Multispectral requirements for whole slide imaging
Teleconference
19 December 2013 • 14:00 (UK) / 9:00 (EST)

The meeting was called to order at 9:00 am (EST) by Craig Revie, acting chair, with the following attendees:

Glenn Davis	Vantana Roche
Craig Revie	FFEI
Marc Mahy	Agfa
Aldo Badano	FDA
Masahiro Yamaguchi	Tokyo Institute of Technology
Po-Chieh Hung	Konica Minolta
Bas Hulsken	Philips Healthcare Incubator
James Vogh	X-Rite
Andy Masia	X-Rite
Max Derhak	Onyx Graphics
John Dalrymple	Independent (ex Sharp)
Wei-Chung Cheng	FDA
Hong Wei	DataColor
Louise Collins	FFEI
Robert Horn	Agfa
Takashi Matsui	Eizo
David Clunie	DICOM
Tom Lianza	X-Rite
Michael Flynn	Henry Ford Health System
Masahiro Nishibori	International University of Health and Welfare
Phil Green	Gjøvik University College

Those present introduced themselves and identified their area of interest.

Mr. Revie reviewed the agenda for the meeting as follows:

1. Background and Introduction (Craig Revie)
2. Requirements from DICOM WG26 (Masahiro Yamaguchi)
3. Review of functionality in ICC Labs (Max Derhak)
4. Discussion Requirements
5. Next steps
   a. Identification of editor for document describing use cases
6. Next meetings

One goal of the meeting was to identify someone to act as a focal point to collect uses cases for this project.

1. Introduction

Mr Revie gave a brief background to the work ICC has been doing to support multispectral imaging [see attached]. He stated that the forthcoming ICC v5 would help address multispectral requirements, and that v5 was scheduled to be published by the end of 2014.

2. Requirements from DICOM WG26

Yamaguchi-san presented a proposal on the multispectral presentation state for Digital Pathology [see attached]. His idea was to use ICC v4 Device Link class profiles in conjunction with a virtual input device to apply spectral unmixing. The link profile would allow conversion from raw sensor responses to the ideal virtual device and from there to visualization and output.

Mr Hulsken referred to a previously circulated proposal for a multispectral presentation state for Digital Pathology [see attached] which it was agreed appeared to be consistent with the workflow shown in Figure 1 of Yamaguchi-san's presentation. However, the latter required ICC v5 to implement the spectral unmixing, while Mr Hulsken's proposal assumed v4.

It was clarified that in Mr Hulsken's presentation the grayscale images shown could be spectral channels, colour channels or other types of image generated by an input device. They were commonly used to represent biomarkers. It was agreed that metadata was needed to distinguish which they were, and whether raw sensor data or transformed, and it was stated that there was a framework for this in DICOM. There was no spatial or frequency component in such images.

3. Review of IccLabs functionality

Mr Derhak discussed how ICC v5 could support multispectral imaging. He began by showing slides from his presentation at the Vancouver meeting [see attached]. The limitation of v4 was a fixed PCS and the lack of support for spectral data and connections. The v5 specification included PCS extensions and more complex transforms through MPE, which would for example allow spectral unmixing in an ICC profile by encoding the appropriate algorithm as a Calc element. He showed an example Calc element workflow.

He then went on to present some new ideas on BioMarker Profiles [see attached]. In this he summarised the problem statements and proposed a Biomarker Connection Space (BCS) within the proposed v5 specification. Two new profile classes would be associated with this: ID class to convert from input to BCS, and Visualization class to convert from BCS to PCS or output device. The CMM is responsible for connecting channels.

He emphasized that it was the framework rather than the actual biomarker names or definitions that were being standardized in this proposal.

Mr Horn suggested there was a parallel with remote sensing where by convention a name maps to a given spectral sensitivity. Mr Hulsken stated that spectral characteristics could vary across different vendors, and so the idea would need to have extensibility and customizable visualization.

Mr Derhak agreed it would make sense to make the concept more generalized. New functionality would need to be added to the current IccLabs document, which would be useful.

Mr Revie concluded the meeting, asking Mr Derhak to modify his proposal specifically to incorporate the needs of the remote sensing / satellite imaging community, and Mr Hulsken and Yamaguchi-san to refine the use case diagram based on the input from the meeting to give a clear view of the requirements.

Next meetings
Mr Revie thanked those attending and noted that the next meeting will be scheduled in the New Year. A Doodle poll will be circulated to determine the best date.

In addition the following is the schedule for subsequent meetings:

16 Jan:	Displays (Mike Flynn)
20 Feb:	Whole Slide Imaging / Digital Microscopy (Craig Revie)
20 Mar:	Medical Photography (was Dental) (John Penczek)
17 Apr:	Mobile (Andy Masia)

Actions:

1. Collect information for a web page on the ICC site on spectral imaging for the medical imaging community – Mr Revie
2. Modify the biomarker profile proposal to make more general and address remote sensing requirements – Mr Derhak
3. Refine use case workflow and diagram to clarify requirements, based on input from the meeting – Mr Hulsken and Yamaguchi-san

Colour in medical imaging task force

Multispectral requirements for whole slide imaging

Teleconference

19th December 2013

Teleconference on Medical Photography has been postponed until 20th March 2014

Agenda

- **Background and introduction (Craig Revie)**
- **Requirements from DICOM WG26 (Masahiro Yamaguchi)**
- **Review of functionality in ICC Labs (Max Derhak)**
- **Discussion of requirements**
- **Next steps**
  - identification of editor for document describing use cases
- **Next meetings / teleconference**
  - 16 Jan: Displays (Mike Flynn)
  - 20 Feb: Whole Slide Imaging / Digital Microscopy (Craig Revie)
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  - 17 Apr: Mobile (Andy Masia)

Background

- **ICC Architecture Working Group has been working on next-generation ICC Specification (currently part of ICC Labs)**
  - —http://www.color.org/icclabs.xalter
- Extract from minutes of December's teleconference of the Calibration Slide for Histopathology task force

  "For spectral data, it was noted that the current ICC profile format allows both colorimetric and spectral data to be included in the profile as metadata, and that the v5 format (likely to be published by the end of 2014) would allow a spectral PCS and spectral processing, as discussed at the Vancouver meeting. Those with an interest in this topic were invited to discuss with Max Derhak. [Max.Derhak@onyxgfx.com]"

- The aim of this meeting is to start to define use cases for multispectral imaging for digital microscopy and to confirm that the ICC developments will be able to address these use cases in the first release

On the multispectral presentation state for Digital Pathology

Dec. 16, 2013 Masahiro Yamaguchi

Requirements from DICOM WG26

1. Ability to define how to display multi-spectral images as true color visible light images.

2. Ability to define how to un-mix multispectral input channels for the purpose of deriving quantitative representations of individual biomarker intensities.

3. Ability to define how to display (un-mixed) multi-spectral images as pseudo color images.

On the multispectral presentation state for Digital Pathology

Dec. 15, 2013 Masahiro Yamaguchi

Requirements from DICOM WG26

1. Ability to define how to display multi-spectral images as true color visible light images.

   Color reproduction: ICC framework can make it!

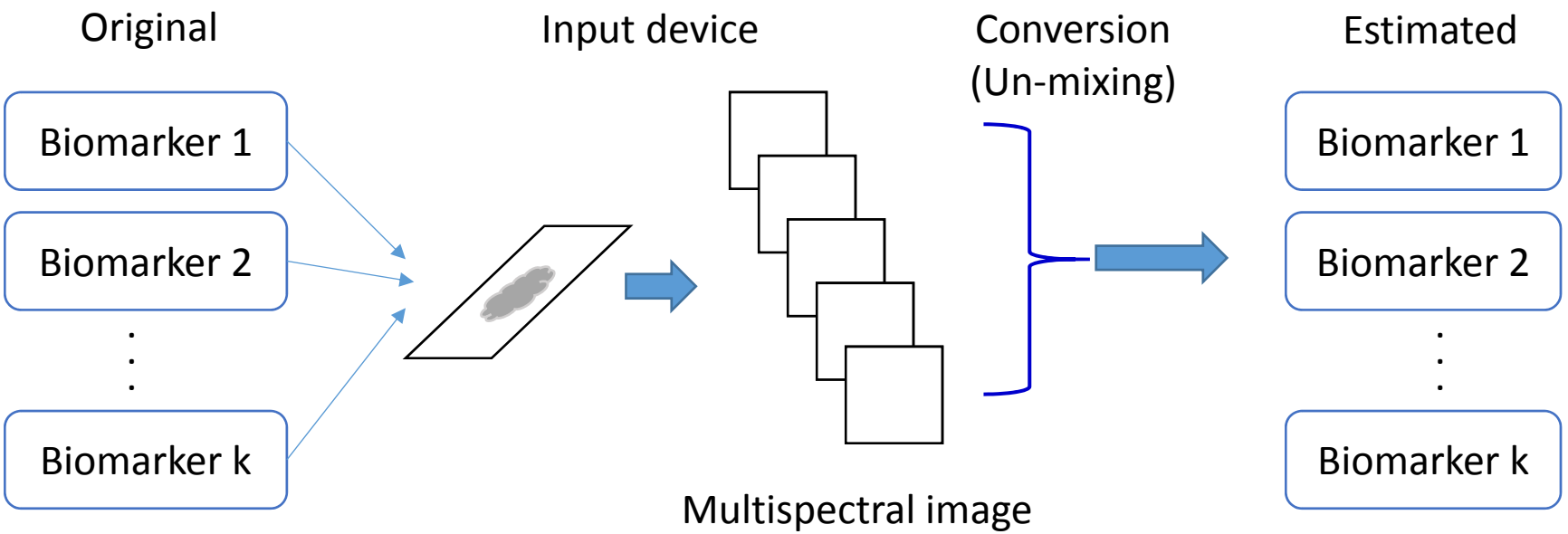
2. Ability to define how to un-mix multispectral input channels for the purpose of deriving quantitative representations of individual biomarker intensities.

   Not the issue of color: PCS is useless…
   Why ICC framework?

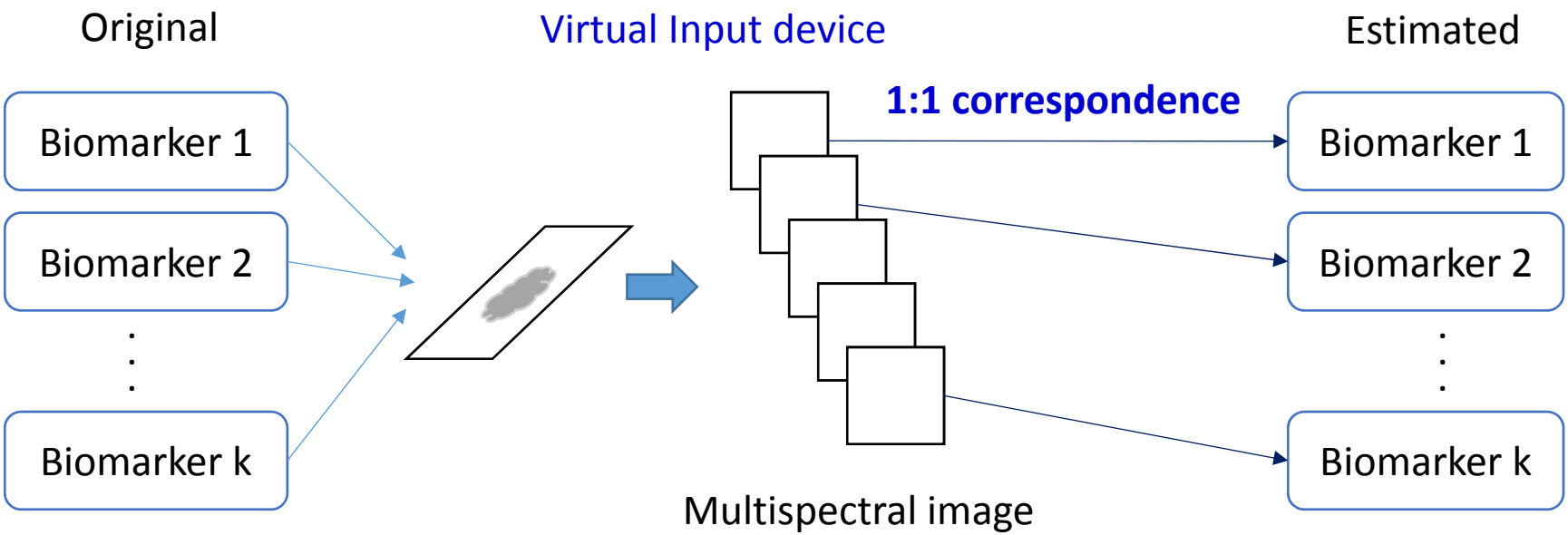
3. Ability to define how to display (un-mixed) multi-spectral images as pseudo color images.

   Color reproduction: ICC framework can make it!

General model for the multispectral un-mixing



Proposal:
Define a virtual input device
that can directly capture un-mixed biomarker images



Virtual input device
that can directly capture un-mixed biomarker images:
Fluorescent case

Sample characteristics

Excitation-emission matrix of k-th dye: $a_k(\lambda_i; \lambda_o)$

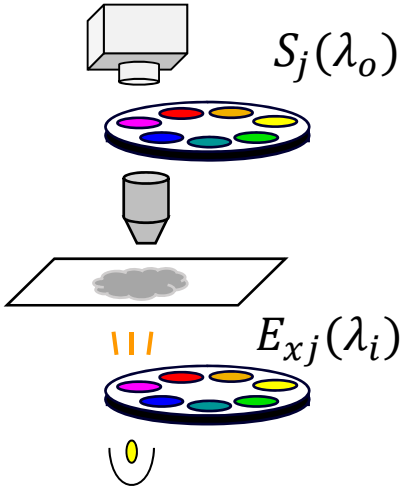
$k = 1 \ \ldots K$, where K is the number of fluorescent dyes.

λ_i and λ_o : Wavelengths of the excitation and emission lights

k-th dye amount image (a single pixel): f_k

Excitation-emission matrix of a sample:

$$f(\lambda_i; \lambda_o) = \sum_{k=1}^{K} f_k \, a_k(\lambda_i; \lambda_o) \qquad (1)$$



Generic input device

j-th set of Excitation light spectrum: $E_{xj}(\lambda_i)$ and spectral sensitivity $S_j(\lambda_o)$,

where $j = 1 \ \ldots N$, N is the number of bands.

j-th band image: $g_j = T\{\int \int f(\lambda_i; \lambda_o) \, E_{xj}(\lambda_i) \, S_j(\lambda_o) \, d\lambda_i d\lambda_o\}$ (2)

$T\{\}$: Tone curve of the input device

$T\{\}$ is linear

Ideal input device

j-th band image: g_j^{ideal}

Design $E_{xj}(\lambda_i) \, S_j(\lambda_o)$ such that $g_j^{ideal} = f_k \, \delta_{kj}$ (3)

Virtual input device
that can directly capture un-mixed biomarker images:
Fluorescent case

Relationship between $\mathbf{g}$ and $\mathbf{g}^{ideal}$

Column vectors $\mathbf{g} = (g_j)$, $\mathbf{f} = (f_k)$

$$\mathbf{g} = T\{\, \mathbf{H}\, \mathbf{f} \,\} \tag{4}$$

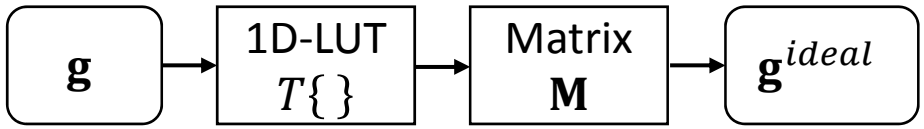
where $(\mathbf{H})_{jk} = \int\int a_k(\lambda_i; \lambda_o)\, E_{xj}(\lambda_i)\, S_j(\lambda_o)\, d\lambda_o d\lambda_o$

$$\mathbf{g}^{ideal} = \left(g_j^{ideal}\right) = \mathbf{f}$$

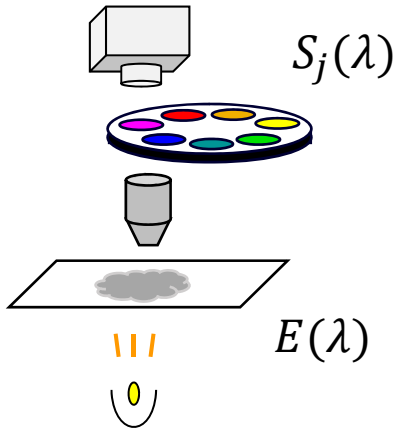
Un-mixing: $\mathbf{g} \rightarrow \mathbf{f} = \mathbf{g}^{ideal}$

$$\hat{\mathbf{f}} = \hat{\mathbf{g}}^{ideal} = \mathbf{M}\, T^{-1}\{\, \mathbf{g} \,\} \tag{5}$$

$\mathbf{M} = \boldsymbol{H}^{+}$ or a matrix designed to estimate f from g.



Virtual input device
that can directly capture un-mixed biomarker images:
Bright field case



Sample characteristics

Spectral absorption coefficient of k-th dye: $a_k(\lambda)$

$k = 1 \ \ldots K$, where K is the number of dyes.

k-th dye amount image (a single pixel): f_k

Spectral absorbance of a sample: $a(\lambda) = \sum_{k=1}^{K} f_k \, a_k(\lambda)$

Spectral transmittance: $t(\lambda)$

$$t(\lambda) = C \exp\{-a(\lambda)\} = C \exp\left\{-\sum_{k=1}^{K} f_k \, a_k(\lambda)\right\} \qquad (6)$$

C : Constant

Generic input device

Illuminant spectrum: $E(\lambda)$, Spectral sensitivity of j-th band: $S_j(\lambda)$

where $j = 1 \ \ldots N$, N is the number of bands.

j-th band image: $g_j = T\left\{\int t(\lambda) \, E(\lambda) \, S_j(\lambda) \, d\lambda\right\}$ (7)

$T\{\}$ is linear

Ideal input device

j-th band image: g_j^{ideal}

Design $S_j(\lambda)$ such that $g_j^{ideal} = f_k \, \delta_{kj}$ (8)

Virtual input device
that can directly capture un-mixed biomarker images:
Bright field case

Relationship between $\mathbf{g}$ and $\mathbf{g}^{ideal}$

$(\mathbf{g})_j = g_j = \int C\, E(\lambda) \exp\{-a(\lambda)\}\, S_j(\lambda)\, d\lambda$, and let

$(\mathbf{t})_l = t_l = C \exp\{-a(\lambda_l)\}$, then

$$\mathbf{g} = T\{\, \mathbf{S}\, \mathbf{E}\, \mathbf{t}\,\} \qquad (9)$$

$-\log(\mathbf{t}) = \mathbf{A}\, \mathbf{f}$, where $(\mathbf{A})_{lk} = a_k(\lambda_l)$

$\mathbf{g}^{ideal} = \mathbf{f}$

Un-mixing: $\mathbf{g} \rightarrow \mathbf{f} = \mathbf{g}^{ideal}$

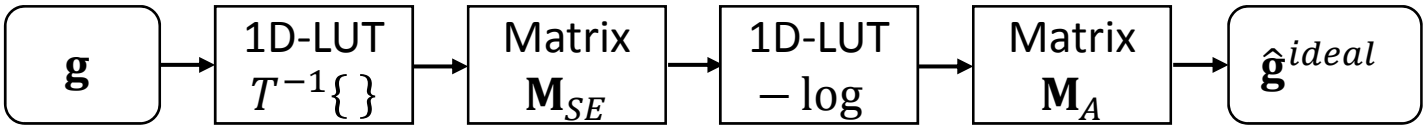
$\hat{\mathbf{f}} = \hat{\mathbf{g}}^{ideal} = \mathbf{M}_A\{-\log(\hat{\mathbf{t}})\}$

$\hat{\mathbf{t}} = \mathbf{M}_{SE} T^{-1}\{\, \mathbf{g}\,\}$

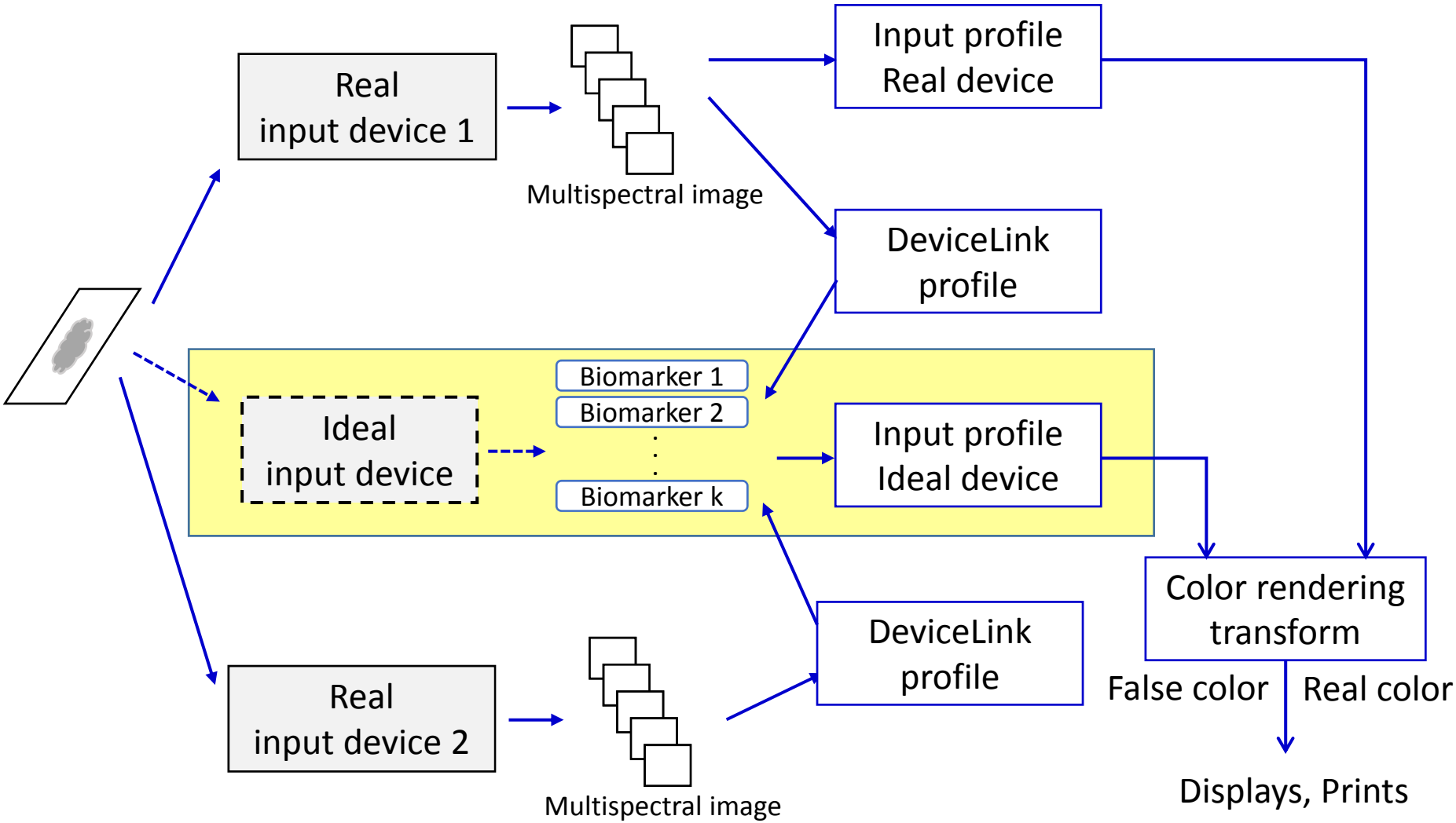
$\mathbf{M}_{SE} = (\mathbf{S}\, \mathbf{E})^{+}$ or a matrix designed to estimate *t* from *g*.

$\mathbf{M}_A = \mathbf{A}^{+}$ or a matrix designed to estimate *f* from *a*.

$$\hat{\mathbf{f}} = \hat{\mathbf{g}}^{ideal} = \mathbf{M}_A[-\log\{\, \mathbf{M}_{SE} T^{-1}\{\, \mathbf{g}\,\}\,\}] \qquad (10)$$



By defining virtual input device,
the color transformation would be more simple and clear.



Notes:

- What are needed in the specification of ideal input device?
  - Names of biomarkers?
  - Spectral characteristics of dyes for input profile.
  - Illuminant spectrum is not important.
  - Excitation-emission matrix is not needed.

- The specification of ideal input device should be provided to the destination system.

- The input profile for the ideal input device determines the relation $\mathbf{g}^{ideal} \rightarrow$ PCS .
  The false-color assignment is included in this profile.

- Spectrum-based color conversion is not mandatory in the case of requirements presented here.
  Spectral reconstruction will be needed for the applications of spectral image analysis, which is not included in this discussion.

Proposal for a multispectral presentation state for Digital Pathology

Use case

For DICOM images containing multi spectral image data, there is a need for specifying how to display the image data (either as a multi-spectral true color image, or as a pseudo color image) in a consistent and device independent manner. Additionally, for the application of molecular pathology, there is a need for describing such a transformation taking into account potential cross-talk between the multispectral channels, in order to arrive at the individual marker intensities (fluorescent or chromogenic).

To provide such functionality, a new multispectral presentation state has to be defined, with the following requirements:

- **1:** Ability to define how to display multi-spectral images as true color visible light images.
- **2:** Ability to define how to un-mix multispectral input channels for the purpose of deriving quantitative representations of individual biomarker intensities, said markers can be fluorescent or chromogenic.
- **3:** Ability to define how to display (un-mixed) multi-spectral images (fluorescent, chromogenic) as pseudo color images. It should be possible to use the un-mixed output from **2)** as input for this mode.

Current limitations in DICOM

Currently DICOM only allows for a limited use of ICC[i] profiles for defining color transformations:

- The ICC implementation in DICOM is limited to specifying an ICC input profile. Other profile types are not supported.
- The ICC implementation in DICOM can only work on composite input images in the RGB color space. *i.e.* ICC input profiles can only be applied to composite 3 channel RGB images.

Implementation proposal

To provide the desired functionality one or multiple multi-spectral presentation states can be associated with each DICOM image. A flexible and straightforward way to specify the required multi-spectral transformations in the presentation state would be to make use of existing ICC functionality. The current ICC functionality provided in DICOM however is too limited to achieve this end. The ICC support has to be extended on two fronts:

1) Allow the use of ICC DeviceLink profiles. The advantage of using DeviceLink profiles, is that they can specify transformations from either *n* to *n* channels, or from *n* to 3 channels, and are not color space specific (see Figure 2). This allows the chaining of multiple transformations in a transformation pipeline, simply by chaining ICC DeviceLink profiles.
2) Extend the ICC Input profile support already present in DICOM. The current limitations (the profile can only be applied to RGB color space composite images) have to be removed, to allow for multiple input channels in an arbitrary color space. The ICC Input profile would always be the last (or only) component in the pipeline, since it transforms to Profile Connection Space (PCS), which can subsequently be transformed by the image consumer (viewing station, printer) to be displayed.

With the above extensions of the ICC support in DICOM, the multi-spectral presentation state can consist simply of a set of ICC profiles: zero or more DeviceLink profiles, and one Input profile. Additionally the connections in the pipeline have to be specified. Each input channel of the set of ICC profiles in the presentation state has to be connected to either a monochrome input channel from the image, an individual channel of a composite image, or an output of another ICC profile in the set of ICC profiles in the presentation state. This is illustrated in Figure 1. The sequence of the chaining, and the connection of the inputs and outputs of the individual blocks in the pipeline cannot be defined within ICC. A simple set of tables to enumerate the ICC profiles, the input images and the connections start and endpoints will have to be added in DICOM to the presentation state object. Such a simple set of tables will be sufficient to describe such a transformation pipeline.

This proposal allows (but does not require) the use of (chained) Devicelink Profiles. In principle the same visual result can be obtained using a single ICC Input Profile (with *n* channel input). *i.e.*, the entire chain of Devicelink Profiles coupled to an Input Profile can be replaced with a single (more complex) Input Profile, which gives exactly the same 3 channel output in PCS. However, the use of (chained) Devicelink Profiles has several advantages:

1. Transformation operations can be broken down into separate transformations, e.g., a first device specific transformation for compensating for detector non-linearities, a subsequent sample specific transformation for linear-unmixing to reduce the cross-talk between the separate fluorescent channels, followed by a final device and sample independent transformation to a pseudo-color image in the Input Profile. Such a break down allows for easier

understanding, and for the recycling of transformations over different applications, samples and/or devices.

2. By isolating the transformation to a pseudo-color image from the device and sample specific transformations (in the Input Profile), it is easy to change the pseudo-color rendering (which colors the individual fluorophores get) in the viewer without taking into account / affecting device specific properties of the image. Functionality that can be achieved this way would be isolating individual fluorophores, or giving specific fluorophores a new color or intensity.
3. By separately specifying device and sample specific transformations (detector non-linearity, linear unmixing), these transformations are also accessible to image analysis algorithms, which can then operate on the multi channel data set while applying device or sample specific correction terms.

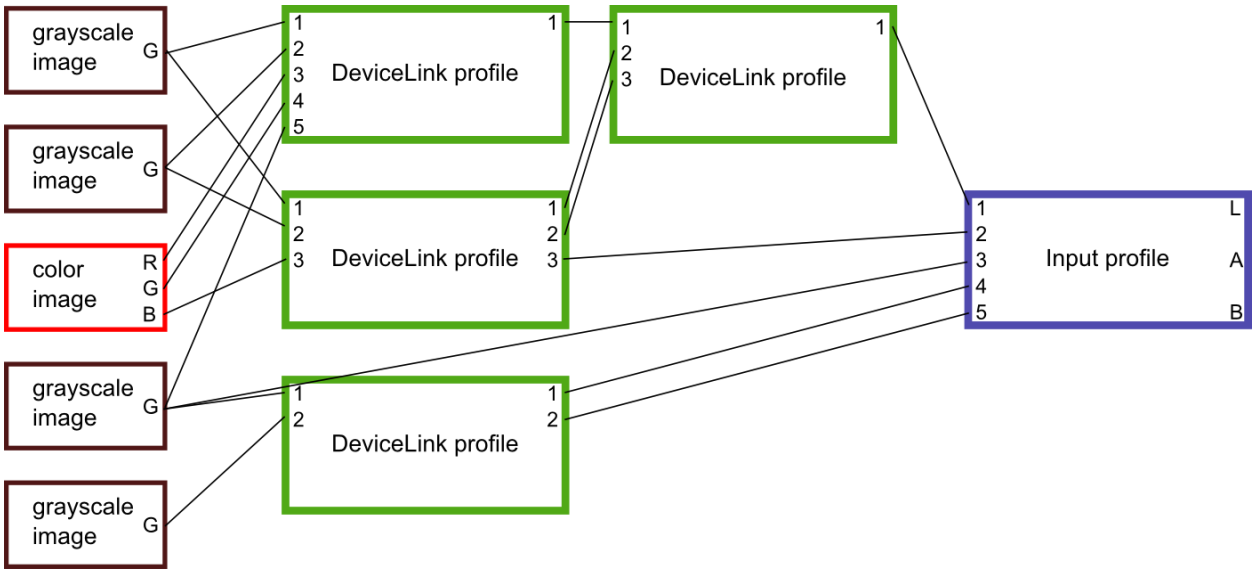


Figure 1: transformation pipeline. Components in the pipeline can be a grayscale or a component image, zero or more DeviceLink profiles, and one Input profile. Connections are drawn by black lines. Each connections start and endpoint would have to be specified in the multi-spectral presentation state.

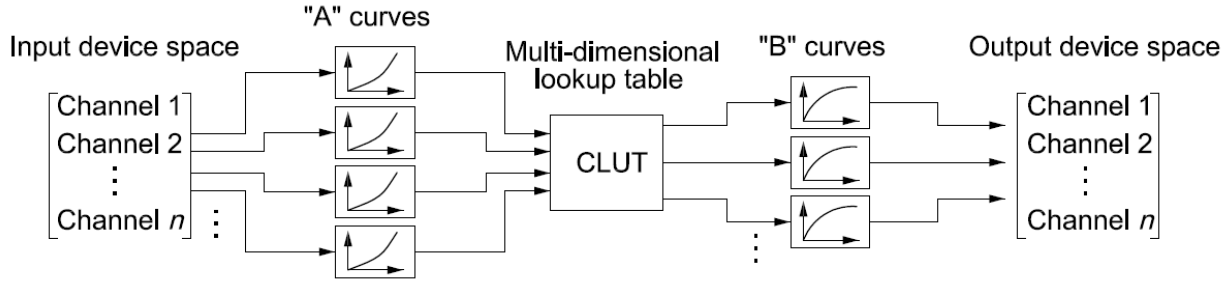


Figure 2: DeviceLink ICC profile, one of the possible transformation models.

Benefits of the multi-spectral presentation state proposal

1. **Enhanced representation of true color images.** This proposal lifts the 3 channel RGB limitation from DICOM, it will be possible to store images in a much wider color gamut, e.g. Images with 4 or more spectral channels. The gamut mapping is performed in an external ICC Output Profile, which is supplied by the display device manufacturer, and if this display device supports wide gamut display (some modern displays go up to 130% of the NTSC gamut), then the image will be displayed in a much wider gamut than currently possible. An additional advantage is that all channels of multi spectral true color images can be stored as they were captured, instead of conversion to 3 channel RGB, which allows for better performance and/or additional functionality of image analysis algorithms. The reverse transformation from RGB back into the original channels is by definition incomplete if there were more than 3 input channels.
2. **Full raw data access for image analysis algorithms.** Algorithms can now have access to all the raw channels of the multi spectral data set, and also have access to the transformation operations on that data as defined in the Devicelink Profiles. Such transformations could be scanner specific operations such as linear unmixing (which is essentially a linear transformation that minimizes cross-talk in fluorescent images), or corrections for detector non-linearity.
3. **Define multiple views of multi-spectral image data, with multiple presentation states.** Different 'views' on the same image, e.g., multiple different pseudo-color representations, or single-spectrum views can be defined by associating multiple presentation states with the multi-spectral DICOM image.
4. **Allows traceable calibration of fluorescent imaging modalities.** The calibration procedure for a fluorescent scanner based on this proposal, would comprise the following steps. A fluorescent reference target will have to be created, with known concentrations of fluorophores. Such a reference target could e.g., contain dilution ranges for the set of fluorophores supported by the scanner. Cross-talk and non-linearities in the scanner could then be corrected for in the Devicelink Profiles, in such a way that the output channels of the last Devicelink Profiles in the chain would be a quantitative and linear representation of the fluorophore concentrations. The final Input Profile, would then contain no scanner or sample specific transformations, and describe a scanner and sample independent way to render fluorophore concentrations as a pseudo-color image.

Restrictions of the multi-spectral presentation state proposal

1. **Restrictions inherent to the ICC Devicelink Profile.** There are two restrictions that apply to Devicelink Profiles:
    a. Devicelink profiles are always coupled to a specific device, since they describe a transformation from one non-standard colorspace to another.
    b. It is not allowed to embed Devicelink Profiles in documents (pdf) or images (tiff, ...).

   The first of these limitations is not a big problem for the current proposal, as the Devicelink Profiles are introduced as a mechanism to allow for advanced color transformations on the

output channels of an imaging device before applying the Input Profile. These transformations are device specific already. I'm uncertain whether the second of these limitations is a problem, there are no technical limitations preventing the embedding of Devicelink Profiles in DICOM, and some software actually does embed Devicelink Profiles (e.g., link-o-later).

2. **Implementation effort of ICC Devicelink Profile support.** Since Devicelink Profiles are intended for direct mapping between devices, it is possible, or even likely that general availability of software implementations is low. This would require implementation work by the vendors. The advantage over using something other than ICC is of course that at least the standard is well defined. Opensource implementations supporting Devicelink profiles are available (Argyll, cctiff, Little CMS).
3. **The final output is in the LAB color space, which has inherent limitations.** The intent is to render a reproducible LAB image at the end of the pipeline, which is ensured by the requirement of having an ICC input profile at the end of the pipeline as shown in Figure 1. This is a practical requirement, since the scanner manufacturer and display manufacturer are generally not the same party, and making Devicelink Profiles to match each of the available scanners to each of the available displays is not feasible, although indeed of higher quality than using an ICC input/output profile combination. It should be noted though that for other purposes than displaying the image (*e.g.,* image analysis algorithms) the direct uncompromised output from the Devicelink profiles can be used.
4. **There is no ICC standard for fluorescent light sources.** There are no standards defined for fluorescent light sources as is the case for visible light sources (D50, D65). This is to a certain extent a limitation when using ICC profiles for displaying true color visible light fluorescent images. However the correction from the input to D50 which is the reference white of the Profile Connection Space (PCS) can be performed by either the Devicelink Profiles or the Input Profile. Therefore it is not necessary to include a spectrum of the fluorescent excitation light source to arrive at a standard color reproduction of visible light fluorescent images. For pseudo color representation of fluorescent images, the problem is not really present, as the reference white has no meaning there.

Impact of ICC v5 on this proposal

The restrictions given above are all consequences of limitations in the ICC version 4 specification. A new ICC specification (version 5) is being worked on, which will address these limitations[ii]. The most important extension of ICC v5 for this proposal is the move to a new Profile Connection Space (PCS) which will allow spectral communication of color information, and will no longer be restricted to a 3 channel D50 color space.

The use of ICC Devicelink profiles in this proposal is an ad-hoc solution to overcome ICC version 4 limitations to the PCS, while still using a well defined standard for communicating multi-spectral information. The ICC v5 specification will take away this limitation, and with that, also the need to use

Devicelink profiles in this proposal. With ICC v5 the Devicelink Profiles can be substituted by one, or a chain of multiple, ICC v5 Input Profiles.

To facilitate an easy transition once ICC v5 is available, it is suggested to include the above considerations in the multi-spectral extension, and to allow the chain of Devicelink profiles in Figure 1, to consist also of a chain of Input Profiles. This will then make the proposal future proof for ICC v5, and only require an update regarding the supported ICC version.

[i] http://www.color.org/specification/ICC1v43_2010-12.pdf

[ii] http://www.color.org/icclabs.xalter

BioMarker Profiles

Problem Statements

- Provide ability to define how to un-mix multispectral input channels for the purpose of deriving quantitative representations of individual biomarker intensities
- Provide means of visualizing these quantitative representations

Concept Proposal – Biomarker Connection Space Profiles

- Add new “Biomarker” Connection Space (BCS)
  - Designated using extended color space signature “bmXXXX”
  - Additional new bioMarkerIdTag [signature 'bmid' (626d6964h)] that provides means of uniquely describing each biomarker channel

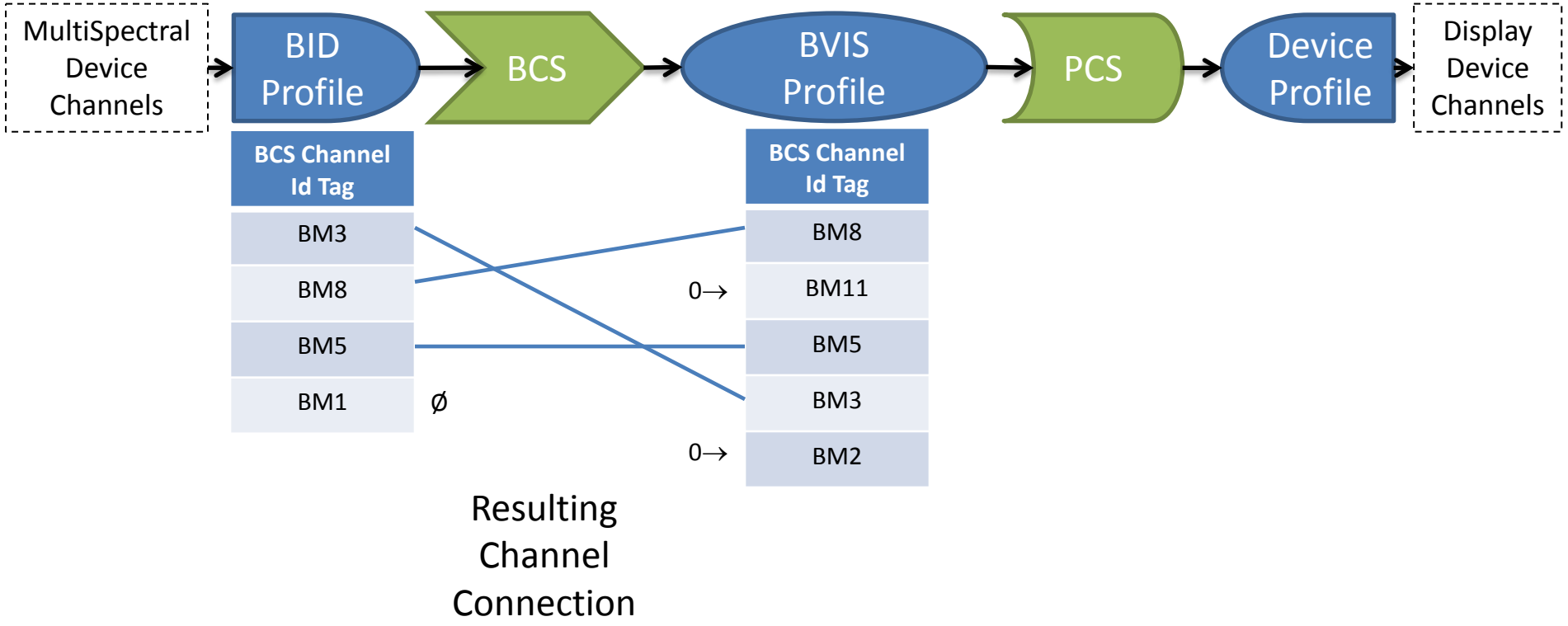
- Create 2 new profile classes that are essentially the same as device link profiles except that they provide transform to/from Biomarker Connection Space
  - Biomarker Identification Class: signature 'bid ' (62696420h)
    - Device to Biomarker Connection Space
  - Biomarker Visualization Class: signature 'bvis' (62766973h)
    - Biomarker Connection Space to PCS/Device

- Define rules for connecting profiles that use Biomarker Connection Space

Biomarker Channel Connection

- BCS connection allowed between source Biomarker Identification (BID) and destination Biomarker Visualization (BVIS) profiles
- Connect channels with same biomarker identification
- Assume zero values (probability) for BVIS BCS channels not present in BID profile
  - This assumes orthogonality of biomarker channels
- *Should BID BCS channels be proper subset of BVIS BCS channels?*
  - *If not then ignore BID BCS channels not present in BVIS profile*

BCS Connection Example



International Color Consortium®

Medical Imaging WG

Nov 18, 2013 · Vancouver, BC · Canada

Multispectral Imaging and IccLabs

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Agenda

- Introduction to Multi-Spectral Imaging
- Color Management and some of its Challenges
  - Aspects of Color Science
- Introduction to ICCLabs
  - Touching upon some technical details
- A color managed spectral workflow example
- Conclusion
  - Discussion about benefits and considerations

Multi-spectral Images

- A multi-spectral image is a collection of several monochrome images of the same scene, each of them taken with a different sensor and/or using a different light source.
- Each image is referred to as a *band*.

Uses of Multi-Spectral Images

- An accurate representation of human visual appearance of elements in the scene can be determined
  - *What does it look like when …?*
- Material characteristics of elements in the scene are often determined
  - *How do the materials interact with light?*
  - *What are they or what is the probability that they are …?*
- Traditionally, color management generally considers the first two questions
- For some medical imaging applications the last question is often the most important

ICC Color Management

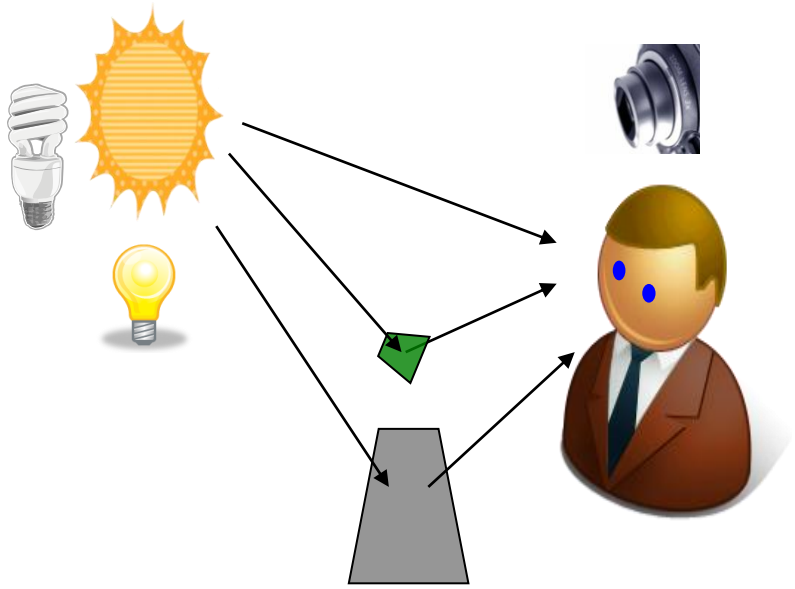
- The purpose of the ICC is to promote the use and adoption of open, vendor-neutral, cross-platform color management systems

- With “Color Management” being defined as the “**communication of** the associated **data** required for unambiguous interpretation of color content data, **and application of** color data **conversions**, as required, **to produce** the **intended reproductions**”

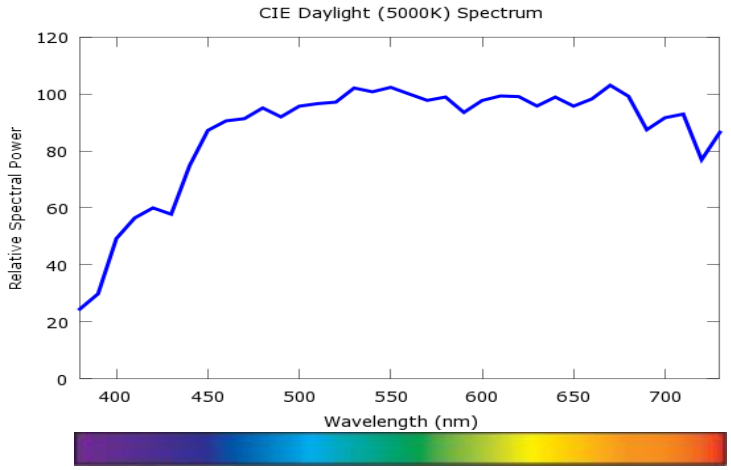
- Its about “communicating color”

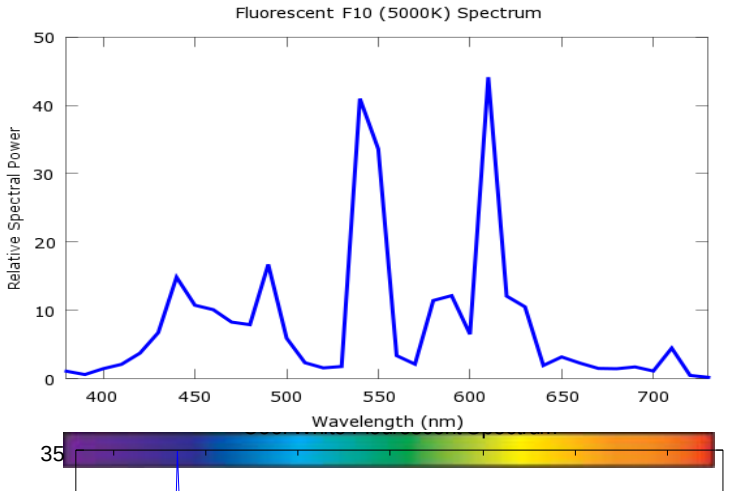
Challenges for Color Management

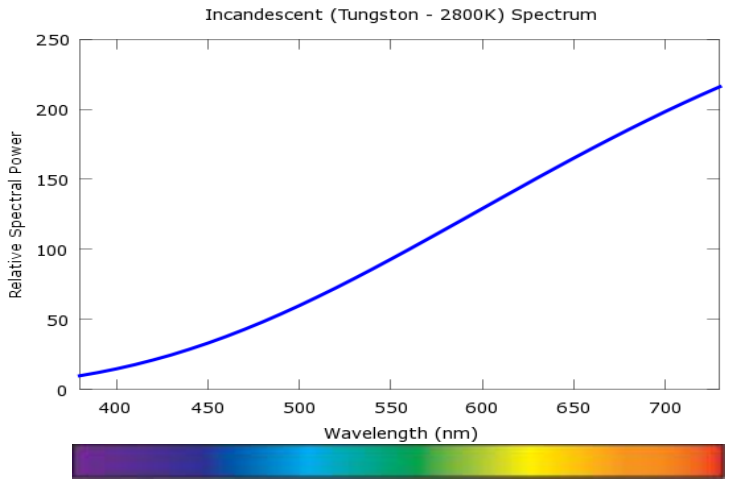
- Different Light Sources
- Characteristics of Surfaces
- Variations in Observer
- Modeling Everything
- Variations in Reproduction Intent

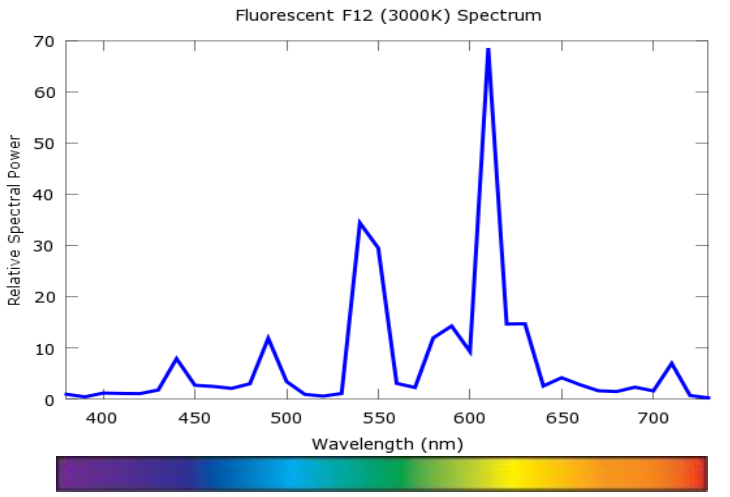


Differences in Light Sources

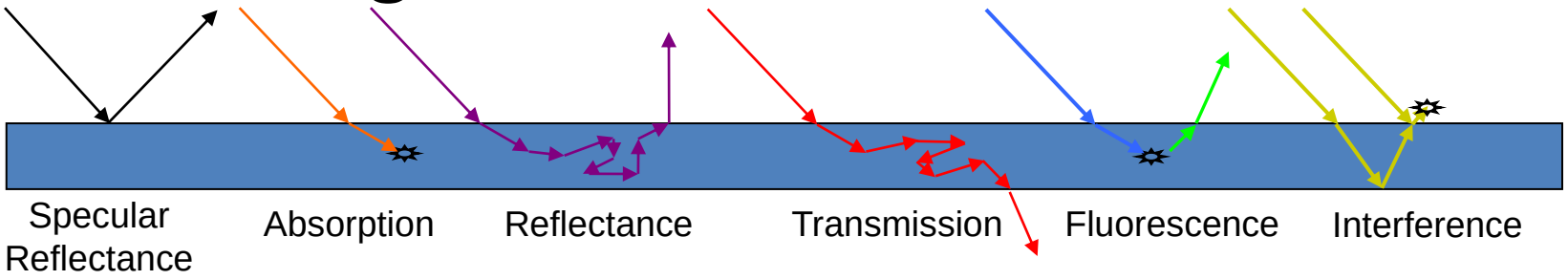








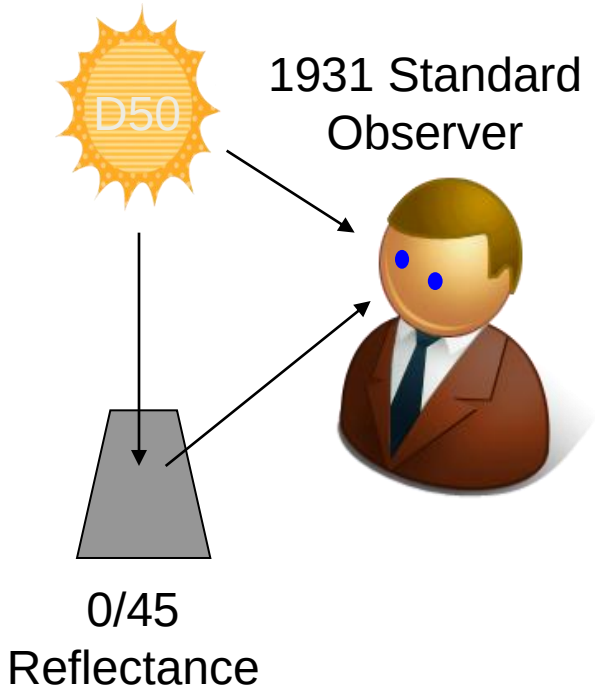
Light-Surface Interactions



- **Specular Reflectance -** light bounces off surface at the opposite angle unchanged (gloss)
- **Absorption** – light enters surface, bounces around and is absorbed – thus raising the energy level of the surface (e.g. thermal heat)
- **Reflectance/Transmission** – light enters surface, bounces around, and eventually leaves surface unchanged at possibly an arbitrary angle
- **Fluorescence** – light enters surface, bounces around, is absorbed and then re-emitted with a longer wavelength (at a lower energy level), bounces around, and eventually leaves (either) surface.
- **Interference** – light enters surface bounces from opposite service where it interferes (constructively or destructively) with light just hitting surface (exhibiting angular dependency)

- **Note***: How a photon interacts with a surface is wavelength dependent*

ICC.1 Color Management Simplifications



- ICC.1 color management simplifications:
  - Fixed Profile Connection Space (PCS) Viewing Conditions
    - D50 Illuminant
    - 500 lx
  - Simple Reflectance Model
    - Flat surface
    - 0/45 geometry
    - No gloss
    - No Fluorescence
  - Standard 1931 Observer
  - Explicit Transforms…

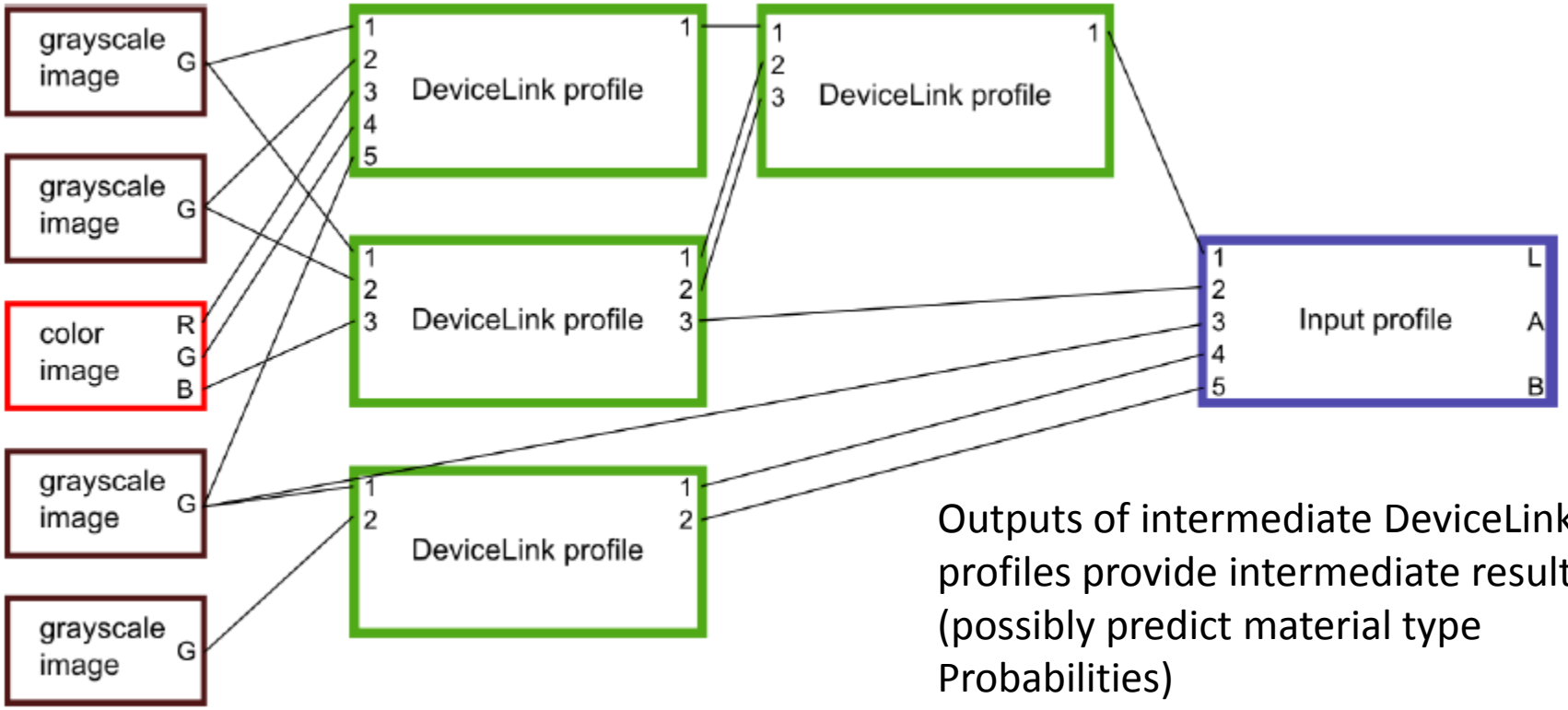
Note: Other Illuminants can be indirectly represented. However, color data in profile MUST always be converted to these viewing conditions for processing by the CMM.

Answering MI Questions with ICC Profiles

Answering these questions using legacy ICC.1 profiles become problematic:

1. What does it look like when…?
   - "Look" is communicated using device independent colorimetric Profile Connection Space (PCS)
   - PCS is limited to D50 illuminant and Standard 1931 2-degree observer
2. How do the materials in the scene interact with light?
   - No spectrally defined PCS
   - No clear/efficient way to encode transforms
   - Limited number of channels can be encoded
3. What are the materials or what is the probability that the materials are …?
   - No PCS needed - can be accomplished using DeviceLink profile
   - Accuracy is limited when input dimensionality is greater than 4 channels

Potential Workflow using ICC.1



Outputs of intermediate DeviceLink profiles provide intermediate results (possibly predict material type Probabilities)

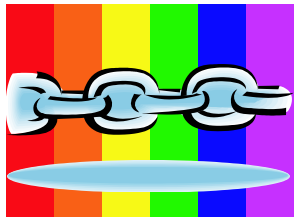
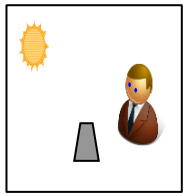
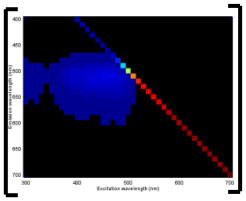
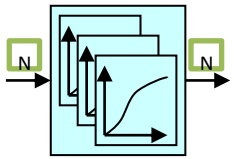
Note: Based on Dicom WG26 multi-spectral state proposal (from Bas Hulsken)

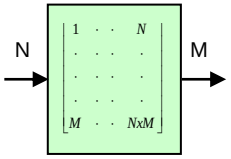
Going Forward with IccLabs

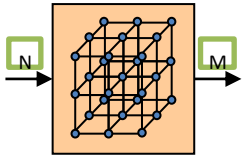
- The main goals of IccLabs address several color management challenges
  - Overcoming limitations of current transforms with D50 colorimetry
  - Adding flexibility and extendibility
- Resulting in a new profile specification and profiles
  - New Color Management Module (CMM) will be backwards compatible with V2 and V4 profiles
  - New profiles (V5) not expected to be compatible with older CMMs
- ICC will provide a reference implementation of an IccLabs based parser and CMM - RefIccLabs

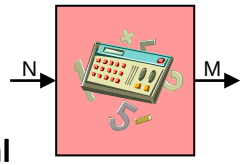
IccLabs – Overview

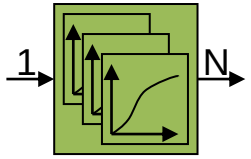
- PCS Extensions
  - **Spectral profile header extensions**
  - **Profile Connection Condition (PCC) tags**
  - **PCS Transforms**
  - **Sparse matrix encoding**
- multiProcessingElements
  - **1-D Look Up Tables (LUTs)**
  - **Matrices**
  - **N-dimensional LUTs**
  - **Calculator element**
  - **ICC Color Appearance Model element**
  - **Tint Array element**
- Hierarchical tag types
  - **Named Color Tag Array**
  - **Support for angular dependencies via Bidirectional Reflectance Distribution Functions (BRDF)**
  - ***Profile Sequence Information***
- Other Extensions
  - **Color Space Encoding profiles**
  - **Gamut Boundary Description encoding**
  - ***Color Measurement (CxF) tag encoding***
  - ***UTF8 text & UTF16 encoding***
  - ***Additional Numeric Array Types***

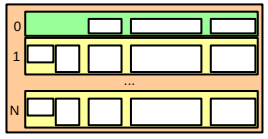





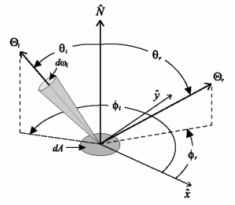
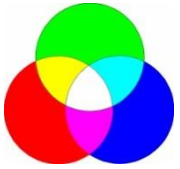
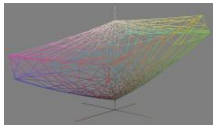






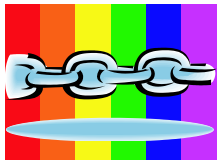




CxF

Flexible PCS Support



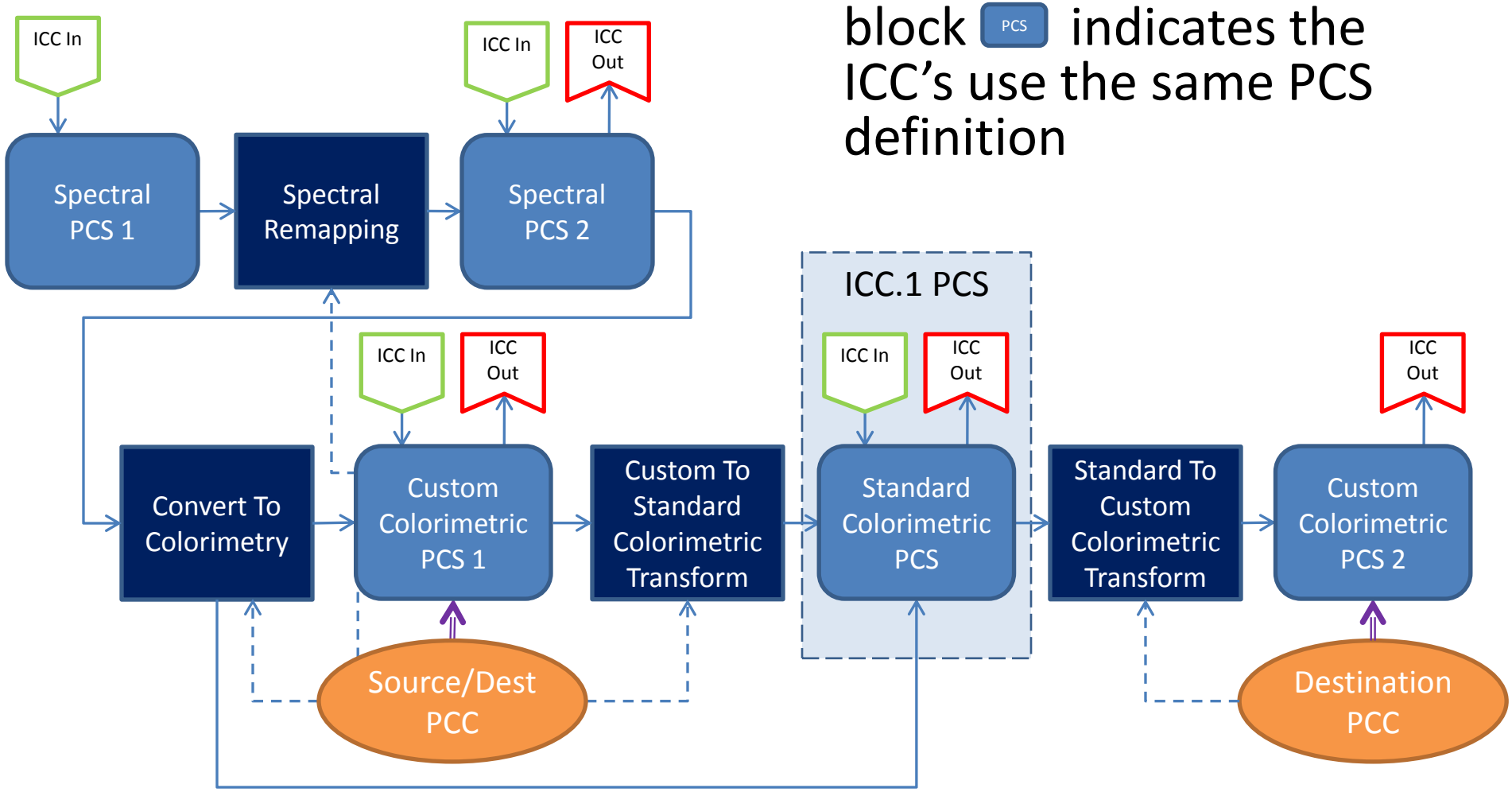
ICC.1 PCS Support

	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	Use 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

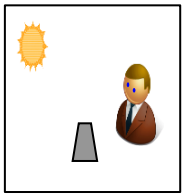
PCC = Profile Connection Conditions

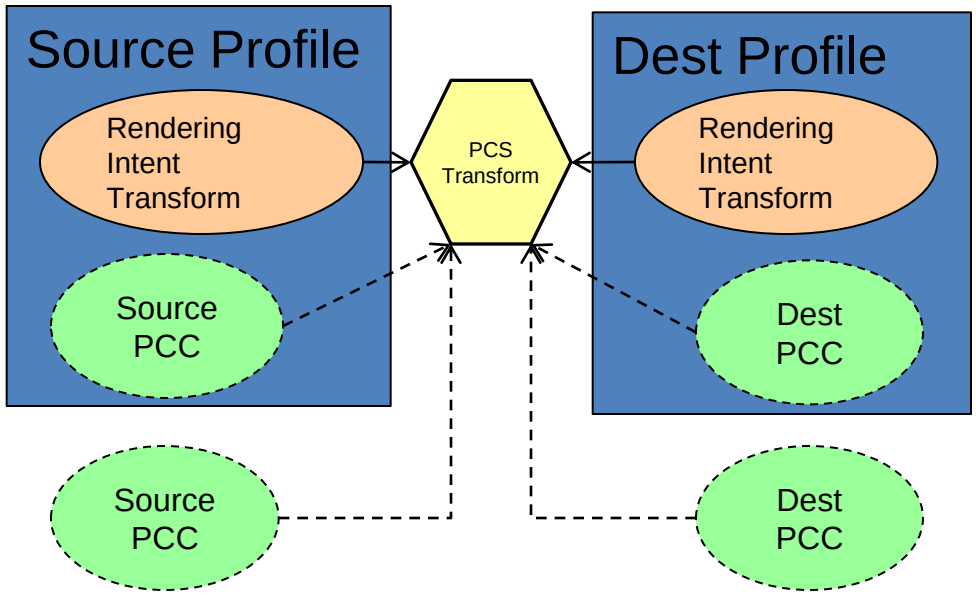
PCS Conversion

- Connect any ICC In to any ICC Out
- Connection to same PCS block PCS indicates the ICC's use the same PCS definition



Profile Connection Conditions





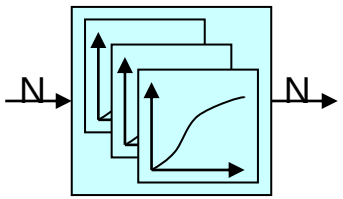
Allows PCS data in profiles to use actual viewing conditions

No need for chromaticAdaptationTag!

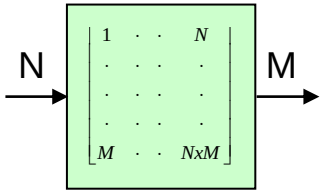
- Profile Connection Conditions comprise of:
  - Color space and spectral PCS metadata in header
  - **spectralViewingConditionsTag**
  - **customToStandardPcsTag**
  - **standardToCustomPcsTag**
- Spectral and custom colorimetric PCS processing is performed using Profile Connection Conditions (PCC)
- 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

Processing with multiProcessElements

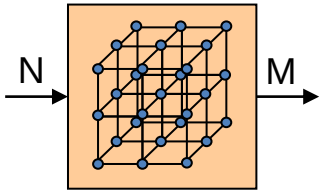
- Allows processing workflows to be defined using an arbitrary order of flexible processing elements with 32-bit floating point processing
- Completely defines transformations from input to output



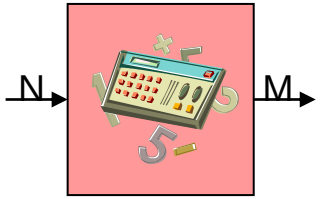
1-D LUTs



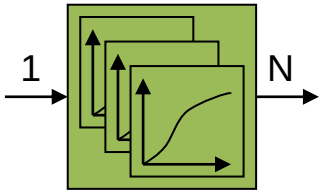
NxM Matrix



Multi-Dimensional LUT



Programmable Calculator



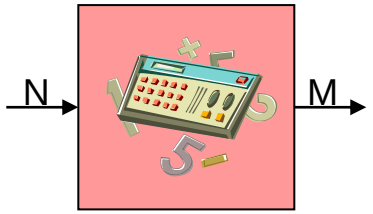
Tint Curves

Color Appearance Model

Placeholder

Programmable Calculator Element

- Provides mechanism for encoding more complex (non-linear) device models
  - Avoids limitations of Color Look-Up Table(CLUT) input channel dimensionality
  - Possible to embed and use other processing elements
  - Results in smaller potentially more accurate profiles



- Defines a script based expression calculator to determine output channels based upon input channels
  - Uses a sequence of operations that apply to an Reverse Polish Notation (RPN) argument stack
  - Finite memory storage for temporary results
  - Nearly all operations are vector based (operating on multiple channels at same time)
  - Secure deterministic behavior

IccLabs General Profile Contents

- Display / Device / Color Space Profiles
  - Header (with spectral PCS)
  - Metadata Tags
  - *Profile Connection Conditions Tags*
  - *Colorimetric Transform Tags*
    - AtoBx / BtoAx : *lut8, lut16, lutAtoB, lutBtoA, multiProcessElementType*
  - *Spectral Transform Tags*
    - DtoBx / BtoDx : *multiProcessElementType*

- *Note 1: PCS and Spectral PCS entries in header determine whether colorimetric and/or spectral transform tags are needed*

- *Note 2: Profiles are valid when only relative or absolute transforms are present*

- Device Link Profiles
  - Header
  - Metadata Tags
  - Transform Tags
    - AtoB0 : *lut8, lut16, lutAtoB, multiProcessElementType*

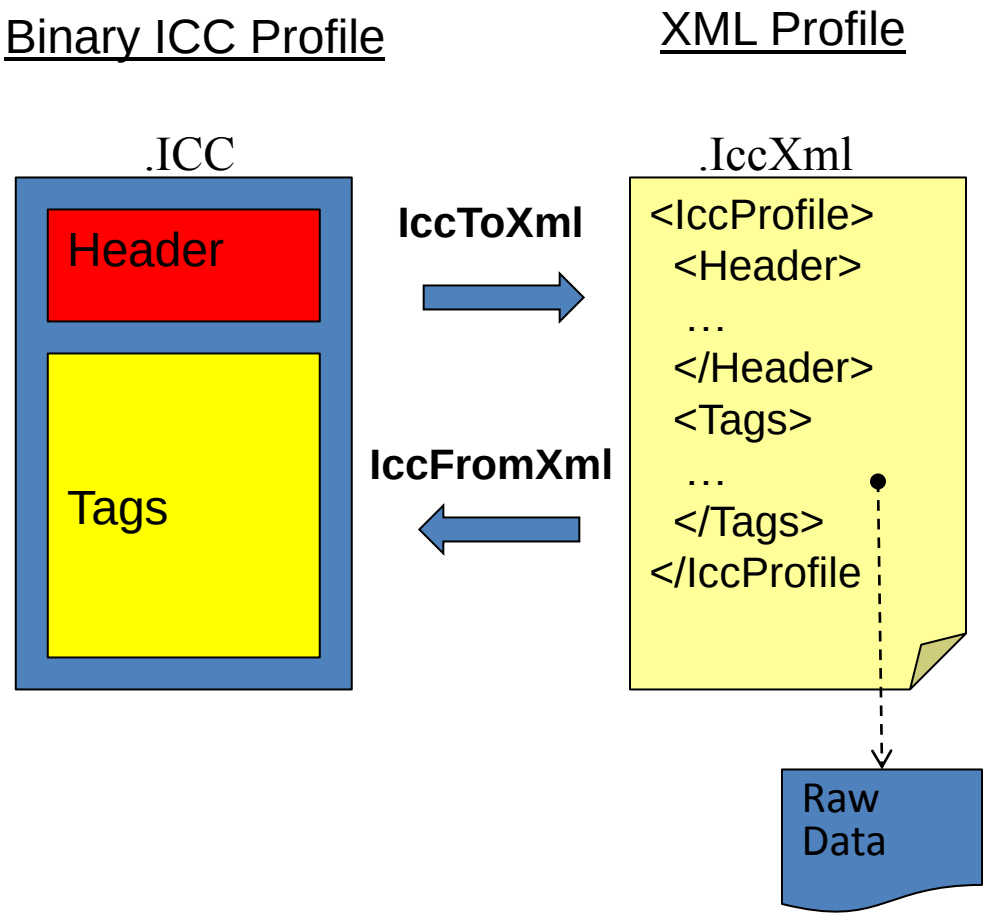
- *Named Color Profiles*
  - Header (with spectral PCS)
  - Metadata Tags
  - Profile Connection Conditions Tags
  - Transform Tag
    - Named Color Table : *namedColorTagType, tagArrayType(namedColorArray)*

- Stadard Color Space Encoding Profiles
  - Minimal Header
  - Encoding Space Type (and Name)
  - *Optionally override color space encoding parameters : tagStructType*

RefIccLabs

- Provides a C++ reference implementation of profile manipulation and application proposed by IccLabs specifications
- Simultaneously supports both binary and XML representations of profile data

- Libraries and tools
  - IccProfLib (.ICC)
    - IccApplyNamedCMM
    - IccApplyProfiles
    - IccDump
    - wxProfileDump
  - IccLibXml (.IccXml)
    - IccFromXml
    - IccToXml



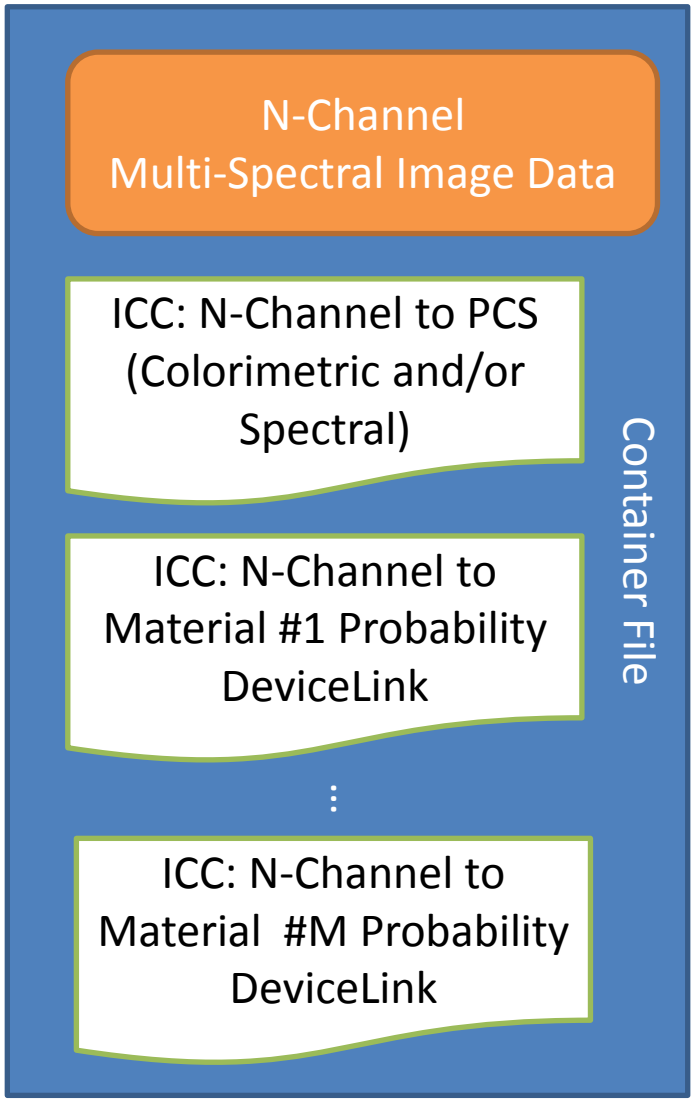
Benefits/Opportunities with IccLabs

- Spectrally based workflows
  - Communicate and account for physical properties of light and surfaces
  - Handle variability in lighting and observer
- Flexible processing elements
  - Enable more complex device models
  - Allow color/vision science to be directly encoded in a profiles
- New data structures, data types and profile class
  - Provide for Named Color specification flexibility
  - Allow for complex data relationships to be easily encoded
  - Allow for easier future extendibility
  - Simplifications for standard color encodings

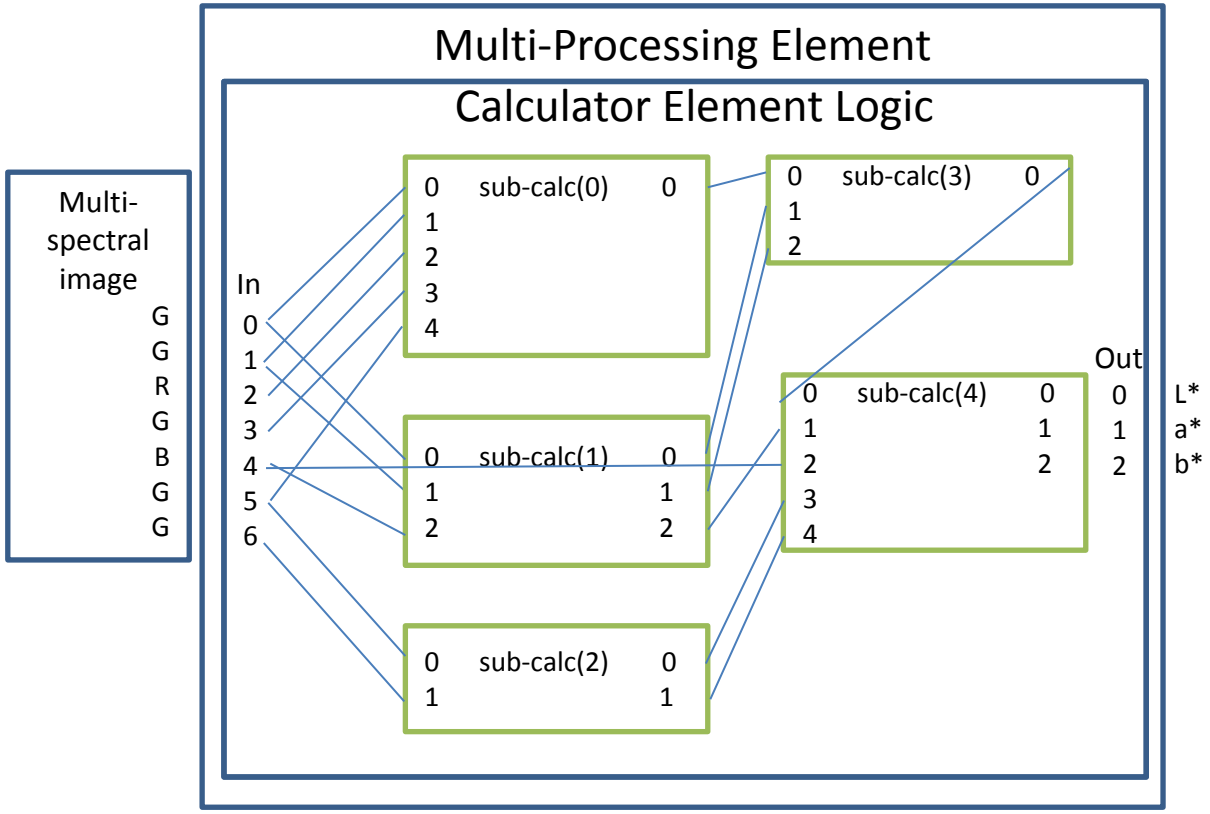
Multi-Spectral Examples

Multi-Use Multi-Spectral Data

- Different questions can be answered by providing different profiles for the same multi-spectral image data
  - All profiles take all same N-Channels as input
  - Output of each profile depends upon use case



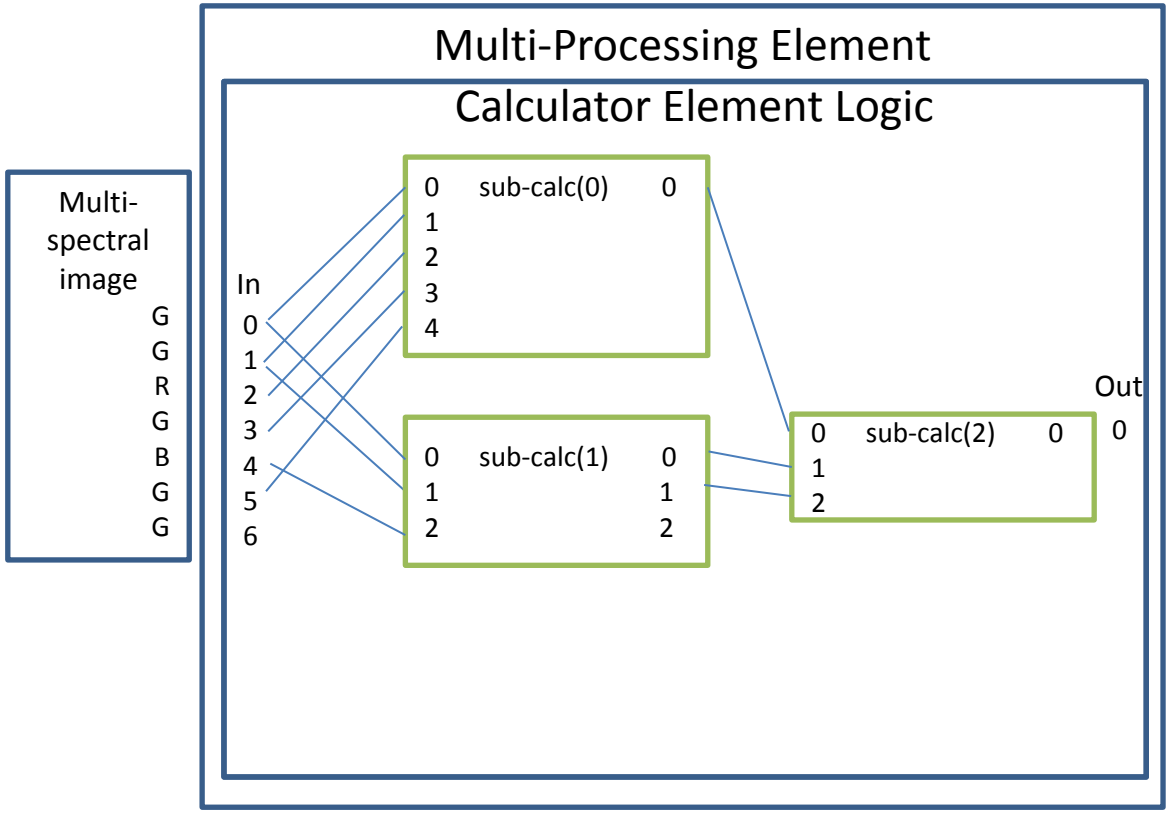
Example Calculator Element Colorimetry



Calculator Element Script

in(0,4)
in(5)
calc(0)
tput(0)
in(0,2)
in(4)
calc(1)
tput(1,3)
in(5,2)
calc(2)
tput(4,2)
tget(0,3)
calc(3)
copy
tput(6)
tget(3)
in(5)
tget(4,2)
calc(4)
out(0,3)

Example Calculator Element DeviceLink



Calculator Element Script

in(0,4)
in(5)
calc(0)
tput(0)
in(0,2)
in(4)
calc(1)
tput(1,3)
tget(0,3)
calc(3)
out(0)

Conclusions

Industries that can possibly benefit by ICCLabs

- Medical Imaging
- Fine Art Reproduction
- Motion Picture and Video Industries
- Academic Research
  - Color Science
  - Vision Science
- Industrial Color

Considerations for Medical Imaging

- It should be noted that ICC V2/V4 profiles could work
  - For conventional RGB based imaging workflows
  - Connecting various DeviceLink profiles to process mulit-spectral information (but requires external logic to make connections)
- Possible advantages from IccLabs
  - Colorimetric imaging
    - Use PCS based upon illuminant (actual monitor white point) used by medical industry (other than D50)
  - Spectral imaging
    - Use of Spectral PCS to communicate how light reflects off surfaces
  - New processing elements
    - Direct modeling in profile (possibly smaller more accurate profiles)
    - Use in DeviceLink profile to convert multi-spectral information directly into material type probabilities (No external logic needed)
  - More resources for Smart CMM's to do a better job

Thank You!

Questions?