Device-Independent Rendering in Display Color Space

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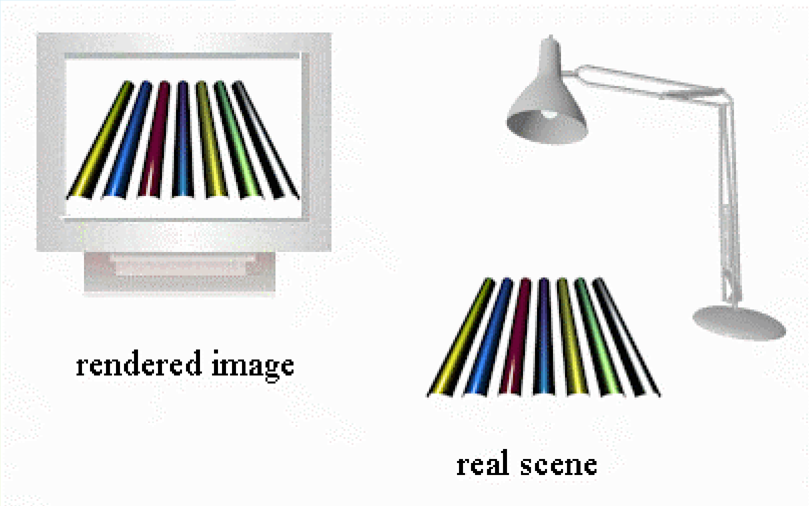
The Problem



- Reproduce colors of real objects on synthesized images
- Ensure identity of rendered colors on different displays (device-independence)

Solutions

- Render in some standard space, spectral or tristimulus (RGB or CIE XYZ), and convert the result to the RGB space of a current display. Drawback: graphics hardware cannot be used.
- Render in the display color space (in the trichromatic approximation). Drawback: lack of device independence.

How to make rendering in display space device-independent?

ANSWER: To make the surface color a matrix - diagonal in some reference space (e.g. CIE XYZ) and non-diagonal in the display RGB space.

The reference space is chosen such that color calculation in it is sufficiently accurate. CIE XYZ meets this criterion (C.F. Borges, 1991).

Main assumptions

- Conversion from the reference space to the display space is linear (chromatic adaptation can be included)

$$\begin{vmatrix} \mathbf{R} \\ \mathbf{G} \\ \mathbf{B} \end{vmatrix} = \mathbf{A} \begin{vmatrix} \mathbf{X} \\ \mathbf{Y} \\ \mathbf{Z} \end{vmatrix}$$

$$\mathbf{A} = \mathbf{M} \quad \text{or} \quad \mathbf{M}\mathbf{R}^{-1}_{\text{display}}\mathbf{R}_{\text{scene}}$$

$$\text{where } \mathbf{M} = \text{XYZ-to-RGB}$$

$$\text{and } \mathbf{R} = \begin{vmatrix} \mathbf{X}^{-1}_{w} & 0 & 0 \\ 0 & \mathbf{Y}^{-1}_{w} & 0 \\ 0 & 0 & \mathbf{Z}^{-1}_{w} \end{vmatrix}$$

- Light is a vector, so the color of a source is converted from the reference to display space as

$$\begin{vmatrix} \mathbf{L}_R \\ \mathbf{L}_G \\ \mathbf{L}_B \end{vmatrix} = \mathbf{A} \begin{vmatrix} \mathbf{L}_X \\ \mathbf{L}_Y \\ \mathbf{L}_Z \end{vmatrix}$$

- Surface color is a matrix, diagonal in the reference space

$$\mathbf{C}^{ref} = \begin{vmatrix} \mathbf{c}_X & 0 & 0 \\ 0 & \mathbf{c}_Y & 0 \\ 0 & 0 & \mathbf{c}_Z \end{vmatrix}$$

- This ensures trichromatic approximation in the reference space

What is the surface color in the display space?

- ANSWER: a matrix. Because we assume trichromatic approximation in the reference space (CIE XYZ), we have

$$\mathbf{C}\begin{vmatrix}\mathbf{L}_{\mathrm{R}}\\ \mathbf{L}_{\mathrm{G}}\\ \mathbf{L}_{\mathrm{B}}\end{vmatrix} = \mathbf{A}\mathbf{C}^{\mathrm{ref}}\begin{vmatrix}\mathbf{L}_{\mathrm{X}}\\ \mathbf{L}_{\mathrm{Y}}\\ \mathbf{L}_{\mathrm{Z}}\end{vmatrix}$$

- and hence the surface color in the display space C is

$$\mathbf{C} = \mathbf{A}\mathbf{C}^{\mathrm{ref}}\mathbf{A}^{-1}$$

Advantages

- Device-independence
- Hardware implementation is possible
- In software implementation, interreflections are possible
- Spaces other than CIE XYZ can also be used as the reference space - RGB or, maybe, even spectrum
- Chromatic adaptation transforms other than relative colorimetric can be used

We ignored

- Out-of-gamut colors
- Gamma correction