# Chapter 7
# High Dynamic Range (HDR)

Distributed Algorithms
for Image and Video Processing

## Introduction to HDR (I)

Source: wikipedia.org

# Introduction to HDR (II)

- High dynamic range classifies a very high contrast ratio in images
- Contrast ratio
  - In digital images: 1.000:1
  - In analogue photos: 10.000:1 (significant advantage)
  - In case of HDR images: 200.000:1
- The range of luminance values is so large that monitors or printers cannot visualize / print these intensities.
- *Tone mapping*: Reduces the luminance range to be presentable on devices.



# Introduction to HDR (III)

- Painter of the middle ages used special techniques to visualize bright and dark regions in painting:
  - Use of saturated colors to increase the dynamic range of image colors
  - Amplification of object contours by adding white or black lines. This technique increases the contrast significantly.

El Greco's *La Agoria en el Jardin* (1590)
Quelle: cybergrain.com

# Introduction to HDR (IV)

Impact on the human visual perception:
It seams that the sun is highlighted. Why?

- The brightness of sun and background is very similar (low contrast)
- The brain receives conflicting signals about the sun:
  - Brain region responsible for basic perception: (motion and perception): sun is invisible
  - Advanced image regions (color): typical sun

Claude Monet, *Impressions at Sunrise*
Source: webexhibits.org



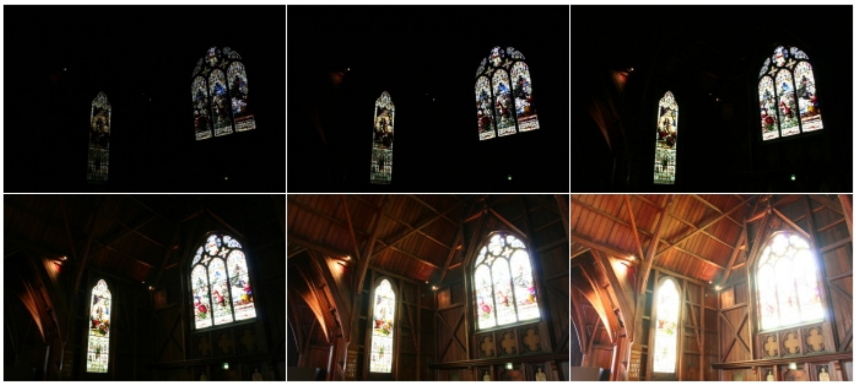
# Approach (I)

**Calculation of HDR images**

- Several shots of the same scene with different exposures are taken (standard exposure, over- and underexposed pictures)
- All images are combined into one HDR image
- Underexposed pictures visualize very bright image regions very well
- Overexposed pictures visualize very dark image regions very well

# Approach (II)

Examples of under- and overexposed pictures



Source: wikipedia.org



# Approach (III)

Result (combination of pictures)

Source: wikipedia.org

# Calculation of HDR images (I)

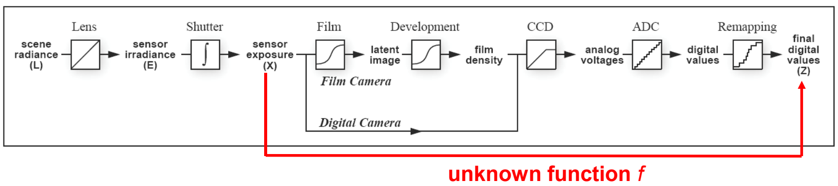
## Steps

- Calculate *response function* to transform the luminance of a scene to pixel values
- Merge the pictures with different exposure times (shutter speed) to one HDR image
- The pixel values of the HDR image are proportional to the real luminance of the scene



# Calculation of HDR images (II)

- The real luminance of a scene is transformed to pixel values by a **non-linear** function:




- Criteria: exposure of an analog film, developing of a film, digitalization (scanning)

Source: Debevec and Malik (University of California at Berkeley)

# Calculation of HDR images (III)

**Estimation of the characteristic curve of a film (*response function*)**

- Definition Exposure $X$: $X = E \cdot \Delta t$
  $E$: film irradiance value, $\Delta t$: exposure duration
- The processing changes X to Z: $Z = f(E \cdot \Delta t)$
  $f()$ is a non-linear function
- We can calculate the real luminance if function $f$ is known:
  $X = f^{-1}(Z)$
- Because the exposure duration $\Delta t$ is known, we can calculate the film irradiance value $E$:
  $E = X / \Delta t.$
- The film irradiance value $E$ is proportional to the amount of light $L$ of a scene



# Calculation of HDR images (IV)

- Given: several images with different exposure times $\Delta t$
- The film irradiance value $E$ is constant for each pixel
- Pixel values of the images: $Z_{ij} = f(E_i \Delta t_j)$
  $i$: pixel position (x/y position),
  $j$: index of the image
- Inverse function: $f^{-1}(Z_{ij}) = E_i \Delta t_j$
- Natural logarithm : $\ln f^{-1}(Z_{ij}) = \ln E_i + \ln \Delta t_j$

# Calculation of HDR images (V)

- Set: $g = \ln f^{-1}$

  → $g(Z_{ij}) = \ln E_i + \ln \Delta t_j$
  *known values*:
  - pixel values $Z_{ij}$,
  - exposure times $\Delta t$

  *unknown values*:
  - film irradiance value $E_i$, function $g$
- $G$ maps a finite number of points ($Z$ describes fixed pixel values)



# Calculation of HDR images (VI)

- Estimate $E_i$ and $g$ by minimizing the following term:

$$\mathcal{O} = \sum_{i=1}^{N} \sum_{j=1}^{P} [g(Z_{ij}) - \ln E_i - \ln \Delta t_j]^2 + \lambda \sum_{z=Z_{min}+1}^{Z_{max}-1} g''(z)^2$$

**error is minimized**

**smooth function *g***

*N*: number of pixels in image
*P*: number of images
estimate $(Z_{max} - Z_{min} + 1)$ values for *g(Z)*
estimate *N* values for $\ln E_i$

# Calculation of HDR images (VII)

**Estimation of $E_i$ and $g$:**

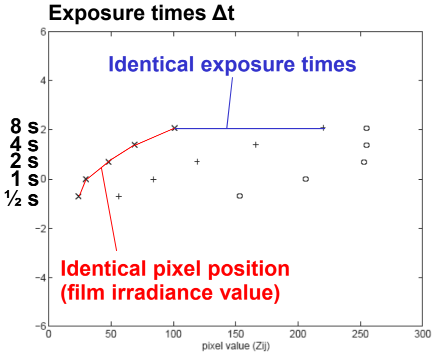
- Define an over-determined system of equations
- Solve it by minimizing the sum of squared differences of function $g$ and the observed pixel values $Z$



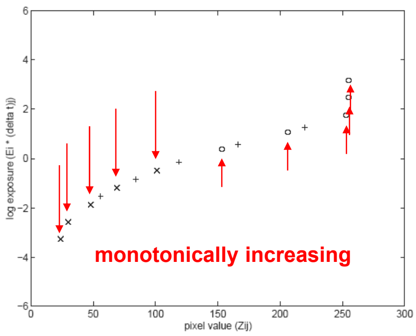
# Calculation of HDR images (VIII)

## Example

**Exposure times Δt**




**Assignment of pixel values to exposure times (film irradiance value $E_i$=1)**




**Consideration of film irradiance value $E_i$**

Source: Debevec, Malik (University of California at Berkeley)

# Tone Mapping (I)

**Visualization of HDR images (Tone Mapping)**

- Tone Mapping reduces the dynamic range (contrast) of images, to enable the visualization of these images
- Simple technique: Very high or low values may be mapped by the next valid values.
  → different pixel are mapped to the same value and the image quality is very low
- The goal of tone mapping is to preserve details

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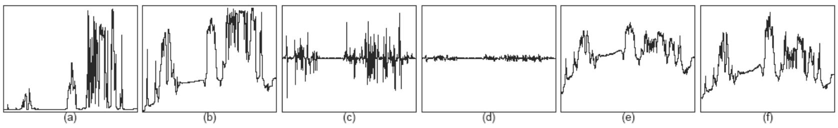
Dr. Stephan Kopf
Praktische Informatik IV

UNIVERSITY OF MANNHEIM

# Tone Mapping (II)

**Visualization of HDR images based on tone mapping**




a) One image row (dynamic range 2415:1)

b) *H(x)* = log (image row)

c) Derivative *H'(x)*

d) Reduced derivative *G(x)*

e) Reconstructed image row *I(x)*

f) *exp (I(x))* with dynamic range of 7.5:1

Source: Fattal, Lischinski, Werman (cs.huji.ac.il)

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Praktische Informatik IV

UNIVERSITY OF MANNHEIM

# Tone Mapping (III)

- Reduce the range of pixel values of the HDR image by normalizing each pixel by an individual factor $\Phi(x, y)$
- The factor should preserve strong and weak edges in images
- Calculate edges (gradient) for differently scaled images
- Merge gradients of the scaled images into one gradient image



# Examples (I)

## Visualization of HDR images

Aggregated gradient image

HDR image

# Examples (II)


**Source:**
chip.de
Philip Mildner
Christian Takacs



# Questions ?