Recent developments in ICC color management

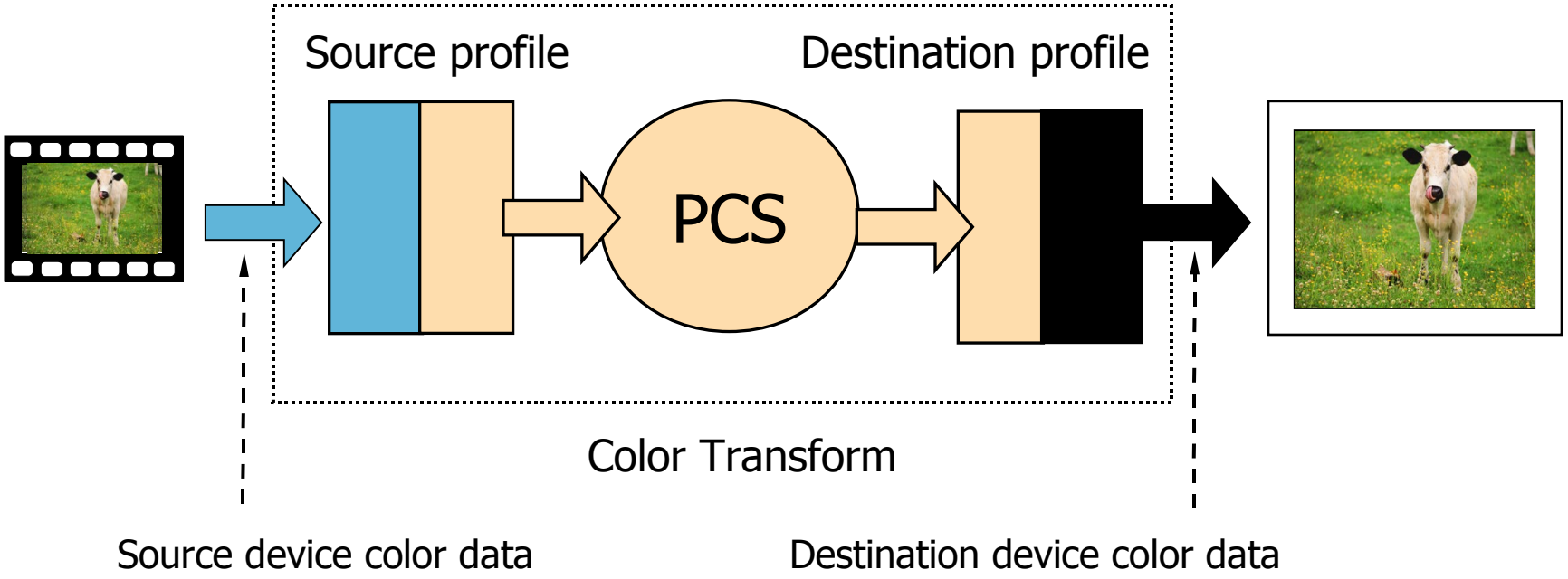
International Color Consortium

Outline

- **ICC profile and workflow**
- **Recent history**
- **Changes in v4**
  - Colorimetric rendering intents and the chromatic adaptation tag
  - Perceptual rendering intents and the perceptual reference medium
- **Recent specification amendments:**
  - Graphic Arts
  - Digital Photography
  - Digital Motion Picture
- **‘Smart’ CMM functions**
  - Black point compensation
  - Others
- **The future**

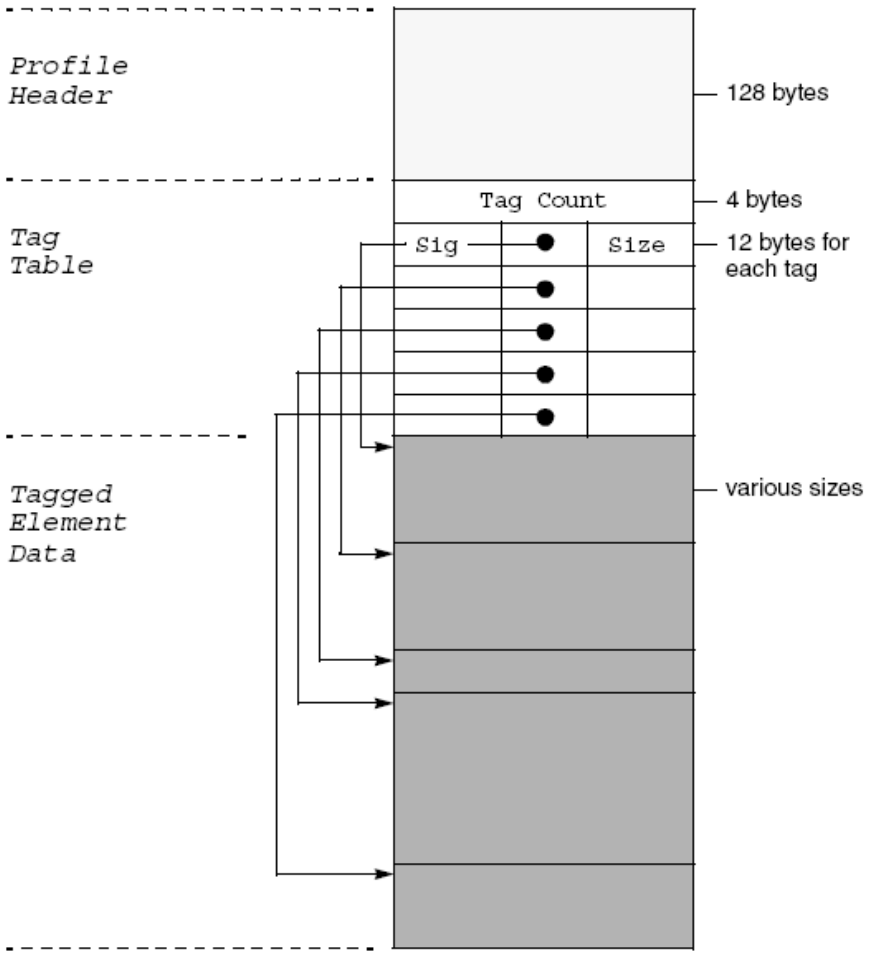
ICC Color Workflow

- **In an ICC color managed workflow, profiles are typically used to transform between a source and destination color encoding (sometimes inexactly called a color space).**



ICC Profile Anatomy

- **ICC profiles use a tagged format.**
- **Profiles made up of header plus individual tags.**
- **Tags can be informational or numeric, optional or required.**
- **Profile version (v2, v4) located in profile header.**



ICC profile spec - recent history

Current version of the specification

- Oct 2004 - ICC.1:2004-10 Specification (v4.2.0)

Published as ISO standard

- May 2005 - ISO 15076-1 (based on ICC v4.2.0)
- May 2006 - ICC.1:2004-10 with errata, identical to ISO 15076-1

Recently approved amendments

- Feb 2005 - Perceptual Intent Reference Medium Gamut
- Jun 2006 - Motion Picture technology tags
- Nov 2006 - Floating Point Device Encoding Range
- Apr 2007 - Profile Sequence Identifier tag
- Apr 2007 - Colorimetric Intent Image State tag

Issues with V2 specification

- **Specification difficult to understand, and ambiguous in some areas**
  - results in variable and sometimes incorrect implementations and user misunderstandings
  - ad-hoc practices to address incorrect implementations not designed for interoperability, or documented
- **Interoperability problems**
  - Profiles may not work well together
    - user may need to test profile combinations
    - architecturally poor work-arounds becoming standard practice
      - causes misunderstandings about how color management should work
      - hinders the development of robust automated systems
  - CMMs may produce different results
    - profile problems are inconsistently fixed
    - unusual profile values may be interpreted as problems and incorrectly “fixed”

Issues with V2 specification

- **Colorimetric rendering intent issues**
  - Widely used profiles contain incorrect mediaWhitePointTags
    - Results in incorrect ICC-absolute colorimetry
      - Some CMMs fix bad profiles, others don't
      - CMMs that fix bad profiles incorrectly interpret good profiles with no or partial adaptation
  - Colorimetric transforms may not characterize device or color encoding
    - may include color re-rendering
      - black point scaling common in display profiles
    - chromatic adaptation applied is unknown
  - Colorimetric transforms do not reliably support 'smart' CMM functions
    - cannot rely on PCS colorimetry to be accurate
    - cannot get to un-adapted source or destination colorimetry

Issues with V2 specification

- **Perceptual rendering intent issues**
  - No standard perceptual reference medium (PRM)
    - sometimes just black scaled colorimetry
    - other times substantial re-rendering to/from some PRM
      - » PRM varies from a 709 display to the entire PCS
    - Perceptual transforms with different PRM assumptions generally do not work well together
  - Ad-hoc practice evolved:
    - perceptual transforms are black scaled
    - output profile perceptual transforms assume PRM is 709 display-like
    - Use perceptual intent only when source is 709 display-like, otherwise use media-relative colorimetric plus black point compensation

Problems with v2 ad-hoc perceptual

- **Aggressive color re-rendering in output profile results in more variability in printed output, where it is most noticeable**
- **Rendering intent selection depends on source profile as well as reproduction goal**
  - not a clean architecture
    - » makes use and automation more complex
- **Perceptual re-rendering produces poor results when source is not 709 display-like**
  - have to use MRC+BPC or CMM color re-rendering for other sources
    - » but CMM color re-rendering difficult and risky
- **v2 ad-hoc perceptual practice not standardized or even documented**
  - —Users cannot count on profiles to be constructed this way

Changes made in v4 vs. v2

- **Reduction of specification ambiguity throughout**
- **New requirements:**
  - Colorimetric rendering intent now measurement-based
    - any black scaling must be done by CMM
  - Media white point tag values clarified
  - Chromatic adaptation transform used must be provided
  - color of nCLR device colorants required
  - Perceptual rendering intent must color re/render to and from the standard PRM.
  - Multiple rendering intents apply to all profiles, including input and display profiles
- **New transform types:**
  - lutAToB, lutBToA types
    - includes 1D LUTs, CLUTs, matrix, offset
  - Parametric curves

Changes made in v4 vs. v2

- **Standard Perceptual Reference Medium (PRM) defined**
  - Reference medium - high quality virtual photo print
    - 288:1 dynamic range
  - Reference viewing conditions
    - ISO 3664 P2
- **Unicode encoding for text types**
- **Profile ID in header**
- **Removal of unused tags from specification**
- **Restructuring of document and rewriting of informative material for improved clarity**

Changes to the Perceptual Rendering Intent

What is ‘perceptual rendering’?

- Reproduction goal is to produce a pleasing reproduction of an original (the source) on some destination output medium.
  - Also called preferred reproduction
- The reproduction doesn’t need to be an exact match to the original, although the artistic intent conveyed in output-referred originals should be maintained.
  - It is also possible to use the perceptual intents of ICC profiles to color render scene-referred images.
    - In this case the artistic intent is conveyed by the profile
- Preferred reproduction (I.e. perceptual) transforms address differences in source and destination media capabilities and user preferences, as well as viewing conditions.

What is different about the ICC v4 PI?

- **With ICC v4, the perceptual intent reference medium (PRM) is defined and standardized.**
  - With v2 profiles, this was not the case, so perceptual intents in profiles from different manufacturers often did not work well together
  - Most input profiles performed minimal (if any) color re/rendering
  - Most display and color space profiles only performed black point compensation
  - Many output profile perceptual intents tried to color re-render the entire PCS to the destination medium, resulting in poor quality
  - Other output profiles assumed some source medium (e.g. sRGB) in the PCS.

The Perceptual Reference Medium Gamut

- **ICC spec amendment approved in 2005**
- **Specifies a target gamut for the PRM**
  - Intended to further drive convergence of PRM gamut assumptions
- **Specified as a "fuzzy" target**
  - Perceptual color re-rendering transforms need to strike the right balance between producing the best results and mapping exactly to the PRMG.
    - the PRM gamut for any given profile may be a little different from the PRMG, but it must be reasonable for the PRM
      - the PRMG should not be used to clip PCS colorimetry
  - The PRMG can be used as a guide for scene-to-picture color rendering
- **New optional tags can be used to indicate whether it is o.k. to interpret the PRM colorimetry as appropriate for the PRMG**
  - allows profile creators to positively indicate correct use of the PRM
  - can also be used to indicate the use of the PRM for the saturation intent, to produce a different "look"

Perceptual Reference Medium Gamut

- **With ICC v4, the source profile perceptual intent transform is intended to color re/render to the PRM, and the destination transform from the PRM**
  - Coincidentally, the PRMG approximates the gamut of commonly occurring surface colors
  - It is defined in ISO 12640-3 (provides data on gamut derivation, gamut surface and primaries)

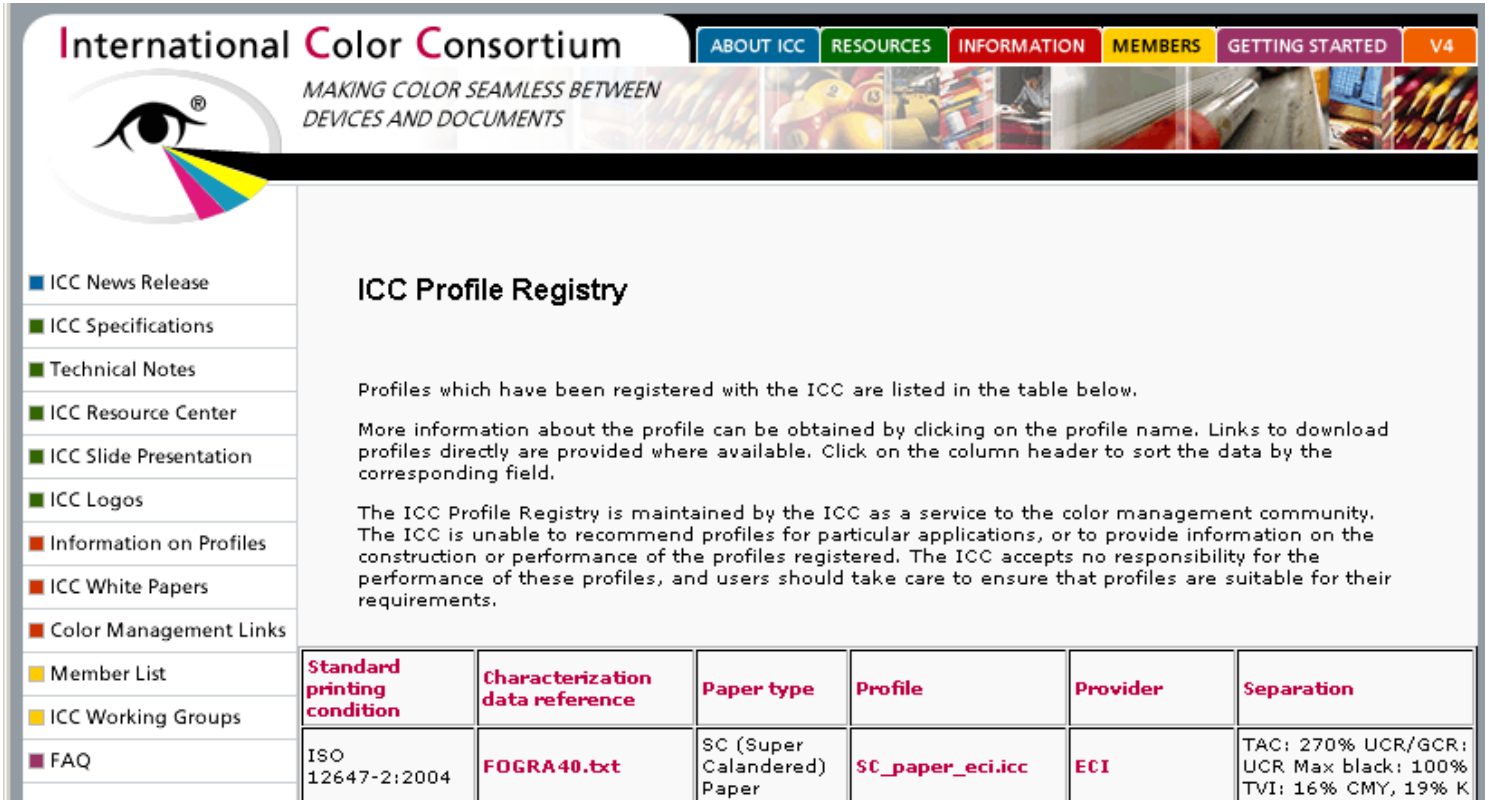
Recent amendments and proposals: Graphic Arts

- **Profile Sequence identifier tag (signature: ‘psid’)**
  - Device Link profiles provide a one-way transform between a pair of devices/encodings without passing through the PCS.
    - Often created by combining regular ICC profiles
  - The new tag supports correct identification of the ICC profiles used to create the Device Link transform

- **Profile Registry**
  - Profiles corresponding to registered printing conditions can be registered with the ICC
  - Supports both manual and automated profile location

Profile registry - manual selection

- Users know the reference printing condition and wish to select a suitable ICC profile for that condition
- http://www.color.org/registry



Profile registry - automated download

- ISO TC130 is defining versions of PDF/X that allow users to include links to resources such as profiles rather than including the resource itself
  - **—to reduce file size**
  - **—to avoid having to include the same resource in multiple documents**
- This is particularly important in variable data workflows
- The ICC Profile Registry supports the following url formats for automated download:

  http://www.color.org/registry/profiles/profilename.icc (serves profile)

  http://www.color.org/registry/profiles/profilename.html (info page)

  http://www.color.org/registry/profileid.html (redirects to profile)

Digital Photography

Colorimetric Intent Image State tag

- Previous ambiguities with the colorimetric and perceptual rendering intents have generally been resolved by the v4 revision and the PRMG amendment
  - The v4 perceptual intent PCS colorimetry is always output-referred to the PRM
- For the colorimetric rendering intents, it is generally assumed that the PCS colorimetry has previously been color rendered, but this is not required
- Some application areas require the ability to communicate the original scene colorimetry or appearance
- The ICC has added a new optional tag to the specification which allows the image state of the PCS colorimetry produced using the colorimetric rendering intents to be specified

Colorimetric Intent Image State tag

- **The CIIS amendment adds an Image State tag to the specification with the following signatures:**
  - scene colorimetry estimate, 'scoe'
  - scene appearance estimate, 'sape'
  - focal plane colorimetry estimate, 'fpce'
  - reflection hardcopy original colorimetry, ‘rhoc’
  - reflection print output colorimetry, ‘rpoc’
- **New image state signatures can be added as desired**
- **This tag allows a user or application to correctly interpret the PCS colorimetry produced by the colorimetric rendering intents**

CIIS tag use case example

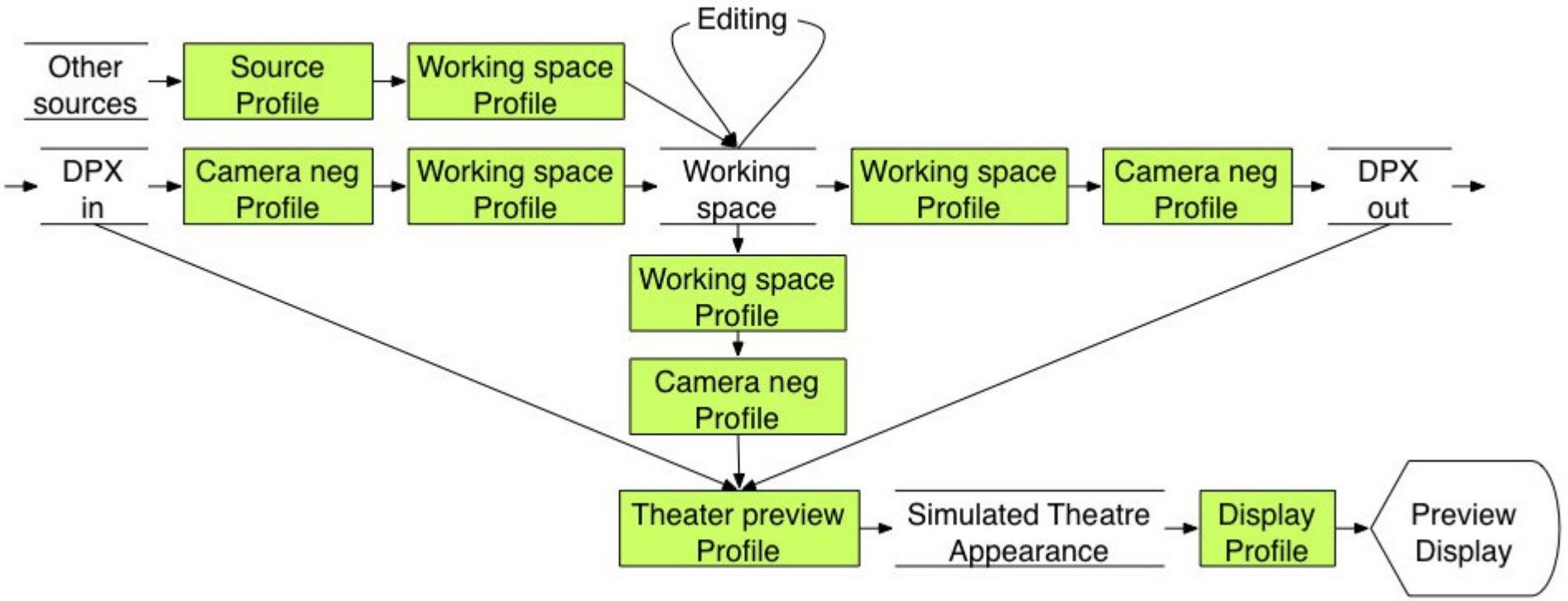
- **If a profile is assigned to a camera raw image and the tag says ‘scoe’, the colorimetric intents can be used to convert the image to a scene-referred color encoding/working space**
  - The ICC-absolute colorimetric rendering intent will map the scene adopted white to the scene-referred encoding adopted white
    - best for colorimetric reproduction
  - The media-relative colorimetric rendering intent will map camera saturation white to the scene-referred working space white clip
    - best for manual color rendering
- **The perceptual intent can be used to convert the image to an output-referred color encoding**

Digital Motion Picture

Floating Point Device Encoding Range

Digital motion picture production workflows have multiple input sources

Output can be DPX (for final print) or theatre preview



Floating Point Device Encoding Range

- The precision of profile elements such as curves and matrices is insufficient for Motion Picture industry processing: transform inversion cannot be performed precisely and quantization errors occur
- Current profile transforms only support bounded device-side color encodings, but unbounded (floating point) encodings are used in the motion picture industry

NOTE There has been some confusion regarding ICC support of above-white device values. Such values are supported by using above-white media white points. Clarifying language is provided in the CIIS amendment.

Floating Point Device Encoding Range

Amendment provides:

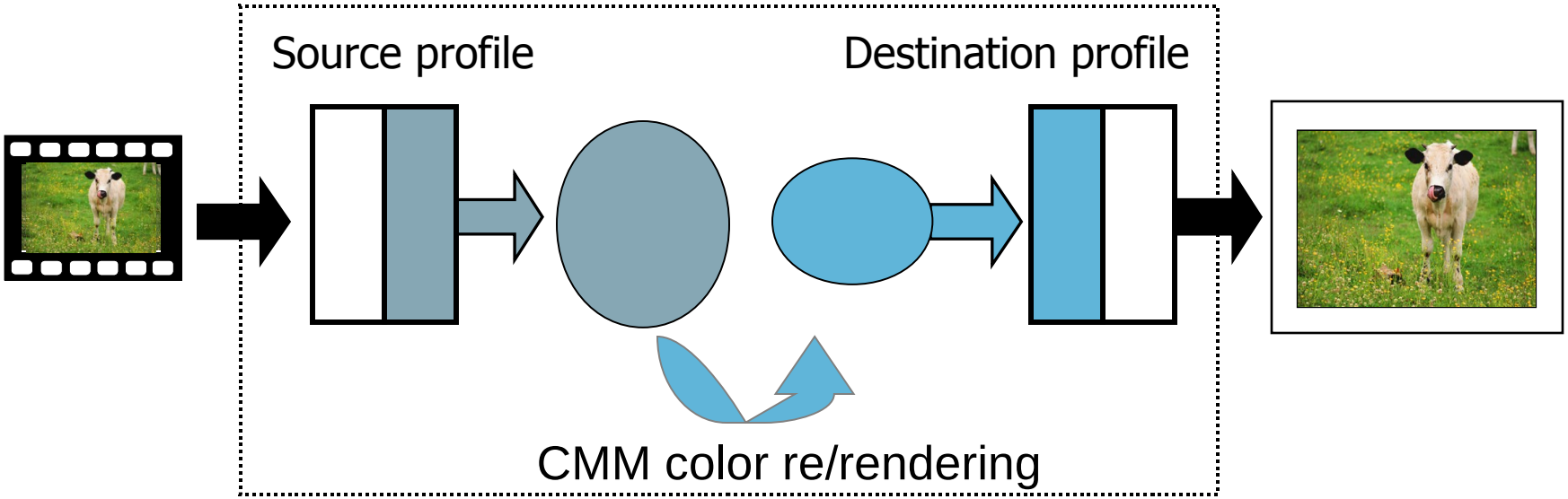
optional DToB / BToD transforms

- 32-bit float encoding (rather than 16-bit fixed in AToB / BToA transforms)
- not bounded to fixed device range
- negative values allowed
- PCS essentially the same, except now encoded using floating point
- separate ICC-absolute colorimetric transform

Multi-process elements tag (‘mpet’)

- Sequence of processing elements
- Elements currently limited to matrix, curve and LUT
- Other elements may be added in future

“Smart” CMM



CMM algorithms color re-render source image colorimetry to be appropriate for actual output medium

- considers source and output medium gamuts and viewing conditions
- supports color appearance model based color re-rendering
- can take advantage of full output medium gamut
- facilitates user adjustment of color re-rendering at time of output

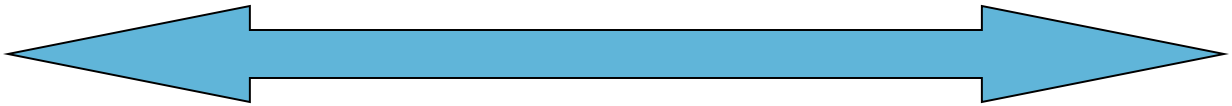
The v4 CMM Continuum

Static

- Smart Profiles
- CMM basically an interpolation engine

Programmable

- Dynamic transforms
- Smart CMM



Smart Operations

- Function Inversion
- Rendering and Re-rendering
- Black Point Compensation
- Gamut Mapping
- Color Appearance Modeling
- Scaling
- Black Generation
- Channel preservation
- Proprietary operations

The Future

- The ICC specification has established an architecture for interoperable and unambiguous communication of color between devices.
- Going forward, there are several challenges for the ICC:
  - The context for color management is widening, and industries and devices beyond the traditional color management users are emerging. The original ICC architecture was not optimal for all of these industries and devices, but now the main challenge is to promote adoption of the v4 spec and the recent amendments.
  - The color processing models defined in the ICC architecture can be significantly extended to support a wider range of color transforms.
  - The user interface to ICC color management needs further development to improve usability.