Introduction to Image and Video Quality Assessment

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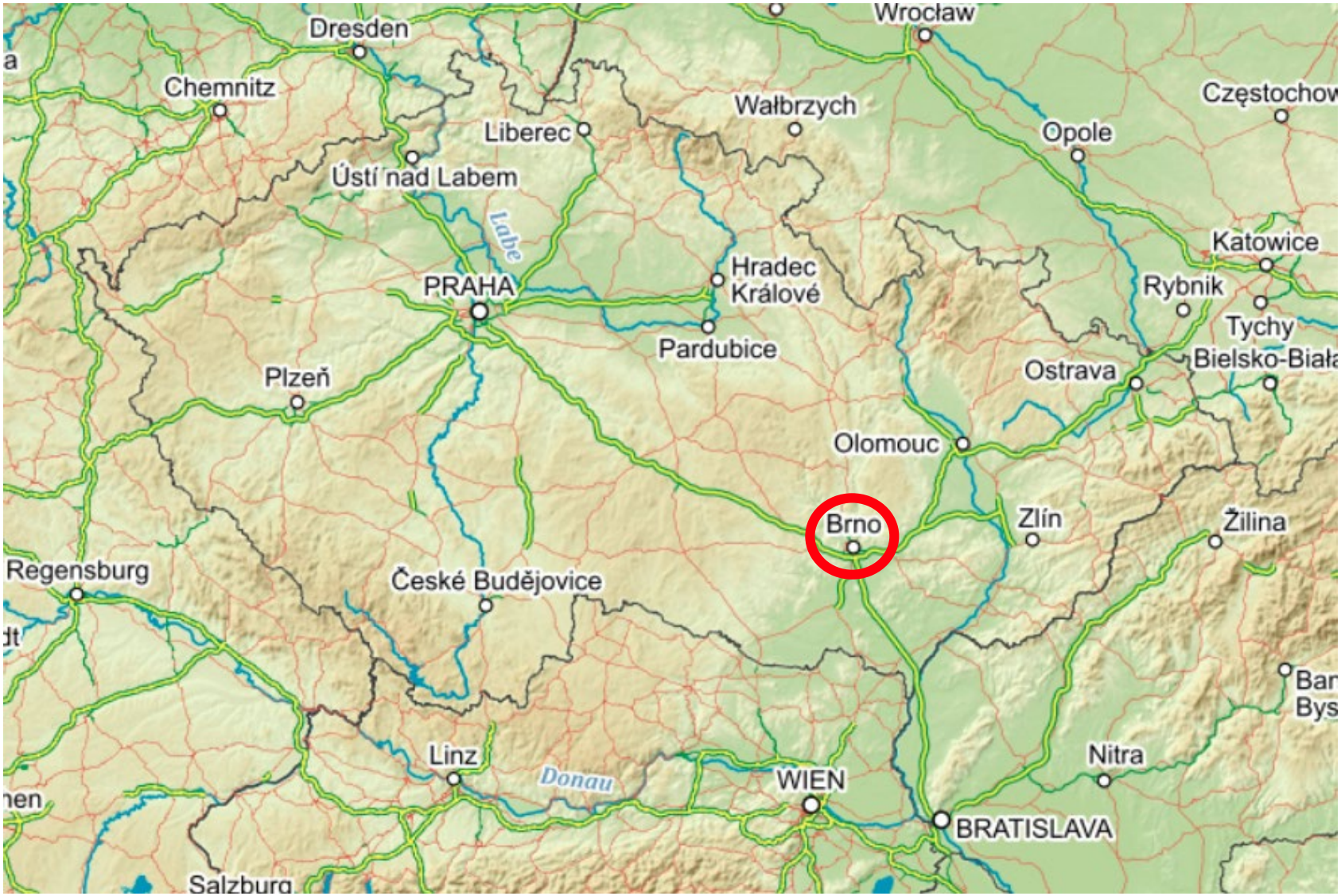


CPhoto@FIT

- CPhoto@FIT http://cphoto.fit.vutbr.cz/
  B.Sc., M.Sc., Ph.D. and other projects
- Computational Photography Course
  http://www.fit.vutbr.cz/study/course-l.php?id=12352
- VGS-IT - Invited Talks on Vision, Graphics, and Speech@FIT
  http://vgs-it.fit.vutbr.cz/

- HiVisualComputing meeting in the mountains
  http://www.hiviscomp.cz/

2014 HiVisComp 2015 HiVisComp 2016 HiVisComp 2017 HiVisComp 2018 HiVisComp 2019 HiVisComp 2020 HiVisComp


HEROBUS

[Zvěřina 18]

[Klusoň 17]

[Ostroukh 17]

[Jelen 19]

[Jedlička 19]

[Ostroukh 17]

Interactive Walkthrough FIT

- http://cphoto.fit.vutbr.cz/fit/

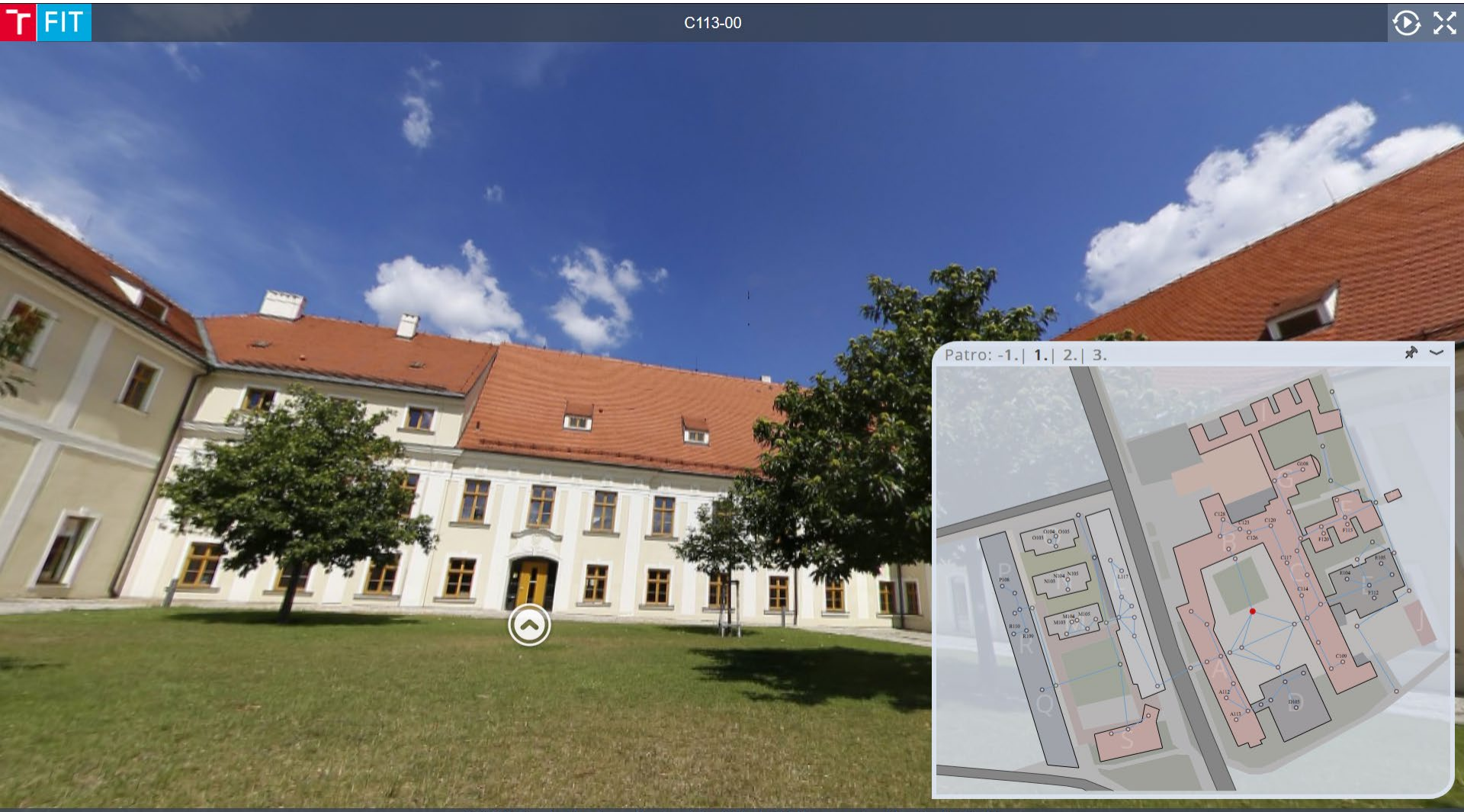


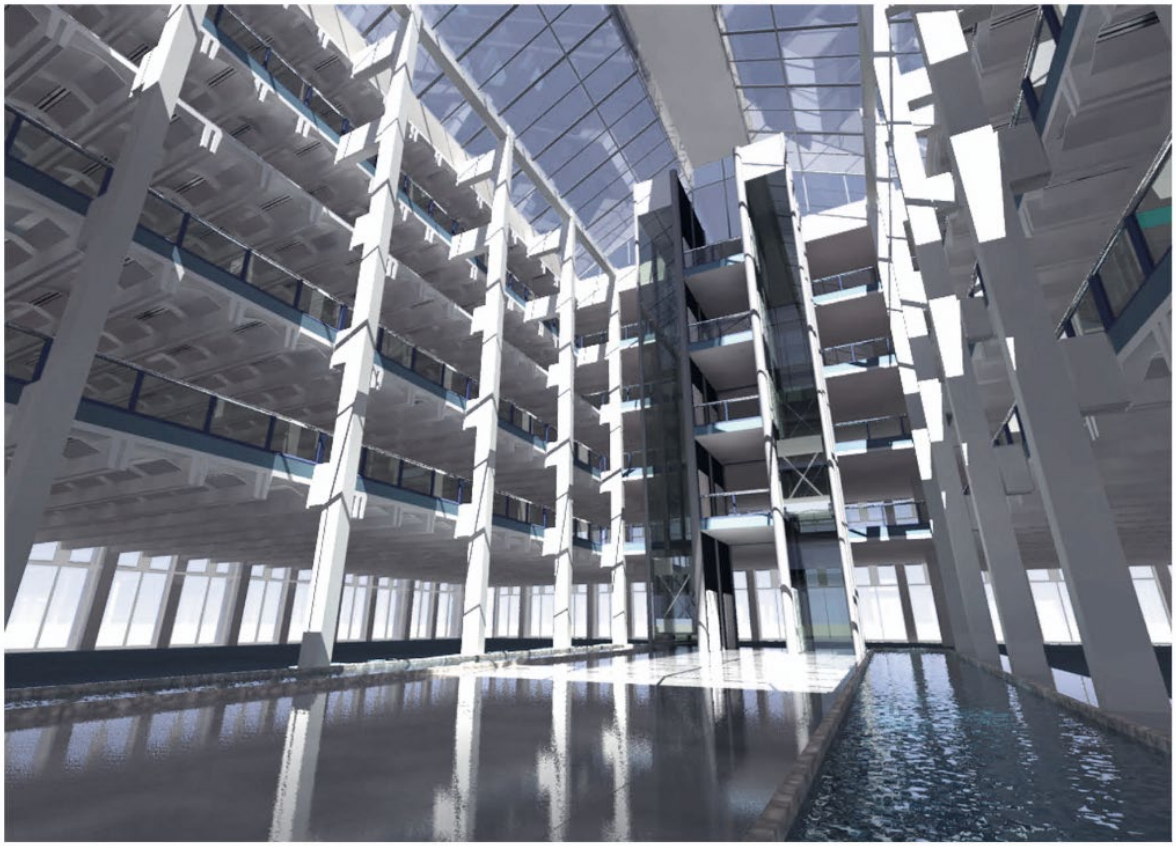
IMAGE AND VIDEO QUALITY ASSESSMENT

Motivation

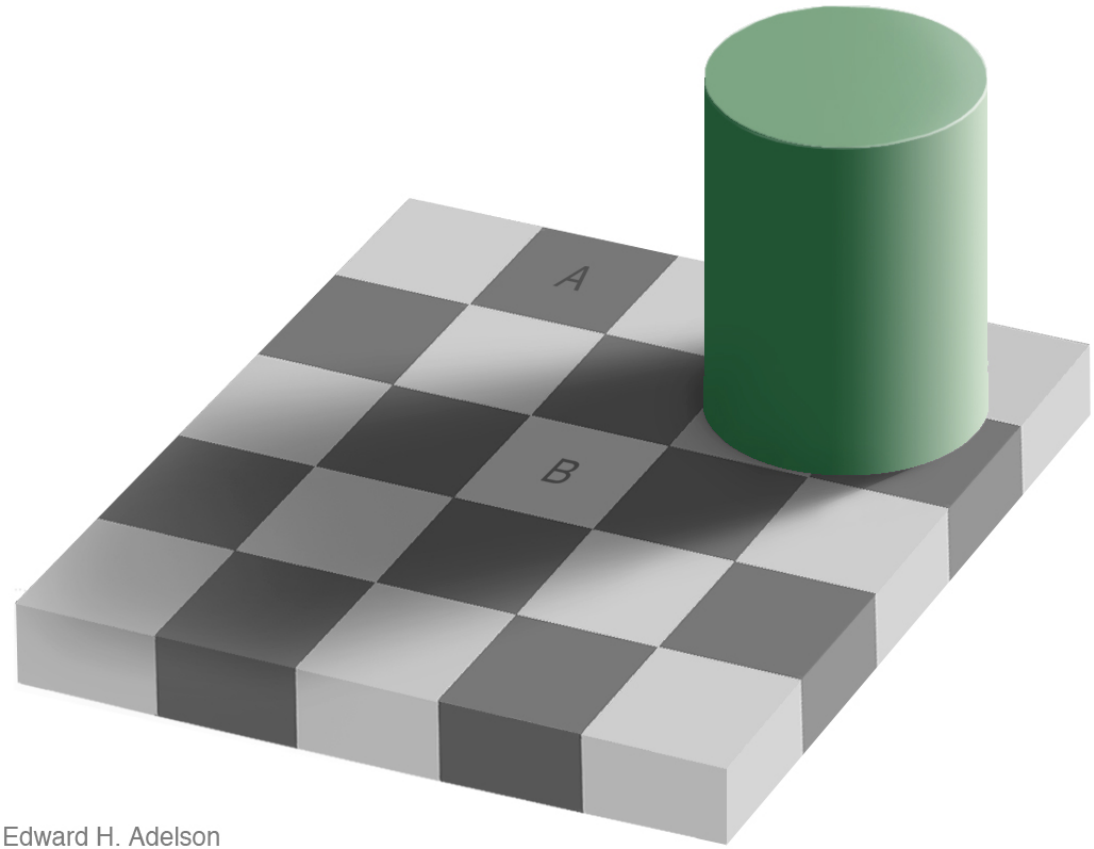
- Physical fidelity
  - Measure illumination
  - RMSE, PSNR

Motivation

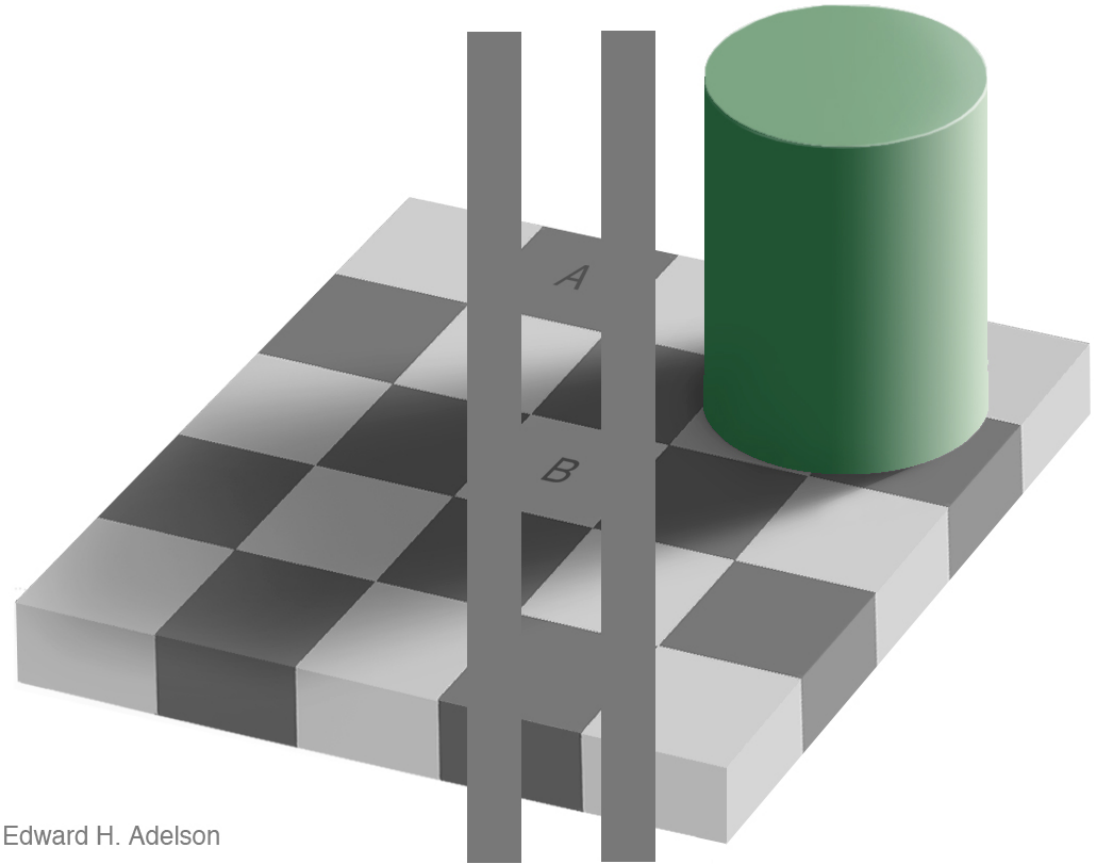
- Perceptual/cognitive fidelity
  - Specialized image/video quality metrics



Human Visual Perception



Edward H. Adelson



Edward H. Adelson

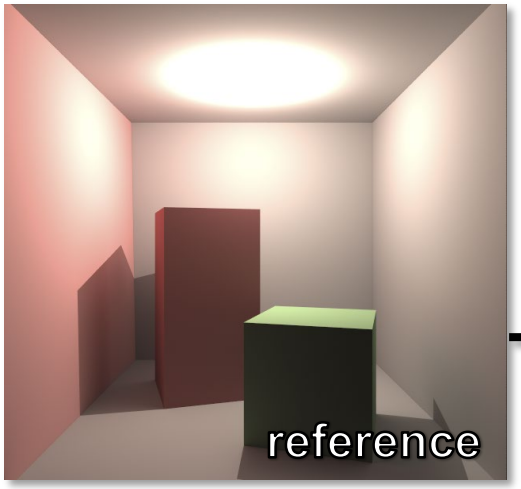
Overview

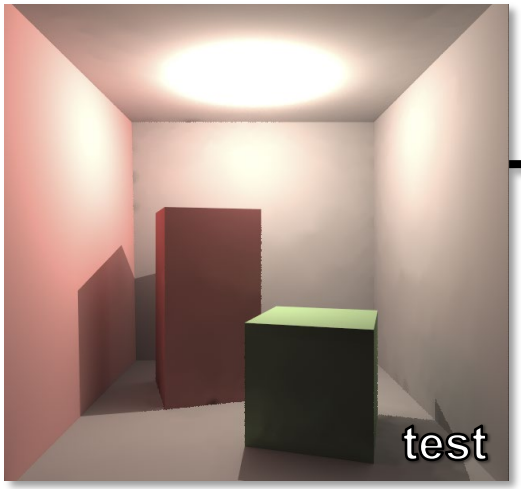
- Introduction to Objective Quality Assessment
- Image Quality Assessment
  - HVS-based Metrics (bottom-up)
  - Structural Similarity (top-down)
  - Data-driven Approaches (top-down)
- Video Quality Assessment

FR Quality Assessment (IQA, VQA)

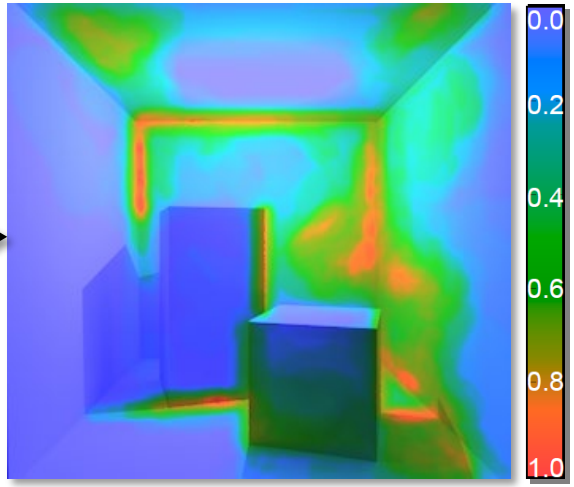
+ Reliable **- High cost**

Full-Reference Image Quality Metrics





FR IQM



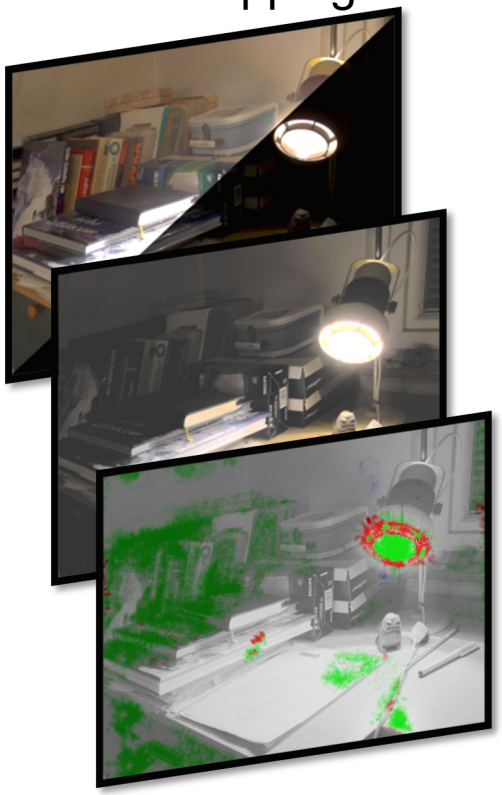
localized distortion map

Image Quality Metrics

- What are they good for?
  - Algorithm analysis/validation/evaluation
  - Quality monitoring for compression/transmission
  - Guiding/parameter optimization of renderers
  - Stopping criterions
  - Speed/quality enhancements
  - Machine learning (loss)

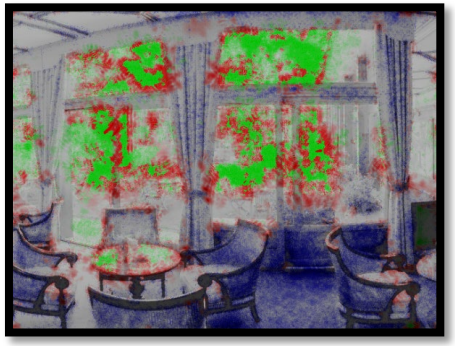
Applications in HDR

Tone Mapping



Inverse
Tone Mapping

Display
Analysis

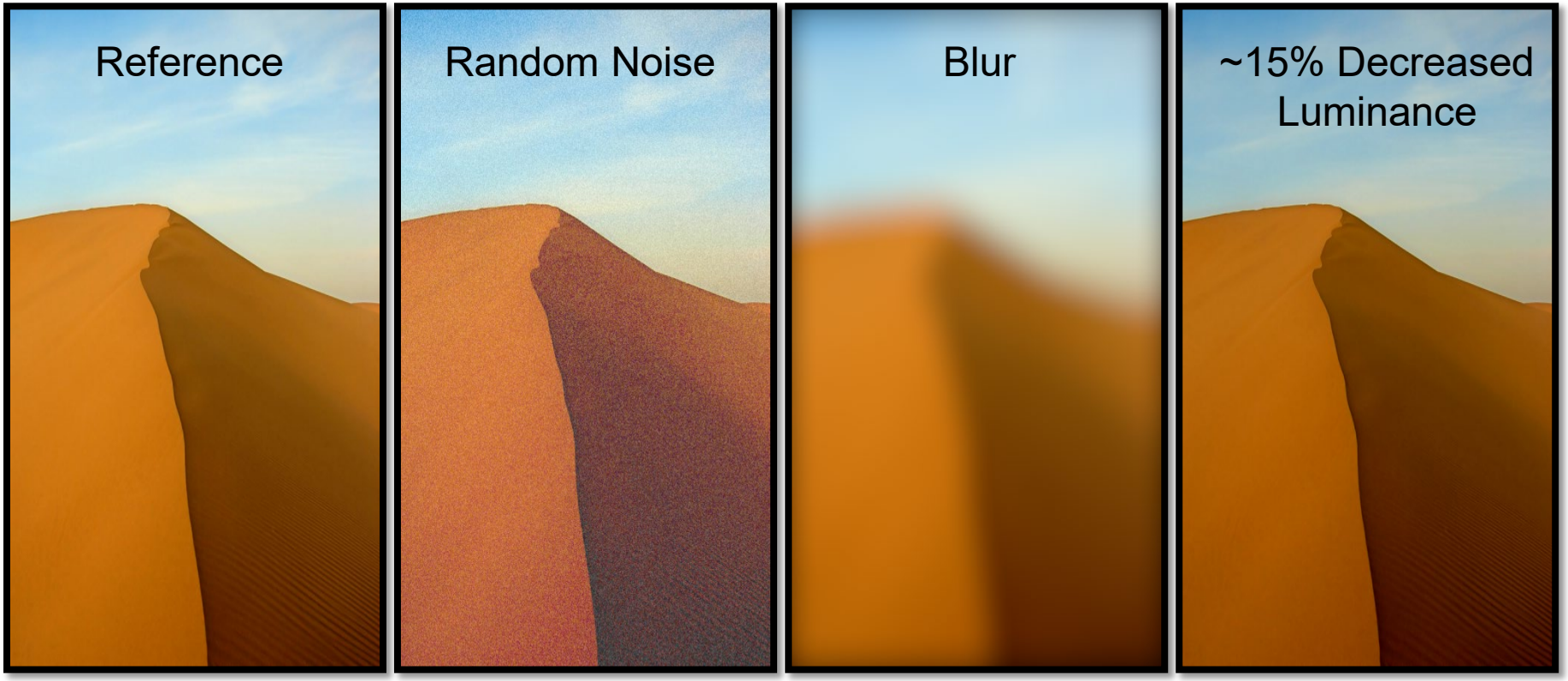


Math-based FR Metrics

- AD $M = |ref - test|$
- (R)MSE $M = (ref - test)^2$ $MSE = \frac{1}{n}\sum_{i=1}^{n}(ref_i - test_i)^2$
- PSNR $PSNR = 10\log_{10}\frac{MAX^2}{MSE}$
- sCORREL $M = SRCC(ref,\ test)$

  (Spearman's rank correlation coefficient)

Simple Full-reference Metrics



MSE = 280 MSE = 280 MSE = 280 !

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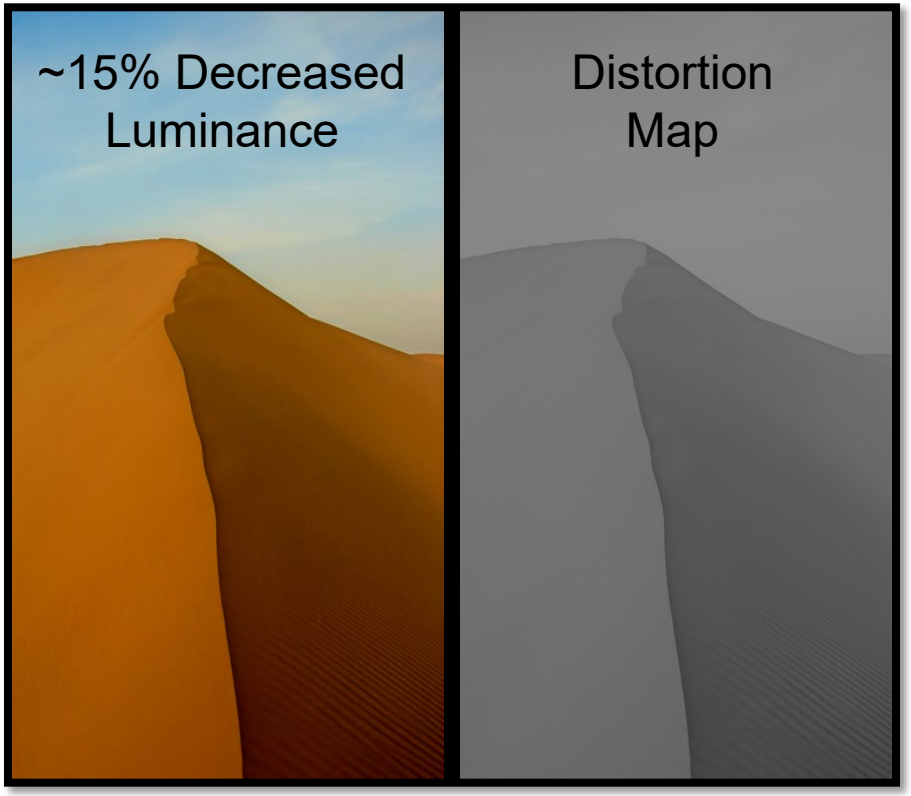
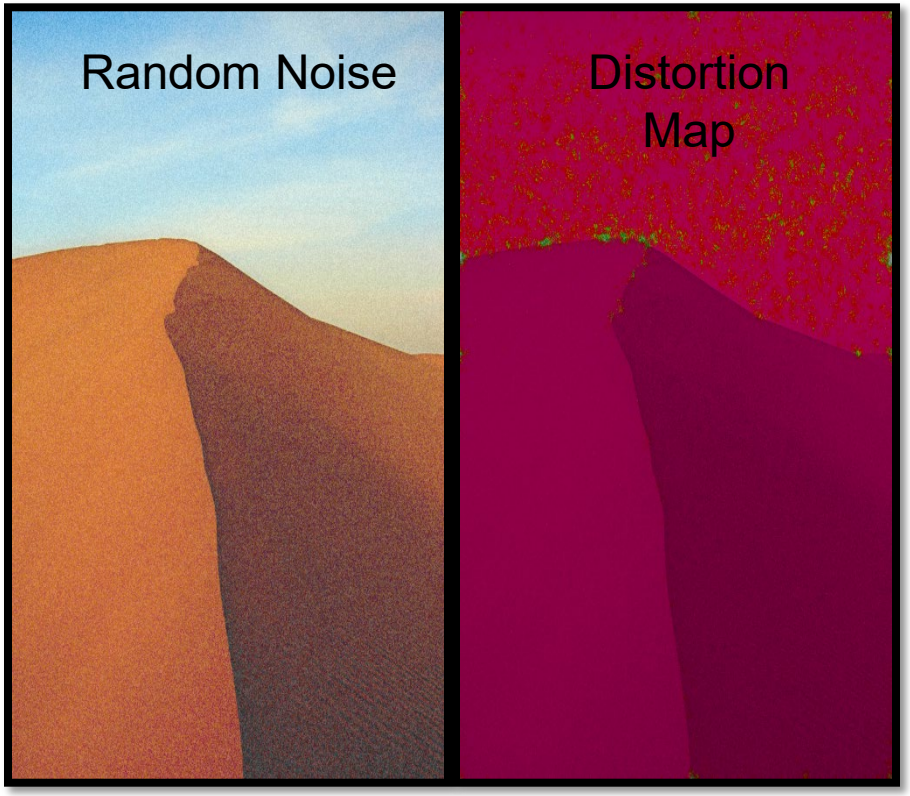
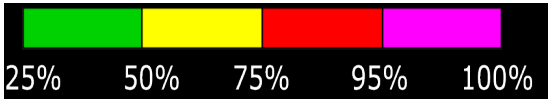
HVS Based Metrics



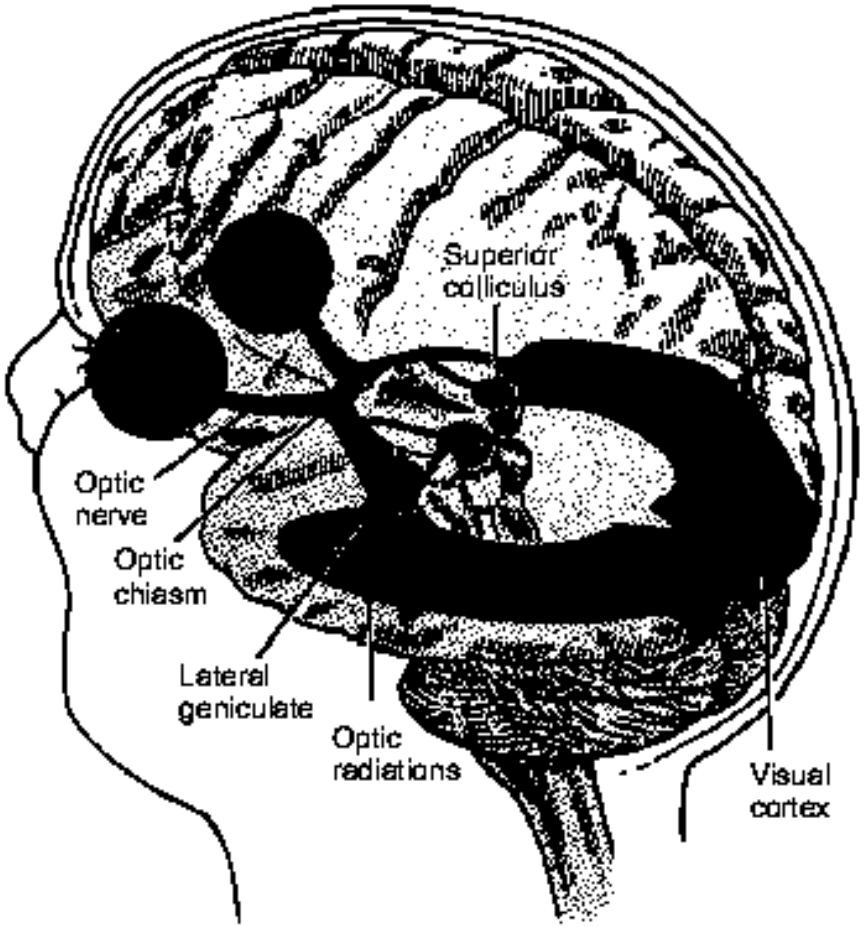


Probability of Detection:



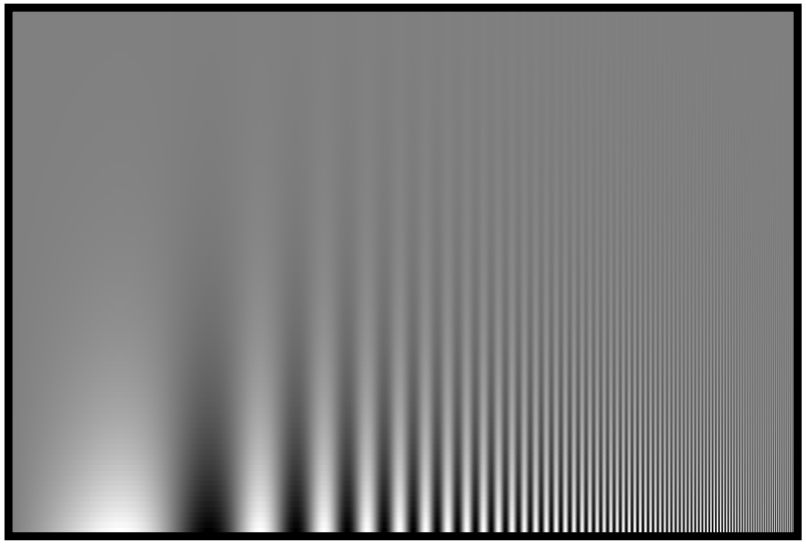
Human Visual System

- Physical structure well established (early vision)
- High-level vision still not fully understood

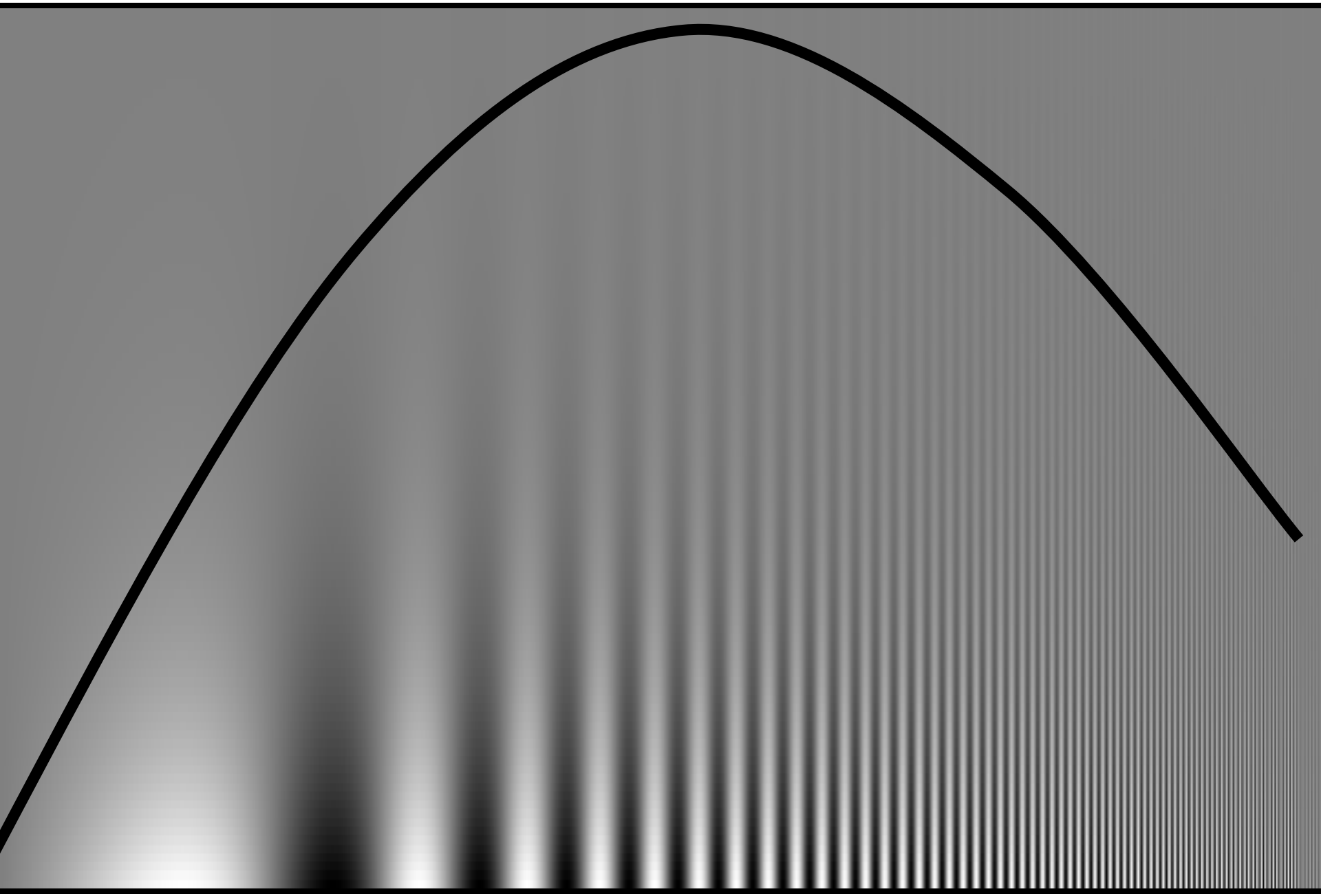


Human Visual System (cont.)

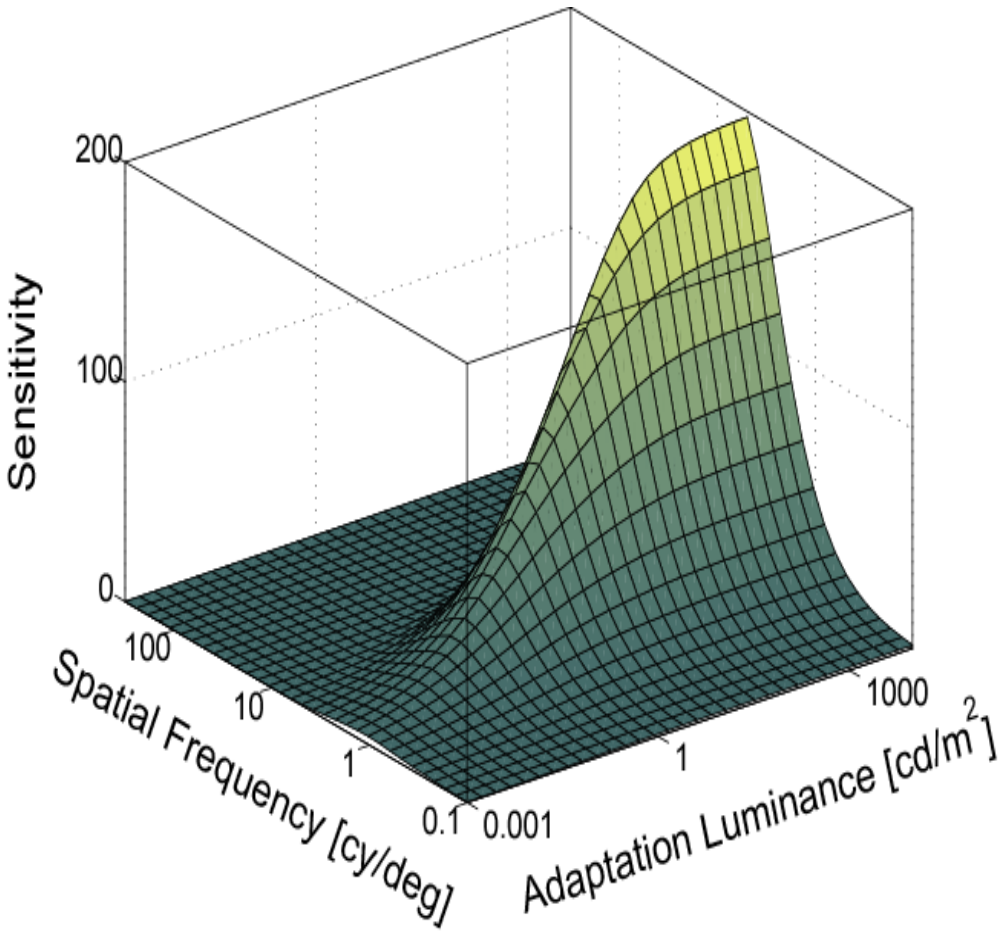
- CSF
  - sensitivity (1/detection threshold) as a function of the spatial frequency
  - depends on
    - spatial frequency
    - adaptation level
    - temporal freq.
    - orientation
    - viewing dist
    - eccentricity, …



[Campbell and Robson 1968]

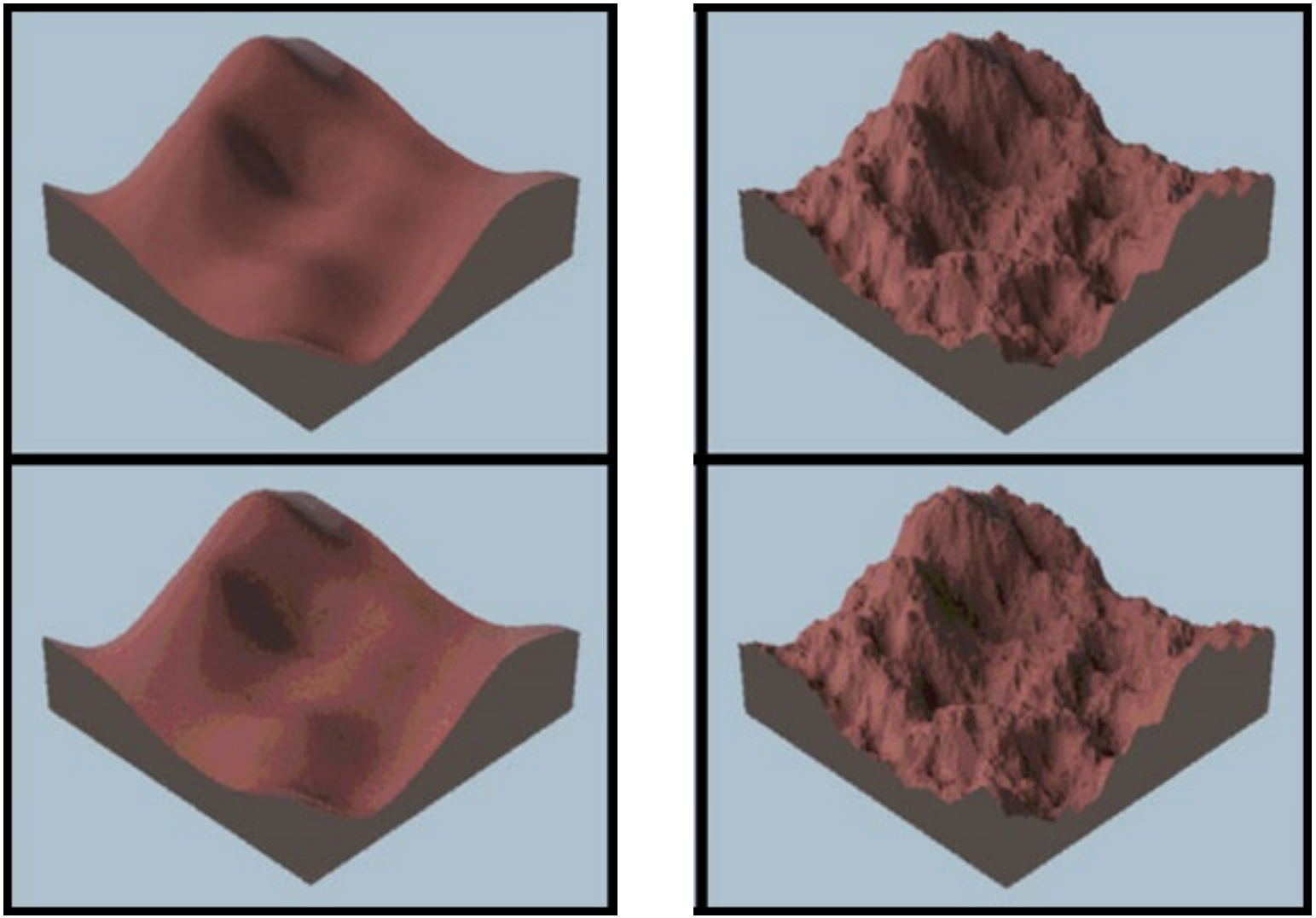


Contrast Sensitivity Function (CSF)



- Steady-state CSF[S]
  - incl. adaptation luminance

HVS – Visual Masking



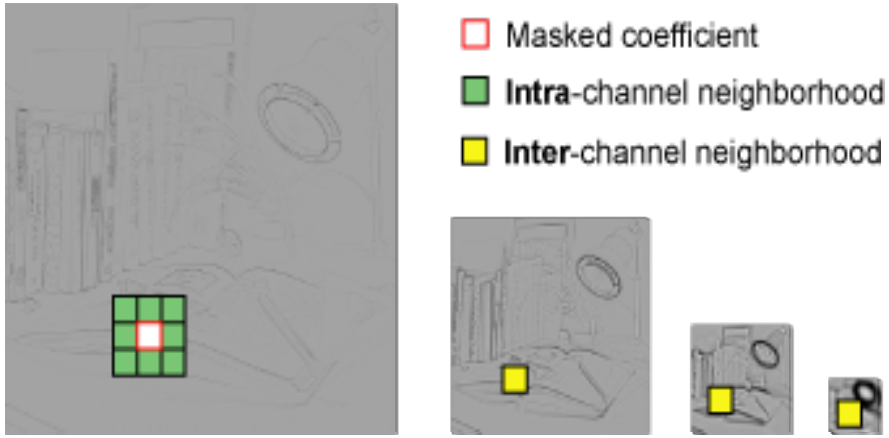
[Ferwerda et al. 97]

Visual Masking

Loss of sensitivity to a signal
with the presence of a “similar” signal “nearby”.

Modeling Visual Masking

- **Example:** JPEG's pointwise extended masking:

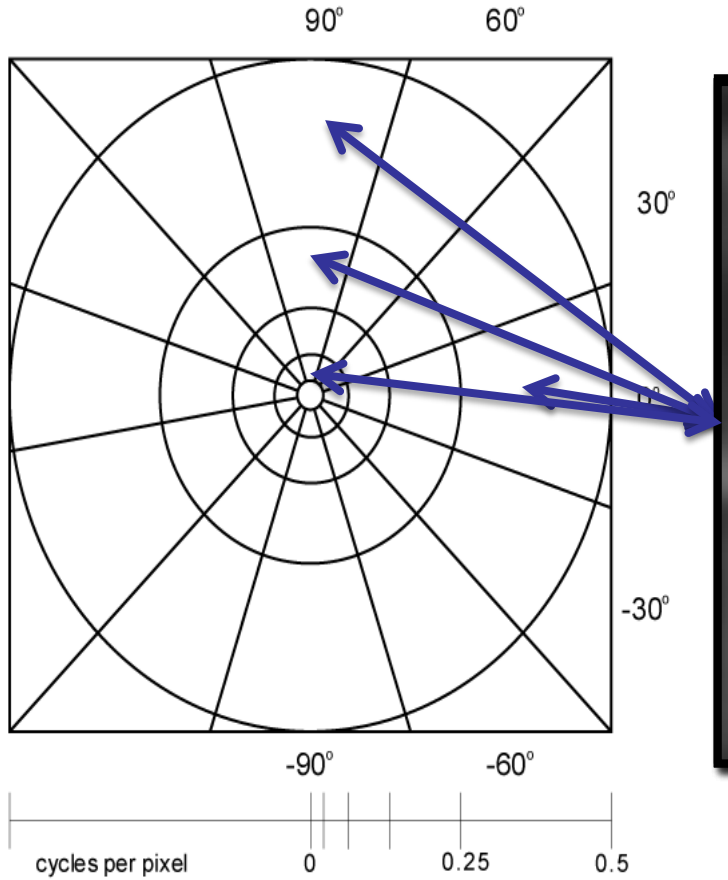


$$R = \frac{sign(C')|C'|^{0.5}}{(1 + \sum_K |C'_k|^{0.2})}$$

C': Normalized Contrast

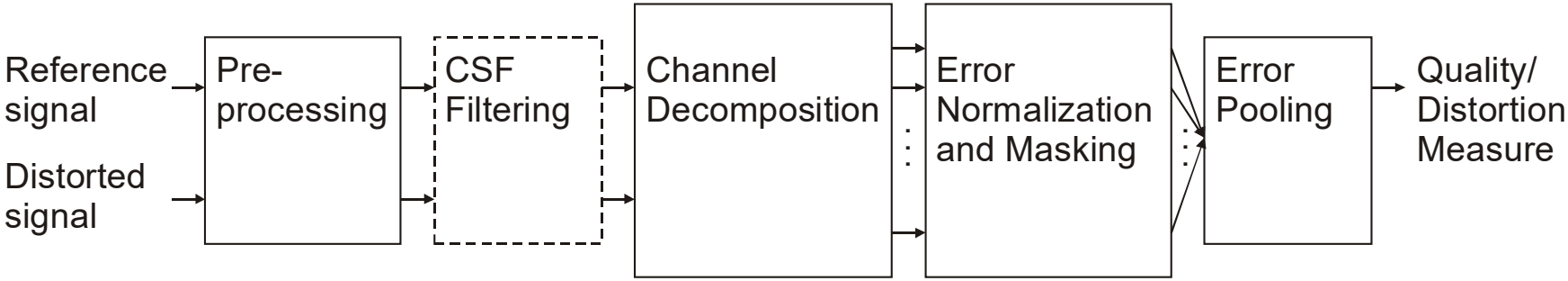
Modeling Visual Masking - Visual Channels

Cortex Transform



Error Sensitivity Based Approaches

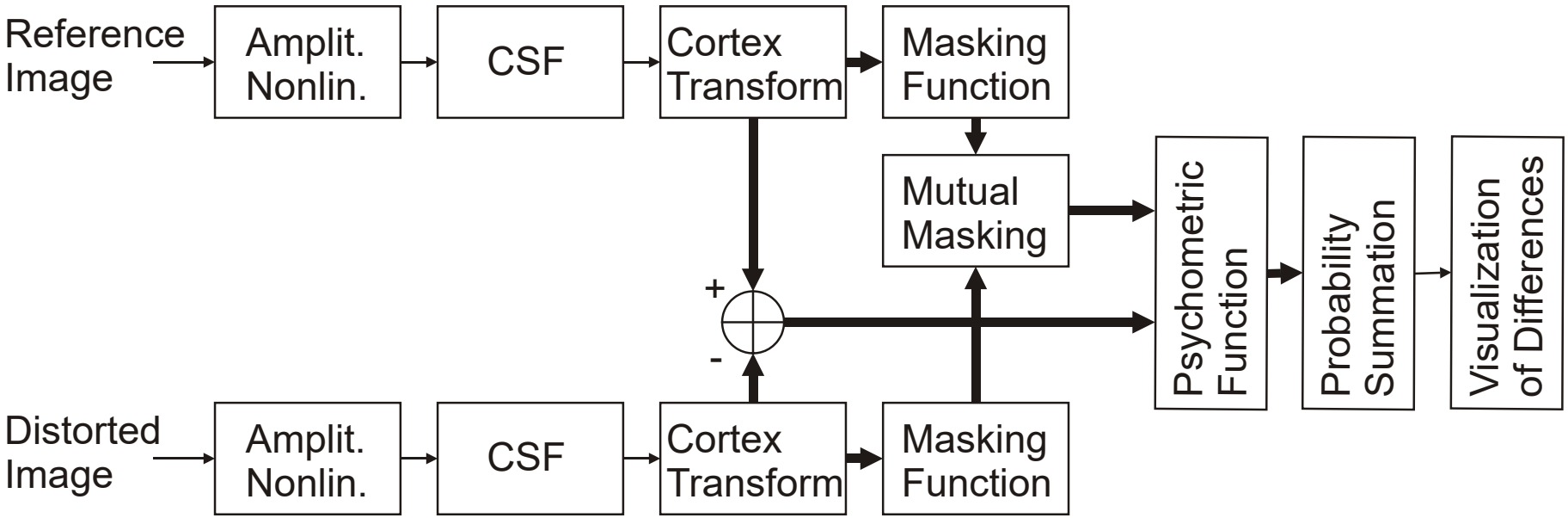
- General framework



- Visible Differences Predictor [Daly93]
- Perceptual Image Distortion [Teo, Heeger 94]
- Visual Discrimination Model [Lubin 95]
- Gabor pyramid model [Taylor et al. 97]
- WVDP [Bradley 99]
- HDRVDP3 [Mantiuk et al. 05, Mantiuk et al. 11]

Error Sensitivity Based Approach

- Visible Differences Predictor (VDP) [Daly 93]



- **Threshold** sensitivity
- Early vision modeling
- Visual Masking

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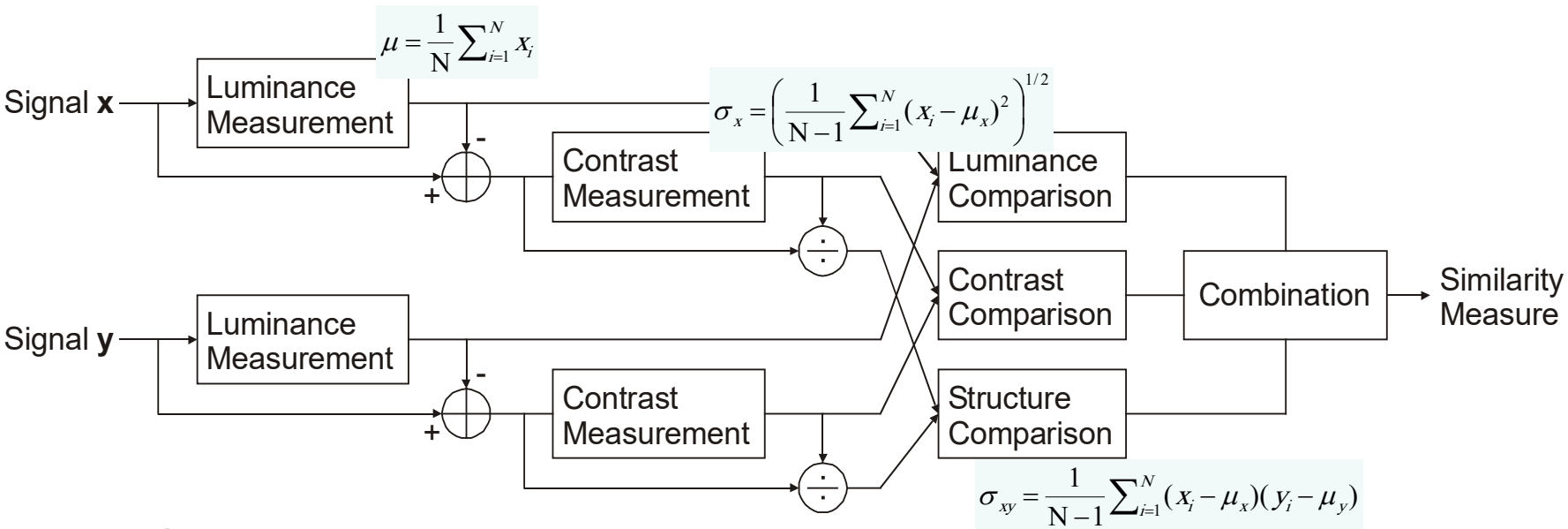
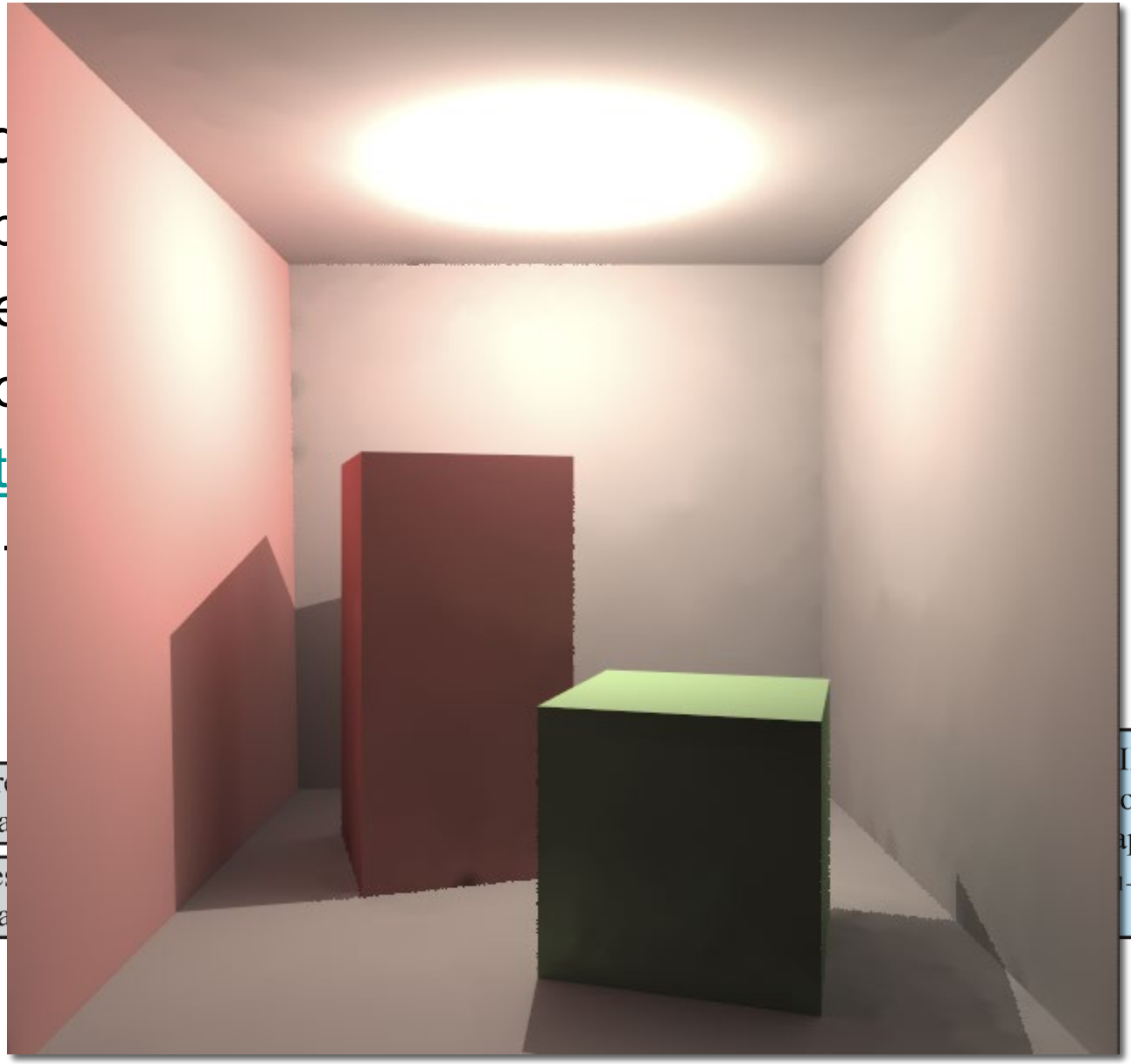
Structural Similarity-Based Approaches



- UQI [Wang 02]
- SSIM [Wang 04]
- M-SSIM [Wang et al. 04]
- Multidimensional Quality Measure Using SVD [Shnayderman 04]
- FLIP [Andersson et al. 20]

FLIP

- [Anc
  - sp
  - pe
  - no
  - ht
  - C



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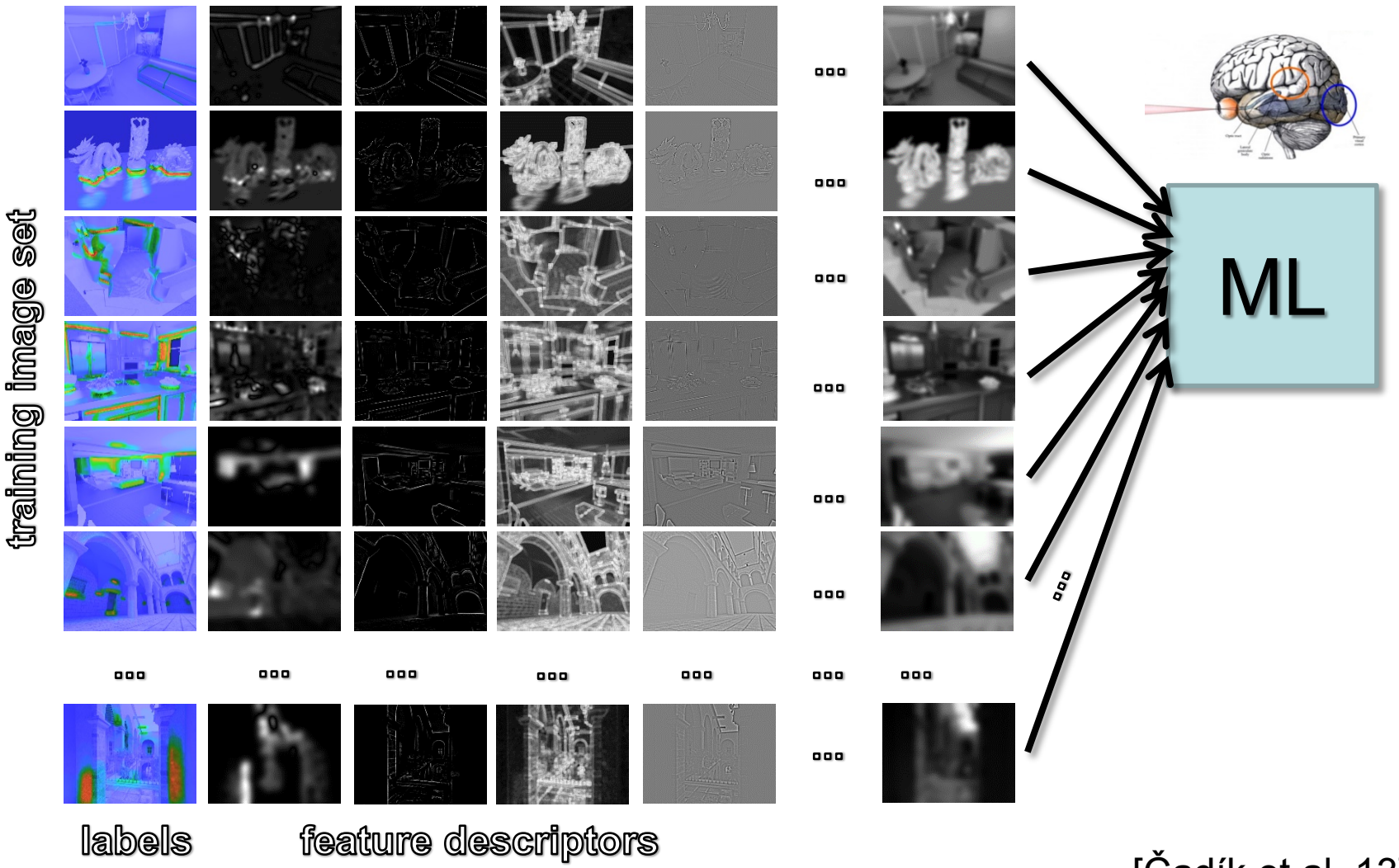
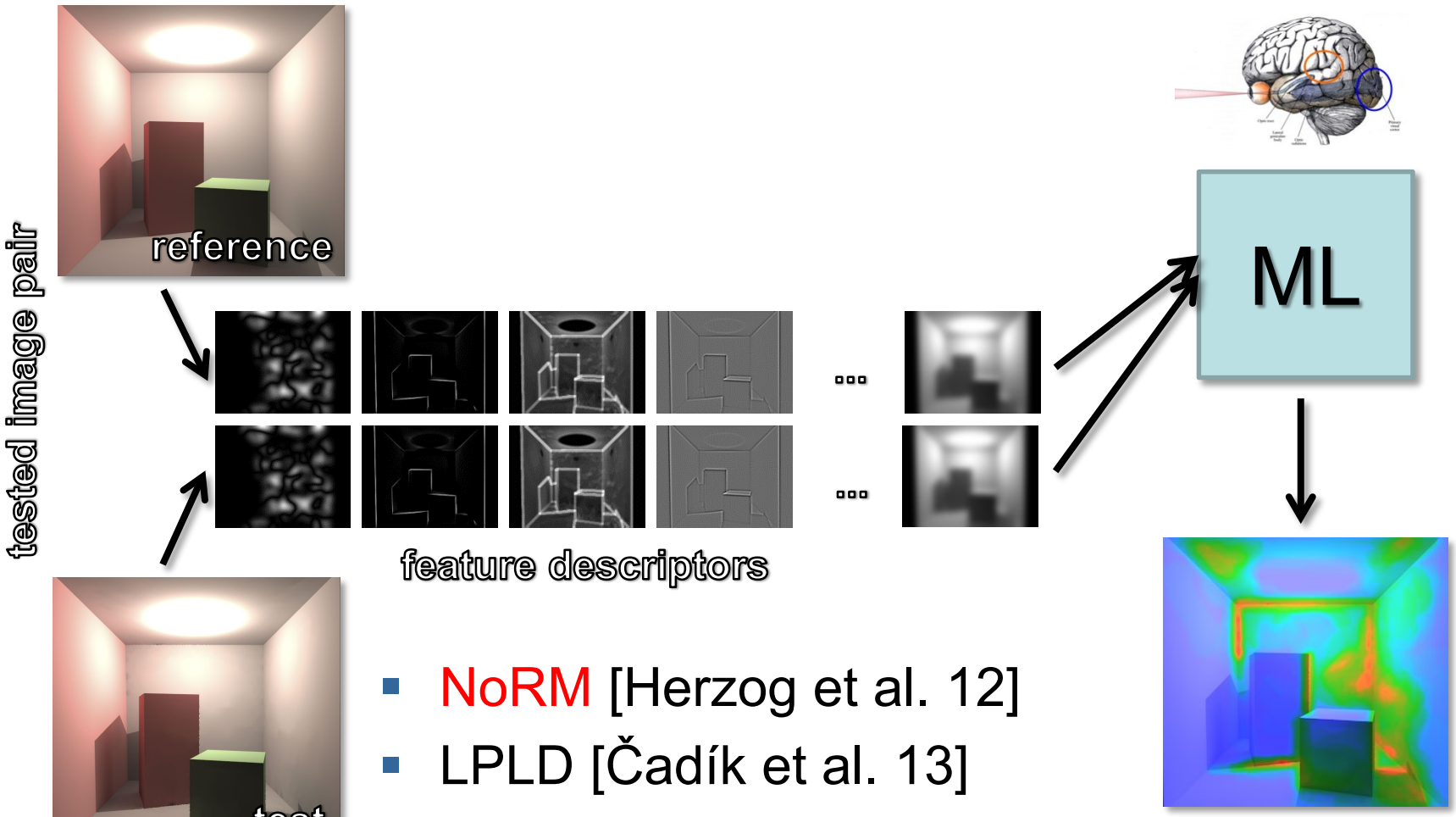
Supervised Learning – Training Phase



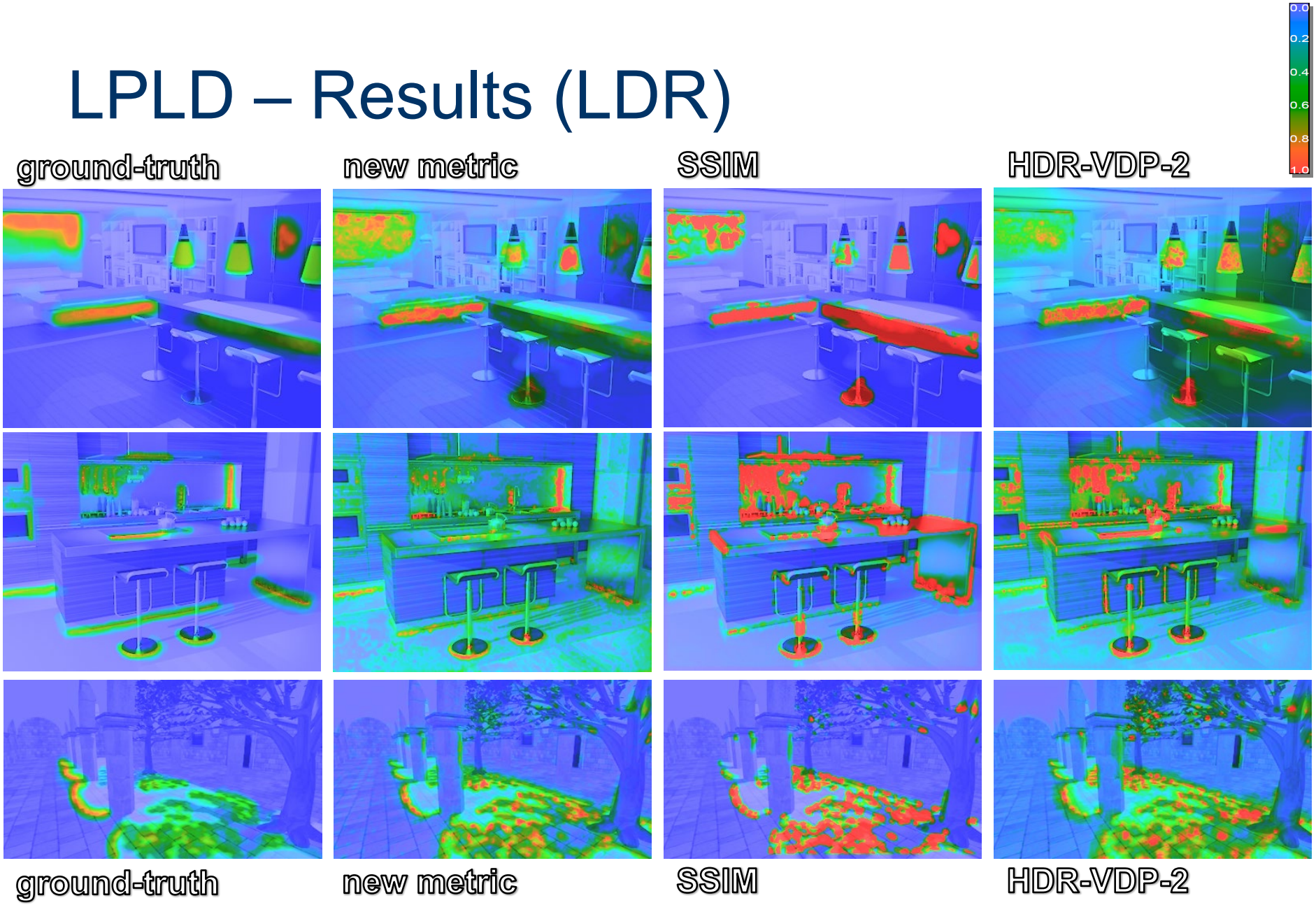
[Čadík et al. 13]

Supervised Learning – Prediction



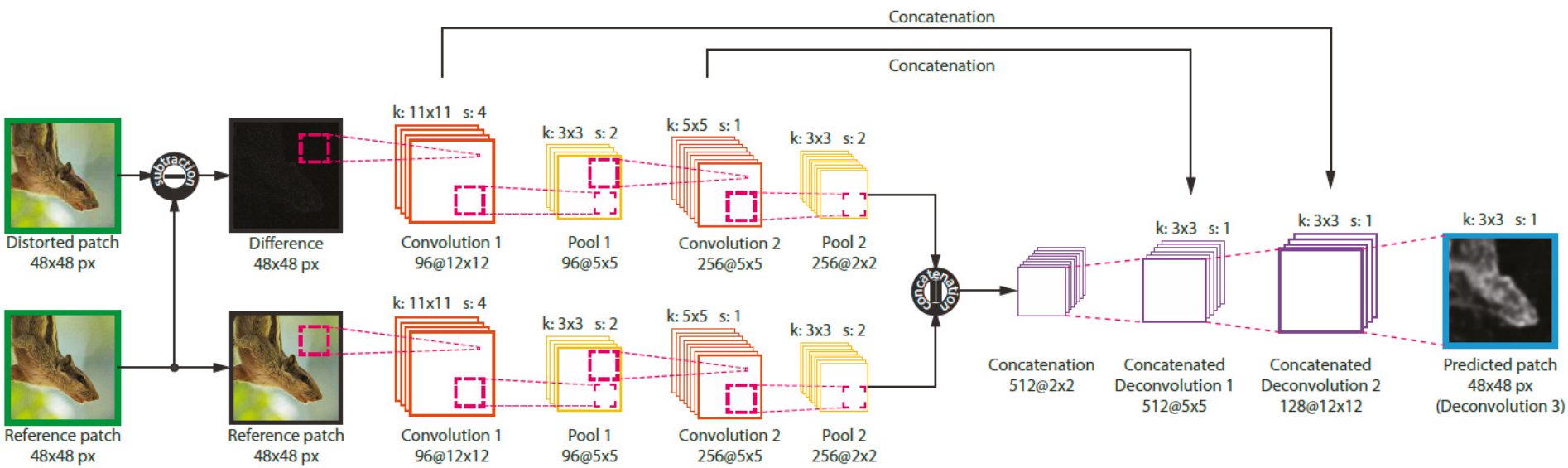
- NoRM [Herzog et al. 12]
- LPLD [Čadík et al. 13]
- Image completion metric [Kopf et al. 14]
- CNN_visibility_metric [Wolski et al. 18]

LPLD – Results (LDR)



CNN Visibility Metric

- [Wolski et al. 18]
  - two-branch fully convoluted architecture
  - separate weights for each branch
  - fine tuning (AlexNet weights)
  - viewing distance, luminance level not considered
  - https://github.com/Chuudy/CNN_visibility_metric



No-Reference Image Quality Metrics

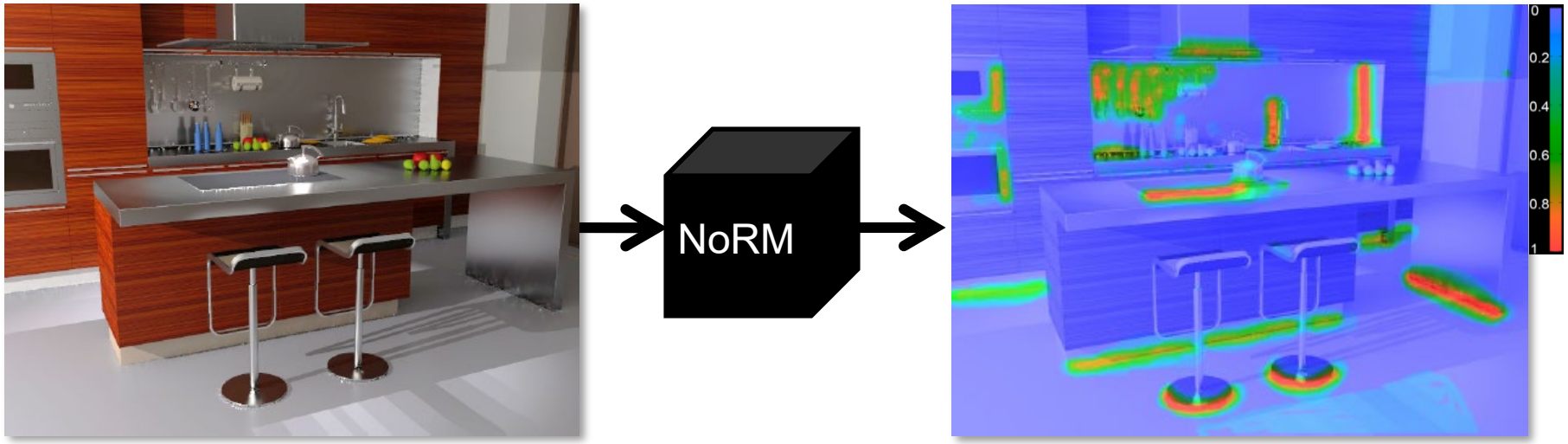
- Detecting blockiness in JPEG/MPEG
  - [Wang & Bovik ’06, Wu & Rao ‘05]
- Blurriness measures
  - [Liu et al. SPIE ’11, Chen et al. SPIE ’11]
- Detection / removal of false contours (color quantization)
  - [Daly S. & Feng SPIE ’04]
- Natural image statistics no-ref. QA
  - [Sheikh et al. ‘05, Jpeg2000]

- “Real” no-ref metric
  - **NoRM [Herzog et al. 12]**

NoRM: No-Reference Metric

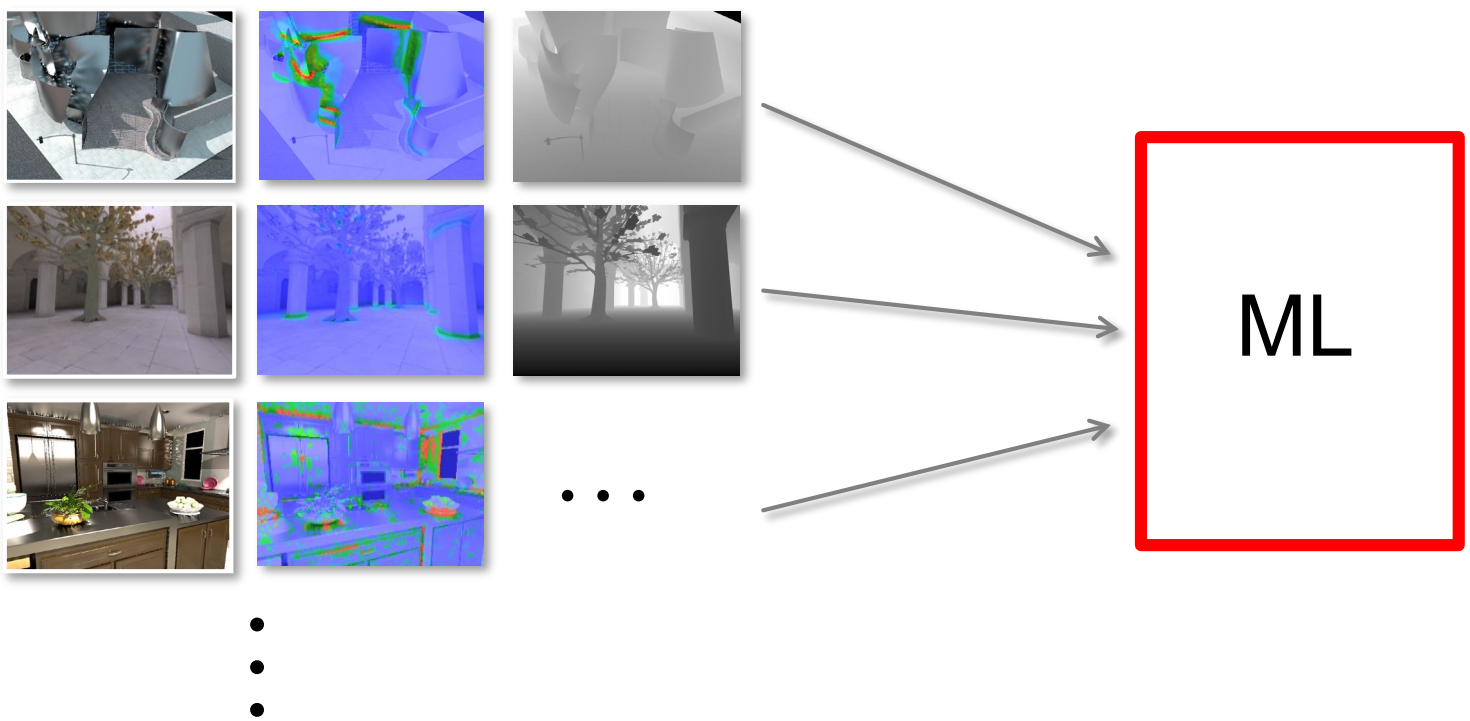
[Herzog et al. 2012]

- Input: distorted image/video frame (no reference)
- Output: map of distortions (possibly perceptually weighted)

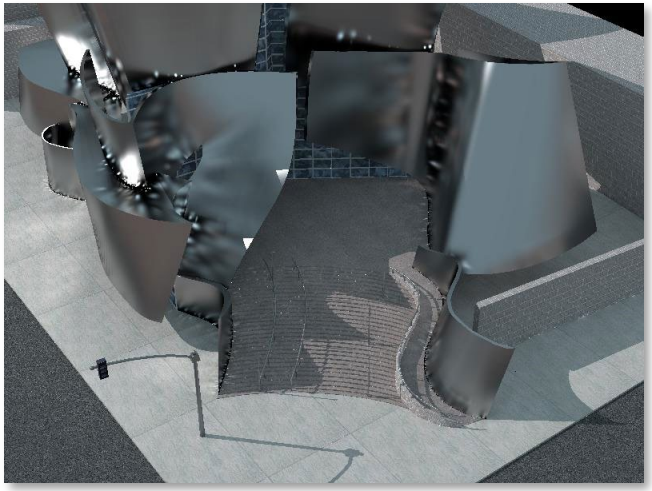


Data-Driven No-Reference IQM

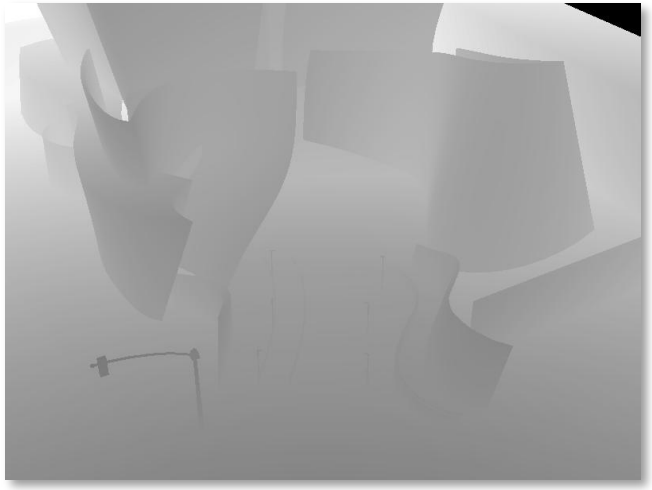
- Feature descriptors (various information available)
- Distortion maps (possibly real subjective data)
- Depth + 3D related information



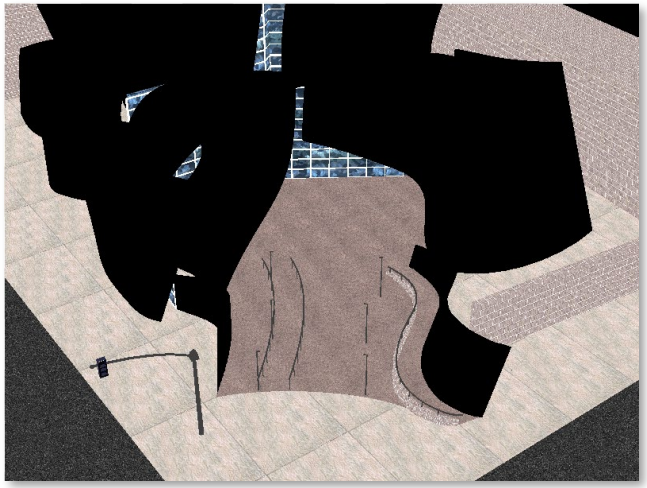
Rendering Output – Classification Input



HDR (LDR) color image
(may contain noise)



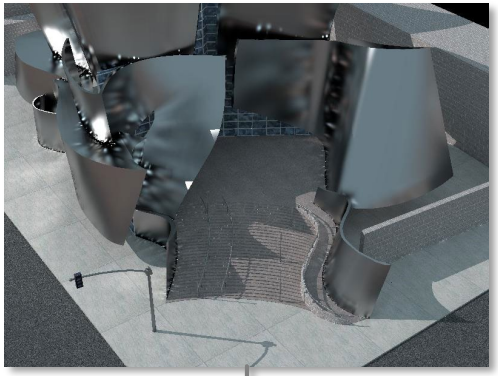
depth buffer
(in high precision, no noise)



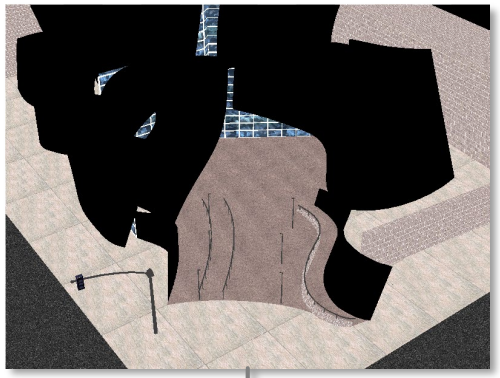
diffuse texture buffer

Computation of Additional Input Data

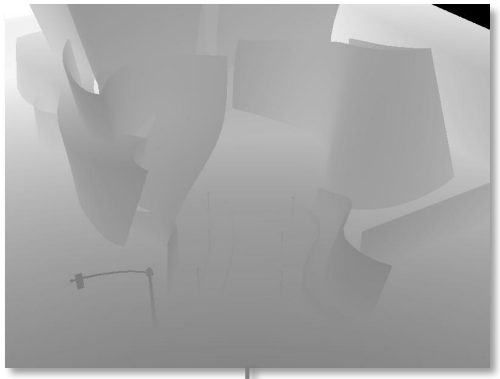
color (pixel radiance)



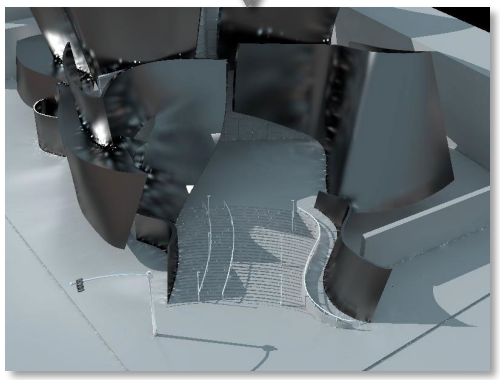
textures



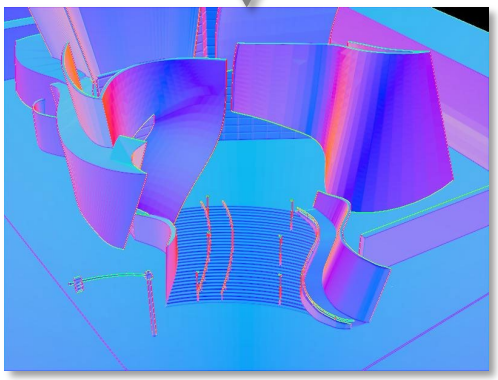
depth



/mat



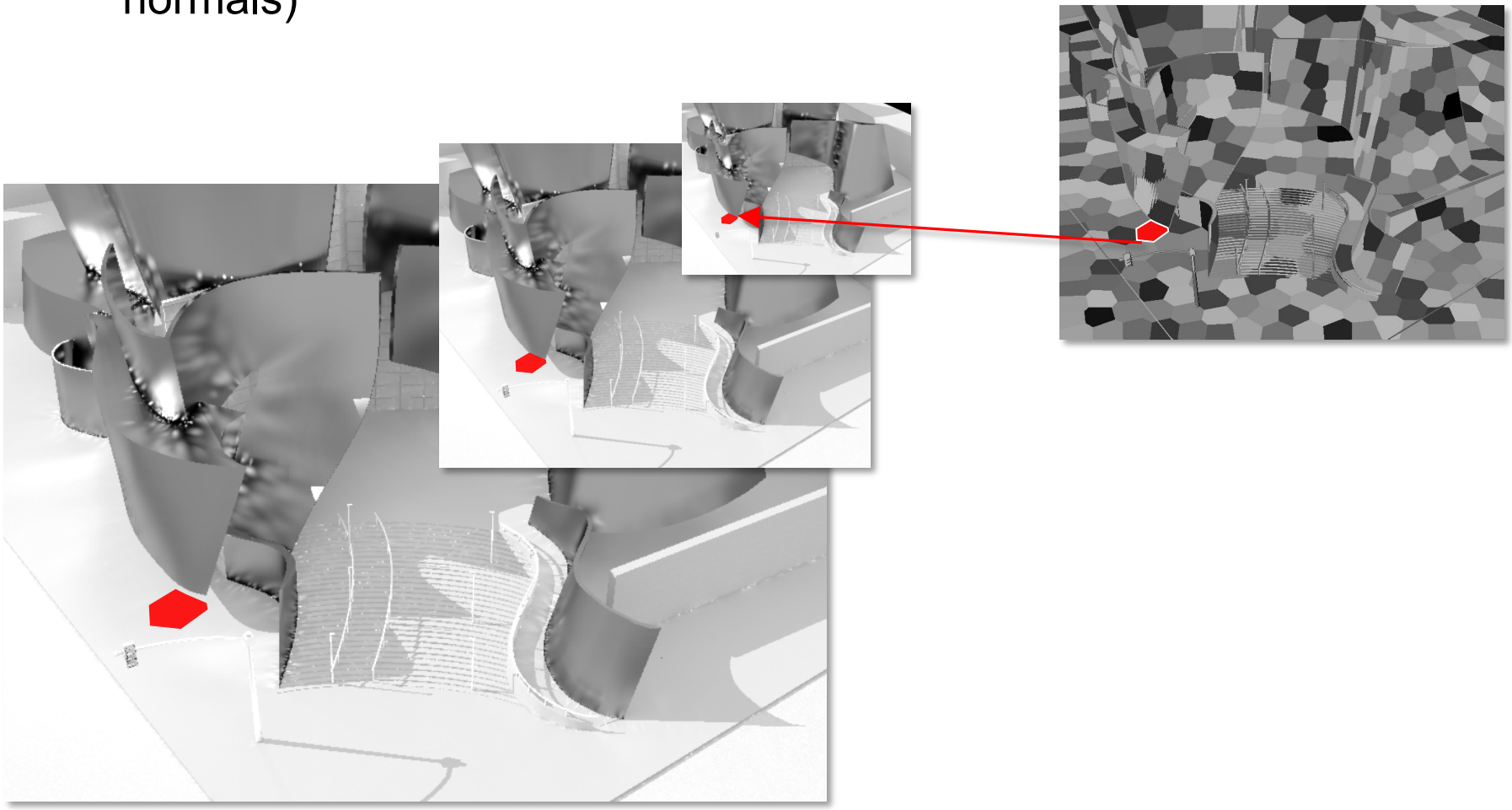
lighting (irradiance)



surface normals
(computed from depth)

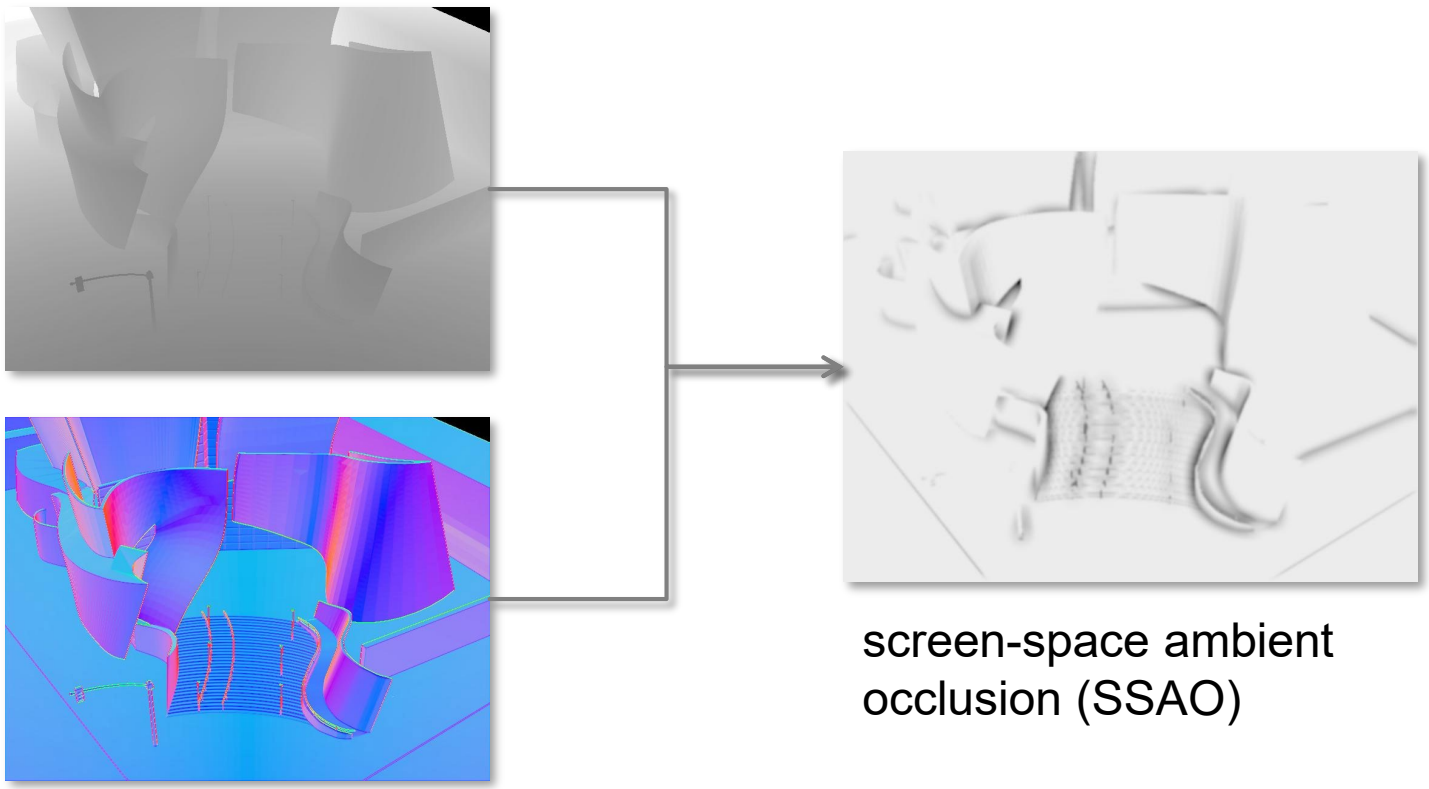
3D Features: Local First-order Statistics

- compute mean, variance, skewness, kurtosis in each segment at different scales of the grey-scale image pyramid (also for depth, normals)

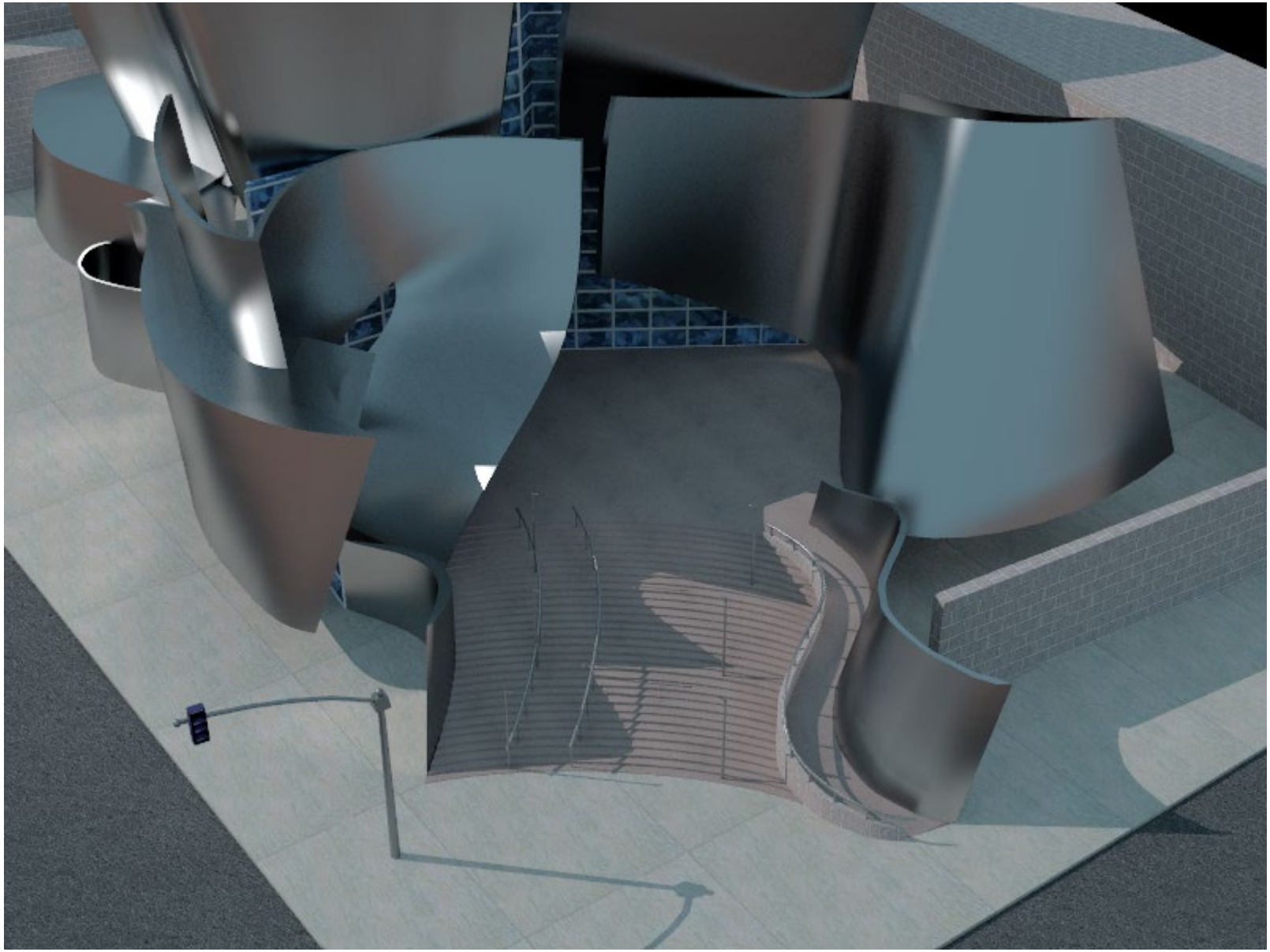


3D Features: Ambient Occlusion

- given depth extract approx. ambient occlusion per pixel (distance to nearest occluder)



screen-space ambient occlusion (SSAO)



REFERENCE IMAGE

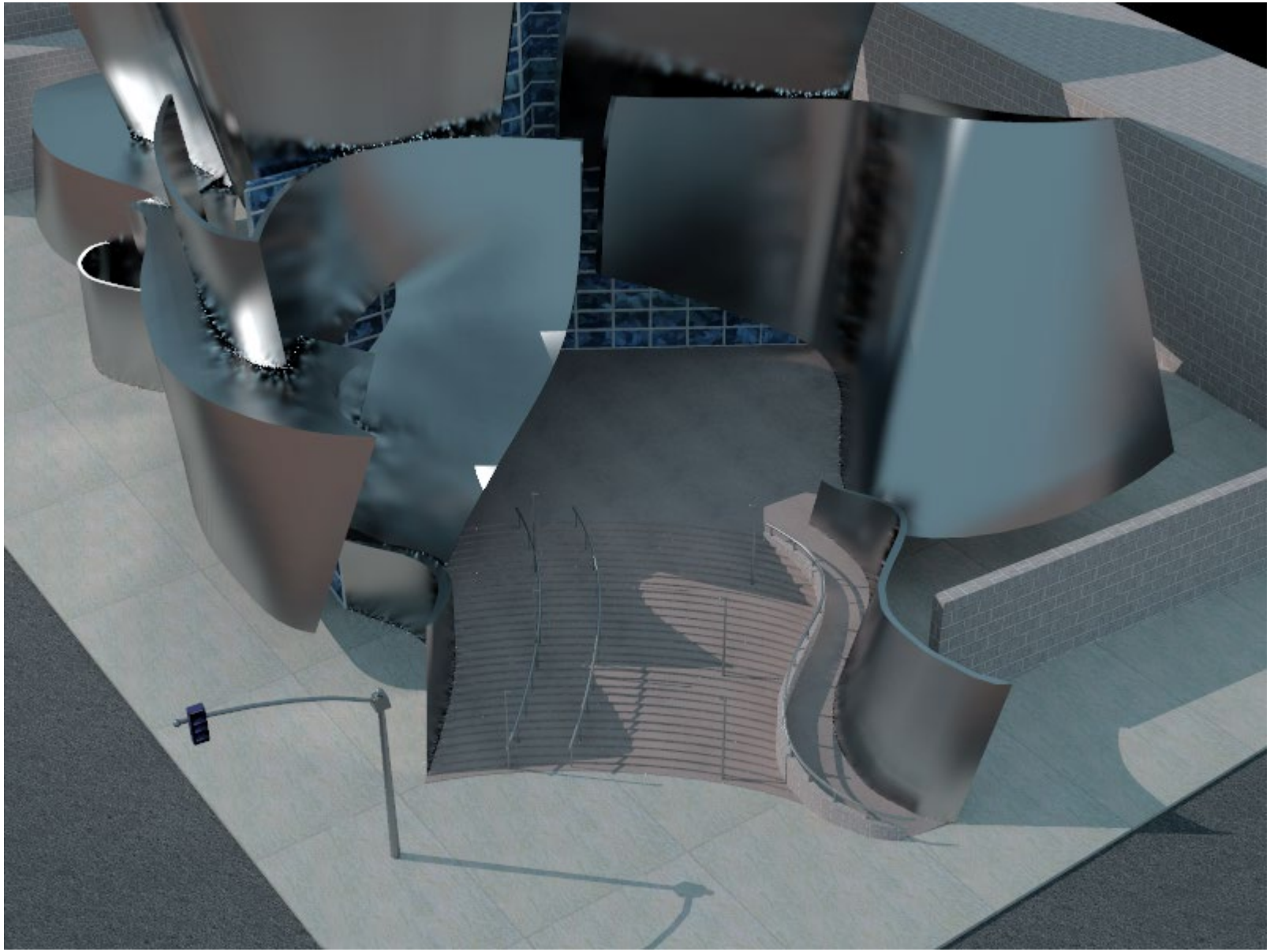
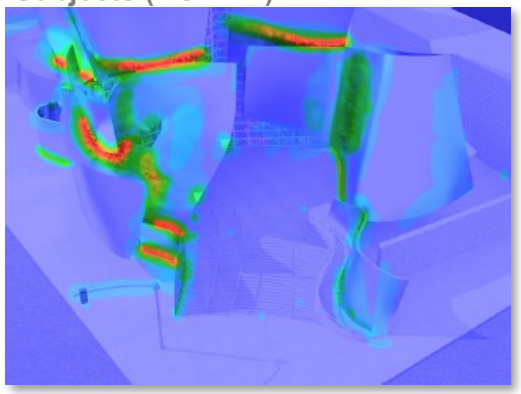


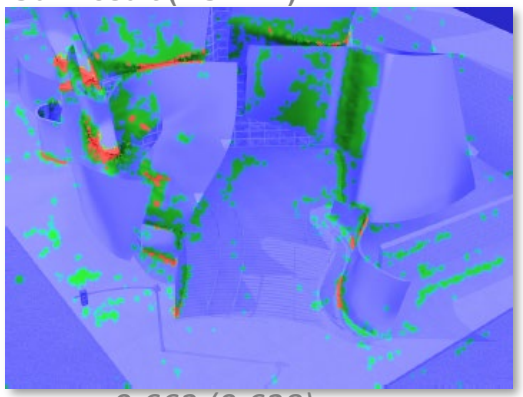
IMAGE WITH ARTIFACTS

Results (VPL noise)

Subjects (NO REF)

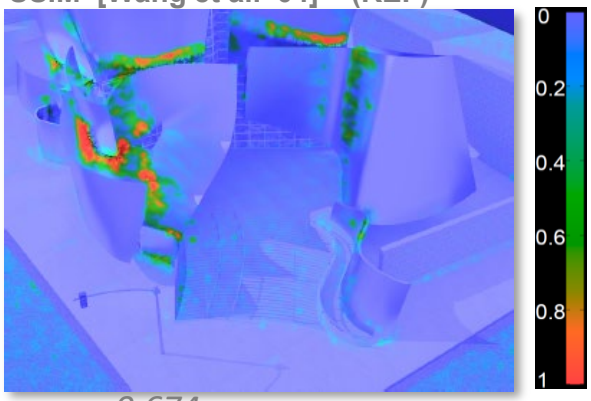


Our Result (NO REF)



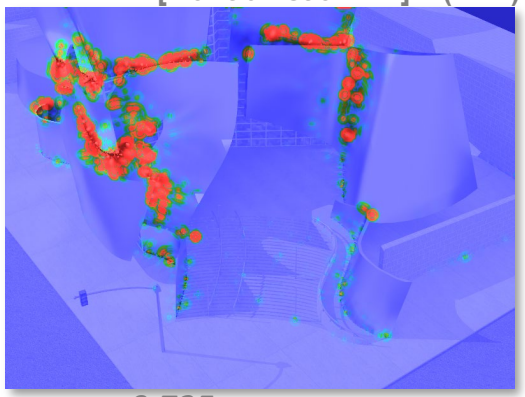
corr = 0.662 (0.628)

SSIM [Wang et al. '04] – (REF)



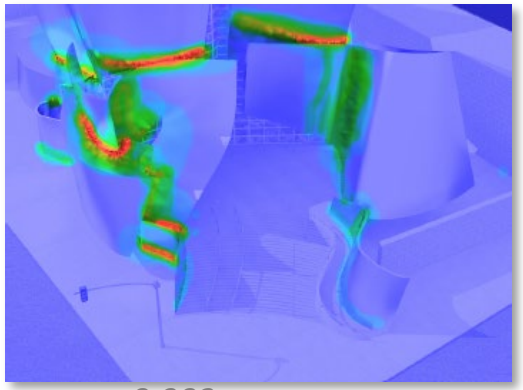
corr = 0.674

HDRVDP2 [Mantiuk et al. '11] – (REF)



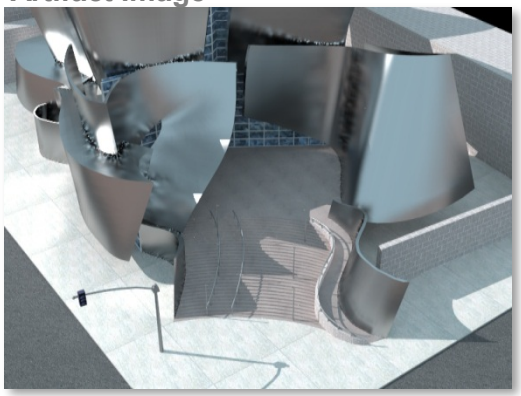
corr = 0.725

Subjects (REF)



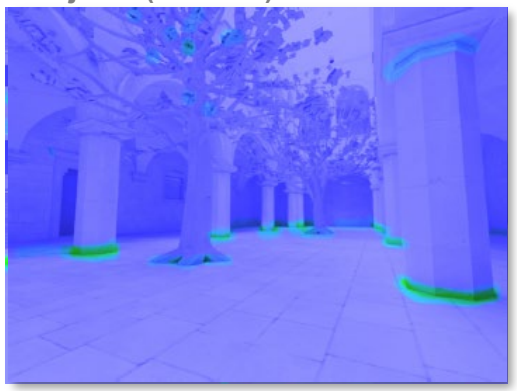
corr = 0.903

Artifact Image

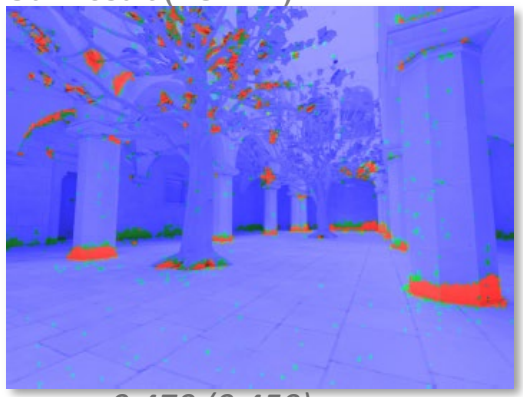


Results (VPL clamping)

Subjects (NO REF)

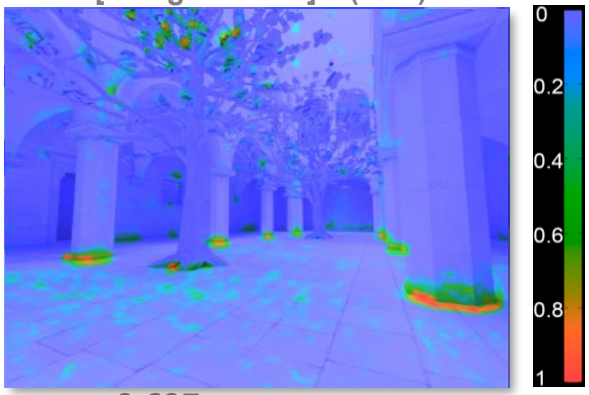


Our Result (NO REF)



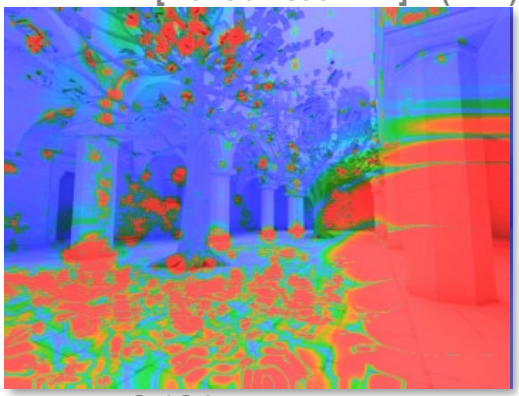
corr = 0.470 (0.450)

SSIM [Wang et al. '04] – (REF)



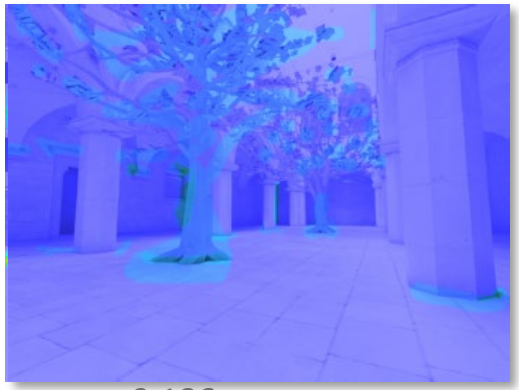
corr = 0.637

HDRVDP2 [Mantiuk et al. '11] – (REF)



corr = 0.134

Subjects (REF)

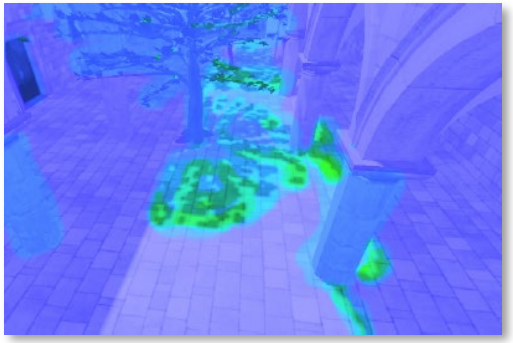


corr = 0.186

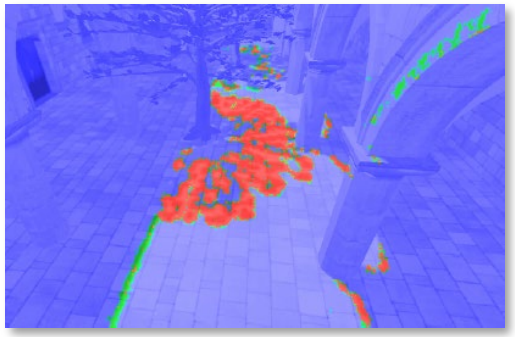
Artifact Image

Results (Shadow aliasing)

Subjects (NO REF)

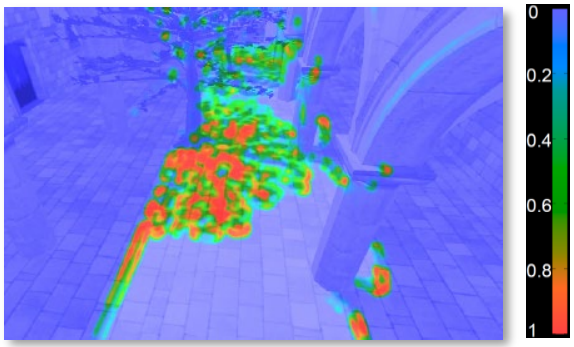


Our Result (NO REF)



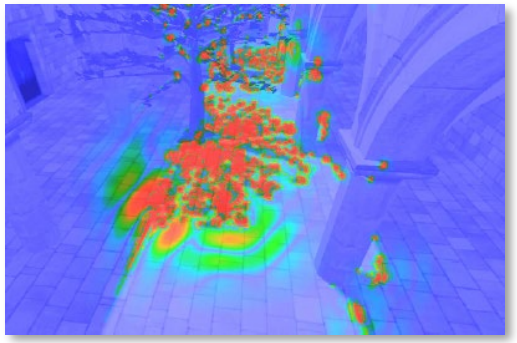
corr = 0.767 (0.638)

SSIM [Wang et al. '04] – (REF)



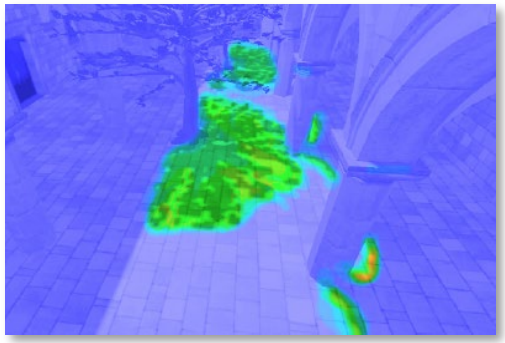
corr = 0.742

HDRVDP2 [Mantiuk et al. '11] – (REF)



corr = 0.669

Subjects (REF)



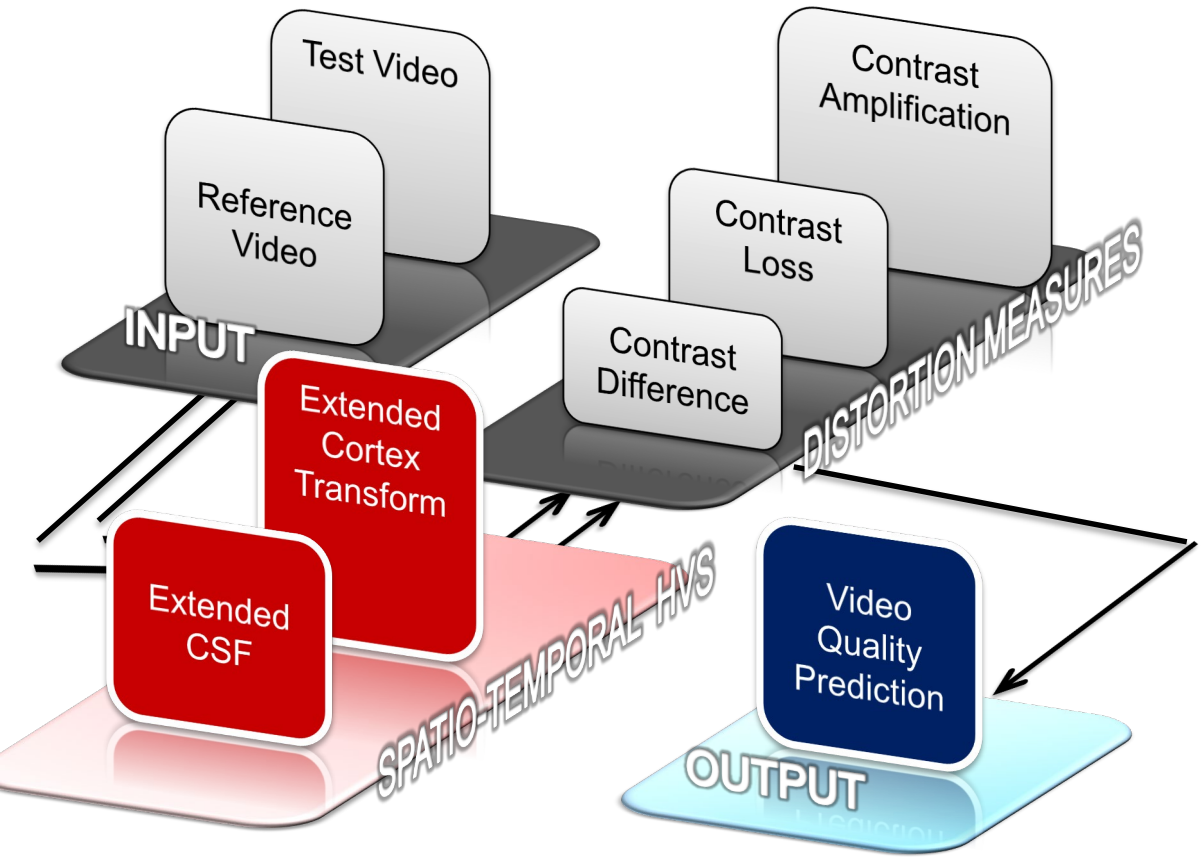
corr = 0.772

Artifact Image

Overview

- Introduction to Objective Quality Assessment
- Image Quality Assessment
  - HVS-based Metrics (bottom-up)
  - Structural Similarity (top-down)
  - Data-driven Approaches (top-down)
- Video Quality Assessment

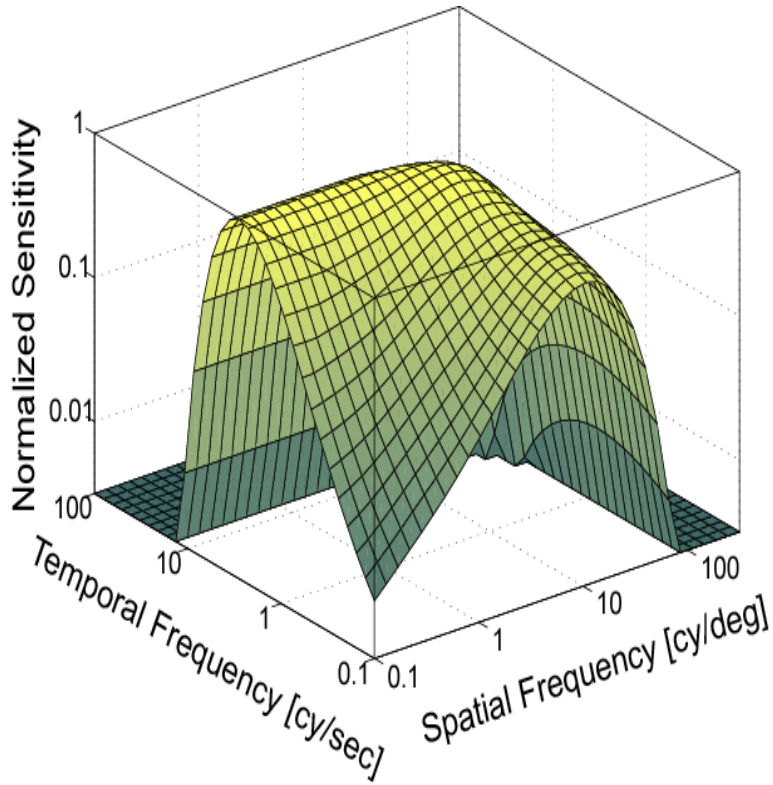
Dynamic Range Independent VQA



- [Aydın et al. 2010]
- **Key Idea:** Extend the Dynamic Range Independent pipeline with temporal aspects to evaluate video sequences
- **Result:** An objective VQM that evaluates rendering quality, temporal tone mapping and HDR compression

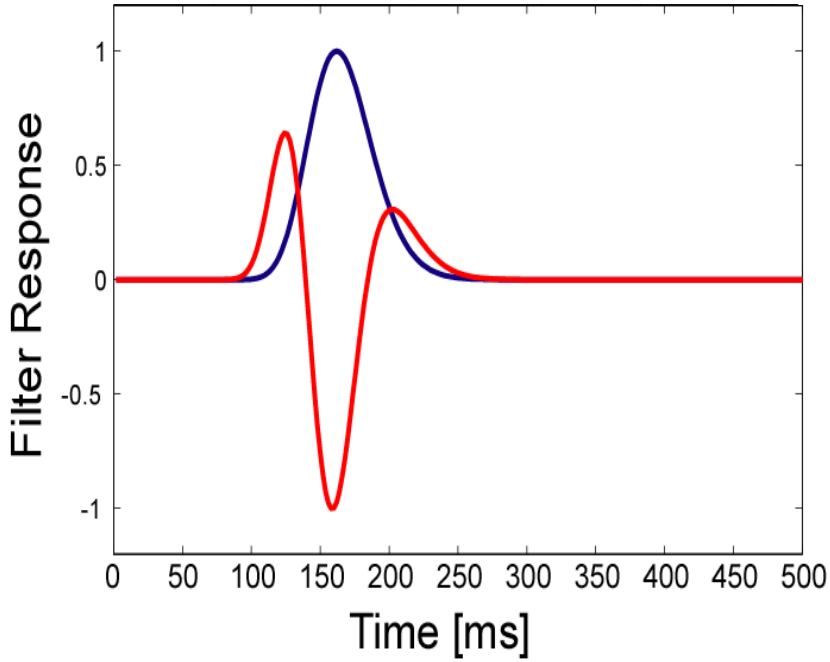
Contrast Sensitivity Function

- *CSF:* $\omega, \rho, L_a \rightarrow S$
  - ω: temporal frequency,
  - ρ: spatial frequency,
  - L_a: adaptation level,
  - S: sensitivity.

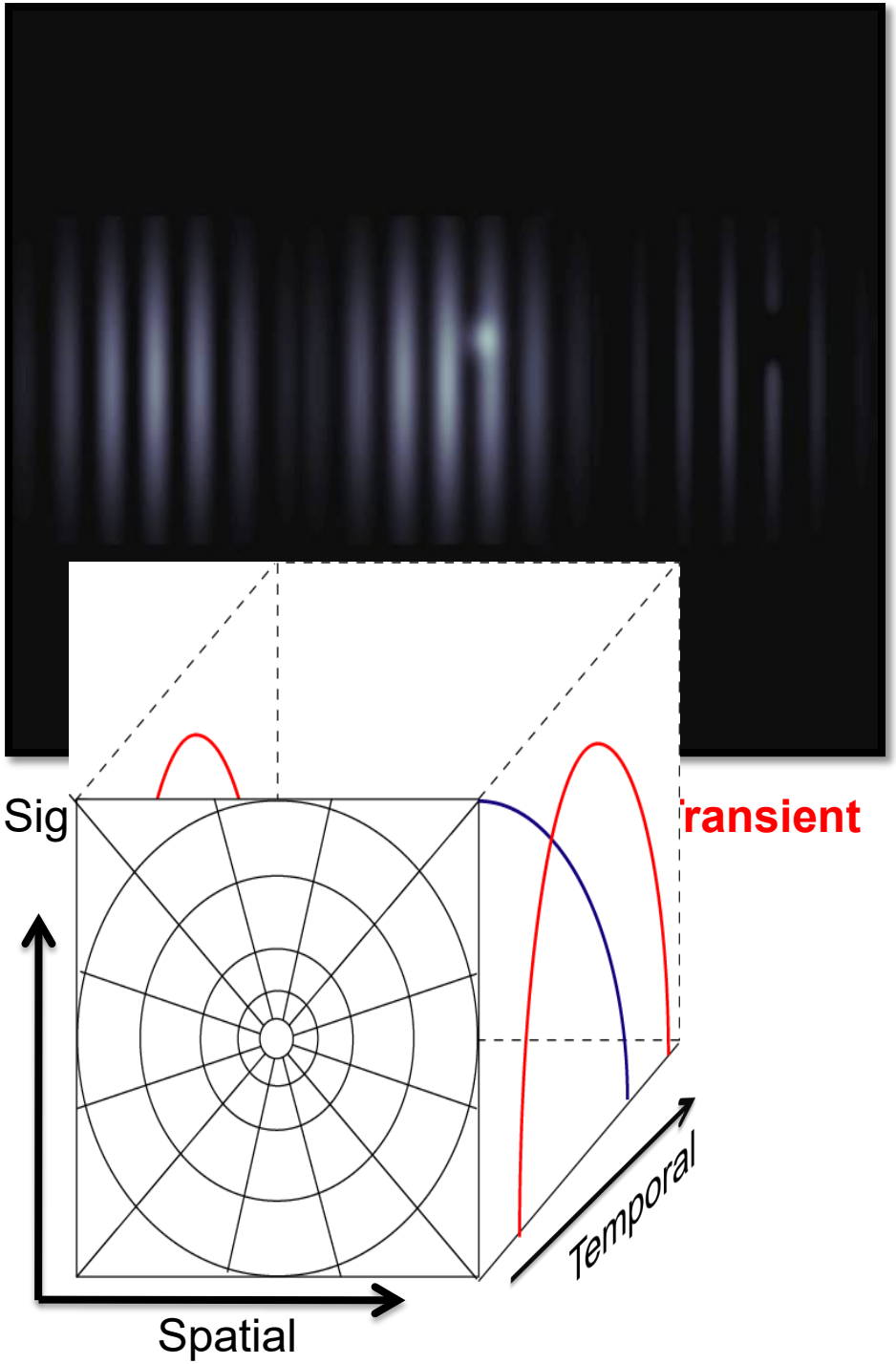


Spatio-temporal CSF

Extended Cortex Transform



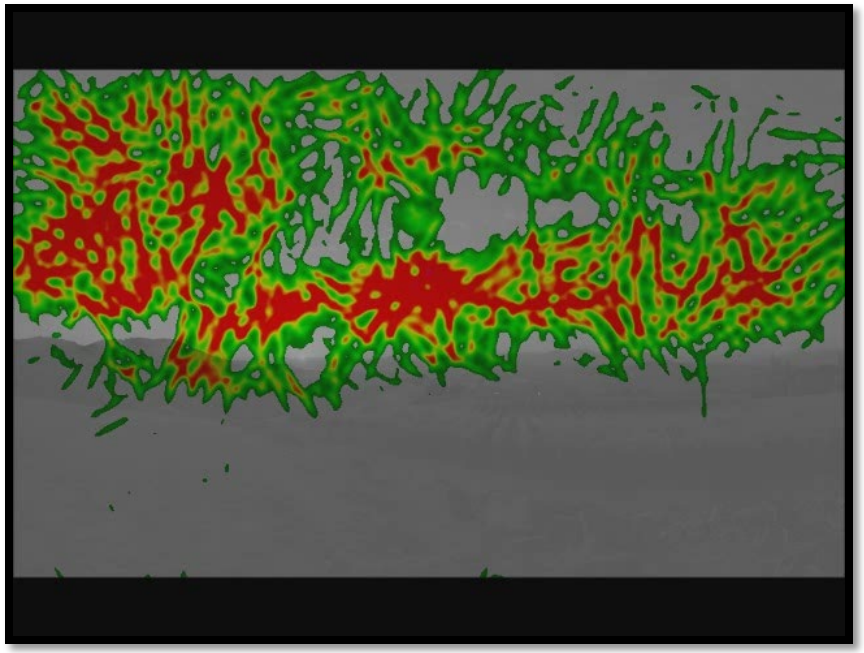
Sustained and **Transient**
Temporal Channels [Winkler 2005]



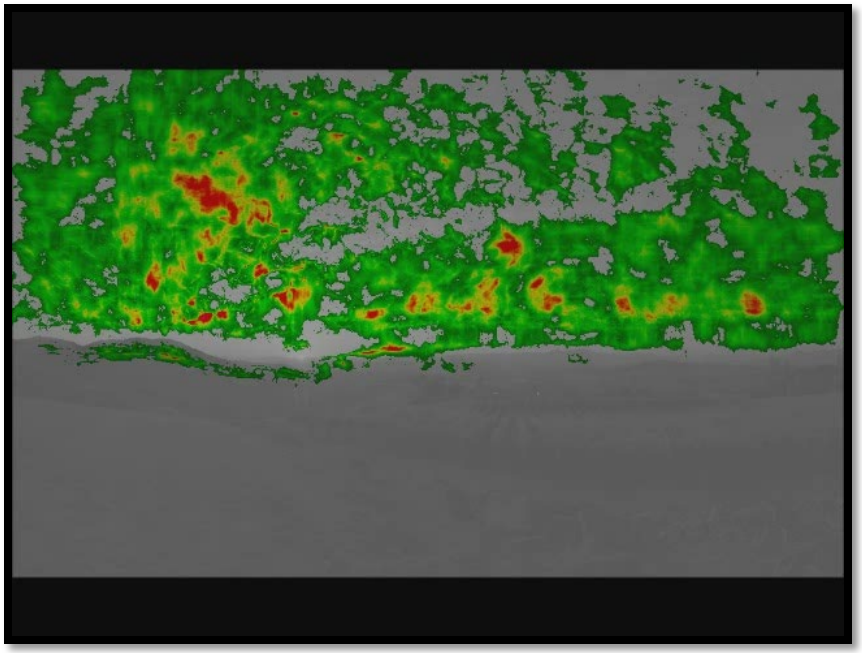
Comparison: Test Scene

- HDR Scene tone mapped with [Pattanaik 2000]
- Spatio-temporal distortion
  - Random pixel noise filtered with a Gaussian.

Metric Comparison LDR-LDR



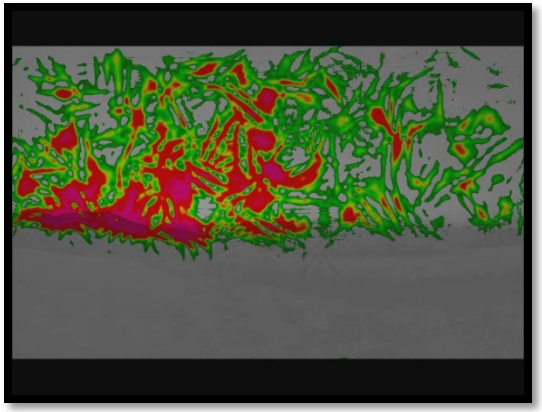
Our Metric

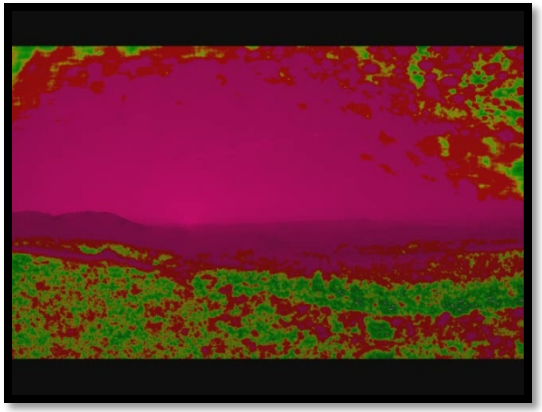


PDM [Winkler 2005]

Metric Comparison HDR-LDR

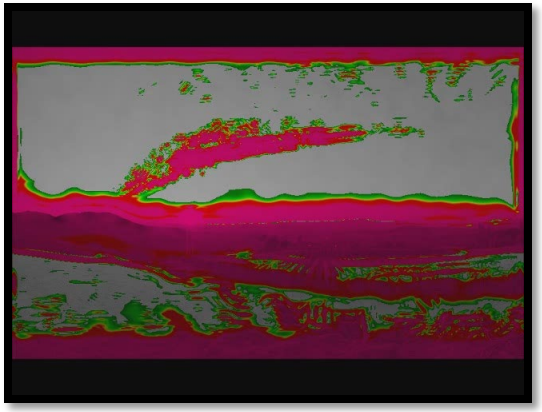
Our Metric





PDM
[Winkler 2005]

HDRVDP
[Mantiuk
et al 2005]

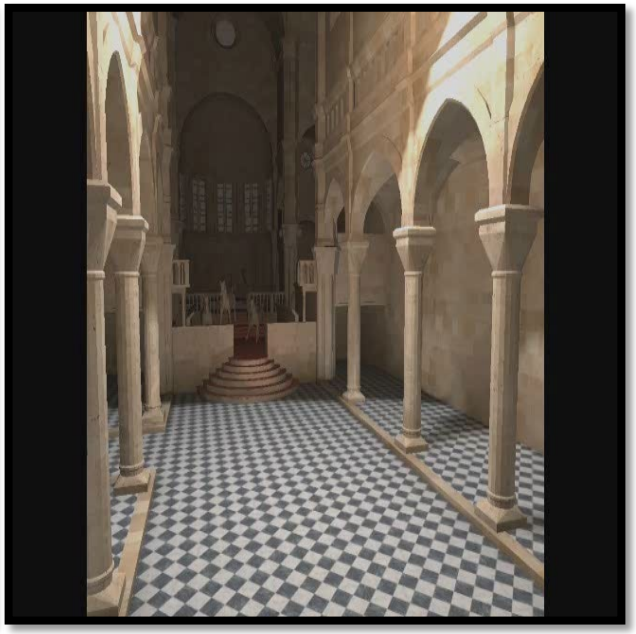


DRIM
[Aydin et al. 2008]

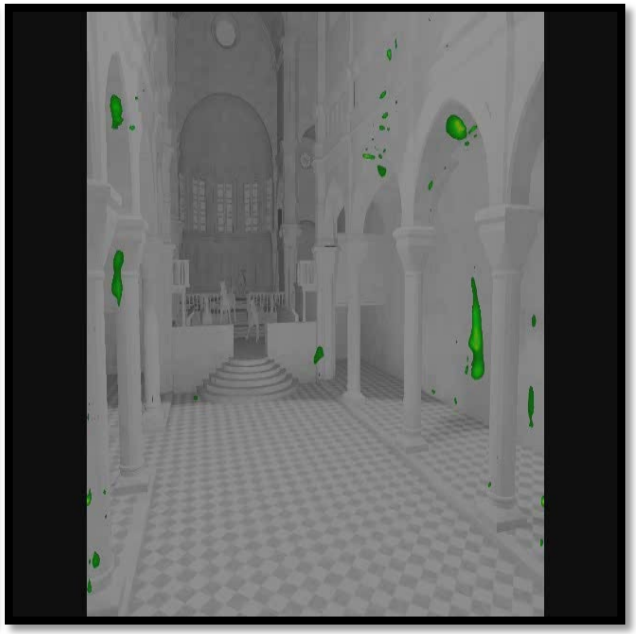
Evaluation of Rendering Methods

- http://drim.mpi-inf.mpg.de/

With temporal filtering
[Herzog et al. 2010]

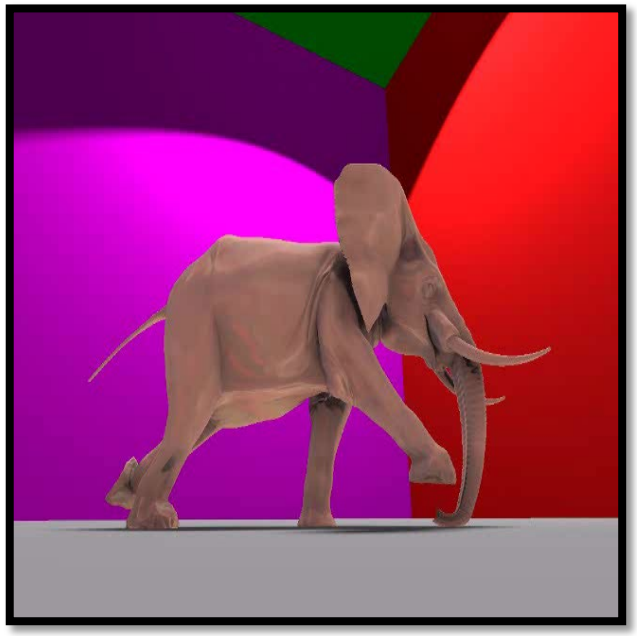


No temporal filtering

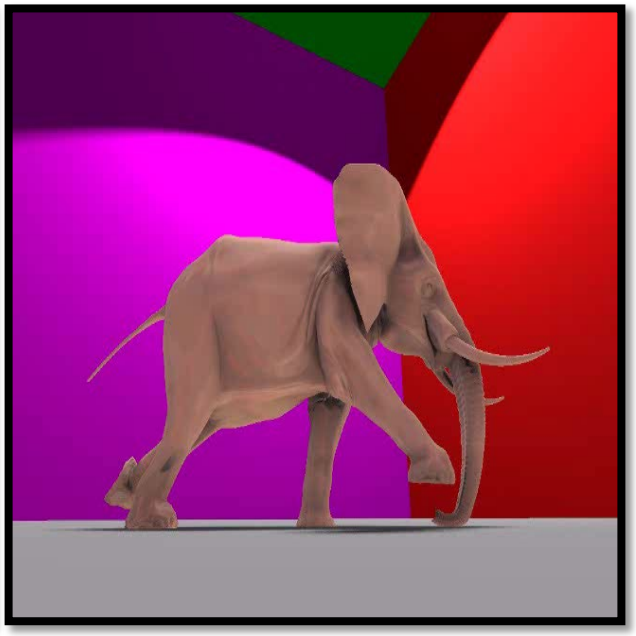


Predicted distortion map

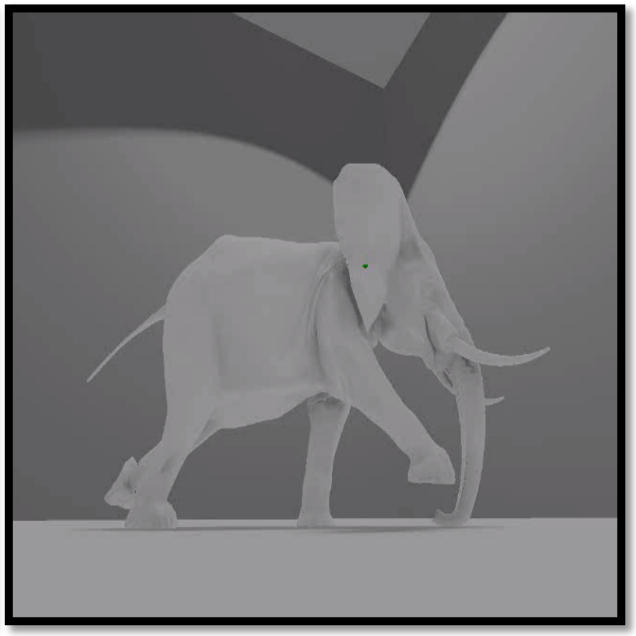
Evaluation of Rendering Qualities



High quality

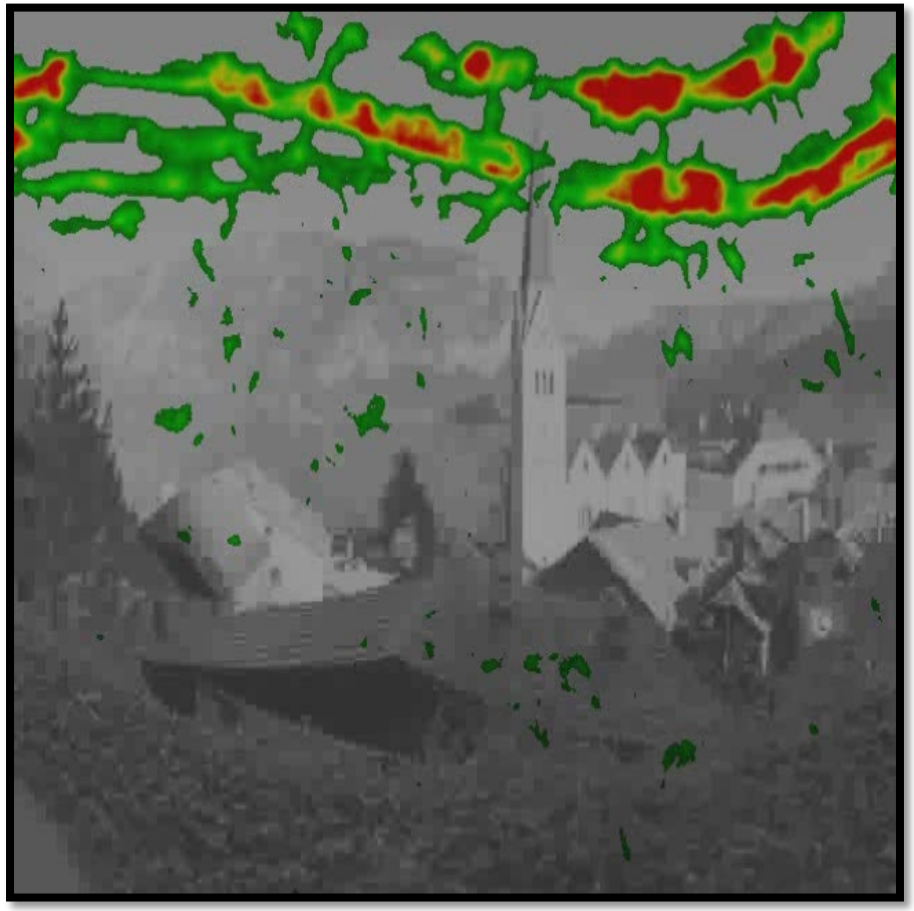


Low quality



Predicted distortion map

Evaluation of HDR Compression

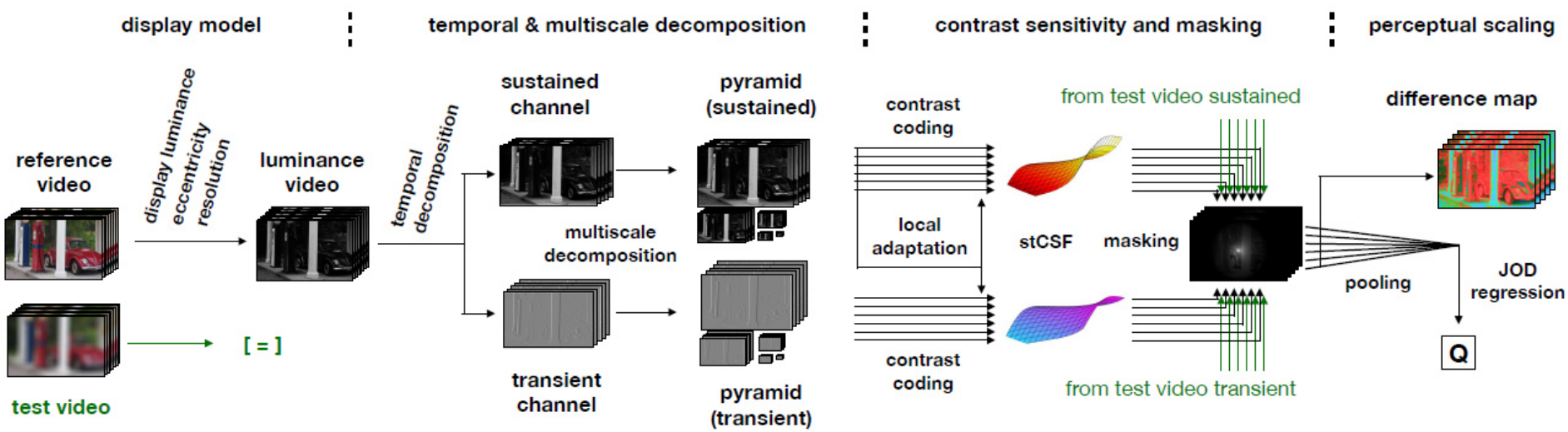


Medium Compression

High Compression

FovVideoVDP

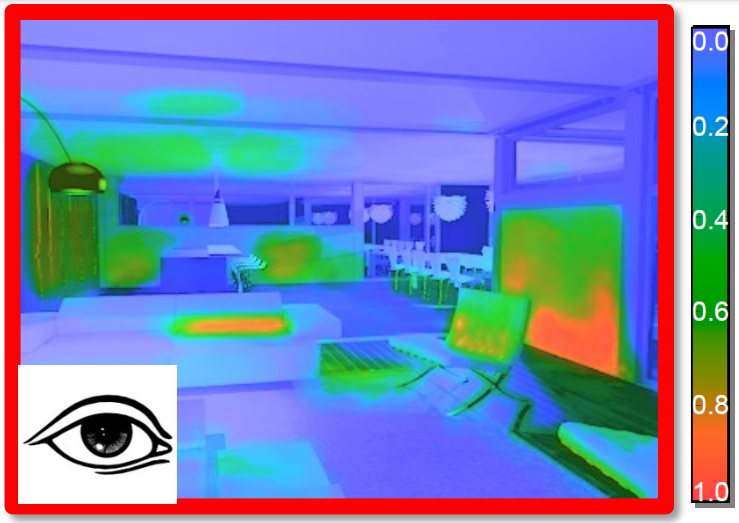
- [Mantiuk et al. 21]
  - spatial, temporal, foveated, peripheral perception
  - CSF, contrast masking
  - supra-threshold
  - no orientation-selective visual channels, no cross-channel masking, no color vision
  - Laplacian pyramid (no cortex transform) → 100x faster than HDRVDP3
  - Pytorch, matlab



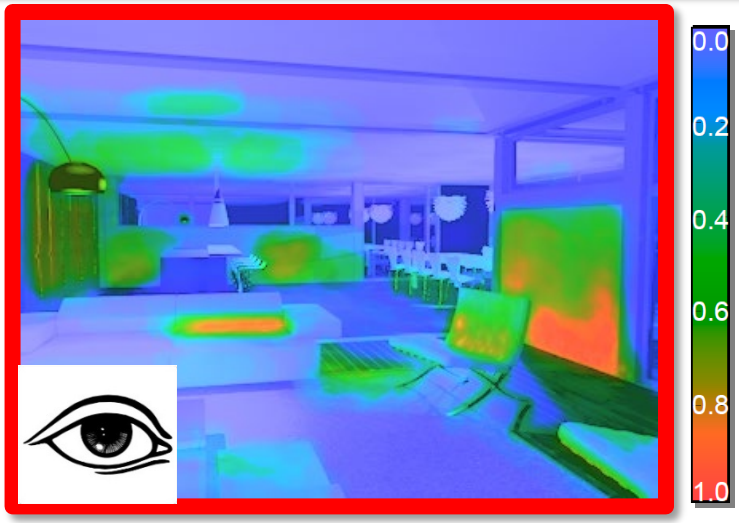
EXPERIMENTAL EVALUATIONS

User Experiment - Mean Distortion Maps

- 37 test images
- 35 subjects (expert and non experts)
- Localization of artifacts
- Scribbling interface

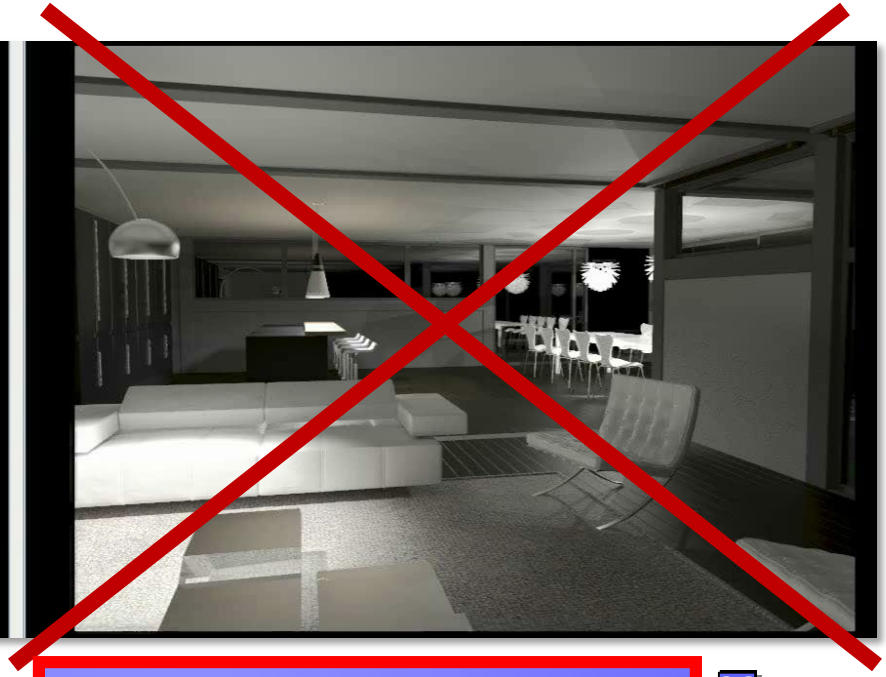


User Experiment – With Reference



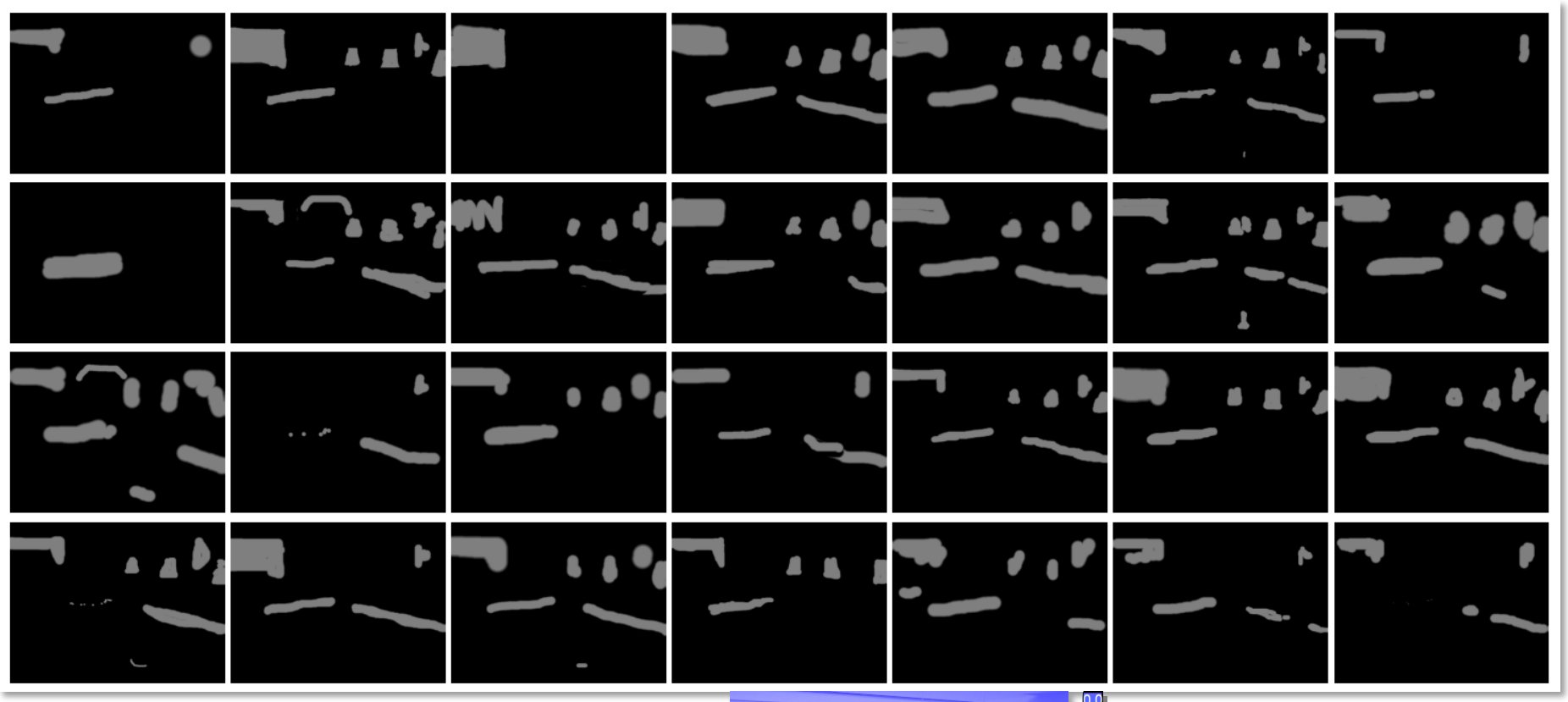
- Noticeable distortions

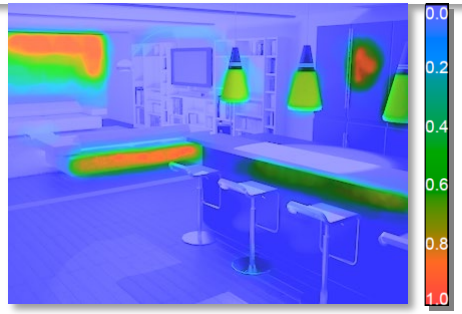
User Experiment – No Reference



- Objectionable distortions

Example User Responses

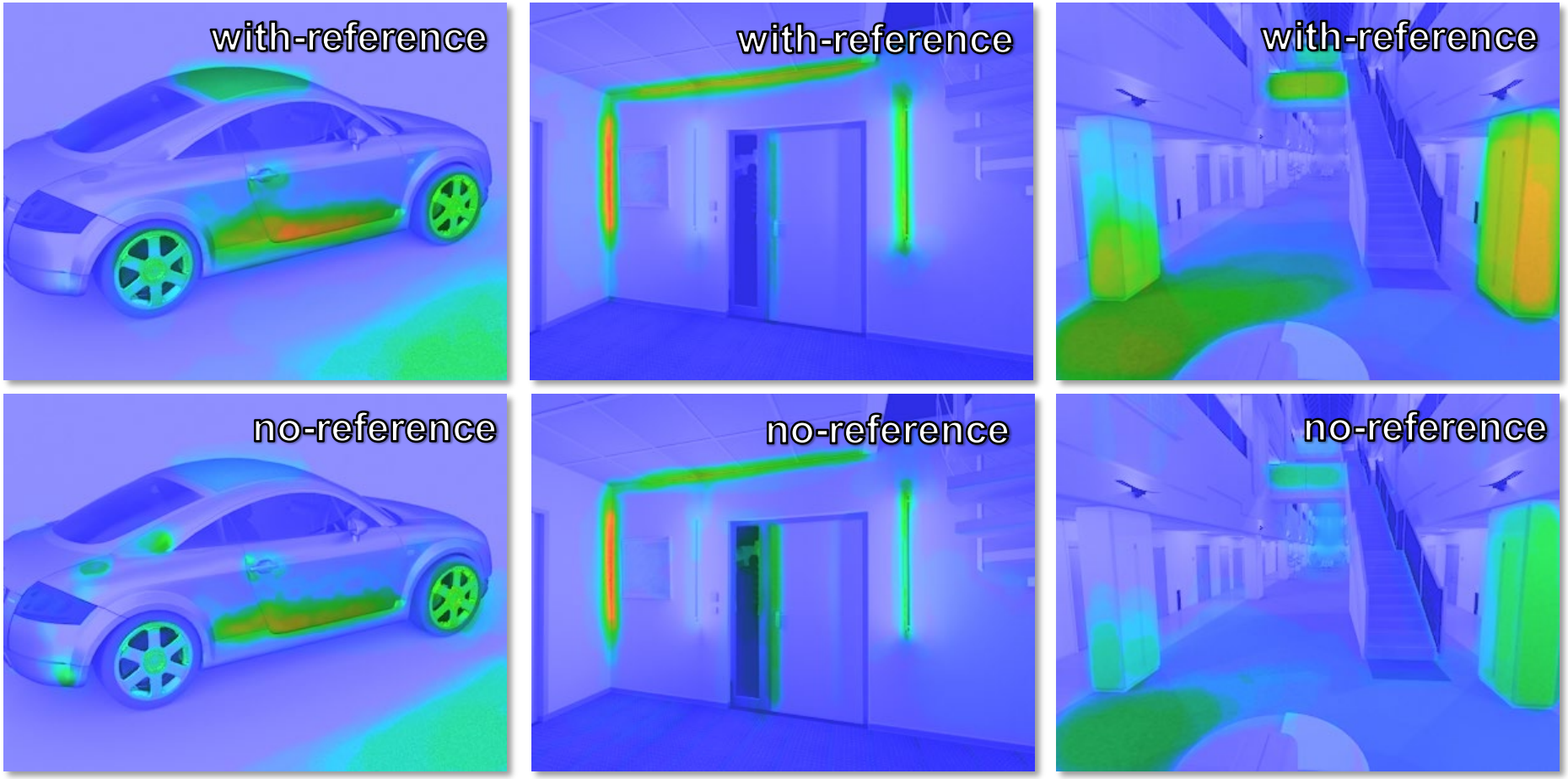




- Probability of detection

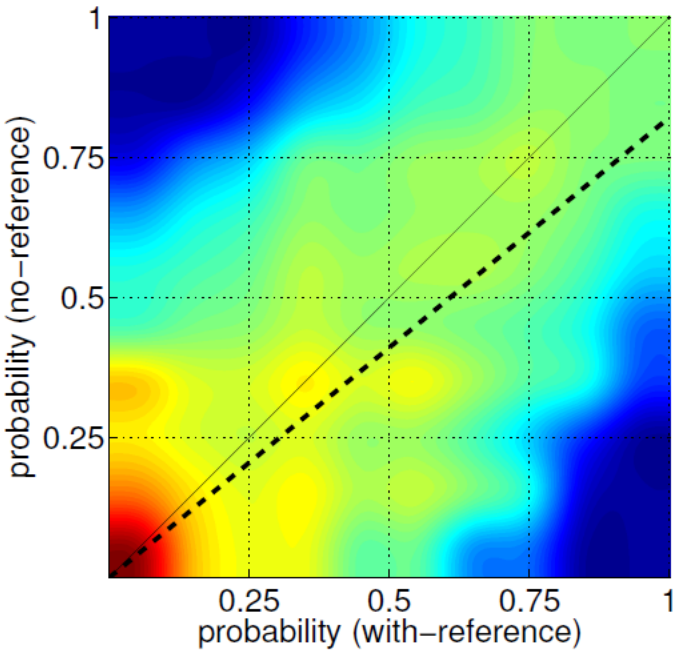
With-reference vs. No-reference

- Results rather similar

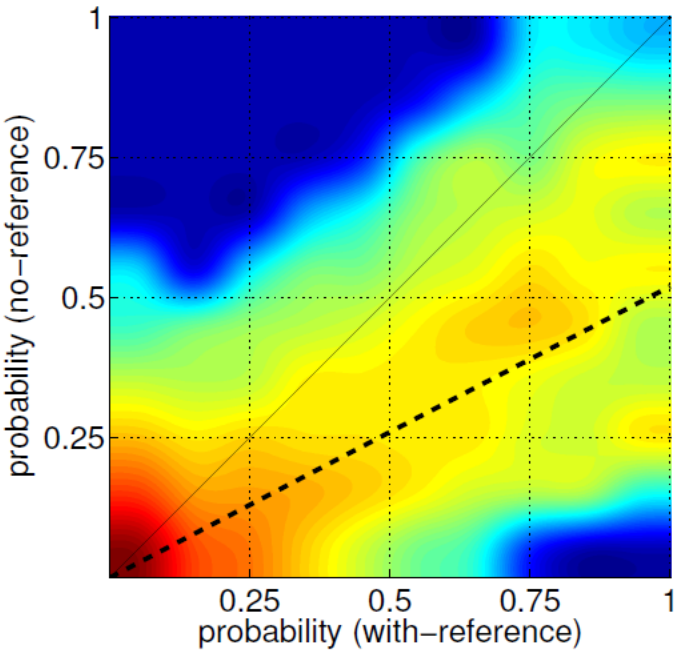


With-reference vs. No-reference (cont.)

- Strong correlation
  - (perhaps people do not need the reference)
- SRCC=0.88 SRCC=0.85



EG'12 dataset

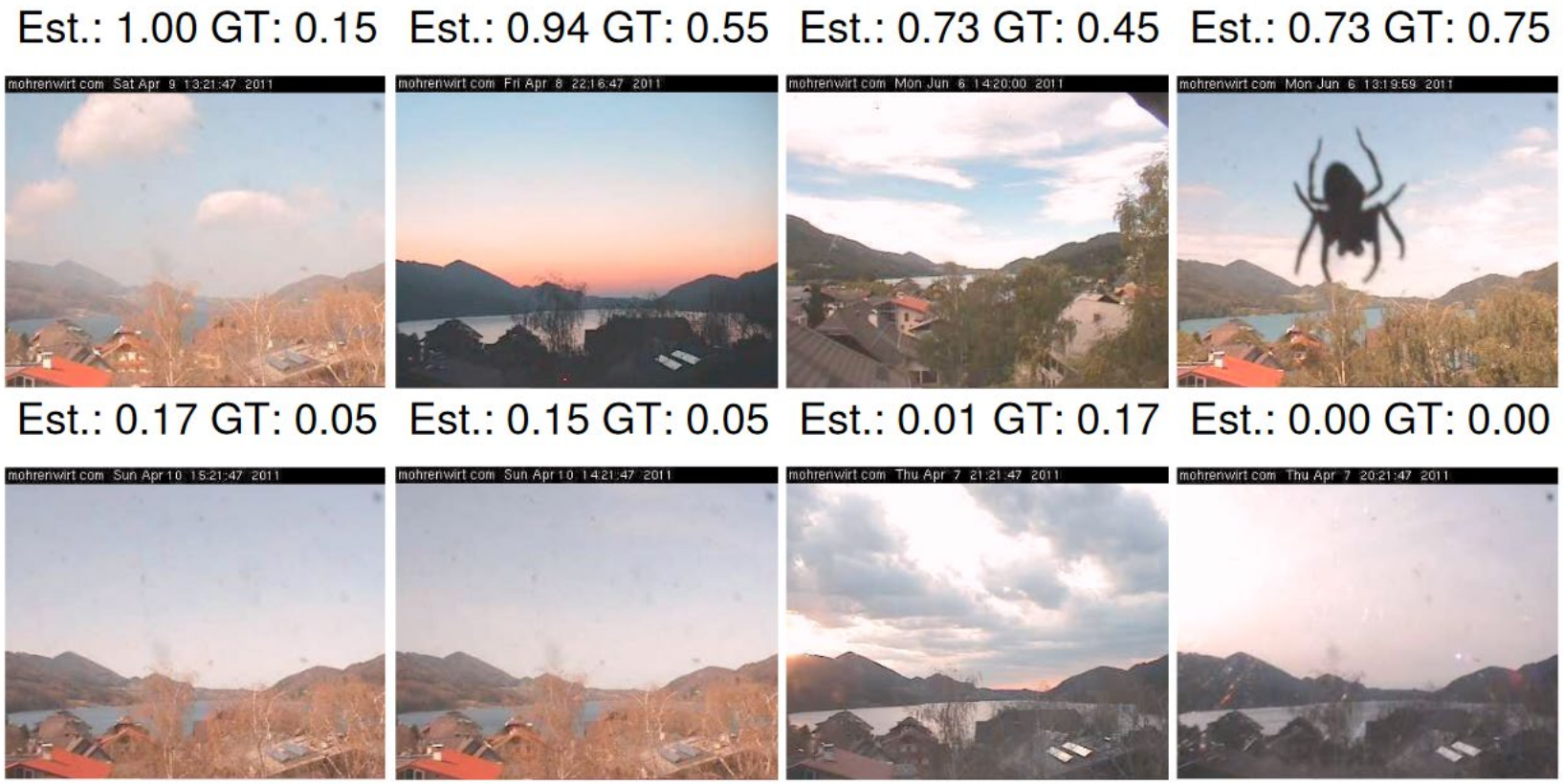


new dataset

OTHER METRICS

Interestingness of Images

- interestingness = aesthetics, unusualness, general preferences [Gygli et al. 13]



Automated aesthetic analysis

- [Aydin et al. 15]

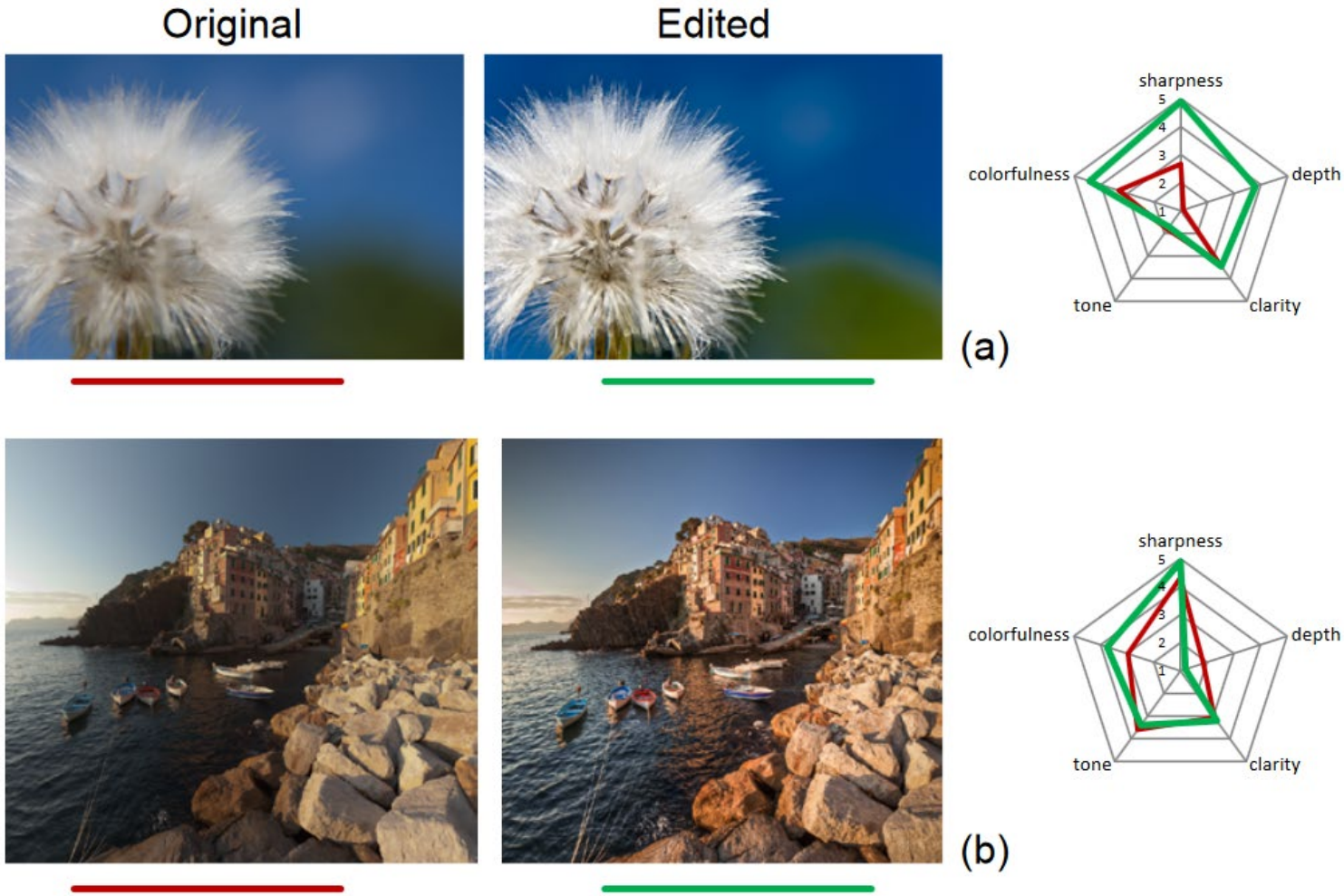


Image completion quality prediction

- [Kopf et al. 12]

Input panorama and quality prediction
(brighter is higher quality)

Full completion

Best crop using only “known” pixels (“conservative crop”)

Our optimized crop based on quality prediction

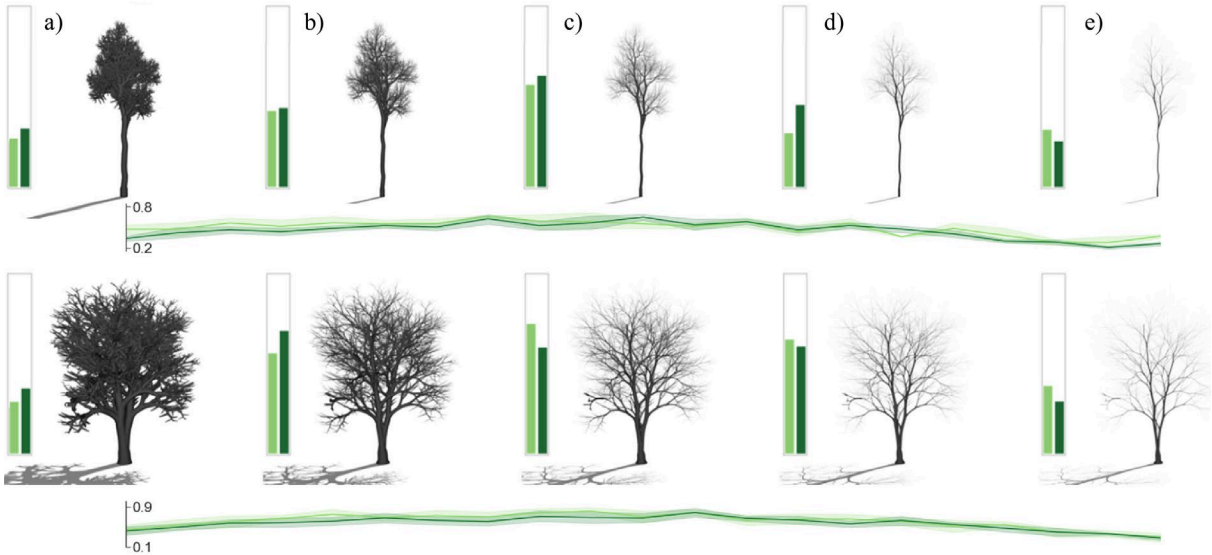
Specific Metrics

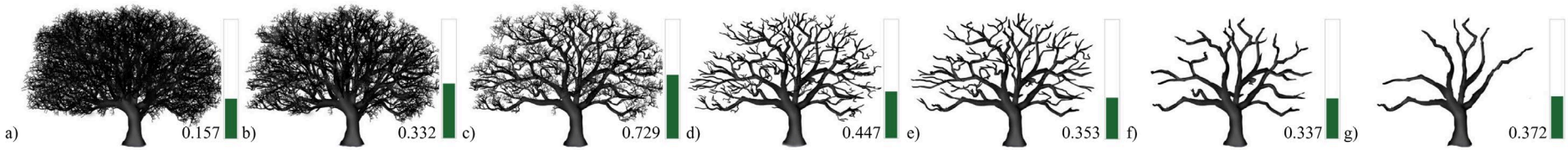
- Spectral metrics
  - [Le Moan and Urban 14]
- Lightfield metrics
- HDR metrics
- …

ICTree

- [Polasek, Hrusa, Benes, Čadík 21]

http://cphoto.fit.vutbr.cz/ictree/

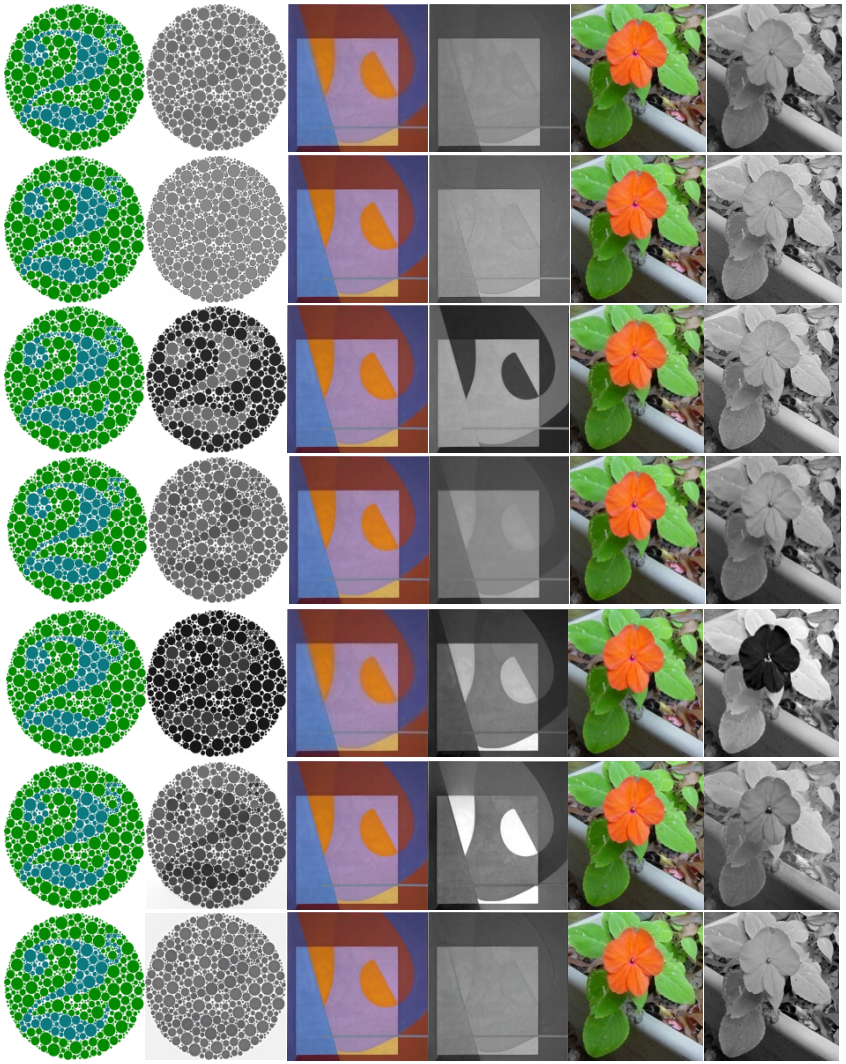




Wrong Usage of IQM/VQM

- Codruta O. Ancuti, Cosmin Ancuti and Philippe Bekaert, "Enhancing by Saliency-guided Decolorization", In Proc. IEEE Computer Vision and Pattern Recognition (IEEE CVPR), Colorado Springs, USA, 2011.

- DRIM used for comparing color-to-grayscale conversions



SUMMARY

Conclusions

- No universal method
- Simple, robust techniques score high
- Advanced fancy methods are nice, but need to improve on robustness
- With reference ~~ no-reference experiments

Methods to Try

- Images
  - HDR-HDR
    - **HDRVDP3** [Mantiuk et al. 11]
  - HDR-LDR
    - **HDRVDP3** [Mantiuk et al. 11]
    - **TMQI** [Yeganeh, Wang 13]
  - LDR-LDR
    - **CNN** [Wolski et al. 13]
    - **SSIM** [Wang, Bovik 04]
    - **FLIP** [Andersson et al. 20]
- Videos
  - HDR-HDR
    - **DRIVQM** [Aydin et al. 10]
  - HDR-LDR
    - **DRIVQM** [Aydin et al. 10]
  - LDR-LDR
    - **FovVideoVDP** [Mantiuk et al. 21]

Thanks for your attention

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http://cadik.posvete.cz

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