Computational Model of Lightness Perception for HDR Imaging

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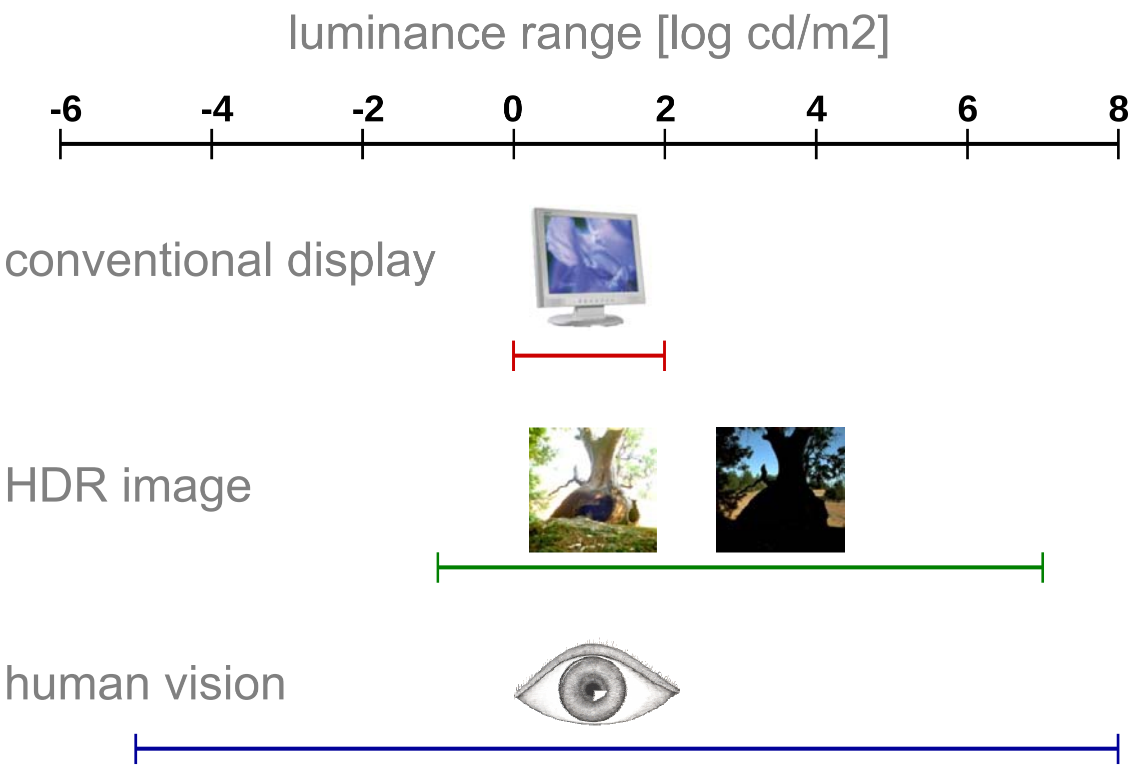
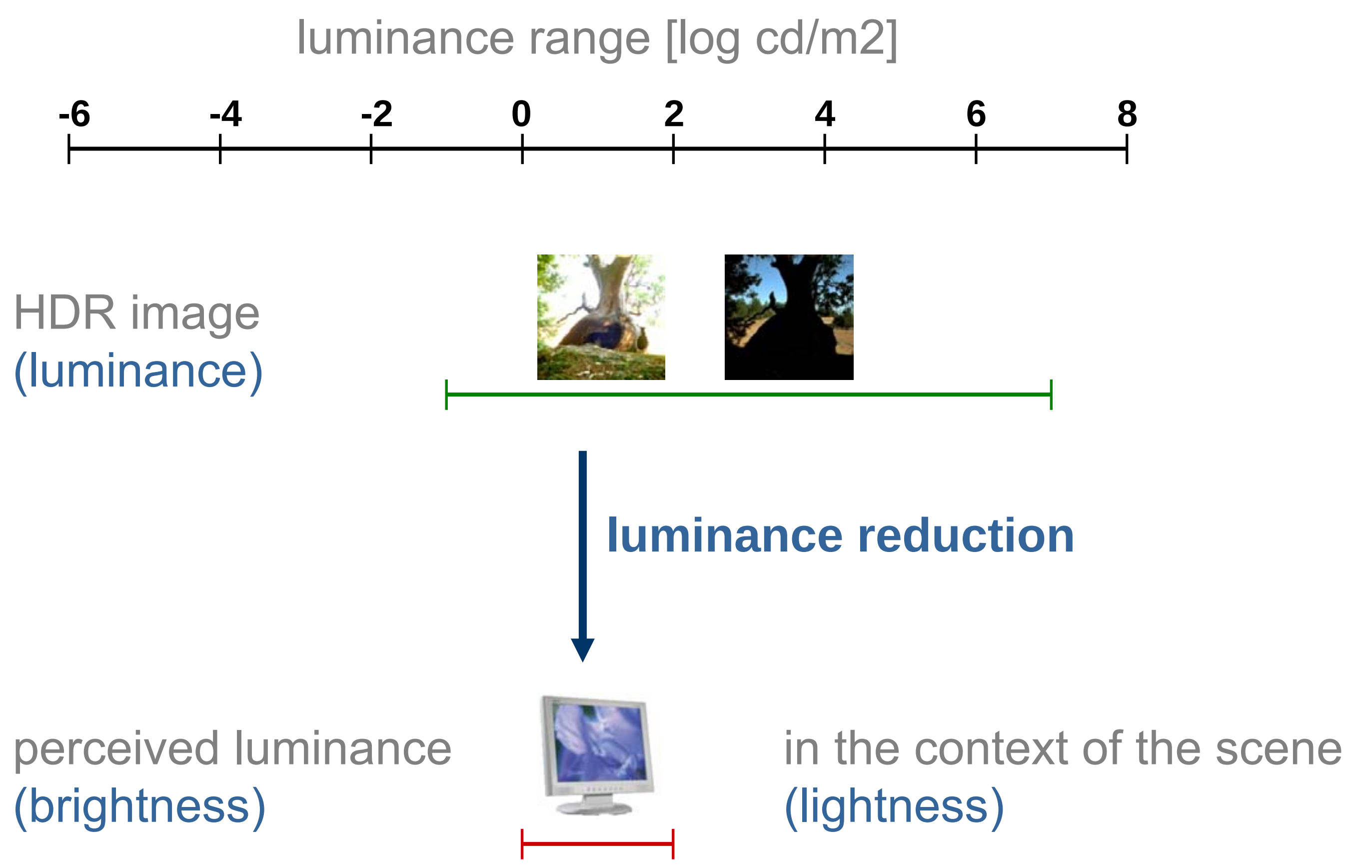
High Dynamic Range



Lightness Perception in HDR



Motivation

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Model the lightness perception corresponding to conditions in the real world.

Constraints while observing HDR scenes on a display:

- Limited dynamic range
- Limited field of view
- Different context of observation
- Different adaptation level
- Inconsistencies in perception (constancy failures not present)

Previous Work – Tone Mapping

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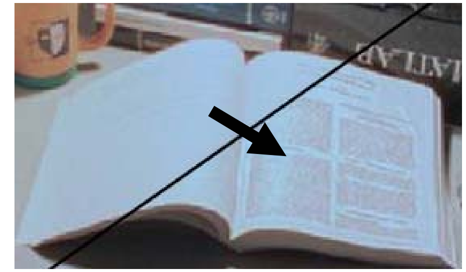


- Brightness, contrast sensitivity and sigmoid functions

  Tumbiln93, Ward94, Ferwerda96, Ward97, Pattanaik98, Reinhard02, Reinhard05 …
- Contrast domain methods

  Horn79, Jobson97, Fattal02
- Intrinsic image models (illumination and reflectance layers)

  Durand02

Problems:

- Loss of fine scene details due to quantization
- Result computed with unknown offset → mapping to gray scale not defined
- Empirical scaling of illumination layer → how is it related to perception?

Contributions

- Computational model of lightness perception
- Correct lightness reproduction for HDR images
- No change in local contrast if possible
- Use frameworks for local image processing

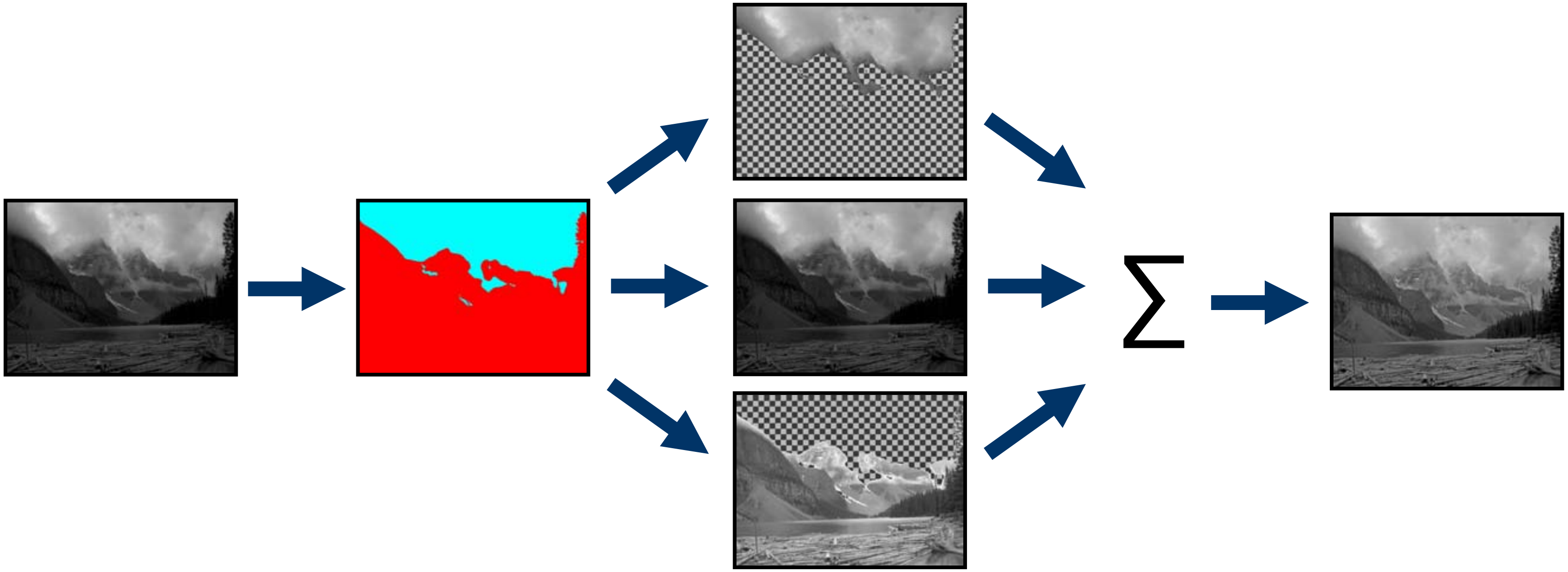
The Theory

"An Anchoring Theory of Lightness Perception"

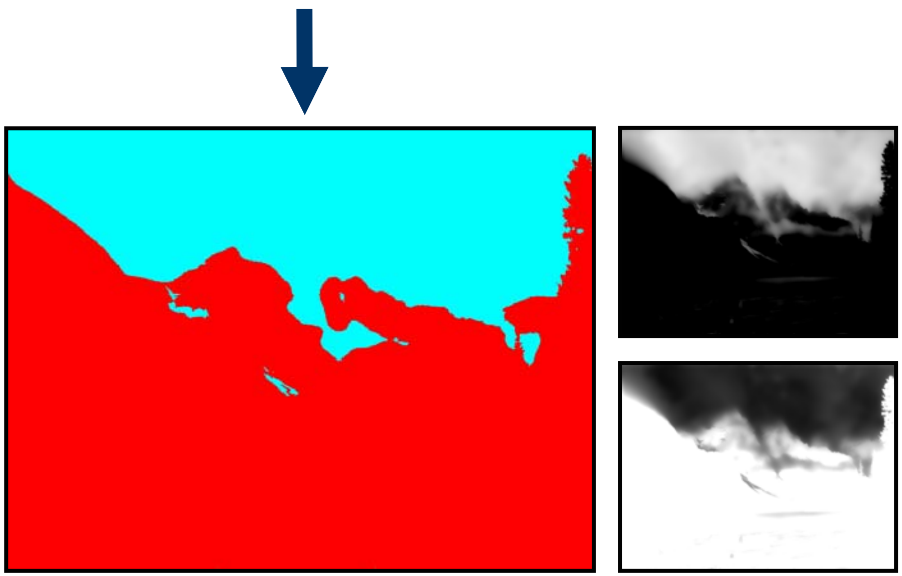
developed by Gilchrist et al. 1999

Key concepts:

- Frameworks – areas of common illumination
- Anchoring – luminance → lightness mapping



Frameworks



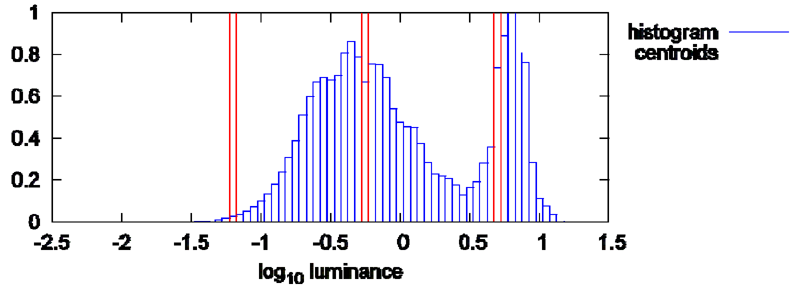
Frameworks allow for lightness estimation in complex images.

Perceptual organization:
- semantic grouping
- good continuation
- grouping of illumination
- proximity

Frameworks:
- defined by probability maps
- each pixel belongs to several frameworks
- one global framework

Computational Model for Frameworks

1.



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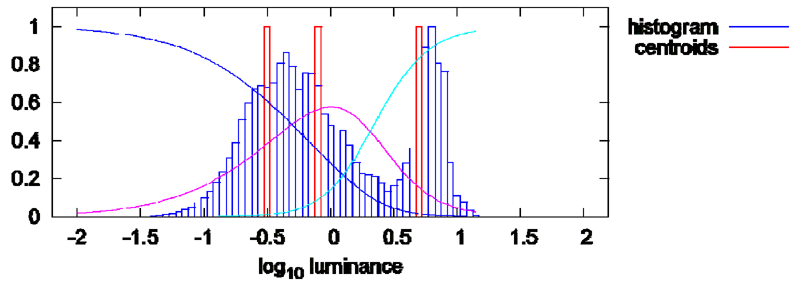
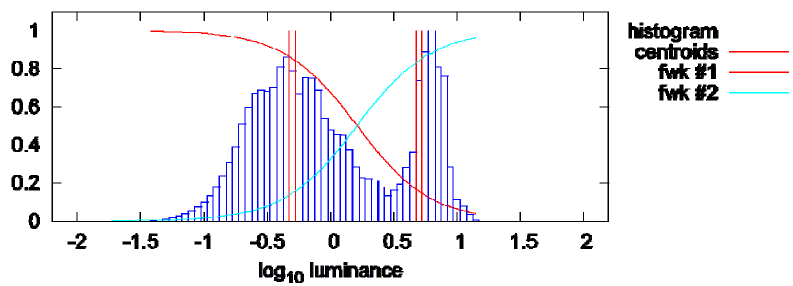


3.



Initially, identify frameworks using luminance.

Centroids define frameworks.

Customized K-means segmentation:

- Initial centroids (1)
- Calculate probabilities (2)
- Remove invalid frameworks
  - no pixels with probability >95%
- Recalculate probabilities if framework removed
- Final centroids with probabilities (3)

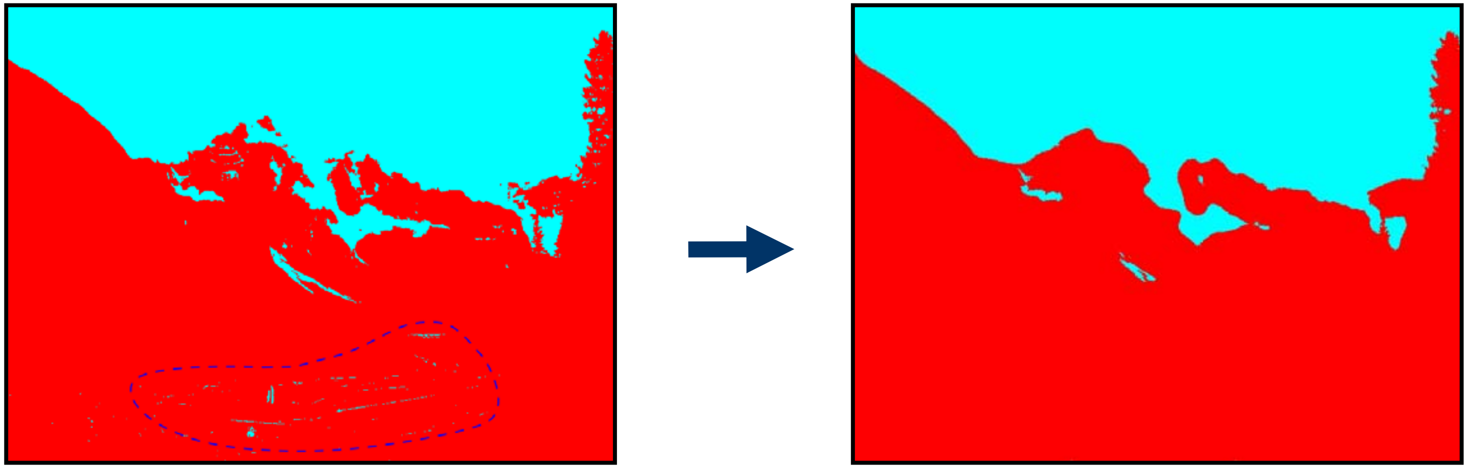
Spatial Influence

Improve perceptual organization

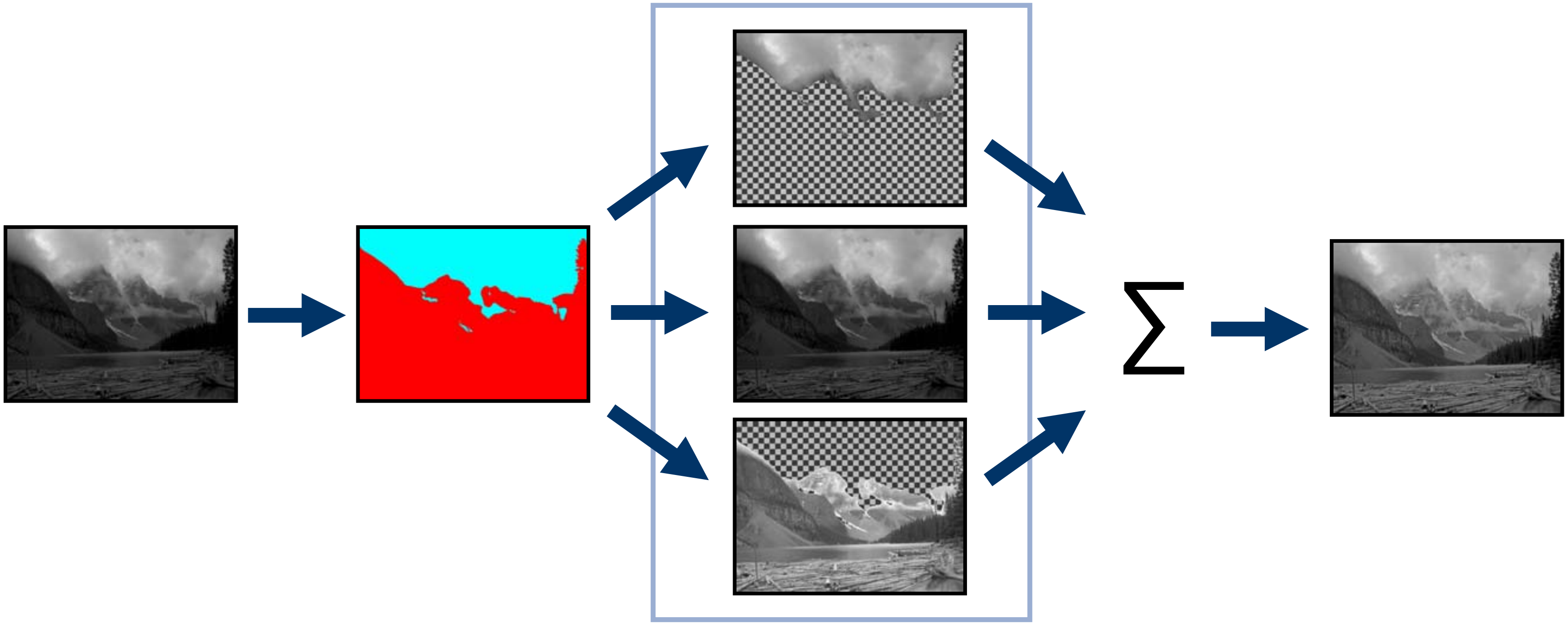
- good continuation
- proximity

Bilateral filtering of frameworks:

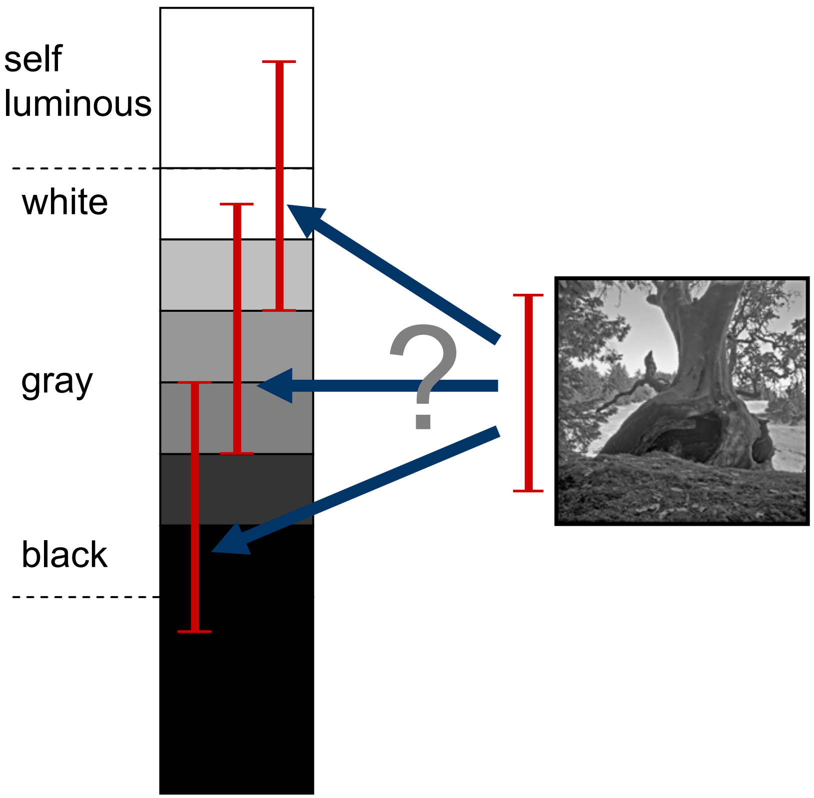
- smooth local variations
- preserve sharp borders



Anchoring



Anchoring



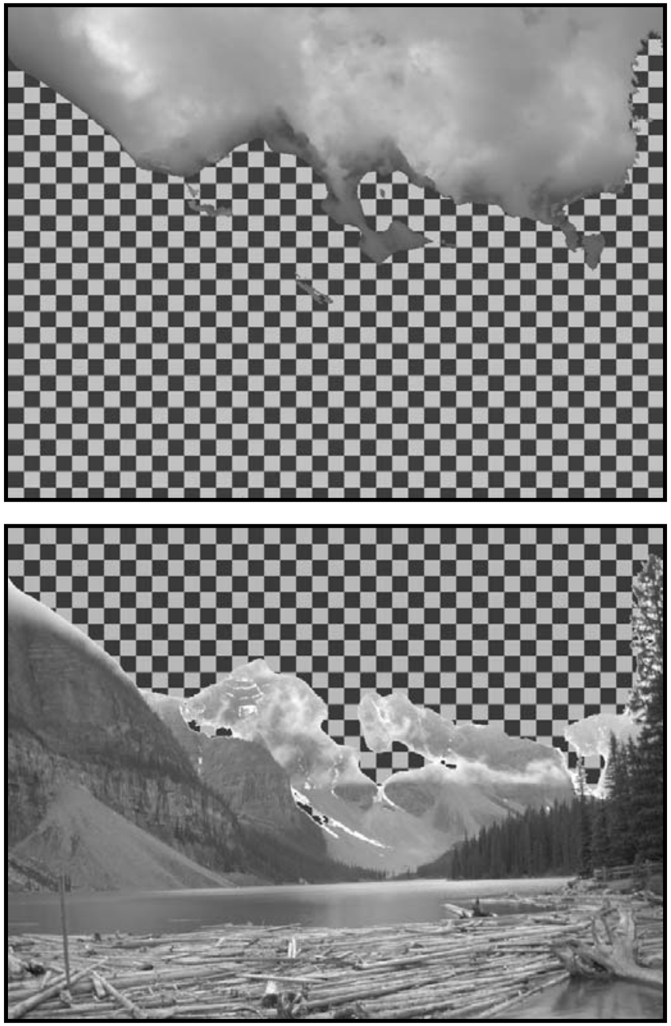
Mapping between
luminance value and
value on a scale of perceived gray shades.

Two possibilities:

- Anchoring to middle-gray
- Anchoring to white

Experimental evidence favors anchoring to white.

Estimation of Anchor



Anchoring to white rule:

- tendency of the highest luminance to appear white
- tendency of the largest area to appear white

Self-luminosity:

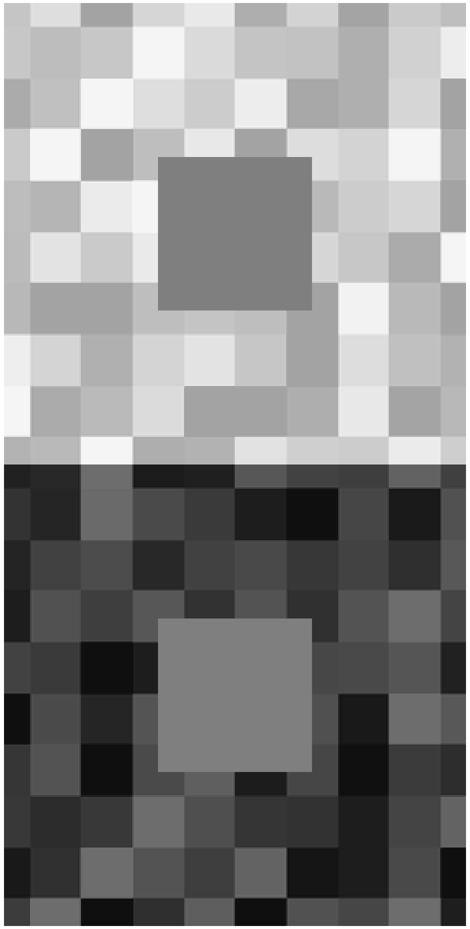
- small white disc surrounded by a large dark area appears luminous

Our approach:

- filter framework area with a large Gaussian kernel to eliminate highlights
- highest luminance in framework becomes an anchor

Articulation of Frameworks

Stronger influence on pixels' lightness by frameworks that are highly articulated.



Estimation of articulation:

- Based on the dynamic range
- Low dynamic range
  → minimum articulation
- Dynamic range above 1:10
  → maximum articulation
- Penalize frameworks with small area

Attenuate belongingness to framework according to articulation.

Net Lightness

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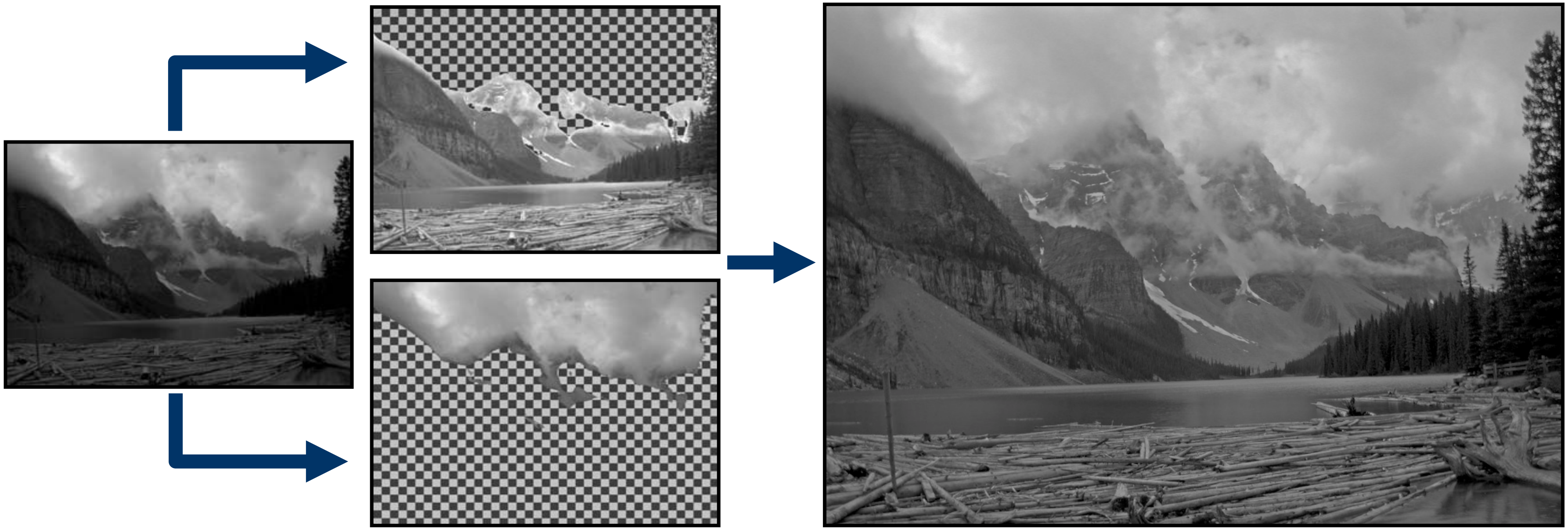
Shift original luminance

- according to local anchors
- proportionally to belongingness (dependent on size and articulation)
- constant influence of the global framework



$$L(x,y) = 30\% \cdot \sum_i (Y - W_i) \cdot P_i(x,y) + 70\% \cdot (Y - W_0)$$

Verification & Applications

- Testing the Model
  - Frameworks within Multi-Illuminant Scenes
  - Anchoring in Gelb Illusion
- Applications
  - Tone Mapping of HDR images
  - Local Image Processing

Frameworks in Natural Scenes

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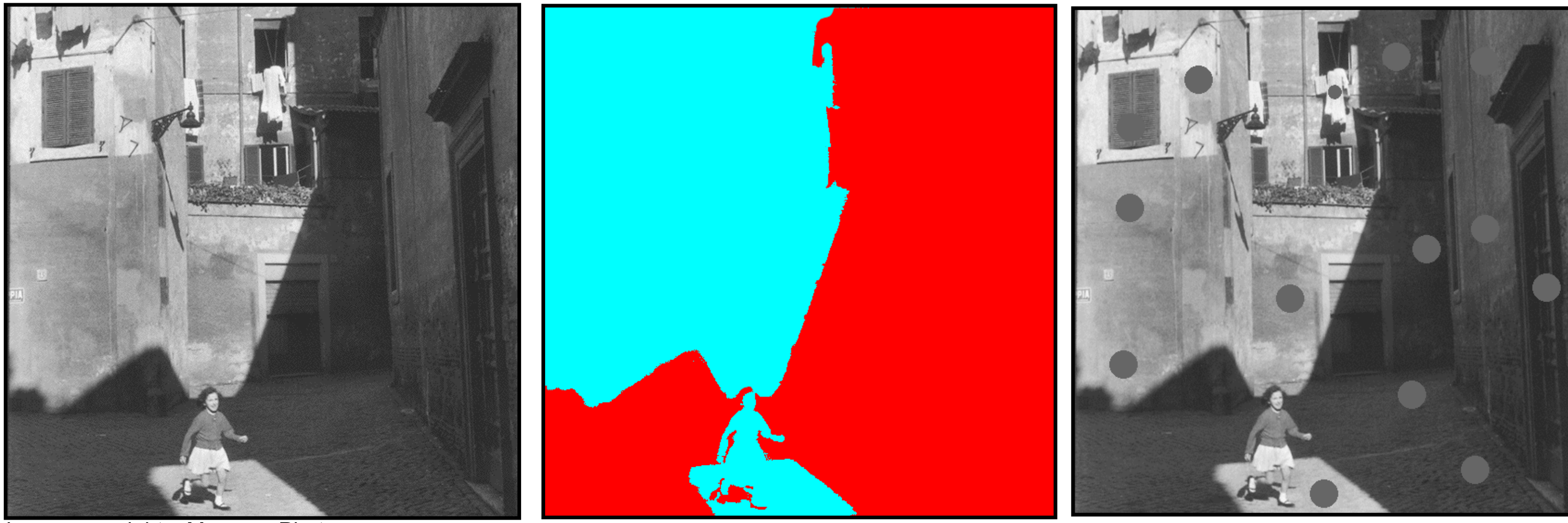


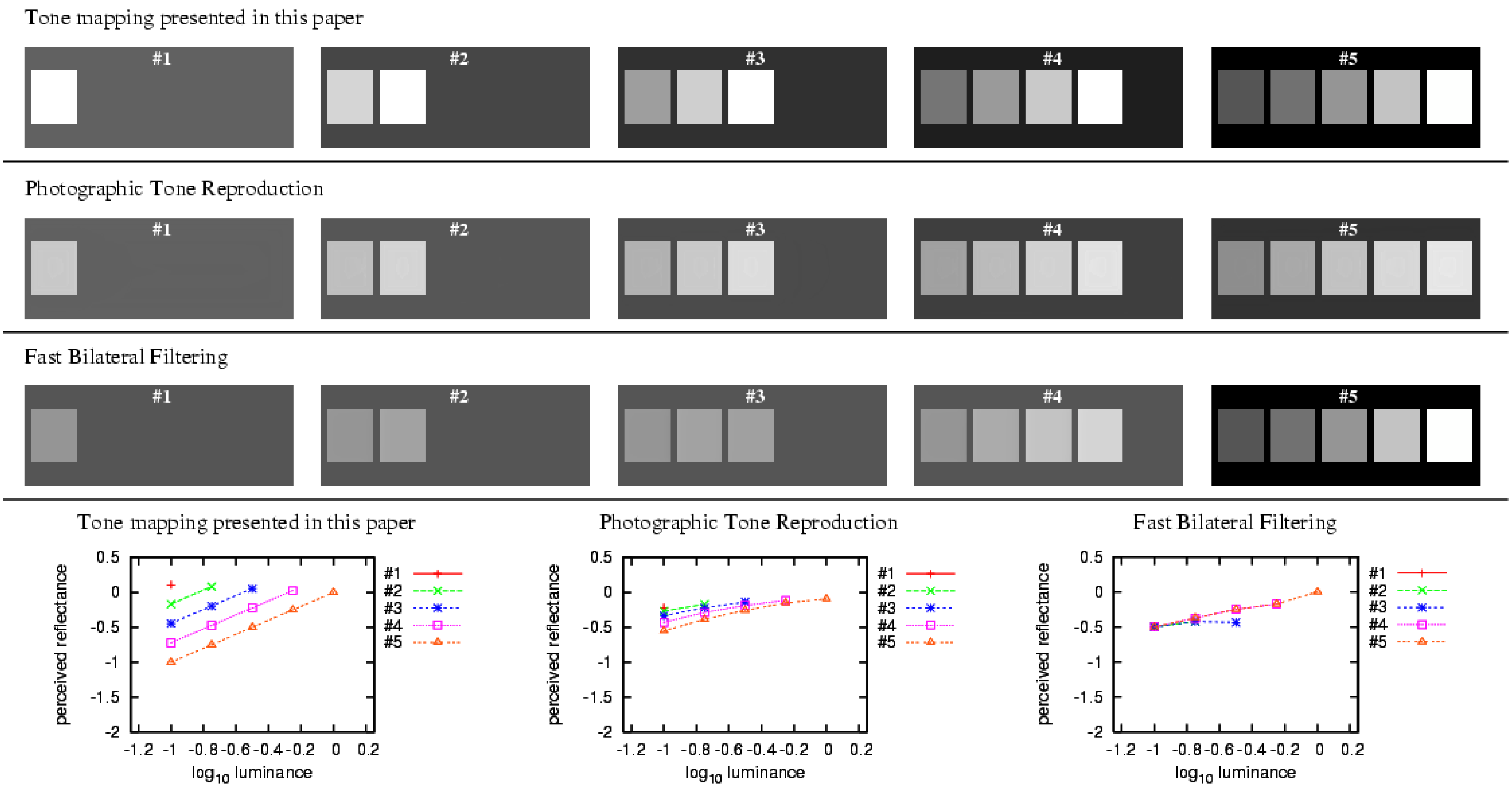
- Experiment originally conducted by Gilchrist and Radonjic
- Probe disks' luminance is constant
- Disk vs. background ratios range from 1:2 to 1:9
- **Constant lightness of probe disks within frameworks**
- **Lightness independent of background ratio**

Anchoring in Gelb Illusion

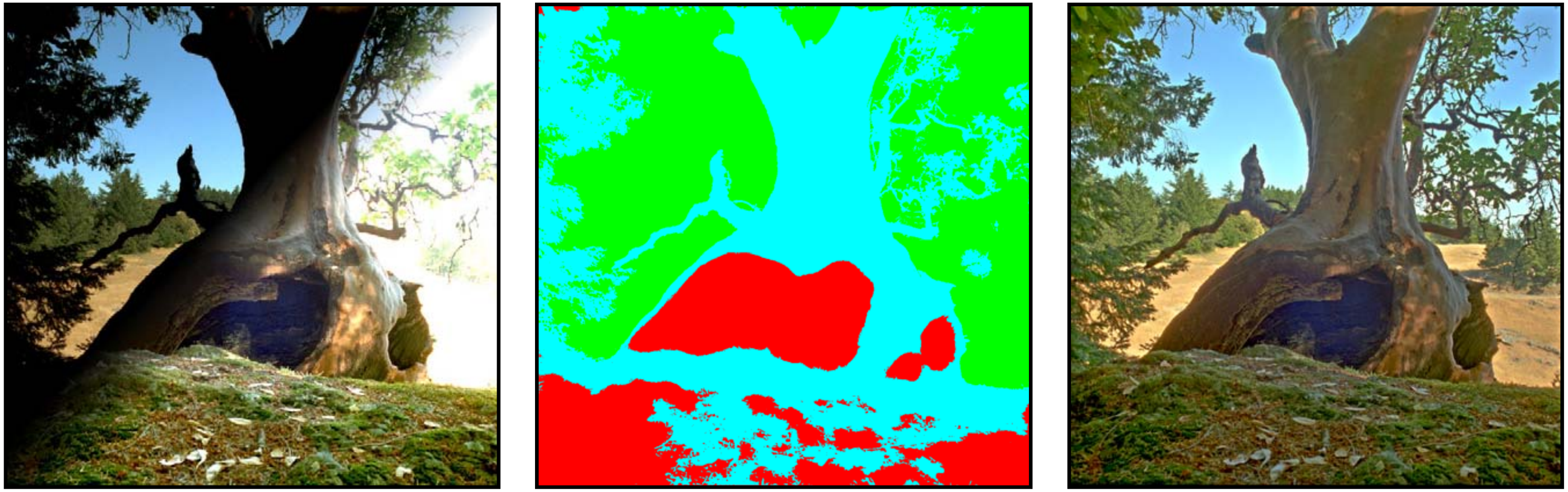
The Gelb Effect is a well known illusion which provides a good example of lightness constancy failure.

- Illusion appears in dark room conditions
- Black paper in a dark room illuminated with light appears white
- Is perceptually darkened by an adjacent paper of higher reflectance
- Cannot be explained with contrast theories
- Supports the anchoring theory and the highest luminance rule

Anchoring in Gelb Illusion



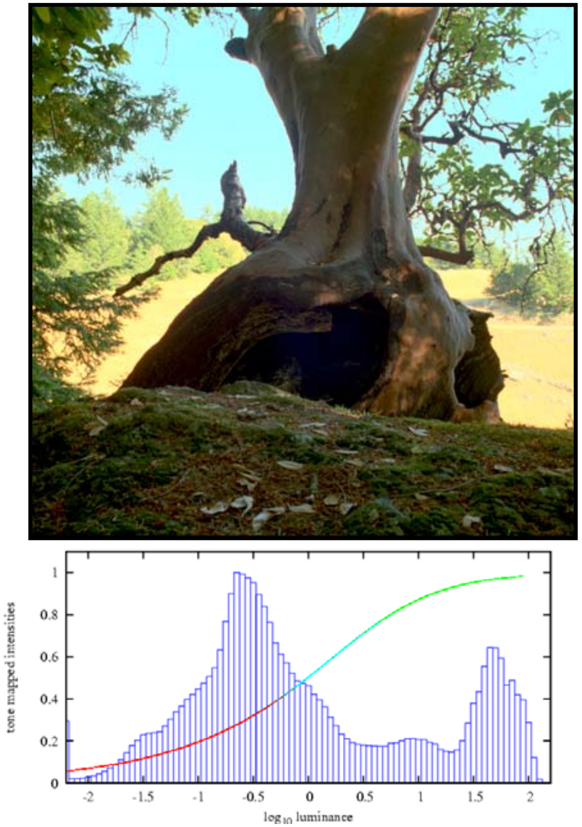
Tone Mapping of HDR Images



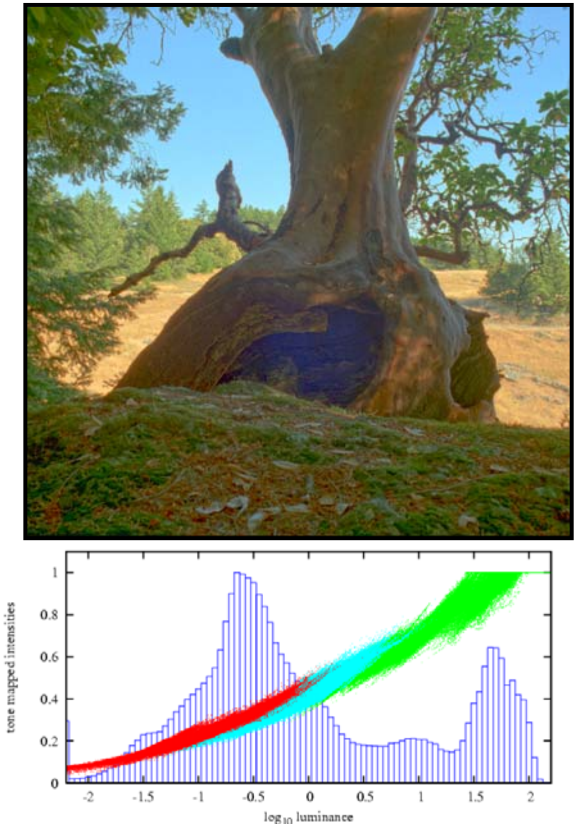
- Luminance compression in CIE Yxy color space.
- Limited influence of the global framework which counteracts the dynamic range reduction
- Scaling of dynamic range in framework if necessary

Comparison of TMO

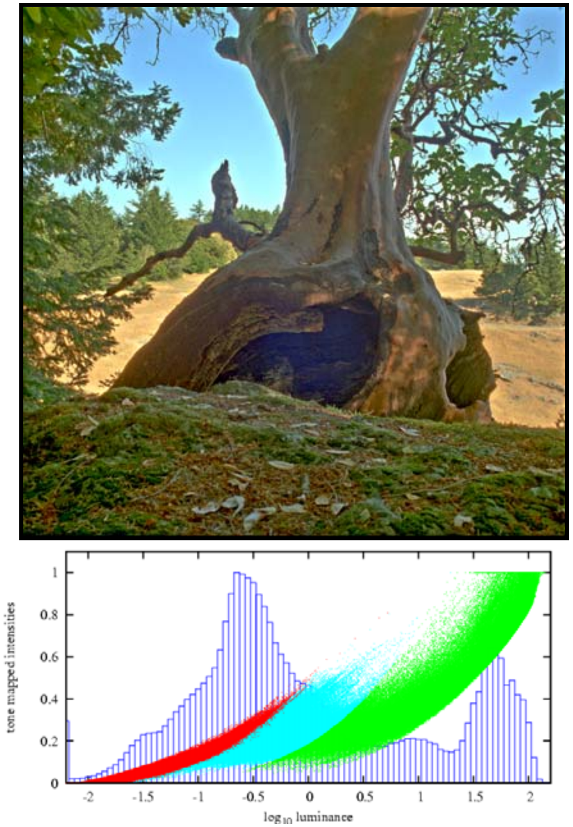
Decomposition into frameworks allows for the most efficient use of available dynamic range.



Photographic Tone Reproduction



Bilateral Filtering



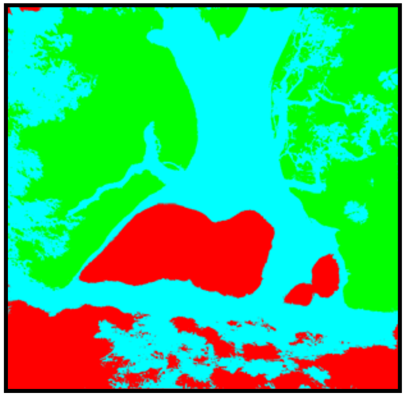
Presented Computational Model

Local White Balance

Global white balance

Original image

White balance within frameworks



Conclusions

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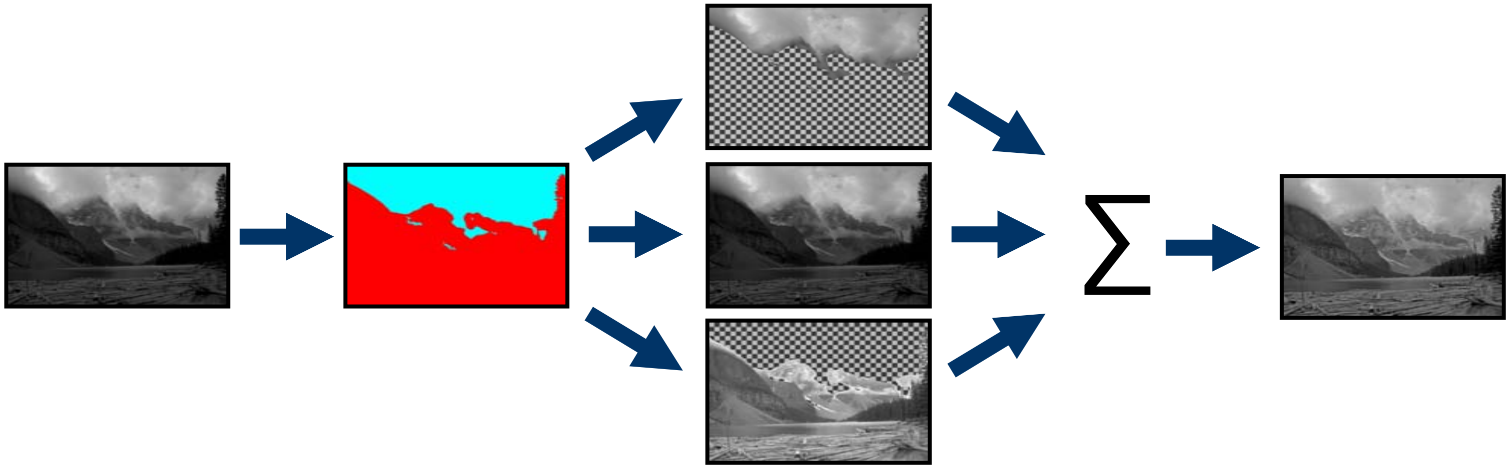
- Computational model of lightness perception theory
- Formalized method for extracting frameworks
- Application of the anchoring theory to tone reproduction in HDR images
- Simulation of lightness experiments
- Frameworks in local image processing

Acknowledgments



Thank you for your attention!

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