The HDR video pipeline

Tone-mapping for HDR video

Aspects of tone-mapping in the context of processing camera captured HDR video material

Tone-mapping principles

Tone-mapping principles

- Tone-curve
  - Scaling
  - Logarithmic/exponential
  - Sigmoid
  - Histogram based
  - Other
- Processing
  - Global - constant tone-curve
  - Local - spatially varying tone-curve
- Intent
  - Visual system simulators (VSS)
  - Scene reproduction operators (SRP)
  - Best subjective quality operators (BSQ)

The tone-mapping pipeline

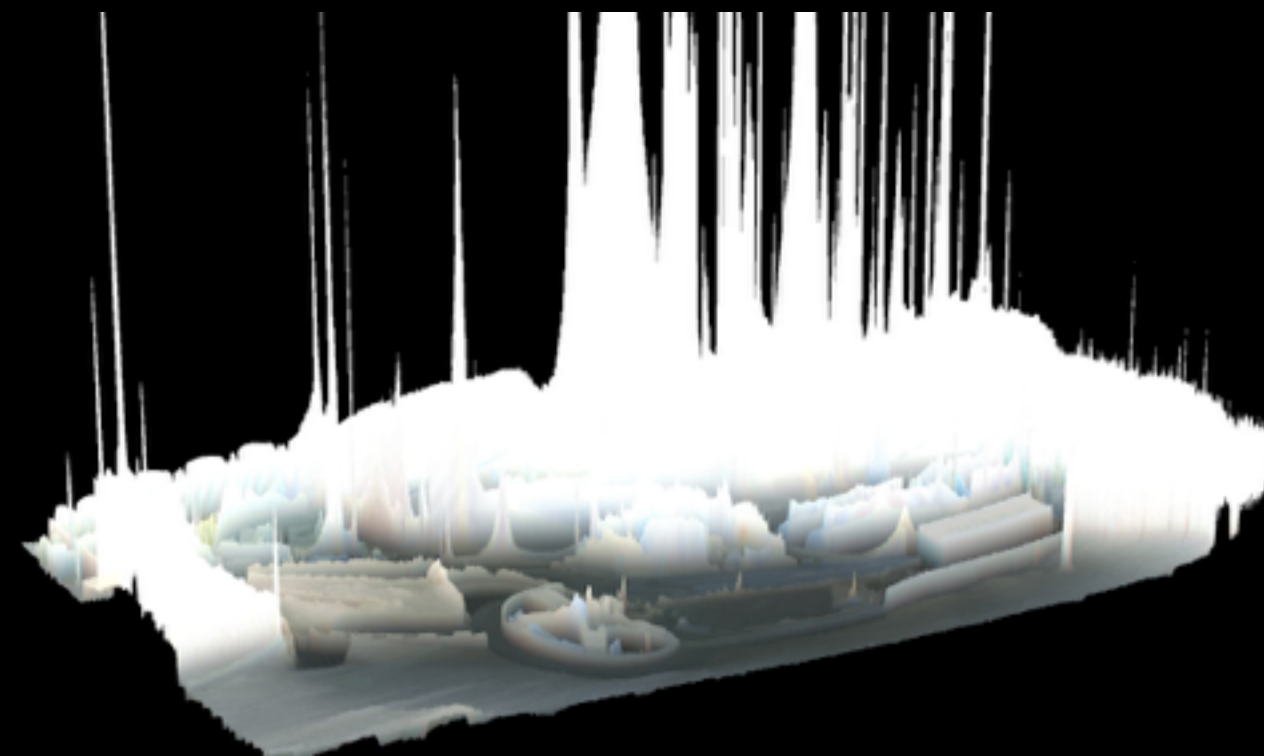
An example of a common approach for constructing a tone-mapping system


Edge pres. filter: *Bilateral filter*
Tone-curve: *Sigmoid S-curve*

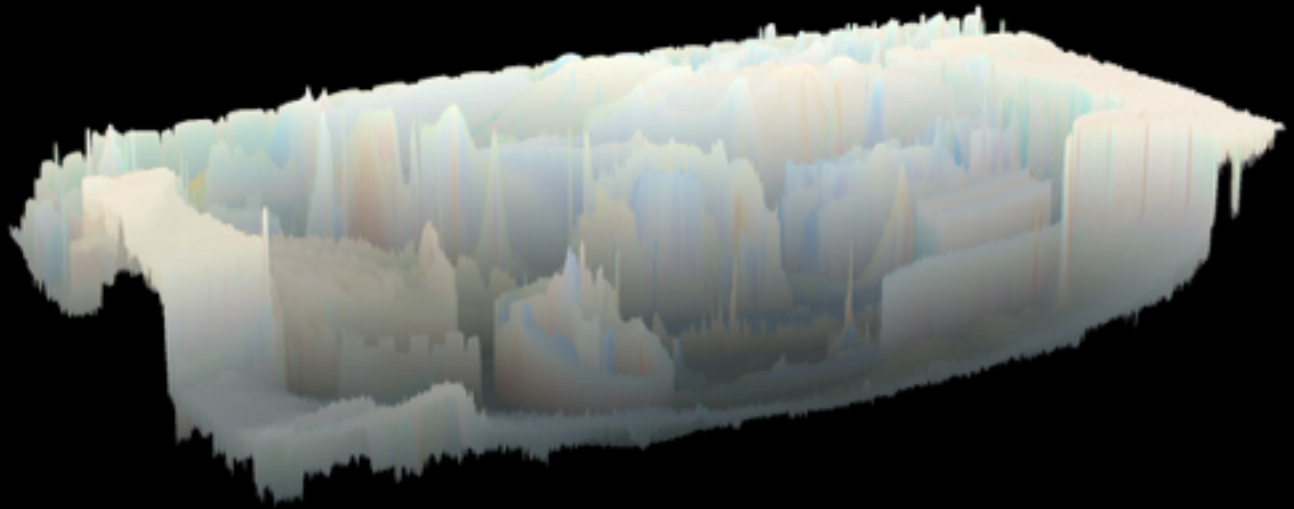
The tone-mapping pipeline

The tone-mapping pipeline

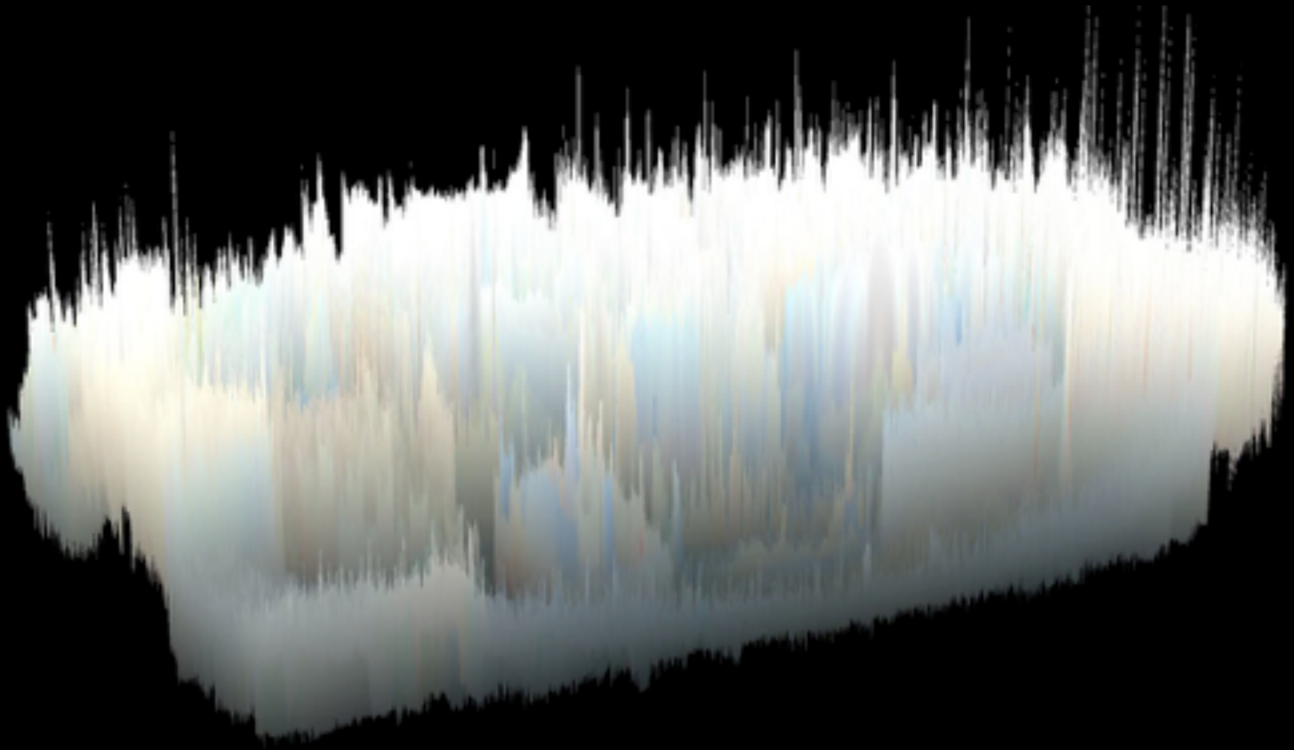
The tone-mapping pipeline



The tone-mapping pipeline



The tone-mapping pipeline



Video tone-mapping

The challenges in tone-mapping of HDR video material, as compared to using static images

Video tone-mapping

- Tone-mapping well-explored
  - Many algorithms, for a wide range of purposes
  - Temporally adaptive operators have been around for almost 2 decades

- High-quality camera captured HDR video
  - Dedicated camera systems for HDR video
  - Appeared about 5 years ago
  - Different properties compared to static multi-exposure

- **FERWERDA J. A., PATTANAIK S. N., SHIRLEY P., GREEN- BERG D. P.:** A model of visual adaptation for realistic image synthesis. *In Proceedings of the 23rd annual conference on Computer graphics and interactive techniques (New York, NY, USA, 1996), SIGGRAPH '96, ACM, pp. 249–258.*
- **PATTANAIK S. N., TUMBLIN J., YEE H., GREENBERG D. P.:** Time-dependent visual adaptation for fast realistic image display. *In Proc. SIGGRAPH 00 (2000), Annual Conference Series, pp. 47–54.*
- **DURAND F., DORSEY J.:** Rendering Techniques 2000: Proceedings of the Eurographics Workshop in Brno, Czech Republic, June 26– 28, 2000. Springer Vienna, Vienna, 2000, ch. Interactive Tone Mapping, pp. 219–230.

Video tone-mapping

The new challenges in tone-mapping of camera captured HDR video:

- Complicated transitions, both spatially and over time
- Camera noise
- Skin tones
- Computational complexity
- Memory consumption
- Parameter tuning

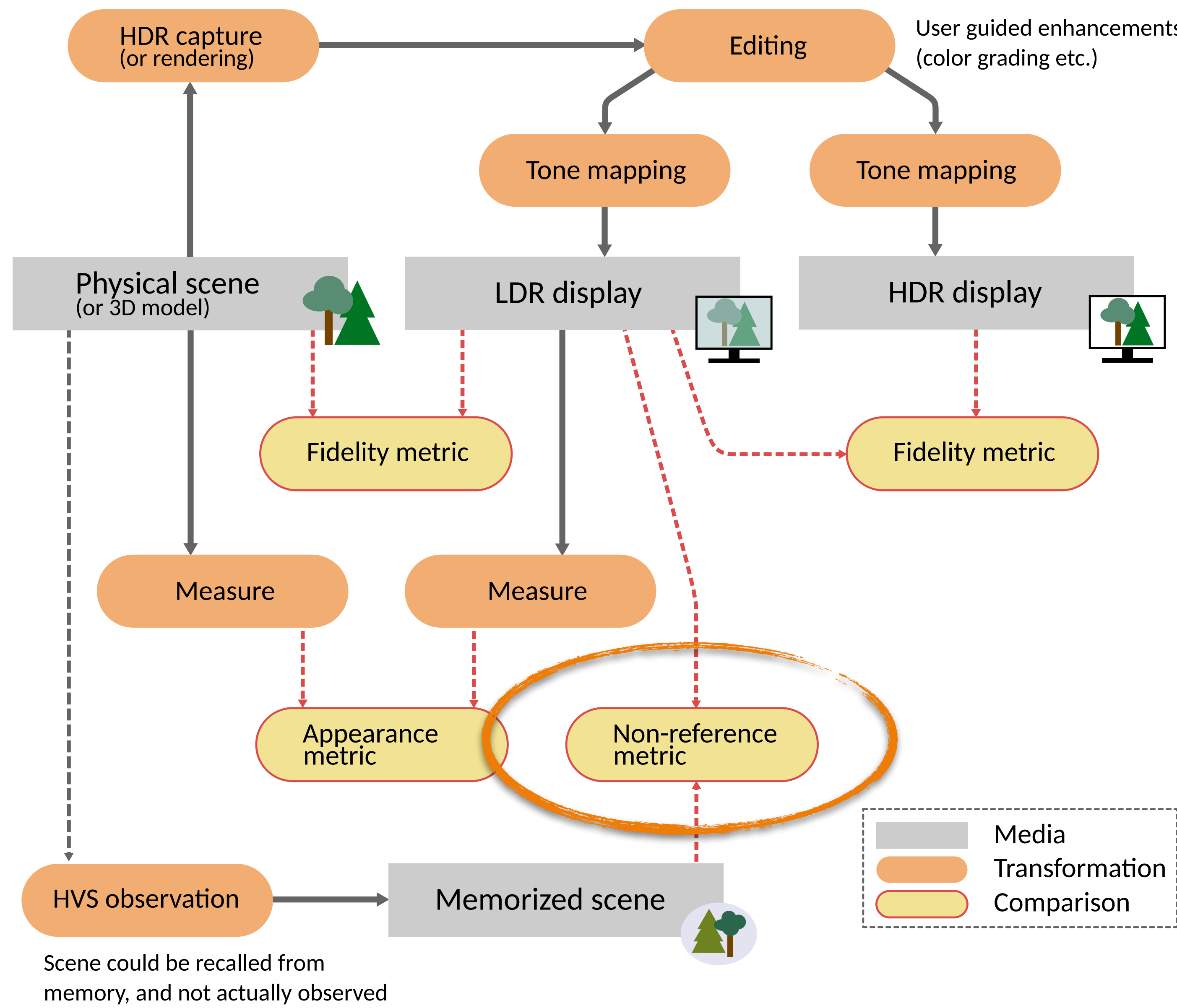
Evaluation of TMOs for HDR video

A first survey and evaluation of existing TMOs for tone-mapping of HDR video, using camera captured HDR video footage

Operator	Processing	Intent	Description
Visual adaptation TMO [FPSG96]	Global	VSS	Use of data from psychophysical experiments to simulate adaptation over time, and effects such as color appearance and visual acuity. Visual response model is based on measurements of threshold visibility as in [War94].
Time-adaptation TMO [PTYG00]	Global	VSS	Based on published psychophysical measurements [Hun95]. Static responses are modeled separately for cones and rods, and complemented with exponential smoothing filters to simulate adaptation in the temporal domain. A simple appearance model is also included.
Local adaptation TMO [LSC04]	Local	VSS	Temporal adaptation model based on experimental data operating on a local level using bilateral filtering.
Mal-adaptation TMO [IFM05]	Global	VSS	Based on the work by Ward *et al.* [WLRP97] for tone mapping and Pattanaik *et al.* [PTYG00] for adaptation over time. Also extends the threshold visibility concepts to include maladaptation.
Virtual exposures TMO [BM05]	Local	BSQ	Bilateral filter applied both spatially for local processing, and separately in time domain for temporal coherence.
Cone model TMO [VH06]	Global	VSS	Dynamic system modeling the cones in the human visual system over time. A quantitative model of primate cones is utilised, based on actual retina measurements.
Display adaptive TMO [MDK08]	Global	SRP	Display adaptive tone mapping, where the goal is to preserve the contrasts within the input (HDR) as close as possible given the characteristic of an output display. Temporal variations are handled through a filtering procedure.
Retina model TMO [BAHC09]	Local	VSS	Biological retina model where the time domain is used in a spatio-temporal filtering for local adaptation levels. The spatio-temporal filtering, simulating the cellular interactions, yields an output with whitened spectra and temporally smoothed for improved temporal stability and for noise reduction.
Color appearance TMO [RPK*12]	Local	SRP	Display and environment adapted image appearance calibration, with localized calculations through the median cut algorithm.
Temporal coherence TMO [BBC*12]	Local	SRP	Post-processing algorithm to ensure temporal stability for static TMOs applied to video sequences. The authors use mainly Reinhard's photographic tone reproduction [RSSF02], for which the algorithm is most developed. Therefore, the version used in this survey is also utilising this static operator.
Camera TMO	Global	BSQ	Represents the S-shaped tone curve which is used by most consumer-grade cameras to map the sensor-captured values to the color gamut of a storage format. The curves applied were measured for a Canon 500D DSLR camera, with measurements conducted for each channel separately. To achieve temporal coherence, the exposure settings are anchored to the mean luminance filtered over time with an exponential filter.

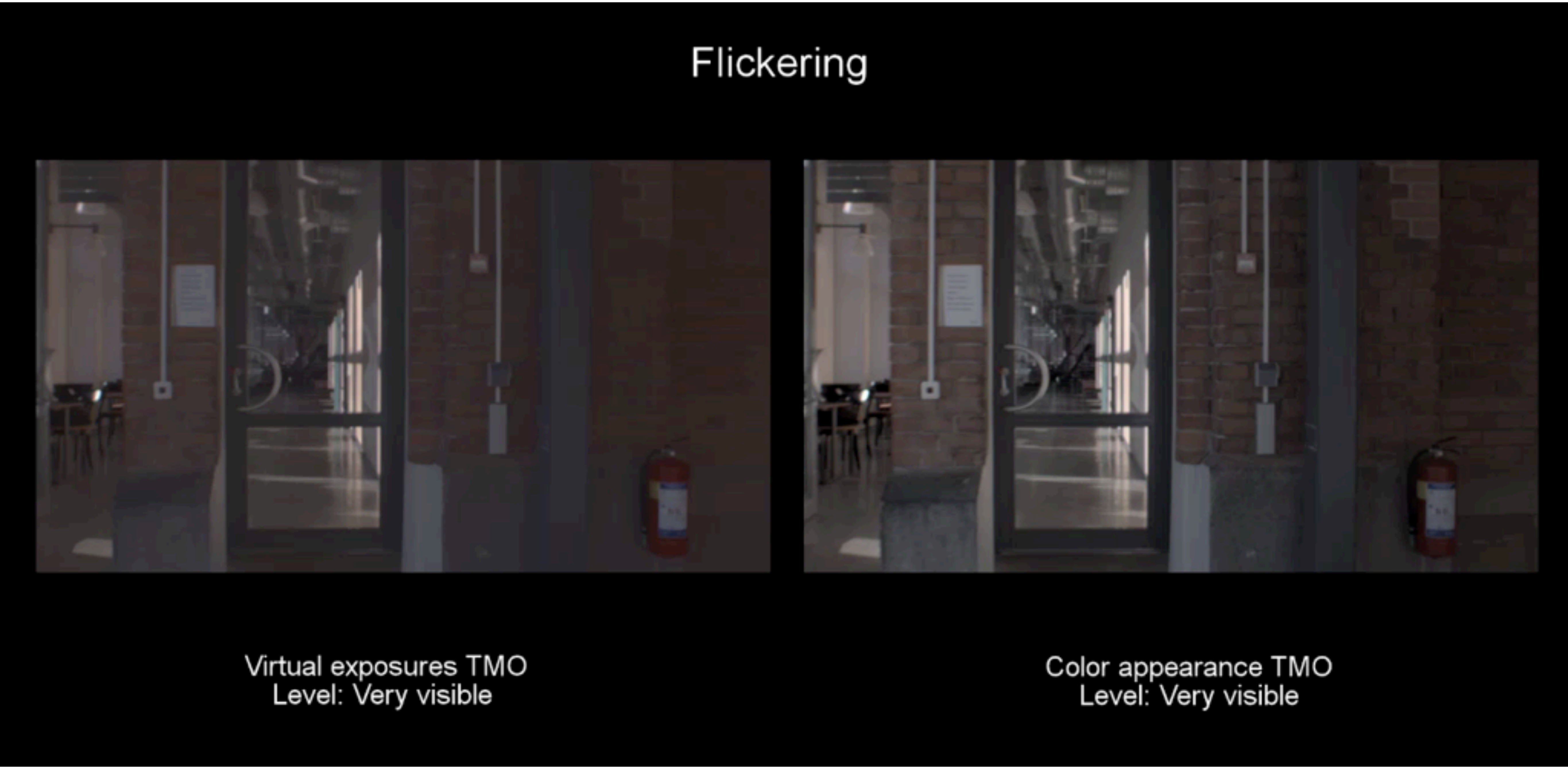
Evaluation of TMOs for HDR video

- 11 video tone-mapping operators (with explicit model for temporal adaptation)
- Categorization from intent
  - Visual system simulators (VSS)
  - Scene reproduction operators (SRP)
  - Best subjective quality operators (BSQ)
- Qualitative evaluation
- Subjective pair-wise comparison experiment

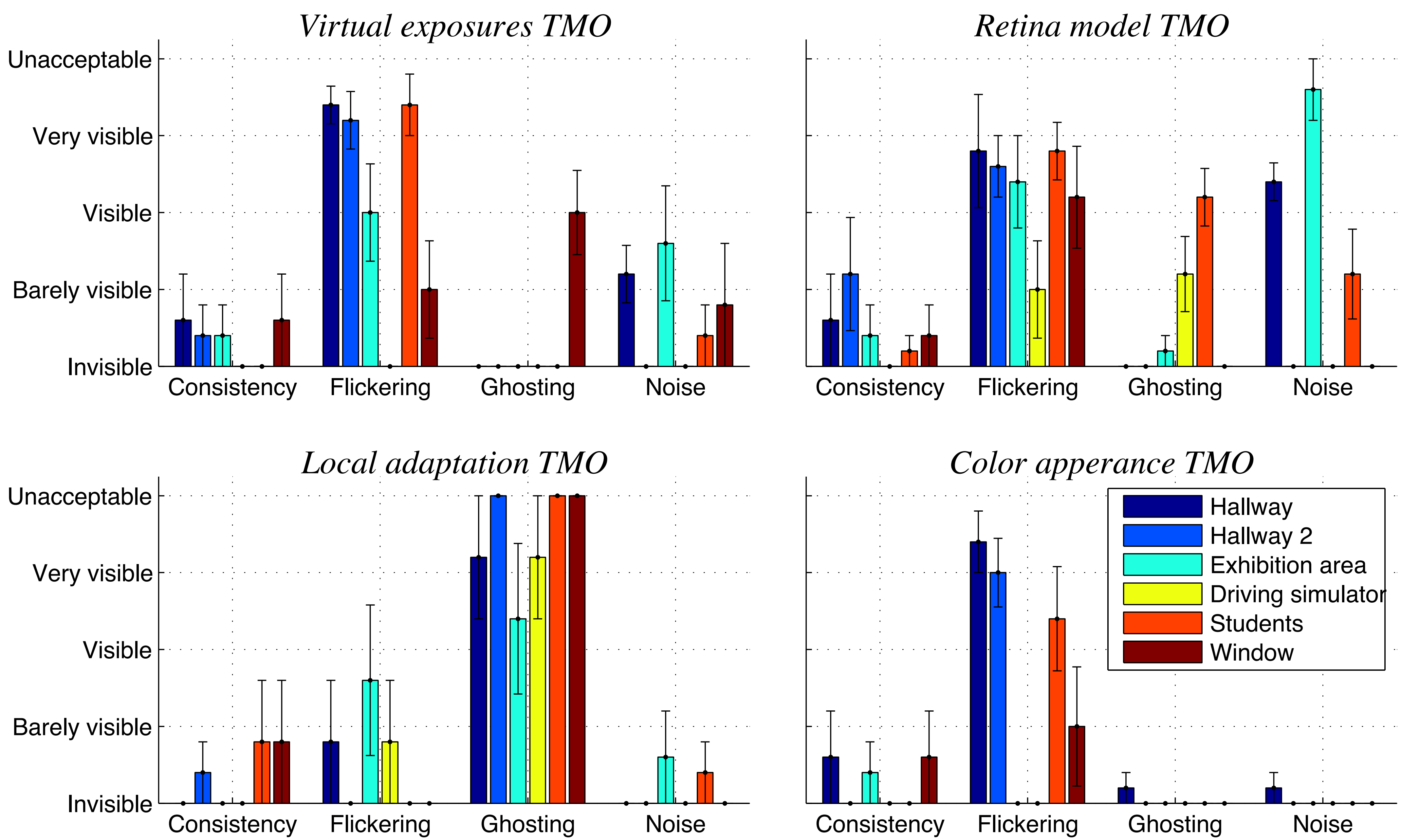


- **EILERTSEN, G., WANAT, R., MANTIUK, R. K., UNGER, J. (2013):** Evaluation of tone mapping operators for HDR-video. *Computer Graphics Forum 32, 7, 275-284*.

Qualitative evaluation

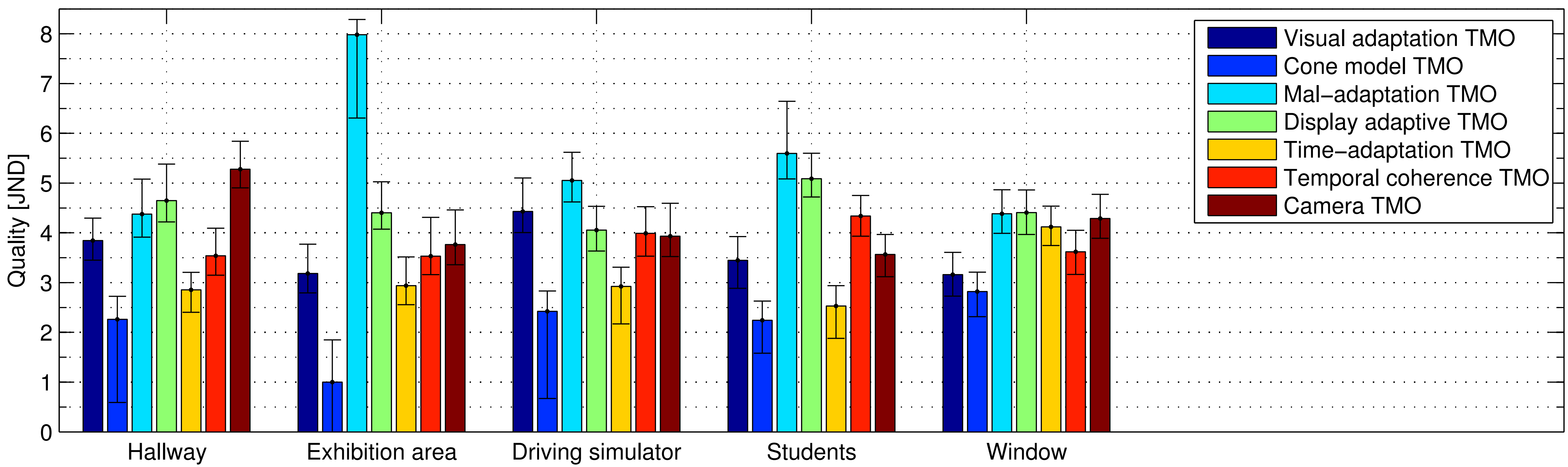


Qualitative evaluation



Subjective evaluation

- 7 tone-mapping operators
- 5 HDR video sequences
- Pairwise, non-reference, comparisons
- Generally global operators favored over local ones



HDR video tone-mapping, requirements

1. Temporal model free from artifacts such as flickering, ghosting and disturbing (too noticeable) temporal color changes.

2. Local processing to achieve sufficient dynamic range compression in all circumstances while maintaining a good level of detail and contrast.

3. Efficient algorithms, since large amount of data need processing, and turnaround times should be kept as short as possible.

4. Low need for parameter tuning.

5. Calibration of input data should be kept to a minimum, *e.g.* without the need of considering scaling of data.

6. Capability of generating high quality results for a wide range of video inputs with highly different characteristics.

7. Explicit treatment of noise and color.

Temporal coherency

Strategies for dealing with temporal adaptation and ensuring coherency over time

Temporal coherency

- Temporal filtering
  - Parameters (those that depend on image statistics)
  - Tone-curve
  - Per-pixel (low-pass, bilateral, optical flow)

Temporal coherency

HDR video sequence from:

- **FROEHLICH J., GRANDINETTI S., EBERHARDT B., WALTER S., SCHILLING A., BRENDEL H.:** Creating Cinematic Wide Gamut HDR-Video for the Evaluation of Tone Mapping Operators and HDR-Displays. *In Proc. SPIE 9023, Digital Photography X (2014), pp. 90230X–90230X–10.*

Temporal coherency

Virtual exposures TMO:

- **BENNETT E. P., MCMILLAN L.:** Video enhancement using per- pixel virtual exposures. *ACM Trans. Graphics 24, 3 (2005), 845–852*.

Temporal coherency

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Display adaptive TMO:

- **MANTIUK R., DALY S., KEROFSKY L.:** Display adaptive tone mapping. *ACM Trans. Graphics 27, 3 (2008), 68:1–68:10.*

Temporal coherency

Cone model TMO:

- **VAN HATEREN J. H.:** Encoding of high dynamic range video with a model of human cones. *ACM Trans. Graphics 25 (2006), 1380– 1399.*

Temporal coherency

Real-time noise-aware TMO:

- **EILERTSEN G., MANTIUK R. K., UNGER J.:** Real-time noise- aware tone mapping. *ACM Trans. Graph. 34, 6 (Oct. 2015), 198:1– 198:15.*

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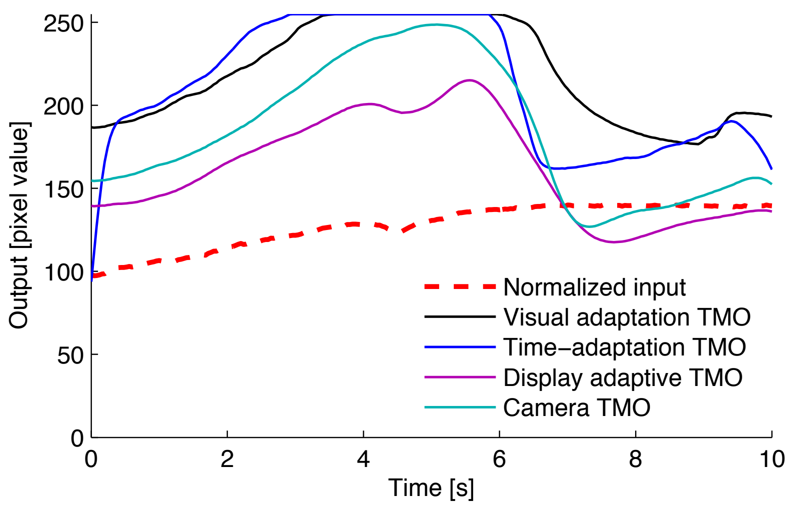
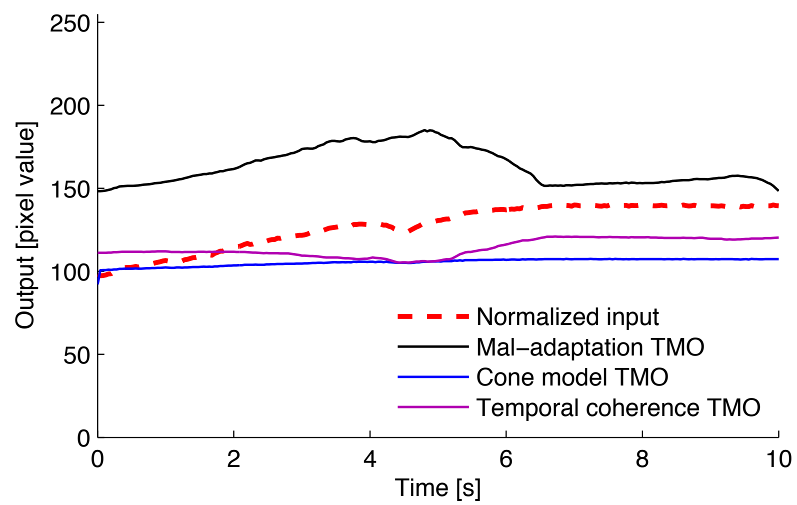
Temporal coherency

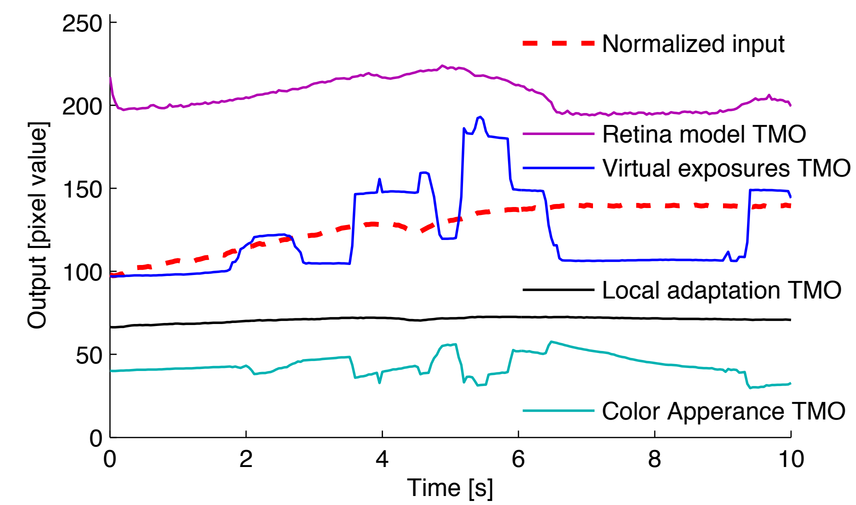
(a) Frames of input sequence, with two measurement points indicated



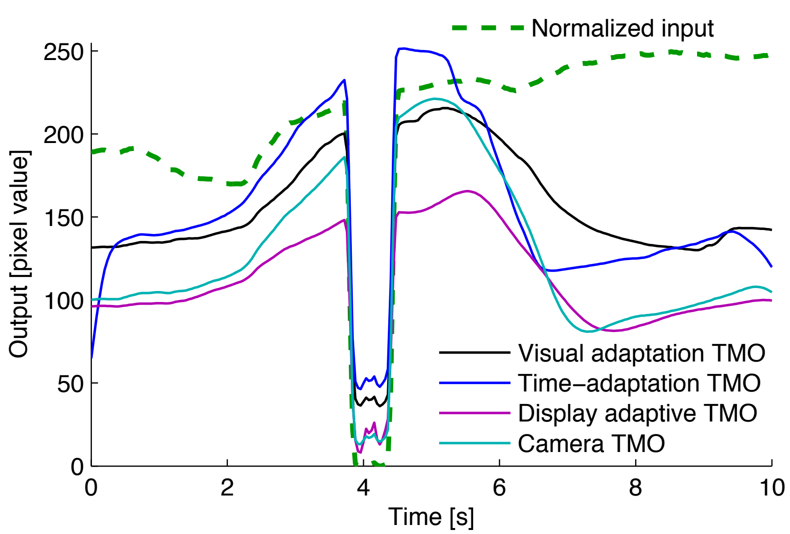
(b) Intensities at red point in (a)



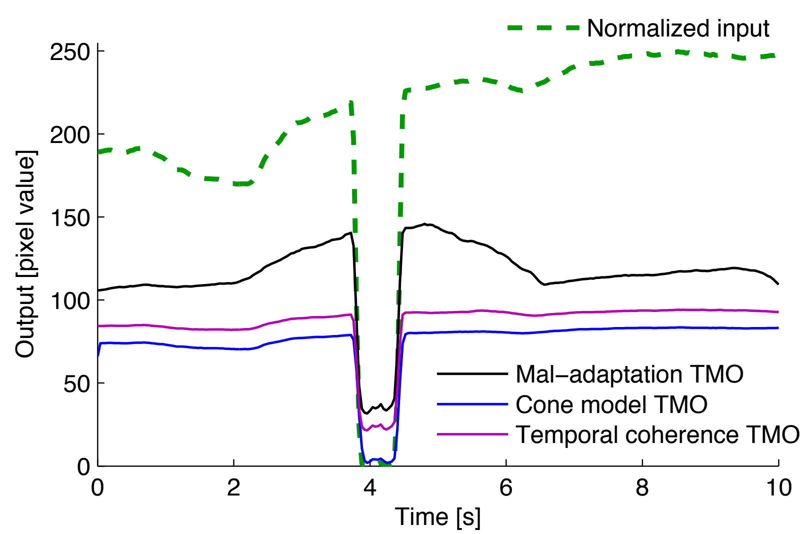
(c) Intensities at red point in (a)



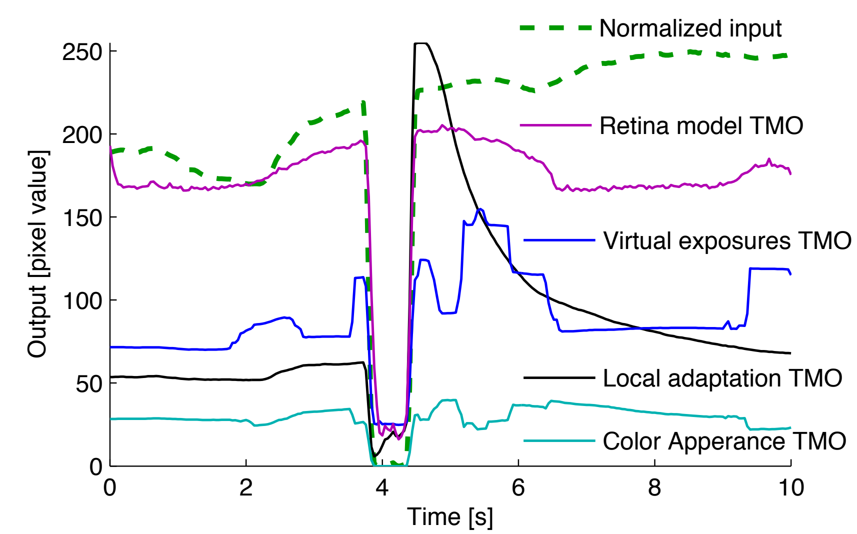
(d) Intensities at red point in (a)



(e) Intensities at green point in (a)



(f) Intensities at green point in (a)



(g) Intensities at green point in (a)

Temporal coherency

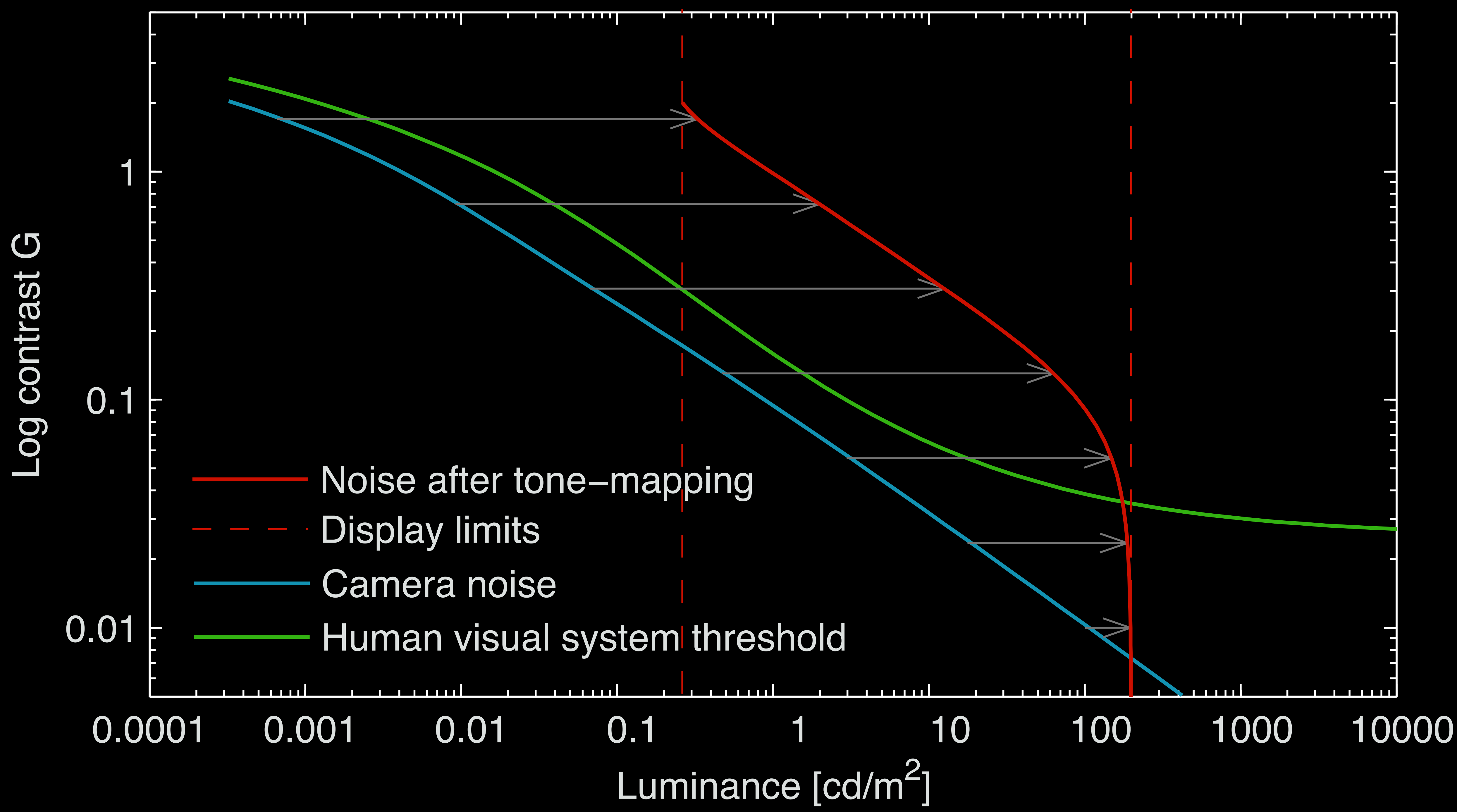
- Temporal filtering
  - Parameters
  - Tone-curve
  - Per-pixel (low-pass, bilateral, block matching, optical flow)

- Post-processing
  - Global methods
    - **GUTHIER B., KOPF S., EBLE M., EFFELSBERG W.:** Flicker reduction in tone mapped high dynamic range video. *In Proc. SPIE (2011), vol. 7866, pp. 78660C–78660C–15.*
    - **BOITARD R., BOUATOUCH K., COZOT R., THOREAU D., GRUSON A.:** Temporal coherency for video tone mapping. In Proc. SPIE 8499, Applications of Digital Image Processing XXXV (San Diego, 2012), pp. 84990D–84990D–10.
  - Local methods
    - **LANG M., WANG O., AYDIN T., SMOLIC A., GROSS M.:** Practical temporal consistency for image-based graphics applications. *ACM Trans. Graph. 31, 4 (July 2012), 34:1–34:8.*
    - **BONNEEL N., TOMPKIN J., SUNKAVALLI K., SUN D., PARIS S., PFISTER H.:** Blind video temporal consistency. *ACM Trans. Graph. 34, 6 (Oct. 2015), 196:1–196:9.*

Noise in tone-mapping

The problem of camera noise in the context of tone-mapping, and ways to alleviate it

Noise in tone-mapping



Noise in tone-mapping

- Increase of noise visibility
    - For non-linear mappings
    - For local TMOs

- Noise reduction
    - Heavy-weight
    - Bilateral, optical flow, higher order (V-BM4D, etc.)

- Noise-awareness
    - Light-weight
    - Control of noise visibility during tone-mapping

Recent algorithms

Dedicated HDR video algorithms with focus on the problems inherent to camera captured HDR video

Temporal coherency TMO

- Enforcing global temporal coherency
  - Anchoring of key to maximum key of sequence
  - Considers all frames of the sequence

- Attempt to prevent flickering AND brightness incoherencies

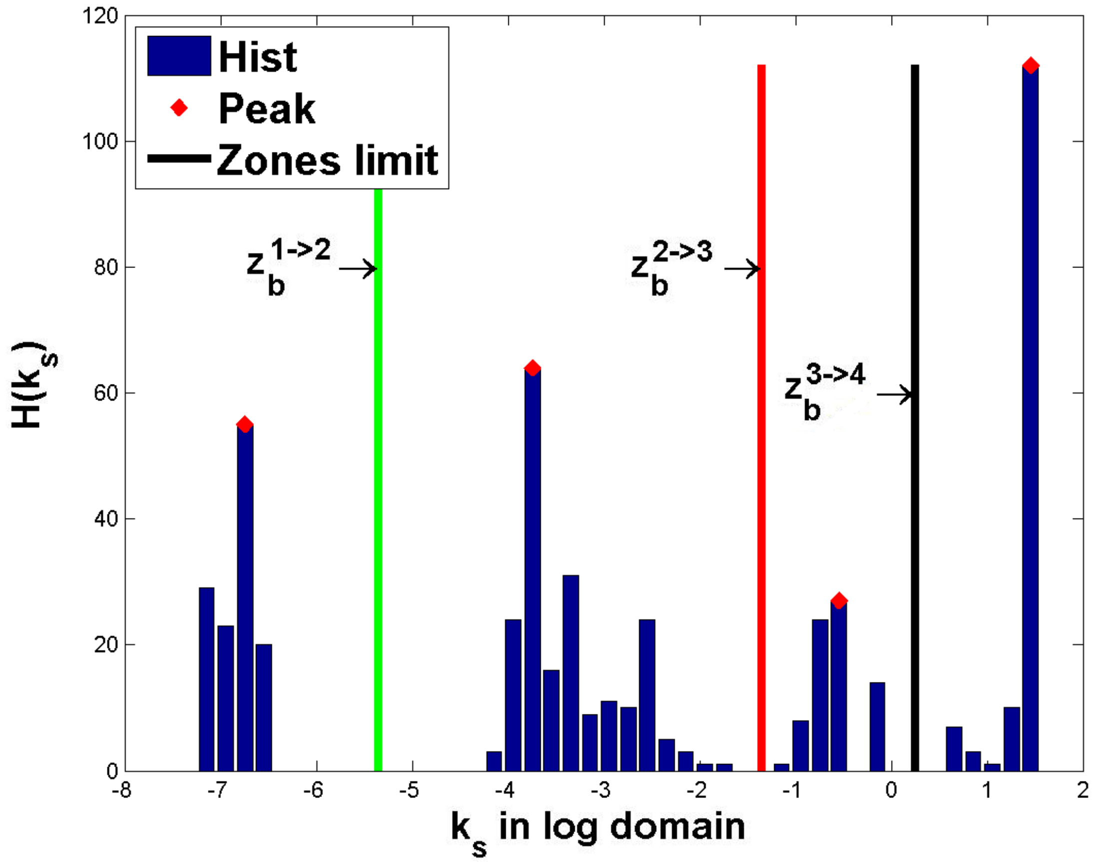
- Applies to any TMO

$$\frac{\kappa_F^{HDR}}{\kappa_{F,max}^{HDR}} = \frac{\kappa_F^{LDR}}{\kappa_{F,max}^{LDR}}, \qquad L'_d = L_d \cdot \frac{\kappa_P^{HDR} \cdot \kappa_{P,max}^{LDR}}{\kappa_{P,max}^{HDR} \cdot \kappa_P^{LDR}}$$

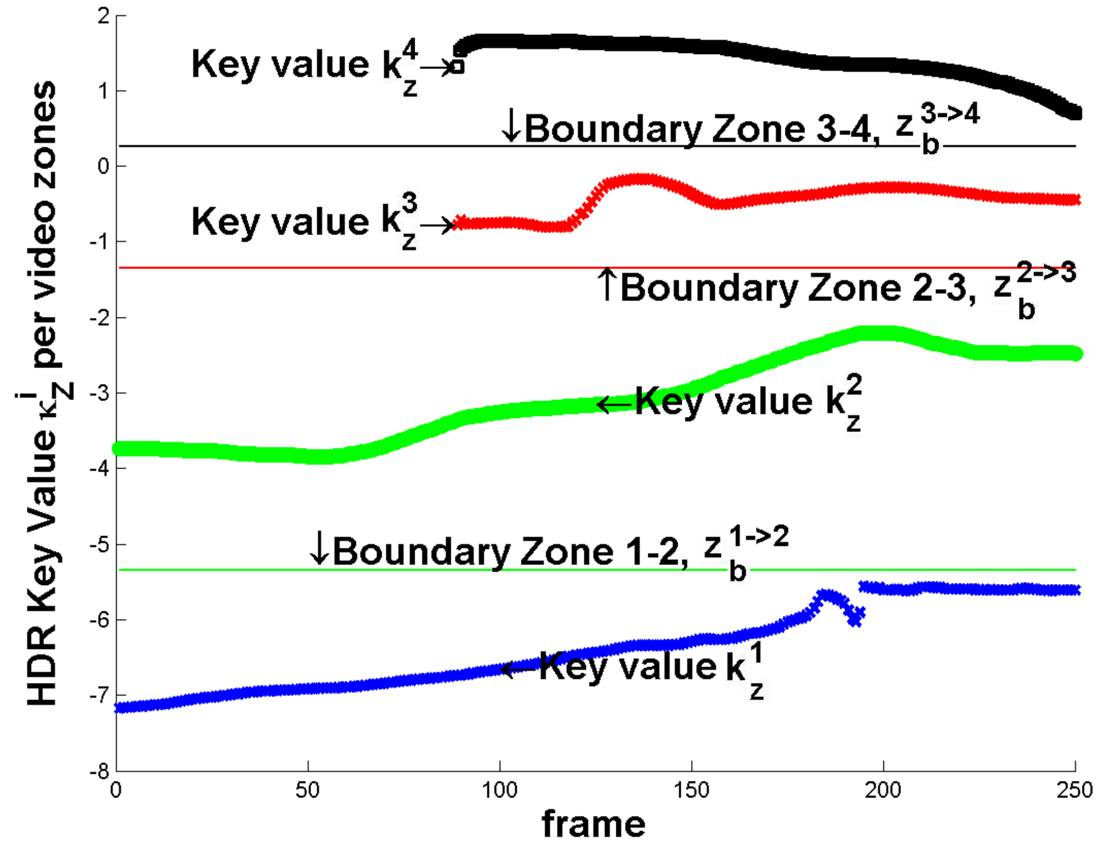
- **BOITARD R., BOUATOUCH K., COZOT R., THOREAU D., GRUSON A.:** Temporal coherency for video tone mapping. In Proc. SPIE 8499, Applications of Digital Image Processing XXXV (San Diego, 2012), pp. 84990D–84990D–10.

Zonal temporal coherency TMO

- Global temporal coherency TMO has problems with contrasts
- One key value per zone
- Zones from histogram segmentation



(a) Segmented key value histogram



(b) Zone's boundary and key value

- **BOITARD R., COZOT R., THOREAU D., BOUATOUCH K.:** Zonal brightness coherency for video tone mapping. *Signal Processing: Image Communication 29, 2 (2014), 229–246.*

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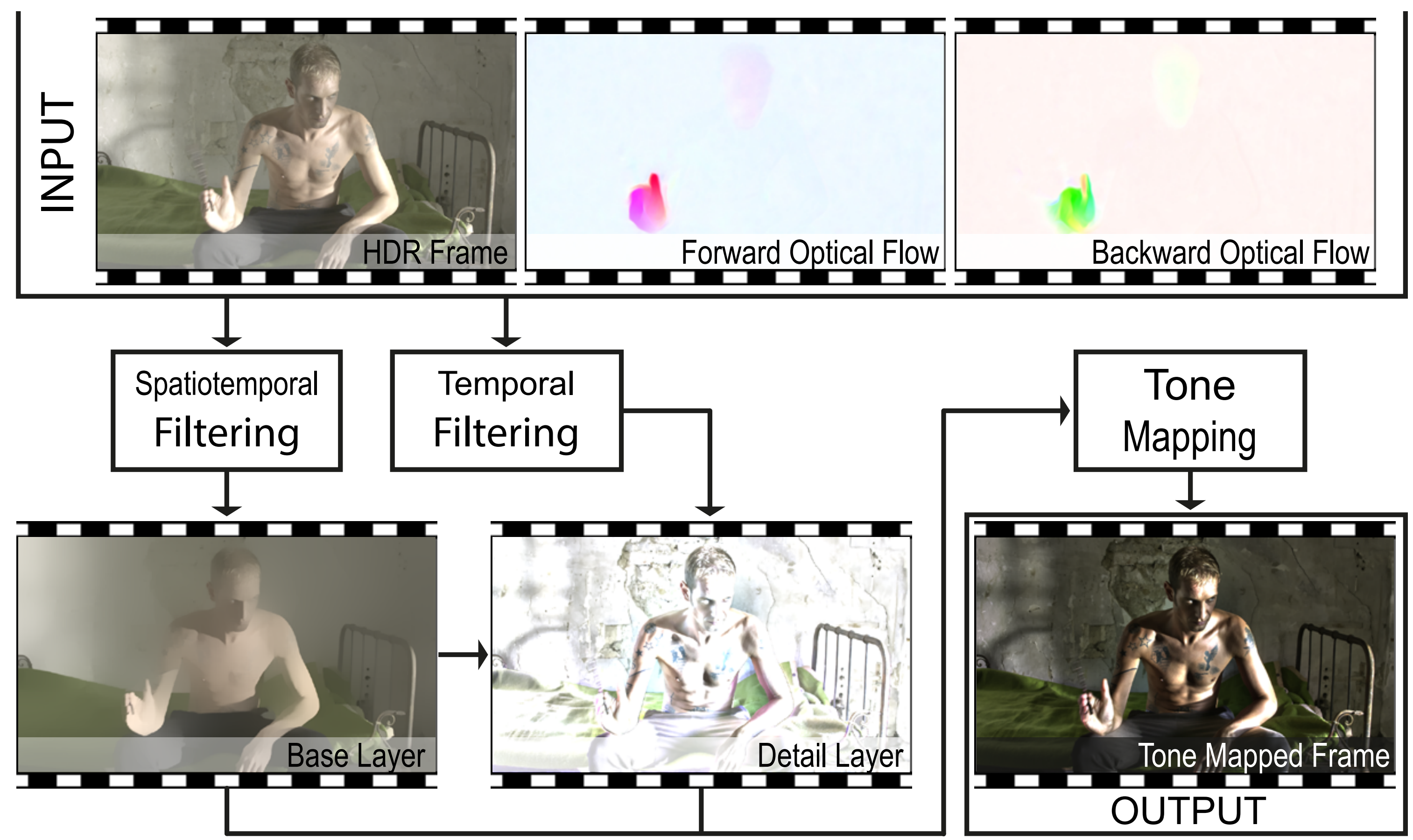
Zonal temporal coherency TMO

Motion-path filtering TMO

- Base/detail separation
  - Permeability filter

- Spatio-temporal filtering through motion paths (optical flow)
  - Temporal coherency
  - Noise reduction

- Standard tone-curve



- **AYDIN T. O., STEFANOSKI N., CROCI S., GROSS M., SMOLIC A.:** Temporally coherent local tone mapping of HDR video. *ACM Trans. Graphics 33, 6 (2014), 1–13.*

Motion-path filtering TMO

Real-time noise-aware TMO

- Aimed at addressing the most important challenges, as recognized from the previous evaluation
- Tone-curve
  - Minimum contrast distortion
  - Local tone-curves
  - Temporal filter (low-pass IIR, edge-stop)
- Detail preservation/enhancement
  - Fast detail extraction diffusion
  - Temporally consistent
- Noise-awareness
- Display adaptation
- Real-time implementation

- **EILERTSEN G., MANTIUK R. K., UNGER J.:** Real-time noise- aware tone mapping. *ACM Trans. Graph. 34, 6 (Oct. 2015), 198:1– 198:15.*

Real-time noise-aware TMO

Real-time noise-aware TMO

Summary

- New challenges as compared to tone-mapping of static images
  - Temporal coherency
  - Computational complexity
  - Etc.

- Dedicated video algorithms
  - Zonal temporal coherency TMO
  - Motion-path filtering TMO
  - Real-time noise-aware TMO

- Future directions
  - Colors, skin tones
  - Parameter adjustments