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 colorimetry
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
Simple perceptual transform from RMG to device gamut

Black Point Scaled RMG (first step of re-rendering)

Plain paper gamut (aim for gamut mapping)

Black Point Scaled RMG

RMG

Plain paper 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
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