Color Management Systems and the ICC Version 4 Model

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Topics

- **General color management system model**
  - Control view
- **ICC components within the general color management system**
- **V4 changes and benefits**
- **V4 ICC perceptual rendering and colorimetric intents**
- **Transformation options via V4 CMM**
  - Three conversion configurations
  - Selection considerations

http://www.color.org/tokyomeeting2006.html

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Color Management System - Color Control Model

A partitioning of color management processes that control color results

Explicitly via purposeful control

Implicitly via lack of control

These 7 color controls can be examined in any digital color system

- **For types of users, regions of the world, markets**
  - —Visualization
- **For each device**
  - —Device Calibration
  - —Characterization
  - —Color Aim Definition
- **For the system**
  - —Communication
  - —Interpretation
  - —Conversion

Communication of color content & metadata between system components | Interpretation of source colors | Conversion of the source colors to the selected target representation

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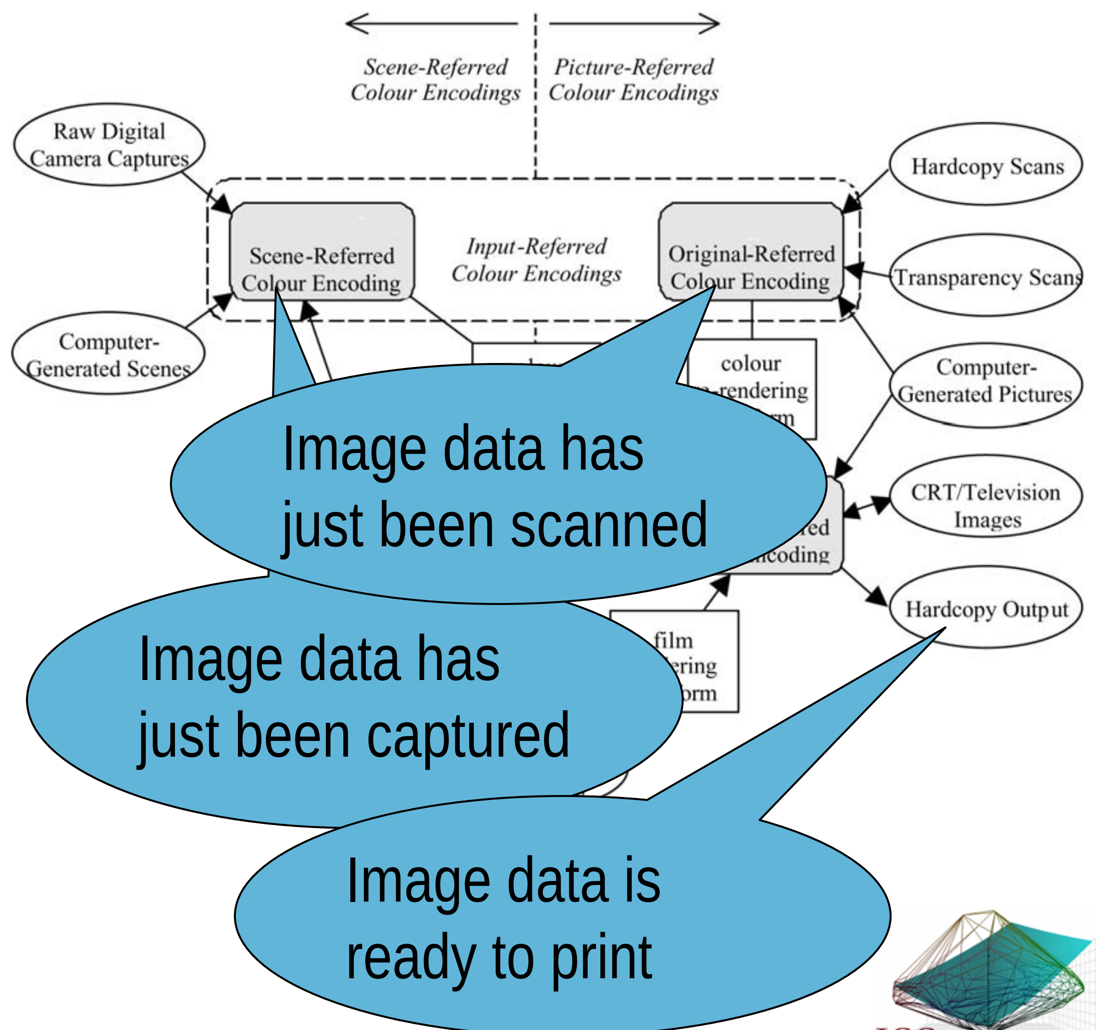
The ICC addresses certain elements of color management systems – key for interoperability

- **For types of users, regions of the world, markets**
  - —Visualization
    - •ISO 3664 viewing conditions
    - •CIE standard observer, color spaces, home lighting, color appearance model
    - •ISO IEC JTC1 SC28 psychophysical image quality measures
- **For each device**
  - —Device Calibration
    - •Proprietary methods, ICC recommendations
  - —Characterization
    - •Proprietary methods, ICC format specification
    - •ISO 13655 instrumentation standard
  - —Color Aim Definition
    - •Proprietary methods, ICC format specification
- **For the system**
  - —Communication
    - •Various standard and proprietary communications protocols, application & system APIs, metadata
  - —Interpretation
  - —Conversion
    - •ICC profile format specification
    - •ICC specification informative annexes
    - •ICC White paper recommendations
    - •CIE Div 8 gamut mapping analysis

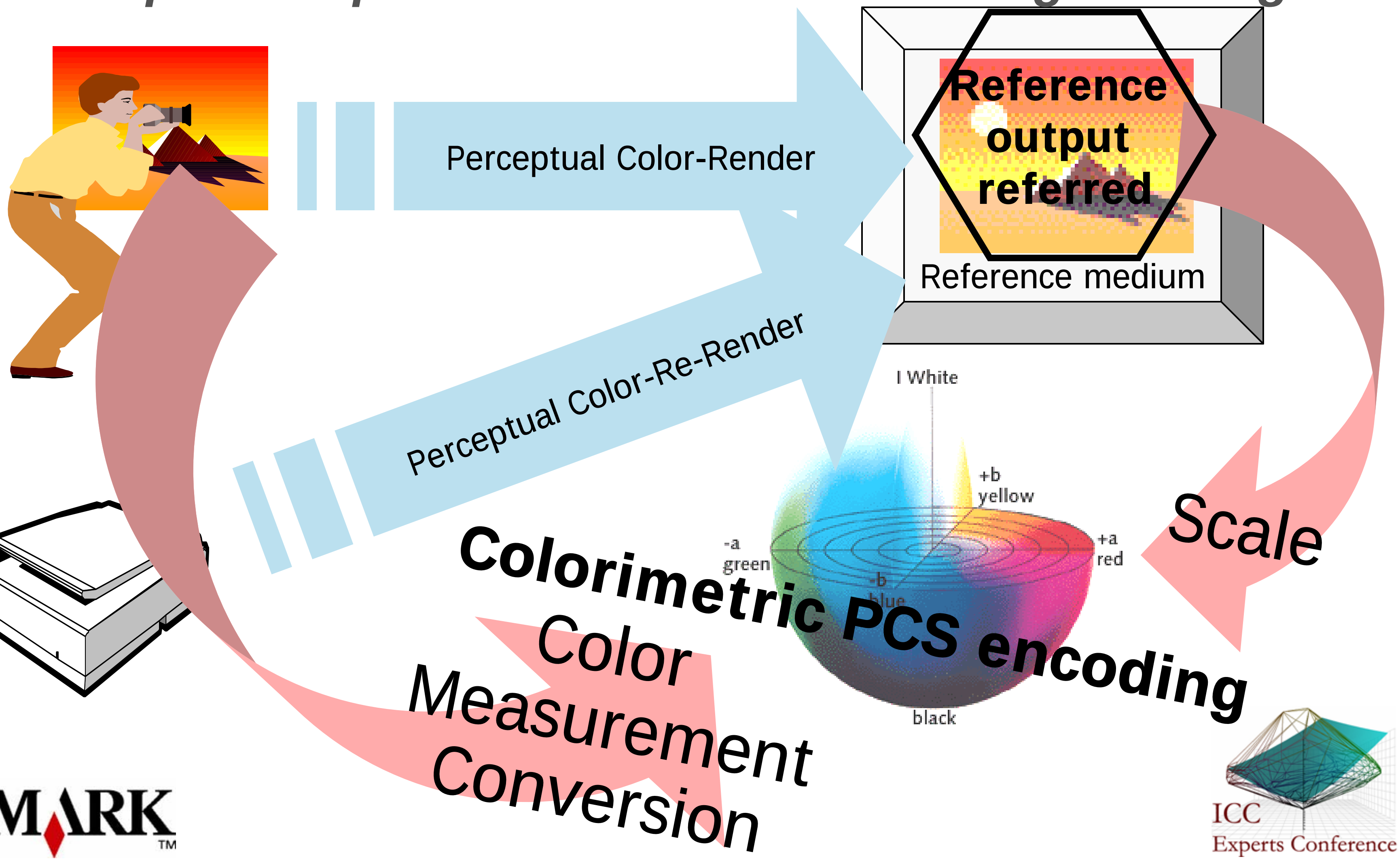
ICC Version 4 provides practical improvements for color interpretation and conversion

- **The image state concept underlies important new features in ICC Version 4 profiles**
- **What does image state mean in practical terms?**
  - How much has the image data changed since it was scanned or captured in the camera?
  - What is the image data ready for?
  - How easily can the data be transformed for a different type of display?



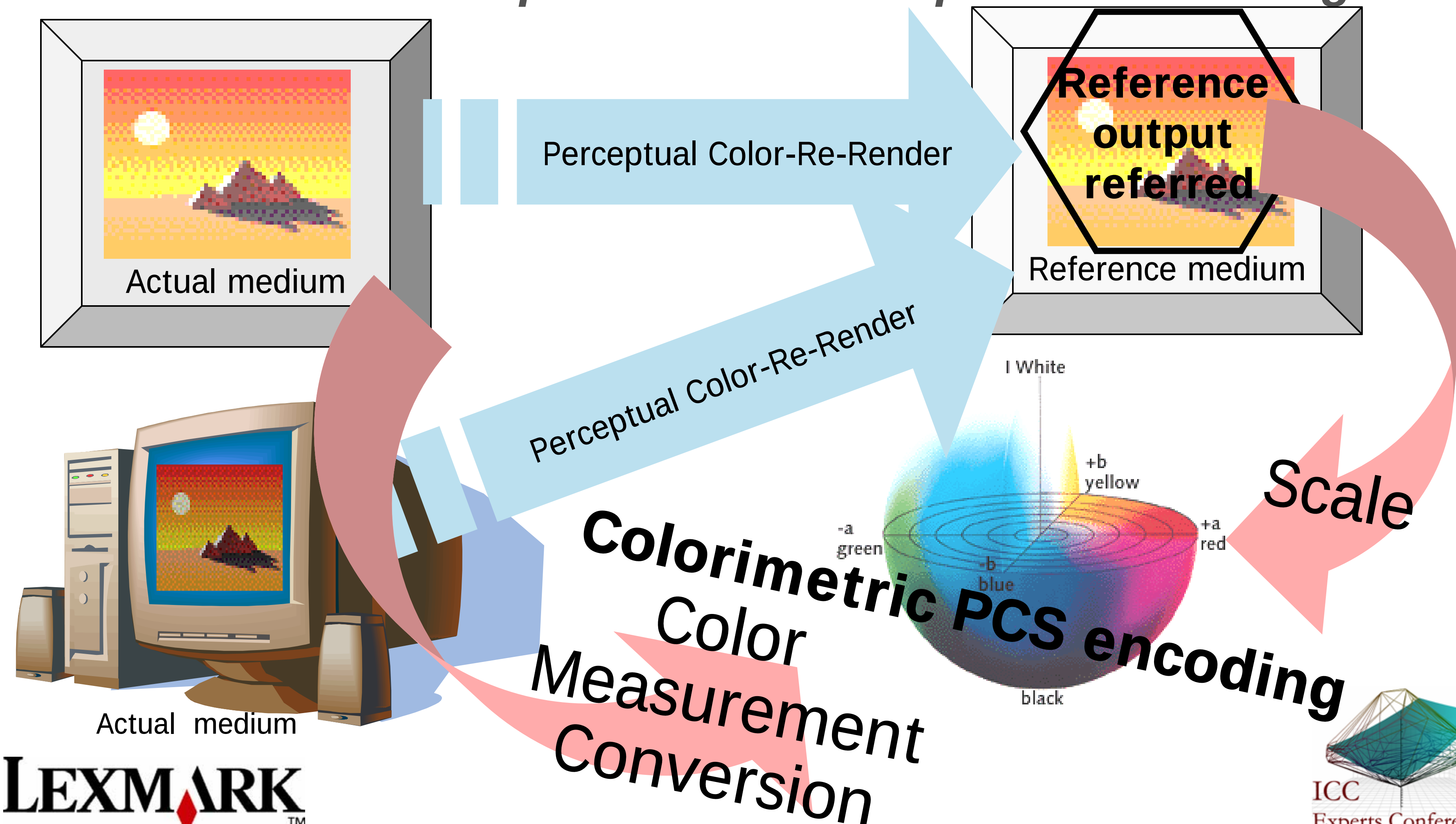
ICC Version 4 provides practical improvements for color interpretation and conversion:

► *two input interpretations for scene and original images*



ICC Version 4 provides practical improvements for color interpretation and conversion:

► ***two source interpretations for output-referred images***



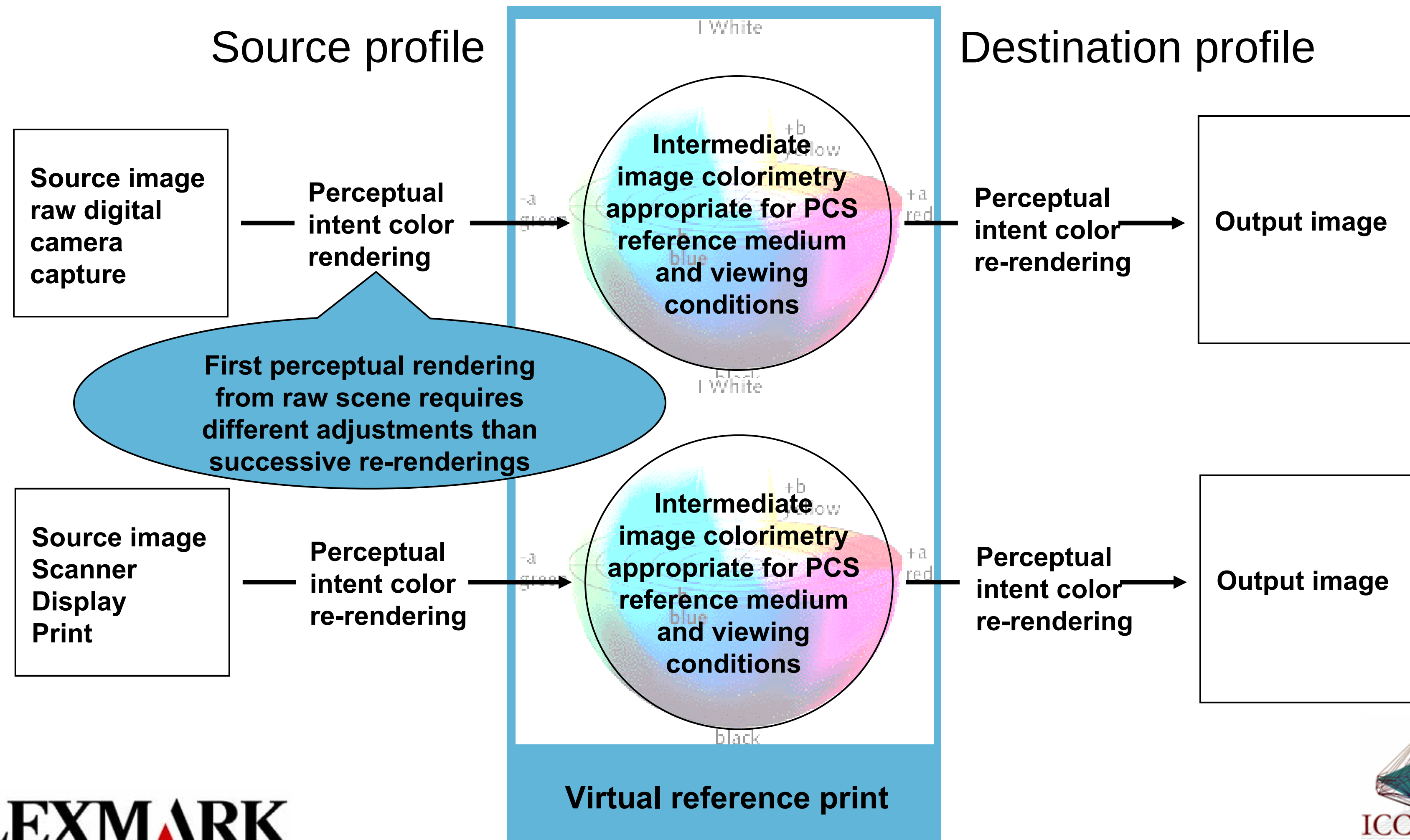
V4 Source Interpretation

- **V4 input profiles have separate transforms for perceptual rendering distinct from media-relative colorimetric color conversions**
  - — A single profile can provide both the ‘match color’ and ‘pleasing color’ color transforms
- **V4 media-relative colorimetric transforms are the reliable “measurement” path**
  - — PCS white point value specified for media-relative colorimetric, perceptual and saturation rendering intent transforms
    - – White point of the actual medium and the white point of the reference medium scaled to L*a*b* = 100, 0, 0
  - — PCS zero reflectance is specified as the black maximum for media-relative colorimetric rendering intent transforms
    - – L*a*b* = 0, 0, 0
- **V4 perceptual intent transforms provide pleasing color connected through a virtual reference print called the ‘perceptual intent reference medium’**
  - — Perceptual Intent Reference Medium provides a specified print output-referred [image state] “color-rendering target” for perceptual rendering intent transforms into & out of PCS
  - — Reference medium linear dynamic range of 287.9 :1 [density range 2.4593]
    - – Neutral reflectance WP= 89%, BP= 0.30911%
  - — Reference medium black point target specified for perceptual and saturation rendering intent transforms
    - – L*a*b* = 3.1373, 0, 0
    - – NOTE: Perceptual transforms that use zero to represent the black point, and thus do not conform to this specification should be adjusted by scaling the black point as needed.

The well-defined ICC V4 Perceptual Rendering target – key interoperability enhancement

- **With ICC V4, the *perceptual intent reference medium gamut* [PRMG] is defined and standardized**
  - Reference medium gamut defined in ISO 12640-3 Annex B – determined from a superset of printing systems
- **With V2 profiles, this was not the case, so perceptual intents in profiles from different manufacturers sometimes did not work well together**
  - Most V2 input profiles performed minimal (if any) color re/rendering
  - Many V2 output profile perceptual intents tried to color re-render the entire PCS to the destination medium, resulting in poor quality
  - Other V2 output profiles were built using an assumed source gamut (e.g. sRGB) in the PCS
- **With ICC V4, source profile perceptual intent transforms [A2B] should color re/render to the PRMG and destination profile perceptual intent transforms [B2A] should transform from the PRMG**

ICC V4 Perceptual path: color rendering and color re-rendering



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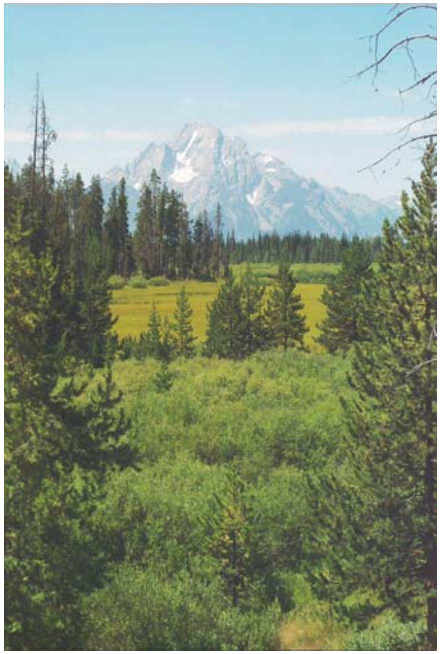
Scene colors rendered for different media & viewing conditions

scene colorimetry

color rendered to sRGB display colorimetry

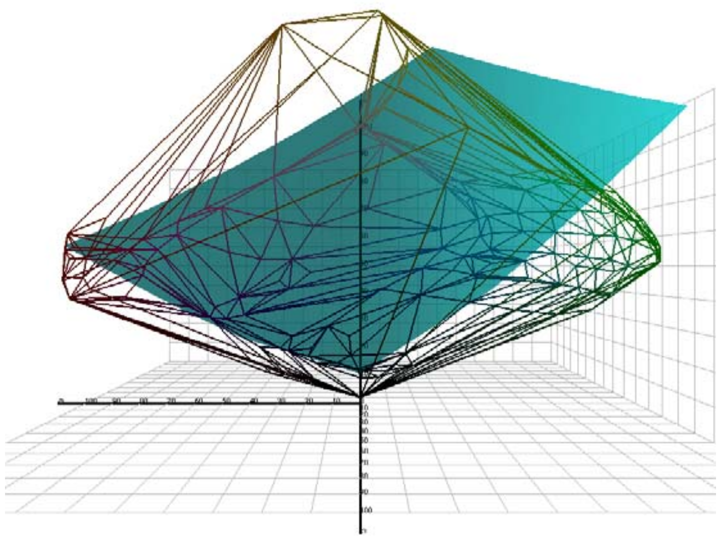


color rendered to plain paper print colorimetry

color rendered to film transparency colorimetry

Why and when is color re-rendering needed?

- **Viewing condition differences may require different colorimetry to maintain appearance**
  - Corresponding color (appearance) models are based on colorimetry, and are evolving
    - Need to keep the corresponding color (appearance) model used selectable
- **Image colors may need to be changed to re-optimize the source image for the destination medium**
  - Otherwise, only the intersection of the source and destination media color gamuts can be used



A large gamut photo print medium (wireframe) vs. the viewer observed sRGB gamut (cyan).

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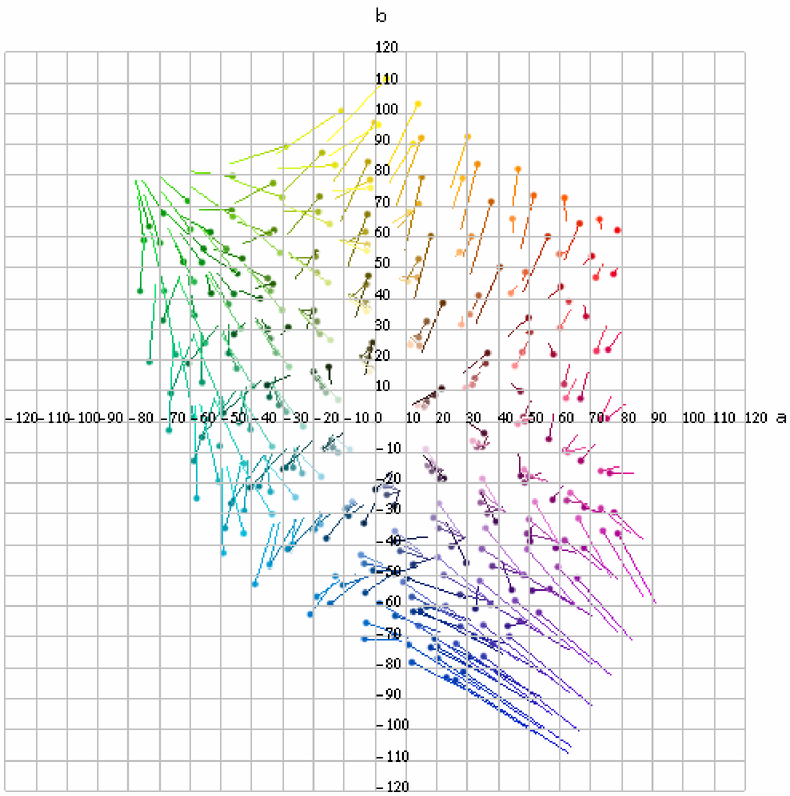
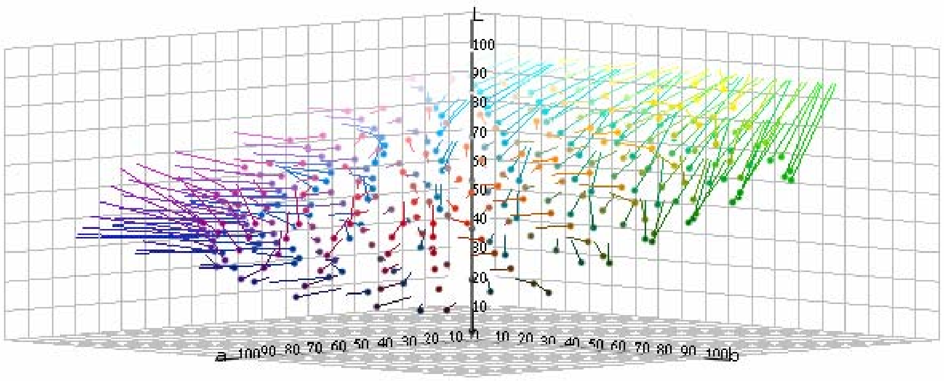
Example sRGB to ICC v4 PRM transform 'color re-rendering'





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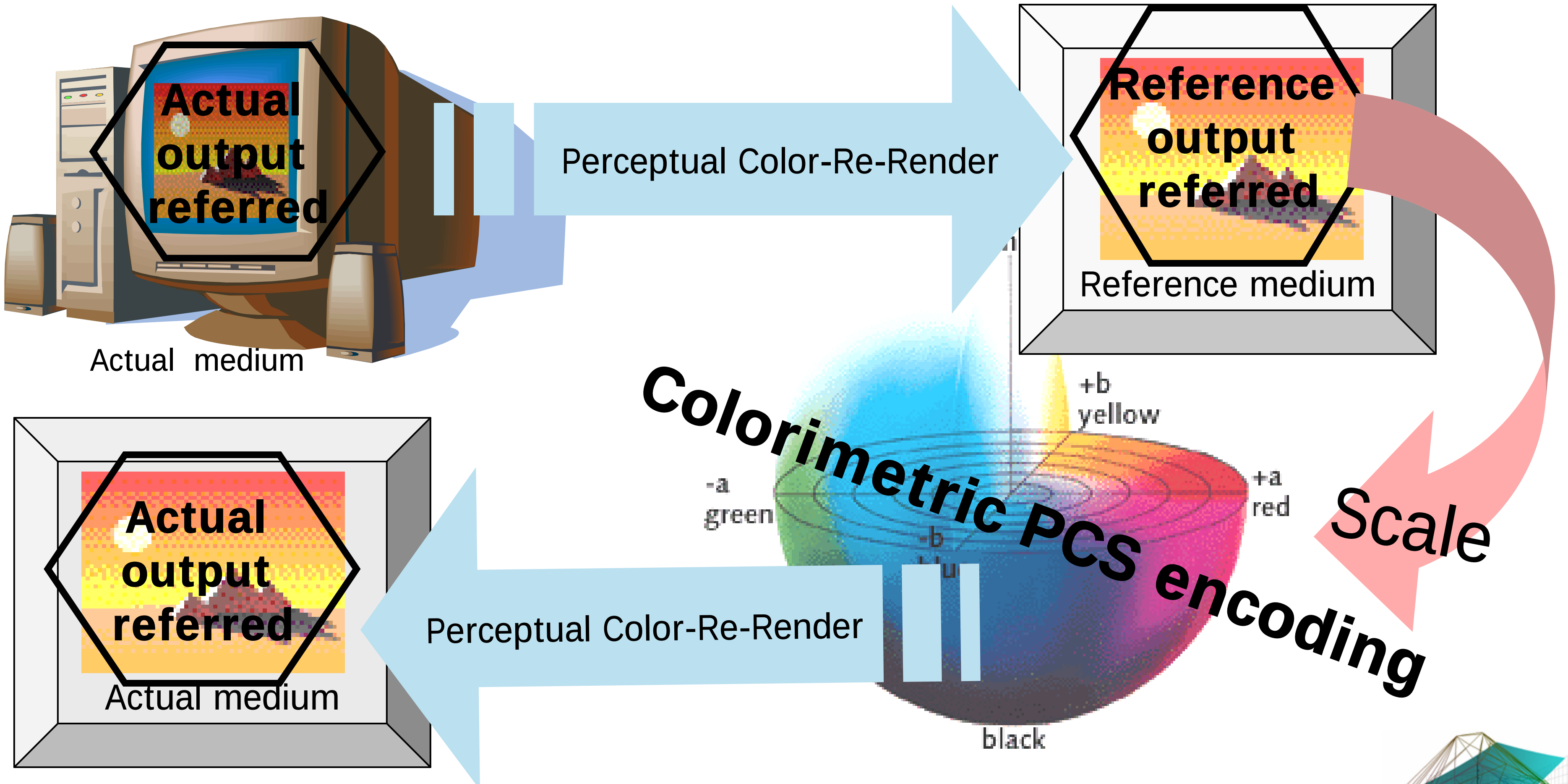
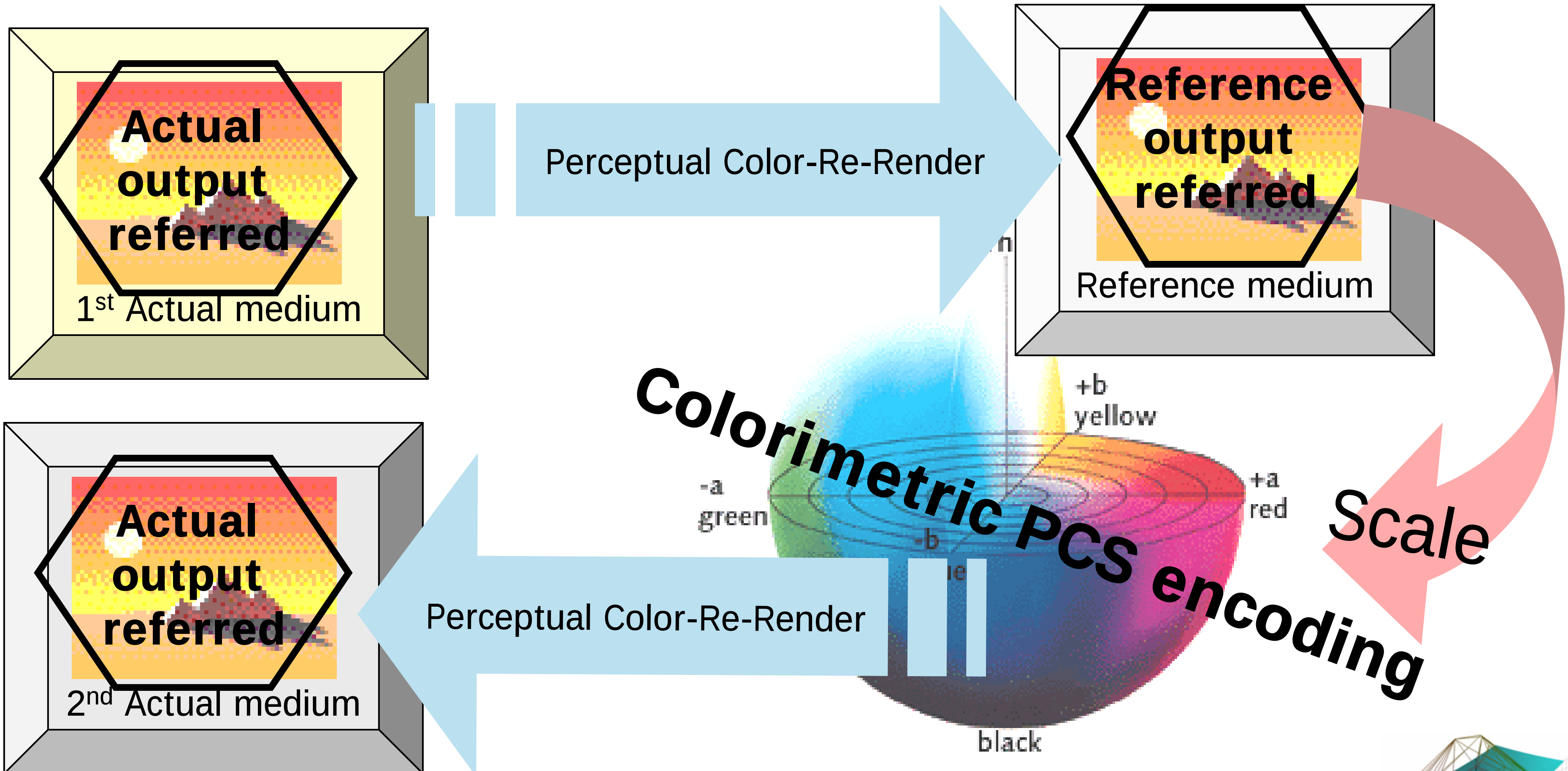
Full Perceptual Rendering path for pleasing color:
►*V4 color re-rendering for output-referred sources*



2nd example Perceptual Rendering path for pleasing color:
► *V4 color re-rendering for output-referred sources*



Color Conversion: V4 enables us to distinguish between color rendering, re-rendering and gamut mapping

- **Color rendering and re-rendering algorithms change the appearance of the content, to optimize it for the next destination**
  - *The source content must be of high quality*
    - » Color re-rendering is not image correction
- **Gamut mapping algorithms try to maintain the appearance to the extent possible**
  - Within the capabilities of the destination medium
  - Color appearance models, which map to and from perceptual correlates, are most directly applicable to gamut mapping
- **Algorithms that attempt to determine corresponding colors can be used to deal with adaptation changes in either case**
  - e.g chromatic adaptation transforms

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Conversion: V4 PCS encoding improvements

- **ICC PCS CIELAB value encoding range is defined to match common CIELAB encoding usage**
  - — L* = 100 is encoded as FFFFh (L* = 100 was encoded as FF00h)
  - — a*, b* = 127 is encoded as FFFFh (was encoded as FF00h)
  - — Note that a legacy exception is allowed
    - – lut16Type and namedColor2Type tag types (and ONLY those tag types) use a legacy 16 bit encoding of L*, a* and b* (version 2 compatibility)
    - – To avoid confusion this encoding is specified in the defining clause for “Lut16Type”
- **Handling of PCS encoding bounds is defined between CIE XYZ and CIE LAB**
  - — Consistent behavior among CMMs when converting between two PCS encodings
  - — Conversions between the CIEXYZ and CIELAB encodings shall use the equations specified in CIE 15.2
  - — Colors in the PCS XYZ encoding range that are outside of the PCS LAB encoding range shall be clipped on a per-component basis to the outside limits of the range of PCS LAB when transforming from XYZ into LAB
  - — Colors that occur in the PCS LAB encoding range that are outside of the encoding range of PCS XYZ shall be clipped on a per-component basis to the PCS XYZ range when transforming from LAB into XYZ

PCS viewing conditions are clarified, defined

- **Default illuminant D50 at 500 lux**
- **Reference Medium viewing condition ISO 3664 P2**
- **Methodology for chromatic adaptation**
  - — If the chromaticity of the 'device' illuminant (light source of the measurement environment) is different from that of D50
    - – Corrections for chromatic adaptation must be incorporated into the media-relative colorimetric and perceptual transforms by the profile builder
      - - Transform real color values - under the measuring illumination - to D50 relative values
    - – The profile must include a Chromatic Adaptation Tag that provides the chromatic adaptation matrix that was used
- **mediaWhitePointTag contains the CIE 1931 XYZ colorimetry of the white point of the actual medium, adapted to the PCS illuminant (D50)**
  - — In a DISPLAY profile - the mediaWhitePointTag must equal D50
- **mediaBlackPointTag contains the CIE 1931 XYZ colorimetry of the black point of the actual medium, adapted to the PCS illuminant (D50) using the same chromatic adaptation matrix**

Conversion: New lutAtoB and lutBtoA for round-tripping

- **Round-tripping capability is critical for proofing, re-purposing, general color re-rendering**
  - The new lutAtoBType and lutBtoAType structures improve on V2 lut16Type and lut8Type
  - B-to-A and A-to-B processing paths can be exact inverses
  - A, B. M curves are curveType or parametricCurveType
  - Matrix can have an offset
  - CLUT can have a variable number of grid points in each dimension
    - Channel response may require fewer or greater # of grid points
- The following sequence lutAtoB combinations are allowed
  - **B**
  - **M → matrix → B**
  - **A → CLUT → B**
  - **A → CLUT → M → matrix → B**
- The following lutBtoA sequence combinations are allowed
  - **B**
  - **B → matrix → M**
  - **B → CLUT → A**
  - **B → matrix → M → CLUT → A**
- Other sequence combinations can be achieved by setting processing element values to identity transforms
- **V4 "N-component LUT-based" display profiles**
  - Next generation wide gamut RGB displays require CLUT-based profiles for accurate color characterization and round-tripping

Perceptual Rendering Invertability in V4

- **Perceptual Rendering Intent transform design should support round-tripping**
  - Design the forward transform while considering the V4 requirement to provide an inverse transform
- **Inverse transforms are used for a variety of purposes:**
  - Depending on whether a profile is used as a source or destination profile, either the AtoB0 or the BtoA0 transform may be the "forward" transform
    - e.g. color re-rendering sRGB SCID to CIELAB SCID, and vice-versa.
  - It is desirable to be able to precisely "undo" a perceptual rendering so that content can be re-rendered to a different destination
  - Providing transforms in both directions greatly reduces loss when the exchange color encoding has gamut limitations that are not applicable to the source and destination

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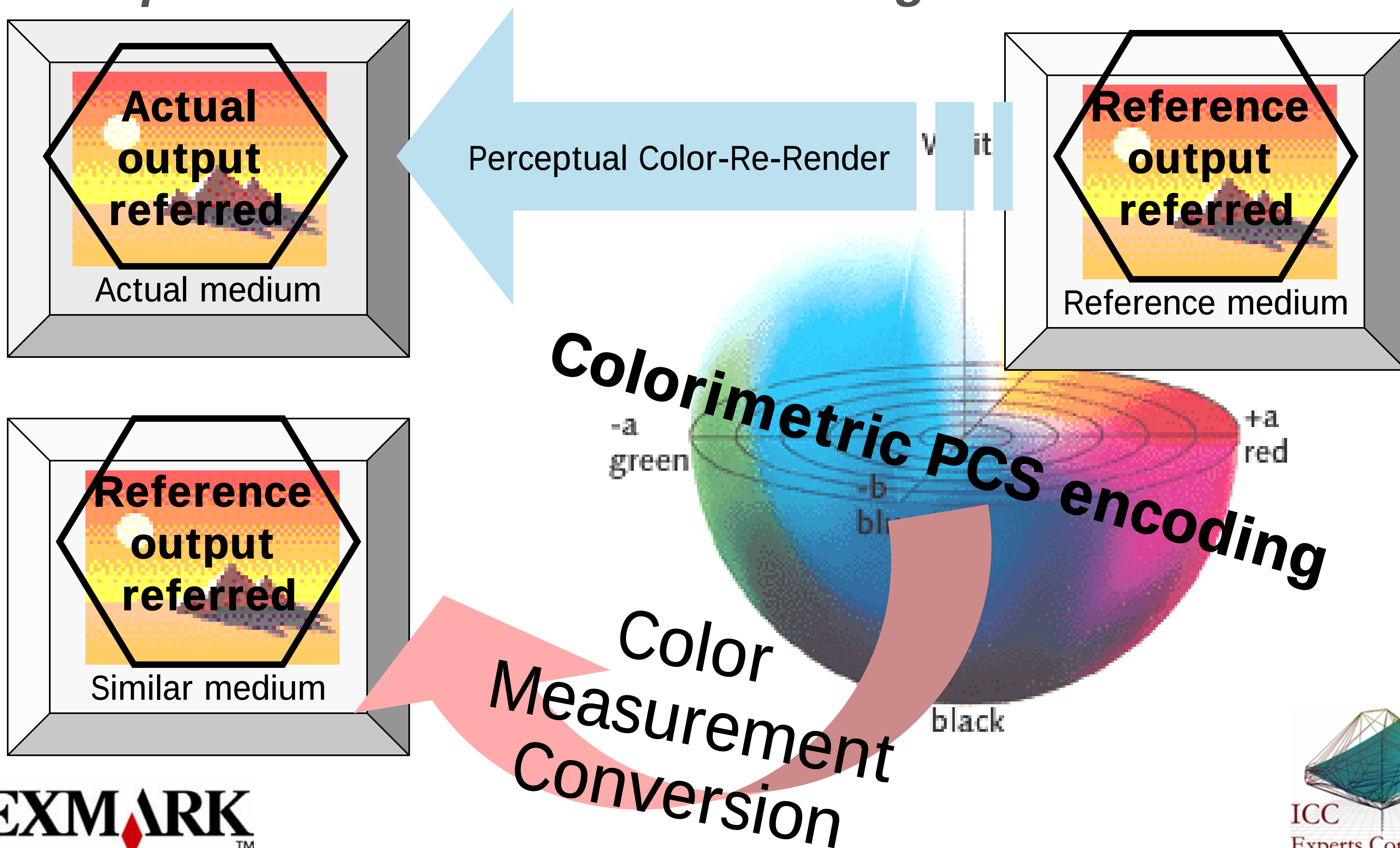
ICC Version 4 provides practical improvements for color interpretation and conversion:

►*output conversions from PCS image states*



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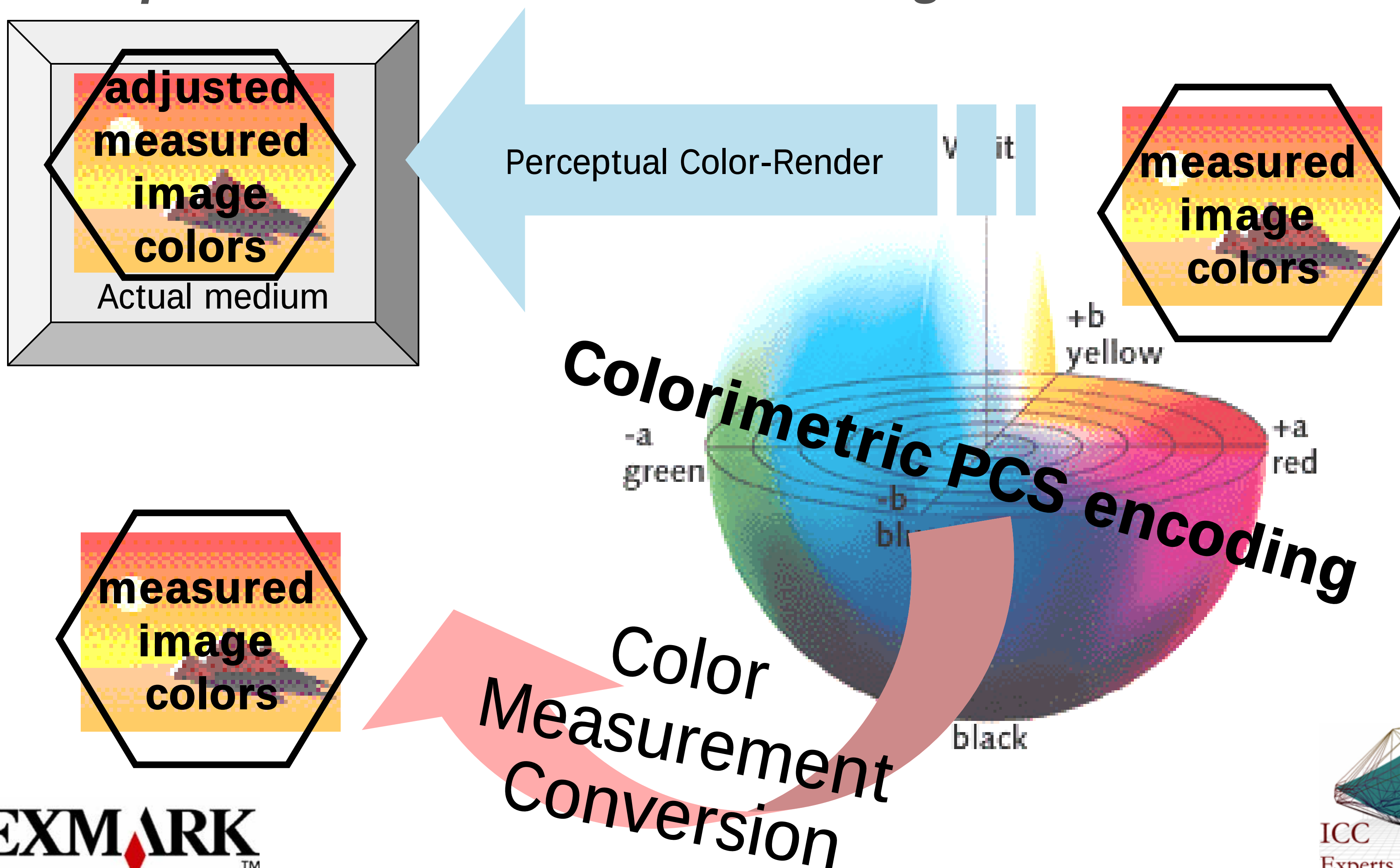


V4 Enables CMM Conversion Mode Options

- **A color management color engine may seek to match colors between source and destination**
- **...or may seek to deliver preference adjusted colors [color rendering and color re-rendering]**
- **V4 supports three conversion modes for either of these objectives**
  - —Locked conversion
  - —Static CMM conversion
  - —Dynamic CMM conversion

- **ICC DeviceLink locked conversion**
  - Device-dependent proprietary color encodings become device-independent and can be interpreted in a standard way
  - Proprietary ‘working space’ color space encodings can be interpreted in a standard way
  - Each profile contains ‘interpretation-from’ and ‘production-to’ transforms for a device/other color image encoding --- referenced to a human visual color image encoding
  - Such color management systems are suited to handle color conversions for a variety of digital color image encodings
- **ICC Static CMM**
  - Proprietary or standard color productions can be defined precisely for specific devices, viewing conditions, image states, media characteristics & preferences
    - Predetermined transforms built into ICC perceptual transforms use color appearance models
  - Both matching and preferred production conversions can be defined
    - Note that TWO preferred productions (perceptual, saturation) can be defined in each profile
    - For certain use cases, certain workflows, other productions may be desired
- **ICC Dynamic CMM**
  - Relative colorimetric conversion components from Version 4++ profiles can be combined with color appearance adaptations, custom gamut mapping, etc., in ICC PCS to provide runtime computed color conversions
  - Note that this method relies on additional algorithmic capability and metadata provided to the CMM

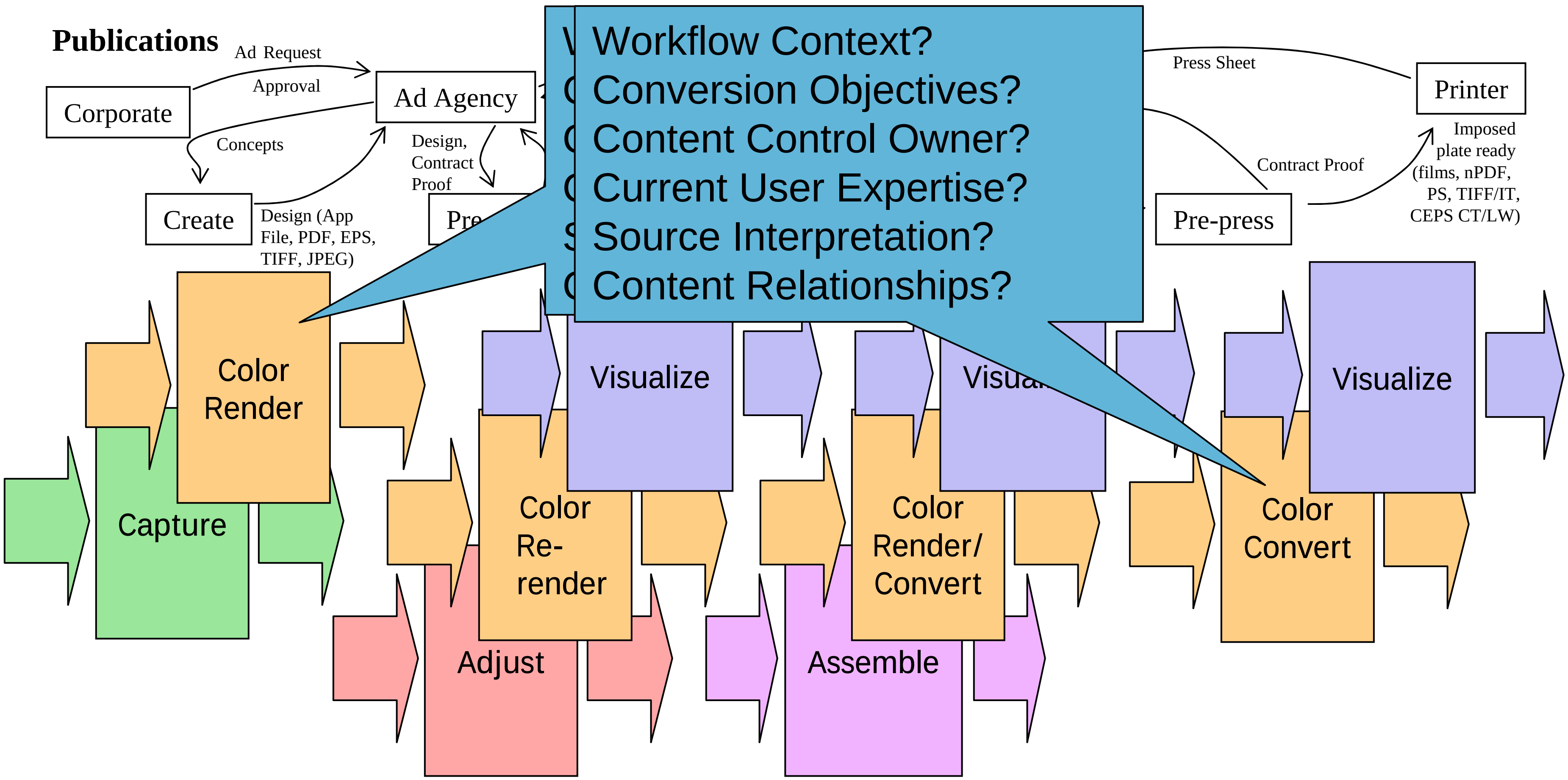
Use Dynamic CMM or Static CMM with ICC Profile perceptual intent transform for pleasing results?

- **Dynamic CMM transforms are determined at time of output, providing greater freedom and control later in the process**
  - Depending on software, user could be able to select (as needed)
    - Corresponding color (appearance) model
    - Color rendering/re-rendering
    - Gamut mapping
  - Caution: Selected transform combination may not be pre-tested
    - Final result may not be what source content provider expects
    - User must be able to evaluate
- **ICC Profile Perceptual intent allows early control of the color transform to be provided with the source image**
  - Predictable output; pre-tested transforms
  - Transforms can be complex and hand-tweaked
    - Multiple working spaces and/or algorithms can be used
  - With good transforms, less user interaction is required

Conversion method selection considerations

- **Workflow context**
  - — Is flexibility desired / is repeatability desired for later conversions
- **Conversion objectives**
  - — Match/Pleasing Adaptation
  - — Static or Changing Viewing Environment
- **Content control owner**
  - — Is the preferred color locked in or still in flux?
- **Current user desires**
  - — Hands On/Hands Off
- **Source interpretation**
  - — Color encoding ambiguity/interpretation
  - — Image state
- **Content relationships**
  - — Object metadata hierarchy
  - — Object layout groupings and spatial relationships

Selecting conversion method in a workflow context



In each color conversion - choices are made regarding adapting to a new viewing situation, creating a new look, preserving a look or design that was created previously, and/or mapping to a new display/print mechanism

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Thank you

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Backup

Color Management System - Color Control Model

These color management system processes control color results

Explicitly via purposeful control

Implicitly via lack of control

These 7 color controls are inherent in any digital color system

- **For types of users, regions of the world, markets**
  - Visualization

Development time can be unrelated to a particular product or system

- **For each device**
  - Device Calibration
  - Characterization
  - Color Aim Definition

Considered an offline activity – computed and stored before actual use (in current systems)

- **For the system**
  - Communication
  - Interpretation
  - Conversion

Real-time executions – depend on design of interfaces, protocols, formats, algorithms – meshing with pre-computed elements

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Color Management System - Color Control Model

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These 7 color controls are inherent in any digital color system

- **For types of users, regions of the world, markets**
  - —Visualization

Sources of error: subjects alignment with target market, experimental design

- **For each device**
  - —Device Calibration
  - —Characterization
  - —Color Aim Definition

Sources of error: measurement devices, device model, gamut boundary determination, LUT size vs. gamut non-linearities, appropriate target definition

- **For the system**
  - —Communication
  - —Interpretation
  - —Conversion

Sources of error: design omissions, mismatched component interface definitions, interpolation inaccuracies, missing metadata