Contrast Restoration by Adaptive Countershading

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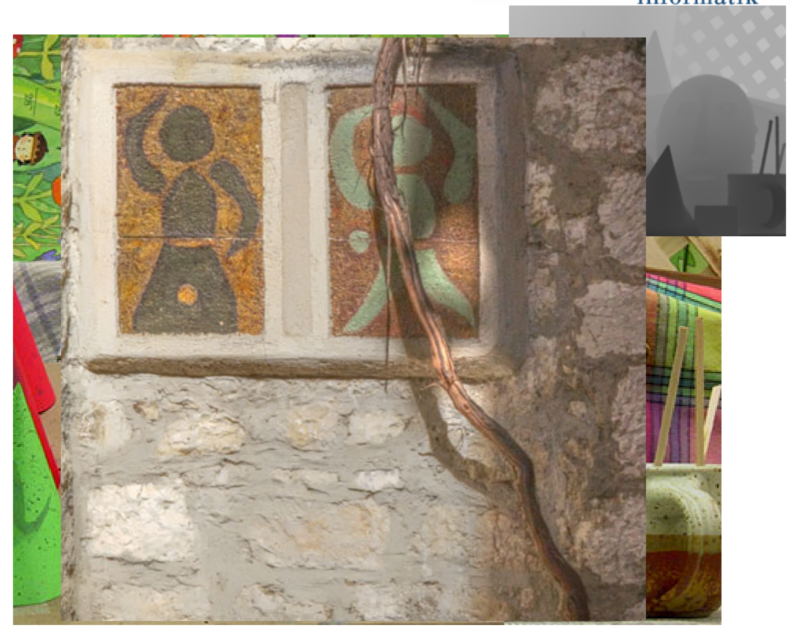
The Importance of Contrast

- Contrast communicates contents of images
  - objects and their texture
  - changes in illumination
  - separates foreground from background
- Contrast influences judgment of overall image quality

Causes of Poor Contrast



- Contrast lost during HDR tone mapping
  - tone mapping is essentially contrast compression
    - studied in [Smith et al. 2006]
  - results are numerically optimized
  - <u>further enhancement requires ‘non-numerical’ knowledge</u>
- Weak contrast in images caused by poor illumination
  - impedes comprehension of spatial organization [Luft et al. 2006]

Purpose: Contrast Restoration

Reference HDR Image

Measure Lost Contrast at Several Feature Scales

Enhance Lost Contrast in Tone Mapped Image

Tone Mapped Image

Enhanced TM Image

communicate lost image contents

maintain image appearance

Purpose: Contrast Restoration

Reference Depth Map

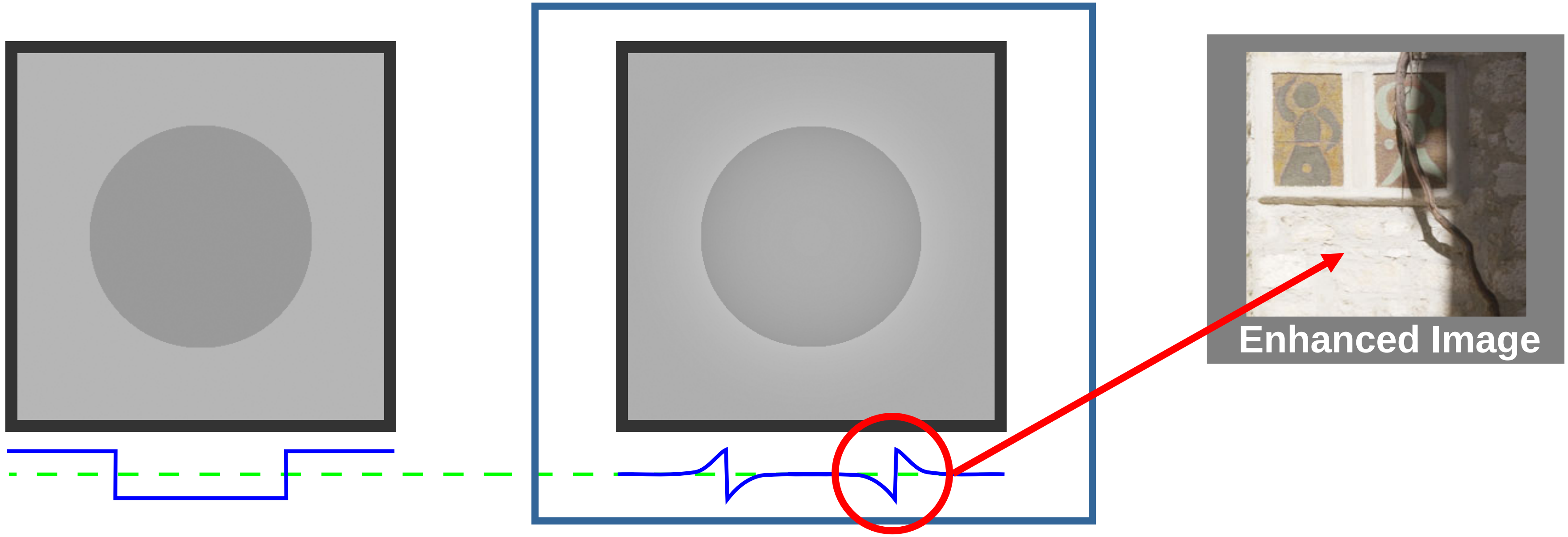
Input Image

Measure Missing Contrast at Several Feature Scales

Enhance Missing Contrast in The Input Image

Enhanced Image

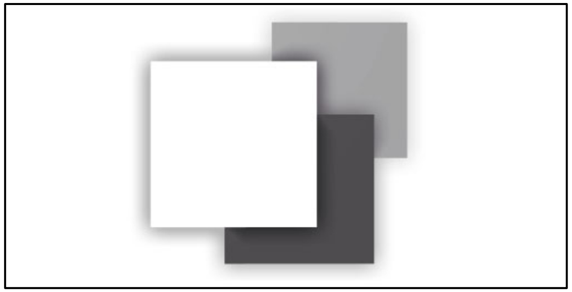
Method: Adaptive Countershading



- Perceptual illusion to enhance contrast – Cornsweet
- **Countershading**
  - **gradual darkening / brightening towards a contrasting edge**
  - contrast appears with 'economic' use of dynamic range
- Possible space to enhance a numerically optimized tone mapping solution (!)

Previous Work

- Image Enhancement without Reference
  - histogram equalization, unsharp masking, etc.
  - manual adjustment of parameters
  - substantial change in the image appearance
- Enhancement with Reference
  - depth-darkening [Luft et al. 2006]
  - enhancement with color [Smith et al. 2006]
- Multi-resolution image enhancement
  - substantial change to appearance of the image
  - amplification of certain frequencies
  - knowledge of HVS often applied

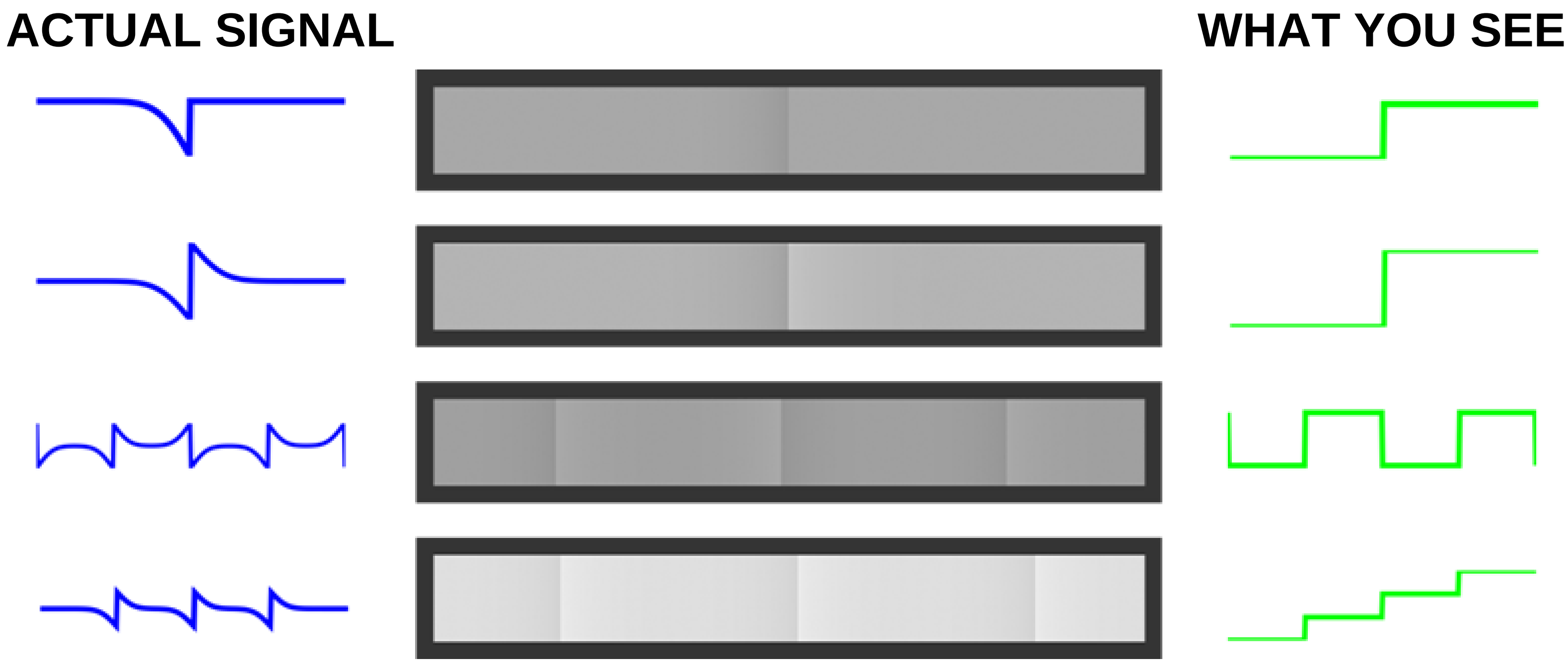


Contributions

Better communicate image contents with a minimal change to the image appearance.

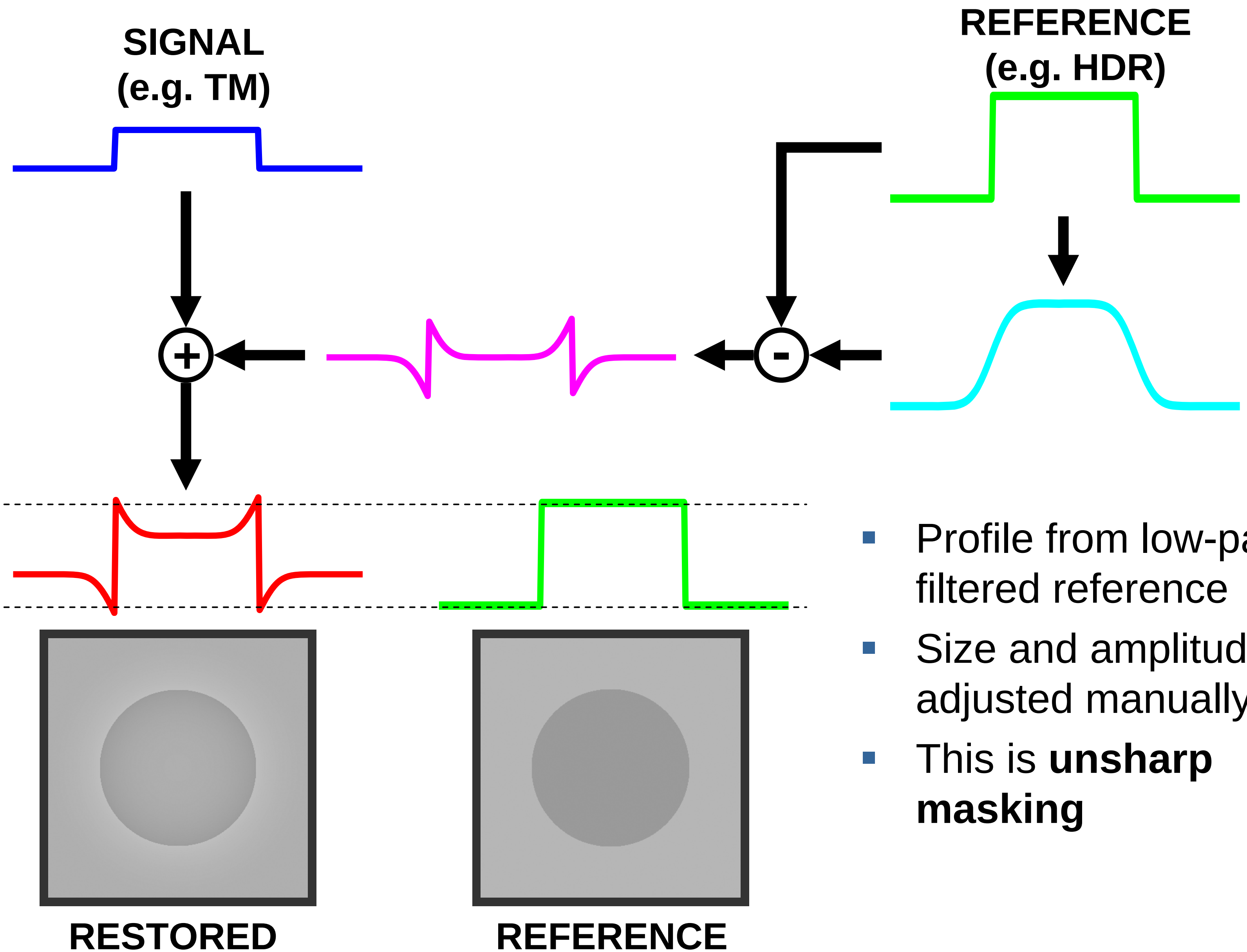
1. Adaptive countershading (enhancement with reference)
   - generalization of unsharp masking
   - application of contrast illusion to image enhancement
2. Multi-resolution contrast metric
   - change in contrast between an image and its reference
   - automatic adjustment of image enhancement
   - considers features at several scales
3. Visual detection model
   - based on the perception of countershading
   - masking of profiles in the image

Details of Contrast Illusion



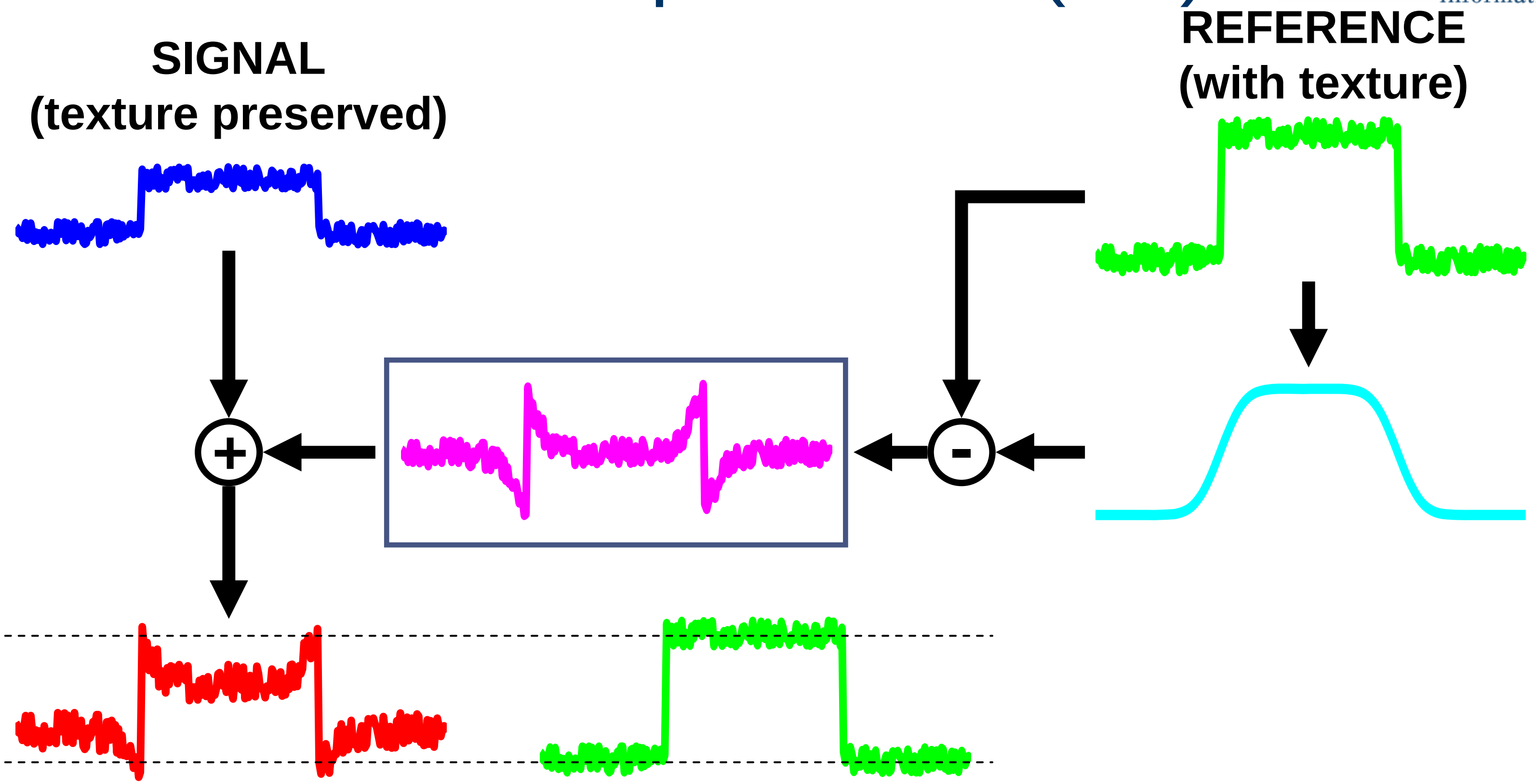
1. Contrast between areas caused by brightness profiles
2. Properties:
   - shape of the profile matches the shape of the enhanced feature
   - amplitude of the profile defines the perceived contrast
   - noise (texture) does not cancel the illusion
   - profiles must not be discernible

Construction of Simple Profile (1/2)



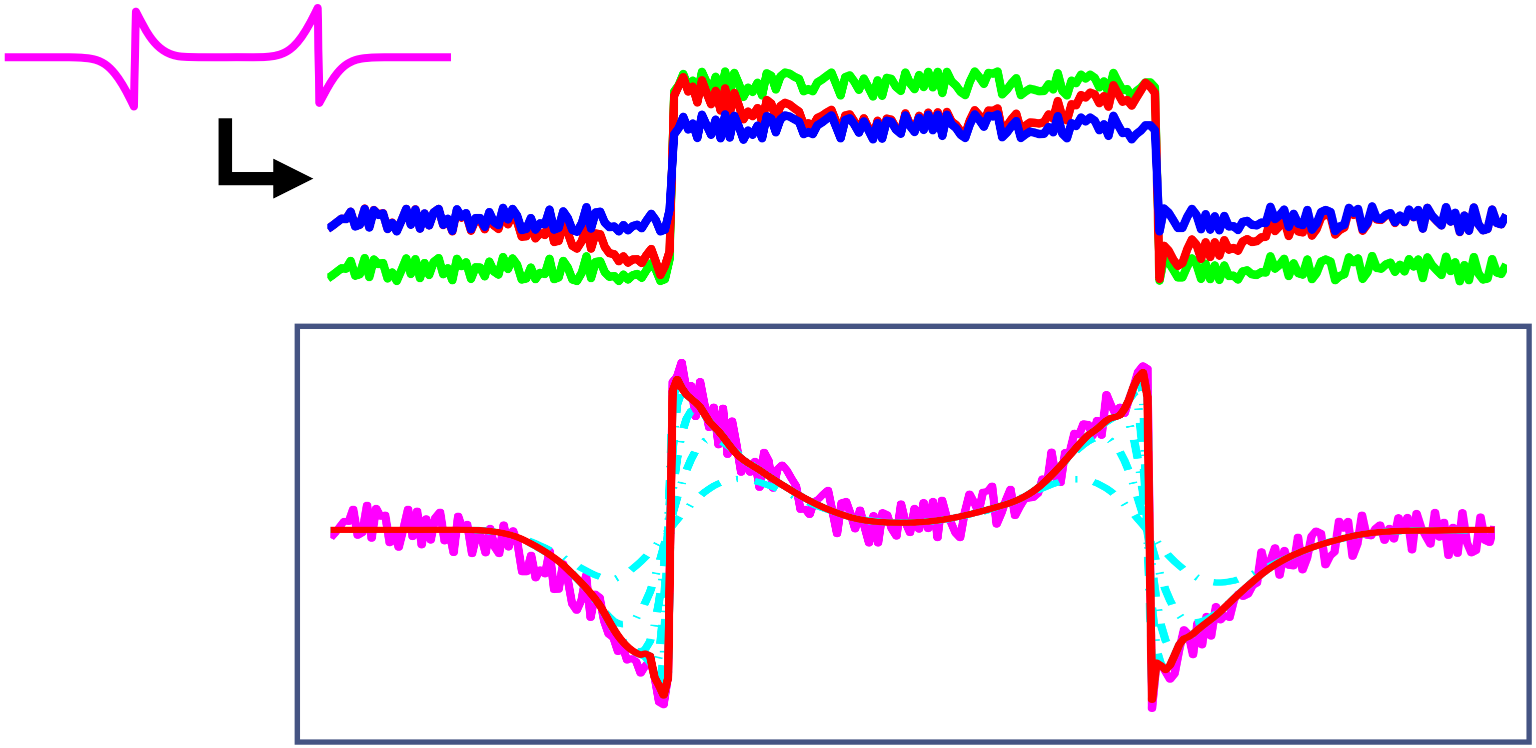
- Profile from low-pass filtered reference
- Size and amplitude adjusted manually
- This is **unsharp masking**

Construction of Simple Profile (2/2)



- Well preserved texture in signal is exaggerated by profile
- **Improved method for constructing profiles:**
  - **profile must contain only features that require enhancement**

Correct Profile for Textured Area



- Profile constructed directly from the reference image contains high frequency features which exaggerate texture
- **Sub-band components allow to select features**
  - **high frequency component present only at high contrast edge**

Multi-resolution Contrast Metric

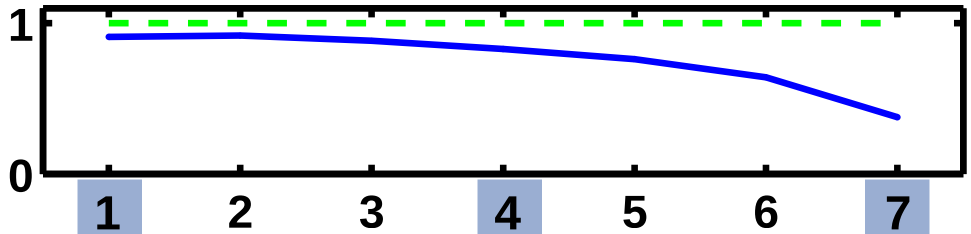
Reference HDR Image

Measure Lost Contrast at Several Feature Scales

$$C_l = \frac{|Y - Y_{mean}|}{Y_{mean}}$$

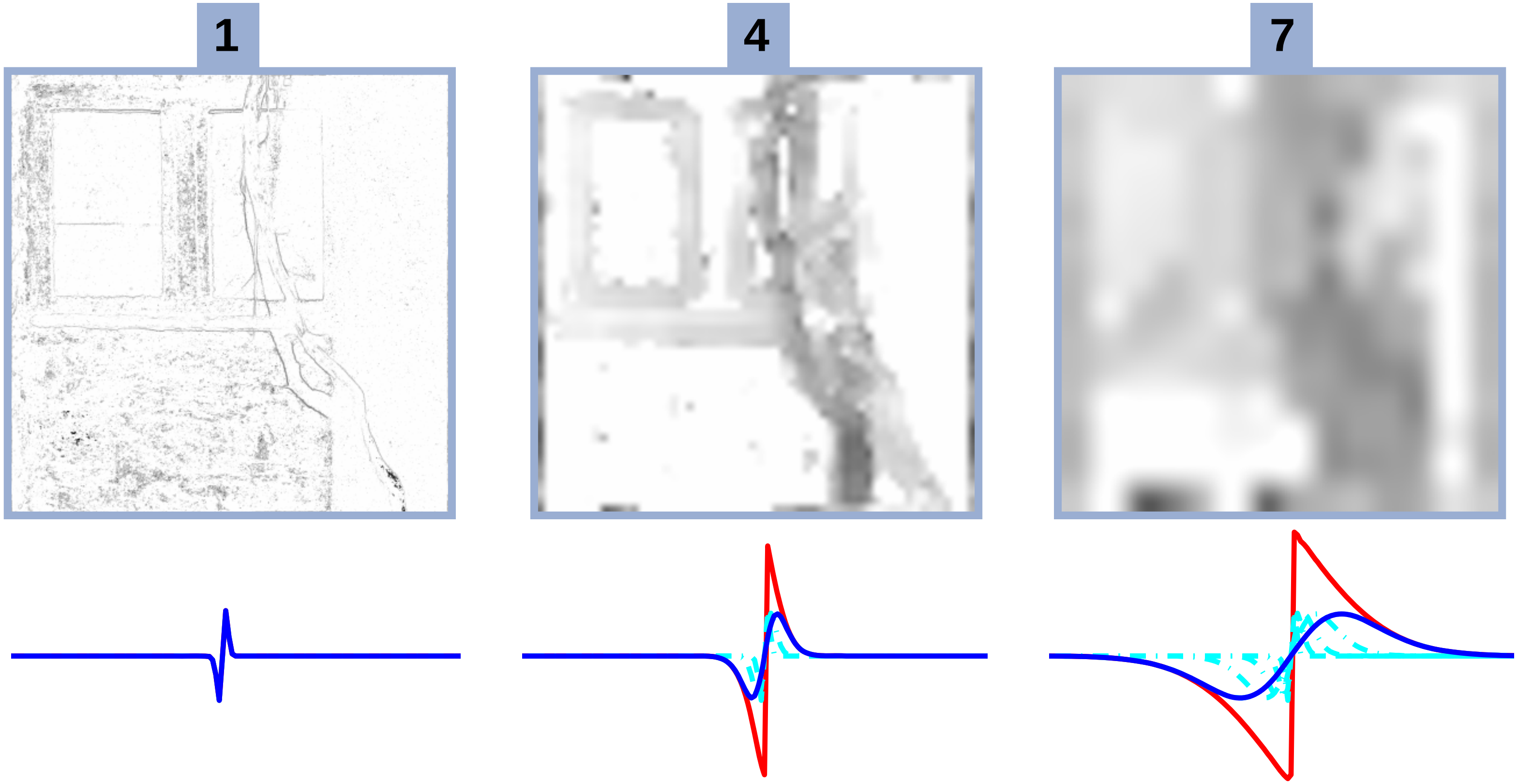
Tone Mapped Image

$$R_l = \frac{C_l^{inp}}{C_l^{ref}}$$



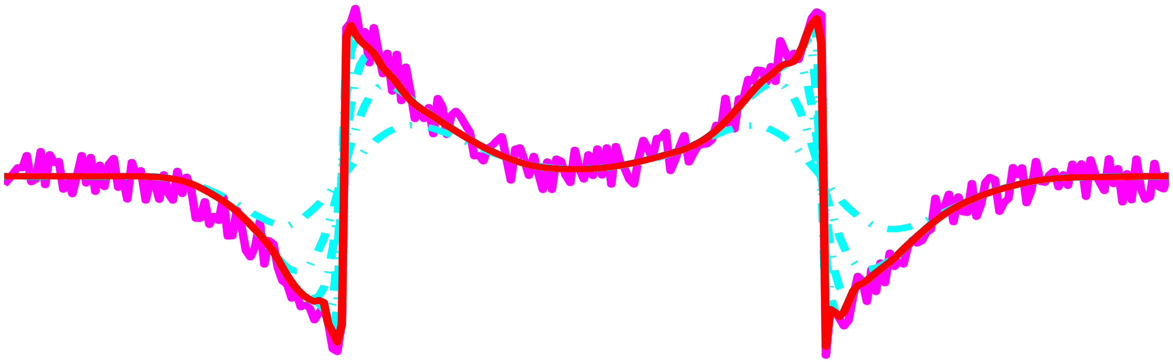
Contrast ratios at several scales.

Link: Contrast Metric & Profiles



1. Scale of contrast measure defines the profile size
2. Contrast ratio at each scale defines the sub-band amplitude (blue)
3. Contrast for larger scales appears also on smaller scales
   - the full profile is always reconstructed (red)

Formula: Countershading Profile



$$P = \sum_{l=1}^{N} (1 - \uparrow R_l) \times (\log Y^{ref}_{\sigma(l-1)} - \log Y^{ref}_{\sigma(l)})$$

amplitude of profile — sub-band component of profile

1. Contrast ratio R_l on scale l drives the amplitude of sub-band component of profile at size l
2. Sum of N sub-band components gives the countershading profiles P that match the contrasts in the reference image

Adaptive Countershading

final contrast restoration

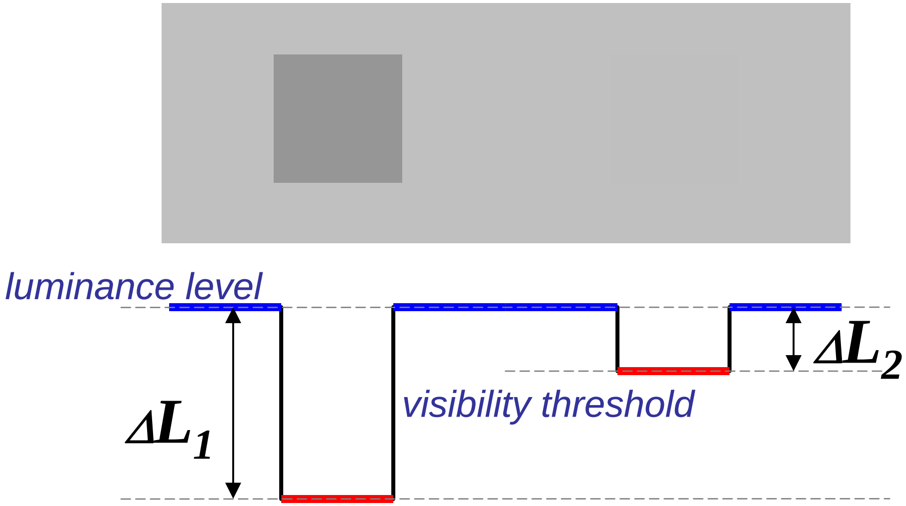
progress of restoration

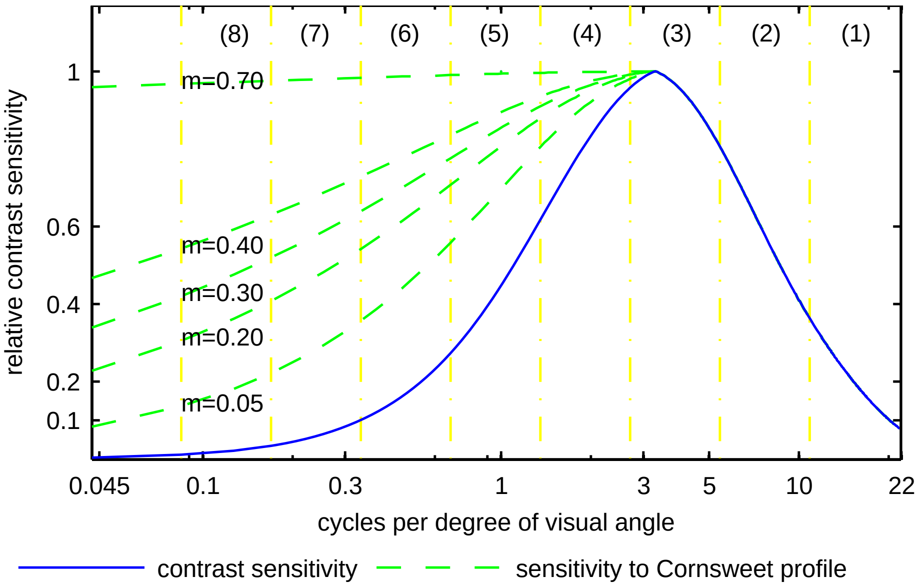
- **Objectionable visibility of countershading profiles**

Recap

- Adaptive countershading (so far)
  - input image compared to its original (reference)
  - profiles enhance selected features in the input image
  - amplitudes match contrasts in the reference image
- Limits
  - visual: profiles become visible
  - technical: image saturation due to dynamic range
- Solution: **Visual Detection Model**
  - detect visible profiles and attenuate their amplitude
  - conflict: attenuation reduces the enhancement

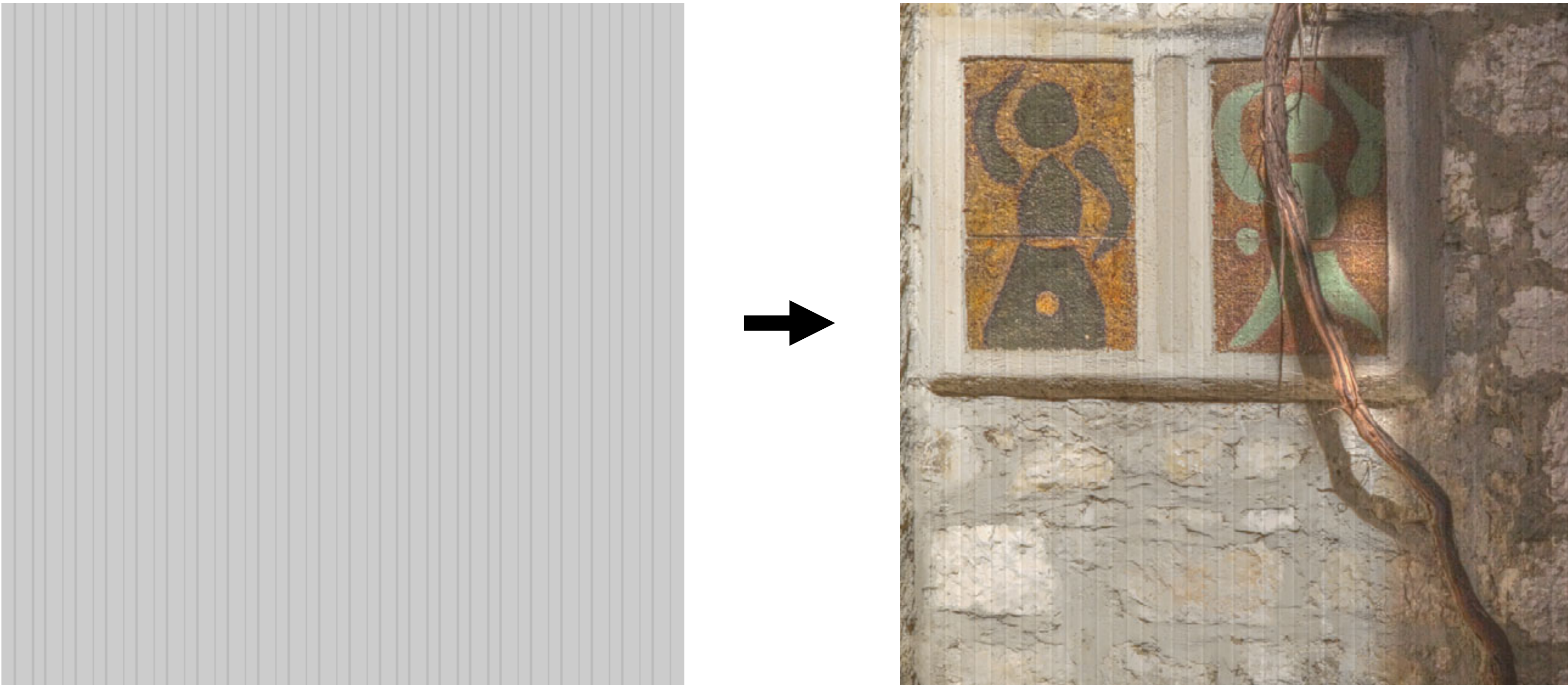
Visual Detection Model





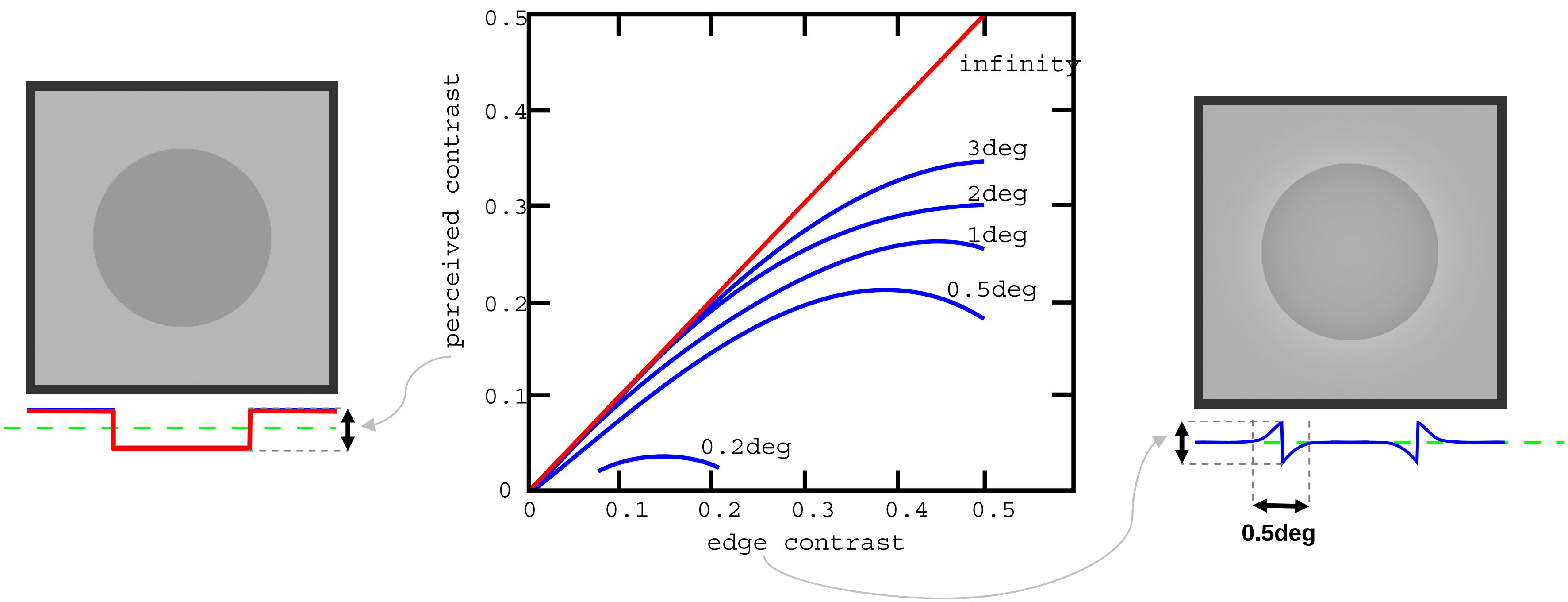
- Luminance masking
  - absolute luminance level L defines minimum perceivable luminance difference ΔL
  - defined by t.v.i. functions
- Spatial contrast sensitivity
  - reduced sensitivity to low frequencies
  - defined by CSF functions
  - improved by supra-threshold measurements of Cornsweet profile

Hiding Countershading Profiles



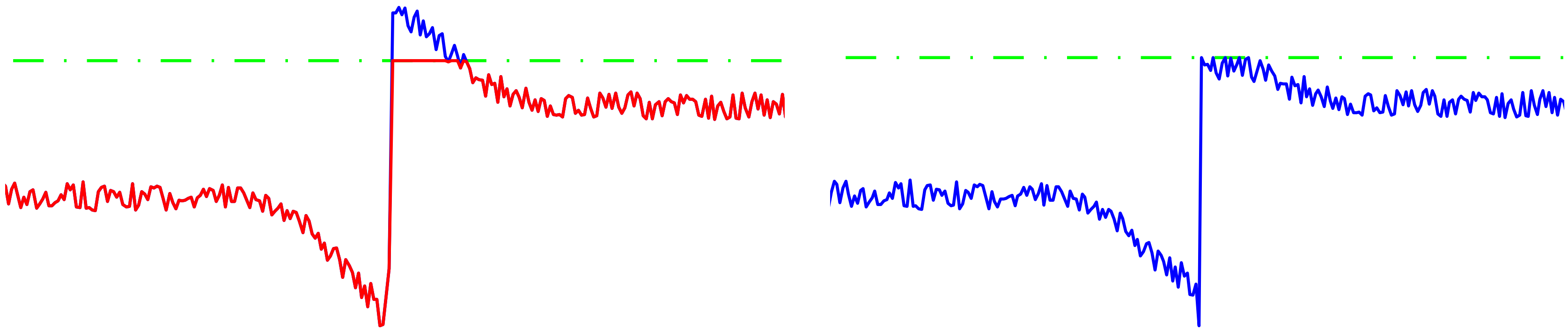
- Contrast masking
  - existing contrast masks new signals of similar orientation and frequency
  - defined by a power function of contrast present in an area
- <u>Essential improvement</u>
  - previous models allow for rather small amplitudes of profiles

Limits of Countershading Profiles



- Measurements plot for the Cornsweet effect
  - contrast at the profile edge (x) and the matching contrast at the step edge (y)
- Masking allows for stronger enhancement
- Maximum correction depends on profile size
  - natural images unlikely require correction of a large contrast with a small profile

Saturation of Profiles



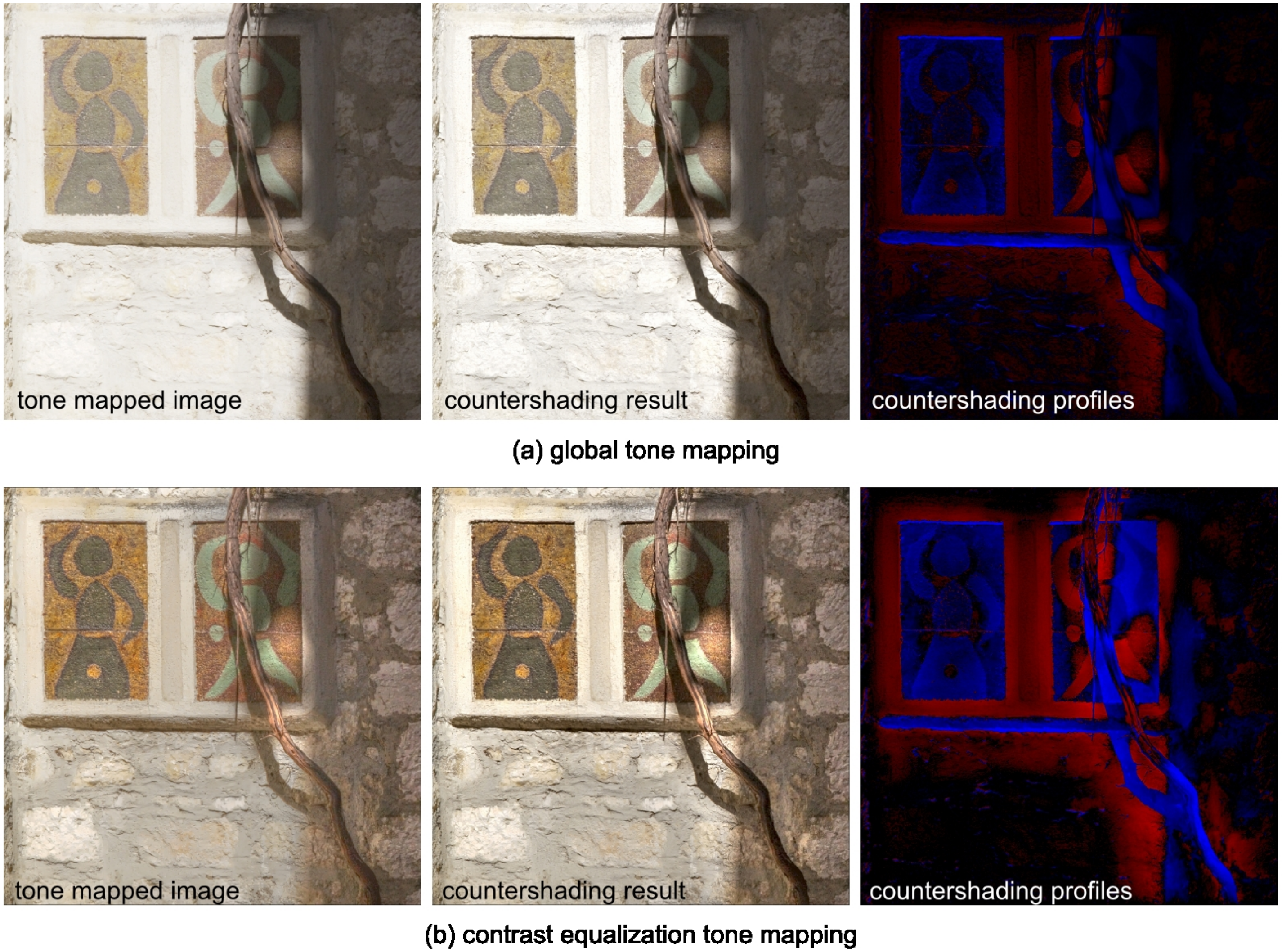
- Profiles which exceed the dynamic range cause loss of details in the image
- To prevent saturation, we limit the amplitudes of larger scale sub-band components

Adaptive Countershading

without visual model

with visual model

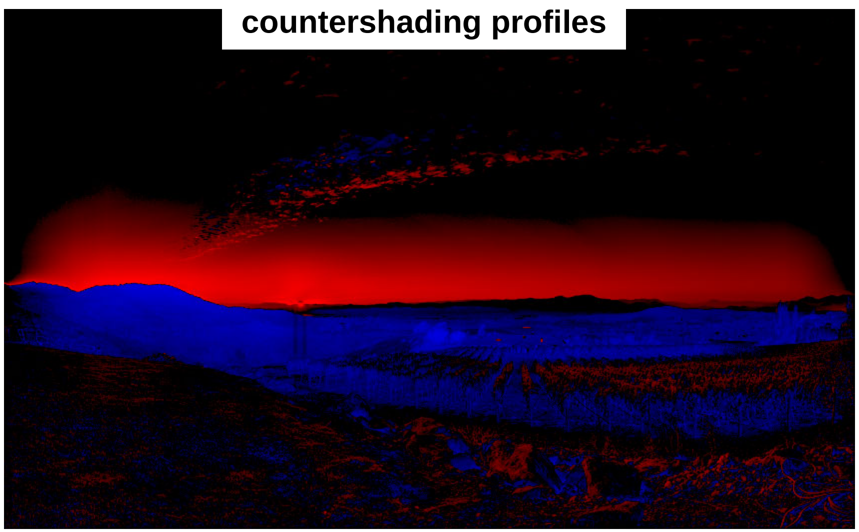
Restoration of TM Images (1/3)

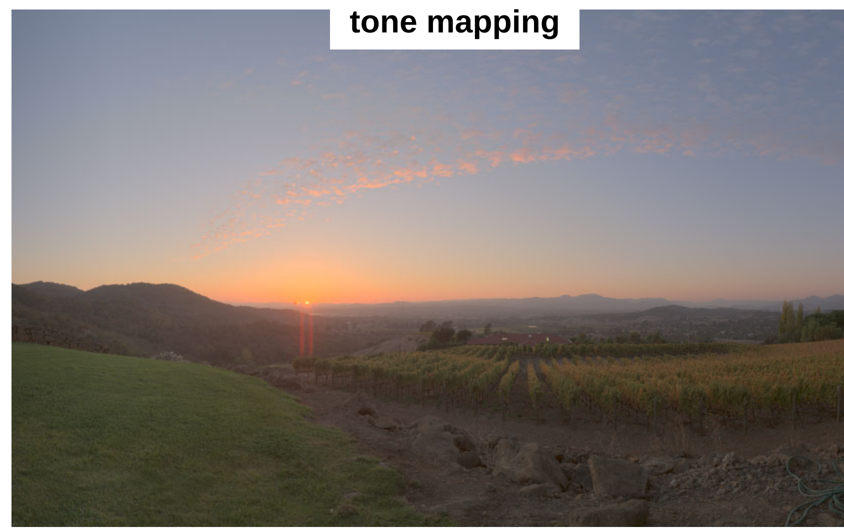


Restoration of TM Images (2/3)


reference HDR image (clipped)


countershading of tone mapping


countershading profiles

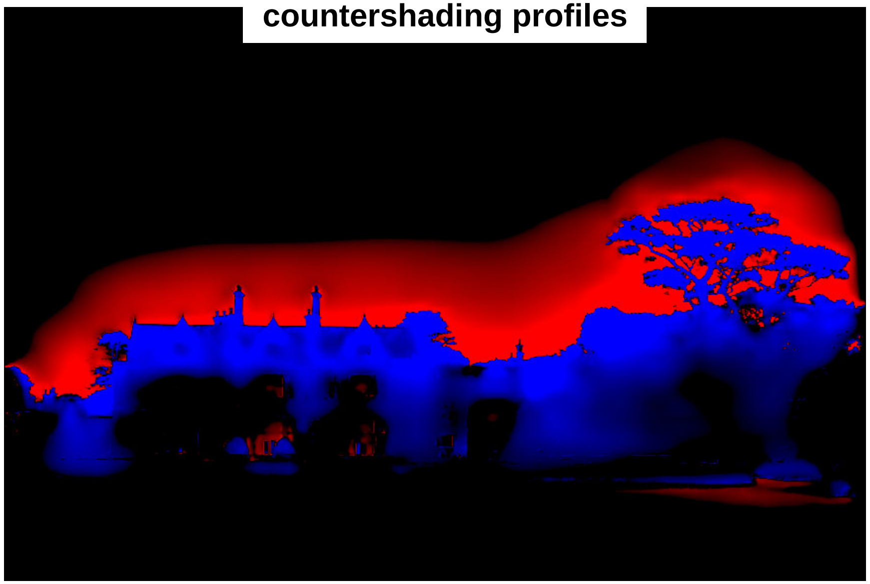

tone mapping

Restoration of TM Images (3/3)

reference HDR image (clipped)

countershading of tone mapping

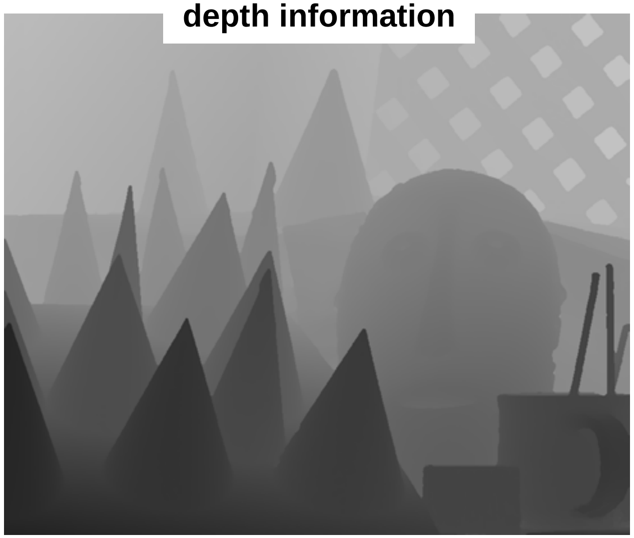
countershading profiles



tone mapping

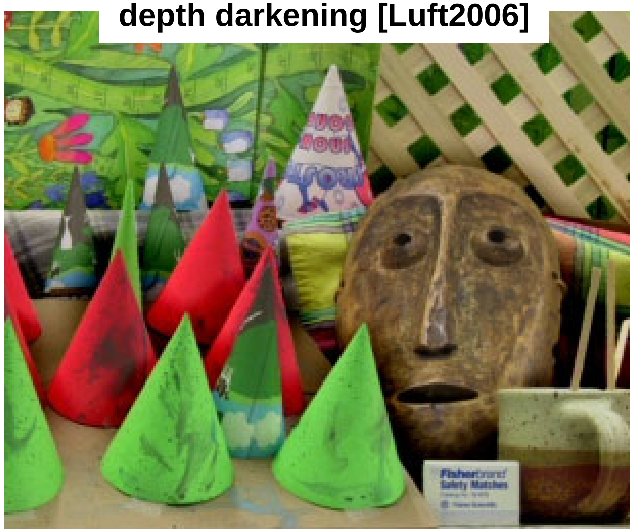
C-shading vs. Unsharp Mask

Depth Map as Contrast Reference


depth information


original image


adaptive countershading


depth darkening [Luft2006]

Conclusions

- Summary
  - application of Cornsweet illusion to image enhancement
  - automatic enhancement given the reference data
  - visual detection model
    - maximize apparent contrast
    - prevent objectionable artifacts
  - generalization of unsharp masking
    - no manual intervention
    - possibility of selective enhancement

- Future work
  - new applications (other reference data for correction)
  - validation with human subjects
  - study the effect in animations

Thank You!


tone mapped image
countershading result
tone mapped image
countershading result