Einführung in die Farbwissenschaft

Other Aspects

Overview

- **H**igh **D**ynamic **R**ange images (HDR images)
- tone reproduction
- digital color management (introduction)

HDRI & Tone Reproduction

- the problem
  - different image types
  - human visual system
  - tone mapping
- tone reproduction
  - linear methods
  - non-linear and perceptual methods

Image Types

- ***type A – relative brightness values***
  - values measured in terms of some maximum output device capability (monitor) or reflectance (paper)
  - can apply to both subtractive and additive images
- ***type B – absolute radiometric values***
  - captures of reality = “scene reference images”
  - this is what digital cameras ought to capture!

High Dynamic Range (HDR) Images

- the range of light in the real world spans 10 orders of magnitude!
- a scene’s luminance values: up to 5 orders of magnitude difference
- CRTs can only display 2-3 orders of magnitude
- ***tone-mapping*** = to produce a good image of HDR data

Maximum Difference in Brightness

- ***type A – relative brightness values***
  - photographic slides: 3 orders of magnitude
  - LCD-screens: 2-3 orders of magnitude
  - printouts: roughly 10 luminance units
  - 8-bit images: 256 steps
- ***type B – absolute radiometric values***
  - real world: more than 9 orders of magnitude (excluding the solar disc)
  - human eye can see 5 orders of magnitude in any adapted situation

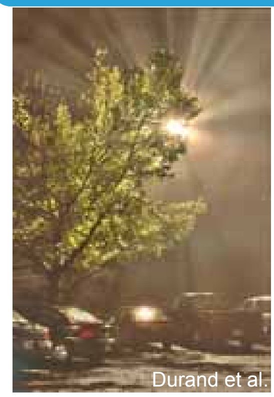
Contrast Ratio

- captures of reality (or realistic rendering) leads to high dynamic range images
- these cannot be displayed directly on normal display hardware
- special image formats are necessary
- a display representation which yields the same visual sensation as viewing of the real scene is also needed (and this does ***not*** restrict the problem to gamut mapping)

In Practice

- it is usually impossible to solve the reproduction task perfectly
- it strongly depends on the output device
- various heuristics of increasing complexity exist
- full perception models are computationally expensive and difficult to handle
- animations pose additional challenges (time dependency)

Different Methods



Storage Image Formats

- capture/output of rendering has to be stored for later processing
  - conventional formats
  - high-dynamic range color space formats
  - spectral formats (possibly including polarization information)
- any format except the last category destroys information gathered during rendering / image capture

Conventional Image Formats

- usually RGB (TIFF, PNG, JPEG)
- TIFF: also CIE L*a*b*
- 8 bits per channel → post processing artifacts
- TIFF: 16 BPC possible
- „brightness ends at 1“→ always relative
- no physical meaning of values
- **advantage:** compact size, standardized
- **disadvantage:** large amounts of information are destroyed

High Dynamic Range Formats

- often CIE Luv or Lab color space
- floating point components → large range
- radiance RGBE, Pixar Log and LogLuv TIFF, ART XYZ (uncompressed), **OpenEXR**
- values have physical meaning
- **advantage:** compact size, standardized, few quantization errors
- **disadvantage:** compression can introduce artifacts, not understood by Photoshop etc.

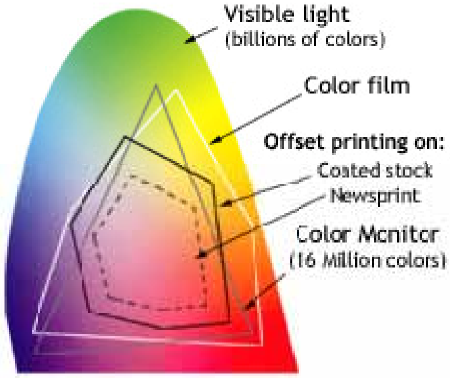
High Dynamic Range Format: OpenEXR

- open HDR image file format
- developed by ILM (Lucasfilm)
- free software license, released in 2003
- includes development tools (C++ library)
- supported by many companies
- 16 bits/channel floating point values:
  - dyn.range of >30 stops of exposure
- supports lossless/lossy compression
- *industry standard*

Tasks – Terminology

- no definitive terminology exists!
- ***gamut mapping***:
  - getting all colors into the display gamut
- ***tone mapping***:
  - fitting the luminance range to a given device
- ***tone reproduction***:
  - whole process – comprises gamut and tone mapping

Color Gamut Comparison



Gamut Mapping

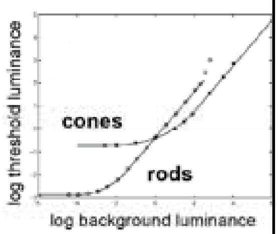
- tone mapping yields luminance values within the display range
- for all methods, the associated color values are not necessarily moved into the gamut through this transformation
- goal: to move the out-of-gamut values into the displayable area with minimal error

Gamut Mapping Approaches

- clipping: not really an option
- **local:** all outlying points are individually moved to appropriate locations
  - fast
  - problem: highlights may be lost
- **global:** all points are analyzed, and the point cloud in color space is shrunk so that it fits into the gamut
  - relation between colors is maintained
  - problem: de-saturation of image

Adaptation of Human Eye

- perceivable: from ~10^{-5} to ~10^{8} cd/m²
- displayable contrast: ~ 10^2 – 10^3



J. Ferwerda, Cornell

- reason: ***adaptation***
  - brightness, colors, resolution, environment, local adaptation, time dependency, …

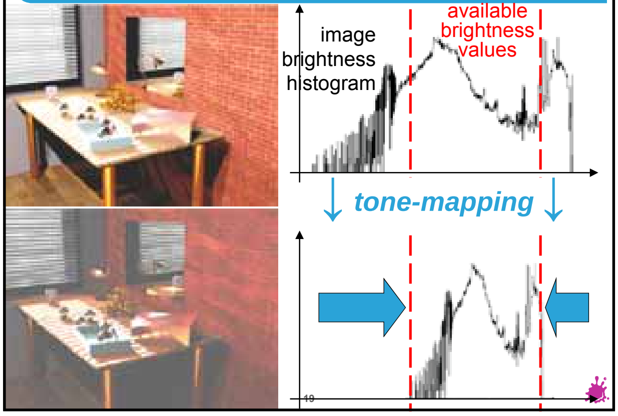
Weber's Law

- ΔL … just noticable difference to luminance L

$$\frac{\Delta L}{L} = \text{constant}$$

i.e. the human eye has a
logarithmic contrast sensitivity!
(by comparison, CCDs are linear)

Tone-Mapping Example



Tone Reproduction Operators

- global methods
- local methods
- perceptual approaches

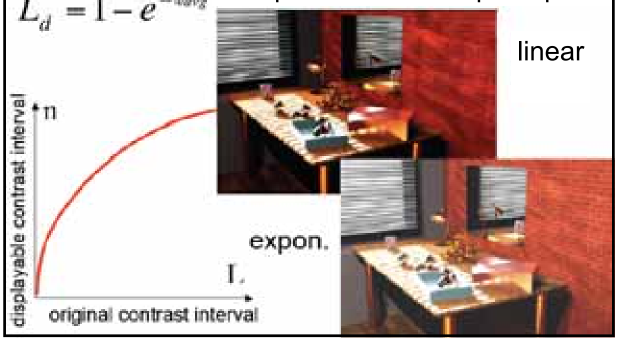
Tone Reproduction: *Global* Methods

- global methods perform the same transformation for all pixels of the image
  - primitive & fast
  - automatic detection of the parameters
  - sufficient for many scenes
  - no color correction
  - no perceptual effects
  - linear or non-linear mapping

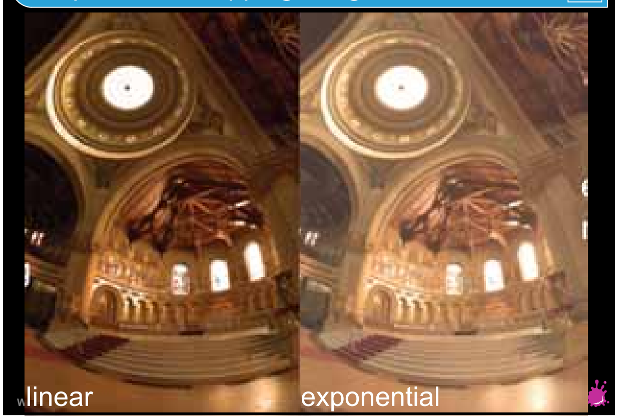
Example for Exponential Mapping

$$L_d = 1 - e^{\frac{-L_w}{L_{wavg}}}$$

exponential function corresponds to human perception



Exponential Mapping Image



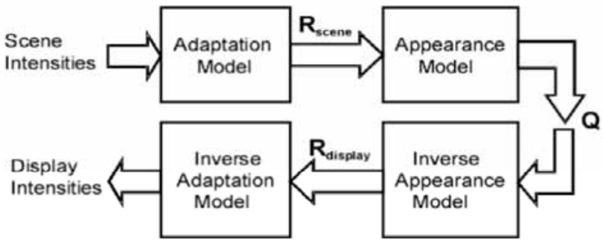
Tone Reproduction: ***Local*** Methods

- local methods perform different transformations at different locations
  - more complex & slower
  - automatic detection of the parameters
  - necessary for some scenes
  - color correction possible
  - no perceptual effects
  - linear or non-linear local mappings

Perceptual Methods

- results from physiology and psychology are used to reproduce the behavior of the human visual system
- two-pronged approach:
  - one has to determine what a person would see if the scene were real
  - and then try to reproduce this sensation using a display device

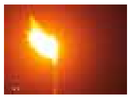
Perceptually Based Methods



- top row computes viewed scene appearance
- lower row attempts to reproduce this perception on display device

Perceptual Effects

- visual acuity
  [Sehschärfe]
- color constancy
- local adaptation
- flare
  [Leuchtschein]



- ciliary bloom
  [Wimperstreuung]

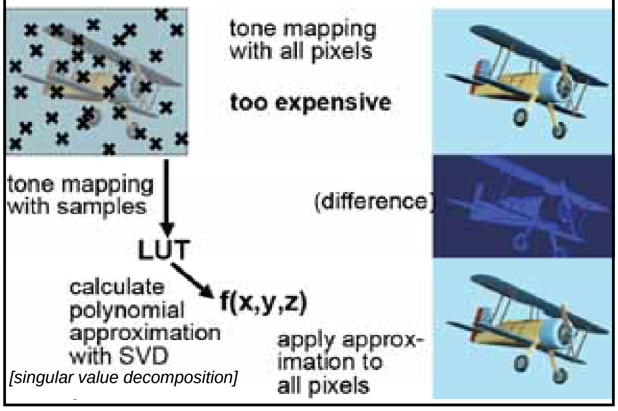
- temporal dependency

Local Adaptation

Interactive Tone-Mapping

- interactive applications
  - walkthroughs
  - games
  - fight/driving simulators
  - …
- additional effects
  - dazzling [Blendung]
  - slow dark adaptation
  - other subtle effects of visual adaptation

Interactive Tone-Mapping

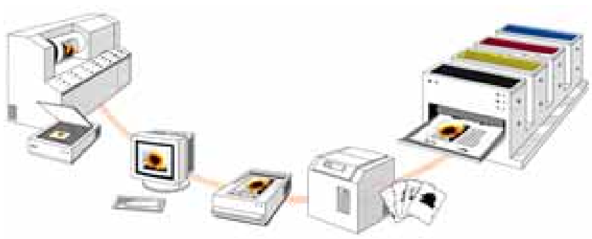


Digital Color Management Introduction

- color workflow
- printing terminology and problems
- ICC profiles and standards

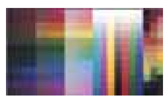
The Digital Printing Pipeline

- a chain that is as strong as its weakest link
- exact characterization of all links is a necessity



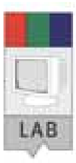
Scanners

- multiband imaging sensors
- wide variety of filters are used
  → raw data not directly useable
- have to be calibrated using known targets
- scanner profile determines exact relationship between obtained RGB values and true L*a*b* values



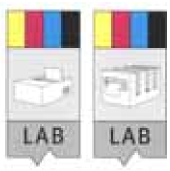
Monitors

- use additive color mixing to display color images
- wide variety of phosphors and TFT/LCD luminaries/filters exist
- calibration using colorimeters is essential for professional use
- has to be performed daily for CRTs after device has warmed up
- only valid for particular brightness



Printers

- subtractive mixing of pigments on paper
- much more complex to charact-erize than additive devices due to different
  - printing technologies
  - paper types
  - inks
  - nonlinearity of color mixing



Characterizing Printers

- it is not possible to characterize a printing device using a single profile
- profiles differ (at least) for
  - paper types
  - color intensity
- profiles have to be computed separately for each paper/ink combination!
- profiles are a mapping L*a*b* ↔ CMYK

Paper Types

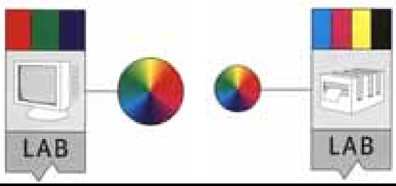
- coated papers
  - used for high quality 4-color printing, e.g. for books and magazines
- uncoated papers
  - equivalent to laser printer / copier papers
- newsprint
  - cheap, uncoated papers of low quality for mass use

Colorsafe CMYK

- CMYK is the de facto standard in the graphical community
- for coated papers the inter-device correspondence on professional equipment is already very high
- scanners, monitors and smaller printers do not comply with these standards → color management is needed for these devices

International Color Consortium

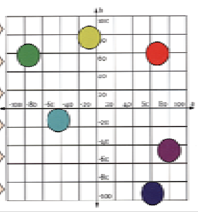
- founded by various software companies to provide a workable interchange standard for color data
- ICC profiles aim to provide mapping between different device categories, even those with widely differing gamuts, and L*a*b*



ICC Profiles (1)

- provide a mapping between color spaces
- enumeration is impossible due to color space sizes
- tables of representative samples are used instead; interpolation is used inbetween

R	G	B	L	a	b
0	191	191	75	-44	-14
191	0	191	54	81	-46
191	191	0	80	-17	75
191	0	0	48	68	60
0	191	0	71	-78	63
0	0	191	30	64	-92

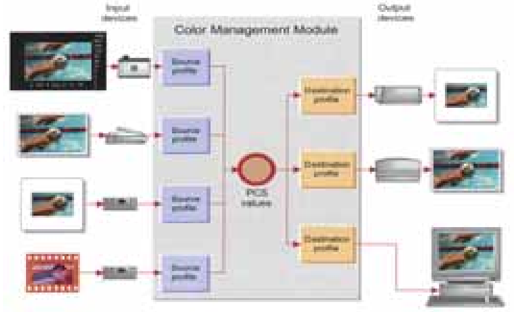


ICC Profiles (2)

- several subtypes of ICC profiles exist:
  - look-up table (LUT) > 1MB
  - matrix shaper (for RGB) ~ 1KB
  - (generic color space)
- # of samples varies with accuracy of profile: between several dozen to 32,000
- transformation CMYK ↔ L*a*b* has additional problem of black composition ambiguity
  - solution: any given ICC profile uses one fixed black composition algorithm

ICC Profile Use

- PCS – Profile Connection Space (CIELAB)



PCS = mostly L*a*b*, but also XYZ