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max planck institut informatik

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Course 10
Realistic Materials in Computer Graphics

Acquisition Basics

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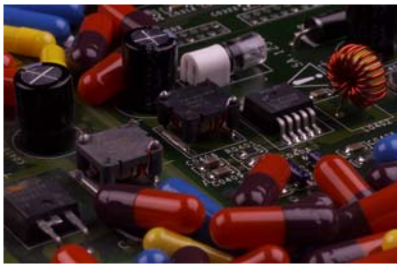
(moving to the University of Washington)

Goal of this Section

- practical, hands-on description of acquisition basics
- general overview, caveats, misconceptions, solutions, hints, …
- biased to the techniques used in our lab

How can we measure material properties?

- color
- texture
- reflection properties
- normals
- ...

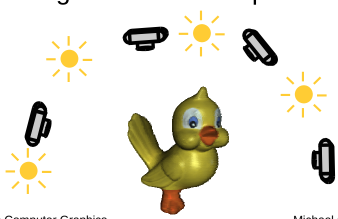


Special Purpose Tools

- gloss meter, haze meter, …
  - various appearance characteristics
- spectrophotometer
  - spectral reflectance of a surface
- often used in industry where single parameters of one material are important

General Purpose Tools

- setup with digital camera(s), controlled lighting, …
- foundation of image-based techniques



General Purpose Tools

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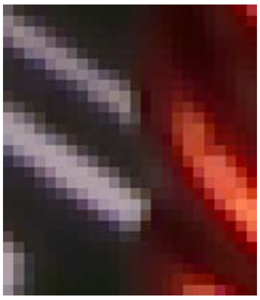
- digital camera as
  - massively parallel sensor
  - mostly tristimulus color
  - often high quality optical system
  - tuned to make good and/or correct pictures



Overview Acquisition Basics

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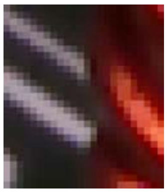
- digital cameras
  - geometric and photometric calibration
  - high dynamic range imaging
- light sources
- lab setup
- geometry acquisition



Pinhole Camera Model

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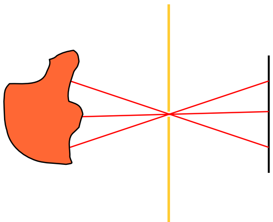
- “each pixel corresponds to one ray through the pinhole onto the object”
- not valid for most digital cameras!!!



(Pessimistic) Digital Camera Model

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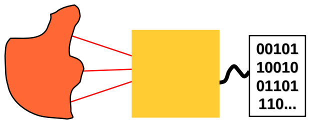
- digital camera as a black box
- take only for granted what you measured (or what is given in the manual)



(Pessimistic) Digital Camera Model

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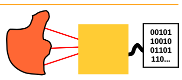

- optical lens system instead of pinhole aperture (aberration, vignetting)
- CCD/CMOS chip and A/D conversion
- normally only one color per pixel (e.g. Bayer pattern) requires demosaicing
- camera image processing
- …

Bayer Pattern

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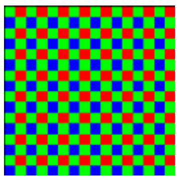
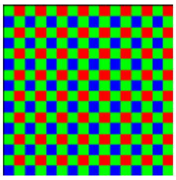
- sensor records only one color per pixel
  - higher sampling rate in green channel (luminance channel)
- remaining two color values per pixel must be reconstructed
  - artifacts possible



Bayer pattern

Demosaicing

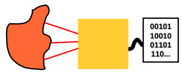
- common approach
  - combining an interpolation and a pattern matching scheme
  - groups pixels into regions and makes some continuity assumption within the regions
  - "nice pictures", but no guarantee that two of the R,G,B values per pixel are correct



Bayer pattern

(Pessimistic) Digital Camera Model

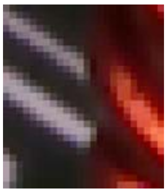
- often globally correct image
- no guarantee that each pixel contains reliable color values



- some issues can be solved using camera calibration

Overview Acquisition Basics

- digital cameras
  - **geometric and photometric calibration**
  - high dynamic range imaging
- light sources
- lab setup
- common problems and solutions



Geometric Camera Calibration

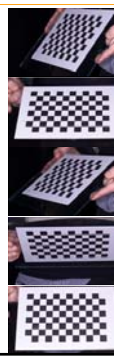
- get transformation between points in space and image coordinates
- intrinsic camera parameters
  - focal length, distortion coefficients, …
- extrinsic parameters
  - position, orientation

Geometric Camera Calibration

- several methods commonly used, e.g., [Tsai '87, Heikkila '97, Zhang '99]
- Matlab calibration toolbox by Jean-Yves Bouguet
  - http://www.vision.caltech.edu/bouguetj/calib_doc/
  - also included in the OpenCV Open Source Computer Vision library distributed by Intel

Calibration Approach

- capture images of test target with known geometry
  - cover space and angles with planar target
- solve for intrinsic and extrinsic parameters
- quality can be checked by reprojection



Photometric Calibration

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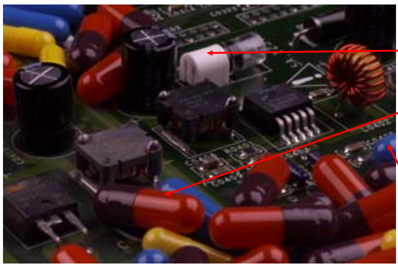

What do these RGB values (digital counts) mean?

Camera Response Curve (OECF)

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- relationship between digital counts and luminance is unknown (and often non-linear)
  - gamma correction
  - image optimizations
  - ...
- can be described by response curve or OECF (Opto-Electronic Conversion Function)

Camera Response Curve (OECF)

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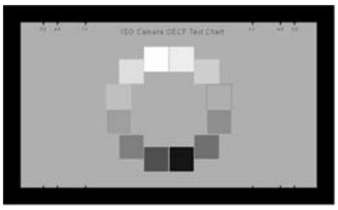
- direct measurement via test chart
  - patches with known gray levels
  - uniform illumination



Camera Response Curve (OECF)

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- patches arranged in a circle to suppress lens effects (e.g. vignetting)
- OECF can be determined for some discrete intensity levels/digital counts
- inversion using OECF leads to pixel values linearly related to luminance values

Overview Acquisition Basics

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- digital cameras
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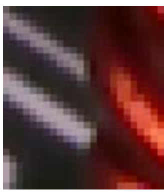
  - **high dynamic range imaging**
- light sources
- lab setup
- common problems and solutions



Sources of Dynamic Range

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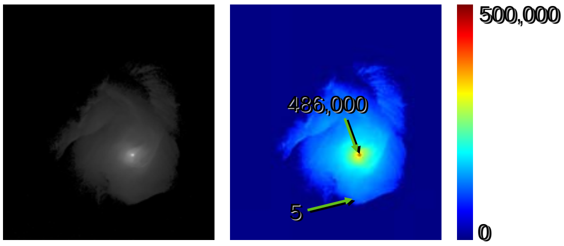
Sources of Dynamic Range



Definition of Dynamic Range

- dynamic range is the ratio of brightest to darkest (non-zero) intensity values in an image
  - assuming linear intensity
- often given as
  - ratio: 1:100.000
  - orders of magnitude: 5 orders of magnitude
  - in decibel: 100 dB

Dynamic Range of Cameras

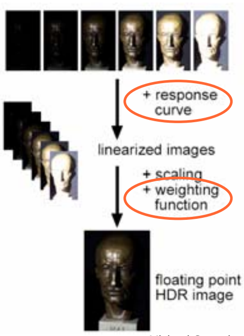
- example: photographic camera with standard CCD sensor
  - dynamic range of sensor 1:1000
  - exposure variation 1/60th s – 1/6000th s (handheld camera/non-static scene) 1:100
  - varying aperture f/2.0 – f/22.0 ~1:100
  - exposure bias/varying “sensitivity” 1:10
  - total (sequential) 1:100,000,000
  - simultaneous dynamic range still only 1:1000

High Dynamic Range (HDR) Imaging

- analog false-color film with several emulsions of different sensitivity levels by Wyckoff in the 1960s
  - dynamic range of about 10^8
- modern CMOS sensors can achieve a dynamic range of 10^6 – 10^8
  - logarithm in analog domain
  - multiple exposure techniques

High Dynamic Range Imaging

- extending dynamic range of ordinary camera
- combining multiple images with different exposure



Determining the Response Curve

- [Madden 1993] assumes linear response
  - correct for raw CCD data
- [Debevec and Malik 1997]
  - selects a small number of pixels from the images
  - performs an optimization of the response curve with a smoothness constraint
- [Robertson et al. 1999, 2003]
  - optimization over all pixels in all images

Algorithm of Robertson et al.

- Principle of this approach:
  - calculate a HDR image using the response curve
  - find a better response curve using the HDR image
- (to be iterated until convergence)
- assume initially linear response

Algorithm of Robertson et al.

- input:
  - series of *i* images with exposure times t_i
  - pixel value at image position *j* is $y_{ij} = f(t_i x_j)$
- find irradiance x_j and response curve $I(y_{ij})$
  - $t_i x_j$ is proportional to collected charge/radiant energy
  - *f* maps collected charge to intensity values

$$f^{-1}(y_{ij}) = t_i x_j =: I(y_{ij})$$

Algorithm of Robertson et al.

- additional input:
  - a weighting function $w(y_{ij})$ (bell shaped curve)
  - an initial camera response curve $I(y_{ij})$ – usually linear
- calculate HDR values x_j from images using

$$x_j = \frac{\sum_i w(y_{ij}) t_i^2 \cdot \frac{I(y_{ij})}{t_i}}{\sum_i w(y_{ij}) t_i^2} \qquad x_j = \qquad y_{ij}$$

Algorithm of Robertson et al.

- optimizing the response curve *I*:
  - start again with definition $f^{-1}(y_{ij}) = t_i x_j =: I(y_{ij})$
- minimization of objective function *O*

$$O = \sum_{i,j} w(y_{ij})(I(y_{ij}) - t_i x_j)^2$$

- using Gauss-Seidel relaxation yields

$$E_m = \{(i,j) : y_{ij} = m\}$$

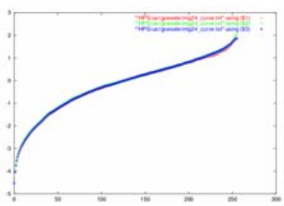
$$I(m) = \frac{1}{\mathrm{Card}(E_m)} \sum_{i,j \in E_m} t_i x_j$$

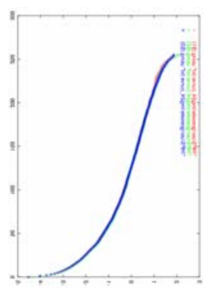
- Card(E_m) = number of elements in E_m

Algorithm of Robertson et al.

- both steps are iterated
  - calculation of a HDR image using *I*
  - optimization of *I* using the HDR image
    - → *I* needs to be normalized, e.g., *I*(128)=1.0
- stop iteration after convergence
  - criterion: decrease of *O* below some threshold
  - usually only a couple of iterations

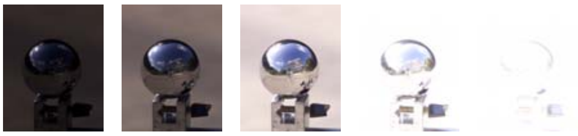
HDR Imaging: Algorithm of Robertson et al.





$\log(I(y_{ij}))$

HDR Example: Capturing Environment Maps



1/2000s 1/500s 1/125s 1/30s 1/8s

series of input images

HDR Example: Capturing Environment Maps

Algorithm of Robertson et al.

- choice of weighting function *w(y*$_{ij}$*)* for response recovery

$$w_{ij} = \exp\left(-4\frac{(y_{ij}-127.5)^2}{127.5^2}\right)$$

  - for 8 bit images
  - possible correction at both ends (over/underexposure)
  - motivated by general noise model

Algorithm of Robertson et al.

- choice of weighting function *w(y*$_{ij}$*)* for HDR reconstruction
  - introduce certainty function *c* as derivative of the response curve with logarithmic exposure axis
  - approximation of response function by cubic spline to compute derivative

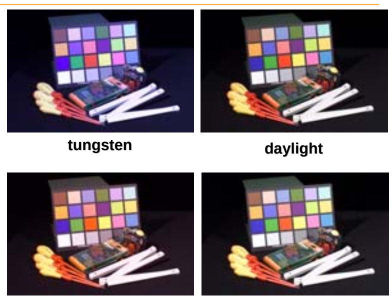
$$w_{ij} = w(y_{ij}) = c(I_{y_{ij}})$$

Input Images for Response Recovery

- my favorite:
  - grey card, out of focus, smooth illumination gradient
- advantages
  - uniform histogram of values
  - no color processing or sharpening interfering with the result

White Balance

capture the spectral characteristics of the light source to assure correct color reproduction



tungsten daylight

flourescent flash

images taken with different camera settings

White Balance

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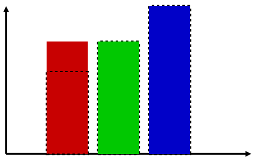
- capture white surface under target illumination
- scale color channels to achieve uniform intensity values
- often built-in function



Color Calibration

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- BRDF model of real object
- long processing pipeline
- which image is (more) correct?

Color Calibration

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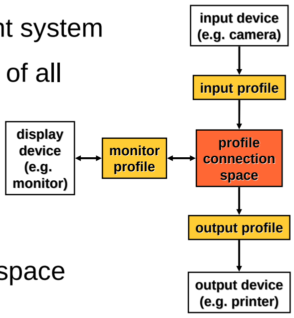
- ICC color management system
- capture the properties of all devices
  - camera and lighting
  - monitor settings
  - output properties
- common interchange space



Color Calibration

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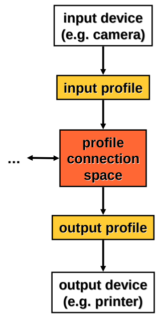
- profile connection spaces
  - CIELAB (perceptual linear)
  - linear CIEXYZ color space
- can be used to create an high dynamic range image in the profile connection space
- allows for a color calibrated workflow



Color Calibration

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[Goesele et al. 2004]

Limits of White Balance and Color Calibration

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- fluorescence effects
  - signal colors
  - optical brighteners
  - test targets
- color calibration, white balancing, … impossible
- similar with unwanted infrared signal

daylight (HMI)

green LED

Overview Acquisition Basics

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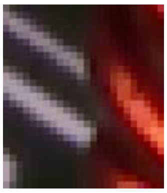

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General Measurement Approach

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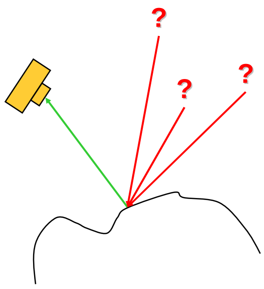
- find relation between incoming and outgoing light at a surface point
- derive information from this data
- knowledge and control over light sources needed



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Lighting Requirements

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- photometric properties
  - uniform spatial distribution
  - color constant over time
  - even spectral distribution
  - very bright and efficient

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Lighting Requirements

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- emission pattern
- requirements depend on application, e.g.,
  - well defined light source
  - incident angle as small as possible
    - ➔ *parallel light source (e.g. laser beam)*
    - ➔ *point light source*
  - lens or reflector based systems are often not ideal

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Point Light Source Example

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- point light source
- 800 W HMI light source
- very efficient
  (equals 2500 W tungsten light)
- (almost) daylight spectrum
- constant colors

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Point Light Source Example

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- more information about lighting in the individual sections of the course …

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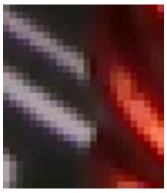

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Lab Setup

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- part of the lighting considerations
- often low and diffuse reflection required to minimize the influence of the environment
- MPI photo studio
  - walls and ceiling covered with black felt
  - black needle fleece carpet

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Lab Setup

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Lab Setup

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- tuned for efficiency and flexibility
  - enough space
  - enough stands, supporting materials, …
- have some lighting available in dark areas
  - e.g., radio controlled light switch
- safety concerns

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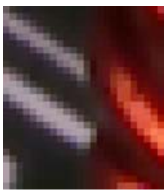

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Geometry Acquisition

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- geometry of test targets often required
- could teach a separate course about the topic
- but some comments …

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Geometry Acquisition

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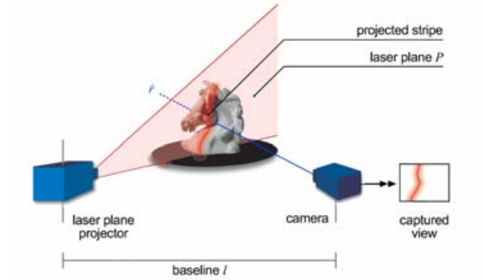
- 3D laser scanning system



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Uncooperative Materials

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- realistic materials are nice to look at but often difficult to scan
- requires some creativity, …
- angel model: based on CT scan

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Uncooperative Materials

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- alabaster horse: covered with white dust

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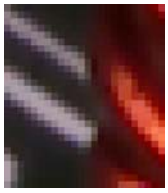

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Schedule

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- 10:30 Homogeneous Isotropic BRDFs (W. Matusik)
- 11:15 Heterogeneous Isotropic BRDFs (H. Lensch)
- 11:45 Translucent Materials (M. Goesele)
- 12:15 Lunch

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