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)

\[
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix} =
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

\[\begin{bmatrix}
R \\
G \\
B
\end{bmatrix} = A \begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

\[A = M \quad \text{or} \quad MR_{\text{display}}^{-1} R_{\text{scene}}\]

where \(M = XYZ - \text{to} - \text{RGB}\)

\[
R = \begin{bmatrix}
X_w^{-1} & 0 & 0 \\
0 & Y_w^{-1} & 0 \\
0 & 0 & Z_w^{-1}
\end{bmatrix}
\]
Light is a vector, so the color of a source is converted from the reference to display space as

\[
\begin{bmatrix}
L_R \\
L_G \\
L_B
\end{bmatrix} = A
\begin{bmatrix}
L_X \\
L_Y \\
L_Z
\end{bmatrix}
\]
Surface color is a matrix, diagonal in the reference space

\[
C^{\text{ref}} = \begin{vmatrix}
  c_X & 0 & 0 \\
  0 & c_Y & 0 \\
  0 & 0 & c_Z \\
\end{vmatrix}
\]

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

\[
\begin{bmatrix}
L_R \\
CL_G \\
L_B
\end{bmatrix}
= \begin{bmatrix}
A C^{\text{ref}} \\
L_X \\
L_Y \\
L_Z
\end{bmatrix}
\]

- and hence the surface color in the display space \(C\) is

\[
C = AC^{\text{ref}} A^{-1}
\]
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