The von Kries Hypothesis and a Basis for Color Constancy

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Introduction and Motivation

- Color constancy refers to the stable perception of object color–despite changes in overall illumination.
- Color constancy should generally not be possible.

Background

- Generalized diagonal (von Kries-like) color constancy:
  - \( D \) is a diagonal matrix with entries independent of material
  - \( B \) is a globally constant matrix

Definitions

Define measurement tensor \( M_{ijk} := \int \rho_k(\lambda)E_i(\lambda)R_j(\lambda)d\lambda \)

- \( \lambda \) = wavelength
- \( \rho_k \) = sensor response function
- \( E_i \) = spectrum of \( i \)th illuminant
- \( R_j \) = spectrum of \( j \)th material

An order 3 tensor (3D data block), \( T \), has tensor rank \( N \) if \( N \) is the smallest integer allowing decomposition as the sum of outer products:

\[
T = \sum_{n=1}^{N} \bar{c}_n \circ \bar{a}_n \circ \bar{b}_n
\]

Goals

1) Derive necessary and sufficient conditions for {sensors, illuminants, materials} to support generalized diagonal color constancy.
2) Compute an optimal global color basis (i.e., an optimal \( B \) matrix).

Theorem: A measurement tensor supports generalized diagonal color constancy if and only if its tensor rank is at most 3.

Algorithm (for determining color basis)

1) Create measurement tensor from input data (database of illuminant and material spectra).
2) Run a nonlinear least squares optimization (TALS) to get closest rank 3 tensor (in Frobenius norm)
3) Algorithm allows us to read off color basis that gives perfect constancy for this approximate tensor

Results and Discussion

Color Matching Functions – normalized so that 1 is the max. response.

Top row: rendered using full-spectral images.
Bottom row: color correction applied to ‘Input’ using diagonals in different color bases.

Each histogram curve plots the % of color vectors obeying diagonal color constancy (under a specified color basis) versus the % allowable error.

- Additional details on experiments can be found at: http://www.people.fas.harvard.edu/~hchong/color.html