# Profile connection and PCS operations

**ICC DevCon 2020 -** The Future of Color Management

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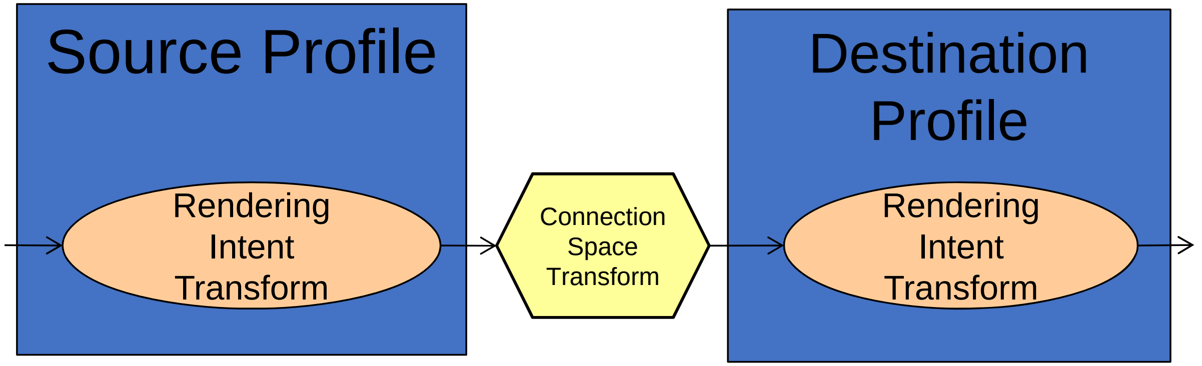
# iccMAX Connections

# Connecting Device Profiles with iccMAX

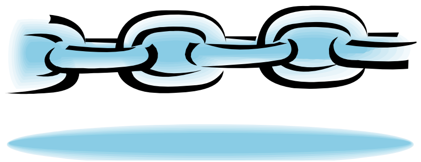
- Source Profile Transform is selected
  - Maps device data color space to a connection color space
- Destination Profile Transform is selected
  - Maps from a connection color space to device data color space
- Transform selection is based on rendering intent and desired connection space
- The Color Management Module (CMM) performs the necessary conversions and/or rendering intent adjustments between profile connection color spaces associated with the Profile Transforms



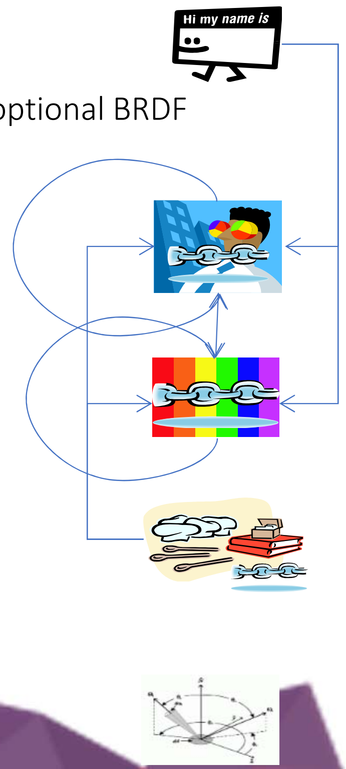

<u>Significant iccMAX Rendering Intent changes</u>

- Absolute intent transforms can be directly encoded
- Intent replacement mapping has been adjusted to allow for relative only, or absolute only profiles

# iccMAX Connections



- iccMAX supports five types of inter-profile connections
- Named Color connections
  - Provides relationship between named colors and colorimetric, spectral as defined by header PCS fields as well as optional BRDF information
  - Can be linked with colorimetric and spectral connection tags
- Colorimetric Connections (How does an observer see it?)
  - Connection provided by B in A2Bx/B2Ax transform tags
  - Can be linked with both Colorimetric and Spectral connection tags
- Spectral Connections (What is its relationship to light?)
  - Connection provided by B in D2Bx/B2Dx transform tags
  - Can be linked with both Colorimetric and Spectral connection tags
- Multiplex Connections (What is it?)
  - Connection provided by M in A2M0, M2A0, M2B0, and M2A0 transform tags
  - M2B0 tags can be connected to B2Ax Colorimetric connection tags
  - M2S0 tags can be connected to B2Dx Spectral connection tags
- BRDF Connections
  - Profile transforms provided in BRDF tags
- Either Colorimetric or Spectral tags (or both) can be defined in the same profile
- Input class profiles can optionally include Multiplex (A2M0) tag in the same profile

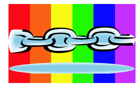


# iccMAX Color Spaces

- Colorimetric Profile Connection Spaces
  - Same as defined in ICC.1 (XYZ and L*a*b*)
  - Observer and Illuminant can vary as defined by spectral viewing conditions tag
- New Extended Color Space Signatures Types
  - Allow from 1 to 65535 channels to be defined
  - Upper 16 bits contain two text characters defining color space type (no conflicts with existing color spaces)
  - Lower 16 bits contain binary value of number of channels
  - Represented in specification as six character string in double quotes with first two characters defining the color space type followed by 4 hexadecimal digits
- Device Color Spaces
  - Color space signatures as defined in ICC.1
  - Additional extended N-channel color space signatures defined
    - Color space type "nc" in upper 16 bits, number of channels in lower 16 bits
    - "nc0001" through "ncFFFF"

# iccMAX Connection Spaces

- New connection spaces are defined by separate fields in profile header with separate CMM connection logic
- Spectral Profile Connection Space Signatures



  - “rsXXXX” defines reflectance spectra with XXXX channels
  - “tsXXXX” defines transmission spectra with XXXX channels
  - “esXXXX” defines radiant/emission spectra with XXXX cannels
  - “bsXXXX” defines bi-spectral (fluorescent) spectra with XXXX channels
  - “smXXXX” defines sparse matrix (compressed fluorescent) spectra stored in space defined by XXXX 32-bit values
  - Additional fields in profile header provide spectral range information for spectral connection spaces

- Multiplex Connection Spaces
  - “mcXXXX” defines named “multiplex” values with XXXX channels
  - Additional tags define multiplex connection channel names and default values

# iccMAX Header Connection Changes

| Byte Position | Field length (bytes) | Field contents | Encoded as |
|---|---|---|---|
| 0 to 3 | 4 | Profile size | UInt32Number |
| 4 to 7 | 4 | Preferred CMM type | See 7.2.5 |
| 8 to 11 | 4 | Profile version and sub-version number | See 7.2.6 |
| 12 to 15 | 4 | Profile/Device class | See 7.2.7 |
| 16 to 19 | 4 | Colour space of data (possibly a derived space) | See 7.2.8 |
| 20 to 23 | 4 | PCS | See 7.2.9 |
| 24 to 35 | 12 | Date and time this profile was first created | dateTimeNumber |
| 36 to 39 | 4 | 'acsp' (61637370h) profile file signature | See 7.2.11 |
| 40 to 43 | 4 | Primary platform signature | See 7.2.12 |
| 44 to 47 | 4 | Profile flags to indicate various options for the CMM such as distributed processing and caching options and MCS connection requirements | See 7.2.13 |
| 48 to 51 | 4 | Device manufacturer of the device for which this profile is created | See 7.2.14 |
| 52 to 55 | 4 | Device model of the device for which this profile is created | See 7.2.15 |
| 56 to 63 | 8 | Device attributes unique to the particular device setup such as media type | See 7.2.16 |
| 64 to 67 | 4 | Rendering Intent | See 7.2.17 |
| 68 to 79 | 12 | The nCIEXYZ values of the illuminant of the PCS. | XYZNumber |
| 80 to 83 | 4 | Profile creator signature | See 7.2.19 |
| 84 to 99 | 16 | Profile ID | See 7.2.20 |
| 100 to 103 | 4 | Spectral colour space signature | See 7.2.21 |
| 104 to 109 | 6 | Spectral PCS wavelength range | spectralRange |
| 110 to 115 | 6 | Bi-spectral PCS wavelength range | spectralRange |
| 116 to 119 | 4 | MCS signature | See 7.2.24 |
| 120 to 123 | 4 | Profile/Device sub-class | See 7.2.25 |
| 124 to 127 | 4 | Reserved bytes shall be set to zero (00h) | See 7.2.26 |

- PCS field defines Profile Connection Space for colorimetric rendering intent transform A2Bx/B2Ax tags
  - Arbitrary observer and illuminants supported
- Spectral PCS fields defines color space for rendering intent transform D2Bx/B2Dx tags
  - Spectral PCS range defines wavelength range
  - Bi-spectral PCS range defines excitation range when bi-spectral color space is used
- Multiplex Connection Space signature defines number of MCS channels
  - Profile flags define MCS channel connection requirements

# iccMAX PCS Support

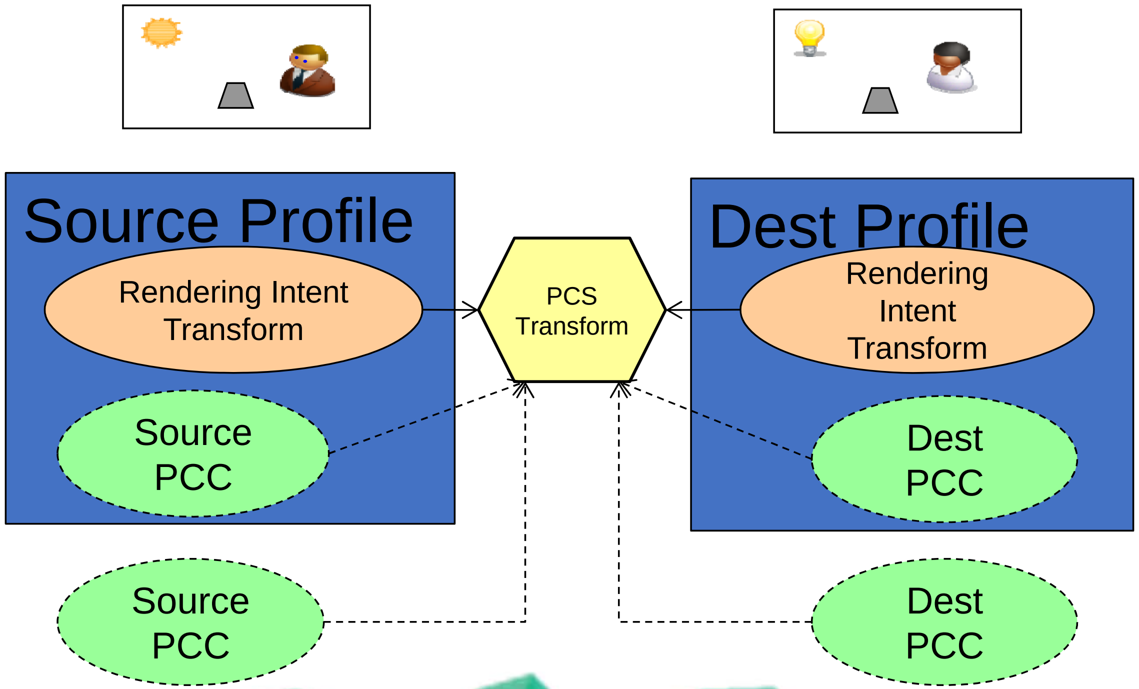
ICC.1 PCS Support

| | From Lab | From XYZ | From Reflectance | From Transmittance/ Transmissive | From Radiant/ Emission | From Fluorescence |
|---|---|---|---|---|---|---|
| ***To Lab*** | Yes | Yes | Using PCC | Using PCC | Using PCC | Using PCC |
| ***To XYZ*** | Yes | Yes | Using PCC | Using PCC | Using PCC | Using PCC |
| ***To Reflectance*** | No | No | Yes | Yes | Extract PCC illuminant | Apply then extract PCC illuminant |
| ***To Transmittance/ Transmissive*** | No | No | Yes | Yes | Extract PCC illuminant | Apply then extract PCC illuminant |
| ***To Radiant / Emission*** | No | No | Apply PCC Illuminant | Apply PCC illuminant | Yes | Apply PCC illuminant |
| ***To Fluorescence*** | No | No | No | No | No | Exact match required |

Operations to perform conversions are outlined in Appendix A of iccMAX Specification

PCC = Profile Connection Conditions

# iccMAX Profile Connection Conditions

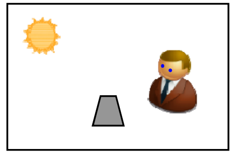



- Profile Connection Conditions provide additional information for PCS processing
- Spectral and custom colorimetric PCS processing is performed using Profile Connection Conditions (PCC)
- PCC information can come from either the profile or externally provided to the Color Management Module (CMM)
- Profile Connection Conditions are NOT required for legacy colorimetric PCS processing

Allows PCS data in profiles to use actual viewing conditions

No need for chromaticAdaptationTag!

# Profile Connection Conditions (PCC)



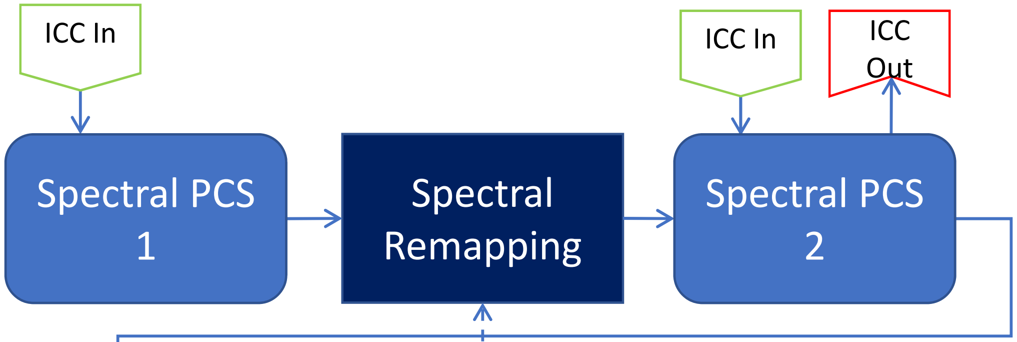
- Profile Connection Conditions (PCC) comprise of:
  - Header color space and spectral PCS metadata
  - Three new tags:
    - spectralViewingConditionsTag defines a *spectralViewingConditionsType* (a new tag type) based tag that spectrally specifies observer and illuminant
      - Illuminant and observer signatures used to determine PCS pass through connection
      - Colorimetric information about surround
    - customToStandardPcsTag defines a MultiProcessElement based tag to convert from custom PCS colorimetry to standard D50 / 2-degree observer colorimetry
    - standardToCustomPcsTag defines a MultiProcessElement based tag to convert from standard D50 / 2-dgree observer colorimetry to custom PCS colorimetry
- PCC information is required whenever PCS is NOT standard D50 using 2-degree observer
  - Provides for interoperability to connect different viewing conditions
  - Provides flexibility for when and how conversions are made
  - Provides colorimetric conversion transforms for changes in observer and / or illuminant

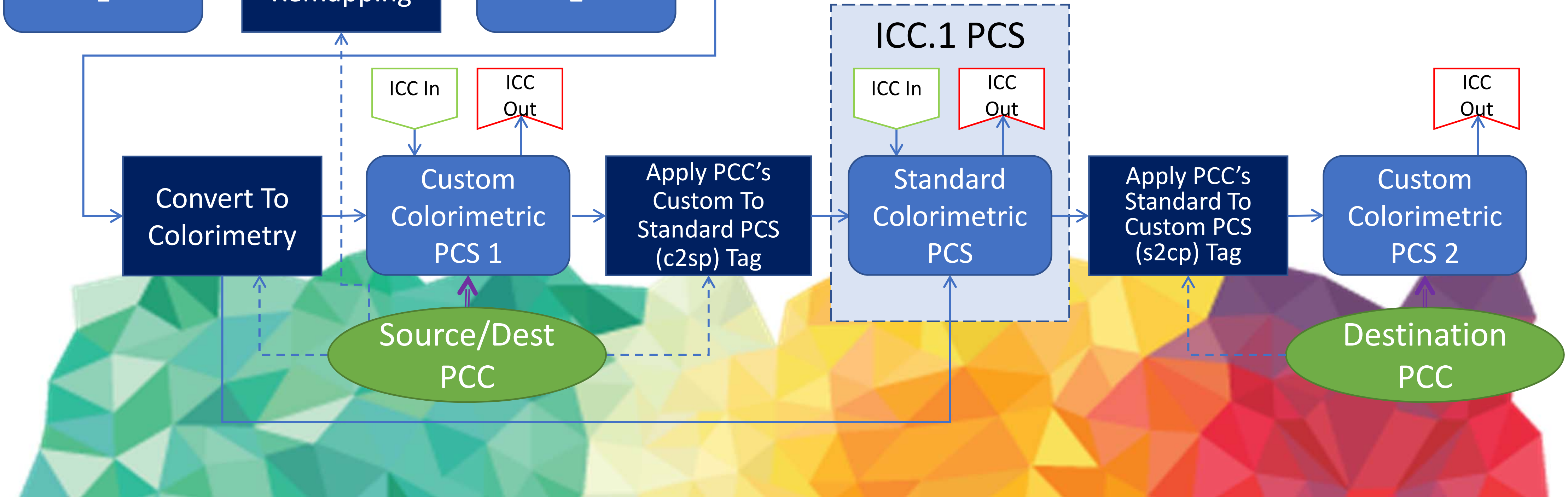
# PCC c2sp /s2cp Tag Transforms

- Appearance matching can be defined by PCC using CAM based MultiProcessElement tags implementing either an Appearance Model based conversion or a matrix based CAT
  - Account for changes in illuminant and/or surround
  - Cannot account for changes in physical observer as corresponding colors do not provide prediction of appearance between physical observers
    - A CAT based on corresponding color data may be possible to predict changes in “observer” due to field size effect changes
- Material matching can be defined by PCC using MultiProcessElement tags each implemented with a matrix based MAT
  - Also accounts for changes in illuminant, but is more appropriate for inter-observer conversions
  - Does not predict actual changes of spectral reflectances (spectral workflow needed)
  - Wpt (Waypoint) normalization based MATs can provide good candidates for defining a PCC c2sp and s2cp transforms

# Spectral and Colorimetric PCS Conversion

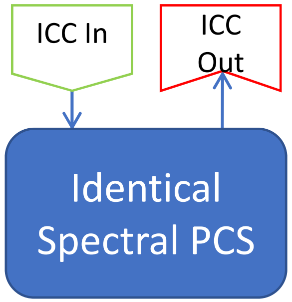
- Connect any ICC In ny ICC Out
- Connection to same PCS block indicate PCS e CMM uses the same PCS definition



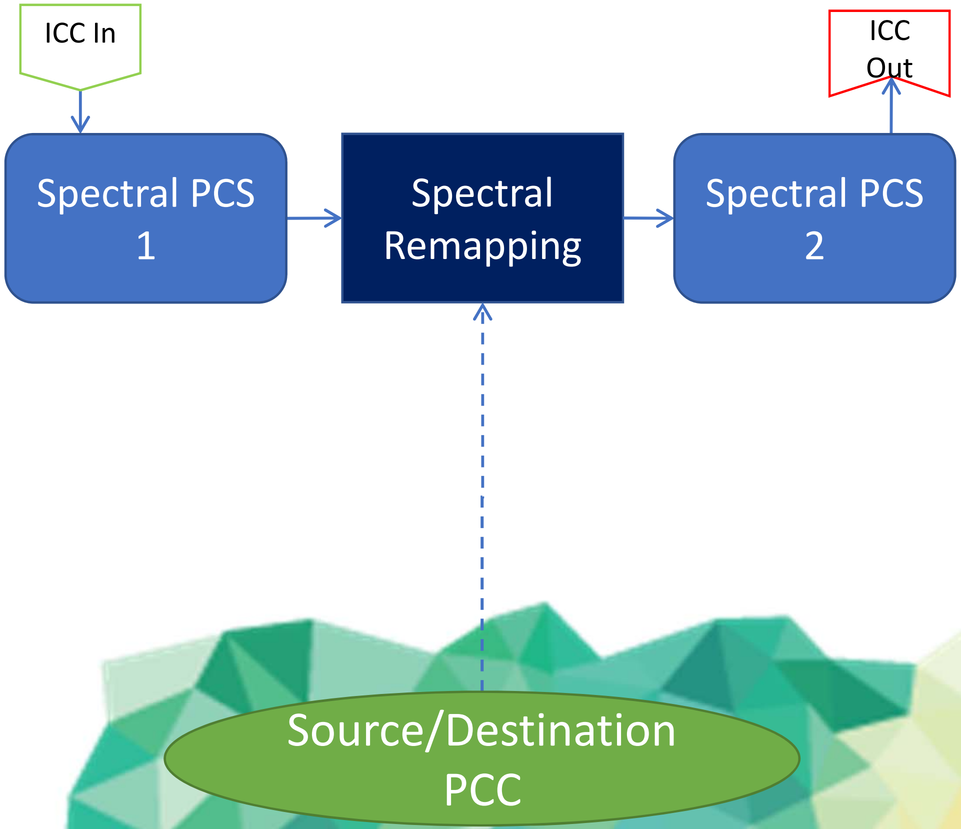



# iccMAX Spectral Profile Connection Workflows

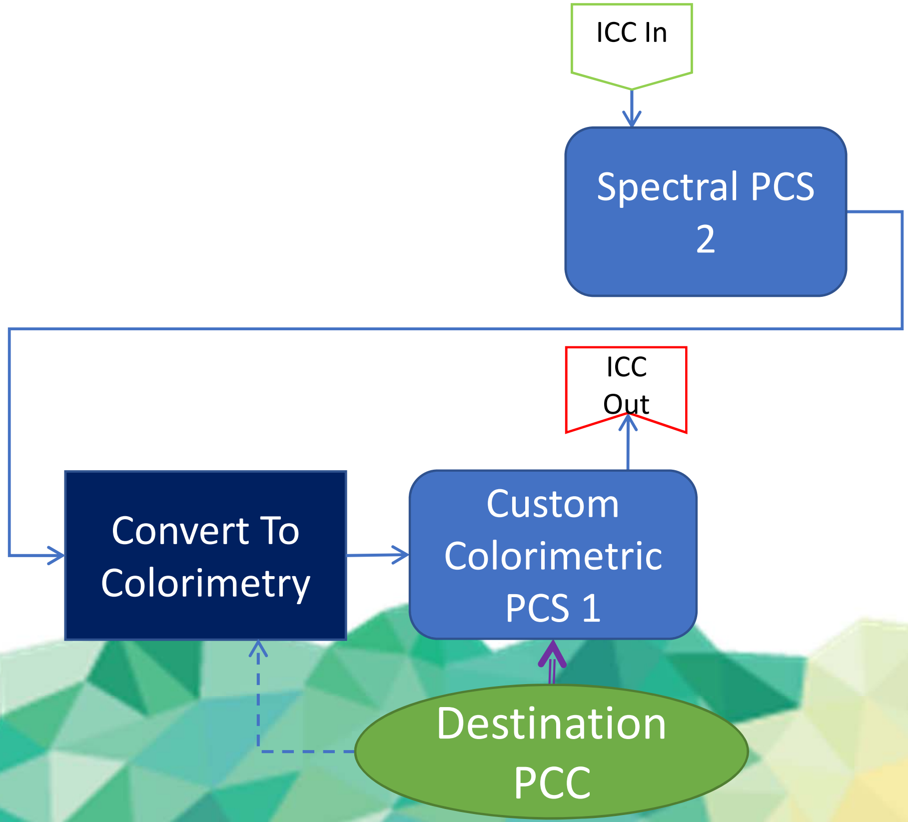
# Basic Multi-Spectral Workflow



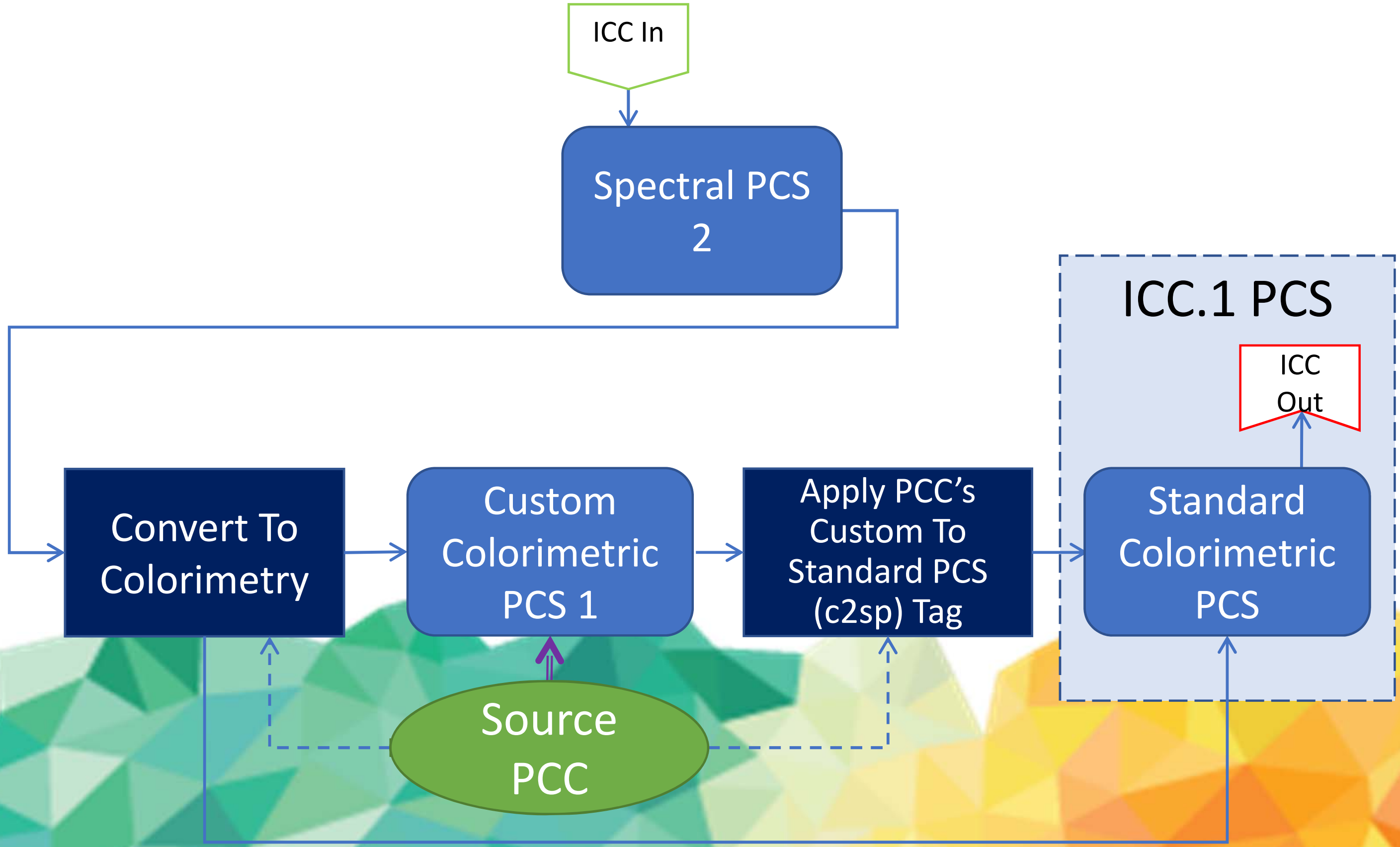
# Extended Spectral PCS Workflow



# Spectral to Colorimetric Workflow

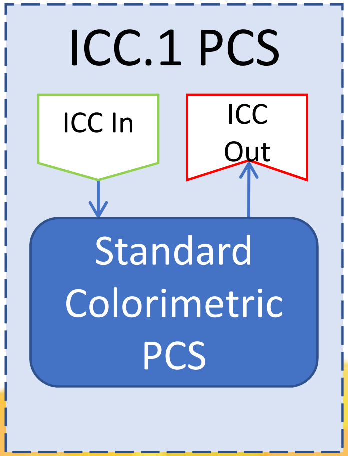


# Spectral to Legacy Workflow

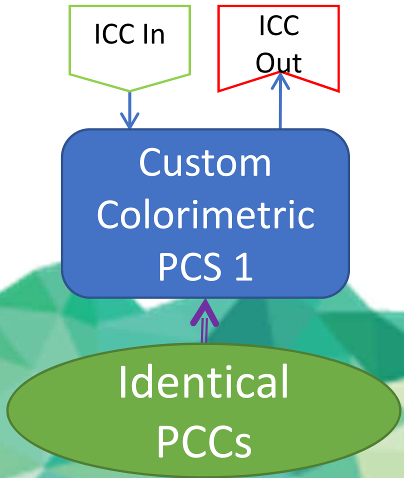


# Colorimetric Profile Connection Workflows

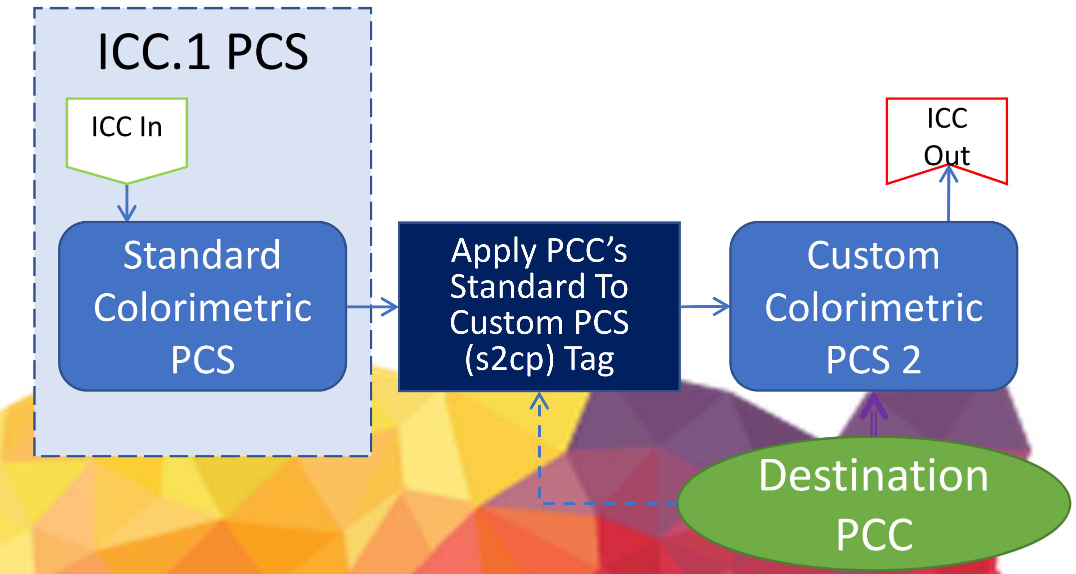
# Legacy Colorimetric Workflow



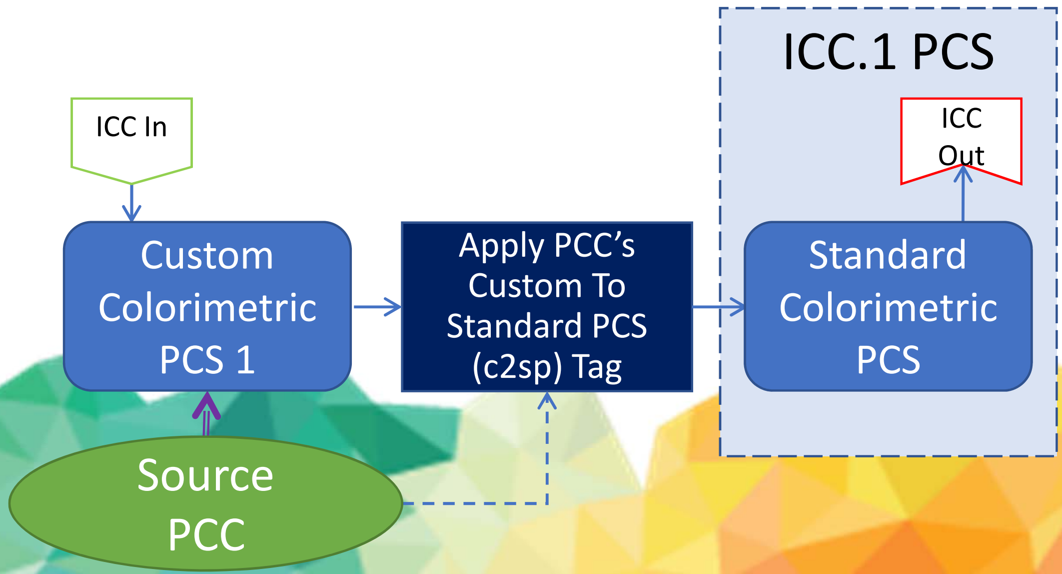
# Alternate Colorimetric Workflow



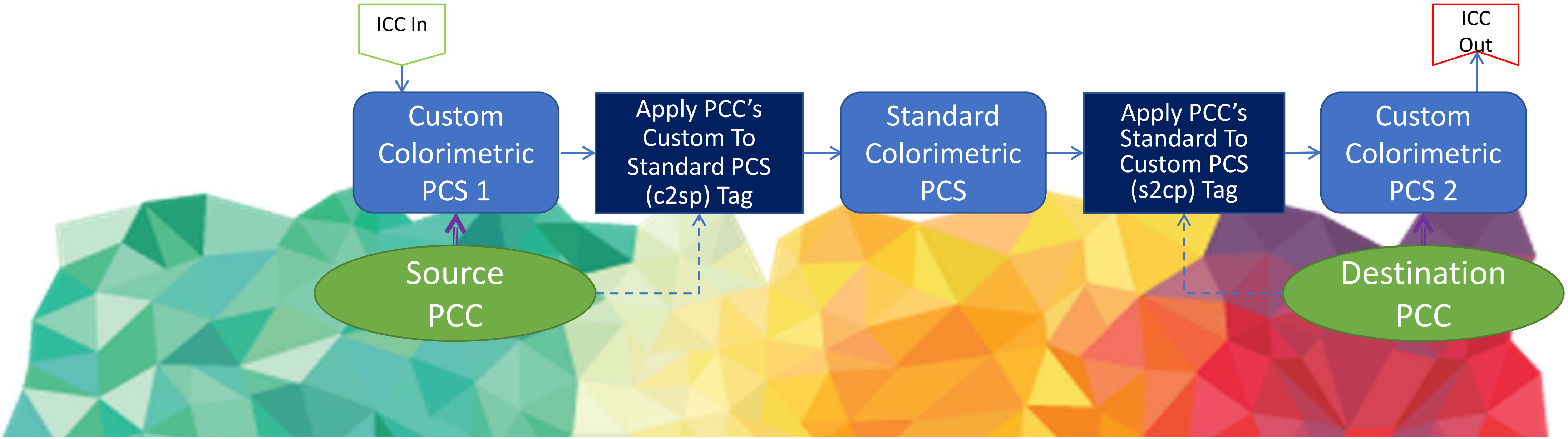
# Legacy to Custom Colorimetric Workflow



# Custom to Legacy Workflow



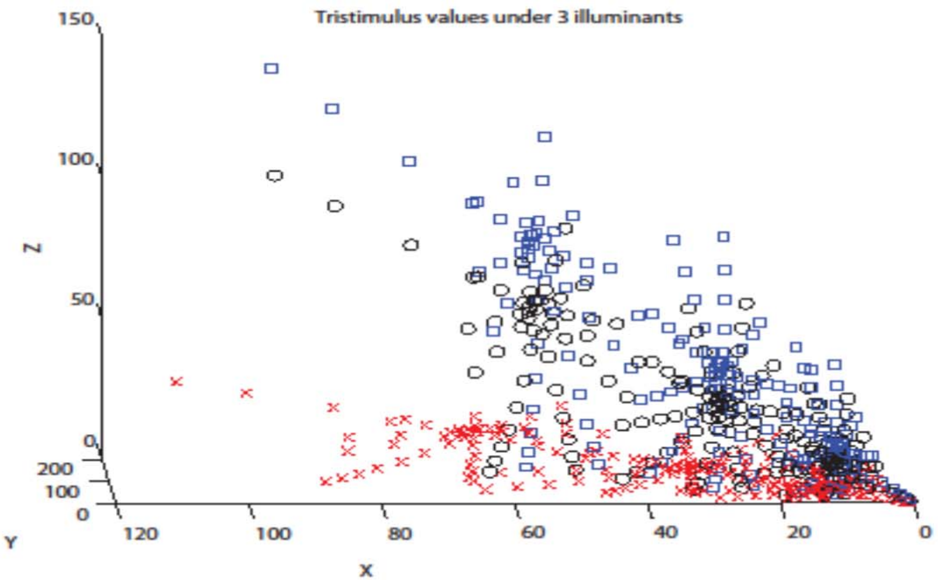
# Custom to Custom Colorimetric Workflow

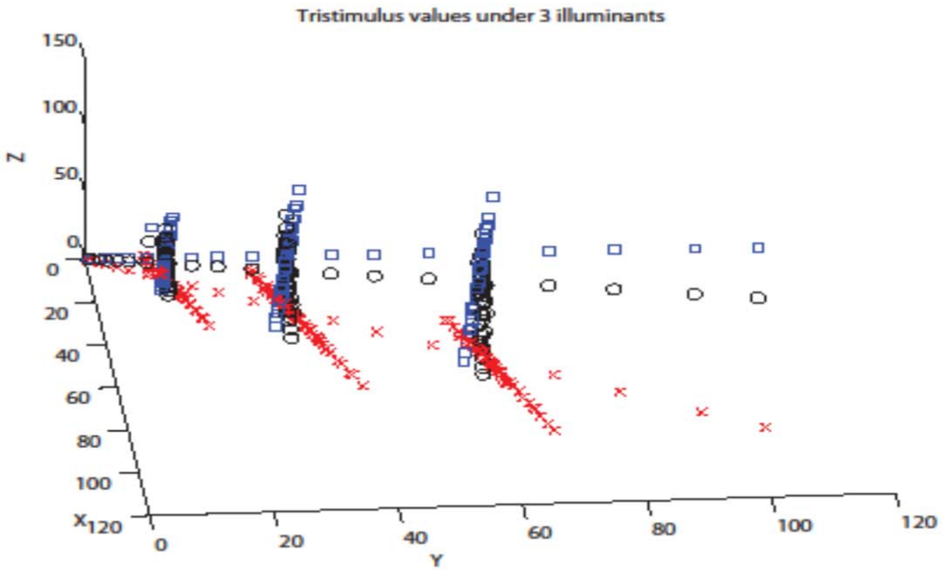


# Conversion of Colorimetry between Illuminants and Observers

Partly Based upon PhD work of Max Derhak

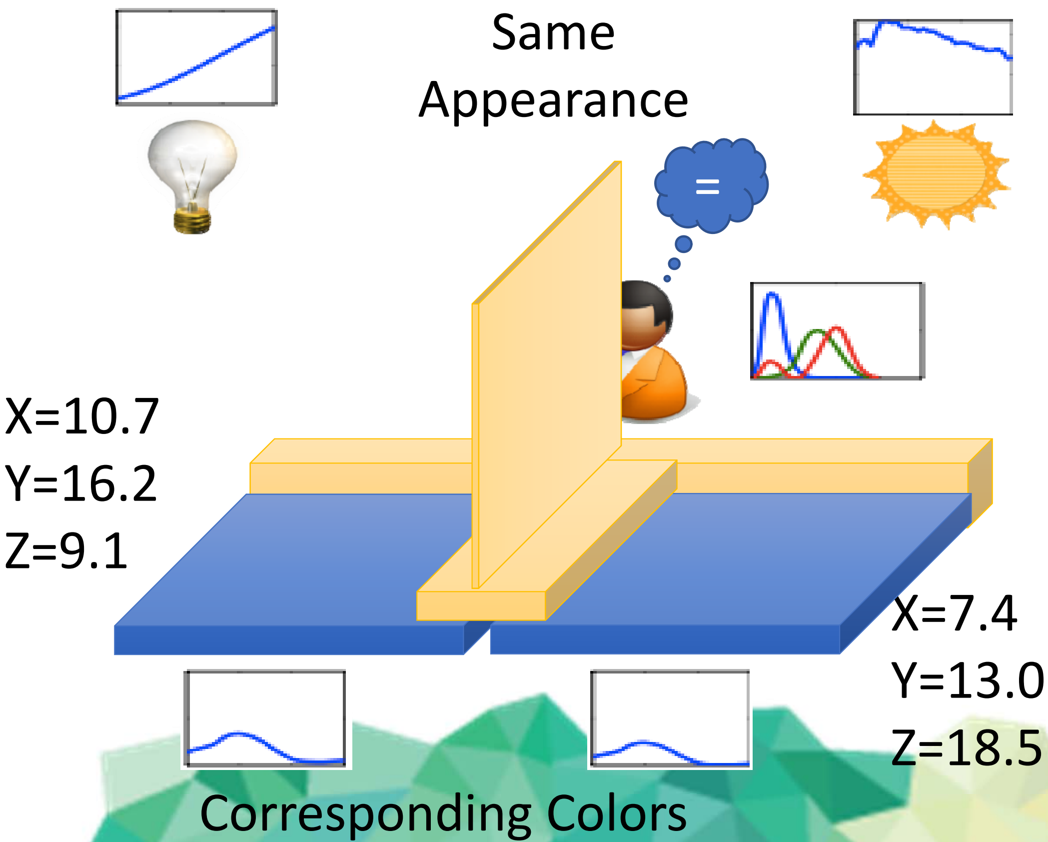
# Sensor values change when Illuminant or Observer changes



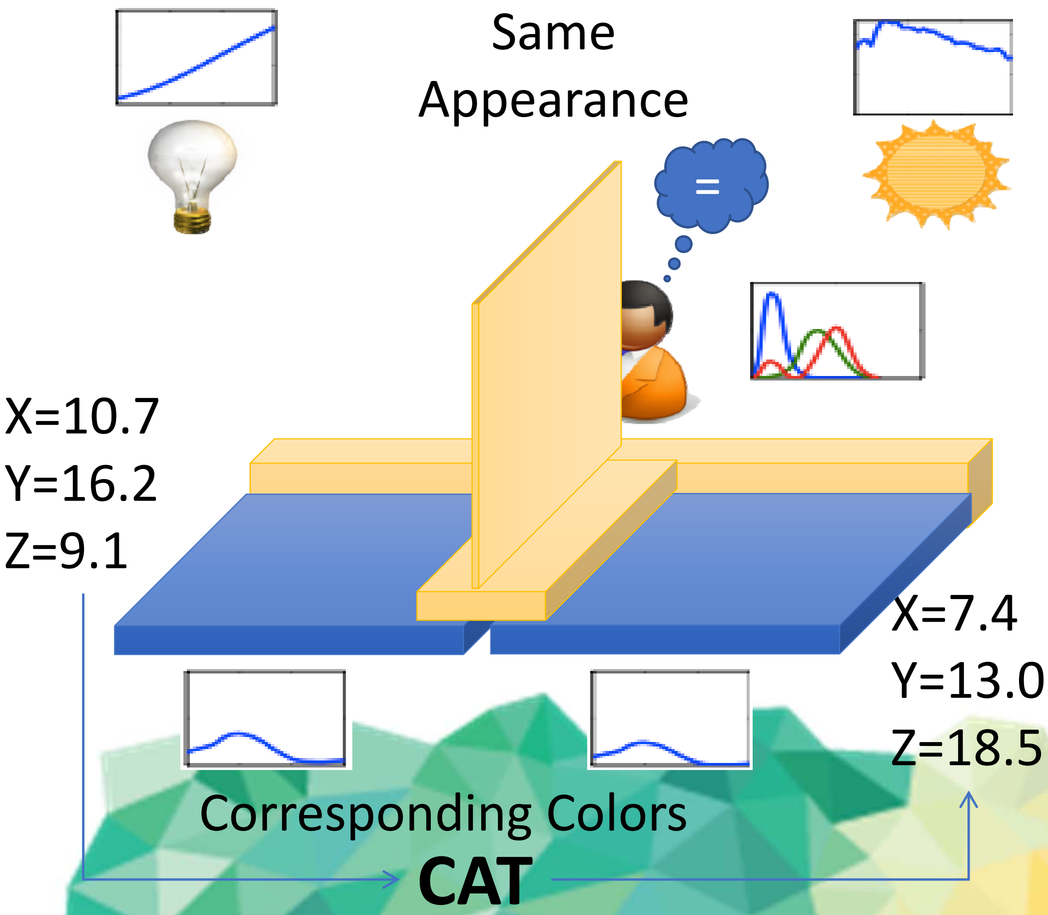



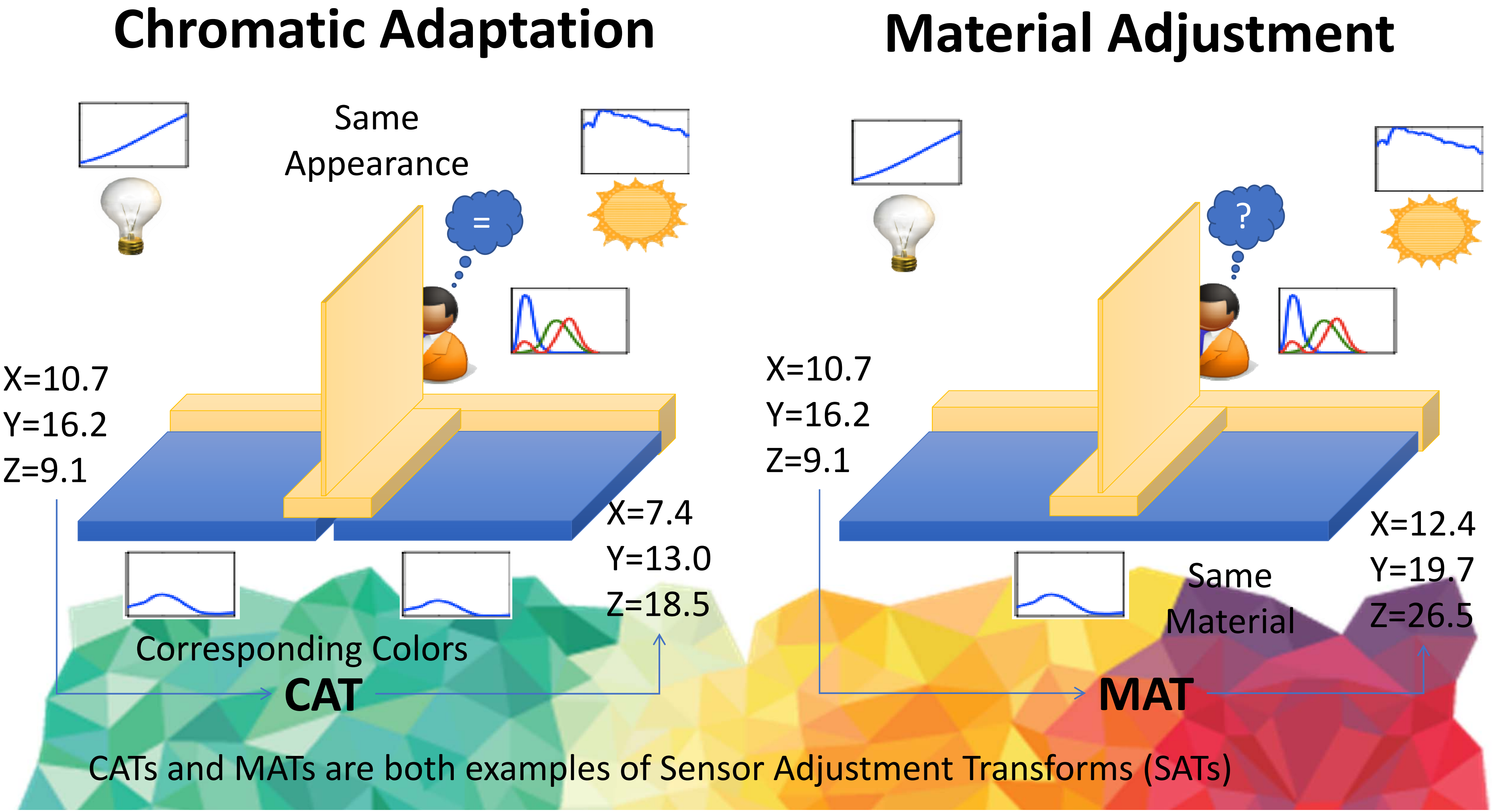

- Figure of Tristimulus values for same Munsell glossy reflectances for 2-degree observer under Illuminant A (red), D65 (black), D100 (blue)
- Similar changes occur for changes in observer
- *To make conversions - What is needed is method of determining “color equivalency” for change in observer and/or illuminant*

# Chromatic Adaptation

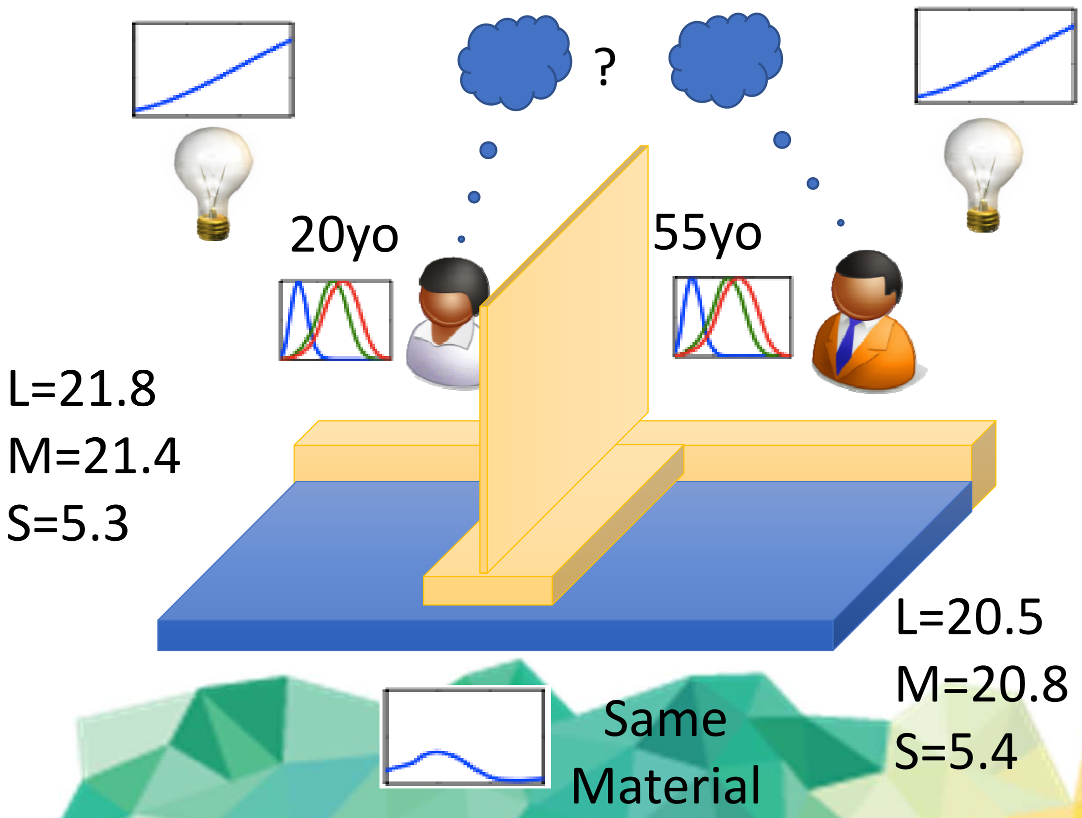


# Chromatic Adaptation

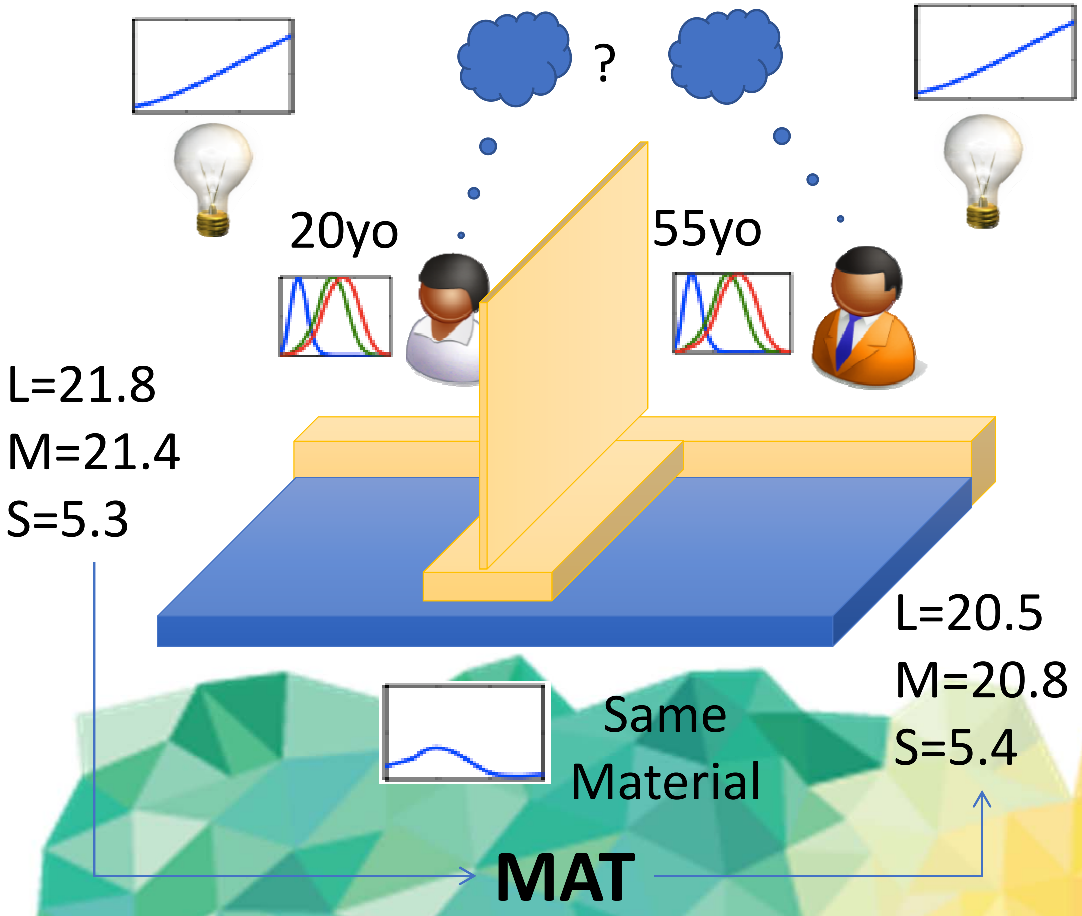



Chromatic Adaptation
Material Adjustment
Same
Appearance
=
?
X=10.7
Y=16.2
Z=9.1
X=7.4
Y=13.0
Z=18.5
X=10.7
Y=16.2
Z=9.1
X=12.4
Y=19.7
Z=26.5
Same
Material
Corresponding Colors
CAT
MAT
CATs and MATs are both examples of Sensor Adjustment Transforms (SATs)

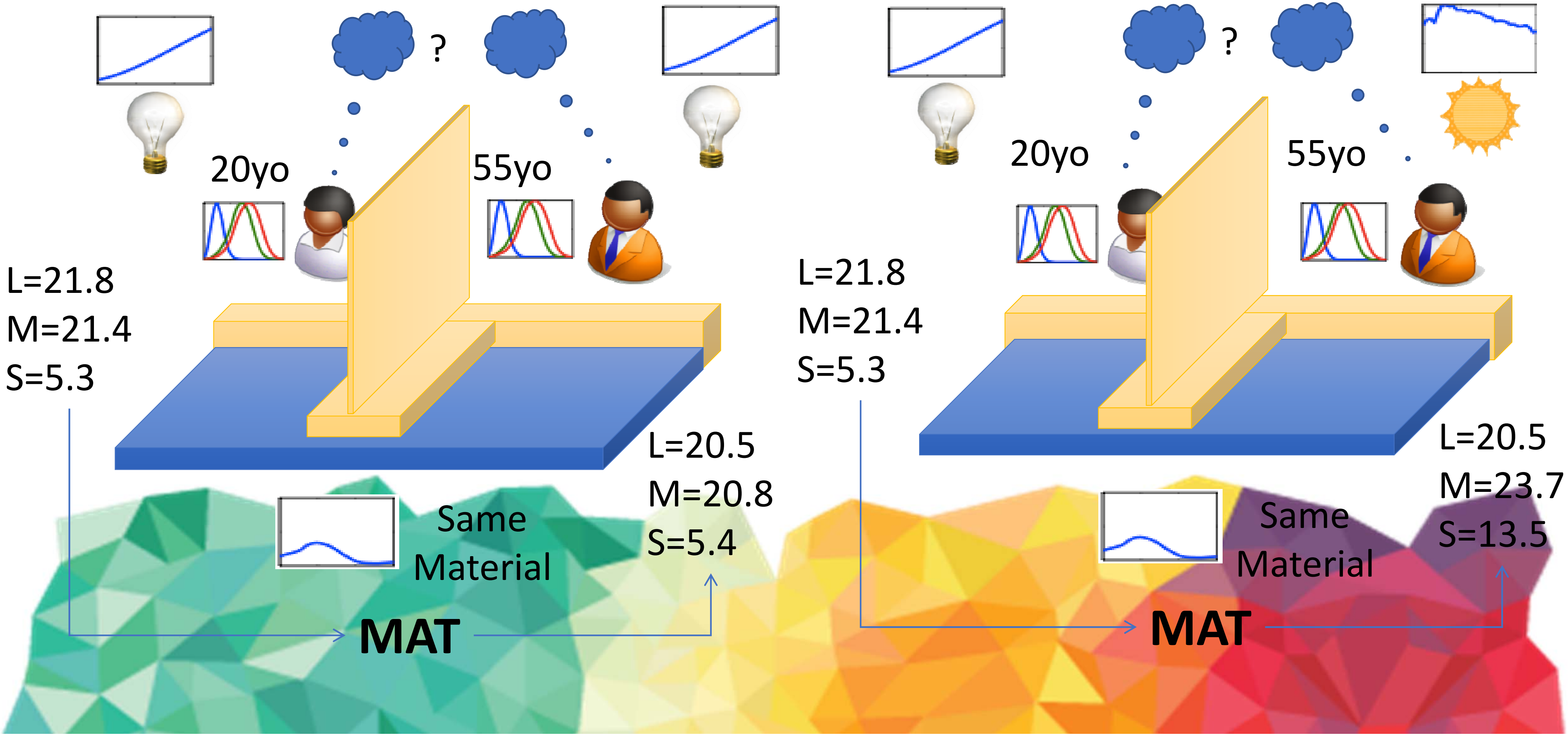
# Adjustments for different observing conditions



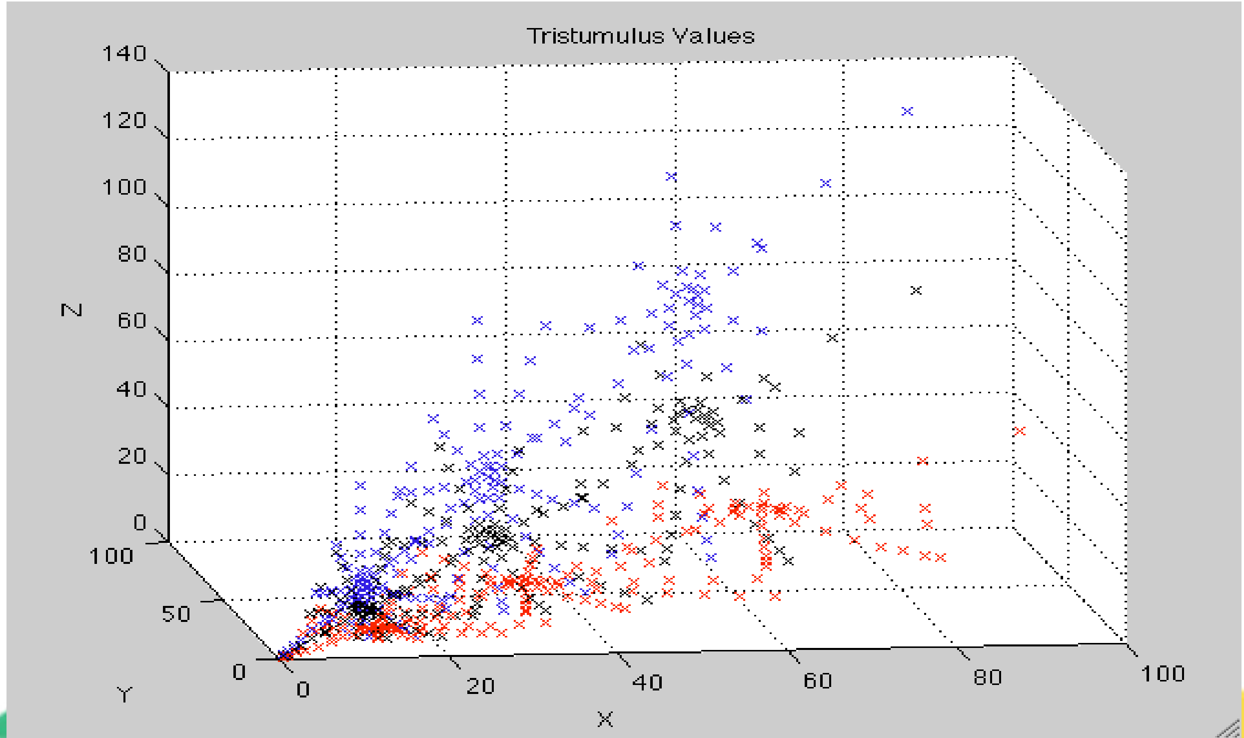
# Adjustments for different observing conditions



# Adjustments for different observing conditions

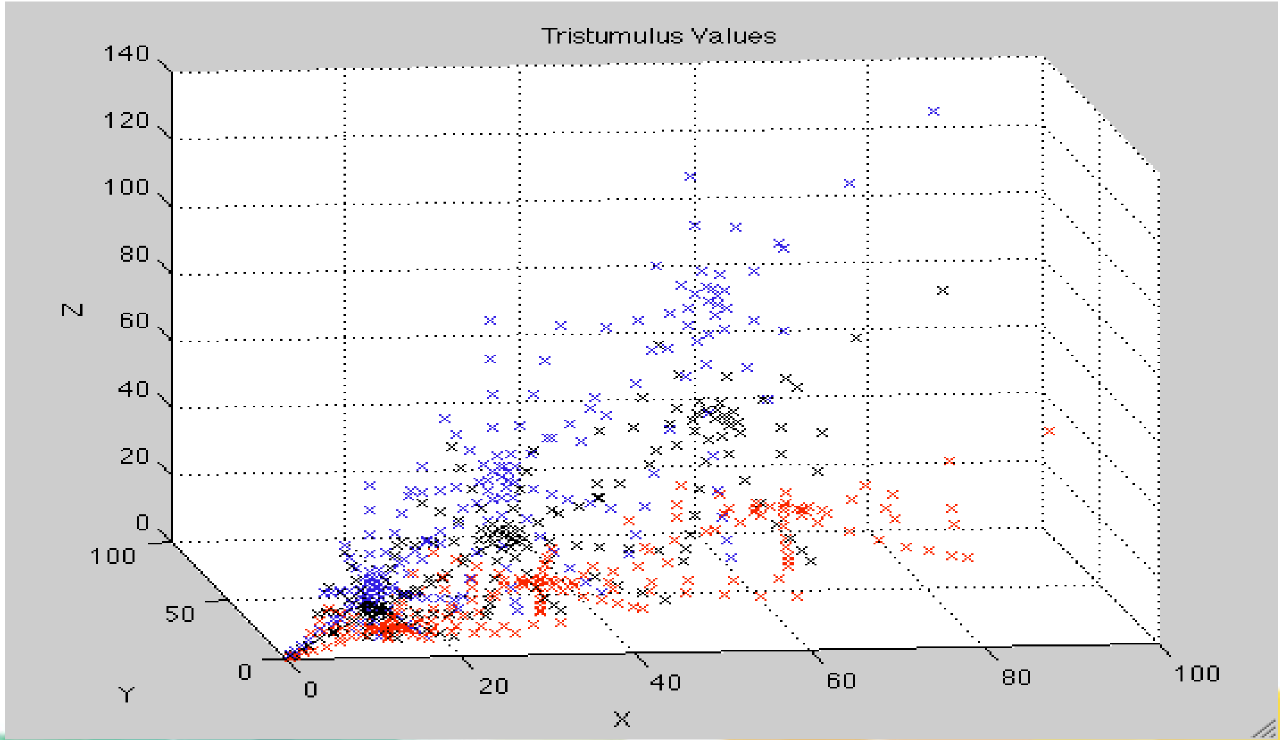


# XYZ Normalization Color Equivalency




- Figure depicts “wrong-vonKries” white balancing of Munsell glossy reflectances for 2-degree observer under Illuminant A- red, D65 black, D100 Blue
- This demonstrates the color equivalency use by XYZ to CIELAB equations

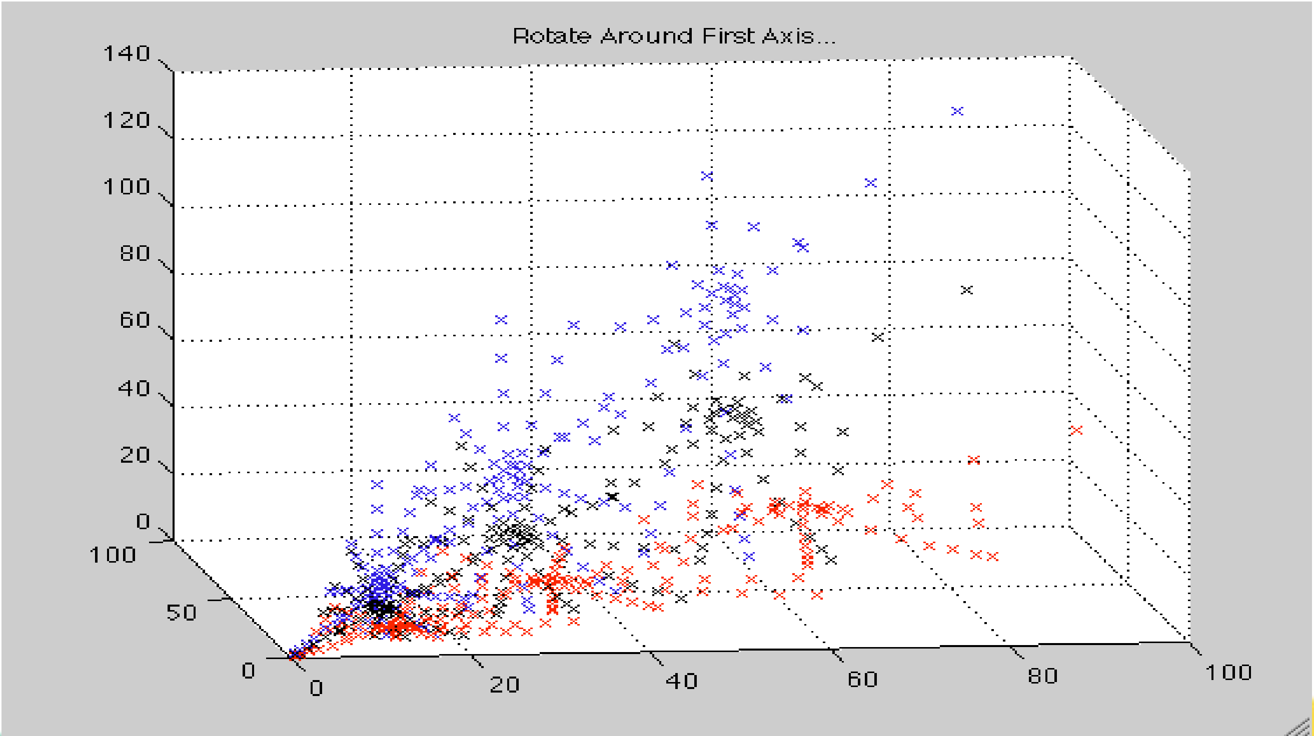
# Color Equivalency Representation of CAT02




- Figure depicts CAT02 normalization of Munsell glossy reflectances for 2-deg observer under Illuminant A- red, D65 black, D100 Blue
- CAT02 predicts corresponding color – not material color

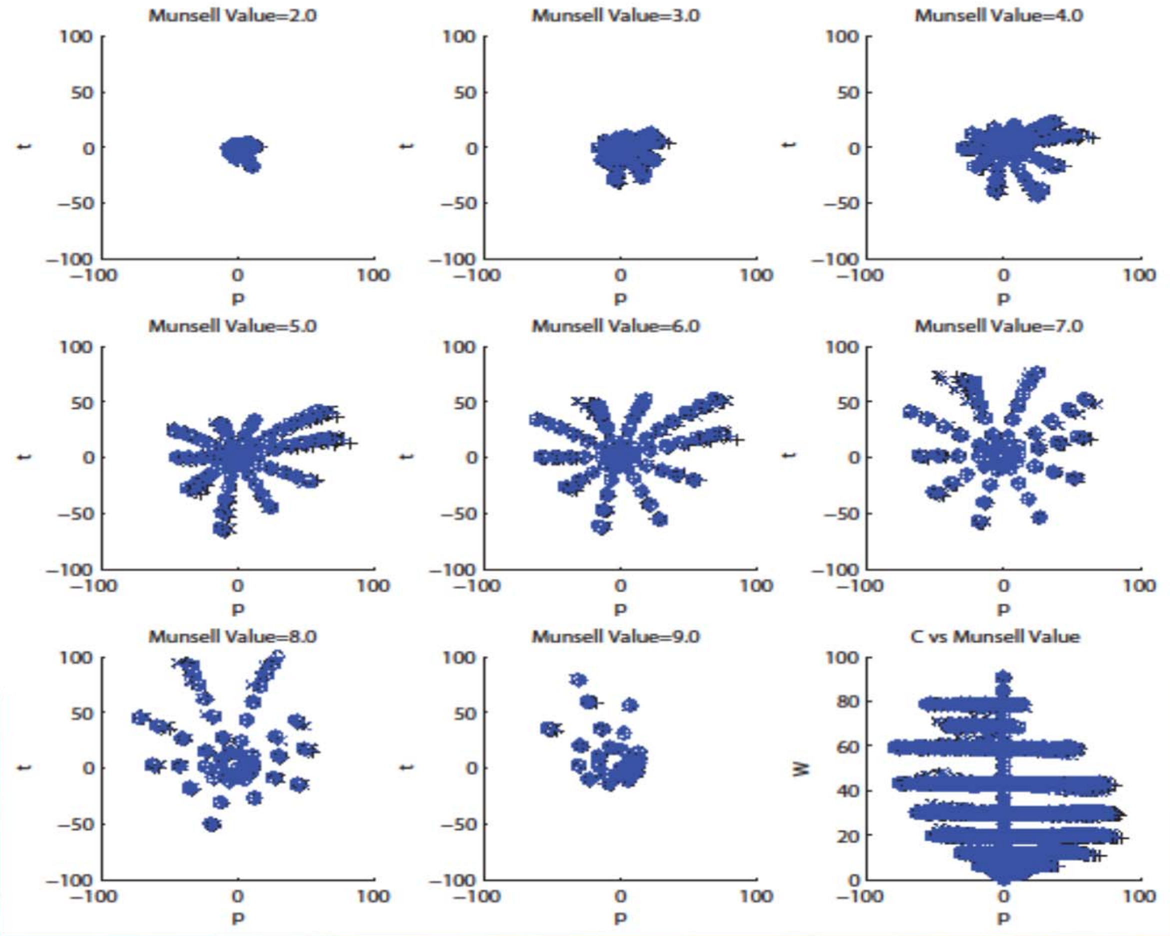
# Wpt (Waypoint) Normalization

## (Described in Derhak PhD – See http://scholarworks.rit.edu/theses/8789/)




- Figure depicts process of Wpt normalization applied to Munsell glossy reflectances for 2-deg observer under Illuminant A- red, D65 black, D100 Blue
- A Wpt normalization based MAT can be used (but is not required part of iccMAX specification) to predict material color changes – not corresponding color

# Color Equivalency Representation of Wpt (Waypoint) Normalization




Wpt (Waypoint) normalization of Munsell glossy reflectances for 2-degree observer (black) 10-degree observer (blue) for F11 : x', Illuminant A: +'s, Illuminant C: points, Illuminant E: circles, D50: squares, D65: diamonds

# Example Wpt Normalization Matrices

| | Standard 2° Observer | | | Standard 10° Observer | | |
|---|---|---|---|---|---|---|
| D50 | -0.06265 | 1.03839 | 0.02669 | -0.03390 | 1.06622 | -0.04107 |
| | 4.68561 | -4.82563 | 0.37293 | 4.98326 | -5.37826 | 0.68588 |
| | 0.28350 | 1.50053 | -2.15101 | 0.48282 | 1.35138 | -2.23437 |
| D65 | 0.02964 | 0.97487 | -0.00280 | 0.07837 | 0.99300 | -0.06271 |
| | 4.83916 | -4.73122 | 0.12117 | 5.12107 | -5.27209 | 0.38828 |
| | 0.54248 | 1.30671 | -1.67368 | 0.78225 | 1.13989 | -1.75315 |
| E | -0.07407 | 1.05436 | 0.01971 | -0.04091 | 1.08336 | -0.04246 |
| | 4.61340 | -4.78331 | 0.16986 | 4.89821 | -5.31600 | 0.41832 |
| | 0.37630 | 1.40421 | -1.78050 | 0.59264 | 1.24324 | -1.83561 |
| C | 0.00000 | 1.00000 | 0.00000 | 0.04888 | 1.02268 | -0.06047 |
| | 4.84591 | -4.80280 | 0.04258 | 5.14072 | -5.36078 | 0.30964 |
| | 0.51873 | 1.30963 | -1.53805 | 0.75497 | 1.15250 | -1.62468 |
| A | -0.33810 | 1.30006 | 0.20048 | -0.36233 | 1.37188 | 0.08758 |
| | 4.40232 | -5.32134 | 1.36425 | 4.76102 | -5.94588 | 1.85883 |
| | -0.41103 | 2.17849 | -4.85343 | -0.29792 | 2.07286 | -4.94818 |
| F11 | -0.12366 | 1.05659 | 0.10608 | -0.13853 | 1.11178 | 0.04893 |
| | 4.38611 | -4.63611 | 0.32299 | 4.73751 | -5.27217 | 0.53588 |
| | 0.37476 | 1.29098 | -2.59413 | 0.47386 | 1.20030 | -2.57966 |

Example MAT creation using Wpt Normalization Matrices

$$\begin{bmatrix} 0.69841 & 0.10047 & 0.24869 \\ -0.30721 & 1.32784 & 0.03867 \\ 0.01624 & -0.02413 & 2.36015 \end{bmatrix} = \begin{bmatrix} -0.06265 & 1.03839 & 0.02669 \\ 4.68561 & -4.82563 & 0.37293 \\ 0.28350 & 1.50053 & -2.15101 \end{bmatrix}^{-1} \times \begin{bmatrix} -0.36233 & 1.37188 & 0.08758 \\ 4.76102 & -5.94588 & 1.85883 \\ -0.29792 & 2.07286 & -4.94818 \end{bmatrix}$$

A, 10° to D50, 2° MAT — Inverse D50, 2° — A, 10°

# Spectral PCS Math and Conversions

# Spectral Resampling

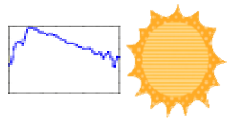
- Illuminants/light sources, emission/radiance, reflectance factor, transmission factor, and observer color matching functions are all expressed as vectors/matrices that are sampled as wavelengths over a range
- The math requires that the spectral sampling is identical when combining or manipulating these vectors/matrices
- Resampling can be performed as a matrix operation

$$\begin{bmatrix} R_{350\ nm} \\ Rr_{400\ nm} \\ R_{450\ nm} \\ R_{500\ nm} \\ R_{550\ nm} \\ R_{600\ nm} \\ R_{650\ nm} \\ R_{700\ nm} \\ R_{750\ nm} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0.5 & 0.5 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R_{400\ nm} \\ R_{500\ nm} \\ R_{600\ nm} \\ R_{700\ nm} \end{bmatrix}$$

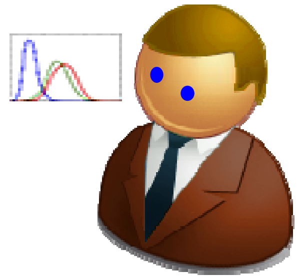
# Integrating to Get Sensor Excitations

- Integral computation of the *i<sup></sup>*$^{th}$ Sensor Excitation
  - $c_i = 683 \int C_i(\lambda) L(\lambda) d\lambda$
    - Intensity Radiance/Emission
  - $c_i = k \int C_i(\lambda) L(\lambda) d\lambda$
    - Relative Radiance/Emission
  - $c_i = k \int C_i(\lambda) O(\lambda) L(\lambda) d\lambda$
    - Relative using reflectance
  - $c_i = k \int \int C_i(\lambda) O(\lambda, \omega) L(\omega) d\lambda\, d\omega$
    - Relative using fluorescence

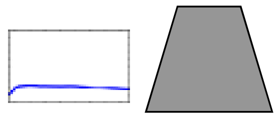
$L(\lambda)$



$C_i(\lambda)$

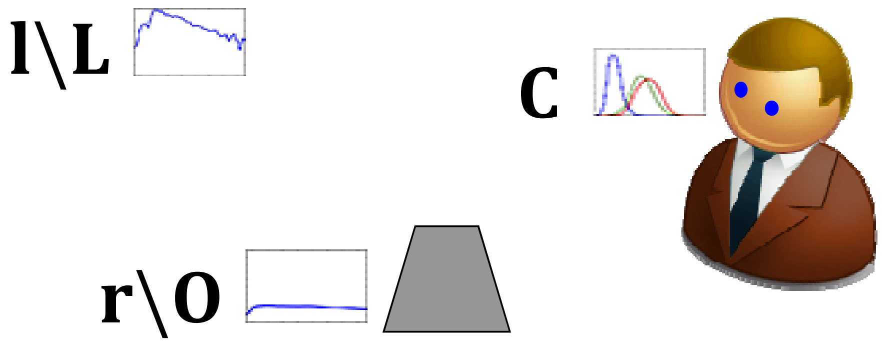


$O(\lambda)$

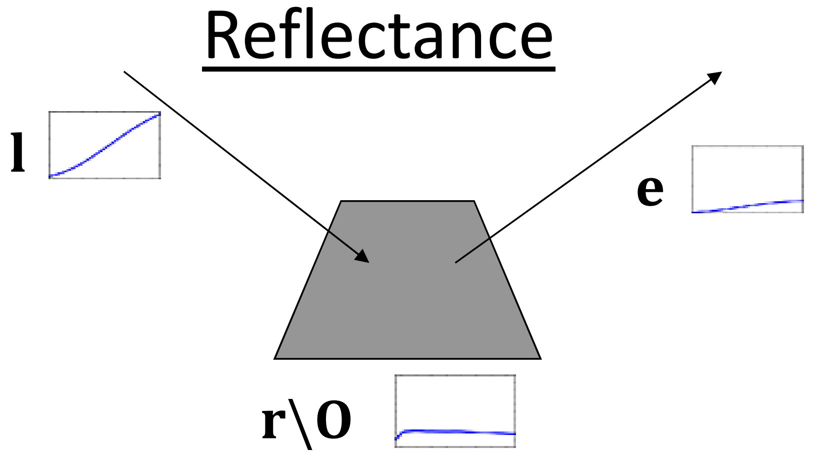


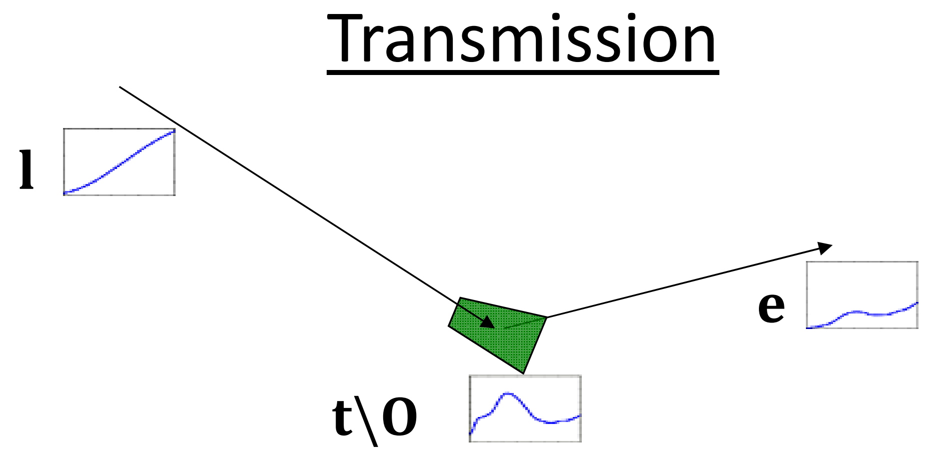
# Sensor Excitations using Linear Equations

- **M**atrix/**v**ector computation of Sensor Excitations ($\mathbf{c}$)
  - $\mathbf{c} = 683\mathbf{Cl}$
    - Intensity Radiance/Emission
  - $\mathbf{c} = k\mathbf{Cl}$
    - Relative Radiance/Emission
  - $\mathbf{c} = k\mathbf{CLr}$
    - Relative using reflectance
    - Light SPD represented as diagonal matrix $\mathbf{L}$
  - $\mathbf{c} = k\mathbf{COl}$
    - Reflectance factor represented as a diagonal matrix $\mathbf{O}$
    - Off diagonal entries in matrix $\mathbf{O}$ represent fluorescence
- *Normalization factor $k$ can be omitted if directly applied to $\mathbf{C}$ matrix*



# Observer Independent Color Descriptions




*Matrix / Vector:*

$$\mathbf{e} = \mathbf{O}\mathbf{l}$$

$$\mathbf{e} = \mathbf{O}\mathbf{l}$$

*Scalar by Wavelength:*

$$e_\lambda = r_\lambda l_\lambda$$

$$e_\lambda = t_\lambda l_\lambda$$

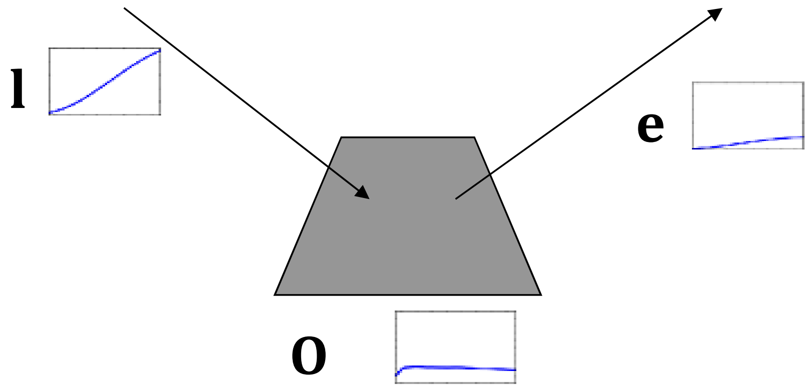
$$r_\lambda = \frac{e_\lambda}{l_\lambda}$$

$$r_\lambda \cong t_\lambda$$

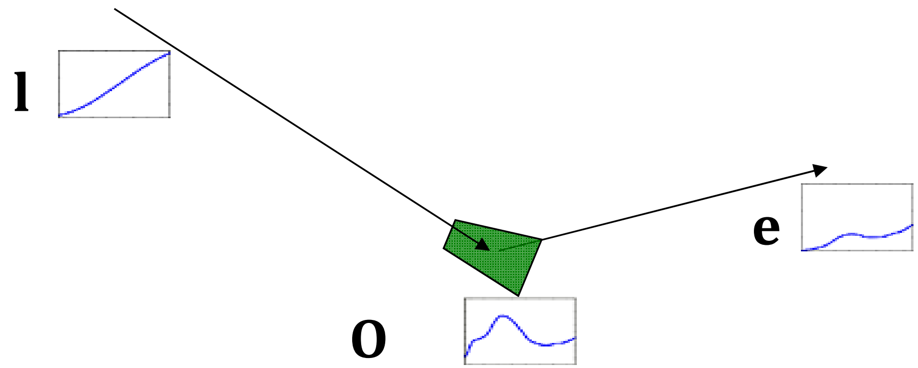
$$t_\lambda = \frac{e_\lambda}{l_\lambda}$$

# Observer Independent Color Descriptions

Reflectance+Fluorescence




Transmission+Fluorescence




*Matrix / Vector:*

$$\mathbf{e} = \mathbf{O}\mathbf{l} \qquad\qquad \mathbf{e} = \mathbf{O}\mathbf{l}$$

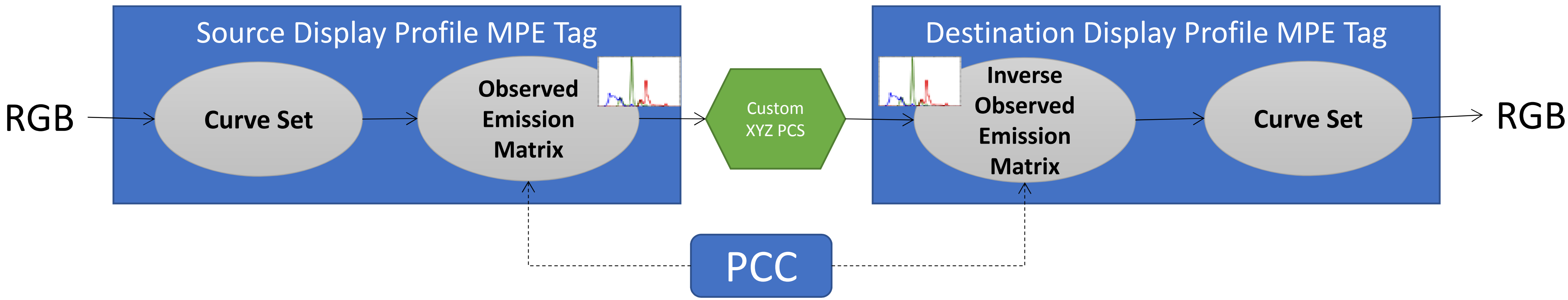
*Works for Fluorescence when* $\mathbf{O}$ *has off diagonal terms*

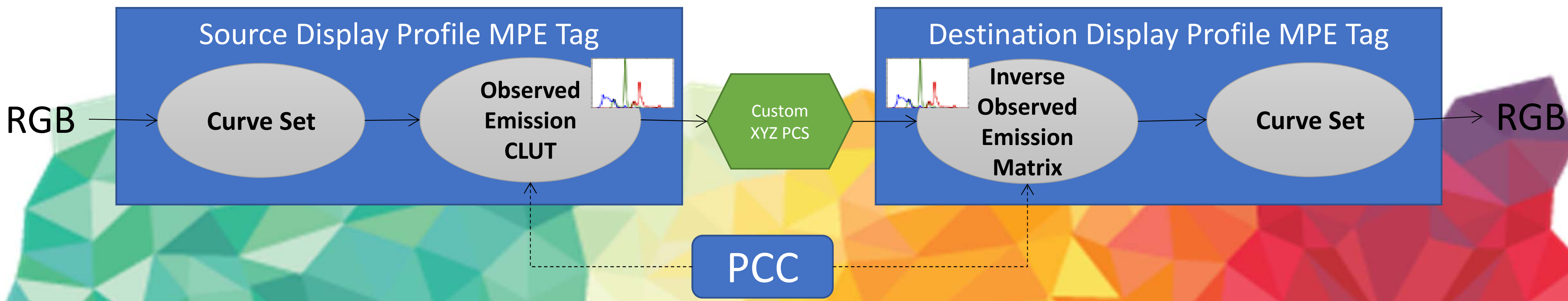
# Late-Binding Spectral to Colorimetric Processing

# Late-Binding Spectral Conversion

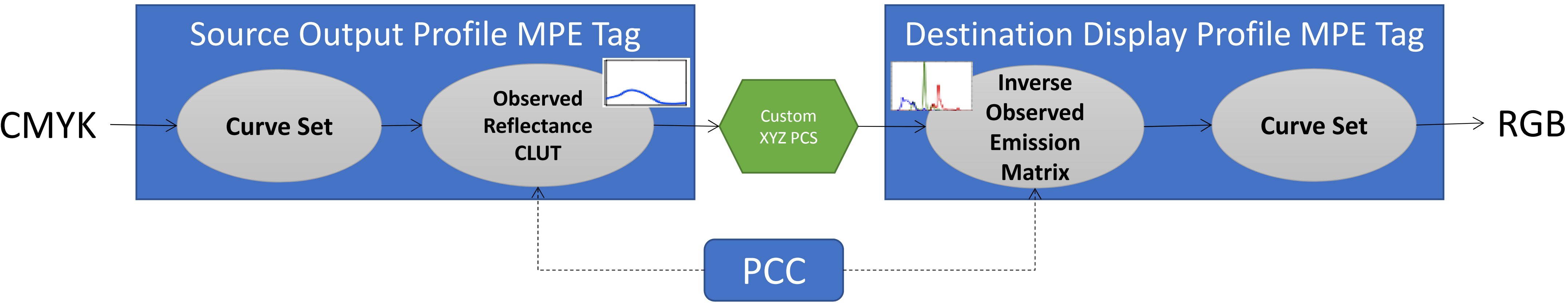
- Spectral PCS processing can have significant processing overhead
- Processing elements can be used that encode spectral information that is converted to colorimetric data for processing by the CMM at the point when profiles are linked
- Provides late-binding of observer and/or illuminant
- Provides for efficient processing of profiles since only colorimetric transforms are used
- PCC provides information for spectral to colorimetric conversions
  - Only a single PCC is used for late-binding purposes

# Custom Observer Display Matching



# Soft Proofing




This allows for both observer and illumination of printed output to vary

# Colorimetric PCC handling

- Checking for use of Late-Binding processing elements is required
  - If both profiles have use late-binding elements then the PCC selected for the first profile will be applied to both profiles.
  - If only one profile has late-binding elements then PCC will come from the profile that does NOT have the late-binding elements.
  - Otherwise, each profile will only use its embedded PCC for tag processing initialization, and standard inter-colorimetric PCS processing is performed

# Multiplex Connection Spaces

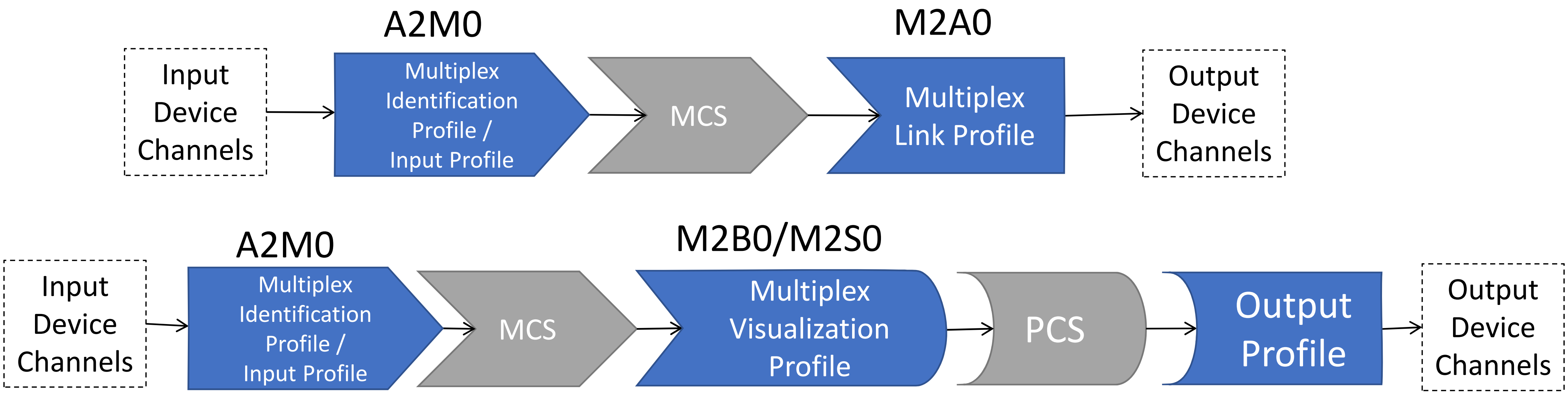
# Multiplex Connection Workflows

- Some workflows require a connection based upon a description that defines what the color channels are rather that how they look or are related to light (PCS's)
- Examples include:
  - Pigment Identification
    - Going from Multi-spectral capture to Pigment identification to Visualization of pigments
  - Medical imaging
    - Scanning to RGB + channels that provide bio-marker information to visualization of scan with bio-markers
  - Ink Visualization
    - Going from printed ink channels to visualization of different ink orders or use of spot inks
- Could be implemented as Device Link Profile – but number of channels and channel order are fixed

# Multiplex Connection Spaces

- Can conceptually be thought of as multiple “device like” channels connected with flexibile routing
- Like device channels, encoding of MCS channel data values is not explicitly defined
  - Encoding of MCS channel values allowed to be defined by domain specific use cases
  - Potentially documented via ICC registry of encodings for MCS channel names
- An MCS is completely separate from a PCS and therefore has no computational relationship to a PCS
  - Relationships are completely provided by MCS to PCS transform tags in profile based on multiProcessElementType
- Rules for connecting profiles and routing channel data are well defined to be clearly implemented by a CMM

# MCS Connection Overview




- Three new profile classes MID/MLNK/MVIS
- Input class extended to allow for A2M0 tag
- Header and Tags define MCS connection

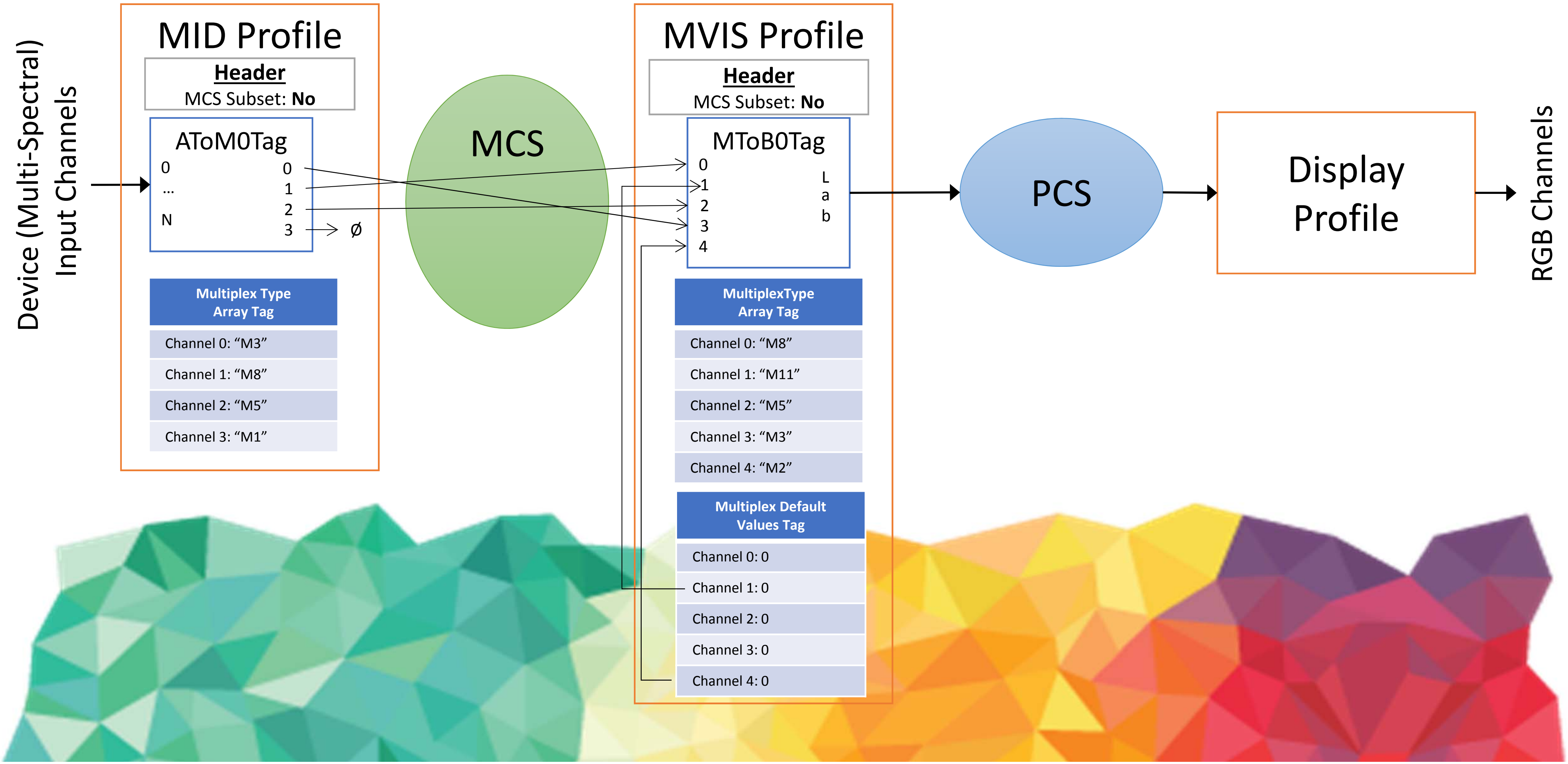
# Setting up Multiplex Connection Spaces

- MCS field in header specifies number of MCS channels
- MCS subset requirement flag in profileFlags field of profile header
  - When set the MCS channels defined by the multiplexIdentificationArrayTag must be a subset of the channels defined in the profile being connected to
  - Profile linking is prescribed to fail if MCS subset requirements are not met
- multiplexIdentificationArrayTag: signature 'mida' (6d696461h)
  - Provides means of uniquely describing each multiplex channel in MCS
  - Used for routing channel data between profiles
- Optional multiplexlDefaultValuesTag: signature ‘mdv ’ (6d647620h)
  - Provides default values for when source multiplex channel values are not available
  - A default value of zero is used if multiplexDefaultValuesTag is not defined

# Multiplex Channel Connection

- MCS connection allowed between source profiles with AToM0Tag [Input class profiles / Multiplex Identification profiles] and destination Multiplex Visualization (MVIS) or Multiplex Link (MLNK) profiles
- Apply MCS subset requirements
  - If profile has MCS subset flag set then it's MCS channels need to be a proper subset of MCS channels in the connected profile
  - This ensures interoperability where channel requirements are needed
- CMM simply passes channel data directly between source profile to destination profile for channels with same multiplex channel identifications
- Use multiplexDefaultValuesTag values as input for MVIS/MLNK MCS channels not present in source MID profile
  - This assumes independence of multiplex channels
  - Use zero if multiplexDefaultValuesTag not present
- Ignore AToM0Tag MCS channels not present in MVIS/MLNK profile

# MCS Connection Example



# In Conclusion

# Making Connections with iccMAX

- iccMAX provides various ways of communicating about color:
  - In terms of visual appearance
  - In terms of physical properties of light and objects
  - Allowing for late binding and adjustment of both observer and/or illuminant
- iccMAX separates color management process into separate stages to allow for open, cross-platform implementation
  - Device to/from color description transformations (inside profile transforms)
  - Conversion between ways of describing color (inside CMM with inter-PCS conversion)
    - This conversion is controlled via Profile Connection Conditions (PCC) either in profiles or separately to CMM
- iccMAX also offers new flexible ways of connecting device like named multiplex color channels
  - When color is described by “What is it?” rather then “What does it look like?” or “How does it interact with light?”

# Thank You!

Questions?