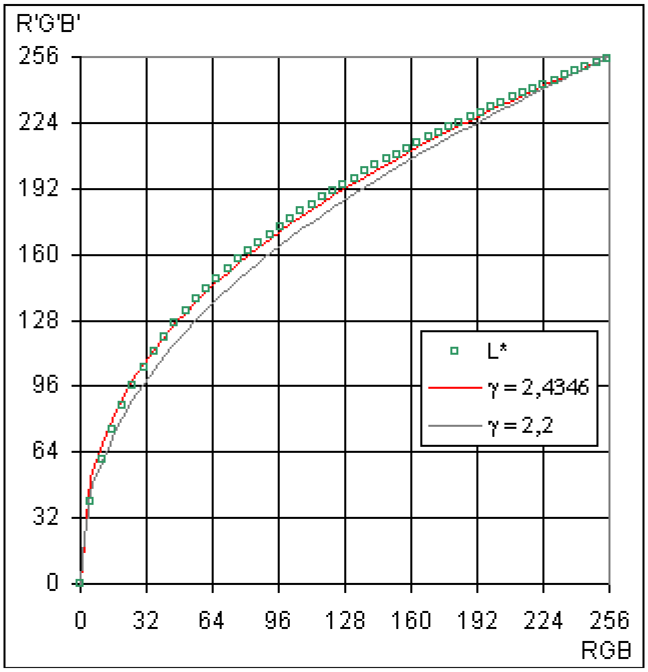
$$L^* = 255\left((1 + 0.16)\sqrt[3]{y} - 0.16\right) \qquad y > 0.008856$$

$$L^* = 255\,(9.033\, y) \qquad y \le 0.008856$$

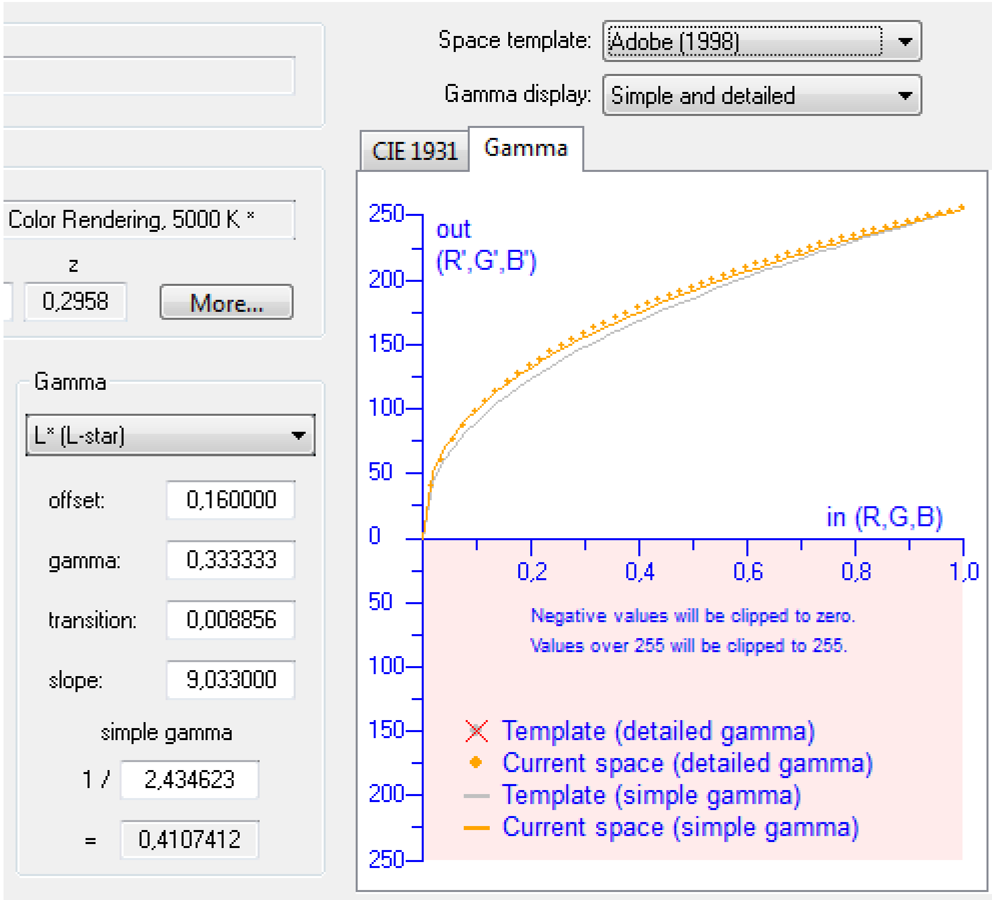
where the detailed gamma is defined by:

offset = 0,16
gamma = 1/3 = 0,333333
transition = 0.008856
slope = 9,033

To derive a simple encoding gamma for L-star, we have traced the detailed gamma (R'G'B' vs RGB) and fitted a curve with a single exponent equation; for comparison purposes, we have also traced the response of a simple 2,2 gamma:



The best fit was obtained for a single exponent (γ) of 2,4346. We see that a simple gamma of 2,4346 provides a better fit to *L** than a generic 2,2 gamma. You will find these values in the Space data dialog. Here is a similar graph that you can obtain with the "Gamma" tab of the Custom RGB space dialog:



We see the same three curves, except that here the linear RGB input is normalized between zero and one. The solid gray curve represents the simple gamma of the "Space template", which was selected as Adobe (1998), and thus represents a simple gamma of 2,2 (and no detailed gamma for this template is available). You will notice that the selected gamma set in the gamma menu is "L* (L-star)", which means that you can easily associate the *L** tone response curve to any custom RGB space.

Note: When we write that a simple gamma of 2,4346 provides a better fit to *L** than a generic 2,2 gamma, this does not automatically mean that it is better. It all depends of the end-use for the RGB space which uses *L**, and where this detailed gamma fits in the vision chain.

14.3.13 DeltaE*

Color-differences can be expressed mathematically for any space but they make practical sense only for the more uniform spaces where the resulting numbers can be better associated to what the eye perceives.

CT&A computes these differences according to many standards and variants. Although all are computed, only one is displayed at a time (see DeltaE* interface). However, all are shown when saving or printing data in the RGB vs RGB tool.

Click on the topic to see the definition and equations of each of the following color-differences:

- CIELAB, ΔE^*_{ab} in abridged form
- CIELUV, ΔE^*_{uv} in abridged form
- CIE94, ΔE^*_{94} in abridged form
- CMC(l:c), $\Delta E_{CMC(\ell:c)}$ in abridged form
- CIEDE2000, ΔE_{00} in abridged form

There is no "best one" although some are better suited to specific applications. The Commission Internationale de l'Éclairage (CIE) recommends CIELAB for large color differences (ΔE^*_{ab} larger than 5). Up until recently, CIE94 was often the preferred choice for small color differences but CIEDE2000 may displace it if usage confirms the preliminary — positive — findings of early CIEDE2000 users. CMC will most frequently be used, especially in the United Kingdom, in the context of the ink and textile industries where the (2:1) variant is found to be well adapted.

DISCUSSION

An accepted "reference" is that a ΔE=1 corresponds to colors which are barely differentiable by 50% of a group of observers; the other 50% would see no difference. This threshold is valid for all the color-difference formulas described herein, even though an exact difference of one will not be obtained by all for the same conditions. As well, when comparing very different colors, the color-differences obtained with the various formulas can also be very different, an indication that the formulas are still not perfectly matched to how the human visual system perceives color.

To place this error in perspective, we should take into consideration the conditions in which the colors will be seen. One of these conditions is the observation time. According to a review article by Has & al. (Ref. 1), an inexperienced user will take approximately 5 seconds, when comparing images, to notice a ΔE^*_{ab} difference of 15 from an original. The time goes up to 10 seconds for a ΔE^*_{ab} of 10, and 15 seconds for a ΔE^*_{ab} of 5. Another study (Ref. 2) has shown that errors of less than 2.5 ΔE^*_{ab} are not visible on real world images shown on a CRT. In essence, the threshold value of ΔE = 1 should be perceived only by prolonged comparative viewing in a controlled environment.

On the hardware side, it has been shown (Ref. 3) that CRTs require a warm-up time varying between 15 minutes and three hours, depending on models, before achieving a long term stability of 0.15 ΔE^*_{ab} on average. On a given CRT subjected to a large luminance variation, an initial ΔE^*_{ab} of 1.0 was seen to exponentially decrease to about 0.1 ΔE^*_{ab} in 60 seconds. As for printed material, errors between 2 and 4 ΔE^*_{ab} are mentioned by Has & al. (Ref. 1) for the offset and rotogravure processes.

14.3.13.1 CIELAB & CIELUV

CIELAB (ΔE^*_{ab})

For the L*a*b* space the color-difference equation (i.e. the "CIELAB color-difference equation", DeltaE*ab or ΔE^*_{ab} in abridged form) is:

$$\Delta E^*_{ab} = \left[(k\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2},$$

where

$$\Delta L^* = L^*_2 - L^*_1; \quad \Delta a^* = a^*_2 - a^*_1; \quad \Delta b^* = b^*_2 - b^*_1.$$

k=1 for samples compared in close proximity (k=0,5 or less for samples compared further away from each other, where the eye is less sensitive to lightness differences). A value of k=1 is used in this software.

An alternate color-difference equation for this space can be expressed in relation to the cylindrical coordinates of lightness, chroma and hue (see the XYZ to L*a*b* section):

$$\Delta E^*_{ab} = \left[(\Delta L^*)^2 + (\Delta C^*_{ab})^2 + (\Delta H^*_{ab})^2\right]^{1/2}$$

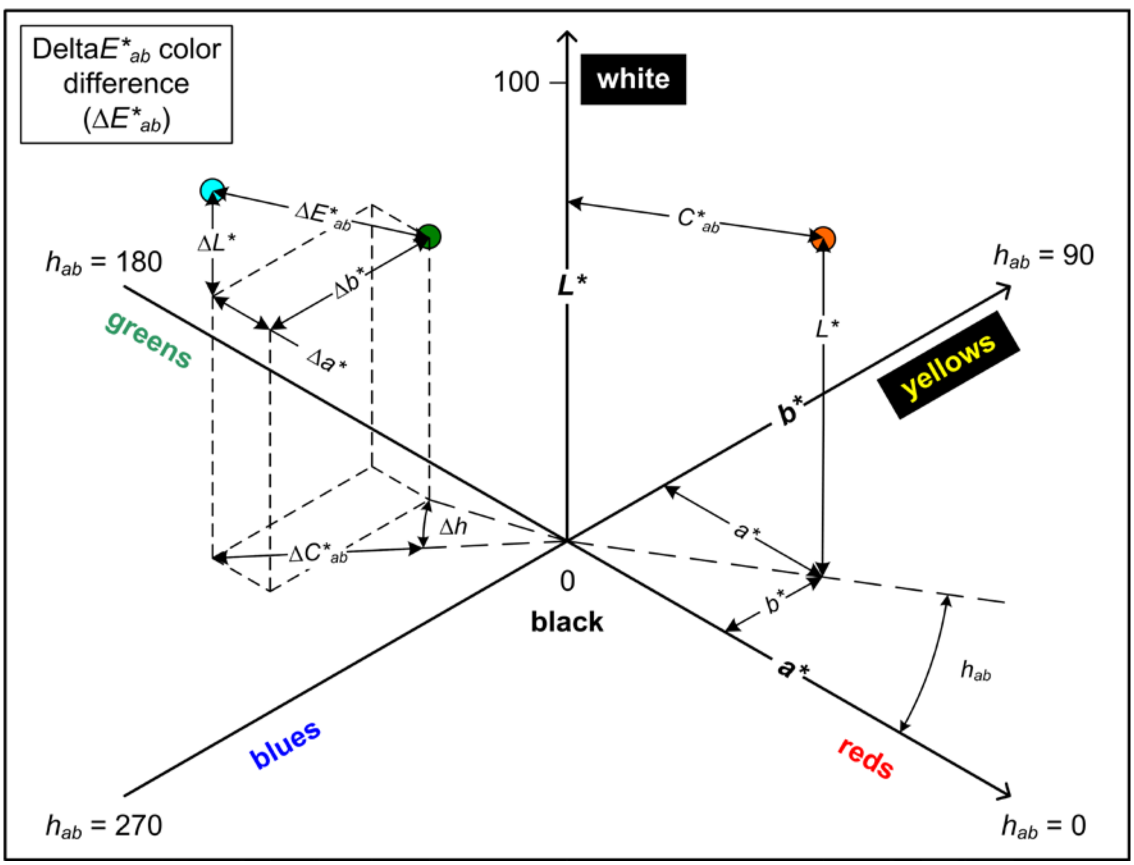
where

$$C^*_{ab} = \left(a^{*2} + b^{*2}\right)^{1/2}$$

$$\Delta C^*_{ab} = C^*_{ab_2} - C^*_{ab_1}$$

$$\Delta H^*_{ab} = \left[(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2\right]^{1/2}.$$

The relation between these variables can be seen in the following diagram:



You will note that the hue difference (ΔH^*_{ab}) is not the hue angle difference Δh_{ab} (= h_{ab2} - h_{ab1}), but is given by what is left after the lightness and chroma differences are removed (see the L*a*b* to L*C*h section for more information on Δh_{ab}).

Even though this equation is a workhouse of the plastic, paint and textile industries, its statistical threshold is a cause of concern, and of possible litigation, in many industrial applications where expert observers' judgments are confronted. For this reason, better color-difference equations are being sought.

CIELUV (ΔE^*_{uv})

Similarly, a color-difference equation is defined for the L*u*v* space (i.e. the "CIELUV color-difference equation", DeltaE*uv or ΔE^*_{uv} in abridged form):

$$\Delta E^*_{uv} = \left[(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2 \right]^{1/2}$$

where

$$\Delta L^* = L^*_2 - L^*_1 \;; \quad \Delta u^* = u^*_2 - u^*_1 \;; \quad \Delta v^* = v^*_2 - v^*_1 \; .$$

As with CIELAV, an alternate color-difference equation can be used:

$$\Delta E^*_{uv} = \left[(\Delta L^*)^2 + (\Delta C^*_{uv})^2 + (\Delta H^*_{uv})^2 \right]^{1/2}$$

where

$$C^*_{uv} = \left(u^{*2} + v^{*2} \right)^{1/2}$$

$$\Delta C^*_{uv} = C^*_{uv_2} - C^*_{uv_1}$$

$$\Delta H^*_{uv} = \left[(\Delta E^*_{uv})^2 - (\Delta L^*)^2 - (\Delta C^*_{uv})^2 \right]^{1/2} \; .$$

The main application fields for CIELUV have historically been the television and video display industries.

14.3.13.2 CIE94

In 1994, the Commission Internationale de l'Eclairage (CIE) proposed a new color-difference formula called CIE94 (ΔE^*_{94} in abridged form; Ref. 21). A simplified version of CMC(l:c), the equation is:

$$\Delta E^*_{94} = \left[\left(\frac{\Delta L^*}{k_L S_L} \right)^2 + \left(\frac{\Delta C^*_{ab}}{k_C S_C} \right)^2 + \left(\frac{\Delta H^*_{ab}}{k_H S_H} \right)^2 \right]^{1/2}$$

where ΔL^*, ΔC^*_{ab}, and ΔH^*_{ab} are defined as in CIELAB:

$$\Delta L^* = L^*_2 - L^*_1$$

$$C^*_{ab} = \left(a^{*2} + b^{*2} \right)^{1/2}$$

$$\Delta C^*_{ab} = C^*_{ab_2} - C^*_{ab_1}$$

$$\Delta H^*_{ab} = \left[\left(\Delta E^*_{ab} \right)^2 - \left(\Delta L^* \right)^2 - \left(\Delta C^*_{ab} \right)^2 \right]^{1/2} .$$

As in CMC(ℓ:*c*), additional correction factors have been defined:

$$S_L = 1; \quad S_C = 1 + 0.045 C^*_{ab\,ref}; \quad S_H = 1 + 0.015 C^*_{ab\,ref} .$$

where $C^*_{ab\,ref}$ is determined according to which of the two color patches is considered the *Reference* (or *Standard*), and which one is considered the *Sample* (or *Trial*), a terminology borrowed from the Quality Control (QC) field. The case where none of the patches is a *Reference* is also treated. This concept of assigning more importance to one patch, which was not included in the CIELAB and CIELUV formulas, can result in quite different results depending on the selected configuration. The value assigned to $C^*_{ab\,ref}$ is:

$$C^*_{ab\,ref} = C^*_{ab_1}$$

if patch #1 is the *Reference* (and patch #2 is the *Sample*), or

$$C^*_{ab\,ref} = C^*_{ab_2}$$

if patch #2 is the *Reference* (and patch #1 is the *Sample*), or

$$C^*_{ab\,ref} = \left(C^*_{ab_1} \, C^*_{ab_2} \right)^{1/2}$$

if neither patches can be assigned as a *Reference*.

In CT&A, you can select the reference mode in the "Math" tab of the Preferences dialog. The two options are:

- **Reference at Left, Sample at Right**
  To be used when doing a Quality Control (QC) check. Here are the *Reference* and *Sample* for the various tools:
  - RGB vs RGB tool: In Compare mode, the LEFT side is the *Reference* and the RIGHT side is the *Sample*. In Convert mode, the side being converted FROM is always the *Reference*, and the side being converted TO, the *Sample*. This setting will also affect the selection of the L*C*h pad patches.
  - FluoCheck tools: For the FI, the *Reference* is M2 and the *Sample* either M0 or M1.
  - Graph tools: The LEFT side is the *Reference* and the RIGHT side is the *Sample*.
  - Metamerism Index tools: For the SMI, the *Reference* and *Sample* correspond to the button labels. For the CII, the *Reference* is the data computed with the illuminant selected in the "CII ref. illum." menu and the *Sample* is the data computed with one of the two illuminant menus on the left of the window.

- **Reference is mean of both patches**
  The default. It should be used when comparing two colors where none of the color has more importance than the other.
    - RGB vs RGB tool: In Compare mode, the reference is the mean of both patches. In Convert mode, this option is overridden and the side being converted FROM is always the *Reference*, and the side being converted TO, the *Sample*. This setting will also affect the selection of the L*C*h pad patches.

In most applications, $k_L=k_C=k_H=1$. The textile industry often uses a variant where $k_L=2$. Setting k_L to 2 lowers the contribution of lightness in the color-difference; in effect, for textiles, lightness differences can be twice the ones of paint samples, where $k_L=1$ would be used, for the same computed error. In some specialized applications, such as when measuring a Color Inconstancy Index (CII), it is appropriate to emphasize the contribution of the hue relative to the lightness and chroma; in this case, k_L and k_C can both be set to 2.

It is generally assumed that when no other indication is given, the k_L, k_C, and k_H factors of the CIE94 formula are all equal to 1 (i.e. CIE94(k_L:k_C) shown as CIE94(1:1) is CIE94; please note that k_H is usually not shown as it is almost always used with a value of 1). The **ΔE^*_{94}-textile** version, with its k_L factor equal to 2, can also be expressed as CIE94(2:1).

In this software, the $k_L=2$ version is identified by **CIE94-textile** when it is computed relative to the space defined illuminant, and **CIE94-tex D50** when it is computed relative to the D50 illuminant.

CIE94 provides better data consistency and is considered by many a replacement for CIELAB for general purpose color-difference assessment.

Important: As per its definition, the CIE94 color-difference will be different depending on which of the two color samples is defined as the reference, or if none of the samples can be considered a reference. The software will automatically adjust the formula according to the definition; as a result, variations in the color difference numbers may be seen in the RGB vs RGB tool when going from Compare mode to Convert mode, or vice-versa, or changing the direction of the conversion.

14.3.13.3 CMC(l:c)

The CMC(ℓ:c) color difference formula ($\Delta E_{CMC(\ell:c)}$ in abridged form) was developed by the Colour Measurement Committee (CMC) of the Society of Dyers and Colourists (SDC). It has a wide acceptance, especially in the textile coloration industry and is now a British (BS6923: 1988) and ISO (ISO 105-J03) standard, as well as an approved test method for the American Association of Textile Chemists and Colorists (AATCC). See Ref. 22 for more information. The formula is:

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

where ΔL^*, ΔC^*_{ab}, and ΔH^*_{ab} are defined as in CIELAB:

$$\Delta L^* = L^*_2 - L^*_1$$

$$C^*_{ab} = \left(a^{*2} + b^{*2} \right)^{1/2}$$

$$\Delta C^*_{ab} = C^*_{ab_2} - C^*_{ab_1}$$

$$\Delta H^*_{ab} = \left[\left(\Delta E^*_{ab} \right)^2 - \left(\Delta L^* \right)^2 - \left(\Delta C^*_{ab} \right)^2 \right]^{1/2} \quad .$$

Additional correction factors have been defined:

$$S_L = \frac{0{,}040975\, L^*_{ref}}{1 + 0{,}01765\, L^*_{ref}} \qquad \text{if } L^*_{ref} \geq 16$$

or

$S_L = 0{,}511$ if $L^*_{ref} < 16$.

$$S_C = \frac{0{,}0638\, C^*_{ab\,ref}}{1 + 0{,}0131\, C^*_{ab\,ref}} + 0{,}638$$

$$S_H = S_C \left(T F - F + 1 \right)$$

where T and F are further defined by:

$$F = \frac{\left(C^*_{ab\,ref} \right)^2}{\left[\left(C^*_{ab\,ref} \right)^4 + 1900 \right]^{1/2}}$$

$$T = 0{,}56 + \left| 0{,}2 \cos\left(h_{ab\,ref} + 168° \right) \right|$$

if $164 \leq h_{ab\,ref} \leq 345$, or

$$T = 0{,}36 + \left| 0{,}4 \cos\left(h_{ab\,ref} + 35° \right) \right|$$

if $h_{ab\,ref} < 164$ or $h_{ab\,ref} > 345$,

and h_{ab} is the L*a*b* hue angle:

$$h_{ab} = \arctan(b^* / a^*) \quad .$$

In the above equations, L^*_{ref}, $C^*_{ab\,ref}$, and $h_{ab\,ref}$ are assigned the values of the first measurement, i.e. L^*_1, C^*_{ab1}, and h_{ab1}, when the first measurement is considered a *Reference* and the second measurement a *Sample*. If neither measurement can be assigned as a *Reference* (i.e. if none of the color has more importance than the other), the following equations are used to determine L^*_{ref}, $C^*_{ab\,ref}$, and $h_{ab\,ref}$.

$$L^*_{ref} = \left((L^*_1 + L^*_2\right)/2$$

$$C^*_{ab\,ref} = \left(C^*_{ab_1}\; C^*_{ab_2}\right)^{1/2}$$

$$h_{ab\,ref} = \left(h_{ab_1} + h_{ab_2}\right)/2$$

.

Finally, the two control parameters, ℓ and c, are selected depending on the application. For perceptibility measurements, when seeking minimal perception differences, ℓ and c should equal one. For acceptability measurements, where pass or fail judgment is required, as in the ink and textile industries, ℓ should be set to 2.

Both versions, identified as CMC(1:1) and CMC(2:1), as well as versions computed relative to the D50 illuminant, can be selected in this software.

In CT&A, you can select the reference mode in the "Math" tab of the Preferences dialog. The two options are:

- **Reference at Left, Sample at Right**
  To be used when doing a Quality Control (QC) check. Here are the *Reference* and *Sample* for the various tools:
  - RGB vs RGB tool: In Compare mode, the LEFT side is the *Reference* and the RIGHT side is the *Sample*. In Convert mode, the side being converted FROM is always the *Reference*, and the side being converted TO, the *Sample*. This setting will also affect the selection of the L*C*h pad patches.
  - FluoCheck tools: For the FI, the *Reference* is M2 and the *Sample* either M0 or M1.
  - Graph tools: The LEFT side is the *Reference* and the RIGHT side is the *Sample*.
  - Metamerism Index tools: For the SMI, the *Reference* and *Sample* correspond to the button labels. For the CII, the *Reference* is the data computed with the illuminant selected in the "CII ref. illum." menu and the *Sample* is the data computed with one of the two illuminant menus on the left of the window.

- **Reference is mean of both patches**
  The default. It should be used when comparing two colors where none of the color has more importance than the other.
  - RGB vs RGB tool: In Compare mode, the reference is the mean of both patches. In Convert mode, this option is overridden and the side being converted FROM is always the *Reference*, and the side being converted TO, the *Sample*. This setting will also affect the selection of the L*C*h pad patches.

Important: As per its definition, the CMC(ℓ:c) color-difference will be different depending on which of the two color samples is defined as the reference, or if none of the samples can be considered a reference. The software will automatically adjust the formula according to the definition; as a result, variations in the color difference numbers may be seen in the RGB vs RGB tool when going from Compare mode to Convert mode, or vice-versa, or changing the direction of the conversion.

14.3.13.4 CIEDE2000

INTRODUCTION

CIEDE2000 (also referred to as DE2000 or ΔE_{00}) is the most recent color difference formula recommended by the Commission Internationale de l'Éclairage (CIE):

ISO/CIE 11664-6:2014 (CIE S 014-6/E:2013)
https://www.iso.org/standard/63731.html

Similarly to CIE94 and CMC(l:c), it includes weighting functions for *lightness*, *chroma*, and *hue*. Among the differences, it proposes a scaling factor to a^* for low chroma colors, to improve the formula performance near the illuminant. It also comprises a factor, R_T, called the *rotation term*, which is affected by the chroma and hue differences, with the goal of improving the performance for blue colors (for hue angles around 275 degrees).

The formula is available in two forms. The original form has a fourth term associated to R_T. The alternate form has three terms, where the rotation term effect is integrated in the individual contributions of chroma and hue differences. More information on the alternate form can be found in this document from the CIE Web site:

CIE R 1-39 Alternative Forms of the CIEDE2000 Colour-Difference Equation
https://files.cie.co.at/524.pdf

This section presents the equations for both forms of the formula.

The original four terms formula, based on L*a*b* data, is:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C' \Delta H'}{k_C S_C k_H S_H}\right)\right]^{1/2}$$

where ΔL^* is defined as in CIELAB:

$$L' = L^* \quad \text{and} \quad \Delta L' = \Delta L^* = L_S^* - L_R^*$$

and where the subscripts *R* and *S* correspond to the *Reference* and *Sample* respectively.

The alternate three terms formula is:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C''}{S''_C}\right)^2 + \left(\frac{\Delta H''}{S''_H}\right)^2\right]^{1/2}$$

which can be further be simplified to

$$\Delta E_{00} = [(\Delta L_{00})^2 + (\Delta C_{00})^2 + (\Delta H_{00})^2]^{1/2} \qquad .$$

The two formulas provide the same ΔE_{00} values and are identical relative to the lightness difference; however, beside the disappearance of the rotation term, $\Delta C'$ and $\Delta H'$ are respectively replaced by $\Delta C''$ and $\Delta H''$, and $k_C S_C$ and $k_H S_H$ are respectively replaced by S''_C and S''_H. The three terms formula can clearly be helpful if we are interested in specifically minimizing the contributions of chroma or hue to the total error in a given process.

The equations required to derive the CIEDE2000 color difference with the four terms formula are presented in the next page. The **additional** equations required for the three terms formula are presented in the last page of this section.

EQUATIONS FOR THE FOUR (4) TERMS CIEDE2000 FORMULA

In the following equations, you will notice that the weighting functions (i.e. S_L, S_C, and S_H) as well as the scaling functions (i.e. G, T, $\Delta\theta$, R_C and R_T) are based on the arithmetical mean of many of the *Reference* and *Sample* characteristics, such as L^*, C^*_{ab}, C' and h'. This explains why the color difference value is the same when the *Reference* and *Sample* are swapped.

$\Delta C'$ is obtained from:

$$a' = (1 + G)a^*$$

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

$$\Delta C' = C'_S - C'_R$$

where G is determined from (be careful not to confuse the C^* (C-star) and C' (C-prime) variables):

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

$$C^*_{ab\ mean} = \frac{(C^*_{ab\ R} + C^*_{ab\ S})}{2}$$

$$G = 0.5 - 0.5\left(\frac{C^{*7}_{ab\ mean}}{C^{*7}_{ab\ mean} + 25^7}\right)^{1/2} \quad .$$

$\Delta H'$ is obtained from:

$$h' = arctan(b^*/a')$$

$$\Delta h' = h'_S - h'_R$$

$$\Delta H' = 2(C'_R C'_S)^{1/2}\ sin(\Delta h'/2) \qquad \text{if } \Delta h' \le 180°.$$

In order for $\Delta H'$ to be of the proper sign—you may recall that it is always positive in older formulas—you should subtract 360 from $\Delta h'$, in the $\Delta H'$ formula, if it is larger than 180 degrees:

$$\Delta H' = 2(C'_R C'_S)^{1/2}\ sin((\Delta h' - 360°)/2) \qquad \text{if } \Delta h' > 180°.$$

The S_L weighting function is obtained from:

$$L^*_{mean} = \frac{(L^*_R + L^*_S)}{2}$$

$$S_L = 1 + \frac{0.015(L^*_{mean} - 50)^2}{(20 + (L^*_{mean} - 50)^2)^{1/2}} \quad .$$

The S_C weighting function is obtained from:

$$C'_{mean} = \frac{(C'_R + C'_S)}{2}$$

$$S_C = 1 + 0.045C'_{mean} \quad .$$

The S_H weighting function is obtained from:

$$h'_{mean} = \frac{(h'_R + h'_S)}{2} \qquad \text{if } abs(h'_S - h'_R) \leq 180°\text{, and}$$

$$h'_{mean} = \frac{(h'_R + h'_S - 360°)}{2} \qquad \text{if } abs(h'_S - h'_R) > 180°;$$

$$T = 1 - 0.17\cos(h'_{mean} - 30°) + 0.24\cos(2h'_{mean}) + 0.32\cos(3h'_{mean} + 6°) - 0.20\cos(4h'_{mean} - 63°)$$

$$S_H = 1 + 0.015C'_{mean}T \qquad .$$

Finally, the rotation term R_T is obtained from:

$$\Delta\theta = 30\ exp\left[-\left(\frac{h'_{mean} - 275°}{25}\right)^2\right] \qquad \text{if } h'_{mean} \geq 0\text{, and}$$

$$\Delta\theta = 30\ exp\left[-\left(\frac{h'_{mean} - 275° + 360°}{25}\right)^2\right] \qquad \text{if } h'_{mean} < 0;$$

$$R_C = 2\left(\frac{C'^7_{mean}}{C'^7_{mean} + 25^7}\right)^{1/2}$$

$$R_T = -\sin(2\Delta\theta)\,R_C \qquad .$$

The three control parameters, k_L, k_C and k_H, are, simply enough, equal to one.

The above equations are all you need if you want to compute ΔE_{00} with the four terms formula. However, if you are interested in the individual contributions of the lightness, chroma and hue differences, this is where the additional equations of the three term formula become useful. These equations are shown in the next page.

EQUATIONS SPECIFIC TO THE THREE (3) TERMS CIEDE2000 FORMULA

Obtaining the individual terms of the three terms formula requires that you first perform all the computations of the four terms formula, so there is no advantage to start reading at this point!

The next step is to obtain an angle (ϕ) from the following equation:

$$\tan(2\emptyset) = R_T \frac{(k_C S_C)(k_H S_H)}{(k_H S_H)^2 - (k_C S_C)^2} \quad .$$

Important: The ϕ angle is expressed in radians and not in degrees like we did with *h'*.

We then use ϕ to derive the remaining parameters of the three terms formula:

$$\Delta C'' = \Delta C' \cos(\emptyset) + \Delta H' \sin(\emptyset)$$

$$\Delta H'' = \Delta H' \cos(\emptyset) - \Delta C' \sin(\emptyset)$$

$$S''_C = (k_C S_C) \left[\frac{2(k_H S_H)}{2(k_H S_H) + R_T (k_C S_C) \tan(\emptyset)} \right]$$

$$S''_H = (k_H S_H) \left[\frac{2(k_C S_C)}{2(k_C S_C) + R_T (k_H S_H) \tan(\emptyset)} \right]$$

to finally obtain:

$$\Delta L_{00} = \frac{\Delta L'}{k_L S_L} \qquad \Delta C_{00} = \frac{\Delta C''}{S''_C} \qquad \Delta H_{00} = \frac{\Delta H''}{S''_H} \quad .$$

REFERENCE AND SAMPLE

Here are the *Reference* and *Sample* for the CIEDE2000 formula in various tools:

- RGB vs RGB tool: In Compare mode, the LEFT side is the *Reference* and the RIGHT side is the *Sample*. In Convert mode, the side being converted FROM is always the *Reference*, and the side being converted TO, the *Sample*.
- FluoCheck tools: For the FI, the *Reference* is M2 and the *Sample* either M0 or M1.
- Graph tools: The LEFT side is the *Reference* and the RIGHT side is the *Sample*.
- Metamerism Index tools: For the SMI, the *Reference* and *Sample* correspond to the button labels. For the CII, the *Reference* is the data computed with the illuminant selected in the "CII ref. illum." menu and the *Sample* is the data computed with one of the two illuminant menus on the left of the window.

Note: The **CIE94/CMC reference mode** setting in the "Math" tab of the Preferences dialog has no effect on this formula.

Important: For the CIEDE2000 formula, the DeltaE* display of the RGB vs RGB tool shows the weigthed ΔL_{00}, ΔC_{00}, and ΔH_{00} values (and $\Delta h'$), instead of the unweighted ΔL^*, ΔC^*, and ΔH^* values (and Δh).

14.4 RGB spaces description

Select the space for which you want a description:

- ACES AP0
- Adobe (1998)
- Apple RGB
- BestRGB
- Beta RGB
- Bruce RGB
- CIE RGB
- ColorMatch
- DCI P3 Theater
- Display P3
- DonRGB4
- eciRGB_v2
- Ekta Space PS5
- Generic RGB
- HDTV (HD-CIF)
- NTSC
- PAL / SECAM
- ProPhoto
- Rec. 2020 (UHDTV)
- SGI
- SMPTE-240M
- SMPTE-C
- sRGB
- Wide Gamut

You can also define a custom RGB space.

14.4.1 ACES AP0

ACES stands for “Academy Color Encoding Specification”, where the “Academy” is the “Academy of Motion Picture Arts and Sciences” which brings us the “Oscar” ceremony each year. ACES is not only an RGB space but also an image file format, a color-management system and an image-interchange framework. ACES is defined in the SMPTE ST 2065-1 color encoding specification and many additional specifications and support documents (Ref. 59).

ACES AP0 is an extremely large gamut RGB space which encompasses ALL visible colors. However, in order to contain the visible spectrum, the blue primary must be defined with a negative “y” value (CIE 1931 chromaticity). This has the effect that many RGB triads correspond to negative “Y” (of XYZ) values and negative L* (of L*a*b*) values. While colors with negative coordinates do not correspond to visible or “real” colors, it is sometimes useful to keep the negative values when converting back and forth between RGB spaces. Traditionally, negative “xyY” and “XYZ” values are clipped to zero when encountered and the processing software must be specifically designed to handle these cases; starting with CT&A version 5.2 this is properly handled with the RGB vs RGB tool and the Custom RGB space dialog.

Note: In order to get negative (i.e. non-clipped) XYZ values, you must first deselect the

☑ Clip “xyY” and “XYZ” to zero in the “RGB vs RGB” tool

checkbox in the “Math” tab of the Preferences dialog.

Note: When referring to the ACES RGB space, the “AP0” suffix is used to identify the primaries which encompass all visible colors. When you see the “AP1” suffix, this refers to a set of primaries more closely fitted to the visible colors of the chromaticity diagram; if required, you can define the AP1 version using the Custom RGB space dialog.

Warning: If you use instrument input in the RGB vs RGB tool with this space, please note that the contribution of camera flare as defined in SMPTE ST 2065-1 section 4.1.1 is NOT included when computing the XYZ/L*a*b* values. Similarly, camera flare is not taken into account when converting colors from another RGB space towards ACES AP0.

The ACES AP0 Illuminant has a Correlated Color Temperature (CCT) of 6000 K (expressed as 6000 K *) and a simple software-encoding gamma of 1 (i.e. a linear tone response).

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.2 Adobe (1998)

Formerly known as SMPTE-240M for Photoshop user, this space has been renamed once the final SMPTE-240M standard committee settled for a smaller gamut. Adobe (1998) RGB is very close to the original NTSC space and represents a good compromise between gamut size and the number of colors available in an 8 bit per primary system. However, if available, 16 bit per primary should be preferred.

When reproducing images encoded with this space, you will find that many colors cannot be reproduced with the ubiquitous CMYK print process, particularly in the green portion of the gamut. Newer six-color or eight-color printing presses offer the potential for a larger gamut but the extra channels of these presses are most often used for spot colors and not for additional primaries. On the other hand, ink-jet printers with additional primaries such as orange and green are more easily found and are commonly used in conjunction with this RGB space.

It is also possible to find wide gamut displays which can show all (or near all) the colors of this space.

A simple software-encoding gamma of 0,455 (=1/2,2 if you define gamma using the reciprocal value) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.3 Apple RGB

A formerly very common RGB space on the desktop that is similar in gamut size to the ColorMatch, Generic RGB, and sRGB spaces. The Apple RGB space has a software-encoding gamma of 0,556 (=1/1,8), which is compensated by a look-up table (LUT) gamma of 0,69 (=1/1,45). The LUT compensation was done at the Macintosh display hardware level. By comparison, sRGB has a "simple" software-encoding gamma of 0,455 (=1/2,2) and a LUT gamma of one. This explains why files created on an old Macintosh will appear darker on a PC if no compensation is done.

In its older OS versions, a Mac user could set the display gamma in a control panel. This display gamma combined the LUT gamma and the CRT gamma; when a value of 1,8 was entered, the LUT was filled with numbers corresponding to a exponential function (i.e. curve) with a gamma (i.e. exponent) of 1,8/2,6=0,69 (=1/1,45).

A simple software-encoding gamma of 0,556 (=1/1,8) is used in CT&A for Apple RGB. This gamma is the same as the one defined for ColorMatch, Generic RGB, eciRGB 1.0, and ProPhoto. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

Here is a short history of Apple RGB and how it was dislodged as the default Mac RGB space. This history is based on messages posted in the Apple ColorSync forum, where current or ex-insiders give their point of view, and on Apple technical notes.

Warning: As with many things associated to Apple, and particularly when related to color management, precise information is hard to get by, and is always subject to change. This is why most of the material is quoted from people who knew something at some time!

Apple RGB origin

> ***From:*** *Robin Myers <xxx@xxx.com>*
> ***To:*** *colorsync-users@lists.apple.com*
> ***SendDate:*** *Fri, 6 May 2005 14:53:08 -0700*
> ***Subject:*** *Re: Setting default RGB in OS X 10.4?*
>
> *(comments from previous forum participants removed; the remainder is unedited)*
> *OK, I guess it is time to explain a little about Apple RGB here. The original Apple RGB values were created from my measurements of about 10 Apple 13" monitors around 1989. The averages, excluding totally wacky monitors like one that had a 17000 K whitepoint, were used in the first ColorSync for the default RGB profile. These values correlated well with values eventually supplied by the Monitor group of the Peripherals Division (for those that did not know this, in the Paleolithic Age Apple made printers, scanners, and monitors). I believe the final version profile was made with the Monitor Group values. The white point for the monitors was 9300 K, not the 6500 K or 5000 K common today. At the time, 9300 K was the only way the monitors could be obtained from the vendor.*
>
> *This was in the pre-sRGB days, so Apple RGB was used as a generic RGB profile. It made sense at the time since much of the color content was artificially generated in FreeHand or Illustrator, thus it was created in Apple RGB. Adobe eventually put Apple RGB into Photoshop as a working space and it thus it has been passed on to today's users.*
>
> *Now that it is the Modern Age, it would be a good idea to drop Apple RGB from system. It outlived its usefulness. Comparing it to sRGB or any of the current LCD or CRT monitors is like comparing a Conestoga wagon to a current automobile.*
>
> *Robin Myers*

From Apple RGB to Generic RGB

The Apple RGB space was put aside in favor of Generic RGB as the default space when Mac OS X was launched. According to Apple literature issued at the time (Technical Q&A QA1430; 2005-10-17):

> *Mac OS X will assume a Generic RGB color space for legacy untagged images that may have been created with an assumed Apple RGB color space.*

This also applied to untagged RGB data sent to the display by non-ICC aware applications. In other words, this meant that “Generic RGB” was assumed to be the source profile for untagged data by ColorSync, which is Apple's color management technology at the operating system level, which then converted it to whatever display profile was selected.

From Generic RGB to sRGB

However, starting with Mac OS X 10.6, as mentioned in Eric Chan's message, Apple may have changed the default space again, this time selecting sRGB as its default space for untagged images.

> ***From:*** *"Eric Chan" <xxx@yahoo.com>*
> ***To:*** *<colorsync-users@lists.apple.com>*
> ***SendDate:*** *18 August 2009 09:41*
> ***Subject:*** *Re: Printing profile test targets WITHOUT photoshop*
>
> *(...)*
> *Moving forward, OS X is taking steps to prevent accidental printing without color management. This makes it unlikely that you can use the standard OS X apps like Preview to print profile targets reliably. Tagging it with Generic RGB will work today, but not tomorrow when Snow Leopard launches (and switches to a default profile of sRGB, not Generic RGB). And tagging the target with sRGB tomorrow may not work for the future (should future versions of OS X switch to another default profile).*
> *(...)*

From sRGB to *"*Anything*"* RGB

Here is another input from someone within Apple:

> ***From:*** *"John Gnaegy" <xxx@apple.com>*
> ***To:*** *<colorsync-users@lists.apple.com>*
> ***SendDate:*** *22 March 2013 17:08*
> ***Subject:*** *Re: 10.8.3 Finder Colour Management*
>
> *Untagged data is assumed to be in the display color space, it has intentionally behaved that way for quite some time.*
> *(...)*

Back to Generic RGB (for untagged images)

According to up-to-date (2015) ColorSync documentation, “Generic RGB” will be assumed to be the source profile for untagged data and converted to the current screen profile. Please note that the assumed source profile does not correspond to the assumed default display space. Standard gamut Mac displays are apparently factory calibrated to something very close to the sRGB space while late 2015 Retina iMacs include displays said to be capable of covering the Digital Cinema Initiative (DCI) P3 gamut, a wide gamut space.

Conclusion

The Apple RGB space is no longer coupled to the display space. A custom calibrated display profile is always preferred; however, if you do not have a custom profile and you are using a display integrated with a Mac computer, select the profile corresponding to factory calibration. If connecting to third party monitor for which you have no reliable profile, select sRGB as the default space for a standard gamut display.

14.4.4 BestRGB

One of two RGB spaces defined by Don Hutcheson (http://www.hutchcolor.com) and dedicated to film based photography, the other being DonRGB4. This one is optimized for Fujichrome Velvia film while DonRGB4 is optimized for Ektachrome.

As per Don's Web site:

> *BestRGB is identical to DonRGB4 except for a modified red coordinate which helps encompass the supersaturated range of reds and magentas found in Fujichrome Velvia. This newly developed color space is the best I can suggest if you want maximum gamut without exceeding the legal CIE xyY diagram.*

A simple software-encoding gamma of 0,455 (=1/2,2) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.5 Beta RGB

This space was defined by Bruce Lindbloom which maintains a well known, well designed, and very complete Web site on colorimetry (http://www.brucelindbloom.com).

Beta RGB was devised after a careful study and comparative analysis of many RGB spaces. Beta RGB is designed to:

- have a gamut which enclose various color sets of "possibly important colors" (in the words of the space's author), such as different film types, color charts and printing gamuts;
- have a gamut which is as small as possible, taking the first criteria into account, in order to minimize quantization errors;
- maximize the percentage of the visible spectrum that it encompasses;
- maximize the encoding efficiency, i.e. the percentage of valid RGB triads, representing real colors.

The following table presents the percentage of the visible gamut encompassed by each space, the **L*a*b* gamut Efficiency** as well as the **Encoding Efficiency** for most of the RGB spaces supported by CT&A (This data was derived by Bruce Lindbloom and is used by permission):

RGB space	L*a*b* gamut Efficiency (%)	Encoding Efficiency (%)
Adobe (1998)	50,6	100
Apple RGB	33,5	100
BestRGB	77,6	96.5
Beta RGB	69,3	99.0
Bruce RGB	41,5	100
CIE RGB	64,3	96,1
ColorMatch	35,2	100
DonRGB4	72,1	98,8
eciRGB	55,3	99,7
Ekta Space PS5	65,7	99,5
NTSC	54,2	99,9
PAL / SECAM	35,7	100
ProPhoto	91,2	87,3
SMPTE-C	31,9	100
sRGB	35,0	100
Wide Gamut	77,6	91,9

Beta RGB encompasses 69% of the colors visible by humans; this is to be compared to 34% for Apple RGB, 51% for Adobe (1998), and 91% for ProPhoto. In comparison, the encoding efficiency for Beta RGB is 99%, compared to 100% for Apple RGB and Adobe (1998), and 87% for ProPhoto.

We see that for smaller spaces, all RGB values are valid (100% encoding efficiency), which is expected, but that larger spaces are less efficient. While it is easy to see why ProPhoto has invalid triads, because two of its primaries are outside of the visible spectrum, others, like BestRGB and Wide Gamut, do suffer of the same problem (to a lesser extent than ProPhoto however). Beta RGB thus offers a very nice compromise.

A simple software-encoding gamma of 0,455 (=1/2,2) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.6 Bruce RGB

Created in 1998 by Bruce Fraser, "...a self-confessed color geek" and co-author of the **Real World Photoshop** series and other books on Color Management (Peachpit Press).

Here is a presentation of Bruce RGB extracted from one of Bruce's numerous articles (Ref. 13):

> *BruceRGB is essentially a compromise between two spaces shipped with Photoshop 5.x -- ColorMatch RGB and Adobe RGB (1998). ColorMatch RGB is a high-quality monitor space, but it is a monitor space nonetheless, designed to accommodate the color range and spectrum of light-emitting RGB devices. Adobe RGB (1998) is a considerably larger space that grew out of wishful thinking for a future generation of video monitors.*
>
> *ColorMatch RGB and Adobe RGB (1998) are in common use in output-centric workflows, but neither was designed with the idea of color-accurate output as the paramount concern. As a result, both spaces suffer from something of a mismatch with typical hard copy output, whether from a CMYK press or a photo-realistic inkjet printer. Both spaces clip (drop out) the saturated yellows and oranges achievable in sheet-fed printing and on photo printers: You'd have to resort to a very large space such as Adobe's Wide Gamut RGB or Kodak's ProPhoto RGB to encompass those. But ColorMatch RGB also clips cyan, as well as the blues and greens that lie adjacent to it, quite significantly. Adobe RGB doesn't clip printable cyan, but it contains a fairly large number of colors that few if any output devices can reproduce, so it wastes a good number of those precious 256 data points in each channel.*
>
> *BruceRGB, in contrast, was designed with output in mind from the start. It clips fully saturated yellows by about the same amount as Adobe RGB, and quite a bit less than ColorMatch RGB. It may clip cyan slighly with very high-quality sheet-fed printing, but not by more than a few percent -- much less than ColorMatch RGB. Equally important, it wastes far fewer bits on unrealizable colors than Adobe RGB.*

A simple software-encoding gamma of 0,455 (=1/2,2) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.7 CIE RGB

A relatively large gamut space specified by the monochromatic primaries at 435,8, 546,1, and 700 nm that were used in the experiments at the origin of the color-matching functions. The gamma values shown for this space are "generic"; for instance, a software-encoding gamma of 2,2 (=1/0,455) is assigned by default to this space by Adobe Photoshop.

A simple software-encoding gamma of 0,455 (=1/2,2) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.8 ColorMatch

This D50 space was originally devised by Radius to be used in conjunction with its PressView line of calibrated displays dedicated to professional use. Often favored over other desktop spaces by critics, the gamut of this space is not significantly larger than the Apple RGB or sRGB. For example, compared with sRGB, it has a slightly larger gamut in the blue-green region but a smaller one in the red-blue region.

The main advantages for its users are a reproducible and well-characterized environment. A calibrated PressView system takes into account, independently for each RGB channel, the CRT gain, offset and brightness combined with the display look-up table (LUT), which it uses for calibration purposes. The resulting display gamma is a "perfect" 1,8 value (=1/0,556) on a 0,33 cd/m^2 black pedestal and a white point luminance of 85 cd/m^2.

The primaries used in CT&A, and shown in the RGB Space data dialog, are different than the ones used in Photoshop. The ones used herein were confirmed by **miro displays**, which purchased the Radius brands and technologies from Radius, now renamed Digital Origin (Note: present company status unknown).

A simple software-encoding gamma of 0,556 (=1/1,8) is used in CT&A. This gamma is the same as the one defined for Apple RGB, Generic RGB, and ProPhoto. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.9 DCI P3 Theater

The Digital Cinema Initiatives (DCI) is an entity created by motion picture studios whose purpose is to define specifications for Digital Cinema (Ref. 61). The DCI P3 RGB space has a gamut somewhat similar in gamut and primaries locations to the Adobe (1998) RGB space.

There are two versions of this space which differ in their Illuminant; the DCI P3 Theater RGB space Illuminant has a Correlated Color Temperature (CCT) of 6300 K (expressed as 6300 K *) while the DCI P3 D65 RGB space has a D65 Illuminant. Both spaces are defined with a simple software-encoding gamma of 2,6.

Note: Only the DCI P3 Theater is defined as a preset RGB space in CT&A. However, you can easily define the DCI P3 D65 using the Custom RGB space dialog.

There is also a variant of this space defined by Apple, called Display P3, which has a D65 Illuminant but with the gamma of the sRGB space.

14.4.10 Display P3

Defined by Apple, Display P3 has the same primaries as the DCI P3 Theater and DCI P3 D65 RGB spaces. It is defined with a D65 Illuminant (same as for DCI P3 D65) but its gamma is the detailed gamma defined for sRGB.

This space has been used by Apple in some of its wide gamut displays. It is interesting to note that Apple selected the DCI primaries instead of the Adobe (1998) RGB primaries which have been used by other display manufacturers in order to bring their display closer to the specifications of Digital Cinema. However, because of its use of the sRGB detailed gamma, some conversion is nonetheless required if DCI P3 values are required.

14.4.11 DonRGB4

One of two RGB spaces defined by Don Hutcheson (http://www.hutchcolor.com) and dedicated to film based photography, the other being BestRGB. This one is optimized for Ektachrome film while BestRGB is optimized for Fujichrome Velvia.

As per Don's Web site:

> *An excellent wide-gamut working space featuring industry-standard D50 white point and 2,2 gamma. Captures the Ektachrome color gamut with virtually no clipping. Known as "DonRGB4" because I tested three slightly different coordinate sets before settling on this one. Used successfully for several years by a number of high-quality photographers and prepress houses.*

A simple software-encoding gamma of 0,455 (=1/2,2) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

You should also consider the Ekta Space PS5, another space dedicated to the Ektachrome film.

14.4.12 eciRGB_v2

The European Color Initiative (ECI), founded in June 1996, is a group of experts which is dedicated to advancing media-neutral color data-processing in digital publishing systems. In particular, they want to standardize data-exchange formats between contractors and clients in the publishing process, and to promote the definition and proper usage of ICC color profiles in this industry. Membership is opened to individuals, not companies, and must be approved by the ECI council (four persons elected by the membership).

The development and release, in 1999, of eciRGB 1.0 is one of the result of this initiative.

eciRGB 1.0

According to the ECI Web site:

- http://www.eci.org/doku.php?id=en:colourstandards:workingcolorspaces

... ECI wanted to see one (ICC profile) that:

- *has a gamut that covers all colors that can be printed on today's printing presses—whether sheet fed or web offset, gravure or newsprint—but not much beyond (in order to not to waste precision for bits that never really get used);*
- *produces a neutral gray whenever the values for Red, Green and Blue are equal;*
- *offers equidistance, i.e. equal difference between two color values in eciRGB mirrors an perceived equal difference when these colors are seen by the human eye;*
- *is based on a Gamma of 1,8 and a light source of 5000K.*

Older CT&A versions were based on eciRGB 1.0. Starting with CT&A version 3, we switched to the definition of eciRGB_v2.

If required, you can easily define a custom space matched to the definition of eciRGb 1.0. In the Custom RGB space dialog, first select "eciRGB_v2" in the "Custom" space menu, then change the space gamma by selecting "default 1.80" in the gamma menu. This gamma is the same as the one defined for Apple RGB, ColorMatch, Generic RGB, and ProPhoto. There is no detailed gamma for eciRGB 1.0.

eciRGB_v2

Defined as a technical revision of eciRGB 1.0, eciRGB_v2 has one major change:

- the gamma of 1,8 is replaced by the L* (pronounced L-star) characterization method, which is the L* of CIELAB.

As we show in the L* (L-star) section, the L* Tone Response Curve is in fact a detailed gamma as defined in the RGB to R'G'B', and gamma section, where the detailed gamma is defined by:

offset = 0,16
gamma = 1/3 = 0,333333
transition = 0.008856
slope = 9,033

and which can also be approximated by a simple software-encoding gamma of 0,410741 (=1/2,43462 if you define gamma using the reciprocal value).

The primaries and Illuminant are the same as in the first version. Work is under way to incorporate this space in the ISO 22028 standard. Again, according to the ECI Web site:

- *In general, ECI now recommends to always use the eciRGB_v2 profile for new projects or when creating new data. This is especially true when converting from RAW data or from 16 bit image data.*
- *For existing projects and files which are not using eciRGB_v2 it is not recommended to convert them to eciRGB_v2 in order to avoid unnecessary conversion or – even more dangerous – assigning the wrong profile to the data. Especially 8 bit data using eciRGB 1.0 should be kept in eciRGB 1.0 (preferably with the eciRGB 1.0 profile embedded) as any colour space conversion will lead to at least some loss of quality.*

- *If you still have the need to bring your old data into the new colour space you have to perform an ICC profile conversion to the new eciRGB_v2 profile. Do not just "assign" eciRGB_V2 as the source profile, as it will lead to color and luminance shifts.*

Starting with CT&A version 3, eciRGB_v2 replaced eciRGB 1.0 in the RGB space selection menu. Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs. Interestingly, the primaries of both versions of eciRGB are those of NTSC.

For conversion of multiple color values in list form, you can use one of the Gamut tools in BabelColor's PatchTool, which enable you to select any standard ICC profile. You can see a Gamut tools screenshot here:

- https://www.babelcolor.com/patchtool_gamut_convert.htm .

14.4.13 Ekta Space PS5

This space was defined by Joseph Holmes (https://www.josephholmes.com), a landscape photographer, to best match the gamut of Ektachrome transparency film (and all E6 type films). According to Mr. Holmes, it also works well when scanning and archiving color negatives.

As per Mr. Holmes' "readme" file that accompanies the profile (18 pages of recommended reading) which can be downloaded from his Web site:

> *"Ekta Space PS 5, J. Holmes" is sometimes referred to as "Joe RGB" or simply "Ekta Space". Like the profile from which it was derived, it is a special RGB color space profile which I designed for high quality storage of image data from scans of transparencies such that little or no clamping of out-of-gamut data would typically occur when the colors are converted from a scanner profile for transparencies into this profile, even when highly saturated colors are present in the film.*

Like all the wider gamut spaces, scanning should be done at 16 bits per channel (48 bits for RGB) whenever possible. Conversion to 8 bits per channel (24 bits for RGB) should only be done at the final stage.

A simple software-encoding gamma of 0,455 (=1/2,2) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

You should also consider the DonRGB4 space, another space dedicated to the Ektachrome film.

14.4.14 Generic RGB

This space gamut is very close to the ones of Apple RGB, ColorMatch, and sRGB. According to Apple literature issued at the time Mac OS X was launched (Technical Q&A QA1430; 2005-10-17):

> *Mac OS X will assume a Generic RGB color space for legacy untagged images that may have been created with an assumed Apple RGB color space.*

This also applied to untagged RGB data sent to the display by non-ICC aware applications. In other words, this meant that “Generic RGB” was assumed to be the source profile for untagged data by ColorSync, which is Apple's color management technology at the operating system level, which then converted it to whatever display profile was selected.

However, in the following years, Apple changed the default space again, this time selecting sRGB as its default space for untagged images, indirectly acknowledging the use of sRGB as the common space for all platforms. When this change was done, Apple added that the default space could be expected to change again in the future, which it did, as we discuss in the Apple RGB section.

Generic RGB, contrary to what its name suggests, is well defined by Apple. It has a gamma of 1,8 and is based on the D65 Illuminant, like Apple RGB, but the chromaticities of its primaries are very close to the ones of ColorMatch (Note: ColorMatch is D50 based). With the same gamma and almost identical primaries, you could think of Generic RGB as a D65 ColorMatch. In any case, the Generic RGB space primaries are, except for the green, quite close to the original Apple RGB values, and the only “valid” reason for the change is a mention by Apple that “Apple RGB” is in fact proprietary to Adobe, and thus does not belong to Apple!

A simple software-encoding gamma of 0,556 (=1/1,8) is used in CT&A. This gamma is the same as the one defined for Apple RGB, ColorMatch, eciRGB 1.0, and ProPhoto. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.15 HDTV (HD-CIF)

Identical to sRGB in terms of gamut, these two spaces differ only in their definition of the viewing conditions, which are simply assumed in ITU-R BT.709-3, a High-Definition-TV (HDTV) standard, and precisely defined in IEC 61966-2-1, the sRGB standard.

With chromaticities not very far from SMPTE-C (and SMPTE-240M), HDTV and sRGB strive to represent the evolution of our standard TV and its convergence with the PC world, while maintaining compatibility with the large quantity of recorded media.

A simple software-encoding gamma of 0,513 (=1/1,95) is used in CT&A. The detailed gamma is the one defined in ITU-R BT.709-3. The same gamma is defined for NTSC, PAL / SECAM and SMPTE-C.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.16 NTSC

The color space of the first North-American TV sets. It is now an obsolete space that has been replaced by one defined with more efficient – brighter – phosphors, SMPTE-C, albeit at the expense of the gamut size. In a strange turn of events, the eciRGB 1.0 and eciRGB_v2 spaces have the same primaries as the NTSC space, while the primaries of the Adobe (1998) RGB space are very close, a sign of the significant recent progress in the printing industry which can print larger gamuts than a few years ago.

A simple software-encoding gamma of 0,513 (=1/1,95) is used in CT&A. The detailed gamma is the same as the one defined for HDTV (HD-CIF), PAL / SECAM and SMPTE-C.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.17 PAL / SECAM

The current 50 Hz television standard. Very similar in gamut size to the current North-American standard (SMPTE-C), and to Apple RGB, SGI RGB and sRGB.

A simple software-encoding gamma of 0,513 (=1/1,95) is used in CT&A. The detailed gamma is the same as the one defined for HDTV (HD-CIF), NTSC and SMPTE-C.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.18 ProPhoto

A very large gamut designed by Kodak which is getting attention from digital camera users as an archiving and working space for RAW — unprocessed camera — data.

Formerly called ROMM RGB while being developed, it was renamed to ProPhoto to make it more noticeable to its intended users.

While it covers most of the visible spectrum, it also extends outside of it. As a result, about 13% of the RGB triads represent non-existent colors. Working at 16 bits per channel (48 bits for RGB) is a minimum with this space, and there are some concerns that even this bit depth is not enough. Some users are also puzzled by the decision to use a 1,8 gamma when the industry is slowly moving towards a standard 2,2 value. In any case, when used with caution for images that DO contain colors outside of the range of medium size working spaces, like Adobe (1998) RGB, it can provide improved color rendering when used in conjunction with modern wide gamut inkjet printers.

A simple software-encoding gamma of 0,556 (=1/1,8) is used in CT&A. This gamma is the same as the one defined for Apple RGB, ColorMatch, eciRGB 1.0, and Generic RGB. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.19 Rec. 2020 (UHDTV)

This is the RGB space proposed by the International Telecommunication Union (ITU) for Ultra-High Definition Television (UHDTV) systems (Ref. 62). Its gamut is larger than the DCI P3 / Display P3 spaces defined for Digital Cinema and smaller than the ACES AP0 space defined for motion pictures.

It is defined with a detailed gamma which is essentially the same as the one for NTSC and PAL / SECAM. The difference is that the gamma parameters have higher precision to better match 10 or 12 bit RGB components.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.20 SGI

The chromaticities of a Sony Trinitron CRT are used in CT&A, but other displays by Hitachi and Mitsubishi, with different chromaticities, are also found in the SGI product line. The relatively low CRT gamma of 0,35 (=1/2,86), quoted by the tube's manufacturer, is common for Sony's GDM series of displays from which the SGI-Sony displays are derived.

When a gamma number is entered by the user in an SGI system, the look-up table (LUT) is filled with values corresponding to a γ_{LUT} = 1/gamma_number. A typical LUT gamma is 0,588 (=1/1,7)

A simple software-encoding gamma of 0,68 (=1/1,47) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.21 SMPTE-240M

SMPTE-240M is a standard for 1125-Line High-Definition analog video. Its primaries are the same as for SMPTE-C.

However, the software-encoding gamma of SMPTE-240M is slightly different than the one defined for SMPTE-C. Even so, a simple generic gamma of 2,2 (=1/0,455) is often used in computer software for both spaces. The simple software-encoding gamma values used in this program for these spaces were obtained by doing a best fit on the detailed gamma functions; they are different for SMPTE-C and SMPTE-240M, and more precise than the generic value.

A simple software-encoding gamma of 0,521 (=1/1,92) is used in CT&A. The detailed gamma is the one defined in SMPTE 240M-1995.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.22 SMPTE-C

SMPTE-C defines the primaries for the current North American and Japanese composite analog video standard, SMPTE 170M-1999. You should note that, for compatibility with existing studio equipment, the primaries of NTSC are also accepted in SMPTE 170M-1999.

Even if the software-encoding gamma of SMPTE-C is slightly different than the one defined for SMPTE-240M, a simple generic gamma of 2,2 (=1/0,455) is often used in computer software for both spaces. The simple gamma values used in this program for these spaces were obtained by doing a best fit on the detailed gamma functions; they are different for SMPTE-C and SMPTE-240M, and more precise than the generic value.

A simple software-encoding gamma of 0,513 (=1/1,95) is used in CT&A. The detailed gamma is the one defined in SMPTE 170M-1999. The same gamma is defined for HDTV (HD-CIF), NTSC, and PAL / SECAM.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.23 sRGB

Identical to HDTV (HD-CIF) in terms of gamut, these two spaces differ only in their definition of the viewing conditions, which are simply assumed in ITU-R BT.709-3, a High-Definition-TV (HDTV) standard, and precisely defined in IEC 61966-2-1, the sRGB standard.

With chromaticities not very far from SMPTE-C (and SMPTE-240M), HDTV and sRGB strive to represent the evolution of our standard TV and its convergence with the PC world, while maintaining compatibility with the large quantity of recorded media.

Advertised as a general-purpose space for consumer use, sRGB is proposed for applications where embedding the space profile (ex: ICC profile) may not be convenient for file size or compatibility purposes. By having all elements in a system sRGB compliant, no time is lost in conversions. The World Wide Web is obviously a target of choice for this space but it should not be discounted for other "scanner-to-printer" applications. An extended gamut color encoding standard has been proposed for sRGB (Ref. 45); it supports multiple levels of precision while being compatible with the base standard.

sRGB is the default space for Windows and a good choice for Mac (see the Apple RGB section for more info). All untagged RGB data sent to the display by non-ICC aware applications is thus assumed to be sRGB. In other words, this means that sRGB is assumed to be the source profile for untagged data by the operating system color-management system, which then converts it through whatever display profile is selected.

A simple software-encoding gamma of 0,455 (=1/2,2) is used in CT&A. The detailed gamma is the one defined in IEC 61966-2-1.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.4.24 Wide Gamut

As its name says, this is an extremely wide gamut. It is based on monochromatic primaries at 700, 525, and 450 nm. Although possible to generate these wavelengths with lasers, the red primary is in a region where the response of the eye is quite low. Since a 700 nm red requires significantly more power to match the brightness of the other two wavelengths, and since cost is proportional to power, it is more cost-effective to use a shorter red wavelength. Accordingly, a display with 610, 530, and 450 nm primaries has been proposed for optimum luminous efficiency (Ref. 20).

A simple software-encoding gamma of 0,455 (=1/2,2) is used in CT&A. There is no detailed gamma.

Numerical data pertaining to this space can be viewed in the RGB Space data and RGB to XYZ data dialogs.

14.5 Decks description

Select the space for which you want a description:

- British Standard 5252F
- FED-STD-595
- Munsell Color System
- RAL CLASSIC

IMPORTANT WARNING

Even if catalogues of color chips and swatches can be measured and presented in electronic form, the ultimate reference traditionally remains a physical sample. There are many reasons why this is often true:

- A physical sample properly represents the effect of the stock (the paper on which the chip is painted or printed).as well as the chip's surface finish, that can go from matte to glossy, with all steps in between. While it is feasible to take into account the stock color in an electronic representation, all surface effects are impossible to display.
- It is impossible to reproduce all the "printable" or "paintable" colors on a standard computer monitor, not to mention fluorescent colors and metallic finishes.

On the other hand, physical samples do have some drawbacks:

- The accuracy of physical samples is strongly dependent on the effective quality control exercised during manufacturing. Reproducibility comes at a cost, with some suppliers offering multiple versions of their catalogues with different prices depending on the overall color accuracy. In comparison, an electronic reference is as accurate as the instrument used for comparison, which can easily be more accurate than high volume manufacturing accuracy.
- Physical samples see their characteristics change with time. They can fade, shift hue (their stock can get yellower), and the surface finish gets damaged. In comparison, an electronic reference obviously does not change with time.

The goal of this tool is to facilitate the task of comparing, matching and converting colors to and from color catalogues and RGB spaces, even colors that cannot be reproduced on a computer display. Once a color chip is identified, we recommend that the user gets a physical sample to confirm that the color and finish match the rendering intent.

14.5.1 British Standard 5252F

The British Standard 5252F color matching fan (**BS 5252F** for short) is a supplement of the BS 5252 framework standard:

BS 5252:1976 *Framework for colour co-ordination for building purposes*

BS 5252F:1976 *Colour matching fan*

The color matching fan is to be used for matching the colors in the BS 5252 standard which are referred to in derived color standards. Please note that a color is only a British Standard color when it appears in a standard derived from BS 5252 for a particular product or function; in other words, a derived standard may not refer to all 237 colors of BS 5252.

The color standards derived from BS 5252 are:

- BS 4800:1989 *Schedule of paint colours for building purposes*
- BS 4900:1976 *Specification for vitreous enamel colours for building purposes*
- BS 4901:1976 *Specification for plastics colours for building purposes*
- BS 4902:1976 *Specification for sheet and tile flooring colours for building purposes*
- BS 4903:1979 *Specification for external colours for farm buildings*
- BS 4904:1978 *Specification for external cladding colours for building purposes*
- BS 6770.1988 *Guide for exterior colours for park homes (mobile homes), holiday caravans and transportable accommodation units*

A BS 5252F patch code has three parts. For example, a bright yellow patch can be found with the following code:

10 E 55

where the number "**10**" describes the color in terms of its hue, the letter "**E**" identifies its grayness group, and "**55**" describes its weight.

The hues are numbered from "02" to "24", corresponding to a hue circle going from red, to orange, to yellow, to green, to blue, and purple. Neutral shades are identified with a "00" hue number. The grayness groups go from "A", high grayness (i.e. colors with low saturation), to "E", very low grayness (i.e. saturated colors). The weights go from "01" to "58", with the weight numbers steadily increasing from one grayness group to the other, with the lower weights located in group "A", and the higher weights in group "E". Also note that patches with a given weight number will be found only within a single grayness group.

In the BS 5252F fan deck, the patches are sorted first in terms of grayness, then weight, and finally hue. In this software, the patches are sorted first in terms of hue, then grayness, and finally weight.

PURCHASING BRITISH STANDARDS

British Standards can be purchased directly from British Standards Online (BSI):

- https://www.bsigroup.com

14.5.2 FED-STD-595

The FEDERAL STANDARD No. 595 (**FED-STD-595** for short), is of mandatory use to all Federal agencies of the United States of America (USA). The revision "B" level defines 611 colors; these are the patches provided in CT&A. Revision "C", issued in 2009, defines 650 colors; this revision was hampered by production issues which affected 40 colors, issues which were resolved in late 2010. FED-STD-595 color chips can be purchased as individual chips, sets of color chips or in a fan deck.

While not exhaustive, it has found many uses outside of its "mandatory" field. For example, many hobbyists use the standard to exchange color information in order to accurately reproduce scaled models.

Chips are identified using a 5 digits numbering system ("**12345**"). The first digit describes the surface finish. Please note that not all colors are presented with the three finishes; many have only one. The second digit indicates an arbitrarily selected color classification grouping. The "misc." group comprises whites, blacks, and others. The last three digits ("**__345**") are assigned in an approximate order of increasing luminance. The numbers are not closely packed sequential numbers; large "holes" between chips are frequent.

1st digit	finish
1	glossy
2	semi-glossy
3	flat / lusterless

2nd digit	color group
0	brown
1	red
2	orange
3	yellow
4	green
5	blue
6	gray
7	misc.
8	fluorescent

Warning: Group No. 8, "fluorescent", is included in the deck but the user should be aware that these colors cannot be displayed on a computer with the same accuracy as the other non-florescent chips. The "fluorescent" group comprises only six chips.

In the FED-STD-595 loose sheet Color Book, chips are first separated by color group; then they are presented by increasing luminance (last 3 digits). Each page is separated in three columns, one per finish, and the chips of a given color appear side by side. For example, in the green color group, you will find the **14516**, **24516**, and **34516** chips on the same row. You will also find additional chips in change notices that are delivered on separate sheets.

The overall grouping of the chips, and the separate location for the change notices make this standard hard to navigate in printed form. For example, you will find chips of all hues in the gray section. You should find that navigation is easier with the L*C*h pad mode.

Important: As per the FED-STD-595, if this standard is called in USA government procurement, it is mandatory to match a color by visual comparison with a physical chip; therefore, you should purchase the selected chip for final approval.

PURCHASING FED-STD-595 CHIPS

Chips can be purchased from company specialized in selling Standards or directly from the General Services Administration (GSA):

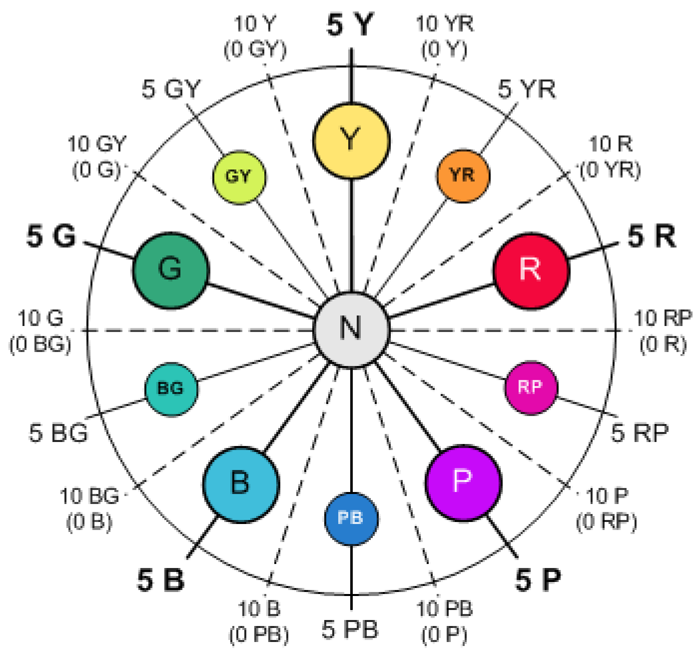
General Services Administration
Federal Acquisition Service
Federal Specifications Program, Suite # 8214
490 East L'Enfant Plaza, SW
Washington, DC 20407

Tel.: +1-202-619-8925
Fax: +1-202-619-8985

14.5.3 Munsell Color System

Originally developed in the early 20th century by the American artist Albert H. Munsell (1858-1918), the **Munsell Color System** is the first widely accepted color order system. It proposes collections of painted samples in either matte or glossy finish, which form the **Munsell Book of Color**. In this system, colors are identified with three parameters: *Munsell **H**ue*, *Munsell **V**alue* and *Munsell **C**hroma*, or **Munsell HVC** for short.

The *Munsell Hue* is separated in 10 hue ranges (please refer to the illustration below). For each hue range, there is a major hue located at the range center. The major hues are Red, Yellow, Green, Blue and Purple, as well as the five hues located between them and named by combining the names of the hues on each side. For example, the hue located between Yellow and Red is called Yellow-Red, instead or Orange; this naming convention minimizes the number of color names one has to deal with.



Each hue range is further divided in 10 sub-zones defined by 11 radii labeled from zero to 10. The major hues are labeled **5R**, 5YR, **5Y**, 5GY, **5G**, 5BG, **5B**, 5PB, **5P**, 5RP. The color circle is, in effect, separated in 100 hue segments where each hue separation is perceptually uniform. A zero to 100 number can be used to describe the *Munsell Hue* but it is seldom seen (the zero is at 10RP, the numbers increase when going counter-clockwise, up to 100, also at 10RP).

The radius labeled "10" in one zone corresponds to the "0" radius of the next zone (the 10Y hue is the same as 0GY); in practice, the 10Y notation is the preferred one.

The Munsell Book of Color has samples with hues located at every 2,5 hue steps. For example: 10RP / 2,5R / 5R / 7,5R and 10R for the red hue range.

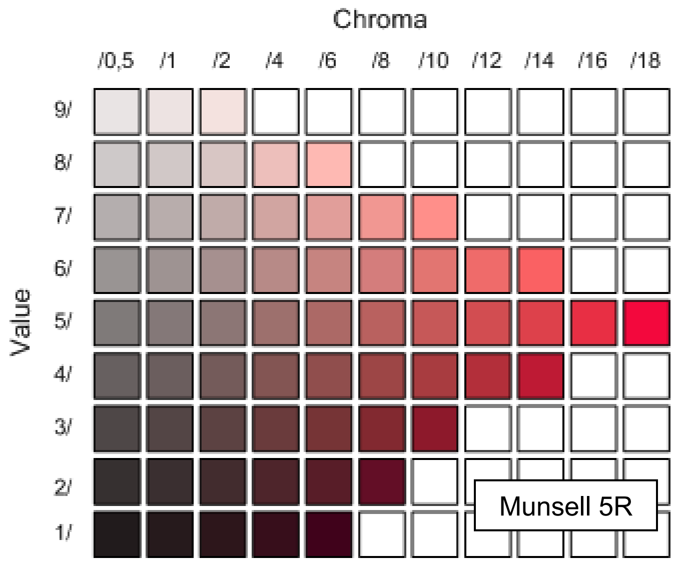
The *Munsell Chroma*, like the *C** of the L*C*h representation, can be considered an approximate counterpart of perceived color saturation, while the *Munsell Value* is associated to the lightness (*L**) of the color. The perceived chroma and value increase uniformly with each unity step. For example, the perceived difference between a **Chroma 1** and a **Chroma 2** sample is the same as the one perceived between **Chroma 4** and **Chroma 5** samples; similarly, the perceived difference between a **Chroma 1** and a **Chroma 3** sample is the same as the one perceived between **Chroma 4** and **Chroma 6** samples.

A color described by the Munsell Color System is presented in the form:

Hue Value/Chroma .

The illustration on the right presents samples at specific value and chroma intervals for the **5R** hue. Please note that the chroma intervals are not uniform in the lower chroma region. Only samples that fall within the sRGB gamut are shown; this explains why the maximum chroma is different across the value range. The most saturated sample in the illustration is "**5R 5/18**".

Neutral colors are presented in the form "**N 5/**" with "N" written for the neutral hue, and no number for chroma since there is zero chroma. Fractional, i.e. higher precision, values are possible for each parameter, and "**5,2R 4,8/17,5**" is a valid Munsell notation. According to ASTM D1535 (see Ref. 23), the estimated precision with which a color can be characterized visually is 0,5 hue step, 0,1 value step and 0,4 chroma step.



In CT&A, bidirectional conversions **FROM** and **TO** the Munsell notation can be performed in many ways:

- Munsell tools: A dedicated tool for **bidirectional** high precision conversion between Munsell and L*a*b*/RGB.
- RGB vs RGB tool RGB to Munsell: Convert RGB data to high precision Munsell notation.
- RGB vs RGB tool Color Deck: A **digital catalogue** equivalent of the Munsell Book of Color. Used to convert samples presented in fixed uniformly distributed steps to XYZ/L*a*b*/RGB coordinates.
- Convert TO Munsell Color Deck: Find the **nearest** Munsell (digital catalogue) sample for a given RGB/L*a*b* input or for a sample from another Color Deck.

First devised as a color description teaching aid, the Munsell Color System was quantitatively formalized in the 1940s. The analysis led to small adjustments in the samples color in order to improve the spacing uniformity between them. This "renotated" system is the one we now use. The Munsell Color System is an international reference, defined in ASTM D1535 and other standards, that is used in many fields of work, from archaeology, when describing the colors of artifacts, to medical studies, when comparing the color of skin affections, to hobby activities such as accurately depicting the colors of scaled vintage airplanes.

A great tool to learn and practice the Munsell system is *The New Munsell Student Color Set*, which combines a color-primer book with color chips and a three-ring binder to store the chips; this tool is produced by Jim Long and Joy Turner Like (see Ref. 34).

See the XYZ to Munsell section for more information on the conversion process. Additional information and data on the Munsell Color System can be found on the Munsell Color Science Laboratory (MCSL) Web site: https://www.rit.edu/science/munsell-color-lab . This laboratory is part of the Rochester Institute of Technology. Please note that MCSL is not the same entity as the Munsell Color Services Division of GretagMacbeth, which is itself now part of X-Rite.

PURCHASING MUNSELL CHIPS

Munsell chips can be purchased directly from X-Rite or from one of their international sales partner:

- https://www.xrite.com
- https://www.xrite.com/partner-locator

14.5.4 RAL CLASSIC

First published in 1927, the RAL color standard was designed to serve the German industry, and it has since been used in many other countries, particularly in Europe.

Note: RAL stands for *Reichsausschuss für Lieferbedingungen*, which translates as *Committee of the German Reich for Terms and Conditions of Sale*; it was founded in Berlin in 1925.

Through time, colors were added to the original set of 40 colors, and a few were removed. This color set is now known as **RAL CLASSIC**, which comprises 213 colors, of which 210 can be found in the CT&A RAL CLASSIC deck. This is still a very limited set, pastel colors being obviously absent, and a more modern and complete color system, called RAL DESIGN, has been defined to replace it. However, RAL DESIGN has far from displaced RAL CLASSIC, which is well entrenched in many companies' specifications.

RAL CLASSIC chips are described by a four digits number ("**1234**"), where the first one describes a broad color group, and the last three have no particular signification. The color groups are:

1st digit	color group
1	yellow
2	orange
3	red
4	lilac / violet
5	blue
6	green
7	gray
8	brown
9	white / black / metallic

Important: While RAL CLASSIC chips are available in both semi-gloss and glossy finishes, the colors found in the program deck are representative of the semi-gloss finish.

Warning: RAL 9006 and 9007 were defined in relation to the appearance of corrosion protection coatings. The RAL 9006 coating is essentially made of aluminum particles, while RAL 9007 is made of layers of iron oxide and aluminum powder. According to RAL, these patches cannot be reproduced with high precision from one edition to the other. In addition, using them for decorative purposes requires an additional transparent layer, which can also affect the perceived color. For these reasons, these two colors are recommended only for corrosion protection applications.

PURCHASING RAL CLASSIC CHIPS

RAL CLASSIC chips can be purchased directly from the RAL Deutsches Institut für Gütesicherung und Kennzeichnung e.V.:

- https://shop.ral-farben.de
- https://www.ral.de (Main Web page of RAL site)

or from one of their international sales partners:

- https://www.ral-farben.de/en/sales-offices-worldwide
- https://www.dorncolor.com (USA, Canada, Mexico)

14.6 References

Click on a reference number to go to the section that called it. You can also click on the Internet links; a separate Web-browser window will open.

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14.7 Specifications – RGB vs RGB tool

Click on a link to go directly to a sub-section:

- RGB vs RGB tool – General Specifications
- RGB vs RGB – Input formats
- RGB vs RGB – Output formats
- RGB vs RGB – DeltaE* formats

14.7.1 RGB vs RGB tool – General Specifications

- Input requirements: The RGB vs RGB tool does not require a color measurement instrument although data can be inputted using such an instrument.
- Supported instruments:
  - **Note: 32 bit and 64 bit drivers availability:** A table showing 32 bit and 64 bit support for each instrument can be found in the Supported instruments section. In addition, for 64 bit packages, the "i1Pro / i1Pro 2 (non-XRGA)" instrument menu selection is not available.
  - **i1Pro** (X-Rite, spectrophotometer): Rev A-D.
  - **i1Pro 2** (X-Rite, spectrophotometer): i1Pro 2 M0/M1/M2 and i1Pro 2 M2-only.
  - **i1Pro 3** (X-Rite, spectrophotometer): i1Pro 3 M0/M1/M2 and i1Pro 3 Plus M0/M1/M2 (M3 not-supported).
  - **i1Display Pro** (X-Rite, colorimeter): Retail version, part #EODIS3-XR). Generic models sold by other companies (third parties, or OEM, part #EODIS-OEM) should also be compatible. Custom models sold by other companies may be supported if the instrument is recognized to be an i1Display Pro by CT&A.
  - **Eye-One Display and Display 2** (X-Rite, colorimeter): X-Rite retail versions.
  - **Eye-One Display 2 bundled with a monitor**: If an instrument is recognized to be an Eye-One Display or Eye-One Display 2 by CT&A, then it can be used in the program and will provide accurate measurements. Example-1: The MDSVSENSOR2, which is part of the SVII-PRO-KIT sold by NEC for their wide gamut Spectraview displays, such as the PA271W model, is compatible with CT&A; please consult the Instrument section of the Help manual for more information. Example-2: The Eye-One Display offered with HP DreamColor monitors is NOT compatible with CT&A.
  - **Spyder5** (Datacolor, colorimeter). Supported models: Spyder5ELITE, Spyder5PRO, Spyder5EXPRESS.
  - **SpyderX** (Datacolor, colorimeter). Supported models: SpyderX Elite, SpyderX Pro.
  - **Supported measuring modes:** reflectance, emission, ambient illumination, flash. These measuring modes are not available in all instrument models.

- General features:
  - Compare two RGB spaces amongst twenty-four (24) pre-defined spaces and one custom space.
  - Translate (Convert) from one RGB space to any other.
  - Compare and Convert RGB spaces to industry standard color catalogues (Color Decks).
  - Input RGB space data in six different formats.
  - Acquire a L*a*b* or L*u*v* input from a colorimeter or spectrophotometer.
  - Obtain output data in up to 11 different formats for RGB spaces and 9 formats for Color Decks.
  - Calculate the color-difference (DeltaE) in up to fourteen formats.
  - Get the individual contributions of ΔL^*, ΔC^*, ΔH^* in the DeltaE* color-difference, as well as Δh.
  - See the "xy" chromaticity coordinates in graphical form (chromaticity diagram).
  - Display the chromaticity data of the X-Rite/GretagMacbeth ColorChecker card, the primaries and secondaries of 8 standard CMYK spaces, and the Planckian locus.
  - Print the chromaticity diagram with or without the numerical colorimetric data.
  - The colors are displayed using the assigned ICC display profile.
  - Get clipping information (an Out-Of-Gamut flag) when converting to a RGB space and when data is entered using the L*a*b* / L*u*v* input mode.
  - Get tabular data on spaces, illuminants, Bradford matrices, and **XYZ to RGB** and RGB to XYZ matrices.
  - Save a report with exhaustive comparative data for the selected colors.

- Custom RGB space:
  - Define an RGB space with custom primaries, a custom illuminant, and a custom gamma.
  - Enter the xyz chromaticity coordinates of the illuminant directly or obtain the coordinates of any D-series (D50, D93, etc.) or blackbody illuminant by simply entering the source temperature, in kelvin (Ex.: 9300 K for D93).
  - Gamma can be either a single parameter or a multi-parameters function, as defined for some standard spaces such as NTSC and eciRGB_v2 (called the L*, i.e. L-star, tone response curve in this space); all parameters are fully customizable.
  - Get the coefficients of the Bradford and CIECAT02 Chromatic Adaptation Transform (CAT) matrix between your custom Illuminant and many standard illuminants. You can also get the inverse matrix coefficients.
  - Export a spreadsheet savvy text report that contains all the parameters required to define and compute the custom RGB space coordinates (includes the XYZ-to-RGB and RGB-to-XYZ matrices).
  - Export your custom RGB space as an ICC profile. This profile can be assigned to an image using image editing programs that support profile embedding, such as Photoshop. It can also be assigned to a color list in BabelColor's PatchTool or used to convert a color list with PatchTool's Gamut Tools.

- Color Decks
  - British Standard 5252F (i.e. BS 5252F, which comprises the colors referred to by BS 4800, BS 4900, BS 4901, BS 4902, BS 4903, BS 4904, and BS 6770)
  - Federal Standard 595B (FED-STD-595B)
  - Munsell Color System (with over 4000 color chips; Munsell Color System description)
  - RAL CLASSIC
  - User-defined list imported using the "BabelColor CT&A Export" dialog of the PatchTool program, which converts color lists saved in Adobe Swatch Exchange (ASE), CGATS, CXF or plain text formats to the Color Decks database format.

- Web Content Accessibility Guidelines (WCAG) Contrast Ratio
  - WCAG V-2.0 Recommendation published by the World Wide Web Consortium (W3C), 11 December 2008.
  - Get the Contrast Ratio for two selected colors on white and black backgrounds and on a background of the other selected color.
  - See if a ratio meets the requirements for Minimum (Level AA) and Enhanced (Level AAA) contrast for both Normal text and Large text as defined by the Guidelines.
  - Print all results in a text-based report.

14.7.2 RGB vs RGB tool – Input formats

For RGB spaces:

Input formats can be **either:**

- **RGB** (in reality: **R'G'B'**)
- **L*a*b*** referenced to the illuminant of the selected space
- **L*a*b*** referenced to illuminant D50
- **L*u*v*** referenced to the illuminant of the selected space
- **L*u*v*** referenced to illuminant D50
- **xy** coordinates selected by clicking in the chromaticity diagram
- L*a*b* or L*u*v* input through Eye-One measurements (input modes are instrument dependant)

For Color Decks:

A color chip can be selected by **either:**

- clicking in any color patch surrounding the center patch (L*C*h pad mode)
- clicking in any color patch over or below the center patch (List view mode)
- selecting a color within the multi-color strip
- clicking the arrows on the top and bottom of the multi-color strip

14.7.3 RGB vs RGB tool – Output formats

For RGB spaces:

Output formats are (for both the space where the input was entered and the destination space, when in Convert Mode):

- **RGB** (in reality: **R'G'B'**)
- Hexadecimal equivalent of R'G'B' (**Hex #**)
- **HSB** (Hue-Saturation-Brightness)
- **Munsell HVC** (Hue-Value-Chroma)
- **L*C*h** based on either L*a*b* or L*u*v* and the D50 checkbox
- **L*a*b*** referenced to the illuminant of the selected space
- **L*a*b*** referenced to illuminant D50
- **L*u*v*** referenced to the illuminant of the selected space
- **L*u*v*** referenced to illuminant D50
- **xyY** referenced to the illuminant of the selected space
- **XYZ** referenced to the illuminant of the selected space
- When using a colorimeter/spectrophotometer in emission or ambient measurement mode, obtain the Luminance (cd/m^2) or Illuminance (lux), as well as the Correlated Color Temperature (CCT, in kelvin).

In addition, **xy** coordinates are shown in the chromaticity diagram .

For Color Decks:

Output formats are:

- the color chip name
- **Munsell HVC** (Hue-Value-Chroma)
- **L*C*h** based on either L*a*b* or L*u*v* and the D50 checkbox
- **L*a*b*** referenced to the illuminant of the selected deck
- **L*a*b*** referenced to illuminant D50
- **L*u*v*** referenced to the illuminant of the selected deck
- **L*u*v*** referenced to illuminant D50
- **xyY** referenced to the illuminant of the selected deck
- **XYZ** referenced to the illuminant of the selected deck

In addition, **xy** coordinates are shown in the chromaticity diagram.

14.7.4 RGB vs RGB tool – DeltaE* formats

For RGB spaces and Color Decks:

Color-differences, DeltaE*, or ΔE in abridged form, can be displayed in the following formats (definitions and equations are shown in the DeltaE* section):

- **ΔE^*_{ab}**
  "CIELAB color-difference", referenced to the selected space or deck illuminant
- **ΔE^*_{uv}**
  "CIELUV color-difference", referenced to the selected space or deck illuminant
- **ΔE^*_{ab} D50**
  "CIELAB color-difference", referenced to D50 illuminant
- **ΔE^*_{uv} D50**
  "CIELUV color-difference", referenced to D50 illuminant
- **ΔE^*_{94}**
  ΔE^*_{94}-textile
  "CIE94 color-difference", referenced to the selected space or deck illuminant. It is generally assumed that when no other indication is given, the k_L, k_C, and k_H factors of the CIE94 formula are all equal to 1 (i.e. CIE94(k_L:k_C) shown as CIE94(1:1) is CIE94; please note that k_H is usually not shown as it is almost always equal to 1). The **ΔE^*_{94}-textile** version has its k_L factor equal to 2, and can also be expressed as CIE94(2:1).
- **ΔE^*_{94} D50**
  ΔE^*_{94}-textile D50
  "CIE94 color-difference", referenced to D50 illuminant
- **$\Delta E_{CMC(2:1)}$**
  $\Delta E_{CMC(1:1)}$
  "CMC(ℓ:c) color-difference", referenced to the selected space or deck illuminant. CMC(2:1) is used for acceptability (pass/fail) measurements while CMC(1:1) is used for perceptibility measurements.
- **$\Delta E_{CMC(2:1)}$ D50**
  $\Delta E_{CMC(1:1)}$ D50
  "CMC(ℓ:c) color-difference", referenced to D50 illuminant
- **ΔE_{00}**
  "CIEDE2000 color-difference", referenced to the selected space or deck illuminant
- **ΔE_{00} D50**
  "CIEDE2000 color-difference", referenced to D50 illuminant

The color-differences are computed for the illuminant of the spaces or decks being compared, only if both sides have the same illuminant, and for illuminant D50, in all cases. In addition, the individual contributions of

- **ΔL^***, the *lightness* difference,
- **ΔC^***, the *chroma* difference, and
- **ΔH^***, the *hue* difference,

to the DeltaE* value, as well as

- **Δh**, the *hue angle* difference,

are shown for each selected format.

14.8 Specifications – Munsell tools

Help section: Munsell tools

- Input requirements: The Munsell tools do not require a color measurement instrument although data can be inputted using such an instrument.

- Supported instruments:
  - **i1Pro** (X-Rite, spectrophotometer): Rev A-D.
  - **i1Pro 2** (X-Rite, spectrophotometer): i1Pro 2 M0/M1/M2 and i1Pro 2 M2-only.
  - **i1Pro 3** (X-Rite, spectrophotometer): i1Pro 3 M0/M1/M2 and i1Pro 3 Plus M0/M1/M2 (M3 not-supported).
  - If you are using an i1Pro 2 with the “i1Pro / i1Pro 2 (XRGA)” driver, an i1Pro 3, or an i1Pro 3 Plus, all measurements will be taken with the three Measurement Conditions, M0 (Ill-A), M1 (D50), and M2 (UV-cut), as defined in ISO 13655-2009. If you are using an i1Pro, or an i1Pro 2 with the “i1Pro / i1Pro 2 (non-XRGA)” driver, the program will select the default measurement conditions supported by the instrument.
  - **Note (64 bit packages):** The “i1Pro / i1Pro 2 (non-XRGA)” driver/menu selection is not available.

- General features:
  - Convert from Munsell to RGB and L*a*b*.
  - Convert from RGB to Munsell..
  - RGB spaces: The (24) predefined spaces plus the Custom space defined in the RGB vs RGB tool.
  - Convert from L*a*b* to Munsell.
  - L*a*b* illuminants: 15 predefined illuminants plus a Custom illuminant defined in the RGB vs RGB tool.
  - Measure spectral data and convert to Munsell.
  - Export a report with tab-delimited data that can be directly imported in a spreadsheet program and opened in many text editing applications. The report spectral measurements can also be read by software, such as BabelColor PatchTool, which can open CGATS compatible files.

14.9 Specifications – Spectral tools

Click on a link to go directly to a sub-section:

14.9.1 Spectral tools – General Specifications

- Input requirements:
  - Four spectral tools (CRI, ISO 3664+, MI, RAL DESIGN) can use a file as input, with NO connected instrument, or input from from an instrument, if available.
  - The other spectral tools (Density, FluoCheck, Graph, Whiteness) only accept an input from an instrument. Note: The Whiteness tool UV filter can also be loaded from a file.
  - The FluoCheck tools require an i1Pro 2 or i1Pro 3 which supports the M0, M1, and M2 Measurement Conditions as defined in ISO 13655-2009.
  - The **Density** and **Graph** tools also support the M3 Measurement Conditions which requires an i1Pro 3 Plus with a Polarizer head adapter.
  - An i1Pro UV-cut (i.e. M2-only) and an i1Pro 2 M2-only cannot be used with the Whiteness tools.
  - Input file requirements: Spectral data is required between 400 and 700 nm. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded. Bandwith requirements are 10 nm for most tools but the CRI tool will also accept 5 nm spectrums.

Here are the possible configurations:

Spectral tool	Instrument	File input with NO instrument	Note on file input
CRI	i1Pro, i1Pro 2, i1Pro 3 w / Ambient adapter	**Yes**	5 nm or 10 nm spectrum (1+ spectrum(s) / file)
Density	i1Pro, i1Pro 2, i1Pro 3 M3 w / i1Pro 3 Plus	No	
FluoCheck	i1Pro 2 (M0/M1/M2) i1Pro 3 (M0/M1/M2)	No	
Graph	i1Pro, i1Pro 2, i1Pro 3 M3 w / i1Pro 3 Plus	No	
ISO 3664+	i1Pro, i1Pro 2, i1Pro 3	**Yes**	Ambient source: 10 nm spectrum (1 spectrum / file) Emission source: 10 nm spectrum (1 spectrum / file)
MI	i1Pro, i1Pro 2, i1Pro 3	**Yes**	Ambient source: 10 nm spectrum (1 spectrum / file) Ref./Sample: 10 nm spectrum (1+ spectrum(s) / file)
RAL	i1Pro, i1Pro 2, i1Pro 3	**Yes**	A file is converted to another file in CGATS format. Input data: 10 nm spectrum (1+ spectrum(s) / file)
Whiteness	i1Pro (M0) i1Pro 2 (M0/M1/M2) i1Pro 3 (M0/M1/M2)	No	You can load a UV filter spectrum from a file. Filter data: 10 nm spectrum (1 spectrum / file)

- Supported instruments:
  - **i1Pro** (X-Rite, spectrophotometer): Rev A-D.
  - **i1Pro 2** (X-Rite, spectrophotometer): i1Pro 2 M0/M1/M2 and i1Pro 2 M2-only.
  - **i1Pro 3** (X-Rite, spectrophotometer): i1Pro 3 M0/M1/M2 and i1Pro 3 Plus M0/M1/M2/M3. The M3 Measurement Conditions are supported only in the Density and Graph tools.
  - **Supported measuring modes:** reflectance, emission, ambient illumination, flash. These measuring modes may not be available in all instrument models.
  - You can select between an “XRGA” compliant driver and a “non-XRGA”/legacy driver
  - If you are using an i1Pro, or an i1Pro 2 with the “i1Pro / i1Pro 2 (non-XRGA)” driver, the program will select the default measurement conditions supported by the instrument (M0 or M2).
  - **Note (64 bit packages):** The “i1Pro / i1Pro 2 (non-XRGA)” driver/menu selection is not available.

- Text reports formats:
  - All text reports are Tab-Delimited and can be opened in a spreadsheet application or a word processor.
  - The CGATS compliant text files can also be opened by many color-management software, including BabelColor's CT&A and PatchTool (Note: A CGATS compliant file does not guarantee that the data can be used by a program!).

14.9.2 CRI tools – Specifications

Help section: Color Rendering Index (CRI) tools

- Test source data: CCT (kelvin); *Duv* (CIE1960); brightness (lux); LER (Light Efficiency Ratio, in lm/W); the Reference source (a blackbody or a D-Series illuminant).
- CRI (CIE 13.3: 1995): A graph of the 14 individual indices and *Ra*; numerical values of *Ra* (a general score based on the first 8 indices and better known as the current CRI), *R9*, *R(9-14)* (for indices 9 to 14) and *R(1-14)* for indices 1 to 14; a graph of the samples (*a*, b**) coordinates; a representation of the samples illuminated by the Reference and Test sources; the CIELAB color difference between the patches (Ref. 33).
- CQS (Color Quality Scale, NIST Version 9.0.3): A graph of the 15 individual indices and *Qa*; numerical values of *Qa* (general score based on the 15 indices), *Qf* (fidelity index) and *Qg* (relative gamut area); a graph of the samples (*a*, b**) coordinates; a representation of the samples illuminated by the Reference and Test sources; the CIELAB color difference between the patches (Ref. 46).
- CRI2012 (nCRI Version 2012): A graph of the 17 individual indices and *Ra,2012*; numerical value of *Ra,2012* (based on the 17 indices); a graph of the samples (a'_M, b'_M) coordinates; a representation of the samples illuminated by the Reference and Test sources; the color difference between the patches (Ref. 47).
- TM-30-15 and TM-30-20 / CIE 224: Numerical values of the Fidelity Index (*Rf*), the Gamut Index (*Rg*); the fidelity index for skin (*Rf,skin*), the color fidelity (*Rf,ces*) for each of the 99 Color Evaluation Sample (CES), and the color difference (*DeltaE'*) for each set of CES patches. Numerical values of the Local Color Fidelity (*Rf,h*), Local Chroma Shift (*Rcs,h*) and Local Hue Shift (*Rhs,h*) for each of the 16 Hue Angle Bins. A graph of the reference source, which is different from the source used in other color rendering metrics when the CCT is **between 4500 K and 5500 K, for TM-30-15**, and **between 4000 K and 5000 K, for TM-30-20**; a bar graph of the color fidelity by sample (*Rf,ces*); a bar graph of the color fidelity by Hue Angle Bin (*Rf,h*); a bar graph of the chroma shift by Hue Angle Bin (*Rcs,h*); a bar graph of the hue shift by Hue Angle Bin (*Rhs,h*); a graph of the average chromaticity (a'_M, b'_M) of the reference and test data of the Hue Angle Bins, which is used to compute the gamut area; a Color Vector Graphic (CVG) used to evaluate color saturation and desaturation; a plot of *Rg* versus *Rf*; and a visual representation of the 99 CES reference and test patches. TM-30-20 only: Color Rendition Categories (Preference, Vividness, Fidelity) in three Priority Levels as defined in TM-30-20 Annex E. (Ref. 54-57-65).
- GAI (Gamut Area Index): Ref. 48.
- *GAI and Ra*: The arithmetic mean of *GAI* and *Ra* (the current CRI)) (Ref. 49).
- MCRI (Memory Color Rendering Index): *Rm* (general memory color quality index); *Sa* (degree of similarity); *Si* (special color quality indicators of the ten objects) (Ref. 50).
- Data input:
  - Instrument or file input; a connected instrument is NOT required for file input.
  - Input file formats: CGATS or Plain text files; 380-400 nm to 700-730 nm spectral ranges; 5 nm or 10 nm bandwidth. The file may contain one or more spectrums; you can drag-and-drop one or more files on the "Load…" button or on the data table.
  - Supported instruments: Any i1Pro series spectrophotometer with ambient adapter (the adapter is an option in some models).
  - Input is processed internally with a 5 nm bandwidth; 10 nm data is interpolated to 5 nm with the user-selected spectral interpolation method (cubic spline / Lagrange).
- Data output:
  - Custom export dialog: Select amongst the data used for the graphs, the general and specific metrics indices, and the Test source data.
  - Export all measurements or only selected measurements.
  - Export in a single file report or in a batch of individual files (one file per measurement), or both options.
  - The single file report or the individual files can be exported in either CGATS format, which can easily be used for file input afterwards, or in Plain text format.
  - TM-30-20 graphic reports: Generate graphic reports as per the TM-30-20 method guidelines (Ref. 57). Three report types are available: **Simple**, **Intermediate**, and **Full**. These reports are saved as images in PNG, TIF, BMP, or JPG format. The image resolution is selectable at 96, 150, 300, or 600 DPI.

14.9.3 Density tools – Specifications

Help section: Density tools

- Measurement Conditions: M0, M1, M2, or M3; as defined in ISO 13655-2009 (as permitted by instrument).
- Reflection Density, with Absolute or Paper White base.
- Dot / Tone (Dot Area): Formulas:
  - Murray-Davies
  - Yule-Nielson with user-adjustable n Factor
  - Spot Color Tone Value (SCTV) as per ISO 20654:2018
- Apparent Trap: Preucil (GATF) or Brunner formulas.
- Print Contrast, with Absolute or Paper White base.
- Hue error - Grayness - Saturation with Absolute or Paper White base.
- Density standards (as defined in ISO 5-3):
  - ANSI Status A: Recommended for measuring densities of photographic color prints.
  - ANSI Status E: Used mostly in Europe to measure printed material. It has a wide-band color response. Equivalent to the DIN status.
  - ANSI Status I: Has a narrow-band interference-type filter response. Equivalent to the DIN NB and SPI statuses.
  - ANSI Status T: The equivalent of ANSI Status E in North America. The difference with Status E is how the yellow filter is weighted.
- Manual or Automatic CMYK filter selection
- Up to five measurements per tool; get the average; select one measurement, or the average, as a reference.
- Export a report formatted for a spreadsheet and a word processor.

14.9.4 FluoCheck tools – Specifications

Help section: FluoCheck tools

- **Important:** An i1Pro 2 or i1Pro 3 which supports the M0 (Ill-A), M1 (D50), and M2 (UV-cut) Measurement Conditions as defined in ISO 13655-2009 is required to use these tools (an i1Pro cannot be used!).
- Fluorescence Index (FI): This index requires only one printed sample; the index is obtained by computing the color difference between a measurement made with the M2 (UV-cut) measurement condition and a measurement made with either M0 (Illuminant A) or M1 (D50). The formula used to compute the color difference can be any of the standard color difference equations listed below.
- Fluorescence Metamerism Index (FMI): This index evaluates if the combined appearance of two printed samples varies between a reference Measurement Condition (M2, UV-cut) and a UV-inducing illuminant (either M0 or M1); it is based on the HunterLab Metamerism Index. The FMI is identified as either *FMI(M0)* or *FMI(M1)*.
- Standard Observer: 2 degree (CIE1931) or 10 degree (CIE 1964).
- Fluorescence Index Color difference formula:
  - CIELAB
  - CIE94, i.e CIE94(1:1)
  - CIE94 textile, i.e. CIE94(2:1)
  - CIE94(2:2) (recommended by Berns for metamerism analysis)
  - CMC(2:1)
  - CMC(1:1)
  - CIEDE2000
- Save all results in a report formatted for a spreadsheet and a word processor.

14.9.5 Graph tools – Specifications

Help section: Graph tools

- Acquire and compare two spectrums.
- Supported instruments: Any i1Pro series spectrophotometer. An ambient adapter is required for Ambient and Flash measurements (the adapter is an option in some models).
- Measurement modes: emission, ambient, reflectance, and flash (the mode can be different for each spectrum; ambient and flash not supported by all i1Pro versions)
- Measurement Conditions: M0, M1, M2, or M3; as defined in ISO 13655-2009 (as permitted by instrument).
- Absolute or normalized scales, with zoom.
- Basic mathematical operations on spectrums: ADD, AVERAGE, SUBTRACT, MULTIPLY
- Compare measured ambient or flash spectrums with theoretical spectrums of ideal blackbodies or D-series illuminants, with the same illuminance.
- Get the illuminance (lux or lux-sec), the Correlated Color Temperature (CCT, in kelvin), and the Color Rendering Index (CRI) of ambient and flash sources.
- Get the luminance (cd/m^2) and the Correlated Color Temperature (CCT, in kelvin) of emission sources.
- Observe coordinates data by moving the mouse over the spectrums.
- Obtain color space data for each spectrum: L*a*b* and L*C*h (ab); L*u*v* and L*C*h (uv); XYZ; xyY.
- Standard Observer: 2 degree (CIE1931) or 10 degree (CIE1964)
- Illuminant selection: A, B, C, D50, D55, D60, D75, D93, E, F2, F7, F11
- Color difference formula for CII and SMI computation:
  - CIELAB
  - CIE94, i.e CIE94(1:1)
  - CIE94 textile, i.e. CIE94(2:1)
  - CMC(2:1)
  - CMC(1:1)
  - CIEDE2000
- Save the measurements in a CGATS compliant text file.
- Export an image of the spectrums and color patches in PNG, BMP, or JPG format. You can select to generate the image at a 1X or 2X scale (double resolution and size).

14.9.6 ISO 3664+ tools – Specifications

Help section: ISO 3664+ tools

- Based on selected requirements of ISO 3664:2009, ISO 12646:2008 and ISO 12646:2014-Final Draft to which are added user-selectable conditions.
- Data input: Instrument or file input; a connected instrument is NOT required for file input. For CRI and MI, 10 nm input is interpolated to 5 nm with a user-selected spectral interpolation method (cubic spline / Lagrange).
- ISO 3664 Viewing Conditions:
  - P1: Prints: Critical comparison (requires an i1Pro with an ambient diffuser adapter)
  - P2: Prints: Practical appraisal (requires an i1Pro with an ambient diffuser adapter)
  - T1: Transparencies (direct viewing)
  - Color monitors (the uniformity measurements can be done using the requirements of ISO 12646: 2008 or ISO 12646:2014-Final Draft; see more details below)
- Measurements:
  - Brightness: ambient illuminance (lux); monitor luminance (cd/m2).
  - Chromaticity: u'v' Uniform Chromaticity Scale (UCS, CIE1976), 10 degree Observer (CIE1964)
  - Correlated Color Temperature (CCT), in kelvin, of a monitor or ambient source.
  - Color Rendering Index (CRI): CIE 13; also provides the index of each sample
  - Daylight simulator Metamerism Index (MI) and Quality Grade: ISO 23603 / CIE S 012 (visible-range-only)
  - Brightness uniformity (for P1, P2, and T1 Viewing Conditions): Measure the brightness, the CCT, the chromaticity, the CRI and the MI for up to nine positions.
  - Brightness uniformity as per ISO 12646:2008, Section 4.4 (for color monitors): The relative brightness of WHITE, GREY, and DARK-GREY targets can be measured on a non-uniform 3 x 3 grid which favors the monitor's center area. For the white targets, the CCT and chromaticity are measured as well.
  - Tone uniformity, i.e. Color uniformity, as per ISO 12646:2014-Final Draft, Section 4.2.2 (for color monitors): Measurements can be done on WHITE, GREY, and DARK-GREY targets positioned on a uniform 5 x 5 grid. The color difference between the center and the other positions is computed using CIEDE2000. For the white targets, the CCT and the chromaticity are measured as well.
  - Tonality Evaluation, i.e. Grey/White Tone ratio uniformity, as per ISO 12646:2014-Final Draft, Section 4.2.3 (for color monitors): Measurements can be performed for up to twenty-five positions located on a uniform 5 x 5 grid. Measurements need to be done with both WHITE and GREY patches for a given position. The deviation of the Grey/White ratio is shown relative to the center position. For the white targets, the CCT and the chromaticity are measured as well.
- Chromaticity "Target center":
  - D50 for "P1", "P2" and "T1" (ISO 3664)
  - D65 for "Color monitors" (ISO 3664)
  - 2856 K, 3200 K, 3500 K, 4100 K, 4700, 5000 K (non ISO 3664)
  - D55, D60, D75, D93 (non ISO 3664)
- CRI "Reference Illuminant":
  - D50 for "P1", "P2" and "T1" (ISO 3664)
  - 2856 K, 3200 K, 3500 K, 4100 K, 4700, 5000 K (non ISO 3664)
  - D55, D65, D75 (non ISO 3664)
  - Automatically assigned from the measured color temperature (CCT)
- MI and Quality Grade "Reference Illuminant":
  - D50 for "P1", "P2" and "T1" (ISO 3664)
  - D55, D65, D75 (non ISO 3664)
- Input file formats: CGATS or Plain text files; 380-400 nm to 700-730 nm spectral ranges; 10 nm bandwidth. The file must contain one spectrum; you can drag-and-drop a file on the "Load…" button.
- Supported instruments: Any i1Pro series spectrophotometer. An ambient adapter is required for ISO 3664 P1 and P2 viewing conditions (the adapter is an option in some models).
- Save all results in a text report.
- Print a well-formatted one-page report which contains information dedicated to compliance-type reports.

14.9.7 Metamerism Index tools – Specifications

Help section: Metamerism Indes (MI) tools

- MI as per CIE15:2004, Section 9.2.2.3.
- HunterLab MI (based on CIELAB).
- Special Metamerism Index (SMI) as per CIE 15 2004, Section 9.2.
- Color Inconstancy Index (CII) computed in relation to a user-selectable reference illuminant.
- Measurement Conditions: M0, M1, or M2; as defined in ISO 13655-2009.
- Standard Observer: 2 degree (CIE1931) or 10 degree (CIE 1964).
- Color difference formula for CII and SMI computation:
  - CIELAB
  - CIE94, i.e CIE94(1:1)
  - CIE94 textile, i.e. CIE94(2:1)
  - CIE94(2:2) (recommended by Berns for metamerism analysis)
  - CMC(2:1)
  - CMC(1:1)
  - CIEDE2000
- Illuminant selection:
  - Standard illuminants: A, B, C, D50, D55, D60, D65, D75, E, F2, F7, F11
  - Two optional ambient illuminants which can be either measured or loaded from a file.
  - The above selection is available for: *Reference illuminant*, *Test illuminant*, CII reference illuminant.
- Chromatic Adaptation Transform (CAT) for the CII: CIECAT02 or Bradford (see the Preferences dialog).
- Data input: Instrument or file input; a connected instrument is NOT required for file input.
- Supported instruments: Any i1Pro series spectrophotometer. An ambient adapter is required for ambient measurements (the adapter is an option in some models).
- Input file formats (reflectance): CGATS or Plain text files; 380-400 nm to 700-730 nm spectral ranges; 10 nm bandwidth. The reflectance values shall be defined between zero and one, with one representing full (100%) reflectance or between 0 and 100. The file may contain one or more spectrums; you can drag-and-drop a file on a "Load…" button.
- Input file formats (ambient): CGATS or Plain text files; 380-400 nm to 700-730 nm spectral ranges; 10 nm bandwidth. The file must contain one spectrum; you can drag-and-drop a file on a "Load…" button.
- See the measured patches as if in a virtual light booth.
- Save all results in a text report.
- The measured reflectance spectrums of the *Reference* and *Sample* patches can be exported in a CGATS compliant text file.
- A measured ambient spectrum can be exported as a CGATS compliant text file.

14.9.8 RAL DESIGN tool – Specifications

Help section: RAL DESIGN tool

- Get the RAL DESIGN Hue-Lightness-Chroma (HLC) coordinates of a color patch. L*a*b* and L*C*h (D65, 10 degree Observer) are also displayed.
- Data input: Instrument or file input; a connected instrument is NOT required for file input.
- Input file formats: CGATS or Plain text files; 380-400 nm to 700-730 nm spectral ranges; 10 nm bandwidth. The reflectance values shall be defined between zero and one, with one representing full (100%) reflectance or between 0 and 100. The file may contain one or more spectrums; multiple files can be inputted with drag-and-drop on the "Load file…" button. The input data is immediately converted and saved in a CGATS text file.
- If you are using an i1Pro 2 with the "i1Pro / i1Pro 2 (XRGA)" driver, an i1Pro 3, or an i1Pro 3 Plus, all measurements will be taken with the three Measurement Conditions, M0 (Ill-A), M1 (D50), and M2 (UV-cut), as defined in ISO 13655-2009. If you are using an i1Pro, or an i1Pro 2 with the "i1Pro / i1Pro 2 (non-XRGA)" driver, the program will select the default measurement conditions supported by the instrument.
- Save all results from an instrument measurement in a text report. The report includes the spectral data for all applicable Measurement Conditions.

14.9.9 Whiteness tools – Specifications

Help section: Whiteness tools

- Measure the whiteness, tint, brightness, fluorescence, and opacity of white papers.
- Whiteness and Tint formulas: CIE-GANZ 82, CIE-Uchida, CIELAB-HE 2007.
- Brightness and Fluorescence: Based on TAPPI T452 / ASTM D985.
  - **Note:** There are sufficient differences between an i1Pro series spectrophotometer and an instrument designed expressly for the requirements of TAPPI T452 or ASTM D985, that you should not expect to match the results obtained with qualified equipment. However, the instrument geometry is close, the lamp source is of the required type, the blue wavelength band is simulated in software, and the reference white can be derived from the standard instrument calibration in reflectance.
- Opacity: As per CGATS.5 / ISO 2471.
- Data input: Instrument input only (except UV filter). An i1Pro M0 or an i1Pro 2 M0/M1/M2 must be used.
- Input file formats (UV filter): CGATS or Plain text files; 380-400 nm to 700-730 nm spectral ranges; 10 nm bandwidth. The transmittance values shall be defined between zero and one, with one representing full (100%) transmittance. The file must contain one spectrum.
- **Important:** Fluorescence measurements with an i1Pro also require a thin, transparent, UV filter, which is not provided. You can use the default UV filter spectrum, load a filter spectrum from a file, or measure your own filter and assigned it as the program default.
- **Note:** Whiteness, Tint, Brightness, and Fluorescence measurements require a compliant white backing. Opacity measurements require a compliant black backing. Backing are not provided but compliance checking tools are included (see below).
- White backing compliance: Check the compliance of a white backing as per ISO 13655.
- Black backing compliance: Check the compliance of a black backing as per ISO 5-4.
- Derive a UV filter spectrum : Derive the spectral characteristics of an unknown UV filter to be used for fluorescence measurements
- Export the results and the measurements in a CGATS compliant text file.
- Export an image of the spectrums in PNG, BMP, or JPG format. You can select to generate the image at a 1X or 2X scale (double resolution and size).

14.10 System requirements

32 bit vs 64 bit: The CT&A 32 bit executable for Windows can run on 32 bit and 64 bit Windows systems. For the macOS, the program is provided in a 64 bit package.

Windows

Minimum:

- Windows 7
- 1.0 GHz
- 2 GB RAM
- 1024 x 768, 32 bit color (the tool bar should be hidden to maximize the display area)

Recommended:

- Compatible with Windows 7 / Windows 8.1 / Windows 10.
- 1.0+ GHz
- 2+ GB RAM
- 1280 x 1024, 32 bit color
- Calibrated display

Mac OS

Minimum:

- Intel Mac: Mac OS X 10.10.5 (Yosemite)
- 1.0 GHz
- 2 GB RAM
- 1024 x 768, 32 bit color (the task bar should be hidden to maximize the display area)

Recommended:

- Compatible from Mac OS X 10.10.5 (Yosemite) to macOS 10.15.5 (Catalina)
- 1.0+ GHz
- 2+ GB RAM
- 1280 x 1024, 32 bit color.
- Calibrated display

macOS 10.15 Catalina support:

- At the time of writing this manual no issues were found while using CT&A with macOS 10.15.5 Catalina. Please consult the Mac OS compatibility page on the BabelColor Web site for more information and the current status.

Help file

- Requires a PDF file type reader. A free “Acrobat Reader” application, from Adobe, is available at the following Web site:
  - https://www.adobe.com/acrobat/pdf-reader.html .

  Note: Acrobat Reader is now available in two distribution modes, called “tracks”: “Continuous track” and “Classic track”. The Continuous track, offered by default, is a “cloud” version which gets updated as required, without user control. The Classic track is similar to the older program version which gets updated at fixed intervals. If you prefer the older version, you can locate the download file by searching for “DC Classic Track Release” with your favorite search engine. This link contains more information:

  https://www.adobe.com/devnet-docs/acrobatetk/tools/AdminGuide/whatsnewdc.html

14.10.1 Display calibration

CT&A is color-managed and will automatically load the profile associated to the display on which a window is displayed (see the Preferences dialog for more info). The tools in which a display profile is used for rendering color patches are: RGB vs RGB, CRI, Density, FluoCheck, Graph, Metamerism Index, and RAL DESIGN.

In order to maximize the usefulness of the color patches displayed in CT&A, a calibrated display is thus strongly recommended; however, a lack of calibration will not affect the numerical values or the conversion accuracy. If you do not have access to dedicated display calibration hardware and software tools, we suggest you use the following contrast adjustment procedure to optimize the display contrast and its dynamic range. If you have access to calibration instruments, then you most likely already measured and assigned a custom ICC profile for your display and no further calibration should be required; in this case, we suggest that you only check your display, without making hardware adjustments (go over Steps 8 and 9).

Note: Monitors' On-Screen-Displays (OSD) sometimes offer presets such as sRGB or Adobe (1998) RGB which, when selected, disable the monitor contrast and brightness controls. In the absence of any calibration equipment, you should select such settings and use the following procedures for checking purposes only.

Note: The following procedures were originally written for CRT (Cathode Ray Tube) displays. Since many LCD (Liquid Crystal Displays) flat panels do not have individual contrast and brightness adjustments, you can only use the procedures for evaluation. In addition, some LCD display technologies are more susceptible to exhibit rapidly changing luminance, color and contrast characteristics with different view angles; if this is the case with your monitor, it is important to maintain the same horizontal and vertical view angles relative to the display.

Important: Since displays can represent only a subset of the colors humans can see, a selected or measured color in CT&A may well be out of the display profile range (*gamut*). When this happens, clip indicators are shown in the bottom-left or bottom-right corner of the corresponding patch. Please note that no clip indicator should appear while doing the following procedures.

Contrast Adjustment/Check

This procedure is based on Ref. 4.

1. Open the computer and let the display stabilize for at least 30 minutes (60 minutes plus recommended), making sure that the screen saver does NOT start during this period.
2. Dim the room lights, and make sure no direct light comes through the room windows.
3. Start CT&A.
4. Open the Preferences dialog. This dialog is called with the "Edit/Preferences..." menu command in Windows or the "CT&A/Preferences..." menu command in Mac OS X. Verify that the proper profile is assigned to each display. If this is not the case, use your OS display control panel to change the assignment (the CT&A dialog can remain open). In the "Math" tab, uncheck "Always use a single parameter gamma". Close the Preferences dialog when done.
5. Open the RGB vs RGB tool window and close all other tool windows. Set both sides to R'G'B' space mode and R'G'B' data input (i.e. the "L*a*b*/L*u*v* input" checkbox should NOT be checked!). Select a space whose gamma corresponds to your display; this will often be sRGB for a standard gamut display and Adobe (1998) RGB for a wide gamut display, but it can also be eci_RGB_v2 with a L-star gamma. You can also define a custom RGB space with a gamma of your liking. Assign the same space on both sides.
6. Bring the "Y" sliders of both spaces to zero (i.e. pure black with R', G' and B' = 0).
7. Raise the "Y" slider of Space #2 to 16 (i.e. R'G'B'=16). This very dark gray is displayed in the smaller center patch.
8. **(Do NOT perform if checking)** Set the display contrast control, usually represented by a circle with two contrasting halves, to its highest setting.
9. **(Do NOT perform if checking)** Adjust the brightness control, usually represented by a "sun" logo (circle with rays), to make the center patch as dark as possible, but not black.
10. If you have problems distinguishing the contrast between the two patches, simultaneously raise all the sliders of Space #2 by increasing the "Y" slider by steps of 1 or 2 and readjust the display brightness control. On the other hand, you can try lowering the Space # 2 values and further increase the display brightness until it is no longer possible to do Step 9. It is not unusual to be able to see the center patch when Space #2 is as low as 12 (i.e. R'G'B'=12), or even lower.

For information: Setting Space #2 at R'G'B'=16 corresponds to a DeltaE*ab color difference of 6,27 in eci_RGB_v2, 4,68 in sRGB, and 2,04 in Adobe (1998) RGB.
Important: We do not recommend increasing the display brightness control above the point where a patch corresponding to RGB values of 10 or less is noticeable with just a glance (i.e. a fraction of a second).

Important: If you had to change a profile using the OS display control panel, make sure the LUTs corresponding to the selected profile are loaded. In particular, for Windows computers, the LUTs are NOT updated when the display profile is changed using the display properties dialog. A dedicated LUT loading application, or a reboot, is required.

Note: This procedure is similar to the first steps of the "Adobe Gamma" Control Panel formerly provided with most products from Adobe Systems Inc. Please note that "Adobe Gamma" used a center patch value of 38 (sRGB) which is, in our view, too high.

Note: Color accuracy is not obtained with this procedure. Also, obtaining neutral grays require additional display adjustments. Nonetheless, relative color comparison can still be done.

Highlight Check

This procedure enables you to verify that your display is not saturated when displaying pure white, i.e., that it can show details in the highlights. The contrast adjustment/check procedure should be done prior to this check.

1. Open the Preferences dialog. This dialog is called with the "Edit/Preferences..." menu command in Windows or the "CT&A/Preferences..." menu command in Mac OS X. Verify that the proper profile is assigned to each display. If this is not the case, use your OS display control panel to change the assignment (the CT&A dialog can remain open) and redo the **Contrast Adjustment/Check** procedure described above. In the "Math" tab, uncheck "Always use a single parameter gamma". Close the Preferences dialog when done.
2. Open the RGB vs RGB tool window and close all other tool windows. Set both sides to R'G'B' space mode and R'G'B' data input (i.e. the "L*a*b*/L*u*v* input" checkbox should NOT be checked!). Select a space whose gamma corresponds to your display; this will often be sRGB for a standard gamut display and Adobe (1998) RGB for a wide gamut display, but it can also be eci_RGB_v2 with a L-star gamma. You can also define a custom RGB space with a gamma of your liking. Assign the same space on both sides.
3. Set all Space #1 RGB values to 255 and all Space #2 RGB values to 251.
4. You should be able to see the lower intensity center patch; these settings correspond to a 1,57 DeltaE*ab color difference in eci_RGB_v2, 1,38 in sRGB, and 1,34 in Adobe (1998) RGB. If the patches look the same, lower the Space #2 values until you see a difference. You could try lowering the display brightness to see if it affects saturation but this may also affect your contrast adjustment and ability to distinguish shadows, so we do not recommend that you change any setting when checking highlights.

14.11 Version history

Version 6.0.7 b407 (2022-04-22) (Maintenance release)

Improvement:

- Spectral data in CGATS and TEXT files (see "**Input file formats**" in Specifications - Spectral tools): In the past, if 380 nm data was detected, 730 nm data was required; also, if spectral data started at 400 nm, the program looked only for 700 nm data. Now, data is required between 400 and 700 nm. Any valid data between 380 and 730 nm will be used. Missing data will be extrapolated to complete the 380 to 730 nm range necessary for processing. Spectral data lower than 380 nm and higher than 730 nm is discarded.
    - This improvement affects the following tools: CRI, ISO 3664+, Metamerism Index (color patches, illuminant), RAL DESIGN, Whiteness.

Bug fixes:

- CRI tools: Now will not round the data on the chroma shift graph of TM-30-20 reports and will show a decimal for values between -10 and +10.
- Density tools:
    - The "Show (Ref.)" checkbox is now unselected and disabled when first opening the tool.
    - SCTV is computed even if another formula (Murray-Davies or Yule-Nielson) is selected in the "Dot / Tone (Dot Area)" tool. The problem was noticeable when saving the measurements.
    - Now properly displays the measurement conditions in the dialog and file name when saving Density measurements for instruments which do not support multiple measurement conditions.
- RGB vs RGB tool: Now updates the RGB vs RGB chromaticity diagram to the mouse-down event position when rapidly dragging the mouse afterwards with the mouse button down. Before the fix the canvas was updated only when not moving, moving slowly, or bringing the mouse outside the chromaticity graph.

Other:

- CRI tools: Replaced TM-30-18 references by TM-30-20 (Ref. 57). The TM-30-20 version integrates Annex E and Annex F (Ref. 67-68) which were published separately after TM-30-18 was issued and it has a new page layout. The computation methods and the technical content are the same in both versions.
- New compiler version version with revised APIs. This compiler improves compatibility with recent OSs.

Version 6.0.6 b402 (2021-11-03) (Maintenance release)

Bug fix:

- TIFF images from CT&A can now be opened in Photoshop CC 23: TIFF images from CRI / TM-30-18 reports and ISO 3664+ / ISO 12646 Targets now include the specific data required by CC 23. Adobe may also have fixed the issue so that TIFF images from previous CT&A versions will also open.

Other:

- i1Pro 2 and i1Pro 3 instruments (from X-Rite): The libraries/DLL (Windows) and Frameworks (macOS) have been updated to their latest versions.

Version 6.0.5 b401 (2021-04-08) (Maintenance release)

Bug fix:
- (macOS Big Sur 11) RGB vs RGB tool: Improved program stability when resizing the window.

New feature:
- ISO3664+ tools: Now shows the MI value as well as the MI Quality Grade on the screen.

Improvement:
- CRI tools: The TM-30 Color Vector Graphic (CVG) graph is now smoothed (screen and reports).

Version 6.0.1 b399 (2020-10-07) (Maintenance release)

Bug fix:
- (Mac 64 bit only) Display profile recognition: Now properly identifies the profile of additional displays connected to a given computer instead of assigning the main display profile. This bug affected the rendering of patches on secondary displays.

Version 6.0 b398 (2020-08-03)

New features:

- Added support for the X-Rite i1Pro 3 and i1Pro 3 Plus spectrophotometers:
    - These instruments are available in all tools.
    - Supported measuring modes: reflectance, emission, ambient illumination. These modes are not available in all tools.
    - M0/M1/M2 Measurement Conditions: available in all tools with reflectance input.
    - M3 Measurement Conditions (i1Pro 3 Plus): available in the Density and Graph tools.
- Munsell tools: A bidirectional set of tools to convert FROM and TO Munsell **Hue Value/Chroma** (HVC).
    - Convert from Munsell to RGB and L*a*b*.
    - Convert from RGB to Munsell.
    - RGB spaces: The 24 standard spaces plus the Custom space defined in the RGB vs RGB tool.
    - Convert from L*a*b* to Munsell.
    - L*a*b* illuminants: 15 predefined illuminants plus a Custom illuminant defined in the RGB vs RGB tool.
    - Measure spectral data and convert to Munsell.
    - Supported instruments: X-Rite i1Pro series spectrophotometer. Measurements Conditions: M0, M1, M2 (when supported by the instrument).
    - Instruments supported in 32 bit and 64 bit packages.
    - Export a report with tab-delimited data that can be directly imported in a spreadsheet program and opened in many text editing applications. The report spectral measurements can also be read by software, such as BabelColor PatchTool, which can open CGATS compatible files.
- Density tools: Added support for the M3 (Pol.) Measurement Conditions. Requires an i1Pro 3 Plus.
- Graph tools: Added support for the M3 (Pol.) Measurement Conditions. Requires an i1Pro 3 Plus.
- CRI tools: Added computation and display of TM-30-18 Color Rendition Categories (Preference, Vividness, Fidelity) in three Priority Levels as defined in TM-30-18 Annex E. The Color Rendition performance can be included in text file and graphics reports.

Improvements (same as for Version 5.5.0 b389):

- Whiteness tools: Now check if there is a measurement with a filter before changing the filter setting.
- (Mac) Now assigns more noticeable background colors to many data fields for “non-English” systems.

Bug fixes (same as for Version 5.5.0 b389):

- Density tools:
    - Now recomputes the Dot / Tone (Dot Area) and Apparent Trap when remeasuring the paper.
    - The paper status stays green if new paper measurements fail. Old measurements remain valid.
    - Now recomputes the SCTV paper data when changing the Measurement Conditions.
    - Now exports the correct “Average D_sol” when saving SCTV data.
- CRI tools: The program will now correctly reselect a previously selected row when a non-selected row is deleted or when many rows without the selected row are deleted.
- Spyder5 and SpyderX: The program now properly detaches these instrument libraries when the instrument is deselected.
- RGB vs RGB Custom space: Now shows the proper primaries when the default Custom space is shown the first time the Custom space dialog is opened.

Other:

- (Mac 64 bit only) The provided 64 bit install files are compliant with current Apple notarization requirements. Notarization is required for some software in macOS 10.14.5 and is mandatory for all software starting with macOS 10.15. Please note that any software meeting notarization requirements may not be fully compatible with a given OS version; see the CT&A system requirements for more information.
- (Mac) The program is now released in a 64 bit package only. This change main effect is to drop support of legacy instruments for which 64 bit DLLs/Frameworks are not available. Please consult the Toolbar “Supported instruments” section for more information.

Version 5.5.0 b389 (2020-08-03) (Maintenance release)

Improvements:

- Whiteness tools: Now check if there is a measurement with a filter before changing the filter setting.
- (Mac) Now assigns more noticeable background colors to many data fields for "non-English" systems.

Bug fixes:

- Density tools:
  - Now recomputes the Dot / Tone (Dot Area) and Apparent Trap when remeasuring the paper.
  - The paper status stays green if new paper measurements fail. Old measurements remain valid.
  - Now recomputes the SCTV paper data when changing the Measurement Conditions.
  - Now exports the correct "Average D_sol" when saving SCTV data.
- CRI tools: The program will now correctly reselect a previously selected row when a non-selected row is deleted or when many rows without the selected row are deleted.
- Spyder5 and SpyderX: The program now properly detaches these instrument libraries when the instrument is deselected.
- RGB vs RGB Custom space: Now shows the proper primaries when the default Custom space is shown the first time the Custom space dialog is opened.

Version 5.4.5 b386 (2019-11-26)

Improvements:

- NTSC RGB space (RGB vs RGB tool): Tweaked the RGB to XYZ and XYZ to RGB matrices of the NTSC RGB space in order to better match the space illuminant coordinates.

Bug fix:

- (Mac 64 bit only) Fixed a bug affecting all windows showing color-corrected patches. The bug generated a NilObjectException error message before shutting down the program. The problem affected the most recent macOS versions (Yosemite, Catalina).

Other:

- macOS 10.15 Catalina support: At the time of writing this manual no issues were found while using this version of CT&A with macOS 10.15.1 Catalina. Please see the CT&A system requirements for other OS requirements.

Version 5.4 b384 (2019-10-01)

New features:

- Added support for the Datacolor SpyderX colorimeter:
    - This instrument is currently used in the "RGB vs RGB" tool (and not in the spectral tools).
    - Supported models: SpyderX Elite, SpyderX Pro.
    - Select any of the four Datacolor-provided calibration matrices: Any monitor, Standard gamut LED, Wide gamut LED, GB LED.
    - Instrument supported in 32 bit and 64 bit packages.
- Added support for the Datacolor Spyder5 colorimeter:
    - This instrument is used in the "RGB vs RGB" tool (and not in the spectral tools).
    - Supported models: Spyder5ELITE, Spyder5PRO, Spyder5EXPRESS.
    - Select any of the four Datacolor-provided calibration matrices: Any monitor, Wide gamut LCD w/CCFL backlight, Wide gamut LCD w/RGB LED backlight, Wide gamut LCD w/CCFL2 backlight.
    - Select between two measurement speeds.
    - Instrument supported in 32 bit and 64 bit packages.

Bug fixes:

- CRI tools:
    - The program will not crash when generating a TM-30-18 report that contains non-valid numbers derived from severely non-compliant light sources (such as red only).
    - A Duv too big is now shown as “OOR” (Out-Of-Range) instead of “1000” (an extremely high Duv value) in TM-30-18 reports.
    - The CRI tool and CRI reports now show “OOR” (Out-Of-Range) instead of “999 K” for values too low and “100001 K” for values too high.
    - (Mac) Changed the tool shortcut letter from “command+shift+Q” (a log-out shortcut) to “command+shift+T”. While this was not a problem in Windows, we changed the tool shortcut letter from “Ctrl+shift+Q” to “Ctrl+shift+T” in Windows.
- RGB vs RGB tool: Now properly refreshes the DeltaE formula menu and the Delta labels when the tool window is first opened.
- (Mac 64 bit only) Selecting "Try to connect again..." in the Instrument menu now correctly selects the previous instrument.

Other:

- Instrument calibration is now required before the next measurement whenever the instrument is changed.
- A “Forced deactivation…” menu item is added to the Help menu. This procedure may be helpful when the status of the Product Key activation is ambiguous (i.e. when the “Activate” menu is available even if the program was known to be activated on this specific computer).
- (Mac 64 bit only) The provided 64 bit install files are compliant with current Apple notarization requirements. Notarization is required for some software in macOS 10.14.5 and will be mandatory for all software starting with macOS 10.15. Please note that any software meeting notarization requirements may not be fully compatible with a given OS version; see the CT&A system requirements for more information.

Version 5.3 b380 (2019-01-15)

New features:

- IES TM-30-18 / CIE 224:2017 (CRI tools): Added the 2018 version of the *IES Method for **Evaluating Light Source Color Rendition*** to the CRI tools (https://www.ies.org/).
    - TM-30-18 is an update of TM-30-15 required in order to harmonize it with CIE 224:2017 (which is only concerned by the Color Fidelity Index (*Rf*)). The *Rf* of TM-30-18 and CIE 224:2017 are identical.
    - In addition to the text file report which is available to all metrics, it is possible to generate graphic reports as per the TM-30-18 method guidelines. Three report types are available: **Simple**, **Intermediate**, and **Full**. These reports are saved as images in PNG, TIF, BMP, or JPG format. The image resolution is selectable at 96, 150, 300, or 600 DPI.
- TM-30-15 and TM-30-18 (CRI tools): We now compute the Local Chroma Shift (*Rcs,h*) and Local Hue Shift (*Rhs,h*) for all Hue Angle Bins in addition to the previously available Local Color Fidelity (*Rf,h*).
    - It is now possible to display the Local Chroma Shift or Local Hue Shift graph in the CRI tool window.
    - It is now possible to export the Local Chroma Shift and Local Hue Shift data in text reports (You can also export Local Chroma Shift and Local Hue Shift data in graphic reports for TM-30-18).
- Spectral interpolation ("Math" tab of the Preferences dialog):
    - In previous versions, when required, interpolation of 5 nm values from 10 nm spectrums was performed with the "Lagrange" method. You can now select between the "Cubic spline" and the "Lagrange" methods.
    - Used for all computations in the CRI tools.
    - Used for the CRI and the Visible Metamerism Index (MI, ISO 23603) in the ISO 3664+ tool.
    - Used to compute the CRI in the Graph and MI tools.

Bug fix:

- RGB vs RGB tool (Windows version only): Fixed the issue where the RGB vs RGB window minimal size was not properly assigned. This problem could be seen in systems with high resolution displays where the display magnification is higher than 100%.

Other:

- TM-30-15 and TM-30-18 (CRI tools):
    - Moved the CIECAT02 gamut fix option to the "Math" tab of the Preferences dialog.
- CRI export data dialog TM-30 data fields:
    - Added the Local Chroma Shift (*Rcs,h*) and Local Hue Shift (*Rhs,h*) data fields.
    - Removed the less pertinent chromaticity and CVG data fields (*J'a'b'*, *a'b'(avg)*, CVG data).
    - You can export either TM-30-15 or TM-30-18 data, or both.
- CRI tools: Tweaked the Out-Of-Range colors and thresholds of the CRI metrics results.

Version 5.2 b374 (2018-07-26)

New features:

- Density tool: Added the SCTV formula for "Dot / Tone (Dot area)" measurements (SCTV: Spot Color Tone Value, as defined in ISO 20654:2018 "*Graphic technology — Measurement and calculation of spot colour tone value*").
- RGB vs RGB tool:
    - It is now possible to define an RGB space with negative chromaticity coordinates when using the Custom RGB space dialog. As before, the Custom RGB space settings can be used to generate an ICC profile.
    - Because negative chromaticities may result in negative xyY and XYZ values, an option to clip or not the xyY and XYZ data values to zero was added to the "Math" tab of the Preferences dialog.
    - Four (4) new standard RGB spaces were added to the RGB space selection menu: ACES AP0; DCI P3 Theater; Display P3 (used on Macs by Apple); Rec. 2020 (UHDTV).

Improvements:

- RGB vs RGB tool: The following control settings are now saved and reassigned when the program reopens: RGB space selection menu; RGB input values; L*a*b*/L*u*v* menu; L*a*b* / L*u*v* in D50 checkbox; L*a*b*/L*u*v* input values; DeltaE* formula selection menu.

Bug fixes:

- Activation: Fixed an issue where an OutOfBoundsException message was shown if attempting activation when the computer Ethernet cable was not connected to a router. The OFFLINE activation dialog is now shown.
- RGB vs RGB tool (macOS): Fixed the issue where the text within some buttons was clipped in high resolution displays.

Other:

- This version was compiled in 32 bit executable files (Mac and Windows) and a 64 bit executable package is also available for Mac.
- (Mac 64 bit only) Instrument support changes:
    - The following instruments/drivers are no longer available:
      Eye One Display, i1Pro / i1Pro 2 (non-XRGA).
    - The following instruments/drivers remain available:
      i1Display Pro, i1Pro / i1Pro 2 (XRGA).
- (Mac) The minimum system requirement is now Mac OS X 10.9.5 (Mavericks).

Version 5.1 b364 (2017-01-31)

New features:

- Metamerism Index (MI) tools:
    - Added the *Metameric Index* (MI) computed according to CIE15:2004, Section 9.2.2.3. This index is computed when the *Special Metamerism Index* (SMI) obtained with the *Reference illuminant* is NOT zero. The MI is derived with a Multiplicative Correction applied to the data of the *Sample* patch obtained with the *Test illuminant*.
    - Note: The MI computed in previous versions, based on the HunterLab formula, is still available. It is now identified as "MI (HunterLab)".
    - File input: It is now possible to enter spectral data from a file in addition to measurement from an instrument. A connected instrument is NOT required for file input. Input can be assigned to any of the supported Measurement Conditions (M0, M1, or M2).
    - Input file formats: CGATS or Plain text files; 380-730 nm or 400-700 nm spectrum ranges; 10 nm bandwidth. The file may contain one or more spectrums; multiple files can be inputted with drag-and-drop.
    - In addition to the MI report, you can now save the *Reference* and *Sample* patches spectrums in a CGATS format text file, which can easily be used for file input afterwards.
- RAL DESIGN tool:
    - File input: It is now possible to convert spectral data from a file. A connected instrument is NOT required for file input. The input data is immediately converted and saved in a CGATS format text file.
    - Input file formats: CGATS or Plain text files; 380-730 nm or 400-700 nm spectrum ranges; 10 nm bandwidth. The file may contain one or more spectrums; multiple files can be inputted with drag-and-drop.
    - Output data: L*a*b* computed with Illuminant D65 and the 10 degree Observer; the color in RAL DESIGN notation; the individual RAL Hue, Lightness, and Chroma (HLC) components.

Improvements:

- CRI tools: Data table interface improvements.
    - Now updates the CRI window when browsing in the data table with the up-down arrows; there is no need to do a carriage return.
    - Will now select all ambient sources added by drag-and-drop in the data table.
    - The last input is always selected for display purposes and the data table is automatically scrolled to the bottom.
    - When measuring a light source with an instrument, the sample name is selected and you can edit it immediately.
- FluoCheck tools: When saving the report from an instrument measurement, the report now includes the spectral data for all Measurement Conditions.
- RAL DESIGN tool: When saving the report from an instrument measurement, the report now includes the spectral data for all applicable Measurement Conditions.
- RGB vs RGB tool: The CIEDE2000 color difference is now computed with the alternate three terms form equation in which the fourth term associated with rotation (RT) is now integrated with the chroma and hue differences. The DeltaE* display of the RGB vs RGB tool now shows the weighted ΔL_{00}, ΔC_{00}, and ΔH_{00} values (and $\Delta h'$), instead of the unweighted ΔL^*, ΔC^*, and ΔH^* values (and Δh).
- Preferences – Color tab: The dialog now includes buttons which open various folders where user and system display profiles are stored.

Other:

- Preferences – Color tab (Mac): Because Apple ColorSync is deprecated, it is no longer possible to provide the path of a display profile. The name of the profile assigned to a monitor is still available.
- Windows OS: Windows Vista is no longer supported.
- i1Pro DLL (Windows): Version 4.2.3 of the library (i1Pro.dll) is now provided with the program.

Version 5.0 b358 (2016-06-20)

New features:

- IES TM-30-15 (CRI tools): Added the *IES Method for* ***Evaluating Light Source Color Rendition*** to the CRI tools (https://www.ies.org/).
    - Data output: The Fidelity Index (*Rf*); the Gamut Index (*Rg*); the fidelity index for skin (*Rf,skin*); the color fidelity (*Rf,ces*) for each of the 99 Color Evaluation Sample (CES); the color fidelity (*Rf,h*) for each of the 16 Hue Angle Bins; the chromaticity coordinates (*J'a'b'*) of all CES reference and test patches; the color difference (*DeltaE'*) for each set of CES patches; the average chromaticity coordinates (a'_M, b'_M) of the Hue Angle Bins; and the normalized chromaticity data used to draw the Color Vector Graphic (CVG).
    - Graph displays: A graph of the reference source, which is different from the source used in other color rendering metrics when the CCT is between 4500 K and 5500 K; a bar graph of the color fidelity by sample (*Rf,ces*); a bar graph of the color fidelity by Hue Angle Bin (*Rf,h*); a graph of the average chromaticity (a'_M, b'_M) of the reference and test data of the Hue Angle Bins, which is used to compute the gamut area; a Color Vector Graphic (CVG) used to evaluate color saturation and desaturation; a plot of *Rg* versus *Rf*; and a visual representation of the 99 CES reference and test patches.
    - Data input: Instrument or file input; a connected instrument is NOT required for file input.
    - Input file formats: CGATS or Plain text files; 380-730 nm or 400-700 nm spectrum ranges; 5 nm or 10 nm bandwidth. The file may contain one or more spectrums; multiple files can be inputted with drag-and-drop.
    - Supported instruments: Any i1Pro or i1Pro 2 with ambient adapter (the adapter is an option in some models).
    - Input is processed internally with a 5 nm bandwidth; 10 nm data is interpolated to 5 nm.
    - Custom export dialog: Select amongst the data used for the graphs, the general and specific metrics indices, and the Test source data.
    - Export all measurements or only selected measurements.
    - Export in a single file report or in a batch of individual files (one file per measurement), or both options.
    - The single file report or the individual files can be exported in either CGATS format, which can easily be used for file input afterwards, or in Plain text format.
- ISO 3664+ tools: Data entry forms were added to fill the reports description data fields. The forms appear when you press the 'Print report…' button. Two forms are presented, one for the P1, P2, and T1 Viewing Conditions, and another for the Color monitors Viewing Condition.

Improvements:

- CRI tools:
    - You can now select one or two of the available metrics, in any order, for better display use.
    - A separate button was added to load a file from an input menu; this is useful if an instrument is not connected when you use the CRI tools. You can also drag and drop one or more files on the button (you can still drag and drop files on the data table!).
    - You can now open files with more than one spectrum.
    - You can now also select the CGATS file type for 'One file' reports; this is useful if you want to open all your measurements from one file afterwards.
    - A 'Resample' option was added to the 'Spectrum bandwidth' section of the CRI export dialog. This option is recommended when you export measurements made with a 5 nm bandwidth to a 10 nm bandwidth.
- ISO 3664+ tools:
    - A separate button was added to load a file (with one spectrum) from an input menu. You can also drag and drop one (1) file on the button.
    - Because of this new button, you can now load a file even if an instrument is NOT connected!

Bug fixes:

- ISO 3664+ tools (Windows version only): Now correctly shows the text and background colors of the PASS/FAIL labels. Please note that the text was always correct.
- ISO 3664+ tools (Mac version only): Corrected a problem where, is some cases, the arrow buttons did not change the measurement position. Before the fix, the workaround was to first press on the 'Tab' key before using the arrow buttons.

Other:

- New licensing system:
  - Licensing is now based on a 'Product Key' which is used to activate a specific computer.
  - You can transfer a Product Key to another computer by deactivating the first computer and activating the second one. If you are connected to the Internet, this process is free and you can repeat it as you require. If the computer is not connected to the Internet, offline activation and deactivation is possible but a service fee is required for each activation; this fee can be paid from the BabelColor Web site.
  - The same key can be used for the Mac and Windows versions (one OS at a time!).
  - Once a Product Key is activated on a computer, an Internet connection is not required.

Version 4.6.1 b346 (2016-04-26)

Bug fix (Windows version only):

- ISO 3664+ tools: Fixed a bug, introduced in Version 4.6, causing printed reports to be empty pages.

Version 4.6 b345 (2016-04-05)

New feature:

- RGB vs RGB tool: Added computation and display of the Web Content Accessibility Guidelines (WCAG) Contrast Ratio for text content (https://www.w3.org/TR/2008/REC-WCAG20-20081211/).
  - Get the Contrast Ratio as well as Go/No-Go flags for the Minimal contrast requirements (Level AA) and for Enhanced contrast (Level AAA), for both *Normal text* and *Large text*.
  - Get the Contrast Ratio and contrast acceptance data for either one of the selected colors against a white or black background, and for one color against the other.
  - The WCAG results can be printed in a text-based report.

Improvements:

- Display profile:
  - When rendering a color patch, the program uses the profile assigned to the display corresponding to the window position. If the window is moved to another display, the patches are rendered with the new display profile; there is no need to manually select a profile in multi-display systems.
  - The Preferences dialog now shows the names and file locations of the profiles assigned to all connected displays. It also shows the profile corresponding to its location.
- (Mac) The program is now compiled using the 'Cocoa' Framework instead of the 'Carbon' Framework, which was made possible by dropping support for PowerPC. Some of the effects of this change are:
  - GUI appearance; for instance, the windows can now be resized by dragging any edge.
  - More accurate color rendition with wide gamut displays, and, for all displays, a better match with the numbers shown by the Mac 'Digital Color Meter' Utility.

Bug fixes:

- CRI: The patches displays are now erased when all measurements are deleted.
- Whiteness tools: Now shows the percentage sign for opacity in the saved image.

Version 4.5.2 b335 (2015-11-23)

Bug fixes:

- Graph and Whiteness tools: Solved an issue where in some OS configurations the saved image was incomplete and was not generated with a 2X scale.
- RGB vs RGB tool: Illuminance (ambient) measurements with the i1Display Pro are now provided with the correct scaling.

Other:

- (Windows) The Help manual is no longer available in a self-contained compiled HTML application; it is now provided as a PDF file.

Version 4.5 b327 (2014-12-19)

New features:

- ISO 3664+ tools / Color monitors: Added support for measuring the Tone uniformity (i.e. Color uniformity, Section 4.2.2) and Tonality Evaluation (i.e. Grey/White Tone ratio uniformity, Section 4.2.3) requirements of ISO 12646:2014-Final Draft.
  - Measurements are performed on targets located on a 5 x 5 uniform grid.
  - Measurements can be performed with White, Grey, and Dark-Grey targets.
  - Export a spreadsheet savvy text report or print a well formatted one-page report which presents the overall characterization information.
  - Built-in dialog to create image files of targets for any display size. Separate files are generated for the White, Grey, and Dark-Grey target patches. File formats: PNG or TIFF; RGB; 8-bit.

Improvements:

- ISO 3664+ tools / Color monitors: Improved the ISO 12646:2008 Brightness uniformity measurements interface (3 x 3 non-uniform grid).
  - Measurements can now be performed with White, Grey, and Dark-Grey targets instead of just White.
  - Built-in dialog to create image files of targets for any display size. Separate files are generated for the White, Grey, and Dark-Grey target patches. File formats: PNG or TIFF; RGB; 8-bit.
  - When doing measurements with the 'Take all' sequence, you can now change the target position at anytime (if you want to go back to redo a bad measurement for instance).

Other:

- Complete revision of Tutorial 8 of the Help manual (Measure your display characteristics with the ISO 3664+ tools).
- (Windows) The minimal system requirement is now Windows Vista. As previously announced, CT&A Version 4.2.1 was the last version to support Windows XP.
- (Mac) The minimum system requirement is now Mac OS X ~~10.6~~ 10.7. As previously announced, CT&A Version 4.2 was the last version to support PowerPC. ~~Future CT&A versions may require Mac OS X 10.7 (Lion) or newer.~~

Version 4.2.1 b317 (2014-10-23)

Bug fix:

- For Windows XP ONLY: The 'i1Pro / i1Pro 2 (XRGA)' instrument selection can make CT&A 4.2 b316 close unexpectedly on Windows XP computers. The problem was fixed by replacing the software libraries of the i1Pro Software Development Kit (SDK) Version 4.2.0 by those of an older SDK; as a consequence, the menu to check i1Pro / i1 Pro 2 lamp restore, introduced in CT&A 4.2, is not available in the software package dedicated to Windows XP.

Version 4.2 b316 (2014-07-28)

New features:

- CRI (Color Rendering Index) tools: Added a set of tools to evaluate the color rendering properties of white-light sources. The tools comprise the current CRI standard as well as proposed replacement metrics, and new metrics for gamut area and memory colors.
    - Test source data: CCT (kelvin); *Duv* (CIE1960); brightness (lux); LER (Light Efficiency Ratio, in lm/W); the Reference source (a blackbody or a D-Series illuminant).
    - CRI (Color Rendering Index): A graph of the 14 individual indices and *Ra*; numerical values of *Ra* (a general score based on the first 8 indices and better known as the current CRI), *R9*, *R(9-14)* (for indices 9 to 14) and *R(1-14)* for indices 1 to 14; a graph of the samples (*a*, b**) coordinates; a representation of the samples illuminated by the Reference and Test sources; the CIELAB color difference between the patches. Ref.: CIE 13.3: 1995.
    - CQS (Color Quality Scale, NIST Version 9.0.3): A graph of the 15 individual indices and *Qa*; numerical values of *Qa* (general score based on the 15 indices), *Qf* (fidelity index) and *Qg* (relative gamut area); a graph of the samples (*a*, b**) coordinates; a representation of the samples illuminated by the Reference and Test sources; the CIELAB color difference between the patches. Ref.: Wendy Davis, Yoshi Ohno, "Color quality scale," Optical Engineering 49(3), March 2010, 033602-1 to -16.
    - CRI2012 (nCRI Version 12.0): A graph of the 17 individual indices and *Ra,2012*; numerical value of *Ra,2012* (based on the 17 indices); a graph of the samples (a'_M, b'_M) coordinates; a representation of the samples illuminated by the Reference and Test sources; the color difference between the patches. Ref.: KAG SMET, J Schanda, L Whitehead, RM Luo, "CRI2012: A proposal for updating the CIE colour rendering index," Lighting Res. Technol. 2013; 45: 689-709.
    - GAI (Gamut Area Index): Ref.: Mark S. Rea, Jean P. Freyssinier-Nova, "Color Rendering: A Tale of Two Metrics," COLOR research and application, Vol. 33, No. 3, June 2008, 192-202.
    - *GAI and Ra*: The arithmetic mean of *GAI* and *Ra* (the current CRI). Ref.: Kevin Smet, Wouter R. Ryckaert, Michael R. Pointer, Geert Deconinck, and Peter Hanselaer, "Correlation between color quality metric predictions and visual appreciation of light sources," OPTICS EXPRESS, Vol. 19, No. 9, 25 April 2011, 8151-8166.
    - MCRI (Memory Color Rendering Index): *Rm* (general memory color quality index); *Sa* (degree of similarity); *Si* (special color quality indicators of the ten objects). Ref.: K.A.G. Smet, W.R. Ryckaert, M.R. Pointer, G. Deconinck, P. Hanselaer, "A memory colour quality metric for white light sources," Energy and Buildings 49 (2012) 216-225.
    - Data input: Instrument or file input; a connected instrument is NOT required for file input.
    - Input file formats: CGATS or Plain text files; 380-730 nm or 400-700 nm spectrum ranges; 5 nm or 10 nm bandwidth. The file must contain only one spectrum; multiple files can be inputted with drag-and-drop.
    - Supported instruments: Any i1Pro or i1Pro 2 with ambient adapter (the adapter is an option in some models).
    - Input is processed internally with a 5 nm bandwidth; 10 nm data is interpolated to 5 nm.
    - Custom export dialog: Select amongst the data used for the graphs, the general and specific metrics indices, and the Test source data.
    - Export a single file report with all measurements or only the selected measurements.
    - Export one file per measurement in either CGATS format, which can be used as file input, or in Plain text format. All measurements or only the selected measurements can be exported in batch.
- Color Management Module (CMM) changed from LCMS 1.19 to LCMS 2.5.
    - Full support of ICC v2 and ICC v4 profiles (LCMS 1.x had partial support of ICC v4 profiles).

Improvements:

- i1Pro and i1Pro 2:
    - Now supports the i1Pro SDK Version 4.2.0.
    - Added a menu to check i1Pro / i1 Pro 2 lamp restore. Lamp restoration is performed, if required, when the menu is called.
- Improved algorithm to compute the CCT. The algorithm is now more accurate over a larger chromaticity area. The acceptable isotemperature zone is between 1000 K and 100,000 K, with *Duv* (CIE1960) between +0.05 and -0.05.
    - Tools which benefit from the improvement: RGB vs RGB, CRI, Graph, ISO 3554+, Metamerism Index.

Version 4.0 b298 (2013-04-03)

New features:

- Toolbar window: The tools can now be accessed with new a top-level window which contains: a toolbar, controls to select a measuring instrument, and status lights for the features supported by the connected instrument (measurement modes, measurement conditions, spectral tools compatibility).
- Separate tools windows.
  - One or more tool can be opened and used at any given time.
  - Simply click on a window and make a measurement by pressing the i1Pro or i1Pro 2 button, even if different measurement modes are selected in each window.
  - The Main screen of previous CT&A versions is now called the "RGB vs RGB" tool. This tool opens in a separate window, like the other spectral tools.
- Added support for the X-Rite i1Pro 2 spectrophotometer.
  - This instrument is used in the "RGB vs RGB" tool and in all spectral tools.
  - Supported models: i1Pro 2 M0/M1/M2 and i1Pro 2 M2-only.
  - Supports the M0, M1, and M2 measurements mode for reflectance measurements.
  - Supports X-Rite's XRGA calibration standard for reflectance measurements.
  - The i1Pro 2 can be used in CT&A on a PowerPC Mac with the older i1Pro driver; in this configuration, the i1Pro 2 behaves as an i1Pro. The new i1Pro 2 features are available only in conjunction with the new i1Pro 2 driver, which requires an Intel Mac with OS X 10.5.8+.
- i1Pro and i1Pro 2:
  - Both the older i1Pro and the new i1Pro 2 drivers are provided. The i1Pro2 driver is XRGA compliant and the older driver is NOT XRGA compliant. The new driver is referred to in CT&A as 'i1Pro / i1Pro 2 (XRGA)'; the older diver is referred to as 'i1Pro / i1Pro 2 (non-XRGA).' You can thus make measurements with your instruments with or without XRGA calibration.
  - Calibration with the 'i1Pro / i1Pro 2 (XRGA)' driver always require that the instrument be positioned on its white calibration tile, even for measurement modes other than reflectance.
- Added support for the X-Rite i1Display Pro colorimeter.
  - This instrument is used in the "RGB vs RGB" tool (and not in the spectral tools).
  - Supported models: i1Display Pro hardware sold by X-Rite (i.e. the retail version, part #EODIS3-XR). Generic models sold by other companies (third parties, or OEM, part #EODIS-OEM) should also be compatible. At this time we cannot say if we will support or not custom models sold by other companies since separate agreements with these parties may be required. More specific info will be provided as new models are released.
  - CT&A can load and assign calibration matrices (contained in X-Rite Emissive Display Reference (EDR) files) specifically designed for various display technologies, and which provide improved measurement accuracy. Eight EDR files are supplied, including ones for OLED and Plasma displays; additional files could be added in the future without a need to reinstall CT&A.
  - Select between two measurement speeds.
  - Note: On Mac, OS X 10.5+ is required (Mac Intel tested, PowerPC TBD).
- FluoCheck tools: Added a set of tools to measure the effect of substrate fluorescence on measured colors. FluoCheck tools provide numerical data on the stability of a color under the M0, M1, and M2 Measurement Conditions as defined in ISO 13655. A Fluorescence Index (FI) is obtained by measuring a color using either M0 (i.e. Ill-A) or M1 (i.e. D50), and M2 (i.e. UV-cut), and computing the color difference between the two measurements. When two colors are compared, a Fluorescence Metamerism Index (FMI) is obtained by using the M2 measurements of the two colors, and either the M0 or M1 measurements (a different FMI is computed relative to M0 and M1).
  - An i1Pro 2 which supports the M0/M1/M2 measurement conditions is required to be able to use the FluoCheck tools.
- Density, Graph, and Metamerism Index tools: In reflectance mode, and if using an i1Pro 2 which support the M0/M1/M2 measurement conditions, you can now select the measurement condition.
- RAL DESIGN tool: In reflectance mode, and if using an i1Pro 2 which support the M0/M1/M2 measurement conditions, you will now obtain the RAL DESIGN measurement for all these measurement conditions.
- Whiteness tools: If using an i1Pro 2 which support the M0/M1/M2 measurement conditions, you can now obtain the fluorescence value by using the measurements corresponding to the M0 and M2 measurement conditions, without the need for an external UV filter.
- Preferences: You can now select between Bradford or CIECAT02 as the Chromatic Adaptation Transform (CAT) to be used for space conversion in the "RGB vs RGB" and "MI" tools, and to compute display colors.

Improvements:

- RGB vs RGB tool (the Main screen of previous CT&A versions):
    - Entering data with an instrument is now done with dedicated controls which appear in the window whenever the "L*a*b* / L*u*v* input" checkbox is selected. Each side, Space #1 and Space #2, can be set to use different measurement modes.
    - This window has a dedicated menu that regroups the functions which are dedicated to this tool. This window also has three dedicated icons on the toolbar, with two of these that can be used to open data tables and change some graphics on the chromaticity diagram.
    - Custom RGB space dialog: This dialog can also be called from the RGB space selection menu in Space #1 and Space #2. Improved data entry feedback in the dialog. The other dialog parameters and the graphics are updated dynamically as you enter the values.
    - The "Bradford matrices" tables has been replaced by "CAT matrices" so that both Bradford and CIECAT02 matrices can be inspected and copied.
- Density tools: The density standards now clearly correspond to those of ISO 5-3. Changing the density status no longer requires deleting previous measurements; the previous measurements are now recomputed according to the selected status.
- ISO 3664+ tools: Improved accuracy for MI (ISO 23603 / CIE S 012) and CRI (CIE 13; also computed in the Graph and Metamerism Index tools).
- Metamerism Index tools: Patches are not completely surrounded by a thin black border; this enables better discrimination for alike colors.
- Improved matching between the displayed colors on the various tools for different combinations of illuminants and CAT. Whenever feasible, a measured color is shown as it would appear under the selected illuminant (as in a virtual light booth).
- Measuring instruments: Instrument detection and connection is more robust and user-friendly.
- Emission measurements: The program now shows the White Point luminance and CCT in the toolbar window when making an calibration in emission mode. The program now better manages the device used for emission calibration (LEFT, RIGHT, or OTHER display). Default values are assigned if there is a problem measuring the White Point.
- Help manual: Simplified Table of Contents structure.

Version 3.1 b249 (2011-09-27)

New features:

- Spectral Tools - ISO 3664+: Added a tuning mode where measurements are automatically taken at user-specified time intervals. This mode is particularly useful to tweak the chromaticity of a display.
- Custom RGB space dialog: Added the capability to save the RGB space as an ICC profile; save the profile with an ICC or ICM extension.

Improvements:

- Spectral Tools - Graph: Added text entry fields for user-assigned Sample names.
- Spectral Tools - Graph: Added 3200 K (TV Studio lighting) in the Reference Illuminant menu when selecting "S1 vs Illum." or "S2 vs Illum."
- Spectral Tools - ISO 3664+: The chromaticity target interface has been enhanced. The target layout indicates if the measured color is too Red, too Green, or too Blue, and the relative position of out-of-range measurements is now shown around the target.
- Spectral Tools - ISO 3664+: Added 3200 K (TV Studio lighting) to the Chromaticity and CRI menus.
- Munsell Color Deck: New higher accuracy Munsell database; this database also improves the conversion accuracy towards the Munsell space.

Bug fixes:

- Main screen: The scrollbars' mouse wheel action will not change the Y, R, G, or B value when the scrollbars are disabled. The scrollbars are now hidden when disabled.
- (Mac OS X 10.7-Intel) Due to a compiler bug, the scrollbars' elevator position remains visible when the scrollbars are disabled. To fix the issue, the scrollbars are now hidden when disabled.

- Custom RGB space dialog: Now correctly assigns the illuminant coordinates when computing the XYZ-to-RGB and RGB-to-XYZ matrices for the file obtained with the "Export to file..." button. The bug happened only for the file obtained with the "Export to file..." button AND when using an "Other..." Illuminant that was just changed, i.e. an Illuminant different from the presets (A, C, D50, D65, and E) and different from the previous "Other" Illuminant. The bug never affected the custom RGB space used in the Main screen as Space #1 or Space #2.

Other:

- Changed the Color Decks database file name to accommodate the new Munsell database. Users who have customized their Color Decks will need to regenerate them.

Version 3.0 b238 (2010-06-07)

New features:

- The program is now color-managed. The patches color in the main screen and in Spectral Tools are corrected using the default, or user-selected, ICC display profile.
- Spectral Tools - Whiteness: Added a set of tools to measure paper whiteness, brightness, fluorescence, and opacity. There are also tools to check if white and black backings are compliant. Some accessories are required; see the Specifications for more information.
- Spectral Tools - Whiteness: Use this tool to measure color patches with and without UV-cut with only a non-UV-cut Eye-One. A UV-blocking filter is required; see the Specifications for more information.
- Spectral Tools - Metamerism Index: There are now two custom Ambient inputs instead of one.
- Spectral Tools - Metamerism Index: You can save a measured Ambient illuminant to a file and load the illuminant from a file.
- Spectral Tools - ISO 3664+: You can print well formatted one-page reports which contains information dedicated to compliance-type reports.
- Spectral Tools - ISO 3664+: You can load an Ambient spectrum from a file instead of having to measure it.
- Custom RGB space: added the L* (L-star) tone response curve in the preset gamma list.
- Main screen: Additional patch layouts are available when increasing the screen dimensions. Compare color patches on various backgrounds and see how text of each color looks like on black and white backgrounds, as well as on a background of the other color.
- Main screen: The chromaticity diagram is now represented in color to help select a colors with a mouse-click, and the coordinates are shown while moving the mouse over the diagram.
- Main screen: You can select a color on the chromaticity diagram with a mouse left-click or a mouse right-click (ctrl + click on a one-button Mac mouse) and assign the input respectively to one space or the other.
- Main screen: Added the option to show the Planckian locus in the chromaticity diagram.
- Added a Page Setup menu to set the margins, paper size, and paper orientation prior to printing.

Improvements:

- Spectral Tools - Graph: You can save an image at twice the screen resolution for improved quality when printing.
- Spectral Tools - ISO 3664+: Updated the requirements to those of ISO 3664:2009(E) (essentially, the expected display Luminance is now 160 cd/m^2 instead of 100 cd/m^2)
- Main screen: The eciRGB 1.0 space has been updated to eciRGB_v2, with a L* (L-star) tone response curve.
- Main screen: You can change the instrument measurement mode with the mouse popup menu.
- The measuring instrument serial number and UV filter information is included in saved files and reports.
- The saved files and reports have been reviewed for presentation uniformity.

Bug fixes:

- Will show a warning message and not an error message when trying to save a file which is opened by another application, or locked.
- (Mac OS X-Intel) The main screen gray background is uniform on program start; before the fix, it was required to resize the display to refresh the background.

Version 2.8.5 b200 (2009-03-11)

New feature:

- Spectral Tools - Graph: Added the capability to measure FLASH light sources (Flash mode).

Improvements:

- Spectral Tools - Graph: The CRI (Color Rendering Index) and the reference illuminant used to compute it are now shown in the Graph tools for Ambient and Flash modes.

Bug fix:

- Fixed the problem where the program would go into an infinite loop with imported Color Decks of less than 20 chips (Note: Custom Color Decks are imported via BabelColor's PatchTool).

Version 2.8.0 b198 (2008-05-05)

New features:

- Spectral Tools - Graph: A contextual menu was added to configure the horizontal and vertical graph grids.
- Spectral Tools - Metamerism Index: The reference illuminant for the Color Inconstancy Index (CII) used to be fixed at D65. It is now possible to select among a list of 12 preset illuminants, or select a locally measured ambient illuminant.

Improvements:

- Spectral Tools - ISO 3664+: The brightness uniformity can now be done on up to nine points as per ISO 12646 and the uniformity tool interface has also been improved. Target images for monitor brightness uniformity measurements have been redone; they are included as individual files.
- Spectral Tools - Graph: Finer scaling steps for the graph display.

Bug fix:

- Fixed a computation problem when measuring reflectance samples (with an Eye-One Pro) with an RGB space based on Illuminant E, in the main screen. The problem did not affect Emission or Ambient measurements in the main screen, or any measurement type, including Reflectance, in the spectral tools.

Other:

- New tutorial: Measuring color patches on a display.
- (Windows) The Color Decks database is now located in the user "Documents" folder, where it can be more easily accessed. As an additional benefit, there is no more a requirement to be a system administrator in Windows XP; this change also makes the program better compliant to Windows Vista security requirements.
- Windows 98 is no longer supported; the last compatible version for this OS is 2.7.1.

Version 2.7.1 b189 (2007-12-06)

Improvements:

- (Windows Vista) The drivers and system libraries (DLL) are now fully approved for this OS.
- (Mac) The program is now offered in Universal binaries and Intel packages.

Bug fix:

- Fixed the reload of the custom RGB space data when starting the program. This bug was introduced in version 2.7.0.
- (Windows Vista) Windows Vista incorporates a Data Execution Prevention (DEP) feature which monitors how applications access memory. In most Vista Home systems, the DEP setting is set, by default, to check only the system programs and services; in this case, even before the fix, BabelColor CT&A started correctly. However, the DEP setting can be changed by the user, either globally or on a program by program basis, and its default setting may also vary for other OS configurations. BabelColor CT&A did not start when the DEP was assigned to all applications, or to BabelColor CT&A only; this has been fixed.

Version 2.7.0 b187 (2007-05-21)

New features:

- A contextual menu was added to most data fields, enabling a copy of all coordinates in a single mouse click. The copied data, in Tab-delimited format, can be pasted in multiple columns within spreadsheets and document tables.
- Because many LCD displays have a natural D60 white point, the D60 Illuminant was added in the selection menus of the Graph Tools and the ISO 3664 Chromaticity measurement.
- The Generic RGB space (ColorSync default space on Mac OS X) was added to the RGB space list.
- Additional selections were added to the display space Options/Preferences setting, and the Generic RGB space is now the proposed default selection for Mac OS X.

Improvements:

- Faster program startup.
- Faster loading of the Color Decks.

Bug fix:

- Fixed a data corruption problem when measuring *emission* data in the main screen after opening the ISO 3664 tools tab and coming back to the main screen (Note: there was no corruption when staying in the main screen or using the other Spectral Tools).

Other:

- Changed the Color Decks database format.

Version 2.6.1 b181 (2007-04-03)

Bug fix:

- Corrected a bug which made the program crash in certain operations when not registered.

Other:

- (Mac) The downloadable file is now compressed in a zip type archive.

Version 2.6.0 b180 (2007-01-03)

New feature (via PatchTool):

- User-defined color lists can now be added as color chips catalogues (Color Decks). Adding a Color Deck is performed using the "BabelColor CT&A Export" dialog of the PatchTool™ program (an external program), which converts color lists saved in CGATS, CXF or plain text format to the Color Decks database format. PatchTool can also remove Color Decks from the deck database. PatchTool's "BabelColor CT&A Export" window is accessible even when the program is not registered; however, accessing all of PatchTool's features requires purchasing a separate license.

Bug fix:

- Fixed a crash problem on Windows OS when using the program from account names defined with letters having accented characters (Ex: Frãnz, János, etc.).

Other:

- The program name was changed to "BabelColor *Color Translator and Analyzer*", or "BabelColor CT&A" in short form, to better differentiate it from other BabelColor products.

Version 2.5.1 b178 (2006-08-18)

New features:

- Added the British Standard 5252F (BS 5252F) and RAL CLASSIC Color Decks.

Bug fix:

- The Eye-One Display and Eye-One Display 2 colorimeters are now properly recognized (Note: the Eye-One Pro instruments were not affected by the problem).

Version 2.5 b175 (2005-06-20)

New features:

- Can input data from the Eye-One™ colorimeters and spectrometers
- Spectral tools which include:
  1. Density tools: Reflection Density; Dot Area; Print Contrast; Apparent Trap; Hue error - Grayness - Saturation;
  2. Metamerism Index tools: HunterLab Metamerism Index (MI); Special Metamerism Index (SMI); Color Inconstancy Index (CII); virtual light booth with ambient illumination input;
  3. RAL tool: get the RAL DESIGN coordinates of a color patch;
  4. Graph tools: analyze reflectance, ambient or emission spectrums; get ambient illuminance (lux), monitor luminance (cd/m^2), ambient Correlated Color Temperature (CCT, in kelvin); spectral math operations (Add, Subtract, Average, Multiply); compare an ambient spectrum to ideal blackbodies or D-series illuminants spectrums;
  5. ISO 3664+ tools: viewing conditions assessment, with Color Rendering Index (CRI; CIE Publication 13), ambient illuminance, monitor luminance, CCT, chromaticity, and illumination uniformity, light booth and daylight simulators evaluation (CIE Standard 12, an updated version of CIE Publication 51).
- Export a spreadsheet savvy text report for most spectral tools (Density, Metamerism Index, Graph, ISO 3664+) and export an image of the spectral graphs.

Bug fix:

- Fixed a registration issue associated with operating systems set in languages using double-bytes font encoding (Unicode), languages such as Japanese, Chinese, etc.

Version 2.1 b100 (2005-01-04)

New features:

- A custom RGB space can now be defined by the user (RGB vs RGB menu).
- A custom D-series or blackbody illuminant can be defined using the source temperature (in kelvin).
- Export a spreadsheet savvy text report that contains all the parameters required to define and compute the custom RGB space coordinates.
- Get the Bradford chromatic adaptation matrix between the custom Illuminant and many standard Illuminants.

Version 2.0.5 b094 (2004-11-01)

New feature:

- Addition of the DeltaE2000 (CIEDE2000) color difference formula.

Bug fixes:

- Solved the issue where it was not possible to precisely select colors near the blue primary of large RGB spaces, such as ProPhoto, by clicking in the "xy" chromaticity diagram.
- Fixed the problem of unstable interface for users in regions of the world where a period is used as a separator for thousands (ex.: 6.123,43). Editing the regional preferences to assign a space to the thousands separator is no longer necessary. Affected regions included: Belgium, German speaking countries, Italy, the Nederlands, Portuguese speaking countries, and some Spanish speaking countries.

Version 2.0.1 b092 (2004-10-17)

Bug fix:

- Solved the issue where the program crashed when entering particular combinations of RGB values (out-of-range parameters were sometimes generated when converting to other color notations).

Version 2.0 b091 (2004-10-12)

New features:

- First release with the "Color Deck" viewing mode where the user can browse and convert colors from and to catalogues of color chips.
- Now provides the individual contributions of ΔL^*, ΔC^*, ΔH^* in the DeltaE* color-difference, as well as Δh.
- Six RGB spaces have been added: BestRGB, Beta RGB, DonRGB4, eciRGB, Ekta Space PS5, and ProPhoto.
- Two color spaces have been added: Munsell HVC (interpolated) and L*C*h.
- User selected Options (Windows) / Preferences (Mac) are now saved, when changed, and loaded when the program starts.

Improvements:

- The data tables in the saved report are easier to read (and import in a spreadsheet).
- The input boxes parsing routine has been redone.
- The tutorials were reviewed for better cross-platform use. A tutorial was added for the new "Color Deck" mode.

Bug fixes:

- Solved the issue where entering negative numbers in the L*a*b*/L*u*v* input boxes resulted in odd data entry point behavior.
- Solved a bug in the CMC DeltaE* computation which introduced a small error for small color differences, but which increased with large color differences.

Version 1.2 b019 (2004-03-15)

New features:

- First release of the Mac version with support for OS 8 and 9 (Mac Classic), and OS X.

Improvements:

- Windows version significantly faster than version 1.1.
- Better Print routine which supports more printers and page widths.
- Improved parsing in input boxes.
- Improved GUI uniformity with various display Appearance settings (Windows).

Bug fixes:

- No more printing limitations when using the program in a 800 x 600 display.

Other:

- Windows 95 not supported anymore.

Version 1.1 (2003-11-03)

First released version. For all Windows versions: 95/98/Me/NT/2000/XP.

15. Tutorials

You will find that most of the tutorials shown here are related to the RGB vs RGB tool. This is because this tool has many options and operational modes which, while powerful, need to be understood in order to maximize its usefulness. Also, since most spectral tools are associated to specific measurements, their usage can be explained with simple examples presented within each tool's section.

Note: All the images in this help manual are heavily compressed in JPEG format. Because of this, the color patches shown in the tutorials are not made of single solid colors; adjacent pixels of a given patch may be of slightly different colors. This is not the case with the patches produced by CT&A.

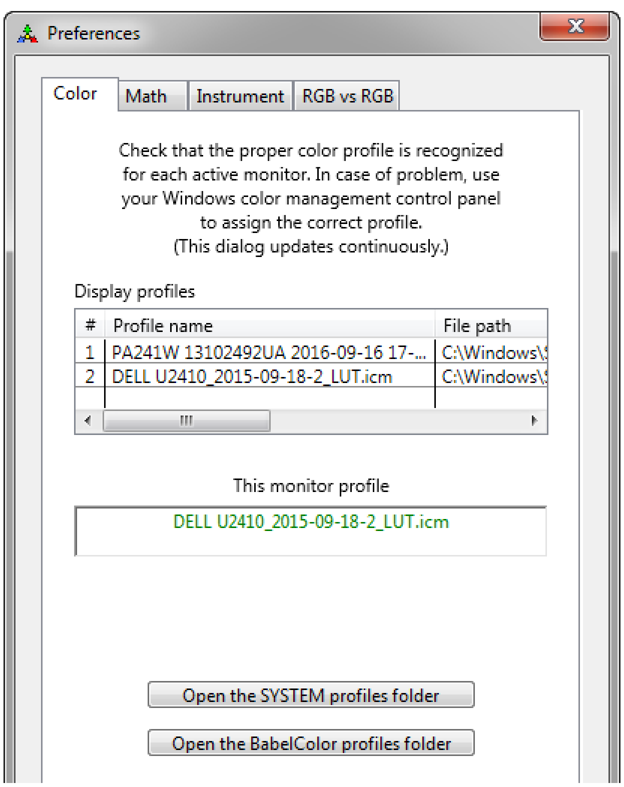
Select a tutorial from the list below:

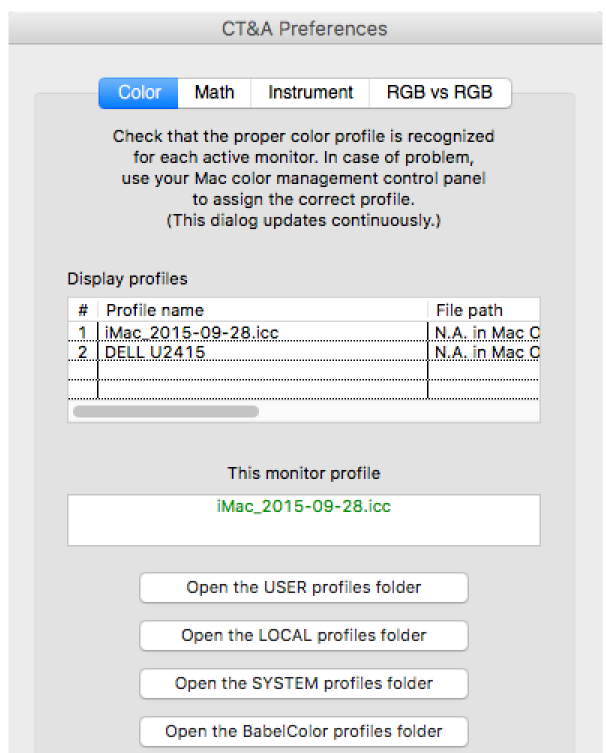
- 1- Comparing two RGB spaces
- 2- Converting between RGB spaces
- 3- Understanding clipping (i.e. when a color is out-of-gamut)
- 4- A color picker with a twist (with three examples)
- 5- L*a*b* / L*u*v* input (with three examples)
- 6- Simulate a ColorChecker color patch
- 7- Using the Color Decks
- 8- Measure your display characteristics with the ISO 3664+ tools
- 9- Measure the display Contrast using the Graph tool
- 10- Measuring color patches on a display

Additional tutorials and application notes are available on the BabelColor Web site:

▶ https://www.babelcolor.com/tutorials.htm .

Important: For more accurate visual results, your display(s) should be calibrated with a custom ICC profile. You can check that the proper color profile is recognized for each active monitor by looking at the “Color” tab of the Preferences dialog. You can also verify your display settings with the procedures described in the Display calibration section. Please note that the display profile has **NO EFFECT** on the accuracy of the computations; it simply affects the appearance of the color patches.





15.1 Comparing two RGB spaces

INTRODUCTION

In this first tutorial we see that the same R'G'B' color coordinates in two different RGB spaces do not correspond to the same color. The tutorial is done with the RGB vs RGB tool.

The tutorial is separated in two parts. The first part shows how identical RGB coordinates in Apple RGB and sRGB really look quite different. Apple RGB was the de facto color space in older Mac computers and many legacy images were created in this space. sRGB has been the standard RGB space for Windows based computers for a long time and a good choice for a recent Mac (see the Apple RGB section for more info). This tutorial will help you understand what happens when you open legacy images generated in Apple RGB, which were most likely not tagged with an ICC profile, in a new computer where the default space is sRGB. The difference between these two spaces is mostly (and not totally!) in the spaces' gamma, which is 1,8 for Apple RGB, and 2,2 (if we use the simple gamma) in sRGB.

The second part compares the same coordinates selected in the sRGB and Adobe (1998) spaces. These two spaces have very similar gammas; the simple software-encoding gamma is the same (=2,2), but sRGB's gamma is more accurately defined a multiple segments detailed gamma. However, they have quite different gamuts, with Adobe (1998) being much larger and capable of representing more colors.

Select the tutorial you want to follow:

- Part 1: Apple RGB vs sRGB tutorial.
- Part 2: sRGB vs Adobe (1998) tutorial.

Important: Before starting a tutorial, please take time to complete the **SETUP** section; this will make sure that the tutorial's screenshots and results match your own. Within each steps you will find links to specific help sections which provide more details if required.

Note: The Apple RGB vs sRGB tutorial cannot be done if CT&A is not activated).

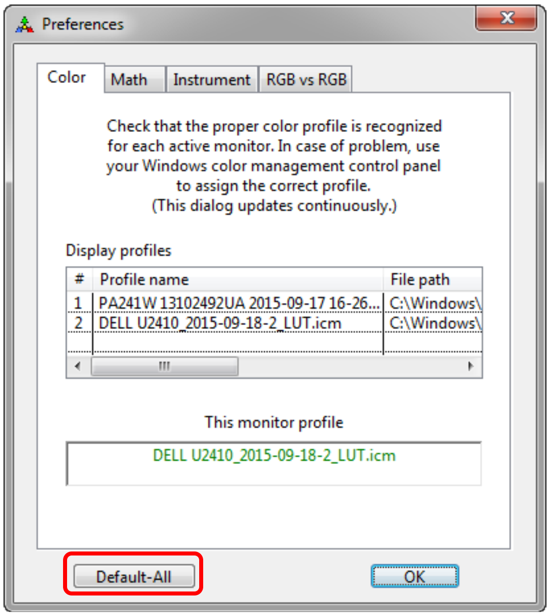
15.1.1 Apple RGB vs sRGB

SETUP

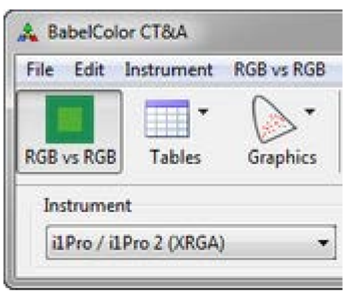
Note: If you are using a non-activated copy of CT&A, you can only select the sRGB and Adobe (1998) spaces and you should do Part 2 of this tutorial.

Set the program as follow:

- Close all CT&A's tool windows with the "Tools/Close all tool windows" menu; you should see only the toolbar window.
- Open the Preferences dialog with the "Edit/Preferences..." menu, in Windows, or the "CT&A/Preferences..." menu, in Mac OS X.
- Reset all the preferences by clicking the "**Default - All**" button in the bottom-left of the dialog, then click the "**OK**" button to close the dialog.



- Open the RGB vs RGB tool window either by clicking on the corresponding icon on the toolbar window, by selecting the "RGB vs RGB/Show window" menu, or by selecting the "Tools/RGB vs RGB" menu.

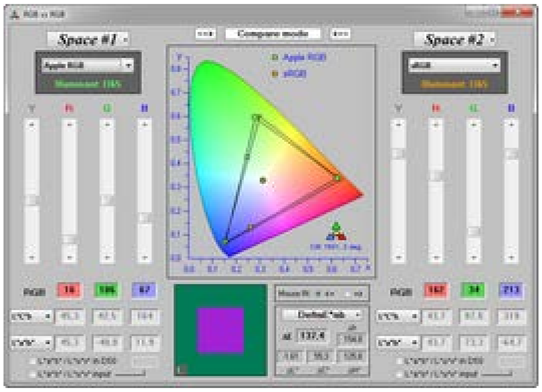


- Make sure the tool is in Compare mode, which can be confirmed by looking at the Mode settings buttons located on top of the chromaticity diagram:

The middle button should be labeled "Compare mode" on a white background, as shown above. If this is not the case, select the compare mode with the "RGB vs RGB/Mode/Compare" menu, or click on the yellow "Convert" button which will change into the white "Compare mode" button.

- Uncheck any "L*a*b* / L*u*v* input" checkbox located at the bottom of each space.

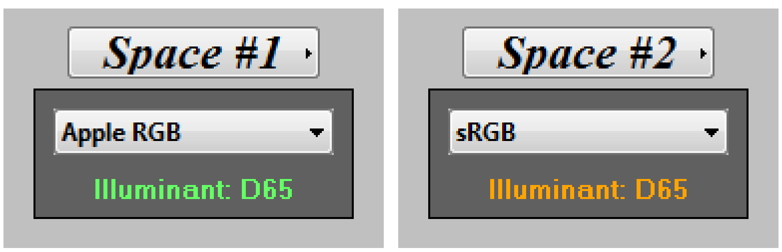
- Reduce the RGB vs RGB tool window to its minimum size by dragging the bottom-right corner (or any edge in Windows). The window should have this appearance (but bigger!):



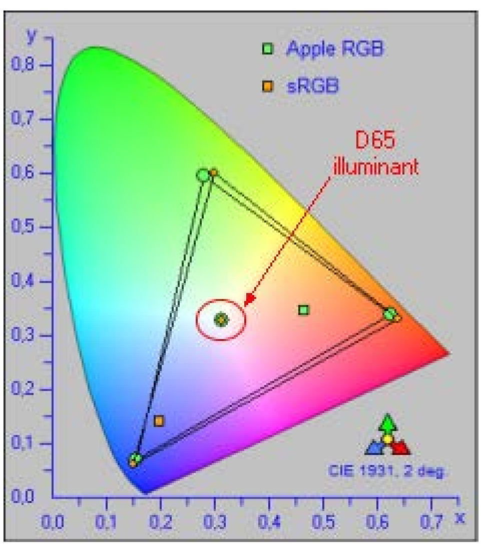
Note: The R'G'B' coordinates are selected randomly each time the program is launched.

STEP 1

Set Space #1 to Apple RGB and Space #2 to sRGB:



You can verify in the chromaticity diagram that the spaces' illuminants are at the same location (x=0.313 and y=0.329, the coordinates of illuminant D65). The diagram also shows the triangles defined by the primaries of each space; they are of similar size but slightly offset from one another:



STEP 2

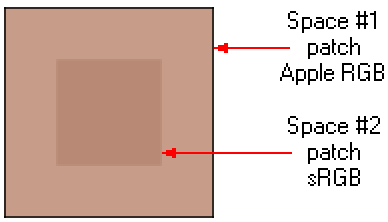
Double click in the data display of Space #1 which has a red background (the R' of R'G'B') to select the displayed value (it should appear highlighted), and type **188**.

Note: A single click may be sufficient to select the displayed value, depending on the platform, Windows or Mac, and the Operating System (Windows 2000, XP, Vista, Windows 7, Mac OS X).

Double click in the data display of Space #1 which has a green background and type **140**; alternately, press the **Tab** key to move from one data box to the other. Double click in the data display of Space #1 which has a blue background and type **116**. The R'G'B' displays should look like:

STEP 3

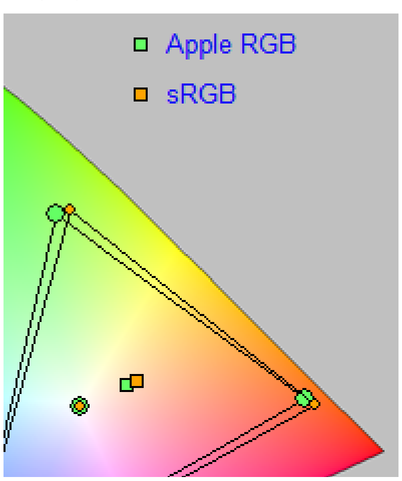
Type the same values in the data displays of Space #2. The color patches display should look like:



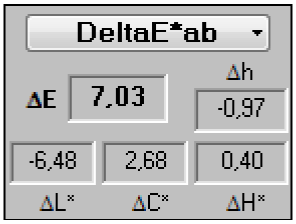
The first thing we notice is that the color looks much darker in the sRGB space even though the R'G'B' coordinates are identical. A similar effect will be seen for all colors in an image, with the resulting image much too dark.

DISCUSSION

The main effect behind this color difference is the spaces respective gammas. The gamma of 1,8 for the Apple RGB space tends to be more linear than the gamma of 2,2 of sRGB. A space with a linear gamma (gamma=1) will have its zero to 255 R'G'B' values uniformly distributed with light and dark colors. As the gamma increases, there are more and more R'G'B' numbers used to represent darker colors; this is consistent with how the human visual system works. Thus, the 2,2 gamma of sRGB will result in more integer values dedicated to darker colors than the 1,8 gamma of Apple RGB. This is why the numbers used to represent a color in Apple RGB actually correspond to darker colors in sRGB. This said, if you look at the chromaticity diagram, you will also notice a color shift. In the cut-out of the chromaticity diagram shown below, the green square, corresponding to Space #1, is closer to the illuminant, meaning that the Apple RGB color is less saturated, i.e. more grayish:



The exact "xy" values can be obtained by selecting the xyY data displays in each space. Now lets look at the DeltaE* display, which should be set to DeltaE*ab. It shows a color-difference of 7,03, a very noticeable difference considering that a value of one (1) is an accepted threshold:



The DeltaE* display also shows the individual contributions of lightness difference (ΔL^*), chroma difference (ΔC^*) and hue difference (ΔH^*) in the total ΔE difference. ΔL^* and ΔC^* also correspond to the differences between the L^* and C^* coordinates shown for each space in their L*C*h displays. While ΔH^* is what is left when you remove the ΔL^* and ΔC^* contributions in ΔE, Δh, the hue angle difference is directly related to the h shown in the L*C*h displays. See the L*a*b* or L*u*v* to L*C*h and DeltaE* sections for the mathematical definition of these parameters.

We see that most of the difference comes from the lightness (-6,48, i.e. darker by 6,48%), with a smaller but noticeable contribution from chroma (2,68), which expresses color saturation, as we also inferred by looking at the chromaticity diagram.

In practical terms, these simple steps show that legacy images created without embedded profiles in Apple RGB, very likely on a Mac a few years ago, will look darker on a Windows based computer, or on a Mac running Mac OS X 10.4+, if no compensation is done. On a Mac running Mac OS X with a version prior to 10.4, the image would look quite similar to the original intent since these previous versions of Mac OS X used Generic RGB as their default RGB space, a space which has the same gamma as Apple RGB (to confirm, simply select **Generic RGB** in Space #2).

If the image has an embedded ICC profile and the software used to open it supports color management, then it will be viewed with correct colors. If the image has no ICC profile but its Mac origin is known, you can manually assign the Apple RGB profile to the image, with Photoshop for example, and again obtain a proper image.

Note: Older, pre-Mac OS X, images originating from a Mac platform should be assumed to be encoded in Apple RGB. More recent images with no ICC profile could be encoded either in Generic RGB or sRGB; If the image looks darker when opened as sRGB, then try Generic RGB.

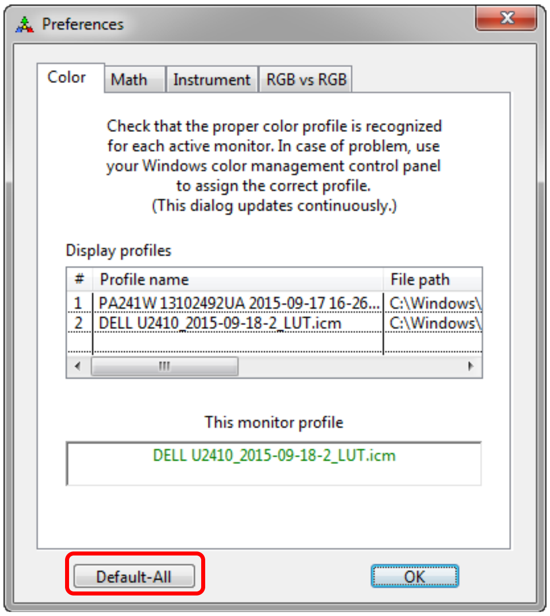
This concludes the first part of this tutorial; click here to go to the second part. Click here to go back to the tutorials' Table of Contents.

15.1.2 sRGB vs Adobe (1998)

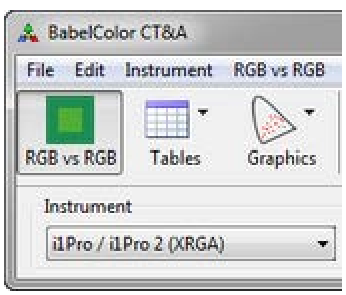
SETUP

Set the program as follow:

- Close all CT&A's tool windows with the "Tools/Close all tool windows" menu; you should see only the toolbar window.
- Open the Preferences dialog with the "Edit/Preferences..." menu, in Windows, or the "CT&A/Preferences..." menu, in Mac OS X.
- Reset all the preferences by clicking the "**Default - All**" button in the bottom-left of the dialog, and then click the "**OK**" button to close the dialog.



- Open the RGB vs RGB tool window either by clicking on the corresponding icon on the toolbar window, by selecting the "RGB vs RGB/Show window" menu, or by selecting the "Tools/RGB vs RGB" menu.

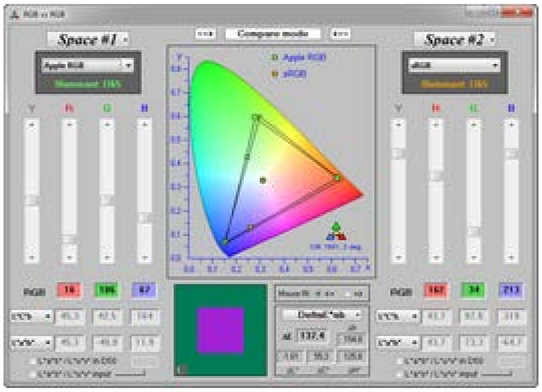


- Make sure the tool is in Compare mode, which can be confirmed by looking at the Mode settings buttons located on top of the chromaticity diagram:

  The middle button should be labeled "Compare mode" on a white background, as shown above. If this is not the case, select the compare mode with the "RGB vs RGB/Mode/Compare" menu, or click on the yellow "Convert" button which will change into the white "Compare mode" button.

- Uncheck any "L*a*b* / L*u*v* input" checkbox located at the bottom of each space.

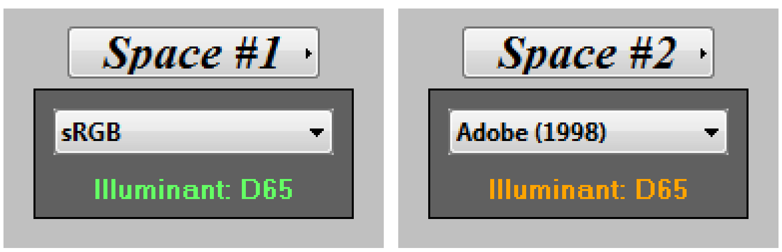
- Reduce the RGB vs RGB tool window to its minimum size by dragging the bottom-right corner (or any edge in Windows). The window should have this appearance (but bigger!):



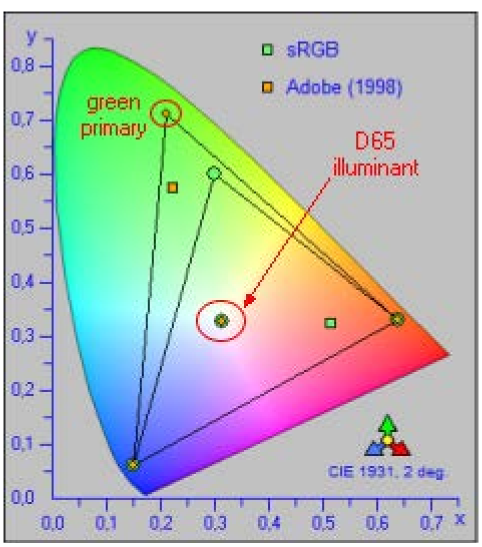
Note: The R'G'B' coordinates are selected randomly each time the program is launched.

STEP 1

Set Space #1 to sRGB and Space #2 to Adobe (1998):



You can verify in the chromaticity diagram that the spaces' illuminants are at the same location (x=0.313 and y=0.329, the coordinates of illuminant D65). The diagram also shows the triangles defined by the primaries of each space. The Adobe (1998) is the larger one, mostly due to its more saturated green primary:



STEP 2

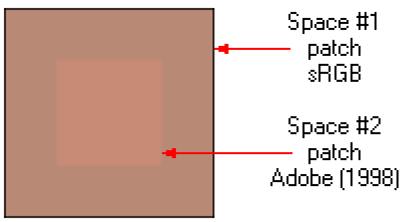
Double click in the data display of Space #1 which has a red background (the R' of R'G'B') to select the displayed value (it should appear highlighted), and type **188**.

Note: A single click may be sufficient to select the displayed value, depending on the platform, Windows or Mac, and the Operating System (Windows 2000, XP, Vista, Windows 7, Mac OS X).

Double click in the data display of Space #1 which has a green background and type **140**; alternately, press the **Tab** key to move from one data box to the other. Double click in the data display of Space #1 which has a blue background and type **116**. The R'G'B' displays should look like:

STEP 3

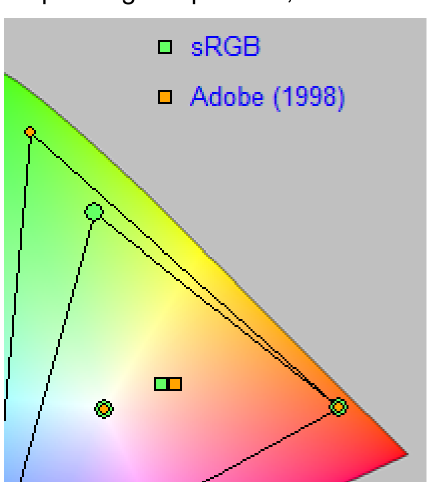
Type the same values in the data displays of Space #2. The color patches display should look like:



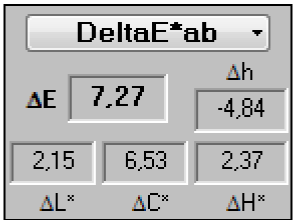
Because these two spaces have very similar gammas, we would expect that the two patches exhibit the same level of lightness, and this is almost the case here, although the Adobe (1998) is slightly brighter (compare the patches L* value). But what we clearly see is that the sRGB color, the larger square, is much less saturated, i.e. less pure or muddy, than the Adobe (1998) color.

DISCUSSION

The main effect behind this color difference is the spaces' respective gamut size. The Adobe (1998) space can represent more colors, and these additional colors are essentially all more saturated than the colors of the sRGB space. If we assume that their gamma is the same, then the darker and lighter colors should be represented by the same numbers. However, because the Adobe (1998) space also contains more saturated colors, all R'G'B' coordinates of this space are more saturated. If you look at the chromaticity diagram, you will notice this saturation shift. In the cut-out of the chromaticity diagram shown below, the green square, corresponding to Space #1, is closer to the illuminant, meaning a less saturated color. Also, the orange square, corresponding to Space #2, is shifted towards the red primary:



The exact "xy" values can be obtained by selecting the xyY data displays in each space. Now lets look at the DeltaE* display, which should be set to DeltaE*ab. It shows a color-difference of 7,27, a very noticeable difference considering that a value of one (1) is an accepted threshold:



The DeltaE* display also shows the individual contributions of lightness difference (ΔL^*), chroma difference (ΔC^*) and hue difference (ΔH^*) in the total ΔE difference. ΔL^* and ΔC^* also correspond to the differences between the L^* and C^* coordinates shown for each space in their L*C*h displays. While ΔH^* is what is left when you remove the ΔL^* and ΔC^* contributions in ΔE, Δh, the hue angle difference is directly related to the h shown in the L*C*h displays. See the L*a*b* or L*u*v* to L*C*h and DeltaE* sections for the mathematical definition of these parameters.

We see that most of the difference comes from the chroma (6,53), with smaller contributions by the hue (2,37) and the lightness (2,15). The hue angle shift, at -4,84 degrees, indicates that we have a slight red shift for the Adobe (1998) color relative to the sRGB color.

In practical terms, these simple steps show that images created without embedded profiles in sRGB will look saturated if an Adobe (1998) profile is assumed. Conversely, an image created in the Adobe (1998) space will look muddy when opened in a program which assumes that the image space is sRGB.

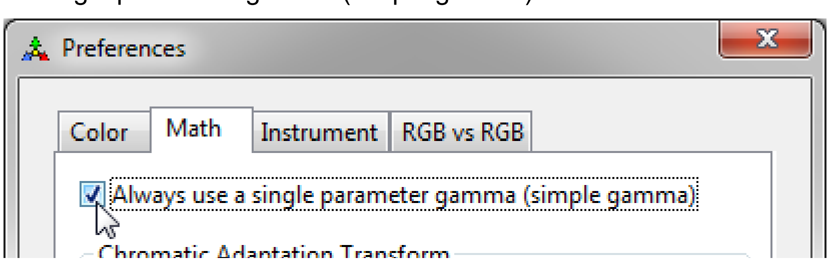
If the image has an embedded ICC profile and the software used to open it supports color management, then it will be viewed with correct colors. If the image has no ICC profile but its origin is known, you can manually assign the sRGB or Adobe (1998) profile to the image, with Photoshop for example, and again obtain a proper image.

However, still, there are many applications which do not support sophisticated color management, Web-browsers coming to mind. In some cases, where color is critical, the fashion business for example, the designer may insist to have its garments viewed in the same way with different computer platforms. To be able to convert color coordinates between two color spaces then becomes useful. This is the subject of the second tutorial: Converting between RGB spaces.

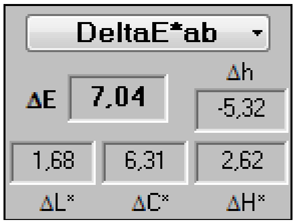
ADDITIONAL INFORMATION ABOUT HOW THE GAMMA AFFECTS THE COLORS

By default, CT&A uses a detailed gamma when such a gamma is available for a given space. Adobe (1998) is defined only by a simple gamma of 2,2 while sRGB is primarily defined by a multi-segment gamma, but with the possibility of using a simple gamma. We will now see how using the detailed gamma or the simple gamma affects the computed color.

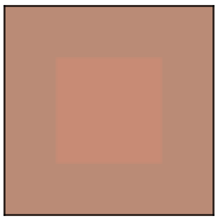
CT&A should still be opened, with the settings and input values obtained in this tutorial. In particular, check that the DeltaE*ab values are the same as the ones shown in the screenshot above. Now go back in the Preferences dialog we opened at the beginning of this tutorial, and select the "Math" tab. Select the "Always use a single parameter gamma (simple gamma)" checkbox:



Notice how the DeltaE*ab values change when you select and unselect the box, which will now look like this:



With the most significant change in the lightness difference which went from 2,15% to 1,68%. The overall color difference is just a tad smaller, 7,04 instead of 7,27, but the difference in chroma is still very high. You will also see a small change in the visual appearance of sRGB patch and its L*a*b* coordinates, but no change in its R'G'B' values:



This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.2 Converting between RGB spaces

INTRODUCTION

In the first tutorial we have seen that if we use identical R'G'B' values in Apple RGB, sRGB, or Adobe (1998), we are in fact describing colors of different lightnesses (intensity), chromas (saturation) and even hues.

For this second tutorial we look at how to convert R'G'B' color coordinates from Apple RGB to sRGB, and then from sRGB to Adobe (1998), so that the colors represented by the RGB coordinates are the same. Please note that we have selected a color in Apple RGB which is not clipped when converted to sRGB and Adobe (1998); clipping is the subject of Tutorial 3 (Understanding clipping).

Note: If you are using an non-activated copy of CT&A, you can only convert between sRGB and Adobe (1998) and you should do the shorter version of this tutorial which looks at the sRGB to Adobe (1998) conversion only.

SETUP

Set the program as follow:

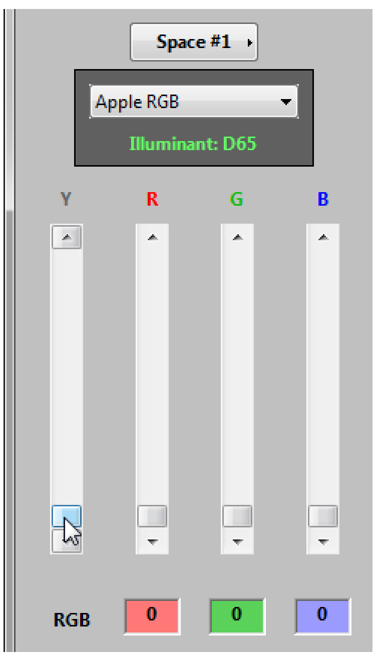
- Open the RGB vs RGB tool window and close all other tool windows.
- Set the RGB vs RGB window in Compare mode with both sides set in RGB space mode.
- Space #1 selection: Apple RGB
- Space #1 input mode: R'G'B'
- Space #2 selection: sRGB
- Space #2 input mode: R'G'B'
- Gamma mode: detailed gamma; leave

  ☐ **Always use a single parameter gamma (simple gamma)**

  unchecked in the Preferences dialog.
- DeltaE* display: DeltaE*ab

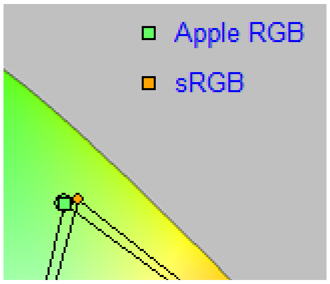
STEP 1

Click and drag the elevator box of **Space #1** Y slider to its lowest position:



All R'G'B' displays of Space #1 should be zero. Click and drag the elevator box of Space #1 **G** (green) slider until the display shows 135; click between the elevator box and the extremities for coarse adjustments (+/- 10) or on the slider's arrows for fine (+/- 1) adjustments (Note: Sliders in the latest Mac OS X versions do not have

arrows, but the Multi-Touch mouse, i.e. Magic Mouse, is precise enough to easily increment or decrement the values by 1 unit by sliding a finger on the surface of the mouse). The green square on the chromaticity diagram should be directly on the Space #1's green primary:



Click and slowly drag the elevator box of Space #1 **R** (red) slider up to the top (R' = 255); as you move, follow the green box on the chromaticity diagram as it slides along the line between the red and green primaries of Space #1. You will also notice how the **Y** slider follows the red slider once it goes beyond the green slider's position.

Click and drag the **B** (blue) slider up to 208.

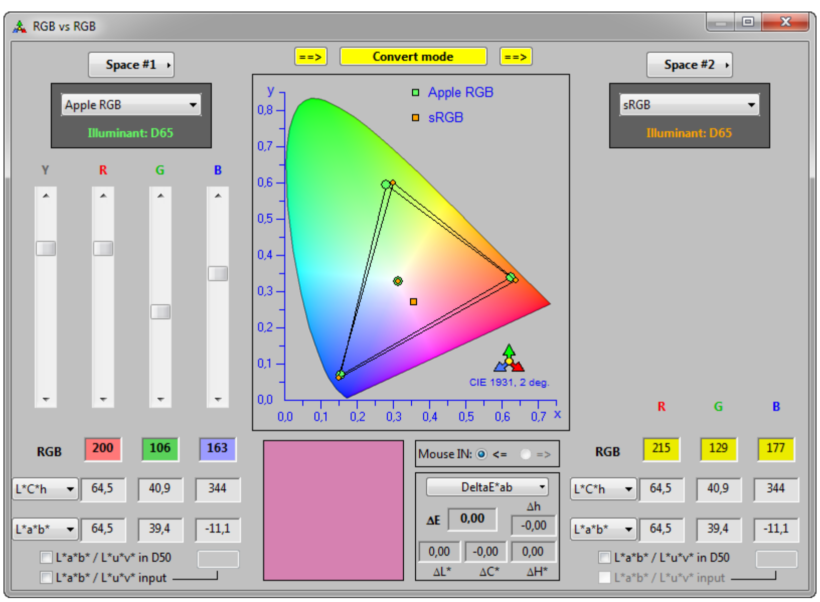
Finally, click and drag the elevator box of Space #1 **Y** slider until the **R** display shows 200 (if you have difficulty adjusting Y to 200, move it until you are close and adjust by clicking on the Y slider arrows for fine adjustments of +/- 1); notice how all the **RGB** sliders move while the green square on the chromaticity diagram does not. This last adjustment affects only the color luminance. The R'G'B' displays should now show:

STEP 2

To convert this color in the sRGB space, simply click on the Compare button located on top of the chromaticity diagram:

After the click, the three buttons' content and color will change to:

and the overall display will look like (RGB vs RGB window shown without the extra patches layouts):



The orange square of Space #2 is now directly over the green square of Space #1 in the chromaticity diagram, and the selected color has been translated to sRGB, with the following coordinates:

DeltaE*ab in the DeltaE* display is zero, this confirms that:

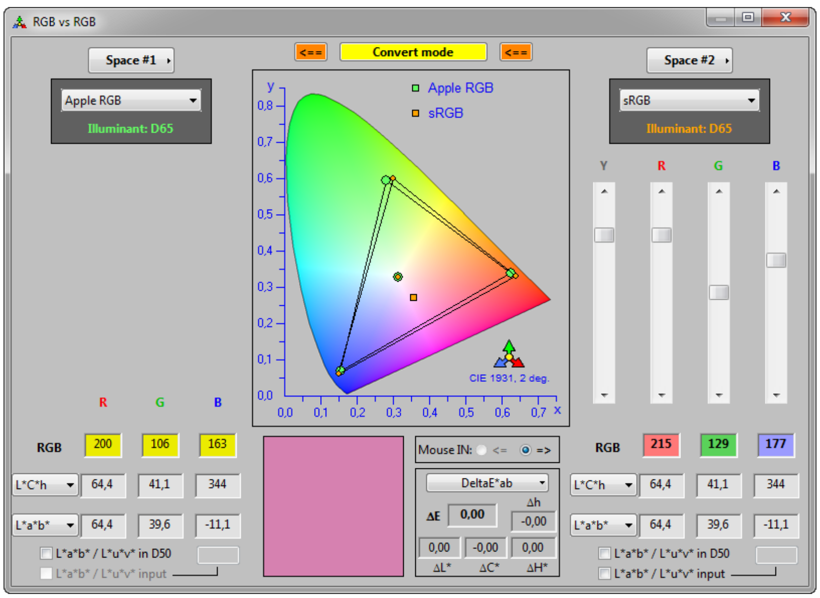
Apple RGB (200, 106, 163) = sRGB (215, 129, 177) .

STEP 3

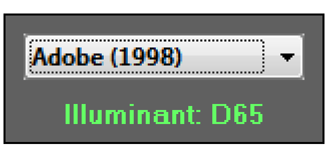
We will now convert these sRGB coordinates in Adobe (1998) RGB. There are many ways to do this but since we already have Space #2 set in sRGB with the correct values, we will simply change the convert direction to be from Right-to-Left. To change the convert direction, click on either one of the yellow arrows on top of the chromaticity diagram:

After the click, the direction arrows color will change to orange:

and the overall display will look like this:



You will notice that the R'G'B' boxes backgrounds have changed, with the ones with a yellow background now seen on the Space #1 side. You can now change Space #1 from Apple RGB to Adobe (1998):



The R'G'B' values shown in Space #1 change to:

The color patches have not changed, just the R'G'B' coordinates of Space #1, which are now shown relative to Adobe (1998) RGB. In other words:

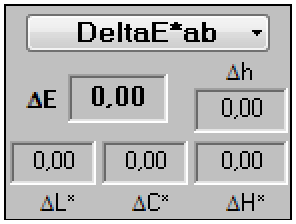
Adobe (1998) (194, 128, 174)

= sRGB (215, 129, 177)

= Apple RGB (200, 106, 163) .

ADDITIONAL INFORMATION

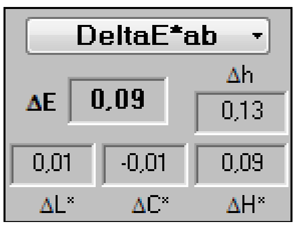
If you look at the DeltaE* display, you will see that the color-difference between the two data sets is zero:



which means that there is no clipping resulting from the conversion (i.e. the Adobe (1998) space can reproduce this sRGB color exactly).

In Convert mode, the program does an exact color conversion, determining the R'G'B' coordinates of the converted space with fractional precision (they are rounded for display purposes only). To see how integer values of R'G'B' in both spaces would compare, simply click on the Convert mode button to go back to Compare mode (you may see changes in the xyY, XYZ, L*a*b* and L*u*v* values):

Following the click, the software replaces the fractional R'G'B' values of Space #2 with the closest integers. The DeltaE* display now shows:



the "real" difference between the Adobe (1998) and sRGB spaces for these R'G'B' data sets.

For more information on how the software treats integer variables, see the data integrity section.

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.2.1 Demo (non-activated) version

INTRODUCTION

Important: This short version of Tutorial 2 is designed for those who use CT&A in demo mode (i.e. not activated). You should do the complete version if the program is activated.

In Tutorial 1 we have seen that if we use identical R'G'B' values in Apple RGB, sRGB, or Adobe (1998), we are in fact describing colors of different lightnesses (intensity), chromas (saturation) and even hues.

For this second tutorial we look at how to **convert** R'G'B' color coordinates from sRGB to Adobe (1998), so that the colors represented by the RGB coordinates are the same. Please note that we have selected a color in sRGB which is not clipped when converted to Adobe (1998); clipping is the subject of Tutorial 3 (Understanding clipping).

SETUP

Set the program as follow:

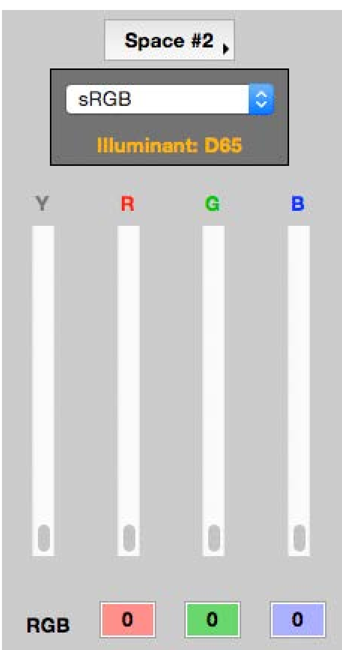
- Open the RGB vs RGB tool window and close all other tool windows.
- Set the RGB vs RGB window in Compare mode with both sides set in RGB space mode.
- Space #1 selection: Adobe (1998)
- Space #1 input mode: R'G'B'
- Space #2 selection: sRGB
- Space #2 input mode: R'G'B'
- Gamma mode: detailed gamma; leave

  ☐ **Always use a single parameter gamma (simple gamma)**

  unchecked in the Preferences dialog.
- DeltaE* display: DeltaE*ab

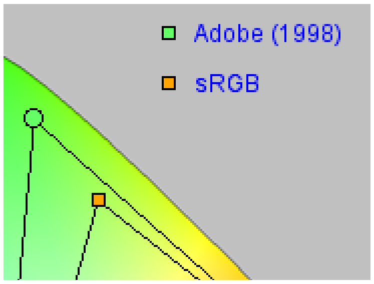
STEP 1

Click and drag the elevator box of **Space #2** Y slider (on the **RIGHT** side of the RGB vs RGB window) to its lowest position:



All R'G'B' displays of Space #2 should be zero. Click and drag the elevator box of Space #2 **G** (green) slider until the display shows 154; click between the elevator box and the extremities for coarse adjustments (+/- 10)

or slide a finger on the surface of the Multi-Touch mouse, i.e. Magic Mouse, for fine (+/- 1) adjustments. The orange square on the chromaticity diagram should be directly over Space #2's green primary:



Click and slowly drag the elevator box of Space #2 **R** (red) slider up to the top (R' = 255); as you move, follow the orange box on the chromaticity diagram as it slides along the line between the red and green primaries of Space #2. You will also notice how the **Y** slider follows the red slider once it goes beyond the green slider's position.

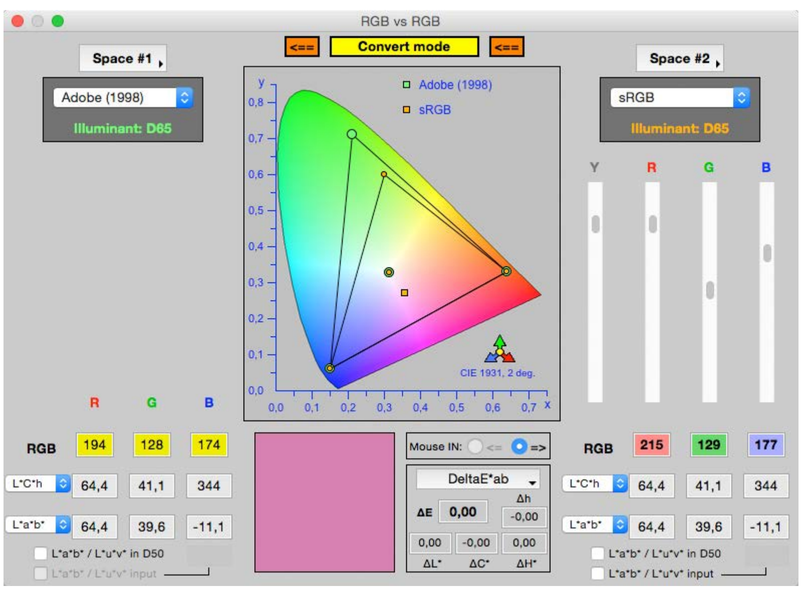
Click and drag the **B** (blue) slider up to 210.

Finally, click and drag the elevator box of Space #2 **Y** slider until the **R** display shows 215 (if you have difficulty adjusting Y to 215, drag the slider until you are close and do fine adjustments by sliding your finger on the mouse surface); notice how all the **RGB** sliders move while the green square on the chromaticity diagram does not. This last adjustment affects only the color luminance. The R'G'B' displays should now show:

STEP 2

To convert this color in the sRGB space, select the "RGB vs RGB/Mode/Convert Right to Left" menu. After the selection, the three buttons button located on top of the chromaticity diagram will change to:

and the overall display will look like (RGB vs RGB window shown without the extra patches layouts):



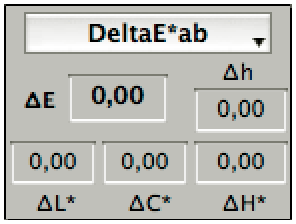
You will notice that the R'G'B' boxes backgrounds in Space #1 are now yellow. The orange square of Space #2, in the chromaticity diagram, is now directly over the green square of Space #1, and the selected color has been translated to Adobe (1998) RGB, with the following coordinates:

DeltaE*ab in the DeltaE* display is zero, this confirms that:

Adobe (1998) (194, 128, 174) = sRGB (215, 129, 177) .

ADDITIONAL INFORMATION

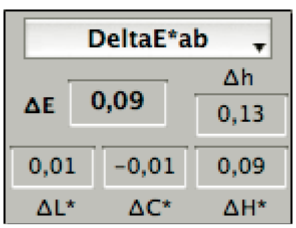
If you look at the DeltaE* display, you will see that the color-difference between the two coordinates data sets is zero:



which means that there is no clipping resulting from the conversion (i.e. the Adobe (1998) space can reproduce this sRGB color exactly).

In Convert mode, the program does an exact color conversion, determining the R'G'B' coordinates of the converted space with fractional precision (they are rounded for display purposes only). To see how integer values of R'G'B' in both spaces would compare, simply click on the Convert mode button to go back to Compare mode (you may see changes in the xyY, XYZ, L*a*b* and L*u*v* values):

Following the click, the software replaces the fractional R'G'B' values of Space #2 with the closest integers. The DeltaE* display now shows:



the "real" difference between the Adobe (1998) and sRGB spaces for these R'G'B' data sets.

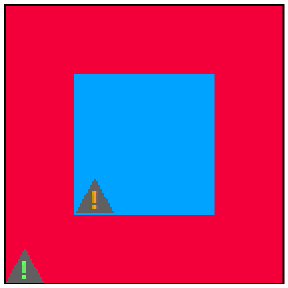
For more information on how the software treats integer variables, see the data integrity section.

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.3 Understanding clipping

INTRODUCTION

In this tutorial we learn how to interpret the clipping indicators (**!**) which appear now and then in the bottom-left or bottom-right corners of the color patches and just above the R'G'B' data displays of converted spaces:



Note: Even if clipping indicators may be seen in all tools' patches, this tutorial is done using the RGB vs RGB tool which enables us to have fine control on the input color.

When converting color data from one RGB space to another, it is often found that a given color or, more generally, a range of colors, cannot be displayed in the destination space. These colors are said to be **out of gamut**. There are basically two choices when this occurs: either clip the color on the edge of the destination space, or "compress" the distance between all colors and maintain the color relations. In addition, some conversion is required to compensate for the "color" of different illuminants which vary from yellowish to bluish. These two requirements are the basis of the "intent" choices offered in high end image editing programs when converting data using ICC profiles.

For most color translation/conversion applications, it is important to maintain the perceived color as uniformly as possible. An often recommended option is **Relative Colorimetric** intent. When selecting this intent, the system first adapts the color of the sample to the color of the destination illuminant. The chromaticity coordinates of the original and translated colors are different, but when they are viewed under their respective illuminants, they are seen as being the same. However, once shifted to match the destination illuminant, the color may still be out of gamut; in this case, it is usually clipped on the gamut's edge.

For proofing applications, it is advisable to keep the same chromaticity coordinates, whenever possible, and clip to the nearest gamut edge if not; this is usually called **Absolute Colorimetric** intent. This type of conversion does not try to make the colors look identical under various illuminant. A white patch under D50, a yellowish white, will look yellowish when seen under D65, and a white patch under D65, a bluish white, will look bluish when seen under D50. This intent is **not** recommended for general imaging applications.

If the perception of colors, when seen together, is more important than their individual accuracy, then the program can modify the colors for the purpose; this is called **Perceptual** intent. With this option, none of the converted colors are accurate. Another choice is **Saturation** intent, which is suggested for applications where the vividness of the colors is more important than their hue, in business graphics for example. Obviously, color accuracy is not a goal here. Variants of the above intents, such as Black Point Compensation (BPC), are offered in some programs, the user should consult their respective documentation.

CT&A emphasizes perceived accuracy; accordingly, colors are converted internally using **Relative Colorimetric** intent, with no BPC, and adapted to the other space illuminant using a Chromatic Adaptation Transform (CAT) matrix.

Whenever clipping happens between the color coordinates shown in a tool and the RGB coordinates used for display purposes, clipping indicators are shown in the bottom of the color patch. Similarly, in the RGB vs RGB tool, when clipping arises in a conversion between the two sides of the tool, clipping indicators appear above the converted space's R'G'B' data displays.

Another type of clipping indicator can be seen when in L*a*b* or L*u*v* input mode. This is discussed in Tutorial 5.

SETUP

Set the program as follow:

- Open the RGB vs RGB tool window and close all other tool windows.
- Set the RGB vs RGB window in Convert mode Left-to-Right (from Space #1 to Space #2) with both sides set in RGB space mode.
- Space #1 selection: Adobe (1998)
- Space #1 input mode: R'G'B'
- Space #2 selection: sRGB
- DeltaE* display: DeltaE*ab
- Gamma mode: detailed gamma (checkbox unchecked in the "Math" tab of the Preferences dialog)
- Display profile: In this tutorial, we need to assign the sRGB profile to our working monitor. This is done using the OS monitor control panel. We could use any profile whose file name contains “sRGB” but since there can be different “flavors” of this color space, we suggest using a profile generated with CT&A; this will ensure that the tutorial screenshots are identical to the ones you will obtain.

  i- Open the Custom RGB space dialog with the “RGB vs RGB/Define custom RGB…” menu.

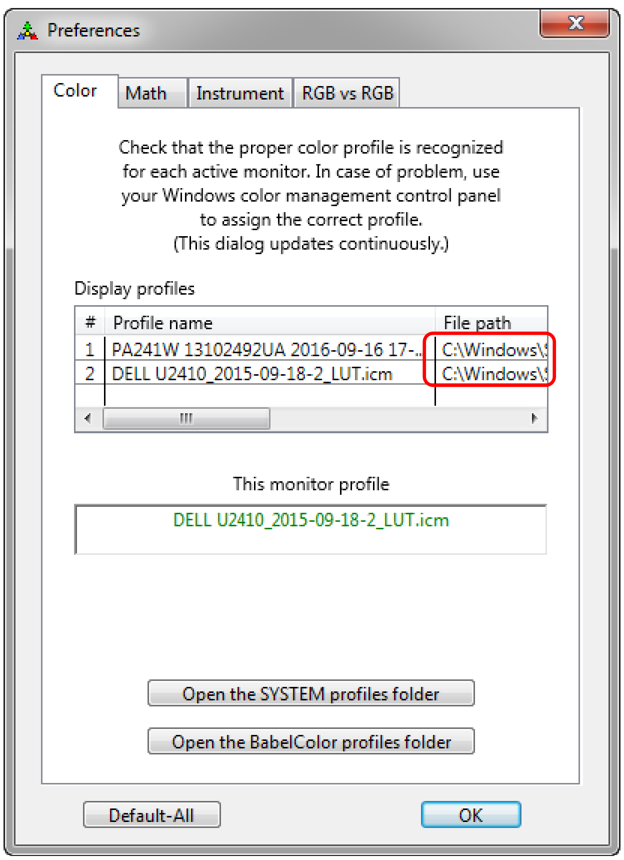
  ii- In the “Space” menu, select “sRGB”; this selection will fill all the other dialog fields.

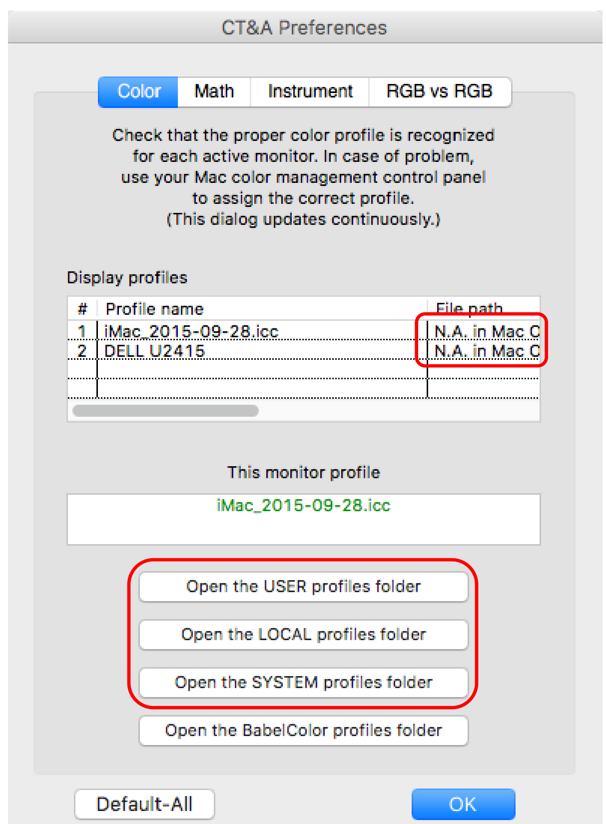
  iii- Save the profile under a name you will recognize, such as “**sRGB-MyProfile**”, and close the dialog.

  iv- Open the Preferences dialog with the "Edit/Preferences..." menu, in Windows, or the "CT&A/Preferences..." menu, in Mac OS X.

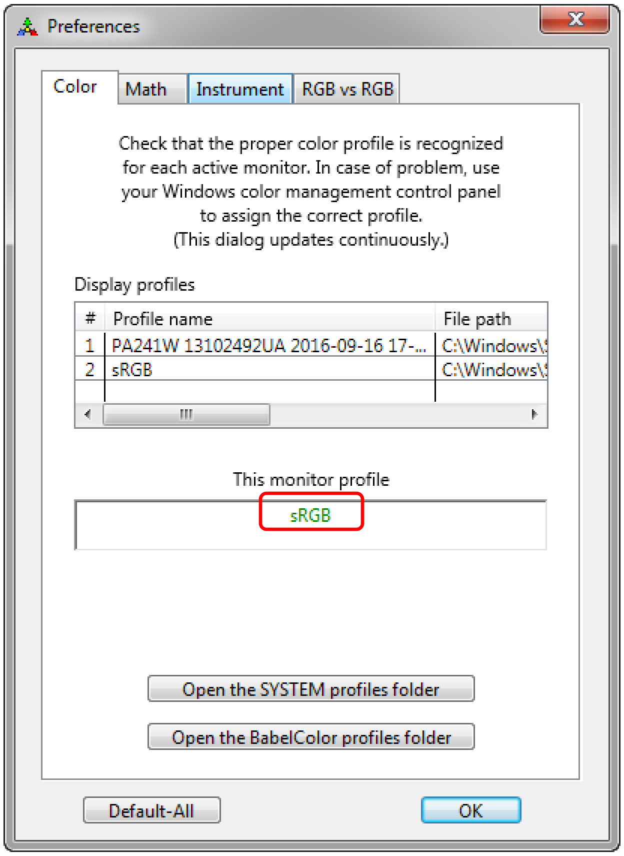
  v- In the “Display profiles” table of the Preferences “Color” tab, look at the “File path” to locate where the OS profiles are located. While leaving the Preferences dialog open, place the sRGB profile you created in Step iii at this location.

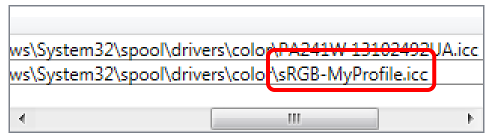
  Note: On the Mac, profiles paths can no longer be automatically located. Use the top three shortcut buttons which will open the standard folders used to store profiles.





vi- Use your OS monitor control panel to assign the sRGB profile to your working display (i.e. the display you will use to complete this tutorial). The Preferences dialog should update automatically to show the new profile, as illustrated in the example below where we assigned sRGB to our second Windows computer monitor.





Note: We do not care if the graphics card LUTs are not loaded or incorrect for the selected profile since we are only interested in the numbers and their effect on the clipping display.

Important: After you have completed this tutorial, do not forget to set your display profile back to what it was when you started it.

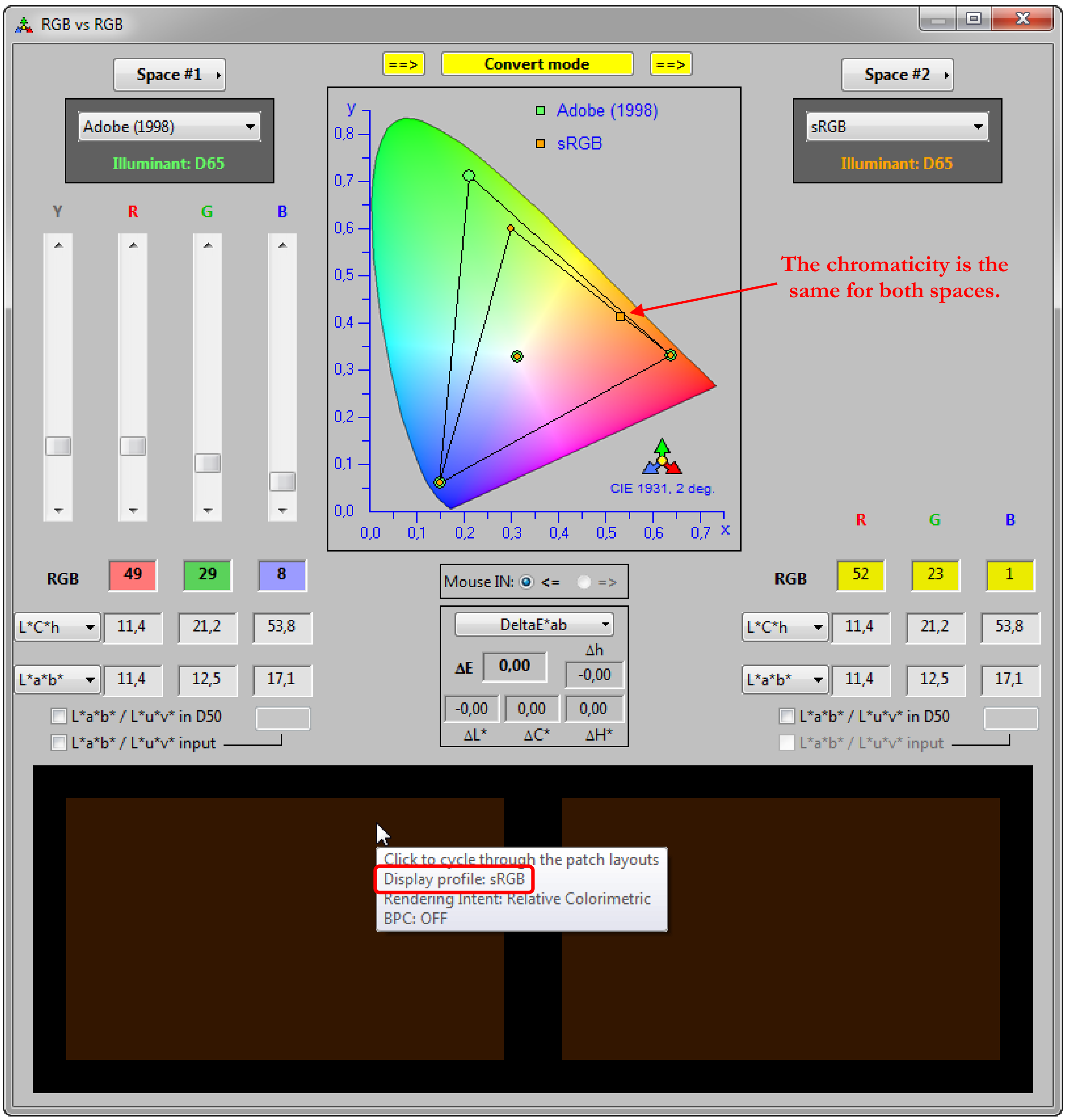
STEP 1

Write the following coordinates in the R'G'B' display boxes of Space #1 / Adobe (1998): R'G'B' = (49, 29, 8).

The coordinates are converted to Space #2 / sRGB, with R'G'B' = (52, 23, 1).

There is no clipping and DeltaE*ab=0. On the chromaticity diagram, the small orange square representing Space #2 is positioned on top of the green square representing Space #1. Since this is a very dark brown, we suggest you increase the window to show the extra patches in the bottom of the display, and click on the patches until they are surrounded by a black background; this background will make the brown more noticeable.

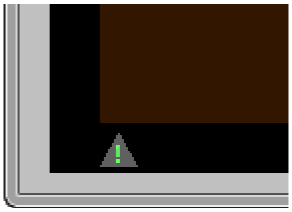
If you bring the mouse cursor over the patches and stop for a second, you will get a Help Tag which indicates the display profile assigned to the window. It should correspond to the profile assigned in the Setup (where we selected sRGB).



STEP 2

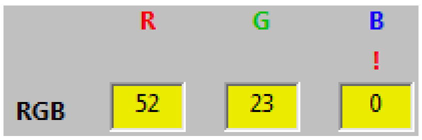
Click and drag the **B** (blue) slider to zero. The coordinates of Space #1 are now R'G'B' = (49, 29, 0). A few things have happened following this action:

- A clipping indicator has appeared on the LEFT patch, corresponding to Space #1:



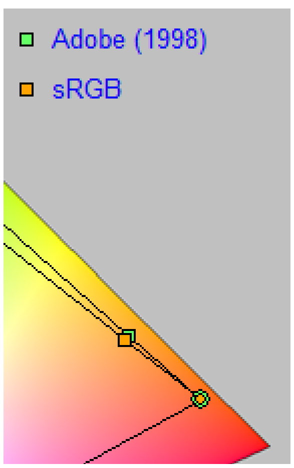
This indicator tells us that one or more RGB coordinate of the color patch is clipped when displayed, i.e. this Adobe (1998) RGB color cannot be accurately represented. We remind you that we have selected sRGB as the display profile.

- A clipping indicator has also appeared on top of the **B** coordinate for Space #2:

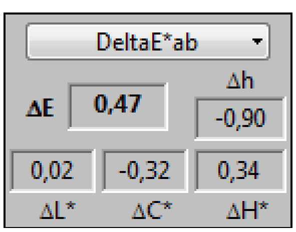


Since we are converting to sRGB, the same RGB space used for the display profile, clipping should be expected. However, here we see that it is only the **Blue** coordinate which is clipped, an information which we do not have in the clipping indicator located below the patches..

- We can see that the orange square of Space #2 is no more over the green square:



- The color difference is not zero anymore:

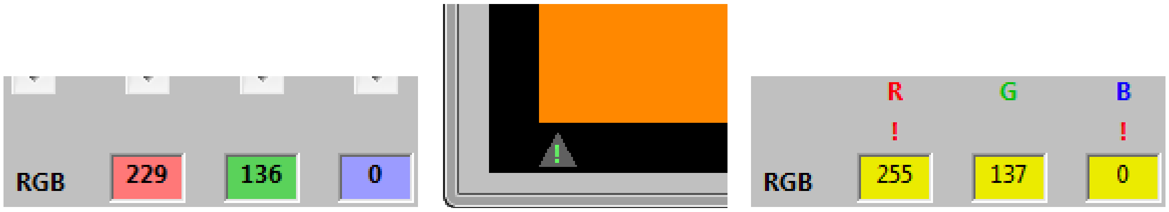


However, in this case, the color difference is quite small and likely not noticeable by most persons.

STEP 3

Click and drag the Y slider slowly up to the top; as you drag, check the R coordinate of Space #2 and the position of the squares on the chromaticity diagram. The squares should remain at the same position until the R coordinate of Space #2 reaches 255 (this corresponds to R=229 in Space #1):

- A second clipping indicator appears on top of the R coordinate for Space #2:

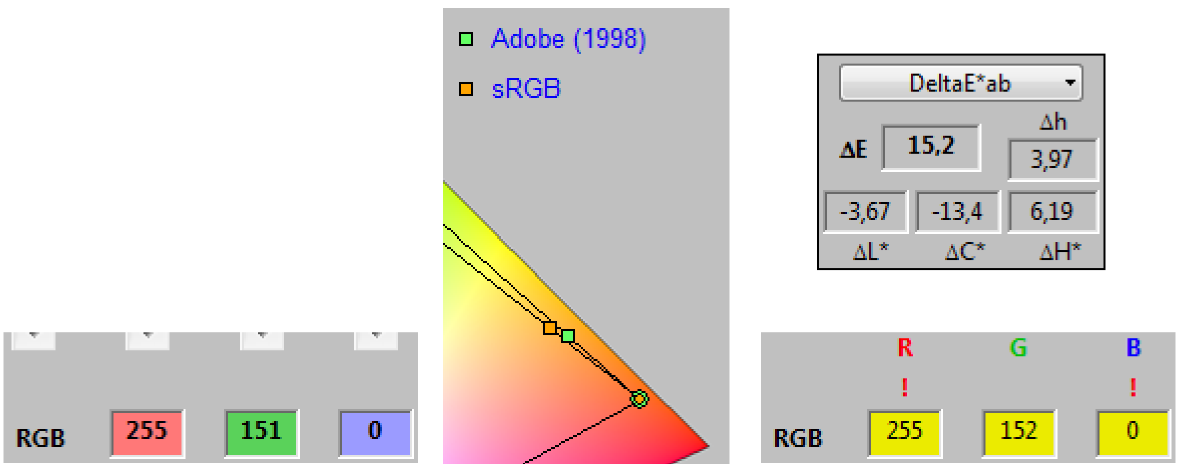


We now see that the sRGB patch representing Space #1 (Adobe (1998)) has both its red and blue coordinates clipped. To match the Adobe (1998) color we would need to add more red than the nominal 255 maximum value for 8 bit encoding, and assign a negative value to the blue coordinate. This is indeed one method to extend the gamut of RGB spaces; see for instance:

PIMA 7667:2001 Standard: "Photography – Electronic still picture imaging – Extended sRGB color encoding – e-sRGB" (PIMA: Photographic and Imaging Manufacturers Association).

While not very common, this method is used in some PatchTool conversions, another BabelColor product (https://www.babelcolor.com) .

- From this point on we can see that the orange square of Space #2 moves away from the green square and the color difference goes up as we increase Y. Below on the left we see the RGB coordinates of Space #1 with Y at its maximum position, where R of Space #1 is now 255 but R of Space #2 is still clipped at 255:



In this tutorial we have seen that:

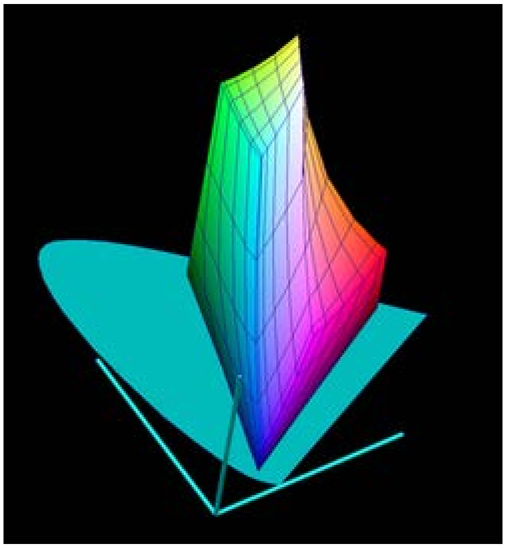
- When an RGB coordinate is clipped by the display profile, a clipping indicator is shown in the bottom of the patch. This indicator has no specific indication of which coordinate is clipped; it could be one of the three coordinates or all three.
- When an RGB coordinate is clipped by an RGB to RGB conversion, an exclamation point appears over the specific R, G, or B data field which is clipped in the destination space. The color difference value is then an evaluation of the amount of clipping in the conversion.

Note: It is hazardous to judge a color difference visually when one or both colors are clipped by the display profile, since clipped colors are not accurate by definition!

Important: Do not forget to reset the display profile, using your OS monitor control panel, to what it was when you started the tutorial.

ADDITIONAL INFORMATION

When converting to another RGB space, it may well happen that a color is clipped even if its "xy" coordinates are within the triangular area defined by the destination space's primaries. To understand why, look at the following illustration which shows all the colors, the gamut, of the sRGB space using xyY coordinates ("x" and "y" define the plane of the horseshoe; "Y", the luminance, is perpendicular to the "xy" plane):



Almost every "xy" coordinates within the triangle defined by the space primaries has a different maximum "Y" value, and the 3D shape of a space's xyY coordinates is far from the uniform cube representation of R'G'B'. Moreover, the 3D shape is different from one space to the other and the maximum Y will likely be different, resulting in clipping in the Y dimension. It is thus risky to only use only the periphery, or area, of the "xy" representation to compare color spaces; the third dimension, "Y", must also be taken into consideration.

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.4 A color picker with a twist

INTRODUCTION

This tutorial shows how to use the RGB vs RGB tool as a color picker with unique features.

Any software which manipulates color images or color objects usually has a color picker. It is often the operating system's default picker but various schemes are proposed. Sometimes, the color picker is made only of R'G'B' sliders and input boxes, but you can also find L*a*b* and HSB (Hue-Saturation-Brightness) input controls. You usually have a color patch showing the current selection and, sometimes, another patch showing the previous selection.

The RGB vs RGB tool offers:

- two identical and independent color pickers in a single screen,
- data displays that show the real luminance (Y) of two samples,
- color selection by clicking in a chromaticity diagram,
- multiple patch layouts to simultaneously compare the patches on standard backgrounds and relative to each other's color,
- simultaneous examples of colored text on standard backgrounds and relative to each other's color with the Contrast Ratio associated with each color pair as defined in the Web Content Accessibility Guidelines (WCAG).

The following examples present these features.

SETUP

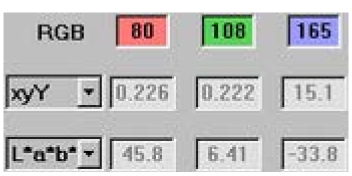
Set the program as follow:

- Open the RGB vs RGB tool window and close all other tool windows.
- Set the RGB vs RGB window in Compare mode with both sides in RGB space mode.
- Space selection: sRGB for both spaces
- Input modes: R'G'B' for both spaces
- Hex # / HSB / HVC / L*C*h / xyY / XYZ display: xyY in both spaces
- L*a*b* / L*u*v* display: L*a*b* in both spaces
- L*a*b* / L*u*v* in D50 checkbox: unchecked in both spaces
- Gamma mode: detailed gamma

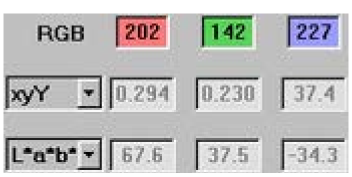
EXAMPLE 1: Setting two different colors to the same brightness

In this example we will match the luminance, or brightness, of two different colors. This can be useful when you want to minimize any one color standing out when they are viewed together.

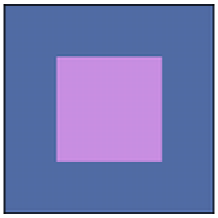
Write the following coordinates in Space #1 R'G'B' display boxes:
R'G'B' = (80, 108, 165). Space #1 displays should be:



Write the following coordinates in Space #2 R'G'B' display boxes:
R'G'B' = (202, 142, 227). Space #2 displays should be:



When seen together, Space #2 color is more noticeable because of its brightness:



Its "Y" value is 37,4 compared to 15,1 for Space #1. The "L*" values (of L*a*b*), more representative of the perceived brightness, are 67,6 for Space #2 and 45,8 for Space #1.

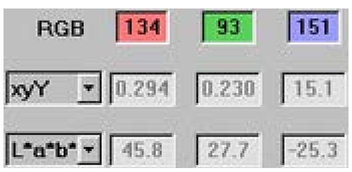
To match their brightness, you have three choices, all done using the "Y" slider:

- increase the brightness of Space #1,
- decrease the brightness of Space $2, or
- increase or decrease the brightness of both spaces!

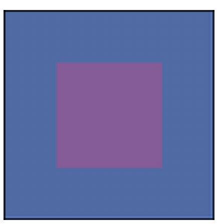
There is a caveat: You cannot arbitrarily increase the luminance ("Y") or brightness ("L*") of a given color; there is a different maximum value for each "xy" data set (see the xyY and XYZ section for more information).

For the purpose of the example, we will simply decrease Space #2 brightness. Click and drag the elevator box of the "Y" slider until its "Y" coordinate approximately matches the value seen in Space #1; you can also do the adjustment using "L*" as a reference.

Space #2 displays should be close to:

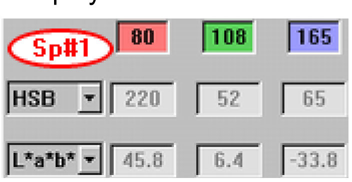


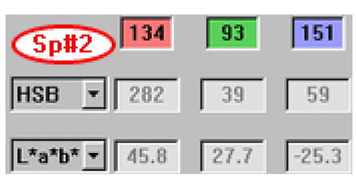
where Y=15,1 for both spaces (note that L*=45,8 also in both spaces), and the color patches display now shows:



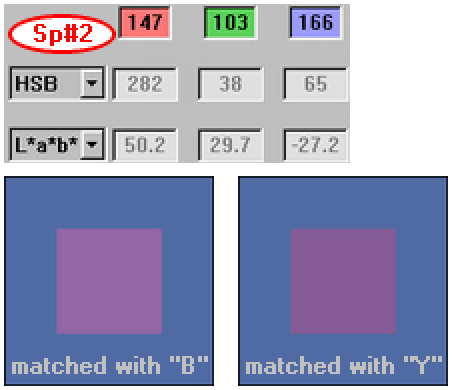
You will find that the perceived brightness is better matched using "Y" or "L*" as references compared to making adjustments using the "B" of the HSB. To visualize this, set the Hex # / HSB / HVC / L*C*h / xyY / XYZ display to HSB in both spaces.

The displays should now be:





Although both spaces have the same "Y" and "L*" values, the HSB brightness of Space #2 is 59 compared to 65 for Space #1. If one was to set Space #2 HSB brightness to 65, using the "Y" slider, the resulting color would be too bright (L*=50,2) as can be seen in the following illustrations (the color patches matched with "Y" are also shown for comparison; please note that actual R'G'B' display numbers may be (146, 102, 165) instead of (147, 103, 166), as shown, when moving the "Y" slider to get B=65):

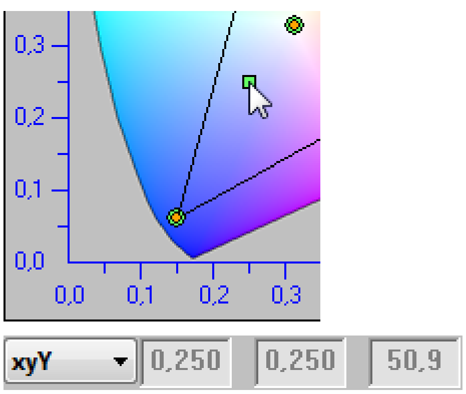


EXAMPLE 2: Selecting complementary colors using mouse input

In this example we will see how we can rapidly select colors by clicking in the chromaticity diagram. The setup for this example is the one defined at the beginning of this tutorial.

Verify, in the "xy" mouse input display, that the Space #1 radio button is selected and that both buttons are enabled:

Click (mouse left-click) in the chromaticity diagram window around the x = y = 0.250 location (plus or minus 0.010). A small display with the x and y coordinates will appear as you move the mouse on the chromaticity diagram; these coordinates will appear in the xyY display of Space #1 when you do a mouse click:



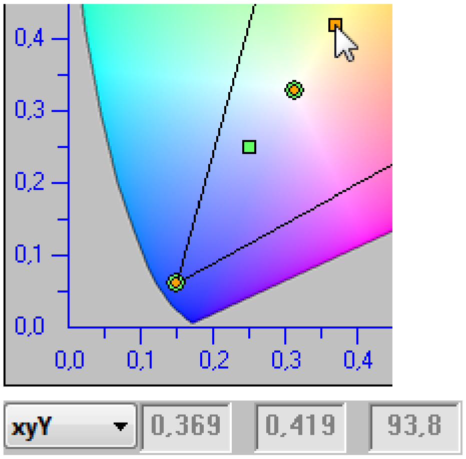
Select Space #2 by one of the two methods:

- **Method 1:** Do a mouse **right-click** (**ctrl + click** on a one-button Mac mouse) in the chromaticity diagram at a location, relative to the illuminant, approximately opposite from Space #1 color (x ≈ 0.37, y ≈ 0.42).
- **Method 2:** Select the right radio button in the the "xy" mouse input display:

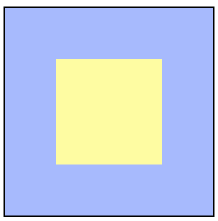
  

  and click (mouse left-click) in the chromaticity diagram at a location, relative to the illuminant, approximately opposite from Space #1 color (x ≈ 0.37, y ≈ 0.42).

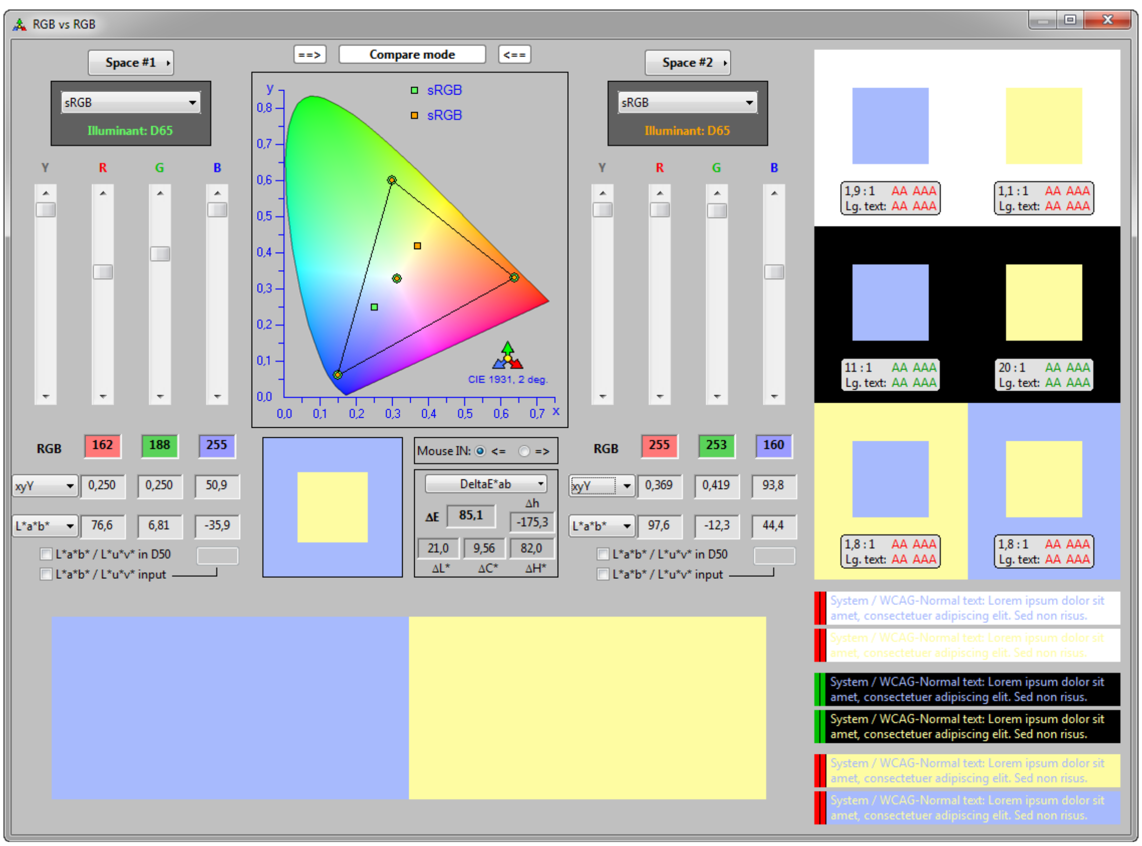
Both methods achieve the same result but Method 1 is faster when you need to switch sides repeatedly.



The color patches display will show you complementary colors:



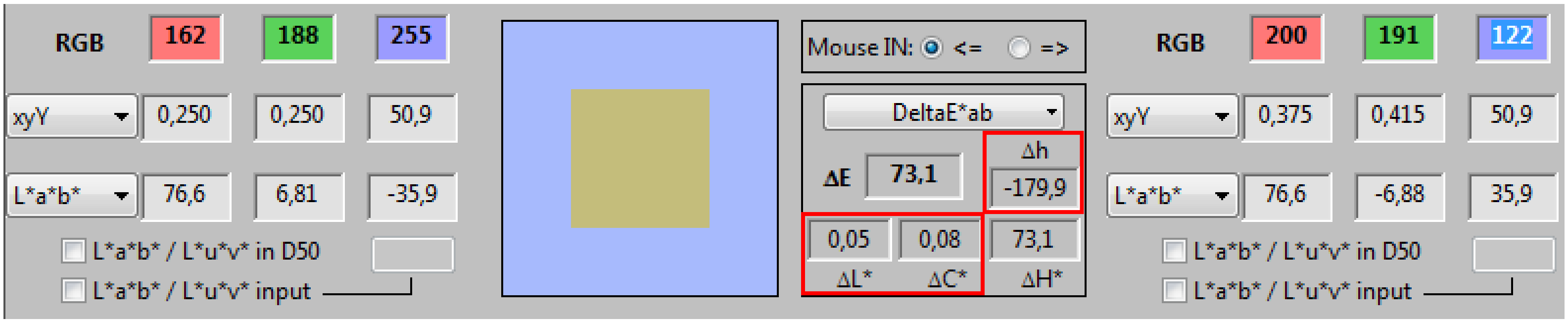
Enlarge the window until you see the extra patches on the bottom of the display and the ones on its right:



If required, click on the bottom patches until you obtain the layout where the patches are side-by-side.

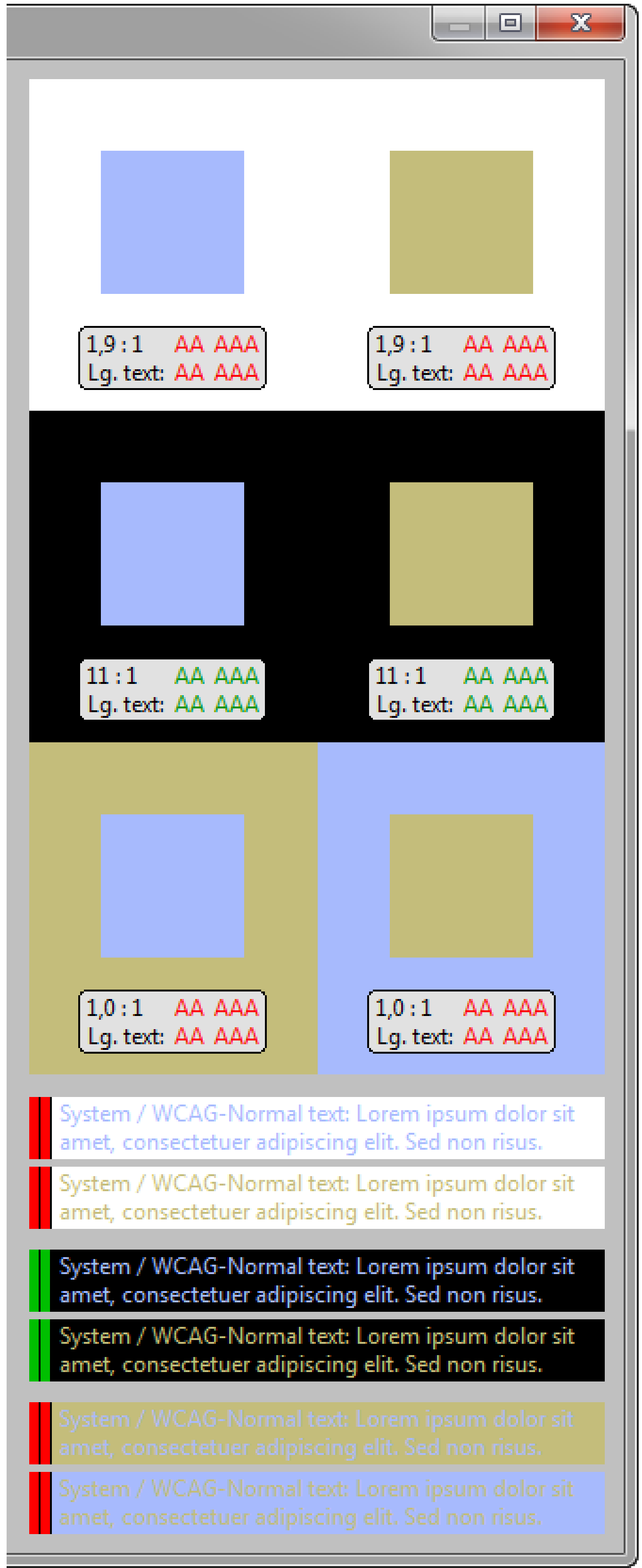
By default, when selecting a color using mouse input, the software will set the luminance to its maximum value. You can further adjust their brightness, using the **Y** slider, without changing their "xy" coordinates. You can also use the **Y** and **RGB** sliders in conjunction with the DeltaE* display to minimize ΔL^* and ΔC^*, and adjust Δh to -180 degrees, which corresponds to the "exact" complementary position (at least in terms of the L*C*h representation).

Have a look at the DeltaE* display shown below, which was obtained by adjusting the position of Space #2 with the goal of minimizing the lightness (L*) and chroma (C*) differences while obtaining an almost exact 180 degrees shift in hue.



EXAMPLE 3: Optimizing two colors to maximize text contrast

This example shows how you can rapidly modify the luminance of two colors to maximize text contrast on various backgrounds.



To do this we will use the patch and text layouts on the right of the tool window. The top layout presents patches of the two selected colors, defined in the Space #1 and Space #2 sections of the window, on white and black backgrounds, as well as on a background of the other color. The bottom layout presents text with the same color combinations used with the patches.

We will start with the complementary colors obtained at the end of the second example. Graphic designers sometimes play with complementary colors for artistic effects. For the purpose of this example, we will keep the same hues and only adjust their respective luminance.

For reference, here are the color settings used for the screenshot on the right:

Space #1: sRGB = (162, 188, 255)
Space #2: sRGB = (200, 191, 122)

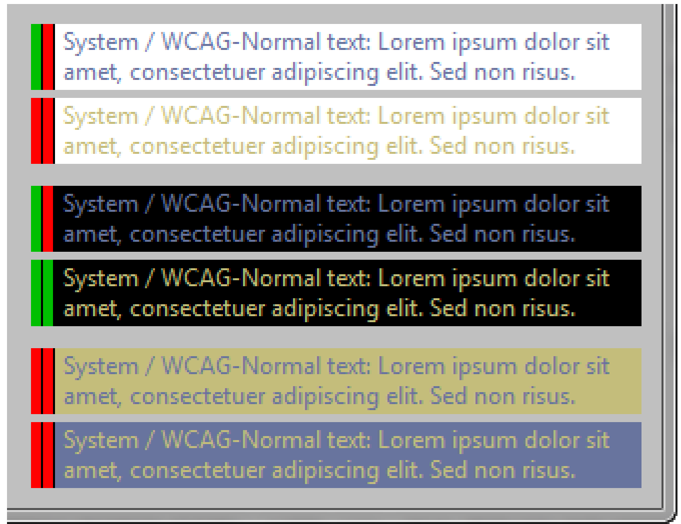
For the font layout, select the following settings with the popup menu which appears with a right-click:

Font name: (you can keep the default font)
Font size: 12
Font type: Regular

In the patch layout you will notice labels with numbers and text corresponding to each color & background combination. The numbers on the first line indicate the Contrast Ratio for the two colors as defined in the Web Content Accessibility Guidelines (WCAG). The "AA" and "AAA" symbols of the first line respectively indicate if this contrast meets or not the **Minimum** and **Enhanced** contrast requirements for *Normal text*. The symbols of the second line indicate similar compliance for *Large text*. *Large text* is defined by the WCAG as being at least 14 points in size and bold, or 18 points and regular; any text smaller is referred to as *Normal text*. Here we see that the contrast ratios meet all WCAG requirements (Minimum and Enhanced contrast, for both *Normal* and *Large text*) for the black background, and fail for all other combinations. In particular, it is impossible to read text of the first color on a background of the other color. This is expected since we matched their luminance in EXAMPLE 2.

The red or green vertical bars in the text boxes correspond to the "AA" and "AAA" symbols of the labels; since the text cannot be normal and large at the same time, we see only two bars..Because we have assigned a 12 points size and a regular type to the text boxes, the first line should present the font name followed by "WCAG-Normal text".

We will use the Y slider of Space #1 to see how it affects the contrast ratios on all backgrounds. Lower the Y slider of Space #1 until the first bar of the blue text on a white background becomes green. This should happen around **sRGB = (100, 117, 161)**, and the text boxes should look like shown on the top-right screenshot, identified by **(A)**.

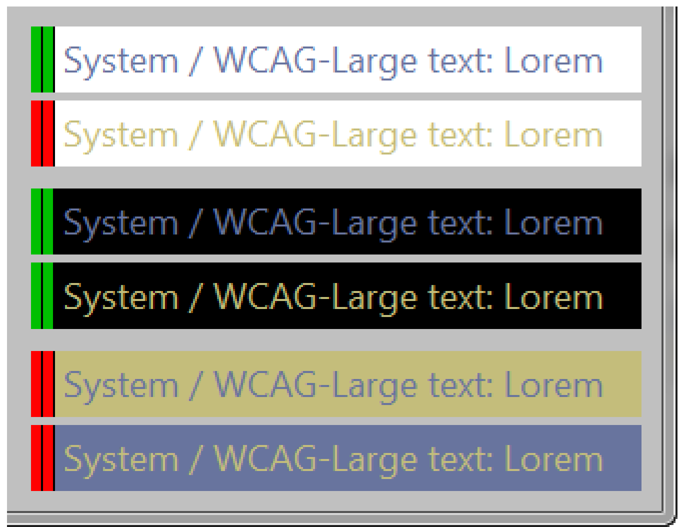


(A)

Warning: Do not bring the luminance slider (i.e. "Y") to its minimum position; this will set all inputs to zero and move the chromaticity point on the illuminant. If this happens, retype the R'G'B' values shown at the beginning of EXAMPLE 3.

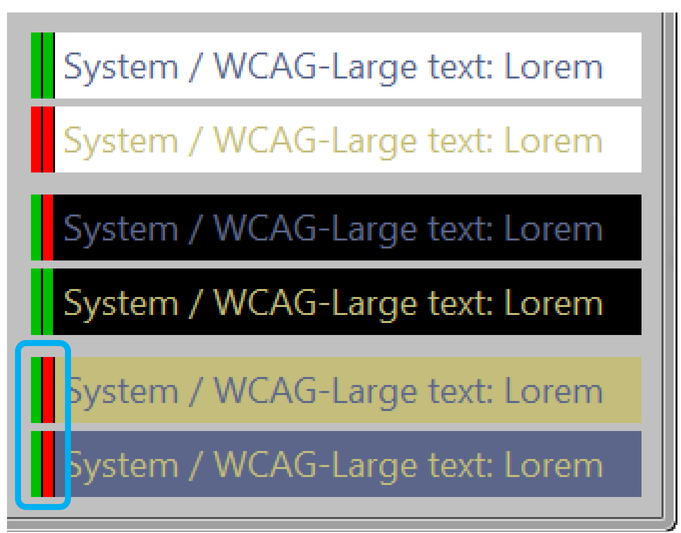
We notice that the increase in contrast of the Space #1 color on white corresponds to a decrease of the contrast on black. We also see a significant improvement of the contrast relative to a background of the other selected color (Space #2), but still not enough to meet the WCAG requirements.

We can also look at the same colors with large text. To do so, let's select "**WCAG-Large (18+, Regular)**" in the popup menu which appears when you do a right-click over a text box. The text boxes in the middle-right screenshot **(B)** show the larger text with the corresponding WCAG compliance results. We see legibility improvement, but still not enough for Space #1 text color on the Space #2 color background (or vice-versa, since the contrast ratio is just based on the colors).



(B)

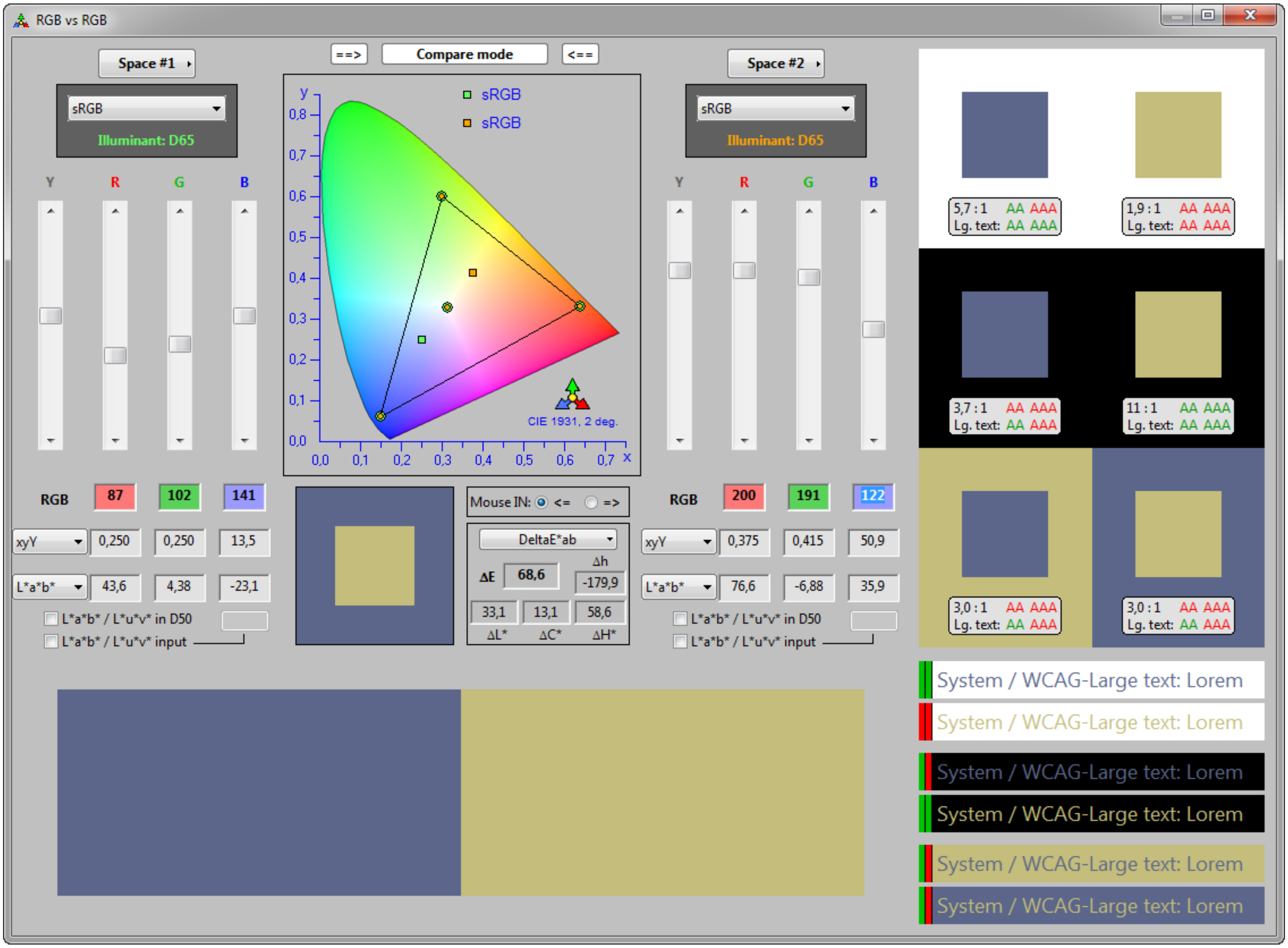
With the text set to "WCAG-Large", let's continue to decrease the Y slider of Space #1 until the first bar of the text on a background of the other color becomes green (either Space #1 text color on Space #2 background or Space #2 text color on Space #1 background). This should happen around **sRGB = (87, 102, 141)**, and the text boxes should look like those shown on the bottom-right screenshot **(C)**.



(C)

At this point, we know that the two selected colors can meet the **Minimum** contrast requirements for *Large Text* as recommended by the WCAG (contrast=3,0+). Unfortunately, they do not meet the **Enhanced** contrast requirement for *Large Text*, nor do they meet any of the *Normal text* requirements (either Minimum or Enhanced). However, if we plan to use large text and our target audience does not have very low visual acuity, this is sufficient; if this is not the case, we need to continue our search for a more contrasting color combination.

On the next page we show the complete window corresponding to our last adjustment. You will notice that the positions of the colors on the chromaticity diagram are the same as the ones we obtained at the end of EXAMPLE 2. You can save the WCAG Contrast Ratios and the contrast compliance results for all text color combinations in the report obtained with the "**Save Data…**" menu item of the RGB vs RGB menu.



This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.5 L*a*b* / L*u*v* input

INTRODUCTION

This tutorial demonstrates the features of the RGB vs RGB tool L*a*b* / L*u*v* input mode.

While R'G'B' inputs are natural when working in RGB spaces, many applications call for the use of more standard colorimetric data such as XYZ, L*a*b* or L*u*v*. For example, specifying a reference color for a company logo will often be done using L*a*b* coordinates determined with a D50 illuminant.

When incorporating a logo in a publicity brochure, there is a need to use the best (should we say exact!) color information. A conversion of the L*a*b* data into the RGB space of the image rendering tools is often required.

You may also have a need to convert L*a*b* **to** L*u*v* data, or convert L*a*b* or L*u*v* data from one illuminant to another, or determine the equivalent xyY and XYZ coordinates. These are all transforms which are independent of the RGB space environment but which are nonetheless possible to do within this window.

These features are demonstrated in the following examples.

SETUP

Set the program as follow:

- Open the RGB vs RGB tool window and close all other tool windows.
- Set the RGB vs RGB window in Convert mode Left-to-Right with both sides in RGB space mode.
- Space selection: sRGB for both spaces

The next three steps are only done to insure that the tutorial's illustrations match the user screen.

- Select "Bradford" as the Chromatic Adaptation Transform in the "Math" tab of the Preferences dialog, then close the dialog.
- Space #1 input mode: R'G'B' (**not** L*a*b* / L*u*v* input **yet**)
- Click and drag the "Y" slider of Space #1 to the bottom: R'G'B' = (0, 0, 0)

Continue with these settings:

- **Now** set Space #1 input mode to: L*a*b* / L*u*v* input
- Hex # / HSB / HVC / L*C*h / xyY / XYZ display: xyY in both spaces
- L*a*b* / L*u*v* display: L*a*b* in both spaces
- L*a*b* / L*u*v* in D50 checkbox: checked in both spaces
- DeltaE* display: DeltaE*ab

EXAMPLE 1: Converting L*a*b* data into R'G'B'

In this example we will determine the R'G'B' coordinates corresponding to specific L*a*b* data.

Make sure that the **L*a*b* / L*u*v* in D50** checkbox is **checked** since the sRGB space illuminant is D65. If the box was left unchecked, the program would assume that the L*a*b* input is in D65.

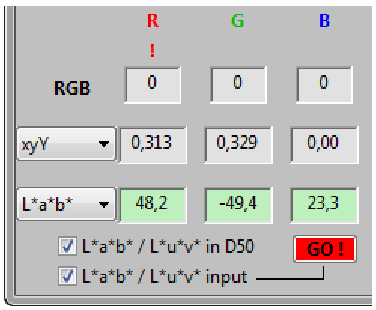
Click the mouse in the L* box, the first box on the left with a green background. Write **48,2** in the box and then press tab on your keyboard to go the next box on the right. Write **-49,4** for a*, then another tab to go to the third box, and write **23,3** for b*.

Do **not** click the 

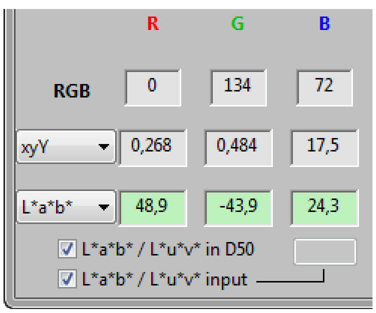
button yet!

The color we just entered is L*a*b* (D50) = (48,2, -49,4, 23,3), a mid-green.

Space #1 display should be:



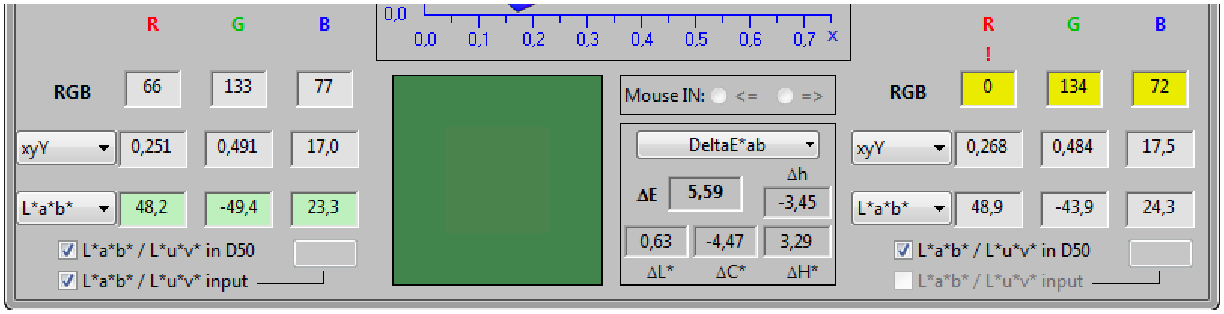
The display will not be updated until the "GO !" button is clicked. The R'G'B' and xyY displays still show the previous data. The clipping indicator (**!**) above the R' display box is an advanced warning that the typed L*a*b* input represents a color which cannot be exactly represented in the sRGB space; it will be clipped. The clipping indicator will disappear when we click the "GO !" button and the closest valid color will be determined. If you now click the "GO !" button (you can also press the **Return** key), the display becomes:



All three L*a*b* coordinates have changed to the closest matching color. The R' display now shows zero, as a result of clipping. In such a situation, there are a few choices:

- clipping is deemed reasonable and the clipped R'G'B' coordinates are used as is (the clipping error will be evaluated next),
- another target space with a larger gamut can be selected,
- a custom spot color could be used for printing, if this is the desired output media.

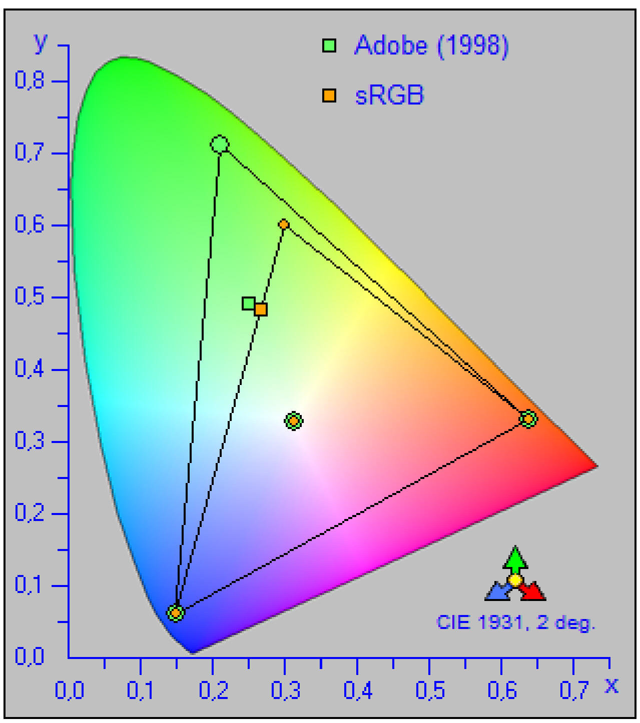
To evaluate the clipping error, **change** the RGB space of **Space #1 to Adobe (1998)**, a larger space and re-enter the L*a*b* (D50) = (48,2, -49,4, 23,3) coordinates. Before clicking the "GO !" button, notice the absence of clipping indicators above Space #1 R'G'B' displays, which indicates that the color is within the gamut of Adobe (1998) RGB. Once the "GO !" button is clicked, the updated display is:



where none of the L*a*b* coordinates have changed relative to the input values. Since we are in Convert mode, and since Space #2 is set in sRGB, Space #2 will show the same R'G'B' values we had when Space #1 was clipped to sRGB (Space #2 sRGB = 0, 134, 72). In addition, the DeltaE*ab display shows a 5,59 color-difference value between the non-clipped and clipped colors.

Note: For those who think the above color-difference value overestimates the perceived difference, you can change the color-difference formula to DE2000. You will get a number (=2,12) which better matches what we see.

Looking at the chromaticity diagram, we see that the green square of Space #1, representing the non-clipped color, is slightly out of the sRGB triangle:



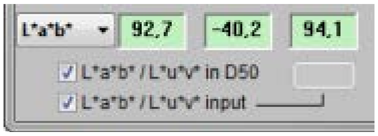
With the above procedure, we learned that the original L*a*b* color is not clipped in Adobe (1998) RGB and we got the corresponding R'G'B' coordinates; we also determined the exact color-difference value resulting from the use of sRGB.

EXAMPLE 2: Converting from L*a*b* to L*u*v*, or vice-versa

The RGB vs RGB tool can be used when there is a need to convert data between the L*a*b* and L*u*v* spaces, or between L*a*b* or L*u*v* and xyY or XYZ, even if there is no use for R'G'B' data.

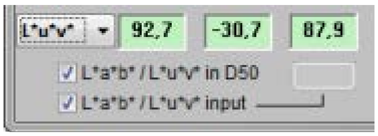
First, if not already set, select the **Adobe (1998)** space for Space #1, then **check** the **L*a*b* / L*u*v* in D50** checkbox, and finally, enter the following L*a*b* (D50) values = (92,7, -40,2, 94,1).

Once the values are entered, you **must** click on the "GO !" button; only then will you be able to get the data for the other representations. Here is a screenshot of the L*a*b* (D50) values:

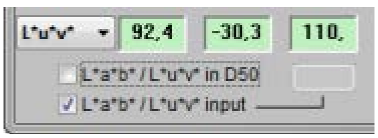


We can also see:

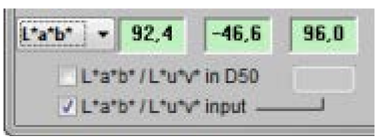
- L*u*v* (D50) by selecting **L*u*v*** in the menu:



- L*u*v* (D65) by un-checking the **L*a*b* / L*u*v* in D50** checkbox:



- L*a*b* (D65) by re-selecting **L*a*b*** in the menu:



As well, Hex #, HSB, Munsell HVC, L*C*h, xyY and XYZ can be displayed for this given L*a*b* (D50) input. However, all of these representations, except L*C*h, are shown relative to the illuminant of the selected space, D65 in this case (for Adobe (1998)). L*C*h is the exception; it will always correspond to the **L*a*b* / L*u*v*** and **L*a*b* / L*u*v* in D50** checkbox selections (click here for more info).

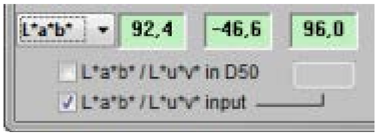
For conversions using this method, you should use the largest space available for a given illuminant:

- for illuminant **C**: NTSC,
- for illuminant **D50**: ProPhoto,
- for illuminant **D65**: Adobe (1998),
- for illuminant **E**: CIE RGB,
- or you can define a large space with any illuminant using the Custom RGB space dialog.

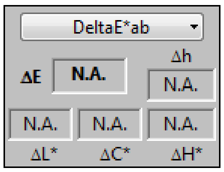
Important: If the L*a*b* or L*u*v* input data falls outside of the gamut of the selected RGB space, the conversion will be clipped and the results will not be valid.

EXAMPLE 3: Converting D65 L*a*b* data into Illuminant E

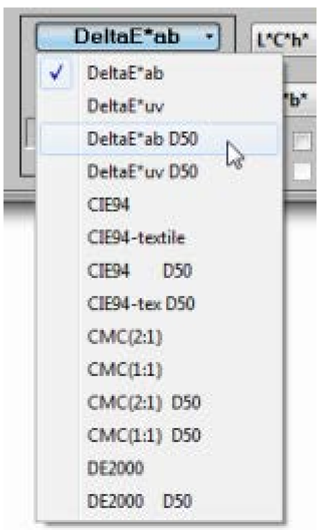
Let's go back to the display at the end of EXAMPLE 2, where the following L*a*b* (D65) values should still be visible. If required, re-select the **Adobe (1998)** space, **uncheck** the **L*a*b* / L*u*v* in D50** checkbox, re-enter the L*a*b* numbers and click on the "**GO !**" button. Also make sure we are still in Convert mode Left-to-Right.



As indicated in this example title, we want to convert L*a*b* (**D65)** data into illuminant **E** values. One possible method is to select **CIE RGB** space for Space #2. We could also design a custom RGB space with Illuminant E for Space #2, but this is not the purpose of this tutorial! After selection the CIE RGB space, you will see that the DeltaE*ab display shows "N.A.", for "Not Applicable", since a color-difference cannot be directly computed from L*a*b* values determined for different illuminants (D65 and E).



Select **DeltaE*ab D50** in the list box:



To compute this color-difference, the XYZ values of Space #1 are first converted from **D65** (the illuminant of **Adobe (1998)**) to **D50**, and those of Space #2 from **E** (the illuminant of **CIE RGB**) to **D50**; the color-difference is then determined using L*a*b* (D50). In this case, a zero color-difference is obtained, meaning no clipping. The patch color may be clipped for display purposes, but this has no effect on the conversion.

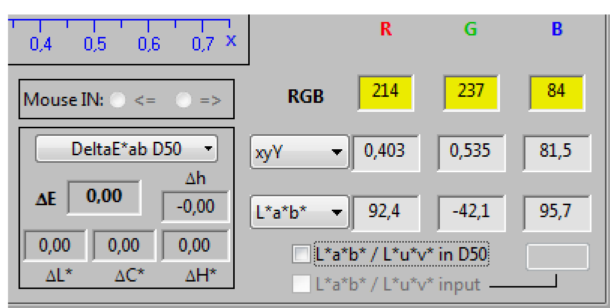
We thus converted:

L*a*b* (D65) = (92,4, -46,6, 96)

to

L*a*b* (E) = (92,4, -42,1, 95,7)

The data for L*u*v* (E) can be obtained as we did in EXAMPLE 2.



Important: The conversion is valid as long as there is no clipping shown over the RGB coordinates of Space #2. If there is clipping, you will need to define a larger custom RGB space for Space #2.

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.6 Simulate a ColorChecker color patch

INTRODUCTION

Here is a procedure that enables you to simulate color patches of the X-Rite/GretagMacbeth ColorChecker chart starting with xyY coordinates.

Note: Of course, if you have the L*a*b* coordinates of the patches, you can always select the L*a*b* / L*u*v* input mode, and enter the coordinates directly, but make sure they are of the proper illuminant.

This procedure uses chromaticity coordinates referenced to illuminant D65; the data is presented in the table below. Similar data for illuminants C and D50 is provided, as well as additional information, in the ColorChecker data section.

		D65		
#	**description**	**x**	**y**	**Y**
1	**dark skin**	0,398	0,360	10,1
2	**light skin**	0,383	0,356	34,6
3	**blue sky**	0,249	0,266	18,9
4	**foliage**	0,343	0,432	13,3
5	**blue flower**	0,269	0,254	23,5
6	**bluish green**	0,261	0,360	42,7
7	**orange**	0,508	0,406	29,7
8	**purplish blue**	0,212	0,184	11,8
9	**moderate red**	0,462	0,312	18,7
10	**purple**	0,292	0,222	6,37
11	**yellow green**	0,377	0,496	44,2
12	**orange yellow**	0,476	0,442	42,1
13	**blue**	0,188	0,144	6,11
14	**green**	0,306	0,489	23,4
15	**red**	0,539	0,322	11,7
16	**yellow**	0,449	0,476	59,4
17	**magenta**	0,369	0,241	19,2
18	**cyan**	0,198	0,270	20,0
19	**white (0.05 D)**	0,316	0,334	91,2
20	**neutral (0.23 D)**	0,312	0,330	58,9
21	**neutral (0.44 D)**	0,312	0,330	36,0
22	**neutral (0.70 D)**	0,311	0,329	19,1
23	**neutral (1.05 D)**	0,310	0,328	8,94
24	**black (1.5 D)**	0,311	0,327	3,20

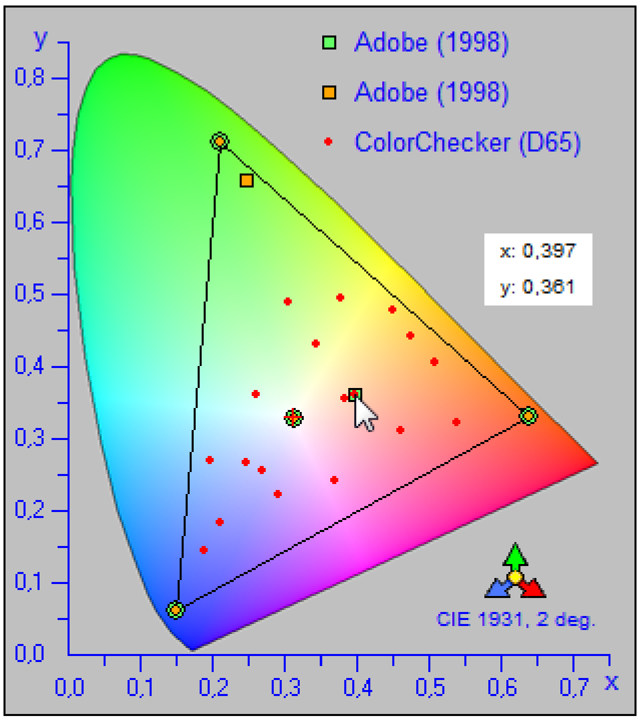
SETUP

Set the program as follow:

- Open the RGB vs RGB tool window and close all other tool windows.
- Set the RGB vs RGB window in Compare mode with both sides in RGB space mode.
- Space selection: Adobe (1998) for both spaces
- Space #1 input mode: R'G'B' (i.e. uncheck L*a*b* / L*u*v* input)
- Hex # / HSB / HVC / L*C*h / xyY / XYZ display: xyY in both spaces
- xy mouse input: Space #1
- Select the "RGB vs RGB/Graphic data/ColorChecker (D65)" menu or the "ColorChecker (D65)" menu of the toolbar "**Graphics**" icon. " (Make sure to select the (D65) version).

PROCEDURE

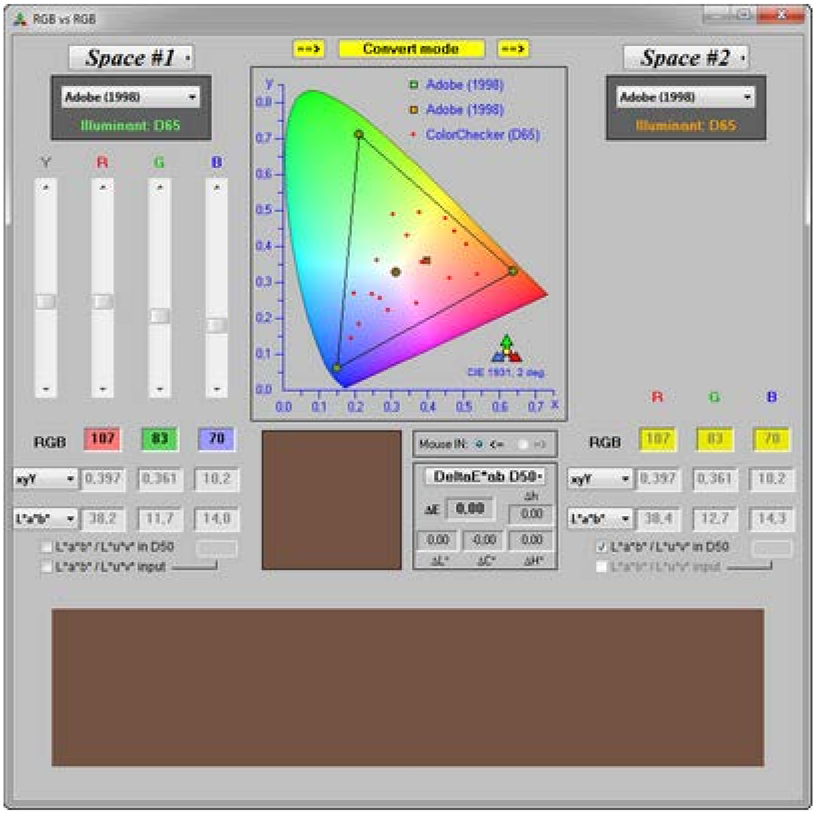
1. Click on any red dot; compare the "xy" coordinates in Space #1 display boxes with the ones in the table shown at the end of this tutorial. Use the data window in the chromaticity diagram as a guide, shown here for patch #1:



   The red dot should be in the green square's center, but an exact value/position match may be difficult to achieve for some patches due to the limited screen resolution; you should tweak the location with the **RGB** and **Y** sliders if required and place emphasis on matching the numerical values instead of the red dot and green square relative positions.

2. Using Space #1 "Y" slider, bring the "Y" of the xyY display as close as you can to the table value.

3. Set the program in Convert mode Left-to-Right by clicking on the "Compare mode" button on top of the chromaticity diagram. You now have a large color patch corresponding to one of the ColorChecker chart's patches (assuming you use a calibrated display!). You can also enlarge the window to show the patch layout in the bottom of the display:



To obtain the color coordinates in any of the other RGB spaces, simply select it in the Space #2 list box. Also, for darker colors, you may want to dim the background of the chromaticity diagram.

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.7 Using the Color Decks

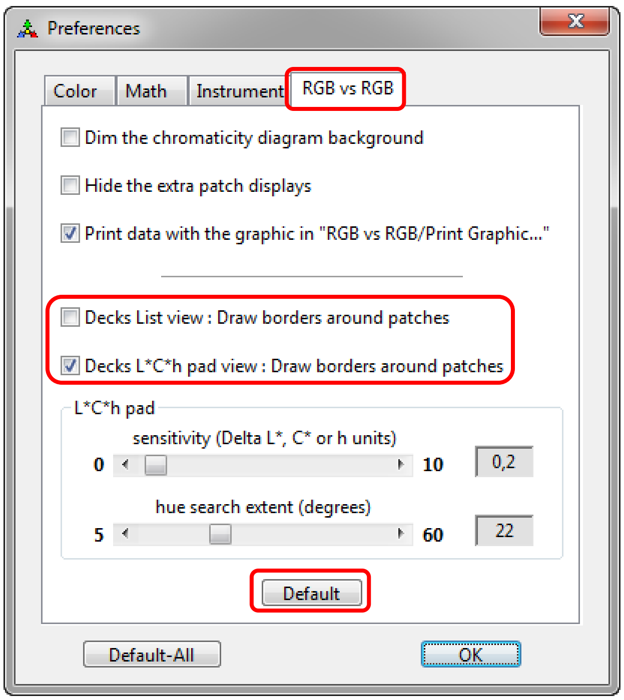
INTRODUCTION

This tutorial is an introduction on the use of the RGB vs RGB tool Deck mode and how it interacts with the RGB spaces.

SETUP

Set the program as follow:

- Open the RGB vs RGB tool window and close all other tool windows.
- Set the RGB vs RGB window in Compare mode with both sides in RGB space mode.
- Space #1 selection and input mode: anything
- Space #2 selection: eciRGB_v2
- Space #2 input mode: R'G'B' (i.e. uncheck L*a*b* / L*u*v* input)
- DeltaE* display: DeltaE*ab
- Go to the "RGB vs RGB" tab of the Preferences dialog and click on the tab's "Default" button. The dialog should appear as shown below:



In particular, please note the default settings for these two parameters which affect the appearance of the patches layout:

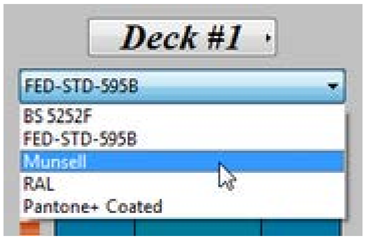
☐ **Decks List view: Draw borders around patches**

☑ **Decks L*C*h pad view: Draw borders around patches**

STEP 1

Change the LEFT side into Deck mode by clicking on the label identified "**Space #1**" and slide the cursor to the "**Deck #1**" selection:

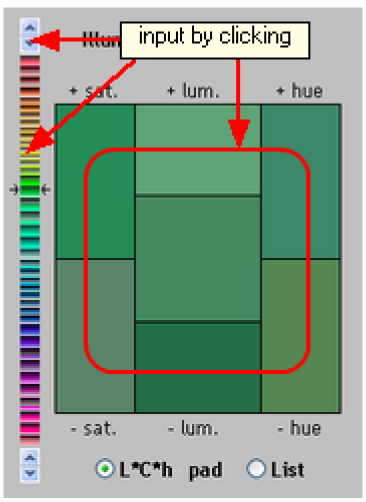
The deck mode will appear. The selected deck will depend on which deck was last used. If not already selected, select the **Munsell** deck:



Note: The deck labeled "Pantone+ Coated" in the above screenshot is not provided with CT&A; however, you can easily add such a deck if you have Photoshop, or if you have color data saved in CxF format. In this case, the data was from a Photoshop color library first exported in Adobe Swatch Exchange (ASE) format and then opened with PatchTool. Once opened in PatchTool, adding a deck to CT&A can be done using PatchTool CT&A Export tool (This function can be done with PatchTool in demo mode, and no purchase is required).

STEP 2

Change the selected chip, located in the center of the L*C*h pad, by clicking either on the color strip, the arrows at each end of the color strip, or on the L*C*h pad patches surrounding the center patch:

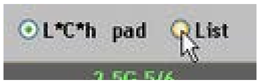


Try clicking on the patches labeled with **+ sat.**, **+ lum.** and **+ hue** and see how they respectively select a chip with more saturation, more luminance, and a hue characterized by a larger *h* angle. Similarly, click on the patches labeled with **- sat.**, **- lum**. and **- hue** to respectively select a chip with less saturation, less luminance, and a hue characterized by a smaller *h* angle.

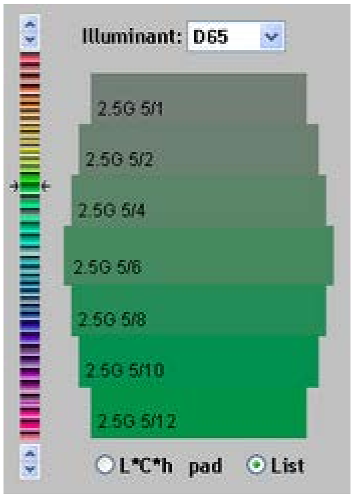
The name of the chip represented by the center patch is shown below the pad. For the names of the chips around the center, simply rest the mouse cursor over the patch and a tag with the chip name will appear. For more information on the features of the L*C*h pad, as well as its interaction with the DeltaE* setting, see the L*C*h pad section.

STEP 3

Click on the "List" radio button located under the L*C*h pad:



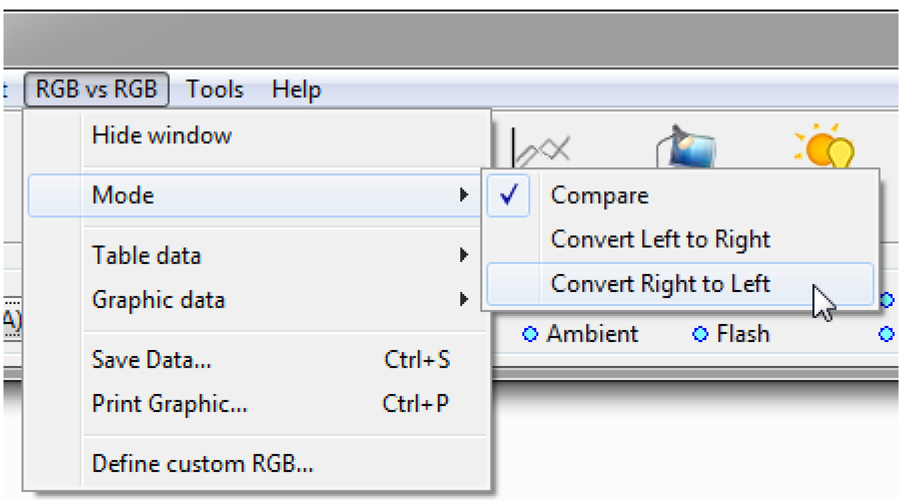
The deck display now has the following appearance (Note: the selected chip may be different):



The largest patch in the center is the same as the one in the center of the L*C*h pad. However, the other patches over and under the central patch are shown according to their position relative to that chip in the deck database, a snapshot of which is shown in the color strip. You can click on any patch in the list to bring it to the central position; as well, like for the L*C*h pad, you can click in the color strip and on the arrows at each end.

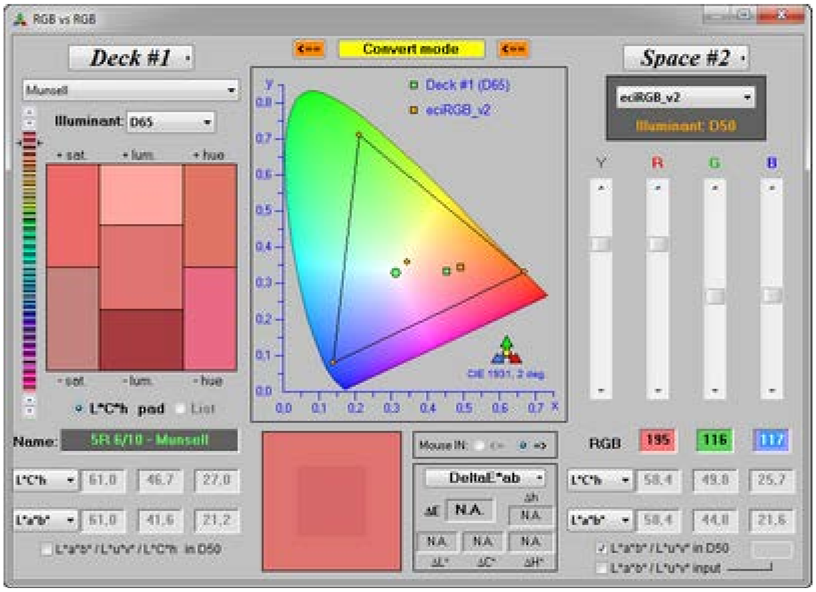
STEP 4

In the RGB vs RGB menu, select the "**Mode/Convert Right to Left**" menu item:

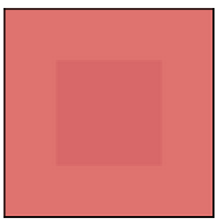


Select "**eciRGB_v2**" in **Space #2** and write the following values in the R'G'B' display boxes: (**195**, **116**, **117**).

The display should look like the following image (as seen on Windows 7):



The program automatically selects the **L*C*h pad** mode when you convert TO a deck; the **List** view is not available. The center patch of the L*C*h pad shows the best match to the R'G'B' coordinates we just entered. It is the **5R 6/10** chip, where **5R** means the middle of the **R**ed **H**ue zone in the Munsell notation, while **6/** is the Munsell **V**alue and **/10** is the Munsell **C**hroma. The match is not exact since there is a visual difference in the patches display in the bottom of the window:

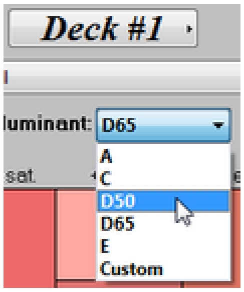


If we want the Munsell **HVC** equivalent to the eciRGB_v2 R'G'B' coordinates, we simply select the Munsell HVC display in Space #2:

Which is shown as:

The **4,5R 5,7/10,4** value is obtained by interpolating between known Munsell chips manufactured at fixed hue, value and chroma intervals. The interpolation process is discussed in the XYZ to Munsell section; for more information on the Munsell notation, please see the Munsell Color System section.

You will also notice that all the data boxes of the DeltaE* interface show "**N.A.**", which is expected since the illuminant of the deck on the LEFT side is D65 while the illuminant on the RIGHT side, for eciRGB_v2, is D50. We could select the **DeltaE*ab D50** formula, but instead we will change the deck illuminant:



With the same illuminant on both sides, values are now shown for **DeltaE*ab**, and we see that we have a Δ***E*** difference of 3,78.

STEP 5

On the other hand, if we want to find the exact eciRGB_v2 equivalent to the Munsell **5R 6/10** chip, we just need to click on one of the conversion direction arrows:

to change the conversion direction from **Right to Left** to **Left to Right**, and we obtain the following eciRGB_v2 R'G'B' coordinates:

under which we see that the interpolated Munsell HVC values are now equal to the Munsell values of the selected chip in **Deck #1**.

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.8 Measure your display characteristics with the ISO 3664+ tools

INTRODUCTION

This tutorial demonstrates how you can characterize your **color monitor** according to selected ISO 3664:2009 and ISO 12646:2014 requirements (brightness, chromaticity, color temperature, color uniformity, and tone ratio uniformity) using the ISO 3664+ tools.

These tools are called ISO 3664 with a "+" since they can not only help in making many measurements required by the ISO 3664 standard, but can also be adjusted to meet your own requirements and also include tools to measure monitor uniformity according to ISO 12646:2008 and ISO 12646:2014. For instance, ISO 3664 specifies D65 as the chromaticity of the monitor while many would prefer using D50, as specified in ISO 12646. This is possible in this tool by simply selecting another reference illuminant. The same flexibility in setting the reference conditions is available for the Color Rendering Index (CRI) and the Metamerism Index (MI), which can be measured when selecting the other viewing conditions (Prints and Transparencies) defined by ISO 3664.

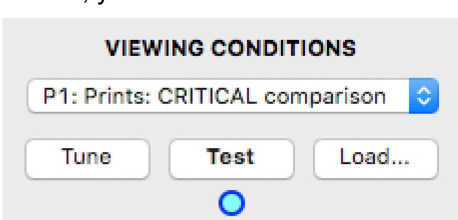
SETUP

Note: When calibrating or checking a display, and before doing any measurements, you should wait at least one hour after powering up the monitor, to give time for the electronic components and the LCD back lights to settle. This is certainly a minimal demand as the ISO 12646:2014 standard mentions that a display to be tested shall be operated in calibration mode for 12 hours in a room where the temperature is between 18 to 28 Celsius, and stable within 0.5 degree, before making the tests. Such stringent demands may make sense in a certification laboratory but are not representative of most working environment we have seen.

Note: It is interesting to see that, for luminance and chromaticity, the 2014 version of ISO 12646 places more emphasis on the **stability** than on **absolute** requirements. For instance, the luminance shall stay within 2% of the average measured during 9 hours, and the white point shall not deviate by more than 0.005 in CIE x and y from the calibration values. Of course, these variations are applicable for an environment where the temperature is controlled as stated in the previous note. This tutorial does not address these specific measurements but uses the luminance and chromaticity requirements defined in ISO 3664:2009.

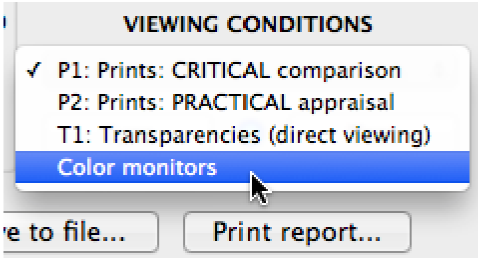
Set the program as follow:

- Open the ISO 3664+ tools window by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/ISO 3664+" menu. You should also close all other tool windows.
- To perform this tutorial, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate", "Tune", "Test" and "Take all" buttons of the ISO3664+ window being enabled (some data entry buttons and controls will remain disabled and some data fields will not be available (shown as "N.A.") if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.
- When the ISO 3664+ tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears below the "Test" button. This indicator confirms that the next instrument key press will be assigned to this window's "Test" button; of course, you can also do a mouse click on any data entry button.



STEP 1

Select the "**Color monitors**" viewing condition:



The window content will change to show only the tools required by the selected viewing condition. In the "Monitor grid" control group, select the "**5x5 (ISO 12646:2014)**" radio button. The display should look as follow:

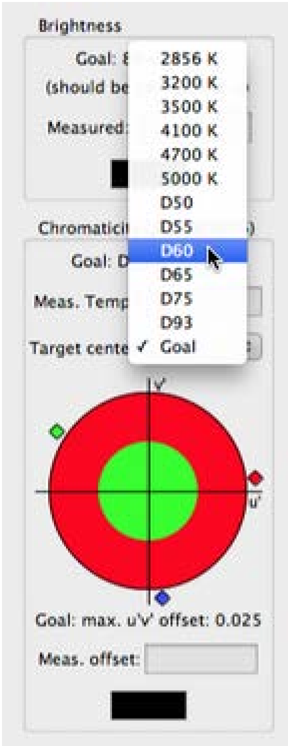
The tools are:

- **Brightness:** This is the brightness of a white patch. Some displays, particularly CRTs, will change their brightness depending on what is displayed on the rest of the screen. For measurement reproducibility purposes, it is recommended to use white patches over a black background.

  The minimal ISO goal of 80 cd/m^2 is considered insufficient by many but may well happen in real life for monitors which are a few years old. However, going overboard on the plus side is not good either. Recent LCD displays can often be adjusted to a brightness of well over 300 cd/m^2 which is considered too bright, also by many, for accurate color work, as it emphasizes the darker shades which will be printed much darker than what is seen on the screen. You should be aware that certain manufacturers of high-end monitors will not honor their warranty if their monitor is set at a luminance higher than 100 cd/m^2.

- **Chromaticity:** Expressed in *u'* and *v'* units of the Uniform Chromaticity Scale (UCS, CIE1976), these are often specified instead of *xy* (CIE1931) units because they are more uniform; i.e. the **perceived** difference between two sets of chromaticity coordinates better matches the **numeric** distance between the two sets. Also, the 10 degree Observer (CIE1964) is used for this measurement.

By default, "Goal" should be selected for the "Target center", which, for the ISO 3664 "Color monitors" viewing condition, corresponds to D65. However, you can select any of the following target centers:



In ISO 3664, the maximum offset for **color monitors** is a 0,025 *u'v'* radius. The radius of the green circle in the illustrated target corresponds to this value. The offset value cannot be changed for a given viewing condition but the provided numerical value will enable you to compare it against other requirements you may have, such as the more stringent 0,010 radius called for in ISO 12646:2008.

The "Meas. Temp." is the *White Point* temperature of your display. Technically, it is the *Correlated Color Temperature* (CCT), in kelvin, corresponding to the measured chromaticity. Expressed otherwise, this is the temperature to which you would set a blackbody in order for it to emit a white of the same chromaticity.

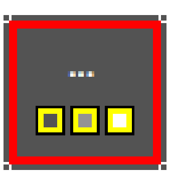
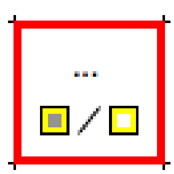
Note: The reference illuminant for the CRI tool will also be based on the "Meas. Temp." (CCT) shown here if "Auto" is selected as the reference CRI illuminant. As mentioned previously, the CRI tool is available only for the Prints and Transparencies viewing conditions.

- **Color and Tone uniformity:** These two tests are not part of ISO 3664, which specifies a brightness uniformity for the Prints and Transparencies viewing conditions only, but are those specified in ISO 12646:2014. They are selected with the radio buttons labeled "**Color**" and "**Tone**". The measurements need to be performed with White, Grey, and Dark-Grey color targets.

  The test selected by the "**Color**" radio button is called "Evaluation of tone uniformity" in the standard but what is described is really a measure of the difference between the color measured at each position and the color measured in the center position. The color difference is computed using the CIEDE2000 color difference formula. The Color test is performed independently for the three target colors; you can measure only the white targets if this is what you need.

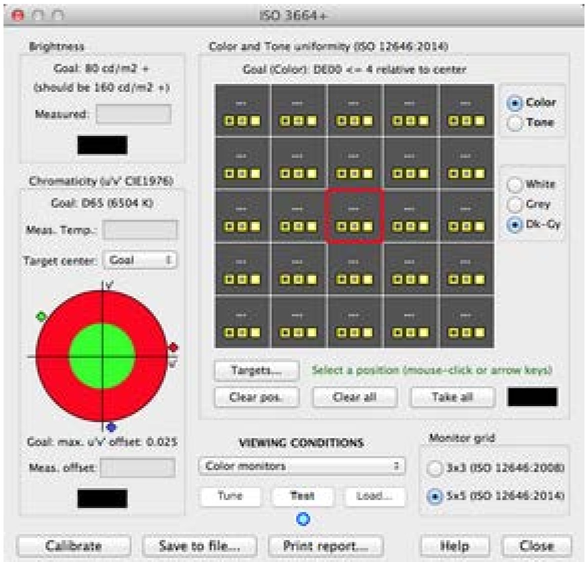
  The test selected by the "**Tone**" radio button is called "Tonality Evaluation (Uniformity)" in the standard and it consists of the deviation between the Grey/White luminance ratio measured at each position relative to the luminance ratio measured in the center position. The equation for computing the deviation is presented in the ISO 3664+ tools description section.

  When making measurement, you should first select a position by clicking on the corresponding grid cell; this is confirmed by a red border around the cell. You should then select the target color you wish to measure; the grid background will change to represent the selected color. You will notice two or three small squares for each position; three squares are shown when doing the Color test and two squares are shown when doing the Tone test.

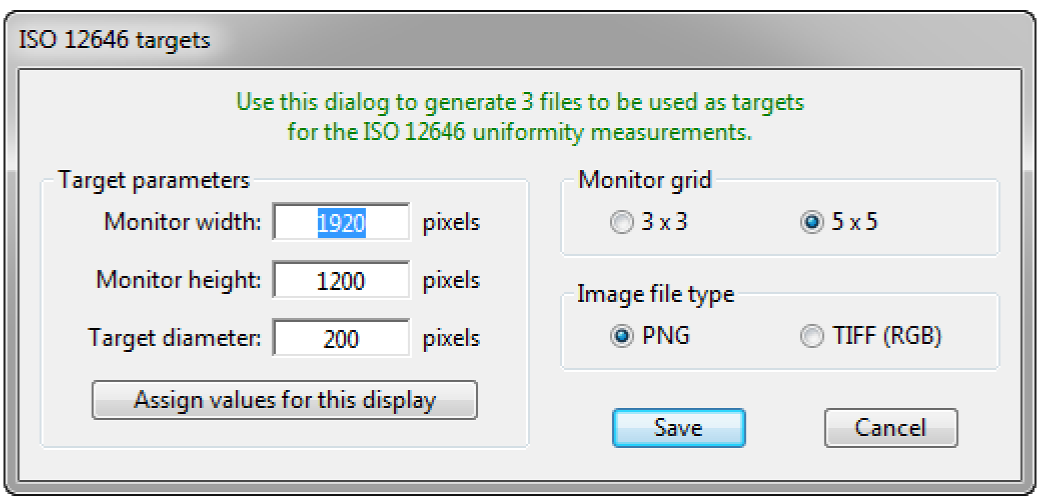
  
  Color test with the Dark-Grey target selected.
  
  Tone test with the White target selected.

  The color in the center of each small square corresponds to the target colors that can be measured for a test; this is why the Tone test cell only shows Grey and White squares (and a slash that indicates a ratio will be computed). The border color of a small square indicates if a target was measured or not, with a yellow border

indicating "not measured" and a green border indicating "measured". In the screenshot below, we are planning to measure a Dark-Grey target in the center position and we see that no targets of any color were measured yet.



It it your responsibility to make sure that the proper target color is used for a measurement, but the program can help you in this regard. First, if you measure the characteristics of a color monitor connected to the computer on which CT&A is running, you simply need to click on the "Take all" button and the proper target color will be shown for all positions; this is discussed further more in STEP 3 below. If the color monitor is not connected to the computer on which CT&A is running, or if you want to make manual measurements, you will need to manually display the target. Fortunately, you can easily generate custom target images by clicking on the "Targets..." button; this will open the following dialog:

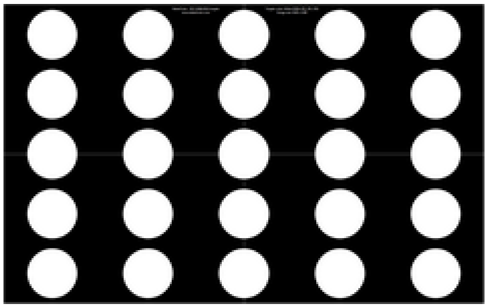


If you need targets for the computer on which CT&A is running, just position the above dialog within the monitor for which you want the targets and click on the "**Assign values for this display**" button; this action will fill the target parameters fields. The target parameters can also be manually set to the values of your choice. Select the monitor grid for which you want the targets as well as the file type and click the "Save" button when ready. A file name will be proposed; edit the name if you wish but please note that a suffix identifying the target color will be added for each of the three image files that will be generated. You can then open the images using the graphic editing program of your choice; we recommend using a program which offers a "Full screen" viewing mode (the photo viewer application in Windows and "Preview" on Mac will do).

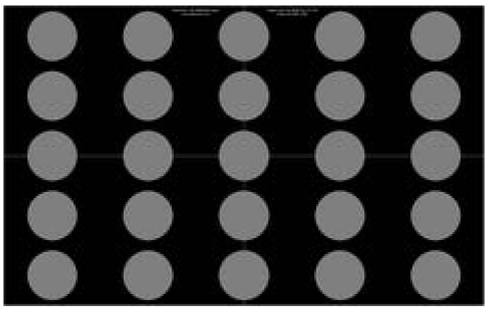
Note: The 3x3 grid defined in ISO 12646:2008 favors the monitor's center area, and the targets are thus non-uniformly distributed on the monitor, while the 5x5 grid defined in ISO 12646:2014 is uniform.

Note: When characterizing an external monitor on which a target image is displayed, you can still use the "Take all" button and do all measurements in sequence.

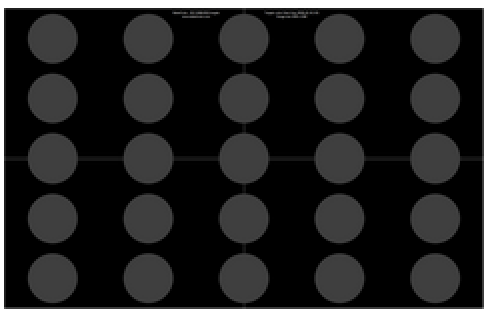
Here are reduced-size screenshots of such target images:



White targets (RGB=255)



White targets (RGB=127)



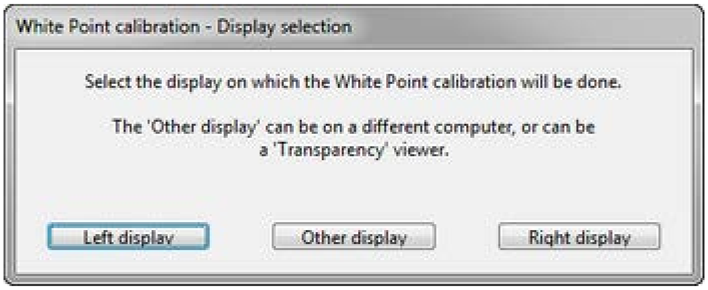
White targets (RGB=63)

Hint: You should keep your monitor resolution settings as fixed as you can, the reason being that the screen brightness, its uniformity and chromaticity, and thus its profile, will be affected by a resolution change. If a change is required, we suggest using different display profiles for each setting.

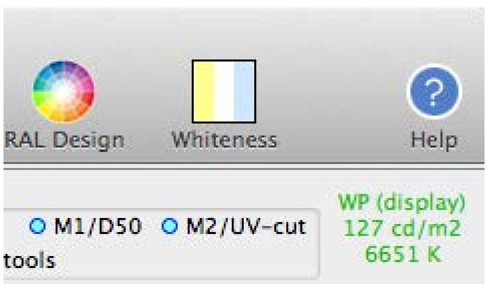
STEP 2

Calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions. The calibration in emission mode is done in two steps. The first step requires that the instrument be placed on its base, to measure the noise floor of the black level, and the second is used to measure the display *White Point* (WP). The WP is measured on a white patch, preferably located on the display or emissive surface on which subsequent measurements will be performed.

When calibrating in emission, CT&A presents a dialog which asks you to specify the calibration display. When two or more monitors are detected, the following dialog is shown:

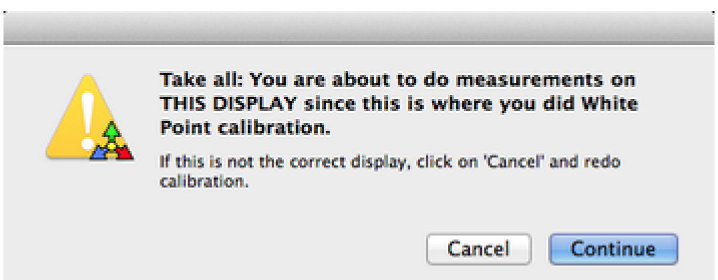


Once the WP is measured, its characteristics (display location, luminance and CCT) are shown in the toolbar window, as seen in green text in the next screenshot (for the screenshot below we measured the WP on the main display of an iMac computer, with no other monitor connected). The display had just been calibrated with a profiling application with a target luminance of 120 cd/m^2 and a D65 WP; this computer (iMac, 21.5 in., Mid 2010) was used for all the measurements shown in this tutorial.



STEP 3

We will now measure the targets at **ALL positions** and for **ALL target colors**. You can measure the targets colors in any order but for the purpose of this tutorial, please reselect the "**White**" target radio button and select the "**Color**" radio button as well. To start the measurements, click the "Take all" button located in the bottom of the "Color and Tone uniformity" group. Assuming that calibration is done, that you did your calibration on a monitor connected to computer on which CT&A is running, and that there is only one monitor connected to the computer, the following dialog will appear:



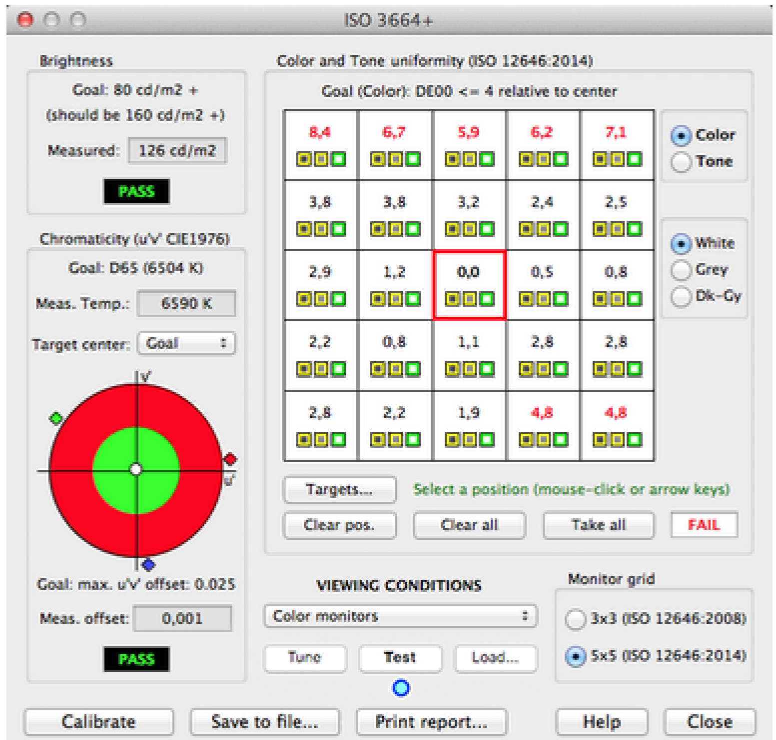
Note: Different messages will be shown depending on where calibration was done and the number of monitors connected to the computer. To better follow this tutorial, please select a monitor connected to the computer on which CT&A is running.

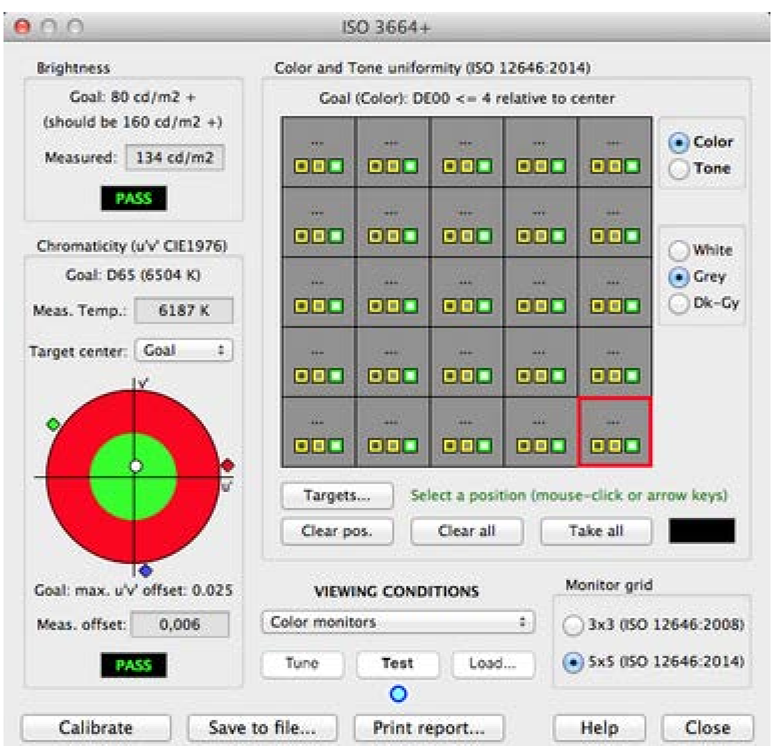
By clicking "Continue", the selected monitor should show a white target in its center. Position the instrument over the white circle and press the instrument button. The target will then move to the upper-left position.

Afterwards, the position moves from left to right, then to the row below, and so on. While doing the measurements, you can use the arrow buttons on the keyboard to change the target position; you should hear a "confirmation beep". Changing the position while doing a sequence is useful if you are not sure of a measurement or if you pressed on the instrument button inadvertently. **If you want to cancel a "Take all" sequence, just press any key (other than the arrow keys!) on your keyboard.**

Important: We do not recommend making measurements with CT&A when MeasureTool or any other program which may wait for an instrument input is active. None of the programs will crash, but the input may be either assigned sequentially to the various programs or not assigned at all.

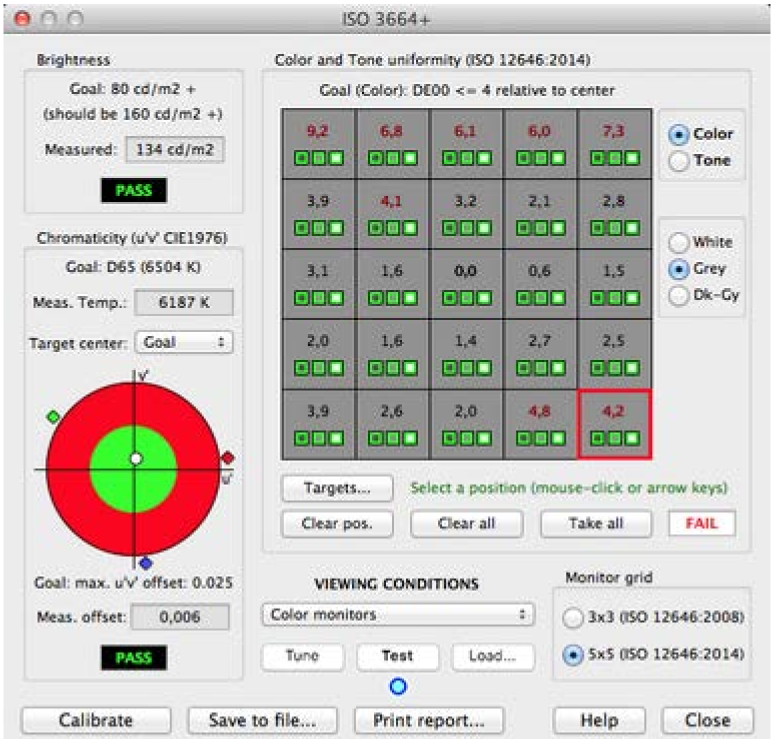
When all measurements with the white targets are done, you will be returned to the ISO 3664+ dialog where you should see numbers at all positions, as shown on the right. We have selected the center position which shows a brightness of 126 cd/m^2 and a CCT of 6590 K, essentially what we measured when we calibrated the display (shown in STEP 2). However, while the center position meets the requirements, the Color uniformity fails. We see that the color difference exceeds the limit (of 4) on the top row and in the bottom-right of the display.

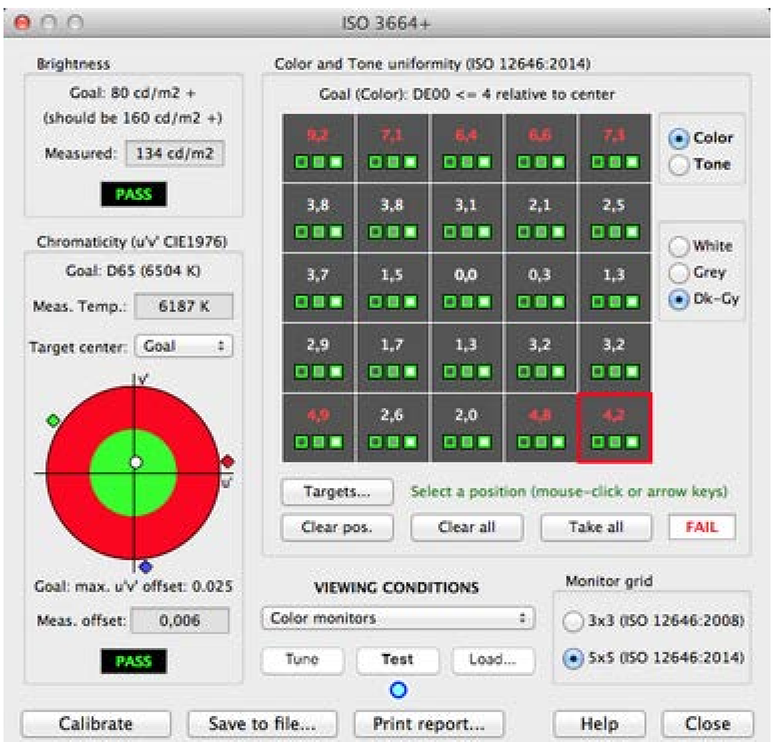




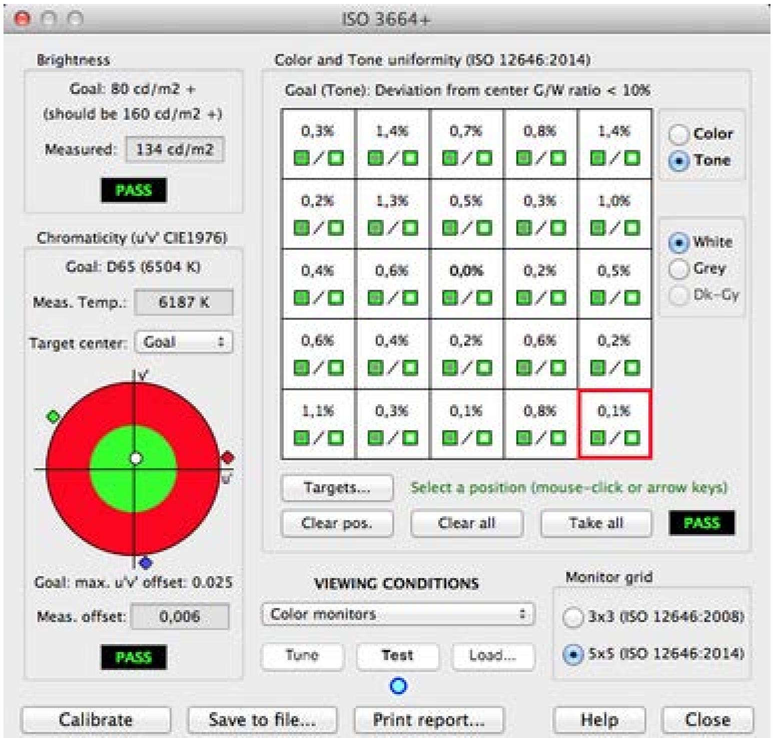
The screenshot on the left is from the same test session as the screenshot above; it was taken just after we completed the white target measurements, and after selecting the "Grey" radio button. We do not see any numbers in the cells since we did not perform the measurements yet. We readily see though that all measurements were done for the white targets since all small white squares have a green border. You will also notice that brightness and chromaticity values are shown (134 cd/m^2 and a CCT of 6187 K); they correspond to the measurements of the white target at the selected position (bottom-right).

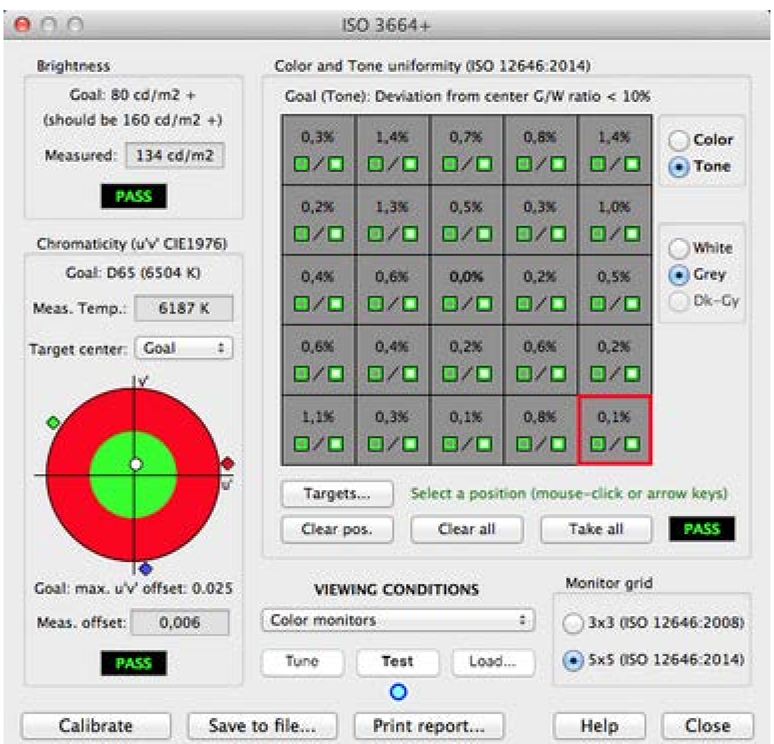
The two screenshots below show the Grey and Dark-Grey Color uniformity measurements. These tests also fail, and for essentially the same positions as for the White Color uniformity.





The next screenshots show the Tone ratio uniformity results. You can see that the numbers shown when selecting either the white or the grey targets are the same. This is by definition since a tone ratio requires both target colors. The uniformity results are quite good and easily meet the requirements. When considering these results in association with the Color uniformity results, we could say that the WP color is not uniform but that the tone/gamma response is nonetheless uniform.





STEP 4

To save the measured data, click the "Save to file..." button located in the bottom of the dialog. The exported report has tab-delimited data that can be directly imported in a spreadsheet program, and opened in many text editing applications (it is suggested to use a monospace font, such as *Courier*, in order to facilitate formatting).

You can also print a one-page report by clicking on the "Print report" button. The printed document presents the measured data in a visual format ideal for compliance-type reports:

The luminance, CCT and chromaticity results of the above report are presented in a larger format on the next page.

Luminance (cd/m2)

89	96	100	99	94
112	114	115	117	116
113	122	126	126	125
118	129	133	137	135
115	132	134	139	134

PASS

CCT (kelvin) / u'v' error

6887 K 0,0038	6685 K 0,0022	6806 K 0,0027	6879 K 0,0033	6704 K 0,0017
6852 K 0,0030	6712 K 0,0023	6765 K 0,0021	6736 K 0,0014	6638 K 0,0006
6781 K 0,0018	6580 K 0,0004	6590 K 0,0006	6623 K 0,0011	6501 K 0,0016
6765 K 0,0017	6536 K 0,0008	6582 K 0,0006	6519 K 0,0030	6397 K 0,0034
6620 K 0,0020	6378 K 0,0028	6468 K 0,0021	6340 K 0,0056	6187 K 0,0063

PASS

It is not unusual to see a monitor whose corners are "hotter" or "cooler" (i.e. have a higher or lower color temperature) than the center. The difference can be a few hundred kelvin for standard commercial monitors. For this iMac monitor, according to our measurements, the min. luminance and max. CCT is in the upper-left while the max. luminance and min. CCT is in the bottom-right; these variations correlate well with the Color uniformity results but while the luminance and chromaticity are within requirements, the Color uniformity fails for all target colors.

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.9 Measure the display Contrast using the Graph tool

INTRODUCTION

This tutorial demonstrates some of the features of the Graph tools. These general purpose tools enable you to observe, compare and analyze two spectrums and their corresponding colorimetric data. The spectrums can be from reflectance, emission, ambient, or flash measurements, and basic mathematical operations can be performed between them.

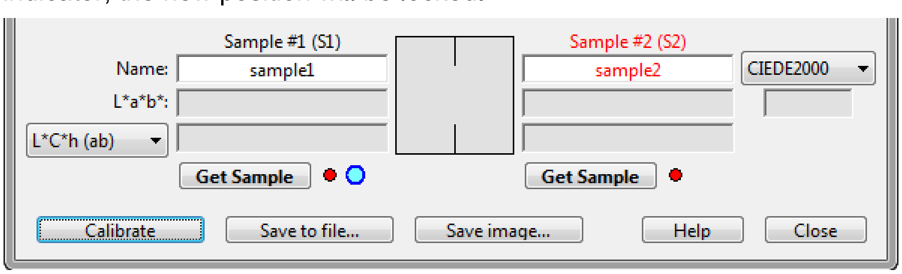
In this tutorial, we select the emission mode to measure the luminance of black and white areas of a saved image, and from these measurements we evaluate the monitor **contrast ratio**. You may have noticed that high contrast values of 800:1 plus are advertised for many LCD displays, much higher than the contrast we could obtain on CRTs. However, a higher contrast is not always better. For press use, the contrast should, in theory, be adjusted to the contrast of the final support medium. Contrast values can range from 500:1 for fine art prints, done with high-end ink jets printers and high quality papers, to 300:1 for standard presses with ink on coated paper, to 200:1 for newspaper images. Because you cannot adjust the black level, and thus the contrast, of most LCD displays, some profiling software will use the display card or monitor Look-Up-Tables to adjust it.

SETUP

Note: For optimal results, your display should be calibrated prior to this tutorial. Also, the calibration, and this tutorial, should be done at least one hour after powering up the monitor, to give time for the electronic components and the LCD back lights, or the CRT tube, to settle.

Set the program as follow:

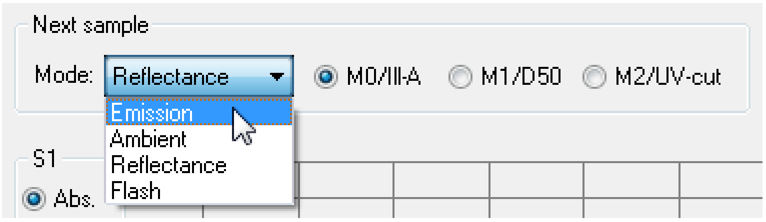
- Open the Graph tools window by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/Graph" menu. You should also close all other tool windows.
- To perform this tutorial, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate" and "Get Sample" buttons of the Graph window being enabled (some controls will remain disabled if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.
- When the Graph tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears next to a "Get Sample" button. This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button. The indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the previous measurement if required, or do a right-click to lock it on a given measurement. You can also do a left-click on a locked indicator; the new position will be locked.

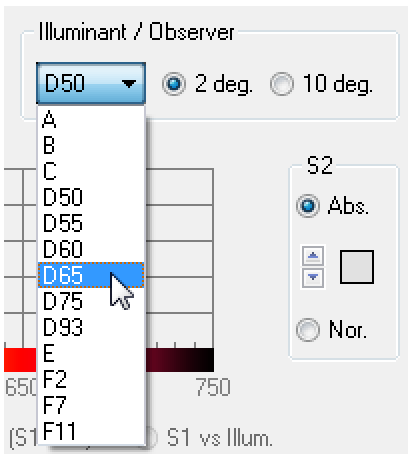
  For this tutorial, the indicator should be left unlocked.

STEP 1

- In the "Next sample" group box, select the "Emission" mode:



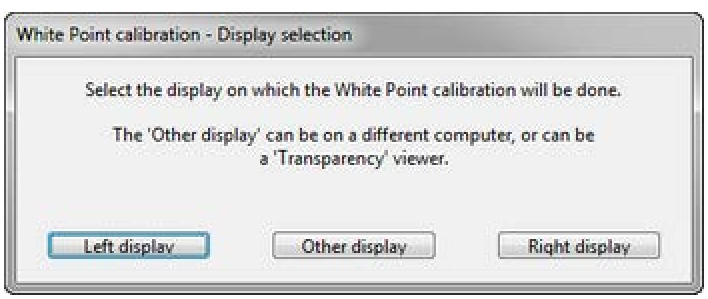
- Select the Illuminant and Observer in the "Illuminant / Observer" group box. These settings are used to compute the colorimetric data shown in the bottom section of the "Graph" window (L*a*b* plus a user-selected color space); they have no effect on the measured and displayed spectrums. We suggest you select the illuminant which corresponds, or is closest, to the *White Point* selected when you calibrated your display; here we have selected D65 and the 2 degree Standard Observer:



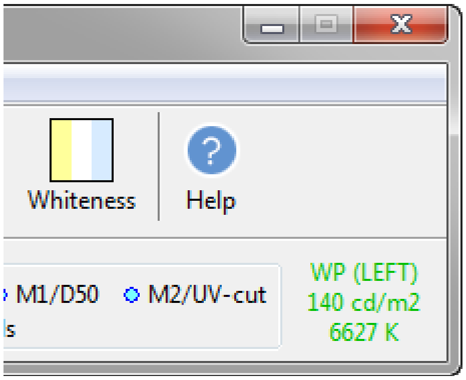
STEP 2

Calibrate the instrument by clicking on the "Calibrate" button and following the on-screen instructions. The calibration in emission mode is done in two steps. The first step requires that the instrument be placed on its base, to measure the noise floor of the black level, and the second is used to measure the display *White Point* (WP). The WP is measured on a white patch, preferably located on the display or emissive surface on which subsequent measurements will be performed.

When calibrating in emission, CT&A presents a dialog which asks you to specify the calibration display. When two or more monitors are detected, the following dialog is shown:



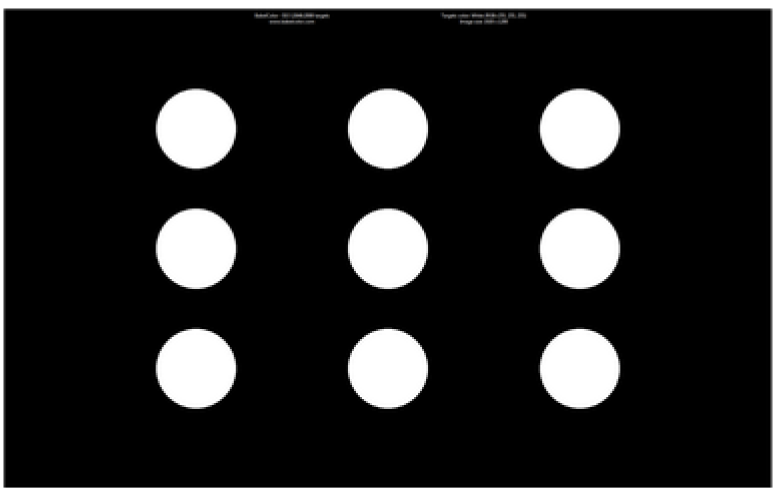
Once the WP is measured, its characteristics (display location, luminance and CCT) are shown in the toolbar window, as seen in green text in the next screenshot (for this screenshot we measured the WP on the LEFT display of a 2 monitor computer).



Note: You may ask why a *White Level* calibration is required in CT&A and not in X-Rite/GretagMacbeth MeasureTool? In effect, MeasureTool also uses a *White Level* reference value, very likely coming from a screen profile saved on your computer. The only difference is that, with CT&A, you can set this reference to any display.

STEP 3

To perform this test we need an image with a white target on a black background. You could devise such an image with any imaging program but you can also use an ISO12646 test image generated within CT&A. To generate the image, open the ISO 3664+ tools window, select the "**Color monitors**" Viewing Condition, and click on the "**Targets...**" button located near the center of the window. This will open a target creation dialog. Shown below is a reduced sized screenshot of such an image for a 3x3 grid.



For the purpose of the test, open the image using any graphics editing or viewing program, and size it so that it fills the screen (which should be at 100% size or zoom if the image resolution corresponds to your monitor resolution). There is a thin white border around the images to help match their size to the monitor's viewing area.

Hint: In Windows, you can open the photo viewer application, then select the slide show (F11), and pause at the selected image; press **Alt + Tab** to switch between opened applications.

Hint: In Mac OS X, open the image using "Preview", select the slide show, and click on the icon assigned to fill the screen with the image.

Note: The ISO 12646 target images are normally used in conjunction with the ISO 3664+ tools (see also the previous tutorial). Yet, they have what we need to measure the contrast ratio. It is not suggested to use small black and white patches over a crowded and colorful desktop. Many displays will change their brightness depending on what is displayed on the rest of the screen. In particular, if there are large zones of high luminosity, the light will leech through the monitor face-plate and influence the black reading. Similarly, ambient (i.e. room) illumination will affect the readings. Just for the fun of it, if you are using a CRT, place a small opaque disk—a piece of cardboard will do—over one of the patches, and see the whitish halo around it, which

looks like the Sun's corona. This shows how light bounces on the monitor glass and contaminates the surrounding colors. This effect is basically inexistent on LCD displays which have thin glass cover plates.

Hint: You should keep your monitor resolution settings as fixed as you can, the reason being that the screen brightness, its uniformity and chromaticity, and thus its profile, will be affected by a resolution change. If a change is required, we suggest using different display profiles for each setting.

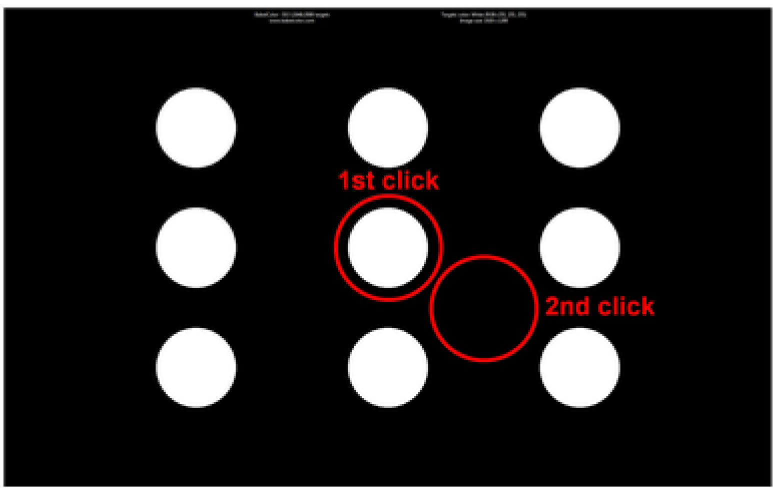
STEP 4

At this point, you should have a test image that fills the monitor screen. You do not need to see the other program windows to proceed with this step, but the Graph tools window should be opened and set as described previously.

Important: For the purpose of this test, make sure your ambient illumination is less than 10 lux. To achieve such a low level, you will need to close the main room lights and pull the blinds; if needed, an indirect desk lamp many feet/meters away should be enough. In particular, when you calibrate the instrument on its base, make sure the instrument is well seated and that no light from the monitor illuminates the base from the side (place your hand as a shield if required).

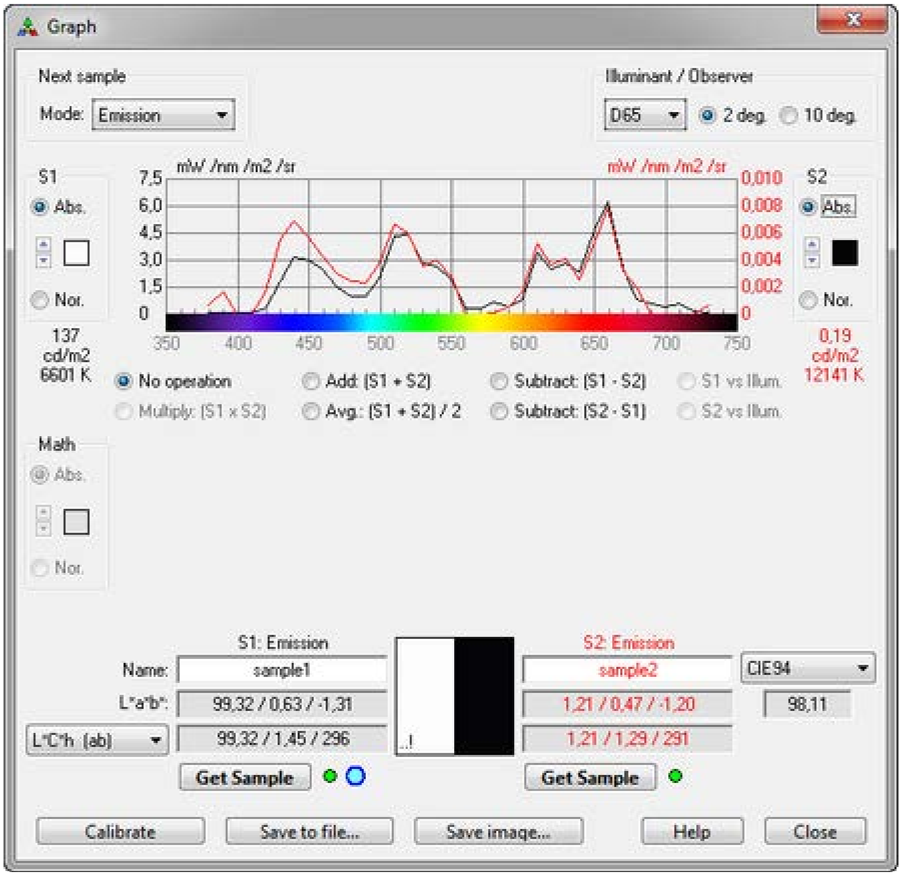
Important: We do not recommend making measurements with CT&A when MeasureTool or any other program which may wait for an instrument input is active. None of the programs will crash, but the input may be either assigned sequentially to the various programs or not assigned at all.

Simply position the instrument on the screen, over the white circle located in the test image **center**, and press the instrument button. You should hear a "beep". Position the instrument over a black area, between the four patches in the lower-right section for example, and press its button again:



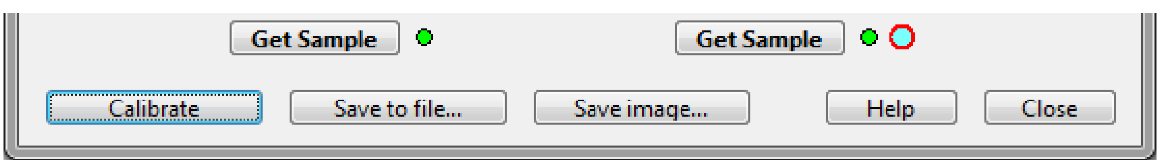
You can now go back to the "Spectral tools' dialog. Do not close the test image as you may want to do more measurements with it.

The dialog will look somewhat like the following screenshot (measurements taken on a Dell U2410 LCD):

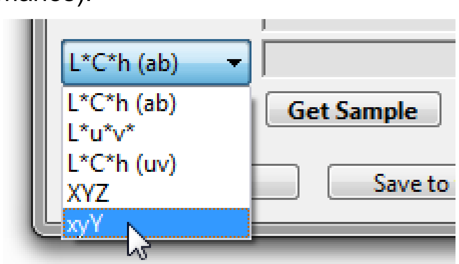


The white center patch has a 137 cd/m^2 luminance while the black area has a 0,19 cd/m^2 luminance. The contrast ratio is 721 (= 137 / 0,19), a typical value for a LCD which was not calibrated with a prescribed black level.

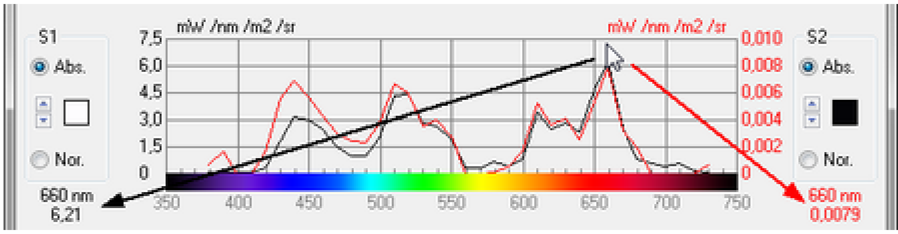
Hint: By leaving the blue indicator unlocked ( ), the input changes sides each time we press the instrument button. However, if you want to measure the black point at multiple positions while keeping your white measurement, just lock ( ) the indicator to the sample (with a combination of left and right mouse clicks on the indicator). In the screenshot shown below, pressing on the instrument button will assign the measurement only to the right sample from now on:



Hint: The chromaticity of the white patch, the monitor *White Point*, can be seen by selecting the "xyY" color space coordinates in the bottom-left list box (which is also useful to verify the coordinates of your monitor primaries):



While somewhat similar, the two spectrums have very different scales. The one for the white patch, on the left and traced in black, has a peak of about 6 mW /nm /m^2 /sr at 660 nm, and the one on the right, for the black patch, has a peak of about 0,008 mW /nm /m^2 /sr at the same wavelength. To better evaluate the spectrums, just move the mouse cursor over them in the graph window and look at the numbers located on each side of the graphs:



You can also compare the two spectrums with their maximum output normalized to one. Simply click on the "Nor." radio button on each side:

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

15.10 Measuring color patches on a display

INTRODUCTION

This tutorial explains what is going on internally in CT&A when you measure color patches on a display, i.e. in emission. Such measurements are very helpful when checking the calibration of a monitor or TV. We will input measurements in the RGB vs RGB and Graph tools and see the differences in how they are processed.

The RGB vs RGB tool is dedicated to the comparison and conversion of RGB spaces and Color Decks. For a given RGB space, color coordinates can be entered directly in RGB, as L*a*b* or L*u*v* values, or converted from another RGB space or Color Deck. In this tutorial, we will use the L*a*b* / L*u*v* input mode which can accept direct measurements from any of the supported instruments.

The general purpose "Graph" tools enable you to observe, compare and analyze two spectrums and their corresponding colorimetric data. The spectrums can be from reflectance, emission, ambient or flash measurements, and basic mathematical operations can be performed between them. Because the Graph tools require spectral data, they can only accept data from an i1Pro series spectrophotometer.

The tutorial is separated in two parts. **PART 1** comprises three steps, which are performed in the RGB vs RGB tool, and which can be done with all supported instruments. **PART 2** has one step which is performed in the Graph tools window, and which requires an i1Pro series spectrophotometer.

PART 1 / SETUP (RGB vs RGB tool)

Note: For optimal results, your display should be calibrated prior to this tutorial. Also, the calibration, and this tutorial, should be done at least one hour after powering up the monitor, to give time for the electronic components and the LCD back lights, or the CRT tube, to settle.

Important: Since these measurements may take some time, you should also temperature stabilize your instrument by leaving it on the display, in its cradle, while the display heats up.

While the display and the instrument stabilize, prepare and save two small images which will be used to perform the measurements of this tutorial. The images characteristics should be as follow:

- Size: 200 x 200 pixels per patch minimum
- Color properties: RGB, 8 bit color
- Color: 1 image filled with white (RGB=255, 255, 255)
1 image filled with light grey (RGB=196, 196, 196)
- File format: Bitmap (*.bmp) or PNG (*.png), with no attached profile

  Hint: Here is an alternate method to generate color patches using a text file and PatchTool as a viewer (in the free demo mode!). Simply write the following three lines, where all values are separated by tabs (tabulation spaces), and save them in a text file (*.txt):

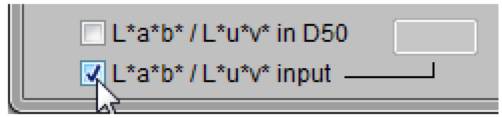
R	G	B
255	255	255
196	196	196

  Open the text file in PatchTool; when asked to assign a profile, select the sRGB space, 8 bit encoding.

Set the program as follow:

- Open the RGB vs RGB tool window by clicking on the corresponding icon on the toolbar window, by selecting the "RGB vs RGB/Show window" menu, or by selecting the "Tools/RGB vs RGB". You should also close all other tool windows.
- Set the RGB vs RGB window as follow:
  - Compare mode with both sides set in RGB Space mode
  - Space selection: Adobe (1998) for Space #1 and ProPhoto for Space #2
  - Hex # / HSB / HVC / L*C*h / xyY / XYZ display: xyY in both spaces
  - L*a*b* / L*u*v* display: L*a*b* in both spaces
  - L*a*b* / L*u*v* in D50 checkbox: unchecked in both spaces
- The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window. If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.

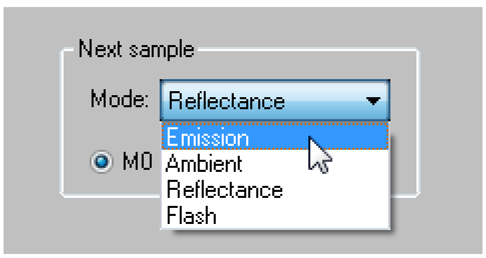
PART 1 / STEP 1

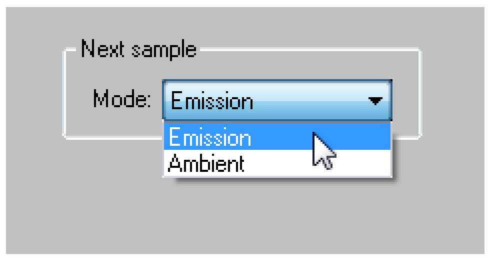


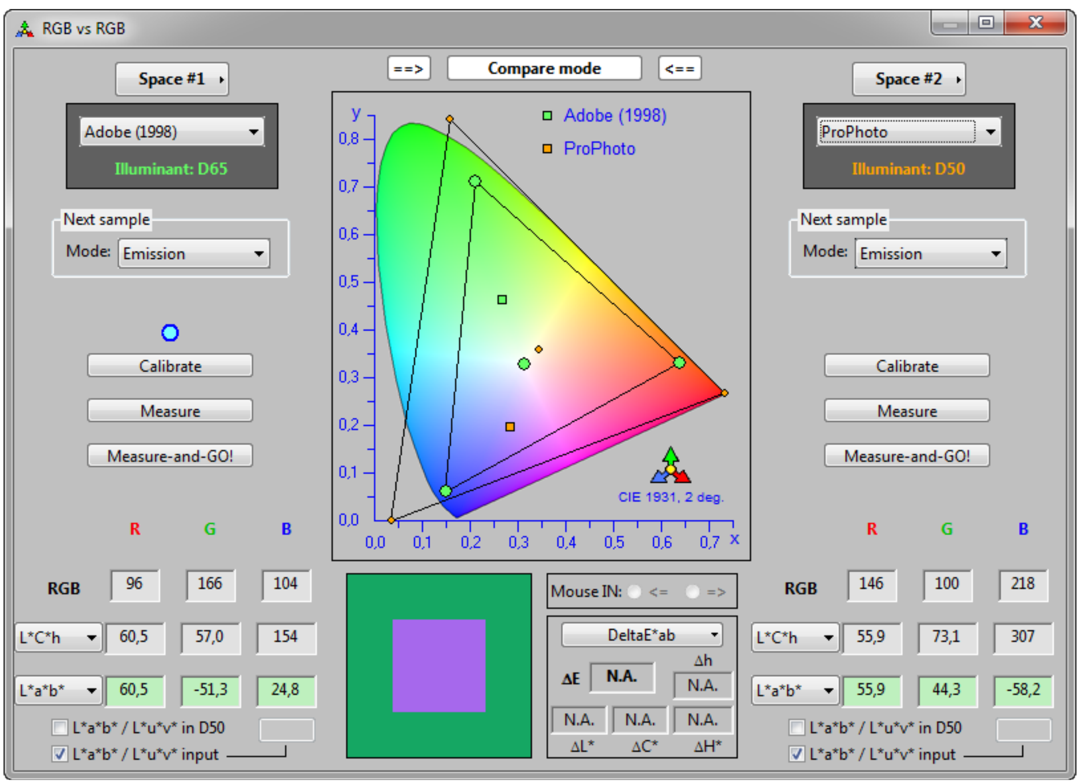
Check the "L*a*b* / L*u*v* input" checkbox of the RGB vs RGB window for **both** spaces.

If an instrument is properly connected and detected by the program, the "Calibrate", "Measure", and "Measure-and-GO!" buttons of the RGB vs RGB window will be enabled; also, the measurement mode menu will offer only the modes supported by the connected instrument. In addition, if using an i1Pro series spectrophotometer, a large blue indicator will appear above a "Calibrate" button when the RGB vs RGB window is selected (brought to the front). The blue indicator identifies the space for which a measurement will be done if you press the instrument button; you can also press any "Measure" or "Measure-and-GO!" button (Note: Pressing the instrument button is equivalent to press the "Measure-and-GO!" button). If both spaces can accept input by measurement, the blue indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the other side if required, or do a right-click to lock it on a given side. You can also do a left-click on a locked indicator; the new position will be locked. For this tutorial, the indicator should be left unlocked.

Select the "Emission" mode for **both** spaces. The screenshot below on the left shows the menu for an i1Pro 2, and the screenshot on the right is the menu for an i1Display Pro. The RGB vs RGB window should look like the screenshot at the bottom of this page.







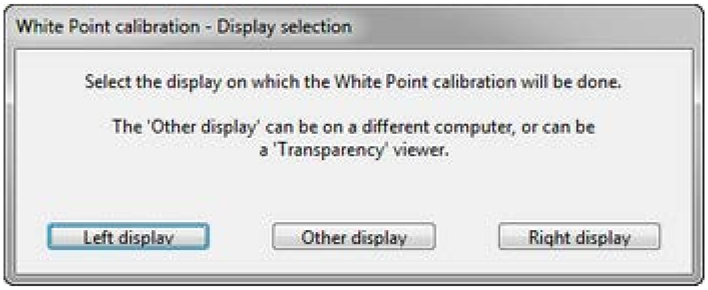
Note: In the above screenshot the color patches will likely be different from yours, and the blue indicator will not be present if an i1Pro series spectrophotometer is not the selected instrument. Also the screenshot shows the RGB vs RGB window reduced to its minimum layout, without any extra patches.

PART 1 / STEP 2

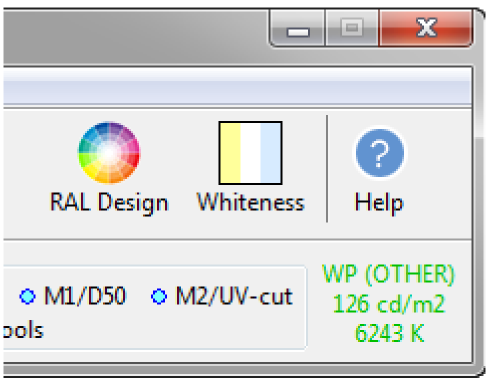
Note: For optimal results, you should do STEPS 2 and 3 of PART 1 in a close sequence, without moving the instrument between measurements.

Calibrate the instrument by clicking on the "Calibrate" button (on either side of the RGB vs RGB window) and following the on-screen instructions. The calibration in emission mode is done in two steps. The first step requires that the instrument be placed on its base, to measure the noise floor of the black level, and the second is used to measure the display *White Point* (WP). The WP is measured on a white patch, preferably located on the display or emissive surface on which subsequent measurements will be performed.

When calibrating in emission, CT&A presents a dialog which asks you to specify the calibration display. When two or more monitors are detected, the following dialog is shown:



Once the WP is measured, its characteristics (display location, luminance and Correlated Color Temperature (CCT)) are shown in the toolbar window, as seen in green text in the next screenshot (for this screenshot we measured the WP on an "Other display", not necessarily connected to the computer on which CT&A is running).



Note: You may ask why a *White Level* calibration is required in CT&A and not in X-Rite/GretagMacbeth MeasureTool? In effect, MeasureTool also uses a *White Level* reference value, very likely coming from a screen profile saved on your computer. The only difference is that, with CT&A, you can set this reference to any display. You could for instance use a white patch on your TV screen or even a white patch from a projector.

Note: Your monitor may or may not be calibrated but, in any case, this is the white to which you will adapt your vision and relative to which all other colors will be perceived. For example, if your monitor was calibrated to D65 but is, in effect, at D62 (or, more precisely, 6243 K), like the one we measured, you will adapt to D62 and never see the difference. The difference will become apparent if you compare the display white with a perfect D65 white; in this case, our monitor would look yellowish.

PART 1 / STEP 3

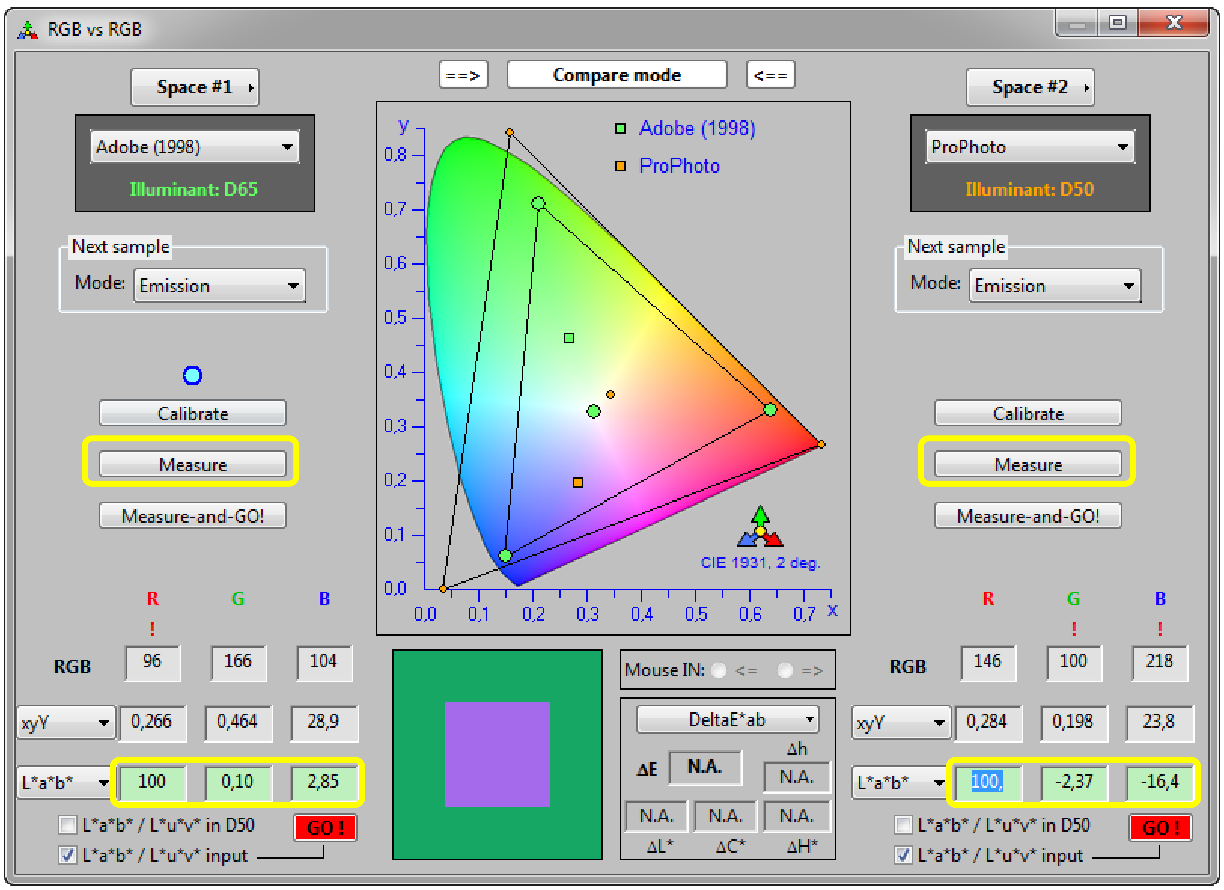
Open the image of the white patch (or of the two patches if you used a file opened in PatchTool, as suggested previously). Open this image with any application you have handy. For a white patch, and any neutral patch for that matter, there is essentially no difference between a color-managed and a non-color-managed application since the white point and the gray ramp are handled via the graphics card's Look-Up-Table (LUT) and not by the monitor ICC profile.

Assuming you just calibrated the instrument as described in STEP 2, your instrument should still be located on the display. Center the white patch under your instrument and make one measurement in Space #1, then Space #2. Here we have two or three choices, depending on your instrument:

- i- Click on the "Measure" button of each space.
- ii- Click on the "Measure-and-GO!" button of each space.
- iii- If you use an i1Pro series spectrophotometer, click twice on the instrument's button.

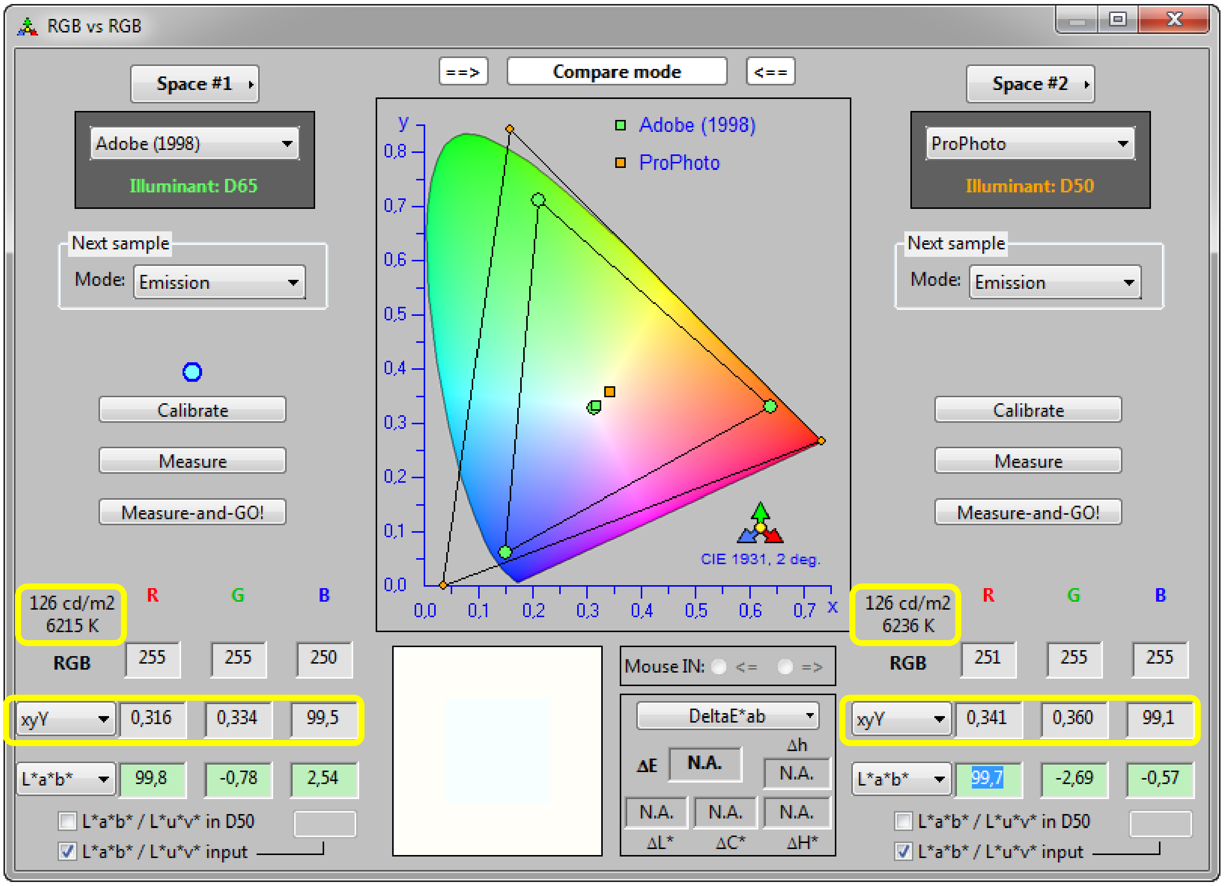
Note: Using the window buttons instead of the i1Pro button minimizes the pressure applied by the instrument on the display, which could possibly affect the measurements, especially on thin LCD screens.

Here is a screenshot of what we obtained after measuring the white patch by clicking on the "**Measure**" button of each space:



Because we pressed the "Measure" button, the measured data was entered in the L*a*b* data fields but the xyY and RGB data fields, as well as the patch color, were NOT updated. We also see clipping indicators (!) for the red coordinate of Space #1 and for the green and blue coordinates of Space #2. As described in the section on L*a*b*/L*u*v* input, this means that the measured color is outside the gamut of the respective spaces. If we now click on the red "GO !" buttons, the input will be clipped and the xyY and RGB values will be computed. The result is shown on the next screenshot.

Important: If we had pressed on the "Measure-and-GO !" buttons, or on the instrument key, we would have seen only the results as shown on the next screenshot, and missed the fact that the input values were clipped by the spaces.

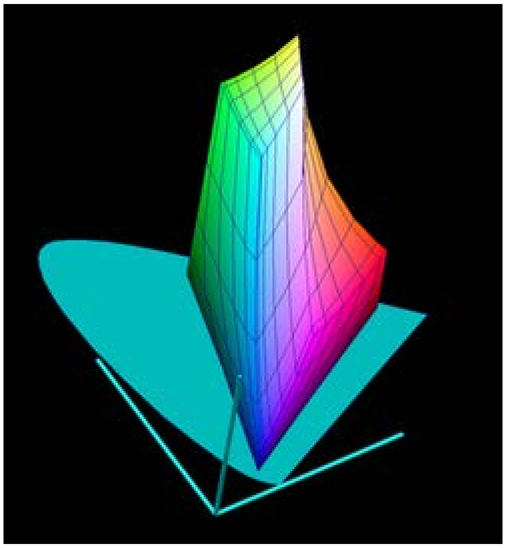


The 126 cd/m^2 luminance is the same for the two measurements, and also identical to the luminance measured for emission calibration in STEP 2. We could accept a variation of a few cd/m^2 since the display in not uniform; however, by not moving the instrument between the calibration and the measurements, we minimized the variance.

The color temperature (CCT) is essentially the same on each side, 6215 K vs 6236 K, and to the CCT obtained during emission calibration (6243 K). Here the match is excellent but the CCT is very sensitive to measurement noise and we could easily see differences of ±100 K if we did many measurements within a few minutes, differences for which we should not be seriously concerned anyway.

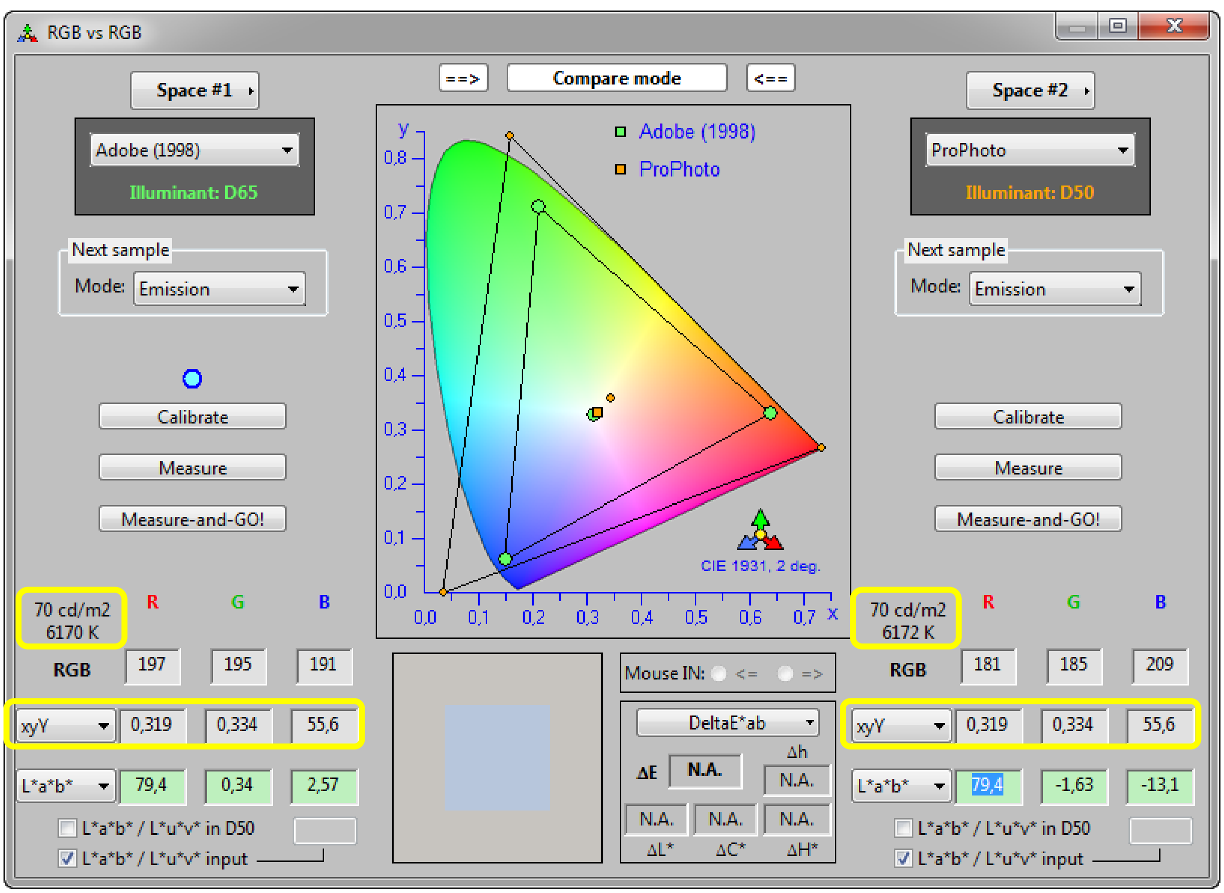
So far so good, but we do note that the measured chromaticity coordinates ("x" and "y") are different, even if the measured color temperatures are the same. Since emission measurements are measured in absolute chromaticity, the measurements should be at the same location for both spaces, and more specifically at a location which corresponds to the 6243 K temperature of the display (slightly towards the yellow side relative to D65). However, the measurements, illustrated by the green and orange squares, are located on, or near, each space illuminant, D65 and D50 respectively. What happened?

Firstly, the xyY coordinates are scaled to the absolute value of Y for the White Point (WP) calibration, so our white patch has a Y of 100, by definition. Secondly, you should keep in mind the three-dimensional shape of an RGB space when represented in xyY coordinates, as shown on the next page. This illustration shows that there is a maximum luminance (Y) for each pair of xy coordinates, and only the White Point (WP), i.e. the illuminant, can have a Y value of 100. Now, unless the white patch has the same chromaticity as the space illuminant, any other chromaticity with Y=100 will be clipped to fit into the space.



Since the measured luminances (126 cd/m^2) and CCT are essentially the same, we know that the xyY coordinates measured were the same before being converted to R'G'B'. Then, the fact that the inputted values are located on the respective spaces illuminant is a consequence of clipping. There are two methods to prove this.

The first method is to make the measurements using the "Measure" button instead of the "Measure-and-GO!" button, which we effectively did in the beginning of this step, and we indeed saw that the input values would be clipped. The second method is to measure a gray patch. The rationale is that a lower luminance (i.e. lower Y) should prevent clipping when we convert the L*a*b*/xyY input to RGB. Open the grey patch image, with R=G=B=196, and assign a measurement to each space with the "Measure-and-GO!" button (you can also try with the "Measure" button to confirm that there is no clipping!). Here is a typical result:



Here again the luminances and color temperatures are essentially the same. However, the chromaticities are now identical, with x=0,319 and y=0,334, as confirmed by the measurements being on top of each other (the orange square is on top of the green square). We also see a more pronounced bluish tint for Space #2 when compared to the screenshot of the white patch measurements, because a patch with a color temperature of 6172 K would look blue if you were adapted to a D50 white, the Illuminant of ProPhoto.

If you intend to do PART 2 of this tutorial, you should leave your instrument on the display.

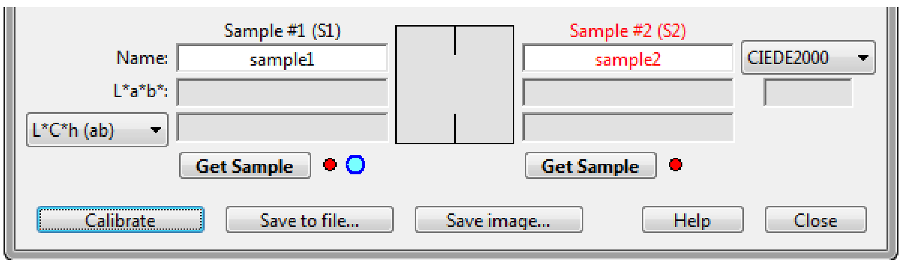
Hint: To get the chromaticity values with more precision, just do a **right-click** (**ctrl + click** on a single-button Mac mouse) with the mouse cursor over a xyY data field. A popup menu will enable you to copy the values. You can then paste the values in a text file or a spreadsheet.

Important: Measurements on a display may be processed in different ways depending on what we want to achieve. Here we measured the absolute coordinates of a display patches, without any attempt to compensate for white point adaptation. It would also be possible to compensate for the actual white point, measured during emission calibration, and shift the coordinates of all measured colors as if the white point was the RGB space white point, doing in fact a Relative Colorimetric correction. Such a method is part of the recommended procedure to certify monitors as specified by Idealliance (https://www.idealliance.org) and is the method used by BabelColor's PatchTool. You will find an Application Note on the BabelColor Tutorials Web page that explains how to perform the Idealliance procedure using PatchTool: AN-4a Using PatchTool for IDEAlliance MONITOR proofing certification.

PART 2 / SETUP (RGB vs RGB tools)

Set the program as follow:

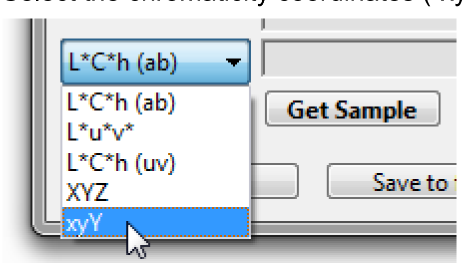
- Open the Graph tools window by clicking on the corresponding icon on the toolbar window, or by selecting the "Tools/Graph" menu. You should leave the RGB vs RGB window open.
- To perform this part of the tutorial, you need to have an i1Pro series spectrophotometer connected to the computer on which CT&A is running. The instrument must also be properly recognized by the program; this is confirmed by a small green light beside the instrument selection menu in the toolbar window, and by the "Calibrate" and "Get Sample" buttons of the Graph window being enabled (some controls will remain disabled if the program is not activated). If you plug an instrument in your computer after the program start, you can attempt to connect the instrument by selecting "Try to connect again..." in the Instrument menu. A status of the selected instrument can always be obtained by clicking on the "Info" button located in the toolbar window.
- When the Graph tools window is selected, i.e. brought to the front, and assuming that a compatible instrument is selected and recognized, a large blue indicator appears next to a "Get Sample" button. This indicator identifies the data that will be measured if you press the instrument button; of course, you can also do a mouse click on any data entry button. The indicator automatically changes location after making a measurement. You can click (left-click) on the indicator to move it to the previous measurement if required, or do a right-click to lock it on a given measurement. You can also do a left-click on a locked indicator; the new position will be locked.



For this tutorial, the indicator can be left either locked or unlocked since we will click on the "Get sample" buttons.

PART 2 / STEP 1

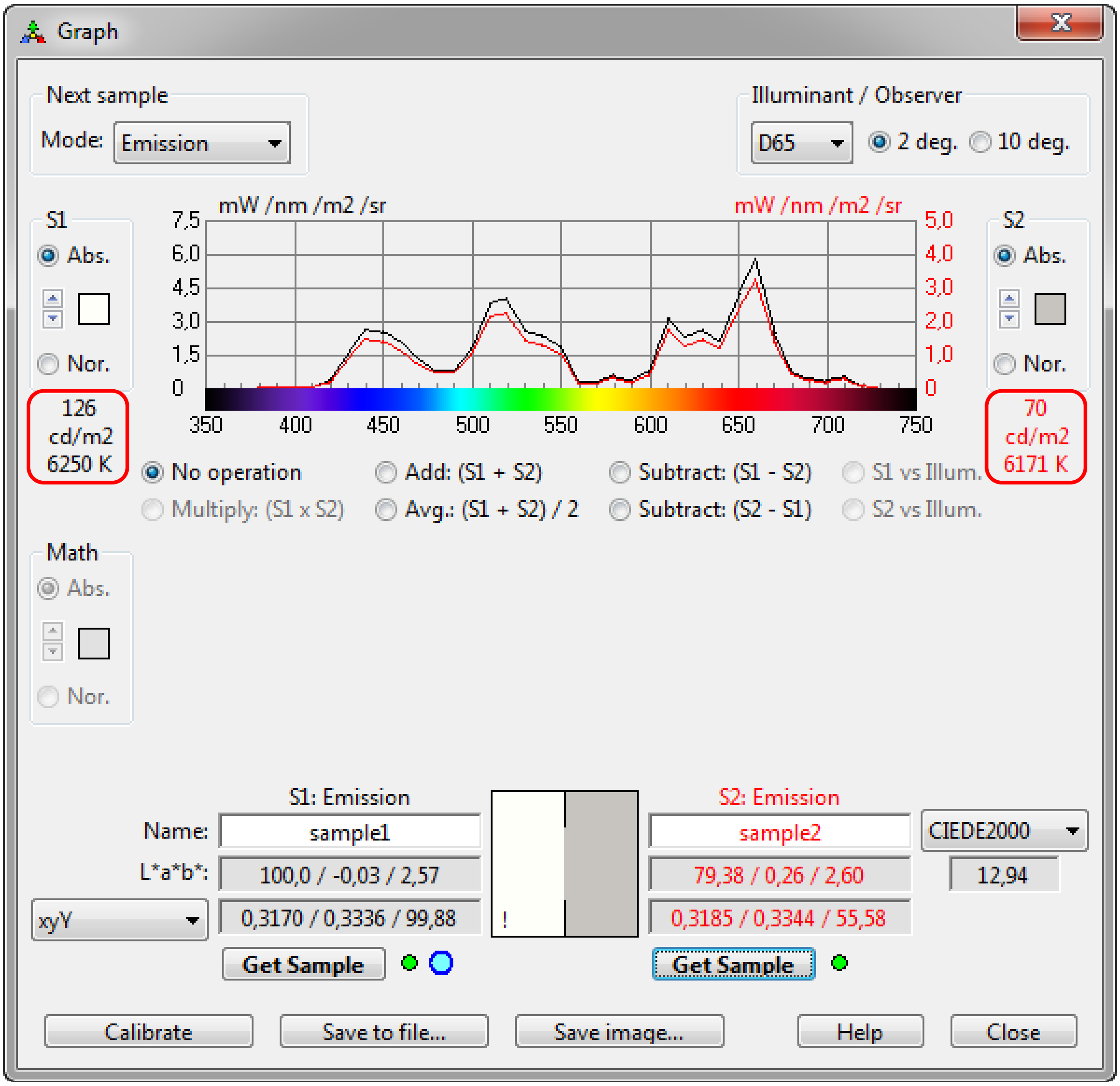
- In the "Next sample" group box, select the "Emission" mode.
- Select the Illuminant and Observer in the "Illuminant / Observer" group box. These settings are used to compute the colorimetric data shown in the bottom section of the "Graph" window (L*a*b* plus a user-selected color space); they have no effect on the measured and displayed spectrums. We suggest you select the illuminant which corresponds, or is closest, to the *White Point* selected when you calibrated your display. For this tutorial we selected D65 and the 2 degree Standard Observer.
- Select the chromaticity coordinates ("xyY") in the bottom-left list box.



- If you just completed PART 1 of this tutorial, you should not need to do a calibration. If you need to, the calibration procedure is the same as the one described in PART 1 / STEP 2 (you should use the "Calibrate" button of the Graph tools since this window is already selected and the measurement mode is set to "Emission").

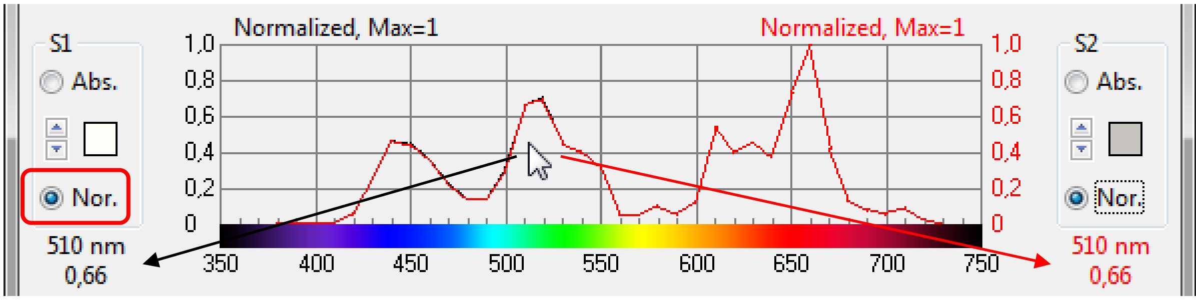
PART 2 / STEP 2

We will now measure the same white and grey patches used in PART 1, but this time with the Graph tools. First center the white patch under your instrument and click on one of the "Get Sample" buttons, then place the grey patch and measure it by clicking on the other "Get Sample" button. Here are our measurements for the two patches, with the white patch measurement on the left (S1, in black), and the grey patch measurement on the right (S2, in red).



The luminance levels are the same as the ones obtained in the RGB vs RGB tool window; the CCT can also be considered to be the same, when taking into account the typical variation seen when measuring this parameter. You will notice that the grey patch spectrum, drawn in red, looks very close to the white patch spectrum, drawn in black, even if the luminance is significantly lower. This can easily be explained by looking at the scales, shown on each side of the graph, which are different.The spectral curves have a similar shape and we can have a better idea of this match by looking at normalized spectrums; this is done by clicking on the "Nor." radio buttons on each side of the graph. The resulting graphs are shown on the next page.

You will also note that the "Y" value of the white patch (on the left) is 99,88. Ideally it should be 100 (i.e. 100%) since we calibrated our display using the same white point. However, a display's brightness is not uniform across its surface, this brightness may change in time, and there is always an intrinsic error in each measurement.



Here we confirm that the two spectrums are essentially identical when normalized and we see only the last spectrum drawn, the red one. To prove this, just move the mouse cursor in the graph window and look at the numbers located on each side of the window. In the screenshot above, we see that the normalized emission is 0,66 at 510 nm for both measurements. Such a good correspondence between a white and a grey patch will happen when your display's grey ramp is well calibrated. This uniformity of the grey ramp is also confirmed by the chromaticity measurements, which are very close of one another.

Note: L*a*b* values are always computed relative to an Illuminant and Observer. For Reflectance measurements, changing the Illuminant or the Observer affects the computed values of all color spaces (L*a*b*, XYZ, etc.). However, in Emission and Ambient modes, you will notice that for a change in Illuminant, the xyY and XYZ coordinates remain the same while the L*a*b* values change. Because the chromaticity values of an emitted light is fixed, the perceived color (relative to adapted white), and thus the L*a*b* coordinates, will vary according to the reference Illuminant used to compute the L*a*b* coordinates.

DISCUSSION

We have seen that the RGB vs RGB tool and the Graph tools will provide the same chromaticities when measuring a display color as long as the input is not clipped by the selected RGB space in the RGB vs RGB tool. We thus have to be careful when inputting data into the RGB vs RGB tool due to the fixed size of RGB spaces. With the Graph tools, you just make measurements without any concern for fitting into an RGB space.

Important: Even if an input is clipped in the RGB vs RGB tool, the luminance or illuminance, and the CCT are always correct, as they correspond to the measured XYZ values before they may be clipped by the RGB space.

Here is a table which describes the difference between the RGB vs RGB tool and the Graph tools relative to **EMISSION** and **AMBIENT** measurements:

Mode	RGB vs RGB tool	Graph tools
Emission	• Y and L* are relative (0-100) to the calibration white Luminance (Yabs) • Y is limited by the maximum xyY values of the selected RGB space (i.e. the input may be clipped) • Patches with chromaticities outside of the RGB space will be clipped	• Y and L* are relative (0-100) to the calibration white Luminance (Yabs) • The input is NOT clipped
Ambient	• Y is the maximum value, for the RGB space, of the input xy coordinates (i.e. one or more RGB coordinate will always be 255) • Patches with chromaticities outside of the RGB space will be clipped	• Y and L* are always equal to 100 • The input is NOT clipped

Note: Only x and y are absolute coordinates. While the absolute luminance and illuminance are provided in cd/m^2 or lux, Y is normalized when shown in the xyY and XYZ data fields.

This concludes the tutorial. Click here to go back to the tutorials' Table of Contents.

16. Technical support

FOR INFORMATION, COMMENTS, SUGGESTIONS, PROBLEMS OR BUG REPORTS

If you cannot find the information you need in this Help manual, please consult our Web site's FAQ. You can also check if a new version of the program was released. Click on the link to open a Web-browser window:

- https://www.babelcolor.com .

If you still do not find an answer to a problem, or if you want to send us your comments and suggestions, click on the link to send an e-mail:

- info@babelcolor.com .

TO REPORT A PROBLEM

Please send us any information that could help in solving the issue, including:

- **Screenshots:** Take a screenshot of any message, dialog, or tool window which illustrates the problem, then attach the image or a file containing the image to your e-mail. Here are suggestions on how to take screenshots:

  Windows:
  1. Activate the window you want to grab by clicking on it.
  2. Press simultaneously on **Alt + Print-Screen** on the keyboard to copy an image of the selected window to the clipboard (Note: If the program is frozen, just press **Print-Screen** to copy the entire desktop).
  3. Paste the window image (usually the "Edit/Paste" menu command) in a graphic edition program or word processor.

  Mac OS X:
  1. Press simultaneously on **⌘ + shift + 3** on the keyboard to create a picture file of the entire desktop, or press simultaneously on **⌘ + shift + 4** to create a picture file of a screen area (after pressing and releasing the key combination, click and drag the mouse over the screen area you want to take a picture of, or press the space bar and then select an individual window).
  2. The file will be saved on the Desktop in the PNG image format.

  OR

  1. Launch the "Grab" application located in the "Applications/Utilities" folder.
  2. Capture the entire screen or a portion of it and save as a "tiff" file.

- **Data reports:** If the problem is data related and the program still operates when the problem is seen, save the current data using the "RGB vs RGB/Save Data..." menu, or any report from the spectral tools, and attach a copy to your e-mail.

- **CT&A related information**: If possible, describe the sequence of events that resulted in the problem and include:

  For the RGB vs RGB tool:
  Operating mode: Compare or Convert (and conversion direction)
  Space description (Adobe, Apple, sRGB, Custom, etc.)
  Input mode: R'G'B', "xy" Mouse input, "L*a*b*/ L*u*v* input", instrument model and measurement mode
  Display mode: Hex #, HSB, Munsell HVC, L*C*h, xyY, or XYZ
  Display mode: L*a*b*, or L*u*v*
  State of "L*a*b*/ L*u*v* in D50" checkbox
  Gamma mode: simple or detailed

  For the other tools (spectral tools):
  Tool name
  Tool settings
  Instrument model
  Measurement mode (emission, ambient, reflectance, flash)

- **Computer related information**: Provide any of the following data that you may find pertinent:

  Computer brand and model
  Operating system (Windows Vista, Windows 7, Windows 8, Windows 8.1, Windows 10, Mac OS X); indicate the service pack level or the exact version number, if known
  Processor type and speed (Intel, AMD, PPC, G4, G5, Mac-Intel)
  Amount of RAM
  International language settings
  Display resolution and bit depth (number of colors)
  Display appearance settings; for Windows: DPI value (96 (100%), 120 (125%), etc.)
  Graphic card brand and model if applicable
  Printer brand and model

17. Index

Note: The index refers to the beginning of the section where the word is used. In many cases, the index page number may not correspond to the exact page the word appears.

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