HMD-TMO

A Tone Mapping Operator for 360° HDR images visualization for Head Mounted Displays

Ific Goudé, Rémi Cozot, Francesco Banterle

June 19, 2019

ific.goude@irisa.fr

CGI'19

AGENCE NATIONALE DE LA RECHERCHE ANR

Percept

UMR IRISA

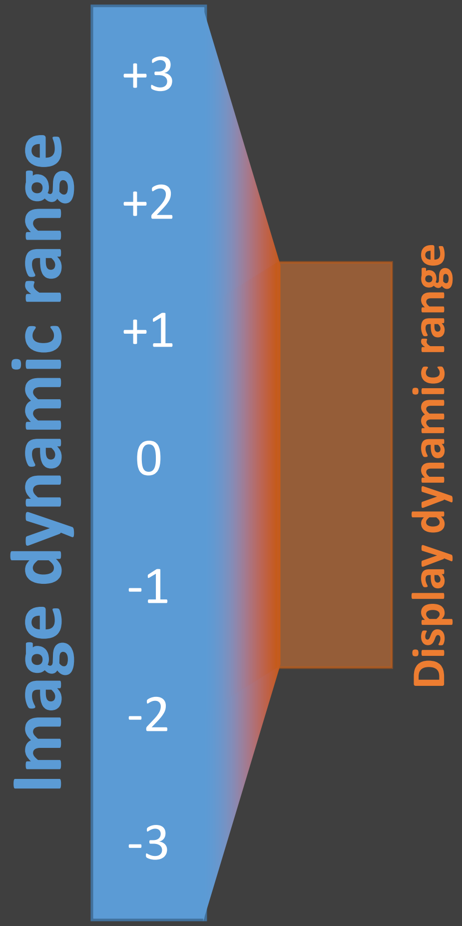
UNIVERSITÉ DE RENNES 1

Plan

- Introduction
- Related work
- HMD-TMO
- Results
- Conclusion

Introduction: High Dynamic Range

Introduction: Visualization conditions



Related work: Global TMOs

Measuring quality of omnidirectional high dynamic range content [Perrin17]

- Measure the preferred TMO
  - 5 Tone Mapping Operators
  - 8 HDR panoramas
  - 25 participants
  - 1 Head Mounted Display
- Results do not show a clear preference

Tone Mapping HDR Panoramas for Viewing in Head Mounted Displays [Melo18]

- Measure the preferred TMO and the fidelity
  - 4 Tone Mapping Operators
  - 5 HDR panoramas
  - 15 participants
  - 2 Head Mounted Displays
- The perceived quality depends on the content and the HMD

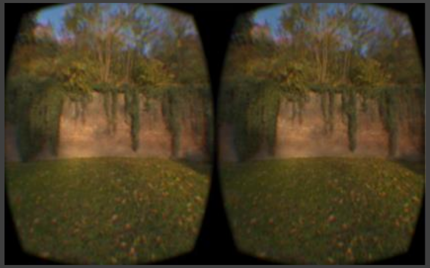
Related work: Viewport TMOs

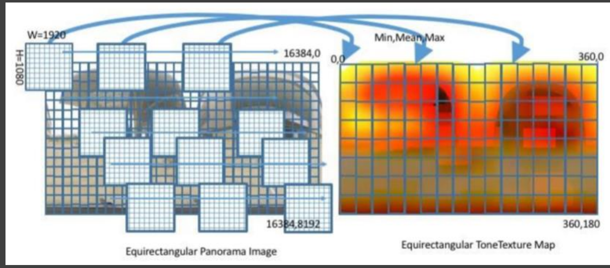
Dynamic tone mapping with head-mounted displays [Yu15]

- Photographic Tone Reproduction applied to the viewport [Reinhard02]
- Simulate eye adaptation to smooth transitions

View Dependent Tone Mapping of HDR Panoramas for HMDs [Cutchin16]

- Classify viewports histogram into four categories
- Store tone mapping coefficients into a *ToneTexture*





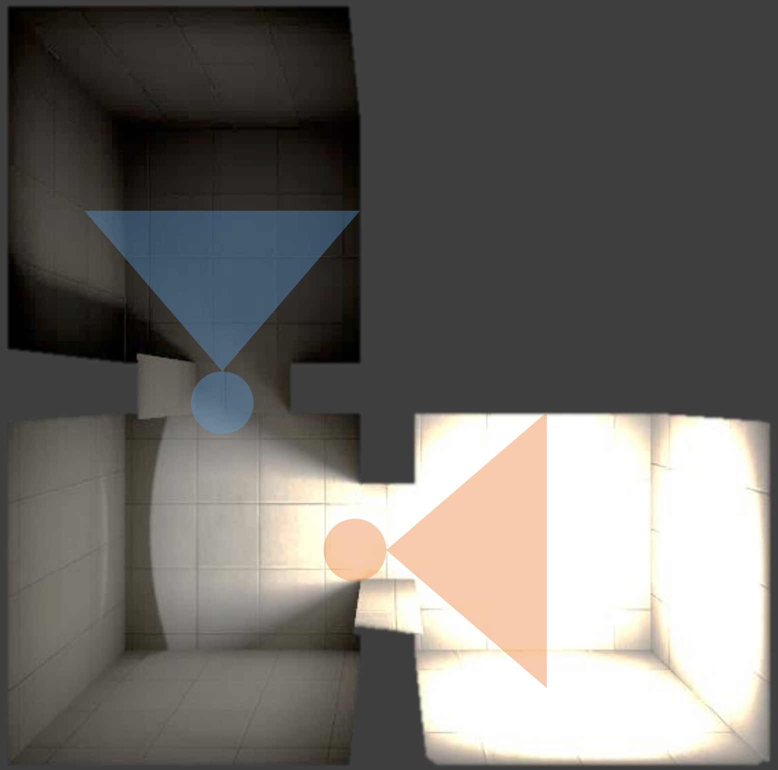
Related work: Conclusion

- Global TMOs
  - No particular preferences
  - The quality depends on the content and the HMD
- Viewport TMOs
  - Produce a better quality in the viewport
  - Avoid flickering due to sudden change in dynamic range
    - Smooth transitions
- Limitation
  - Lack of global coherency

HMD-TMO: Proposed framework

- Preserve **global coherency**
- Enhance **local contrast**
- Tradeoff between Global and Local TMOs

HMD-TMO: Proposed framework

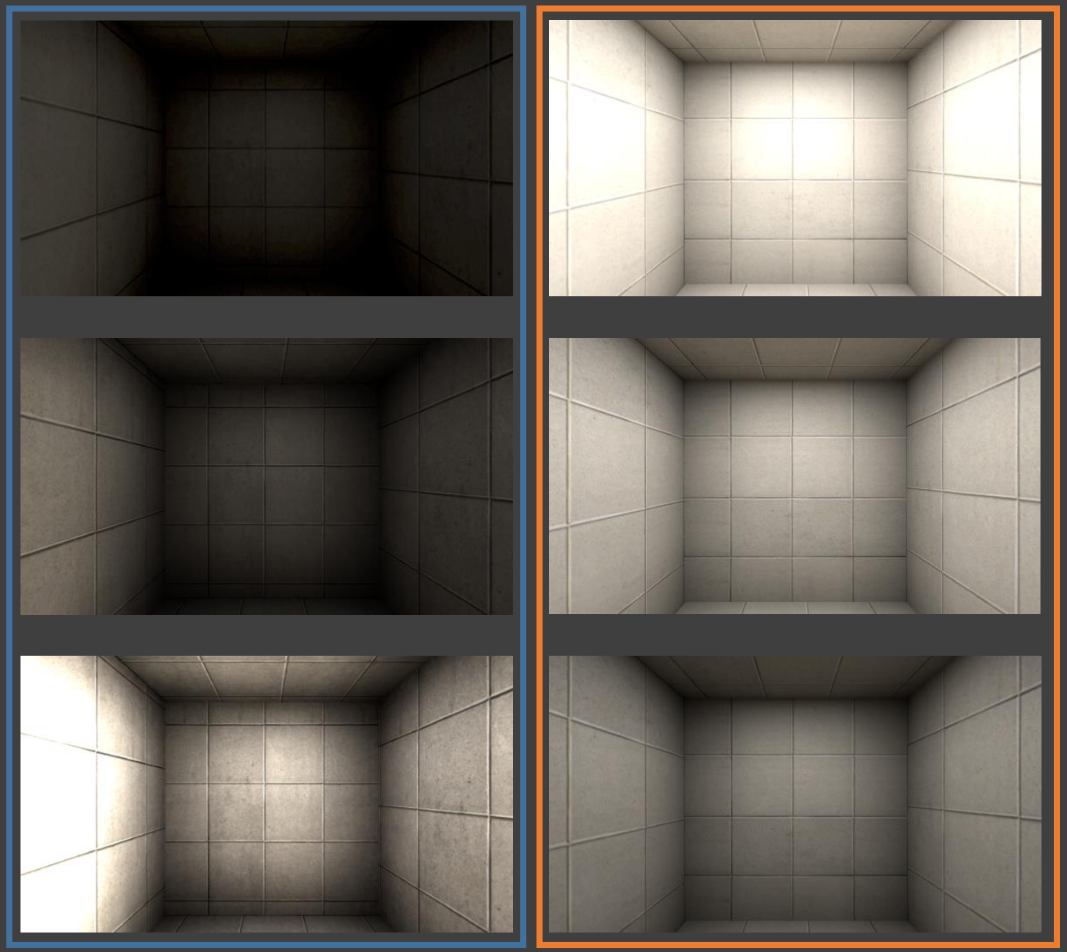


HDR 3D Scene

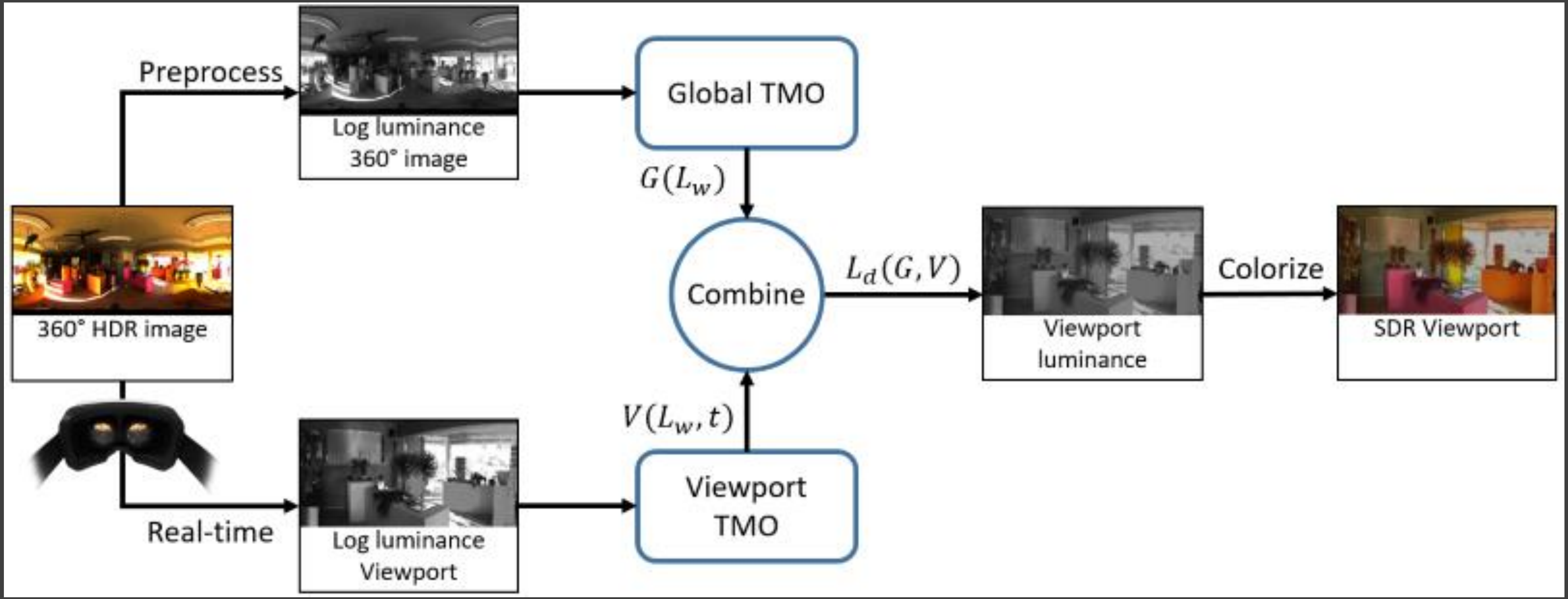
Global TMO

Expected TMO

Local TMO



HMD-TMO: Proposed framework



HMD-TMO: Proposed framework

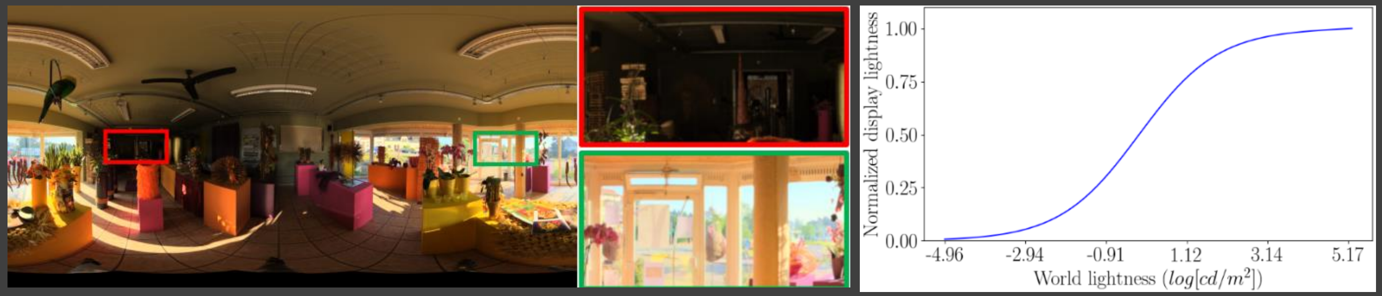
- Global TMO
  - Preserve global coherency
  - Based on the Visibility Matching Tone Reproduction operator [Ward97]
  - Compute the *Cumulative Distribution Function* of the entire panorama

$$P(b) = \frac{\sum_{b_i<b} f(b_i)}{\sum_{b_i} f(b_i)}$$

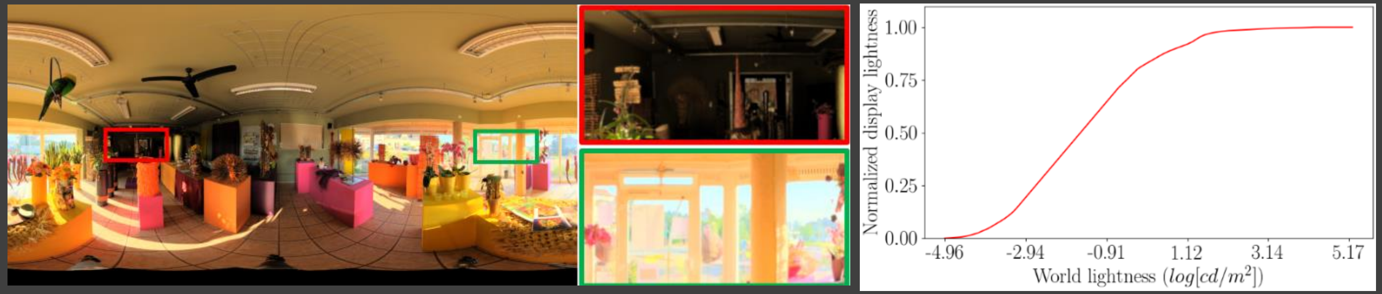
$$G\big(L_w(x,y)\big) = \exp(\log(L_{dmin}) + (\log(L_{dmax}) - \log(L_{dmin})) \times P(L_w(x,y))$$

HMD-TMO: Proposed framework

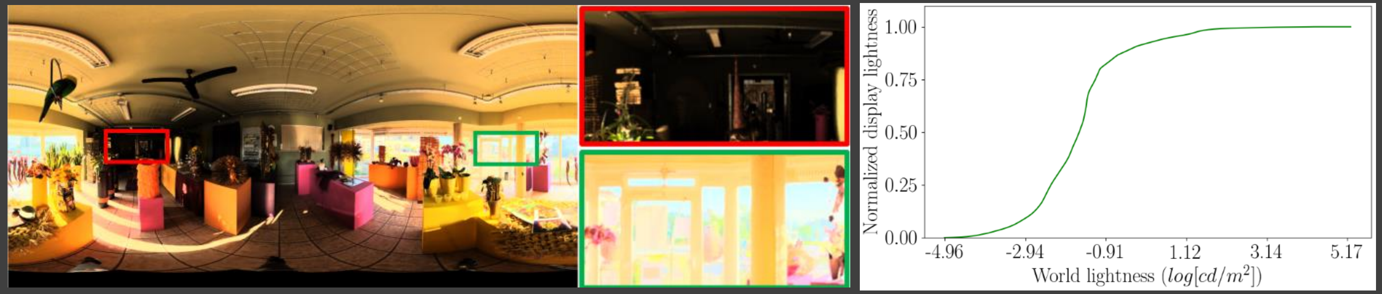
- Global TMO
  - Photographic Tone Reproduction [Reinhard02]



  - Visibility Matching Tone Reproduction [Ward97]



  - Cumulative Distribution Function



HMD-TMO: Proposed framework

- Viewport TMO
  - Enhance contrast in the viewport
  - Based on Yu's method with eye adaptation [Yu15]
  - Compute the log-average luminance of the current image

$$\bar{L}_w\big(V(t)\big) = \frac{1}{N}\exp\left(\sum_{x,y}\log\big(\delta + L_w(x,y)\big)\right)$$

Log-average

$$\bar{L}'_w(t) = \alpha\ \bar{L}_w\big(V(t)\big) + (1-\alpha)\ \bar{L}'_w(t-1)$$
$$L'_{white}(t) = \alpha\, L_{white}\big(V(t)\big) + (1-\alpha)\, L'_{white}(t-1)$$

Smooth values (eye adaptation)

HMD-TMO: Proposed framework

- Viewport TMO
  - User defined resulting exposure (commonly *a* = 0.18)

$$L(x,y,t) = \frac{a}{\bar{L}'_w(t)} L_w(x,y)$$

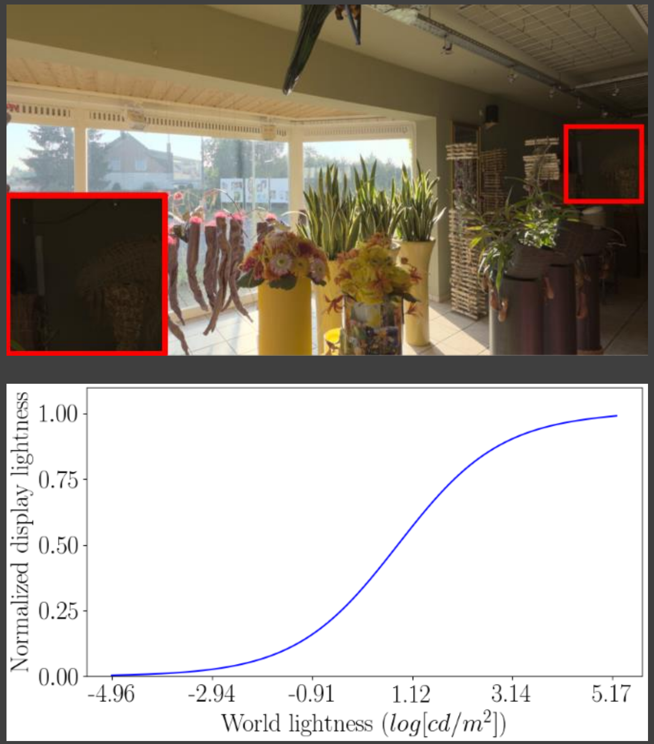
Yu's final equation

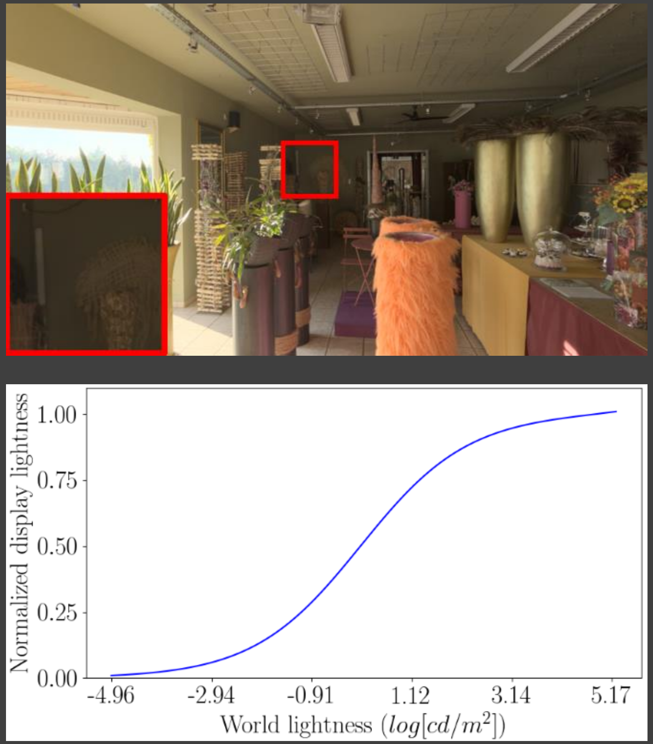
  - The final luminance of the viewport, avoiding clipping high luminances, is given by

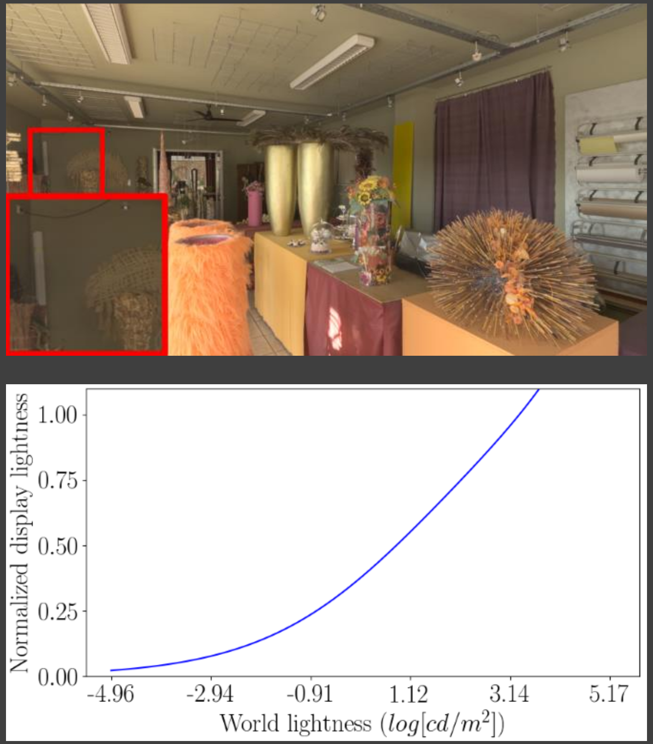
$$V(L_w(x,y),t) = \frac{L(x,y,t)\left(1 + \frac{L(x,y,t)}{L'_{white}(t)^2}\right)}{1 + L(x,y,t)}$$

HMD-TMO: Proposed framework

- Viewport TMO







t0 → *t1* → *t2*

HMD-TMO: Proposed framework

- TMOs combination
  - Preserve global coherency
  - Enhance viewport contrast
  - Combining the luminances provided by both Global and Viewport TMOs

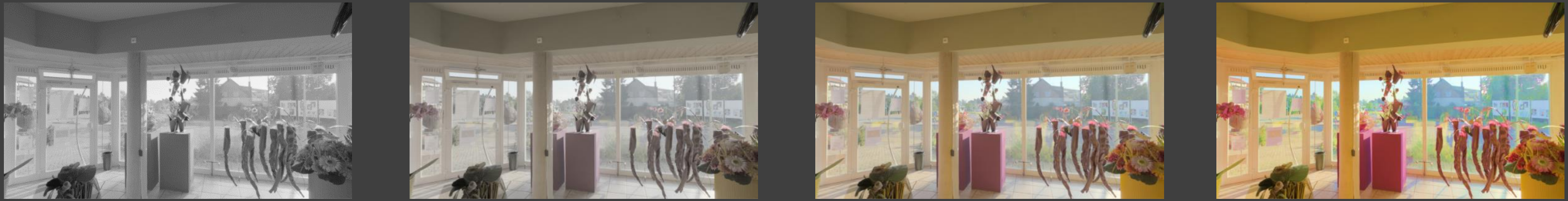
$$L_d(x, y, t) = \exp\left(\frac{1}{2}\ln(V(L_w(x, y), t)) + \frac{1}{2}\ln(G(L_w(x, y)))\right)$$

$$= \sqrt{V(L_w(x, y), t) \times G(L_w(x, y))}$$

HMD-TMO: Proposed framework

- Colorize final image
  - Tone mapped luminance image
    - $L_w = 0{,}2126.R + 0{,}7152.G + 0{,}0722.B$
  - Schlick's approach [Schlick94]
  - User defined saturation parameter (*s* = 0.7 in our results)

$$C' = \left(\frac{C}{L_w}\right)^s L_d$$



0.0 → *0.3* → *0.7* → *1.0*

Results

HDR Panorama

Global TMO

Combination

Local TMO

Conclusion

- HMD-TMO
  - Combination of Global and Viewport TMOs
    - Preserve global coherency
    - Enhance viewport contrast

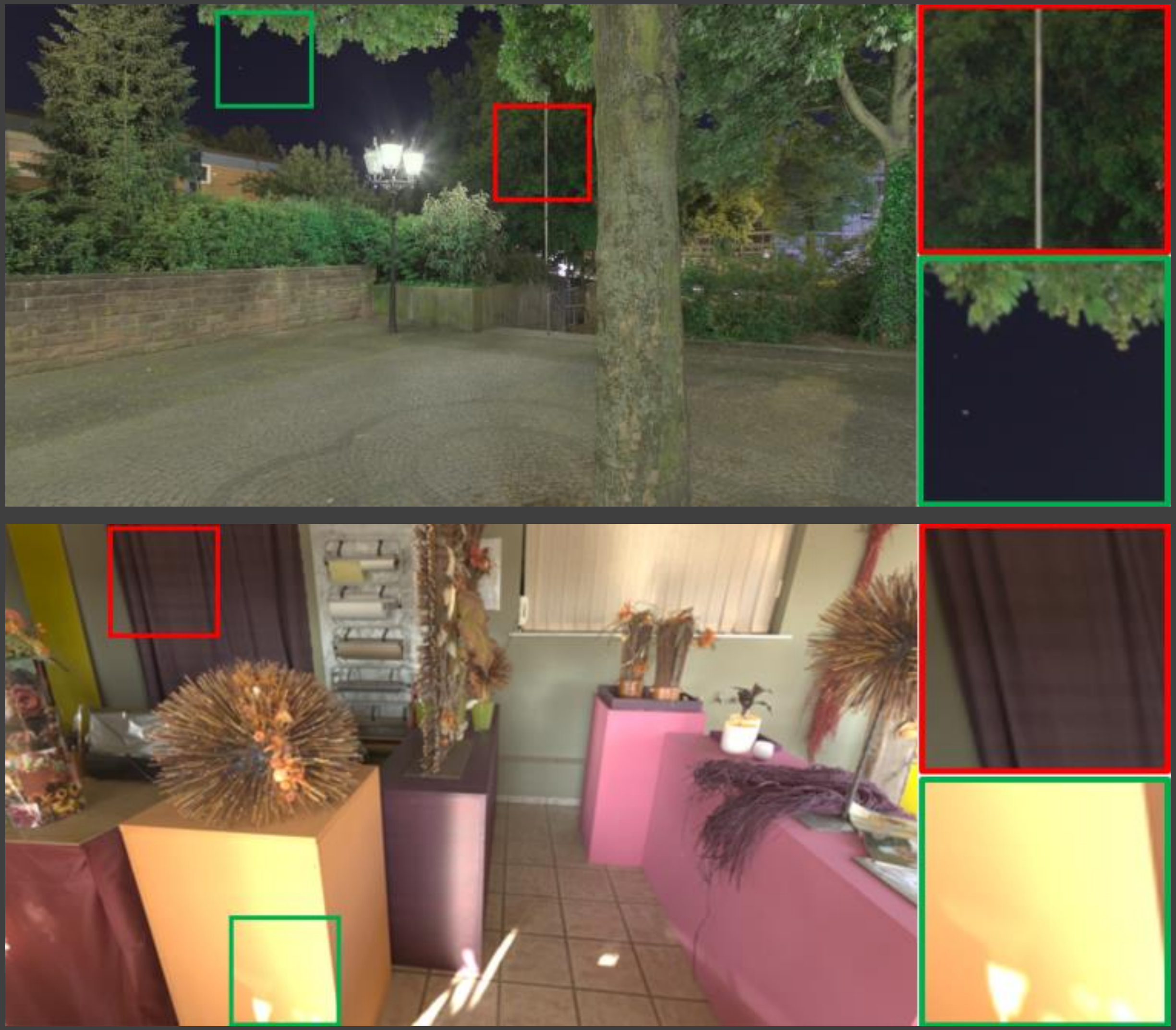
- Future work
  - How to tackle the limits of Viewport tone mapping
    - Case of a very high dynamic range in a viewport

  - 360° HDR **videos** visualization for HMDs
    - Temporal coherency
    - Sudden change in luminance range through time
    - Naturalness of time adaptation

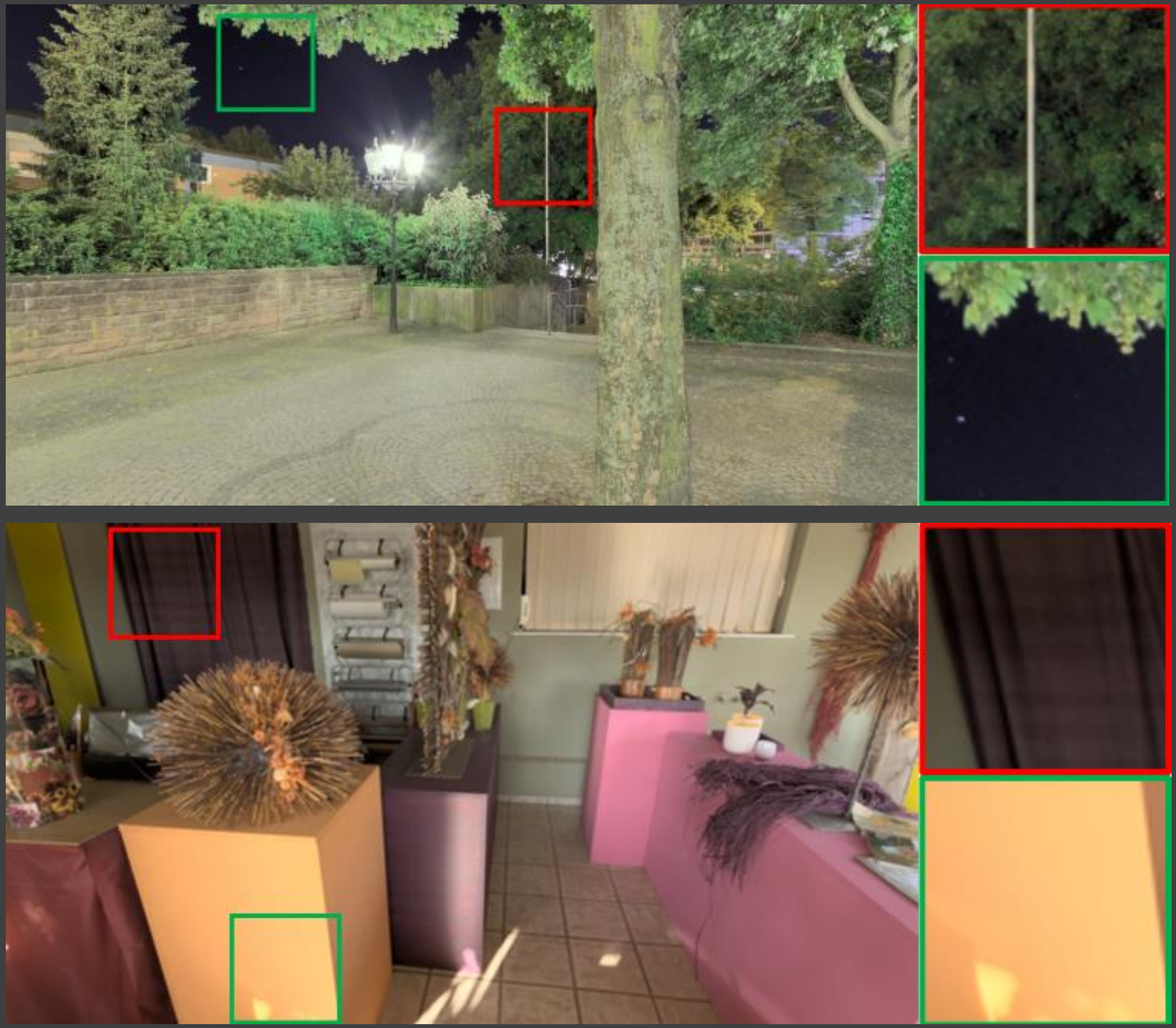
Yu’s method

Our method

Yu’s method



Our method



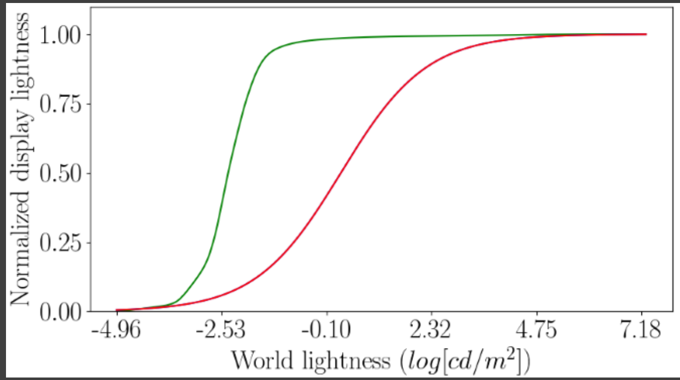
TMQI scores

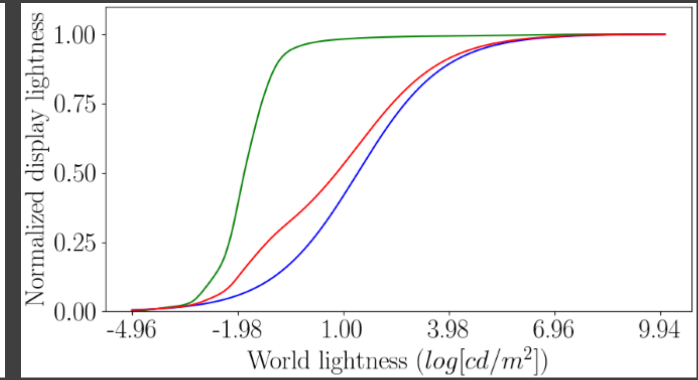
- Tone Mapped Image Quality Index [TMQI13]
  - Computed to 90 different viewports
  - Compared with 3 other TMOs
    - Photographic Tone Reproduction (on the entire image) [Reinhard02]
    - Visibility Matching Tone Reproduction (on the entire image) [Ward97]
    - Dynamic tone mapping with HMDs [Yu15]

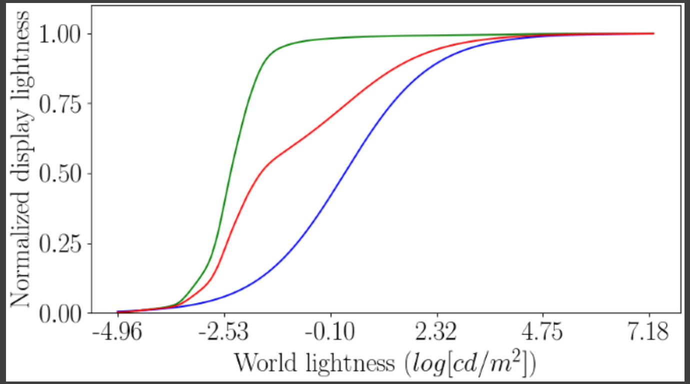
	Photographic Tone Reproduction	Visibility Matching Tone Reproduction	Dynamic tone mapping with HMDs	Ours
TMQI quality	0.798	0.854	0.865	**0.887**

Arithmetic combination

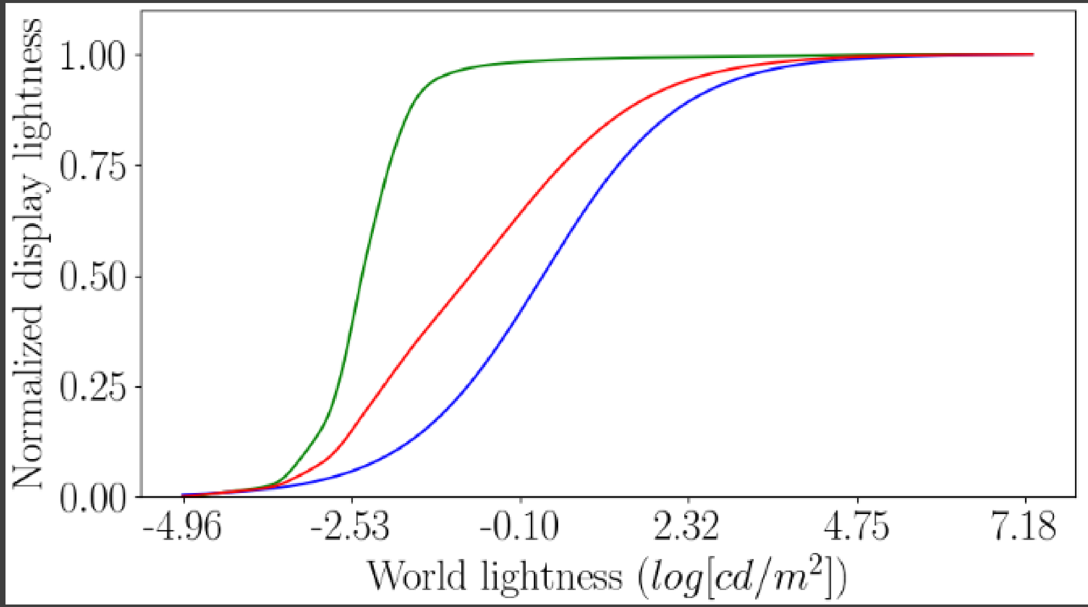
- Comparison of weighted sums (viewport weights: 1.0, 0.8, 0.5)







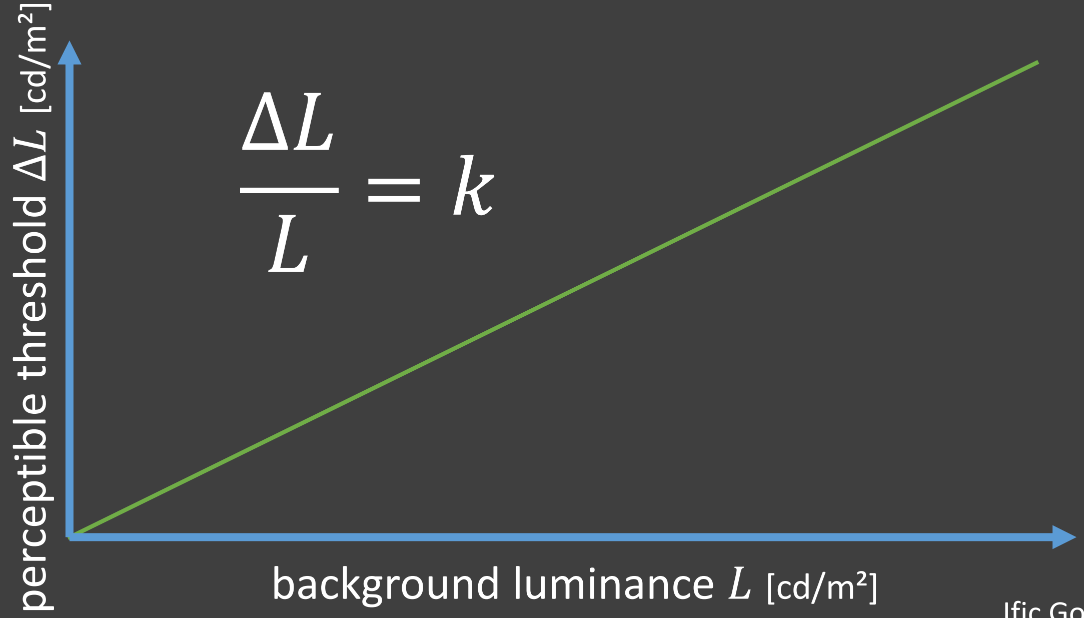
Geometric mean



HMD-TMO: Lightness perception

Weber’s law

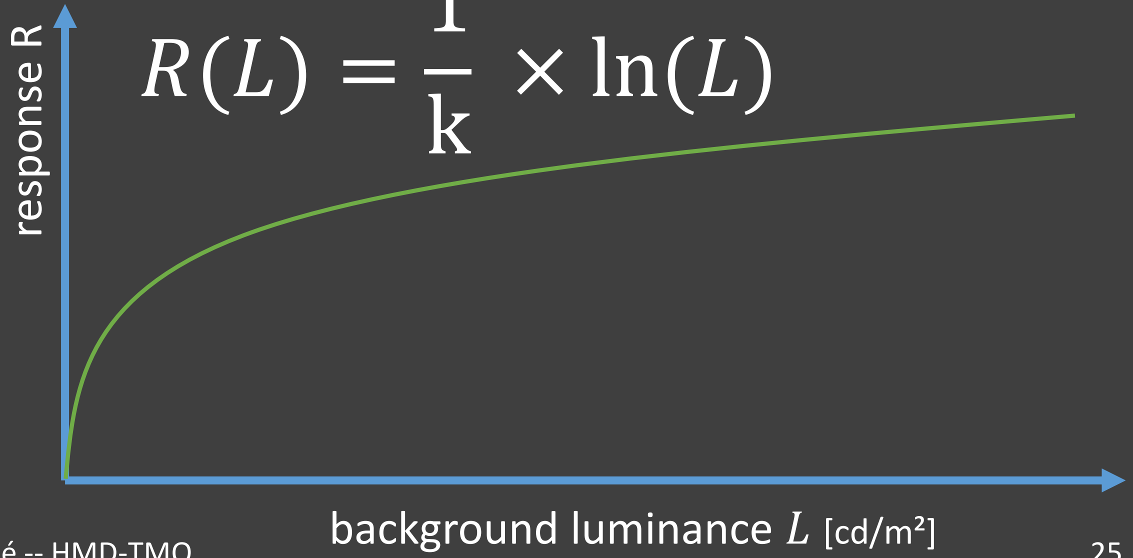
- Minimal perceptible threshold is proportional to the background luminance



$$\frac{\Delta L}{L} = k$$

Fechner’s integration

- Derivate of response relative to the luminance [Fechner66]



$$R(L) = \frac{1}{\mathrm{k}} \times \ln(L)$$

Fechner’s demonstration

- Derivate of the response relative to the luminance [Fechner66]

$$\frac{dR}{dl}(L) = \frac{1}{\Delta L(L)}$$

$$R(L) = \int_0^L \frac{1}{\Delta L(L)} dl$$

Weber: $\Delta L = kL$

$$R(L) = \int \frac{1}{kL} dL = \frac{1}{k} \times \ln(L) + a$$

HMD-TMO: Lightness perception

- Sensitive response is **Logarithmic**

Global Linear Scaling Operator

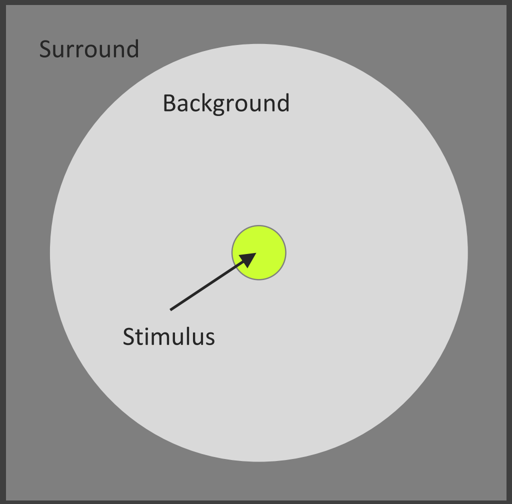
Logarithmic Tone Mapping Operator

« Valay Shah online HDR course » http://cs.brown.edu/courses/cs129/results/proj5/valayshah/

HMD-TMO: Lightness perception

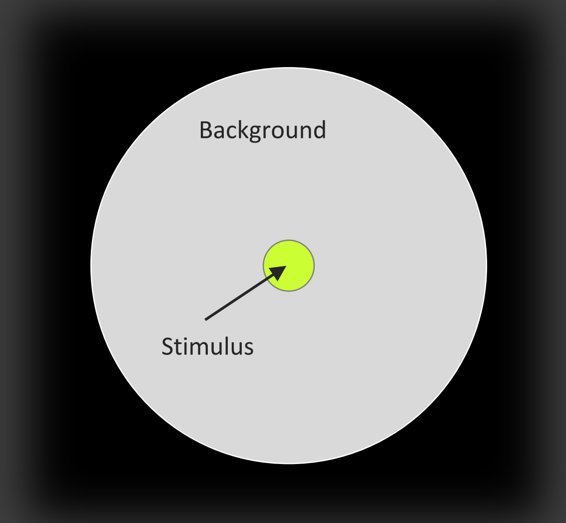
CIE CAM 02

- Stimulus: 2°/ 4°
- Background: 20°
- Surround: Field of view



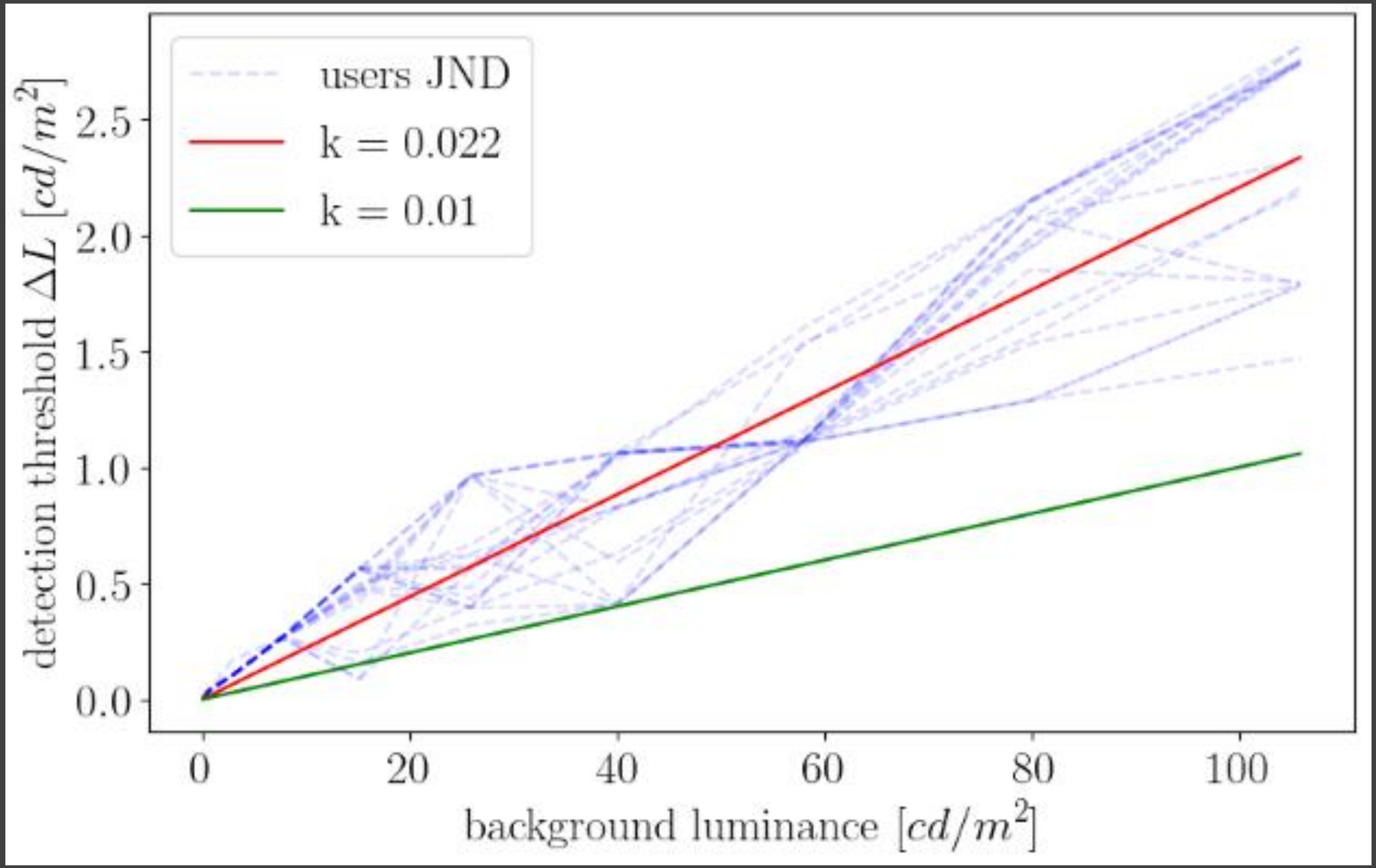
Head Mounted Display

- Stimulus: 2°/ 4°
- Background: 100° (HMD FoV)
- *Surround: None*



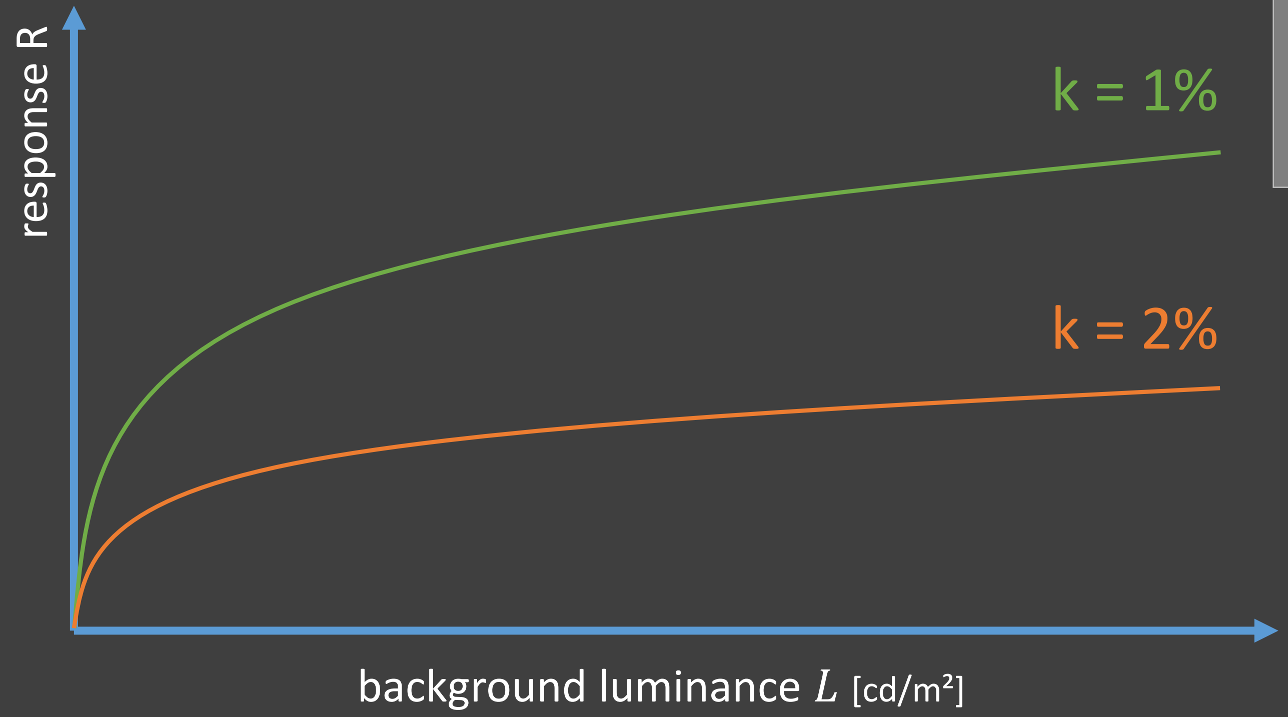
HMD-TMO: Lightness perception

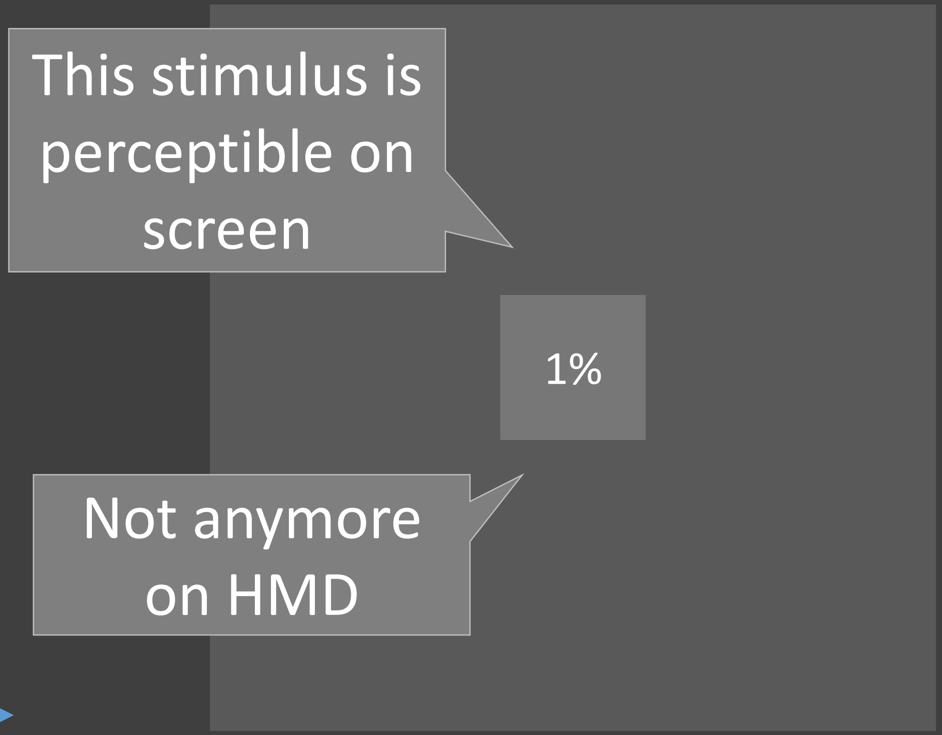
- Linear perception
- Different slope
  - k = 1% [HDRI10]



HMD-TMO: Lightness perception

- Perception is still **Logarithmic**





References

[Reinhard02] E. Reinhard, M. Stark, P. Shirley, and J. Ferwerda: Photographic Tone Reproduction for Digital Images. Conference on Computer Graphics and Interactive Techniques. (29), 267–276 (2002)

[Drago03] F. Drago, K. Myszkowski, T. Annen, and N. Chiba: Adaptive logarithmic mapping for displaying high contrast scenes. In *Computer graphics forum* (22), 419—426 (2003)

[Mantiuk06] R. Mantiuk, K. Myszkowski, H.P. Seidel: A perceptual framework for contrast processing of high dynamic range images. ACM Transactions on Applied Perception (TAP), 2006

[Perrin17] A.-F. Perrin, C. Bist, R. Cozot, and T. Ebrahimi: Measuring quality of omnidirectional high dynamic range content. Optics+Photonics Optical Engineering+Applications Applications of Digital Image Processing XL. 38 (2017)

[Melo18] M. Melo, K. Bouatouch, M. Bessa, H. Coelho, R. Cozot, and A. Chalmers: Tone Mapping HDR Panoramas for Viewing in Head Mounted Displays. International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications. 232-–239 (2018)

[Yu15] M. Yu: Dynamic Tone Mapping with Head-Mounted Displays. Standford University Report. 5 (2015)

[Cutchin16] S. Cutchin and Y. Li: View Dependent Tone Mapping of HDR Panoramas for Head Mounted Displays. The Eurographics Association. (2016)

[Fechner66] G. T. Fechner Howes, D. H. Howes, E. G. Boring: Elements of psychophysics. Holt, Rinehart and Winston: New York. 1, (1966)

[HDRI10] E. Reinhard, W. Heidrich, P. Debevec, S. Pattanaik, G. Ward, and K. Myszkowski: High Dynamic Range Imaging: Acquisition, Display, and Image-Based Lighting. Elsevier Science. (Second Edition), 238 (2010)

[Ward97] G. W. Larson, H. Rushmeier, and C. Piatko: A Visibility Matching Tone Reproduction Operator for High Dynamic Range Scenes. IEEE Transactions on Visualization and Computer Graphics. 3(4), 291–306 (1997)

[Schlick94] C. Schlick: Quantization techniques for the visualization of high dynamic range pictures. Photorealistic Rendering Techniques, Springer-Verlag Berlin Heidelberg New York, Eurographics, 7–20 (1994)

[TMQI13] H. Yeganeh and Z. Wang: Objective Quality Assessment of Tone Mapped Images. IEEE Transactions on Image Processing, 22(2), 657–667, (2013)

Recap

- HMD-TMO proposal
  - Global TMO preserves coherency
  - Viewport TMO enhance contrast
  - Perceptual combination of both

- Subjective study
  - Model of lightness perception on HMD
  - Logarithmic is still valid
  - Contrast is lost on HMD