International Color Consortium

Design & Use of the Perceptual Rendering Intent for v4 Profiles

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Outline

- **What is ICC v4 perceptual rendering?**
  - — What is “perceptual” rendering?
  - — Differences from ICC v2
- **Color rendering, color re-rendering, and gamut mapping**
  - — Preferred reproduction algorithm components
- **Ways to obtain preferred reproductions using ICC**
  - — Profile transforms (colorimetric, perceptual, saturation)
  - — CMM extensions (ICC-absolute, BPC, and so on)
  - — Whether to use smart profile or smart CMM transforms
- **Constructing perceptual intent transforms**
  - — Baseline best practices
  - — Getting fancy
- **Evaluating the quality of perceptual transforms**
  - — Color re/rendering, smoothness, invertability
- **Closing suggestions & cautions**

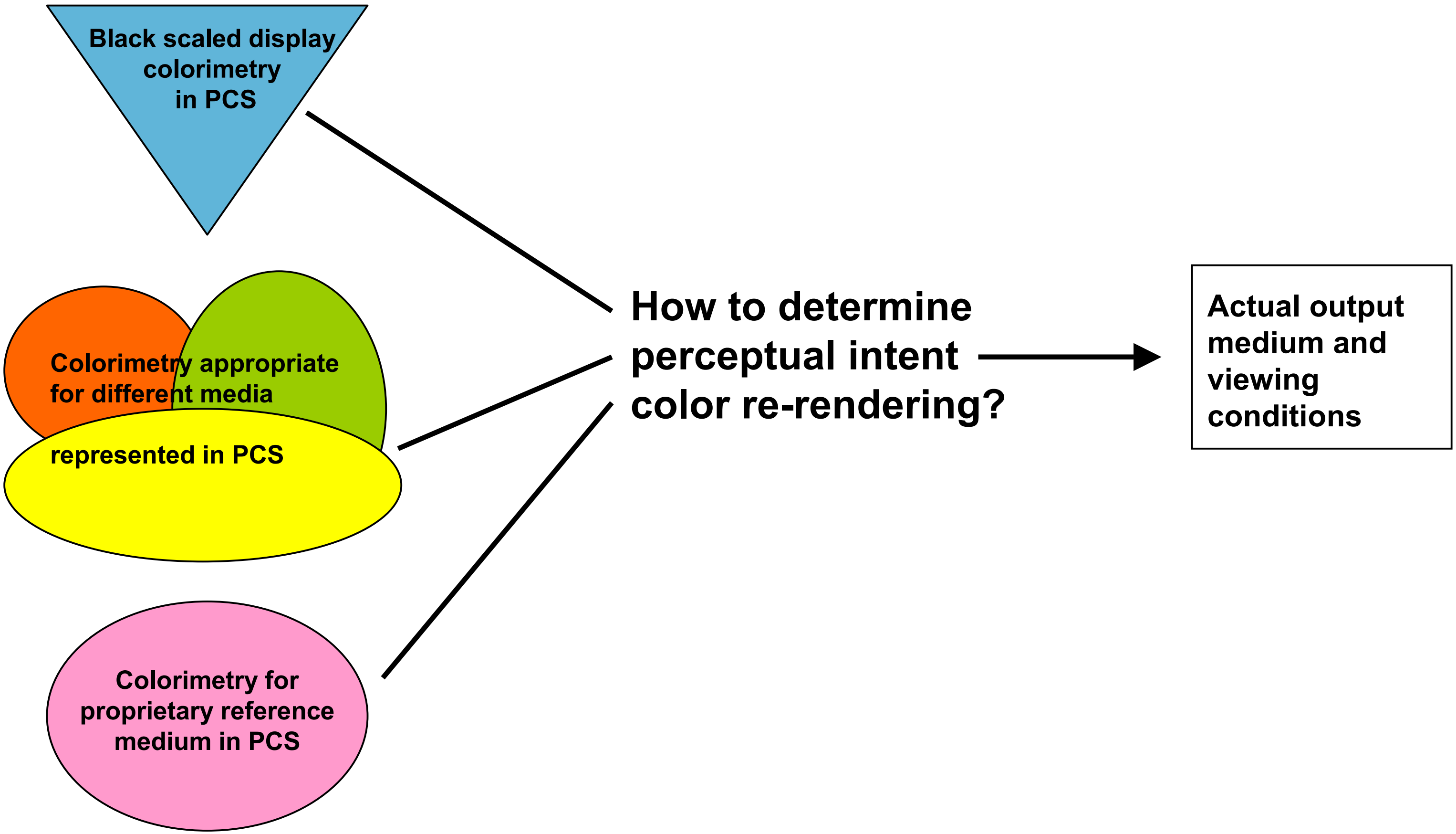
What is “perceptual” rendering?

- **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 are affected by differences in source and destination media capabilities and user preferences, as well as viewing conditions.**

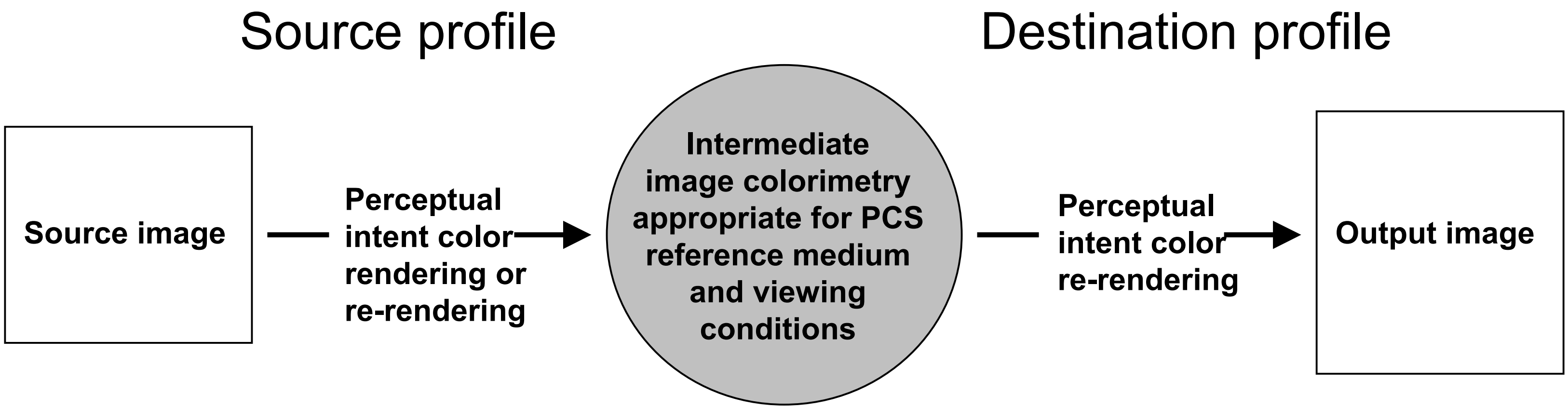
What is different about the ICC v4 PI?

- **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.
- **With ICC v4, the source profile perceptual intent transform is required to color re/render to the PRM, and the destination transform from the PRM.**

A v2 output-side profile knows the destination, but there are many possible starting points in the PCS



ICC v4 Perceptual path



CMM connects profile PRM colors in the PCS

- minimal gamut mapping needed because image colorimetry in PCS is matched for input and output
- source and output media (and viewing condition) differences are dealt with in perceptual intent color maps

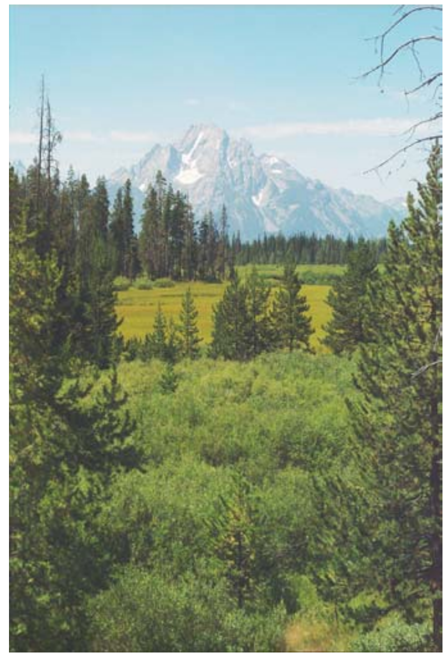
Color rendering

- **simple definition – starting with the colors captured in a (three-dimensional) scene, and creating the desired colors for a reproduction of the scene for some anticipated output medium and viewing conditions.**
  - See ISO 22028-1 for exact definition
  - There is usually a significant difference between the scene colors, and the optimized reproduction of the scene on some output medium
    - Color rendering choice is subjective which implies image state change
- **Sometimes the term color rendering is used generically to mean the creation of the desired colors for a reproduction medium, regardless of the starting image state, or even for the rendering of colors on some output device.**
  - I will try to follow the strict definition – scene to picture

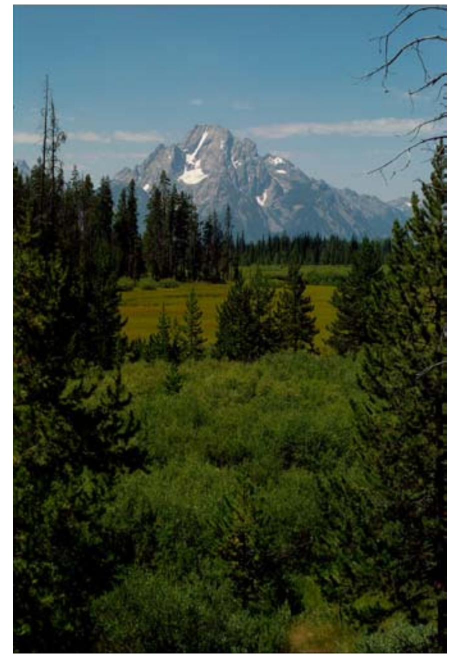
Scene colors rendered for different media & viewing conditions

scene colorimetry

color rendered to
sRGB display colorimetry



color rendered to
plain paper
print colorimetry



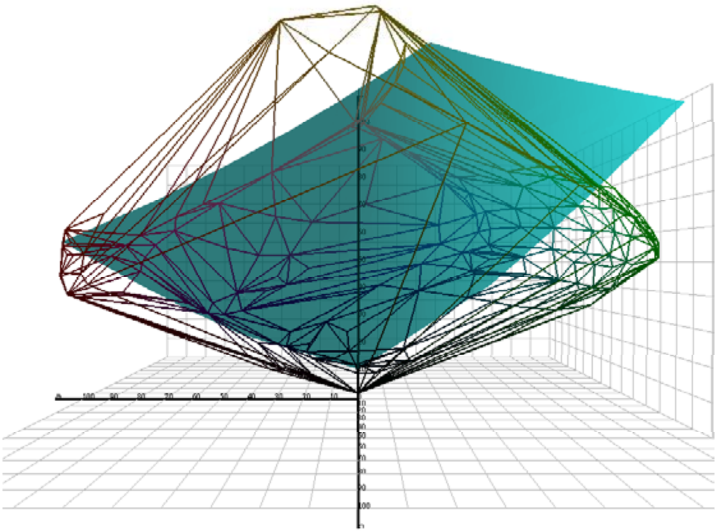
color rendered to
film transparency colorimet

Color re-rendering

- **simple definition – starting with the colors of a two-dimensional image (a picture), and creating the desired colors for a reproduction on some different anticipated output medium**
  - See ISO 22028-1 for exact definition
- **If the reproduction goal is exact color matching, or the source and destination media and viewing conditions are the same, color re-rendering is not needed**
- **If the reproduction goal is preferred reproduction, color re-rendering will re-optimize the colors of the source image, considering its medium and viewing conditions, for the destination medium and viewing conditions**
  - The source image is interpreted to be the desired artistic intent
    - Perceptual intent transforms often perform color re-rendering
    - sRGB printer color maps often perform color re-rendering

Why is color re-rendering needed?

- **Viewing condition differences may require different colorimetry to maintain appearance**
  - But 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).

Gamut mapping

- **simple definition – mapping the colors of a source image to fit within a destination medium gamut**
  - The source colors are assumed to be those desired on the destination medium
    - The reproduction goal IS color matching (measurement or appearance)
    - It is not necessary to consider the source medium characteristics
- **Term sometimes used generally to include color re-rendering**
- **It may be necessary to compensate for different visual adaptation states to achieve color matching if the source and destination medium viewing conditions are different**
  - ICC profile colorimetric intents include chromatic adaptation
    - Use viewing conditions tag info to deal with other adaptation effects
  - Luminance and surround adaptation effects can be difficult to quantify, and to separate from cross-media color optimization

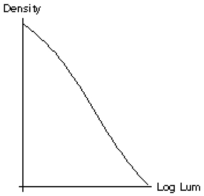
Why distinguish between color rendering and re-rendering and gamut mapping?

- **Color rendering and re-rendering algorithms change the appearance of the content, to produce a pleasing adaptation for the intended destination**
  - While maintaining the artistic intent of the source
    - *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
- **Algorithms that attempt to determine corresponding colors can be used to deal with adaptation changes in either case**
    - e.g chromatic adaptation transforms
  - But color appearance models, which map to and from perceptual correlates, are most directly applicable to gamut mapping

Practically, what are the implications?

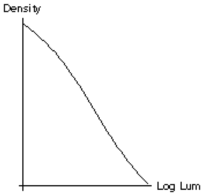
- **Color rendering and re-rendering operations are typically best performed in a color space based on physical correlates**
  - Directly related to quantities of light
    - e.g. CIE XYZ, colorimetric RGB encodings
  - Adjustments in a physical space may cause changes in perceptual correlates, but colors remain natural
- **Gamut mapping is typically best performed in a color space based on perceptual correlates**
  - Directly related to perception
    - Hue, colorfulness, chroma, lightness
    - e.g. CIELAB, CIECAM
  - Adjustments in a perceptual space makes it easier to maintain perceptual attributes, but large changes may produce un-natural results

Example - color rendering, 24:1 scene



color rendered to sRGB using
tone curve applied to RGB channels

scene colorimetry



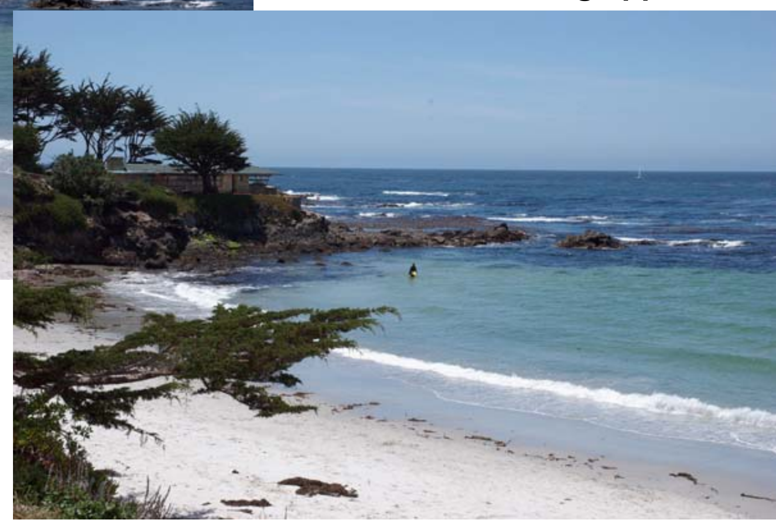
color rendered to sRGB using
tone curve applied to L* values

Color rendering - 215:1 scene

scene white = repro white
colorimetric reproduction

scene gray = repro gray
colorimetric reproduction

image specific tone curve
color rendering applied



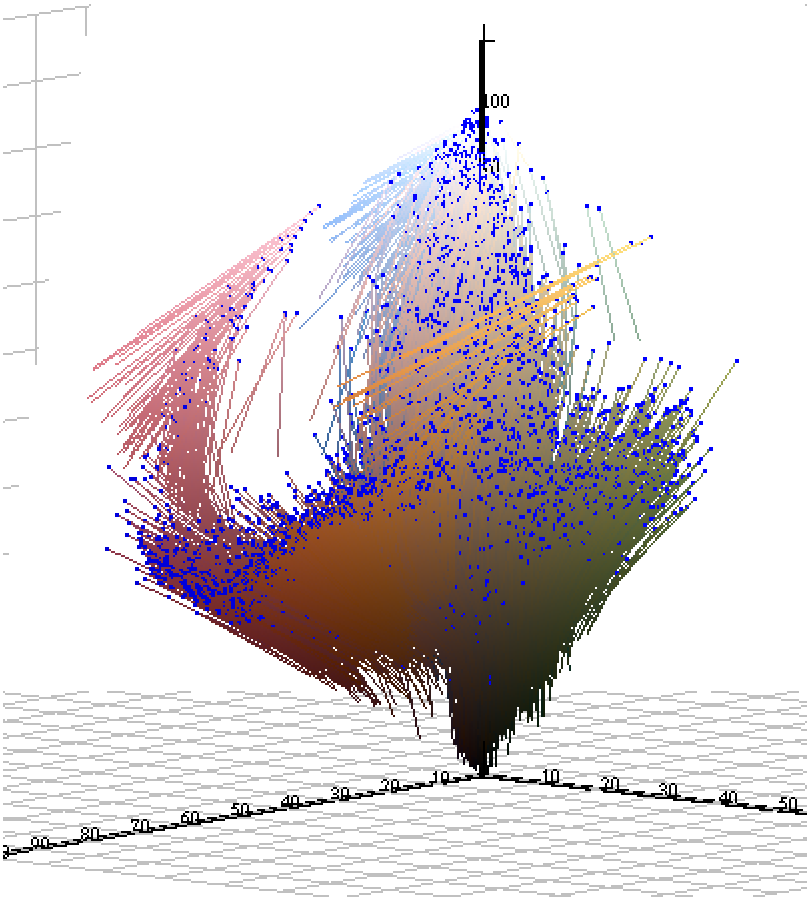
Color rendering - 530:1 scene

scene white = repro white
colorimetric reproduction

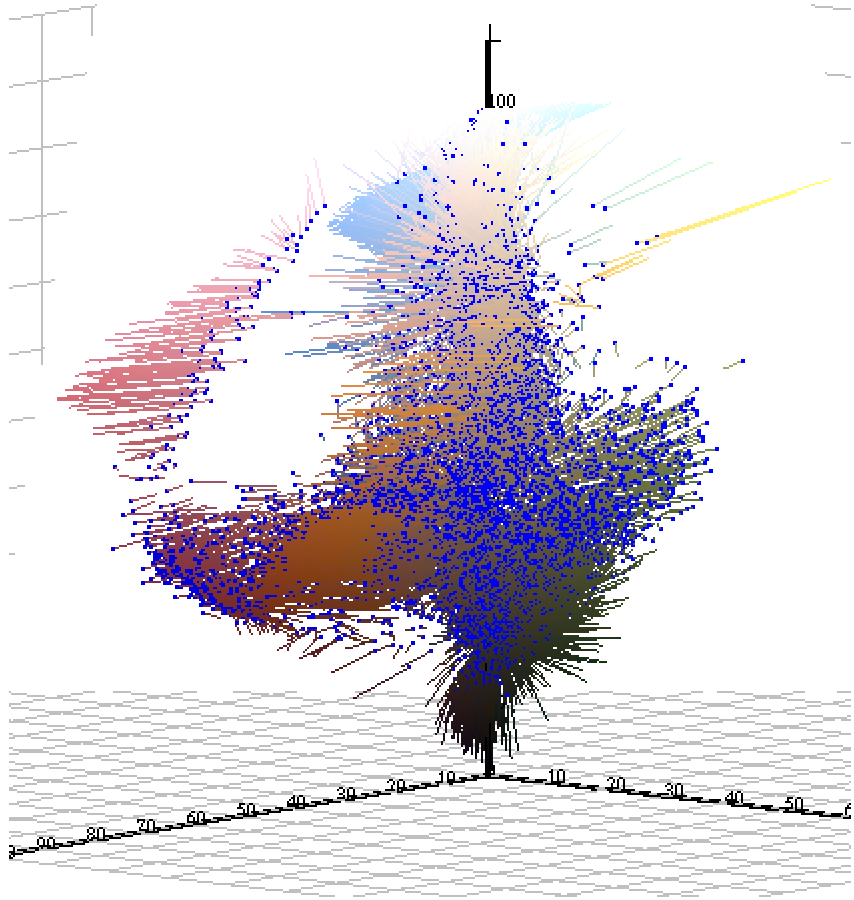
scene gray = repro gray
colorimetric reproduction

image specific tone curve
color rendering applied

What’s happening to the colors?



CIE L*u*v* color changes – white SR to rendered



CIE L*u*v* color changes – gray SR to rendered

Example - color re-rendering

original sRGB image

preview of plain paper reproduction

back to sRGB using RGB scaling

back to sRGB using L* scaling

Preferred reproduction algorithm components

- **Interpretation of appearance of source color encoding values**
  - Device/encoding colorimetric characterization,
  - Estimation of adaptation state
  - Consideration of media capabilities
- **Color rendering or re-rendering to produce desired destination appearance (optimize image for destination)**
  - White and black point mapping; RGB tone curves
  - Gamut/primary warping & preference adjustments
  - Compensation for differences in adaptation state
- **Gamut mapping to fit colors in destination medium gamut**
  - If necessary
- **Conversion of destination medium colors to device values for output**

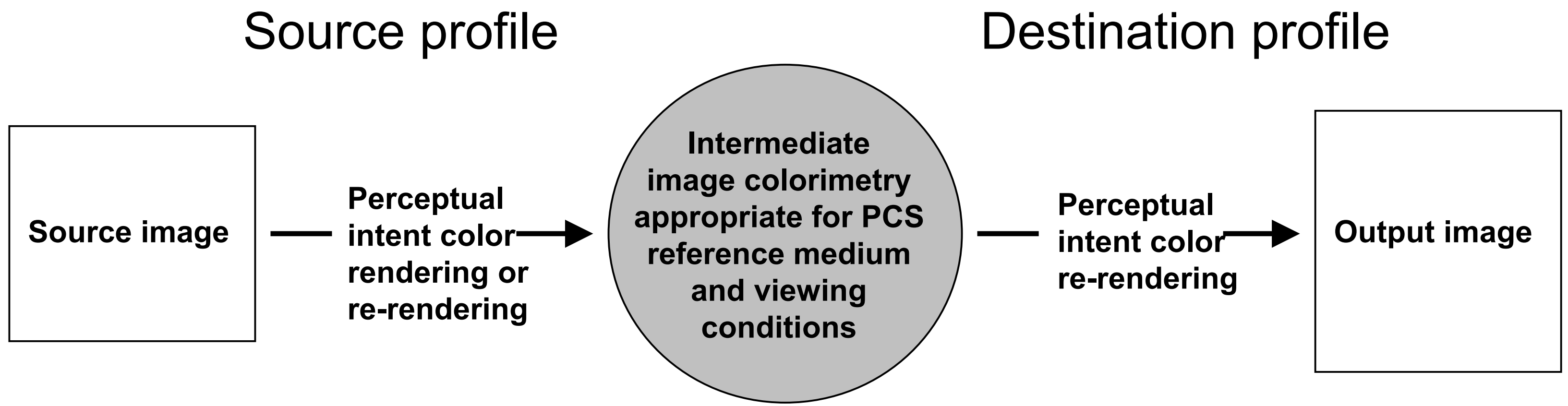
Ways to obtain preferred reproduction

When exact color matching is not the goal

- e.g. NOT proofing or preview

- **Use ICC v4 profile perceptual rendering intent transforms**
  - The source profile AtoB0 and the destination profile BtoA0 tags are combined to produce the preferred reproduction transform, which is then applied
- **Use ICC CMM-based preferred reproduction algorithms**
  - Black point compensation through XYZ scaling
  - More algorithms likely to come
    - CMM-based preferred reproduction is more difficult, because transforms must be determined algorithmically on-the-fly
      - No hand tweaking

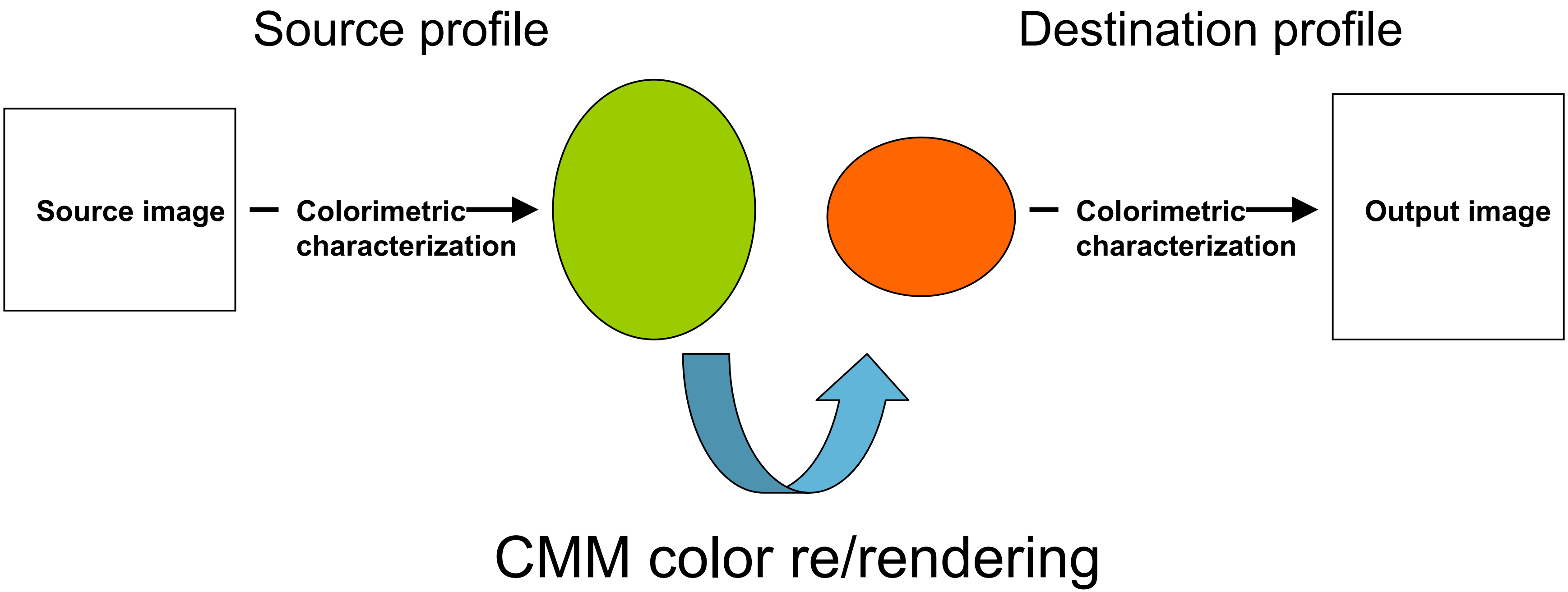
ICC v4 Perceptual path



CMM connects profile PRM colors in the PCS

- minimal gamut mapping needed because image colorimetry in PCS is matched for input and output
- source and output media (and viewing condition) differences are dealt with in perceptual intent color maps
- source and destination profile transforms are typically combined to produce a single transform

“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
- enables unlimited “CMM rendering intents”
- facilitates user adjustment of color re-rendering at time of output

Smart CMM or perceptual intent transform?

- **Smart 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 (e.g. BPC, tone curves, gamut warping)
    - gamut mapping
  - Selected transform results may not be pre-tested
    - final result may not be what source content provider expects
    - user must be able to evaluate
- **Perceptual intent allows intended 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

Perceptual transform characteristics

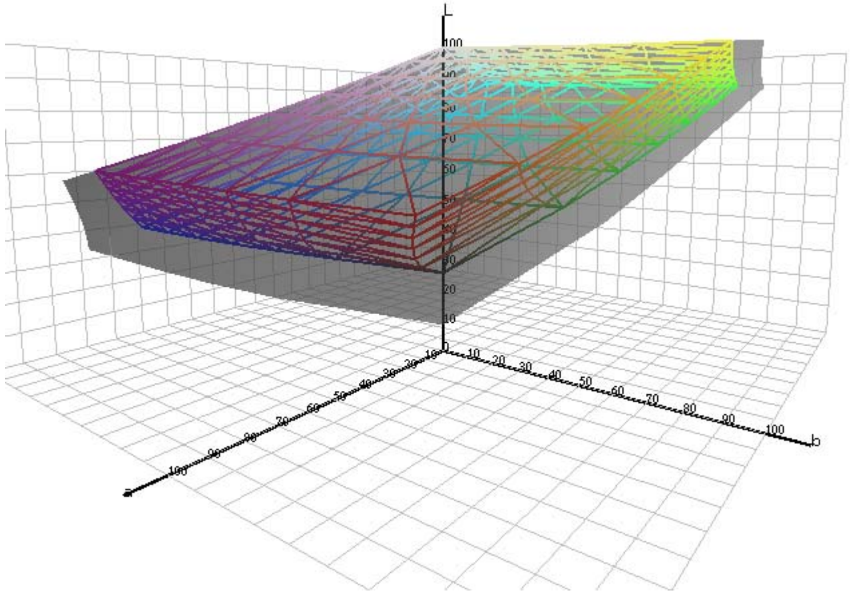
- **Useful for general image reproduction across devices/media**
  - Enables fully automatic ICC workflows
- **Color re-rendering typically proprietary, so profiles from different sources may produce different "looks"**
  - Users select profiles based on color re-rendering preferences
    - However, this is currently difficult due to confounding of v2 issues and lack of coordinated color management (OS, App, Driver/RIP)
  - If differences between actual media and the ICC perceptual reference medium are small, perceptual and colorimetric intents should converge
- **Currently, users are cautious about the perceptual intent because of v2 experience**
  - Need availability of good v4 profiles and coordinated color management to gain confidence in all-perceptual workflows

Baseline best practices

- **Applicable to both perceptual intent transforms and smart CMM color re-rendering (PCS reference medium may be source or destination).**
  - Use chromatic adaptation transform to convert source adopted white chromaticity to destination
  - Map source white point to destination white point
    - Media-relative-colorimetric
    - Luminance factor matching
      - Maintain source media white chromaticity
  - Map source black point to destination black point
    - XYZ scaling; how to define black point
  - Gamut mapping
- **Works best if source and destination gamut shapes are similar**

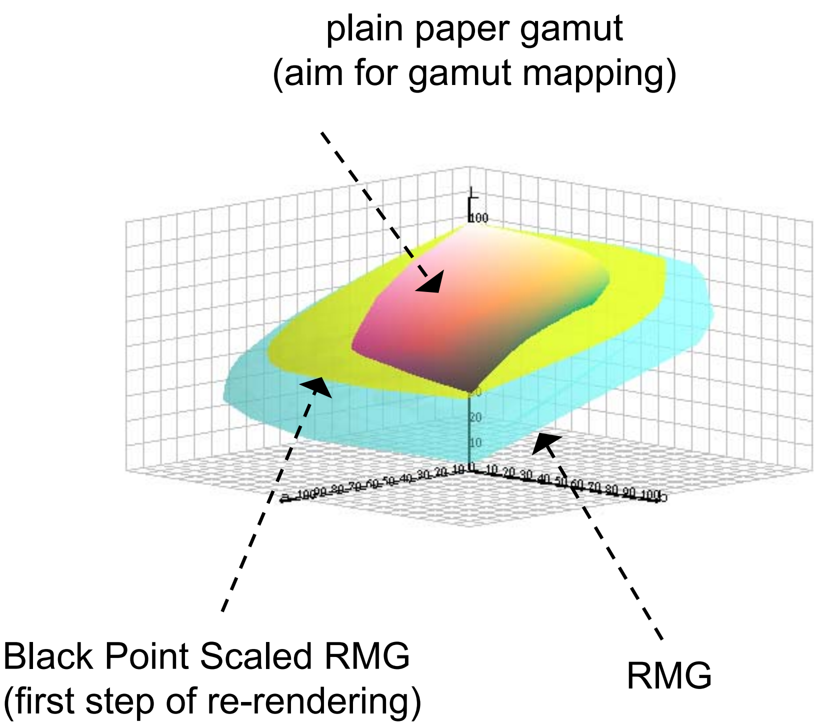
Effect of BPC on gamut

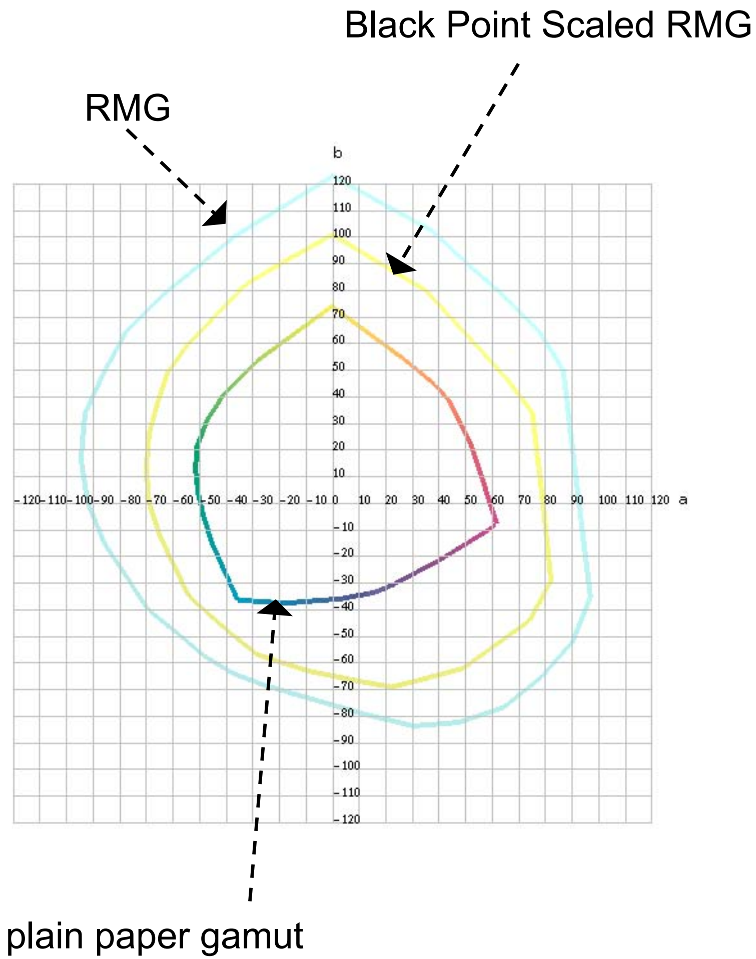
- **Black point compensation through XYZ scaling simulates varying levels of veiling glare, which plausibly changes the source gamut to more closely match the destination gamut**
  - Whole gamut expands and contracts
  - All colors except white are affected
- **Black points of source and destination media must be appropriately selected**



Effect of BPC on display gamut

Simple perceptual transform from RMG to device gamut

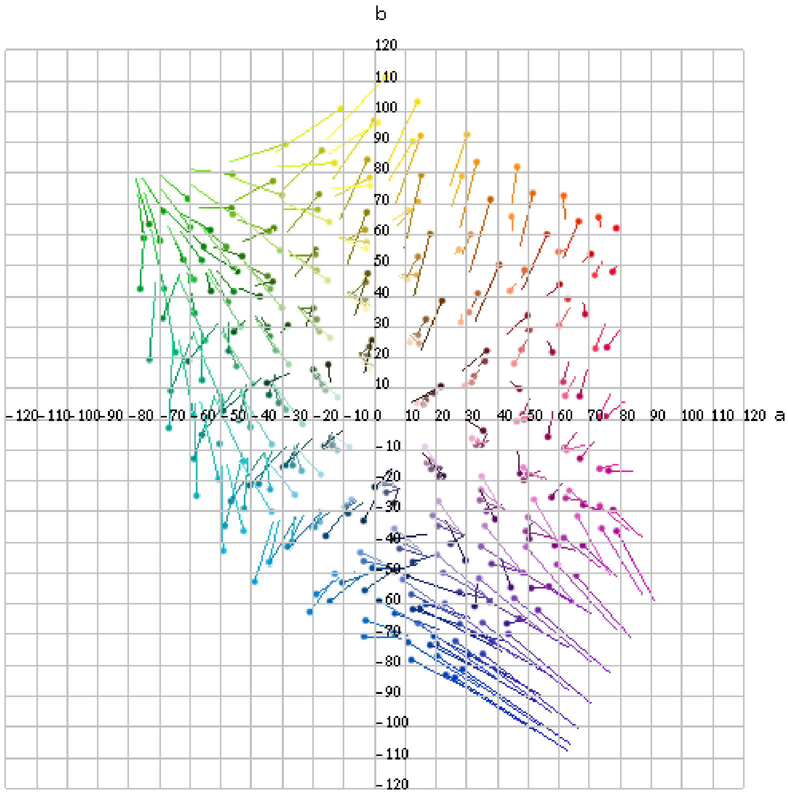


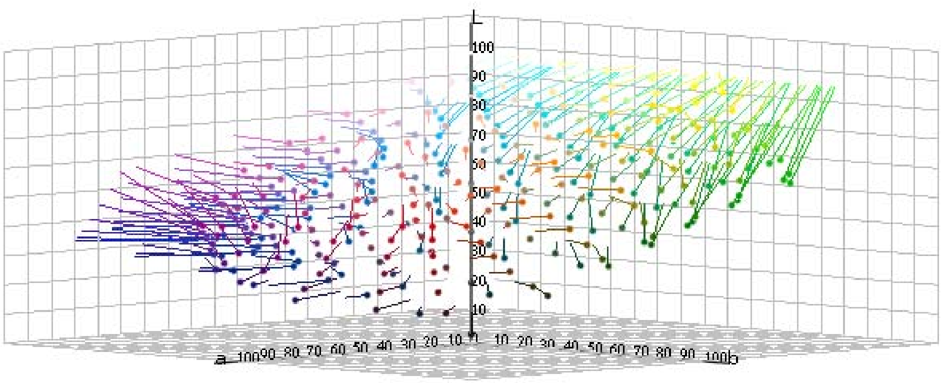


Going further

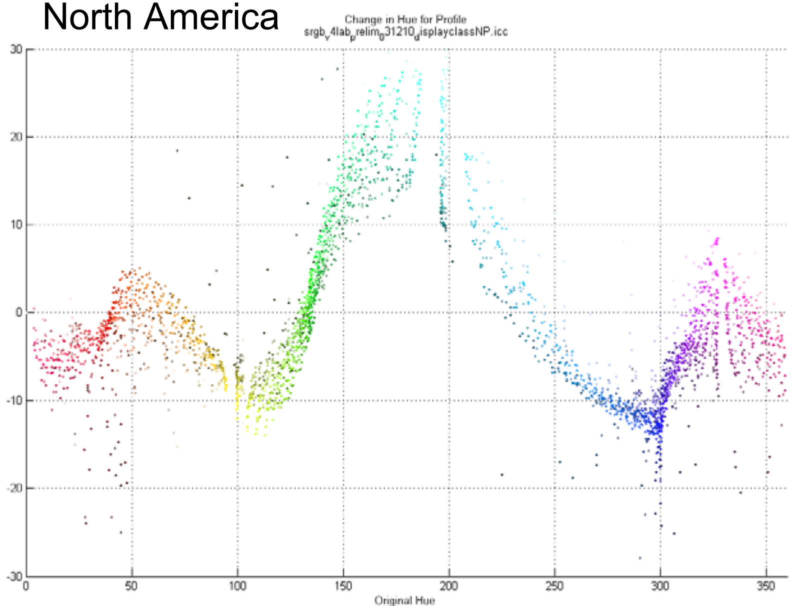
- Color appearance models (like CIECAM 02) can be used to produce corresponding colors for some different adaptation states, but this must be done carefully
  - May de-optimize colors for destination
  - Understanding of color appearance continues to evolve
    - Spatial effects in images are significant, but only beginning to be considered
    - Perceptual correlates are not as well-founded as CIE XYZ, Lab, etc.
- Different working spaces are often best for different operations
  - RGB spaces tend to be best for applying tone curves, and for chromatic adaptation
  - Perceptually uniform color spaces are usually best for gamut warping, primary mapping, and gamut mapping (out-of-gamut error minimization)
- Hand tweaking
- TESTING!

Example sRGB to ICC v4 PRM transform

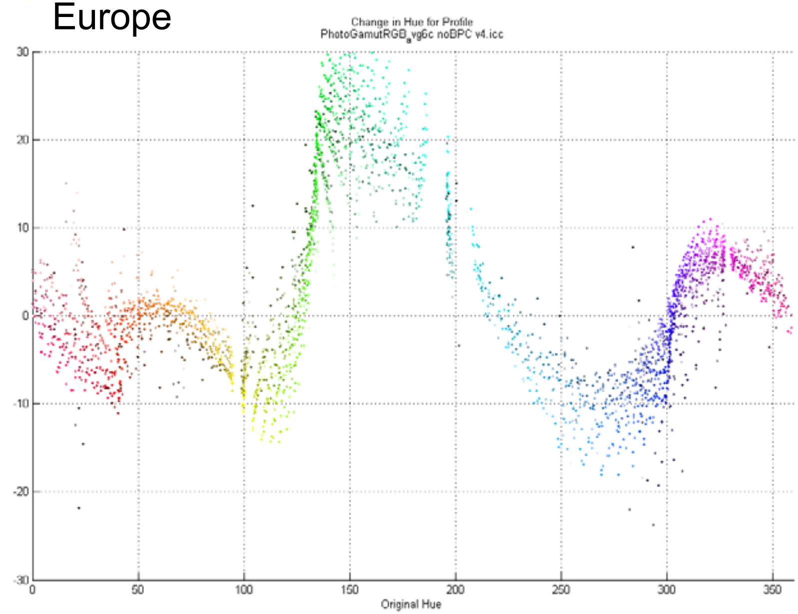




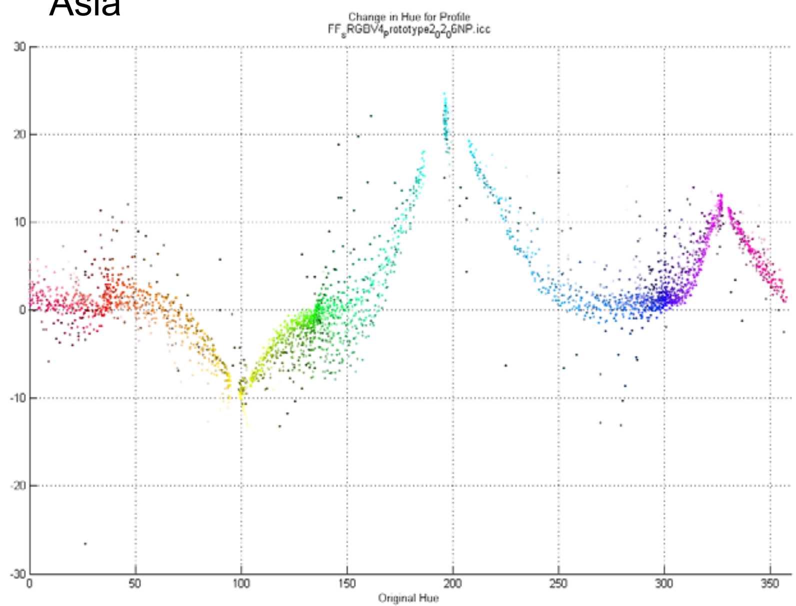
North America



Europe



Asia



Comparing hue shifts from three independently developed sRGB-to-print color re-renderings

PRM to sRGB example result

MRC+BPC baseline

advanced perceptual transform

AtoB0 transform components

- **Transform from source values to working space for color re-rendering (usually colorimetric, radiometrically linear RGB)**
  - Determine white point mapping (includes chromatic adaptation)
  - Determine black point mapping (select black points, then scale)
  - Apply color re/rendering tone curve (for larger media/viewing condition differences)
- **Transform to perceptual correlates working space for gamut morphing & mapping (e.g. CIECAM)**
  - Primary & secondary mapping
  - Preference adjustments (including gamut expansion, contraction)
  - Final gamut mapping (to clean up remaining out-of-gamut colors)
- **Transform to PCS values**

Evaluating perceptual rendering transforms

- **There is no objective metric, subjective evaluation is required**
- **You have to use images (lots of them)**
  - Natural images to check naturalness and pleasingness
    - The source test images need to be processed to the appropriate image state for the evaluation to be meaningful
      - ISO 12640-1 CMYK SCID to test CMYK to PRM transforms
      - ISO 12640-2 sRGB SCID to test sRGB to PRM
      - ISO 12640-3 CIELAB SCID to test PRM to actual output transforms
  - Test charts to check for smoothness, artifacts, etc.
    - But the test charts themselves need to be smooth and free of artifacts.
- **A few expert observers can replace a large number of inexperienced observers, making subjective evaluations tractable**

Invertability

- **It may be necessary to design the forward transform 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 often desirable to be able to "undo" a perceptual rendering so 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

Closing suggestions

- **It is important to distinguish between the corresponding color and preferred reproduction goals**
  - We do not know the best answer regarding corresponding colors
  - There is no single answer regarding preferred color reproduction
  - Don’t confuse trying to maintain source colors with trying to optimize them for the destination
- **When creating perceptual transforms, don’t do more than necessary**
  - Use MRC+BPC if it produces good results
  - When transforms with more complex color re/rendering are needed, choose the correct order of operations, working spaces & algorithms
- **Test results on large numbers of images**
  - Typically it is better to have many images and a few expert observers as image content is a large source of variability