Evaluation of Color Pixel Encoding for High Dynamic Range Imagery

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Purpose of the study

Measure the minimum bit-depth at which the contouring artefacts remain invisible – depending on:

- Perceptual Transfer Function (PTF)
- Color Difference Encoding

Overview

Perceptual Transfer Function (PTF)

Color Difference Encoding

Conclusion

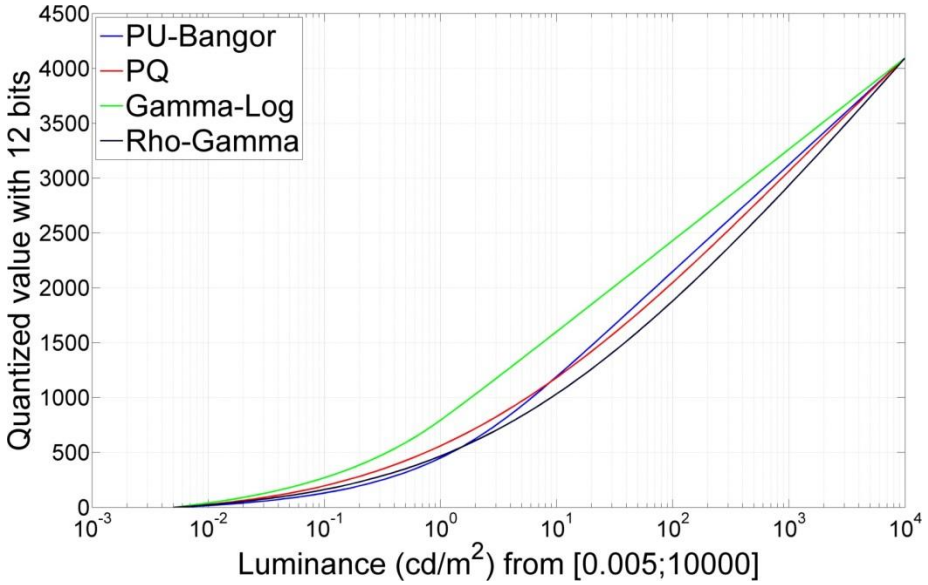
Perceptual Transfer Function

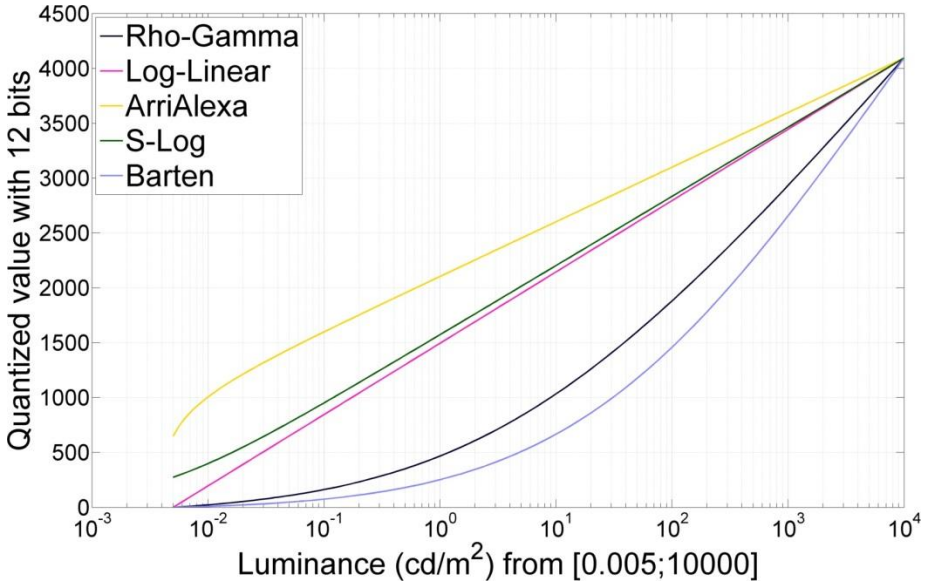
Study of different PTF:

- Bangor-PU: [Mantiuk et al., 2004]
- Perceptual Quantizer: [Miller et al., 2013][Kunkel et al., 2014]
- Gamma-Log: [Touzé et al., 2014]
- Rho-Gamma:
- S-Log: Sony's transfer function for camera normalized
- Barten curve: [Barten et al, 1992]

Perceptual Transfer Function

Response





- Most of the code values used for luminance > 1cd/m²
- Linear in log domain for high luminance (Weber-Fechner law)

Perceptual Transfer Function

Perceptual experiment - evaluate the quantization threshold of luminance encoding:

- 1 - Log(Y)
- 2 - PQ(Y)
- 3 – PU-Bangor(Y)
- 4 – Gamma-Log(Y) with fixed pre-defined settings

Tests performed on a high-bit depth display (NEC pa241w)

Process

- Four patches presented with smooth gradients, in which only one was quantized
- Observers asked to select one that appears different from the others (4AFC)

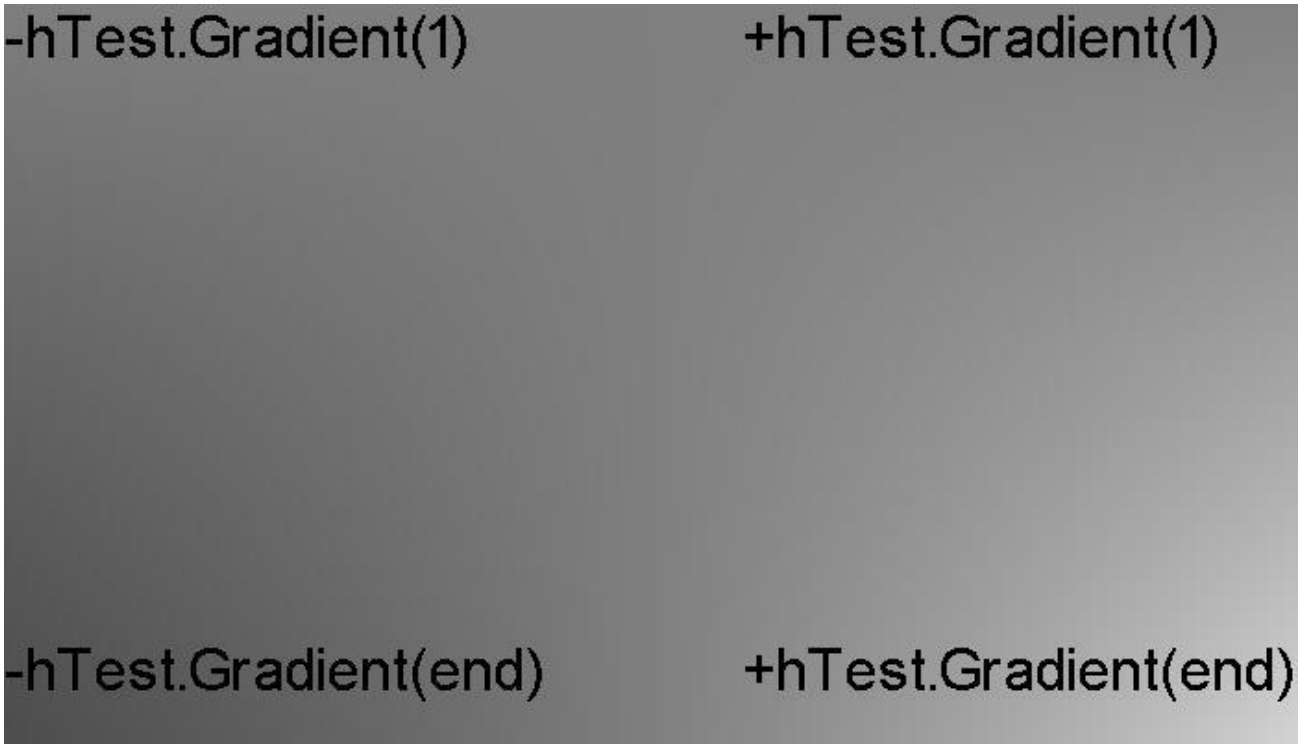
QUEST procedure to determine the detection threshold

- 20 iterations [Watson et al., 1983]
- 4 stimuli forced choice

Perceptual Transfer Function

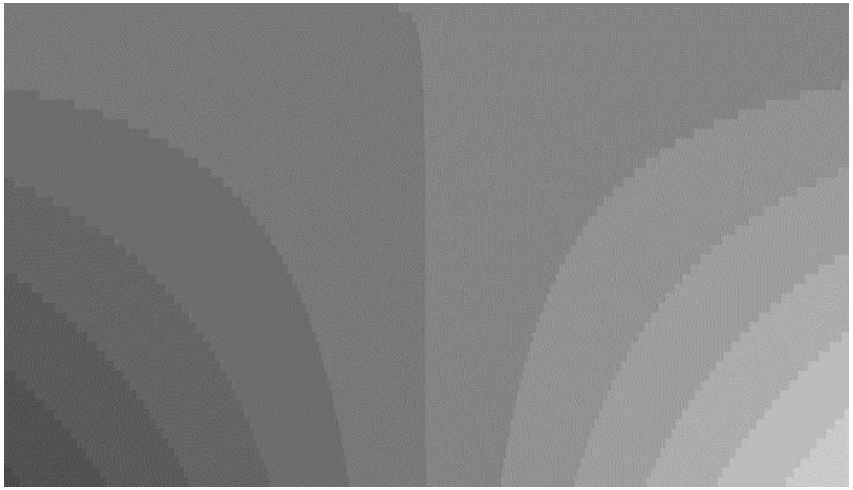
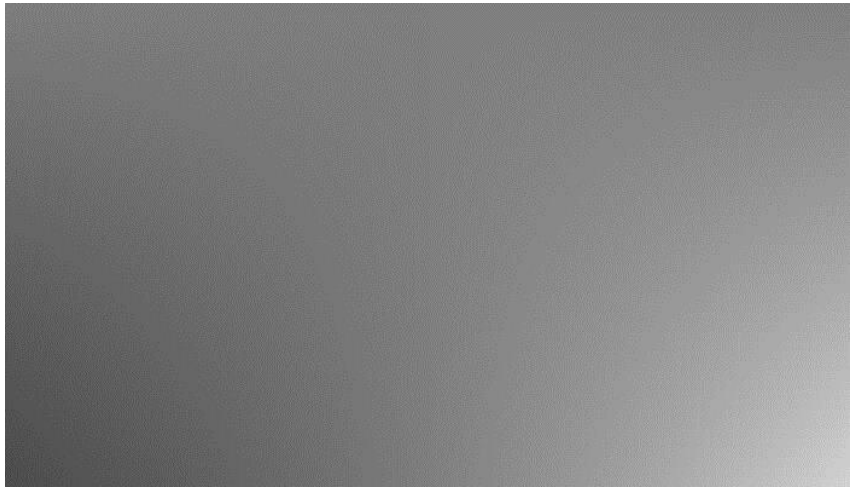
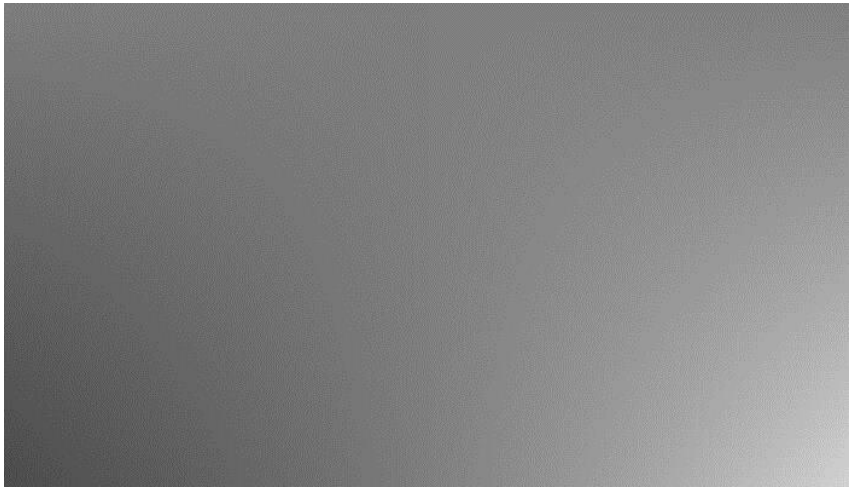
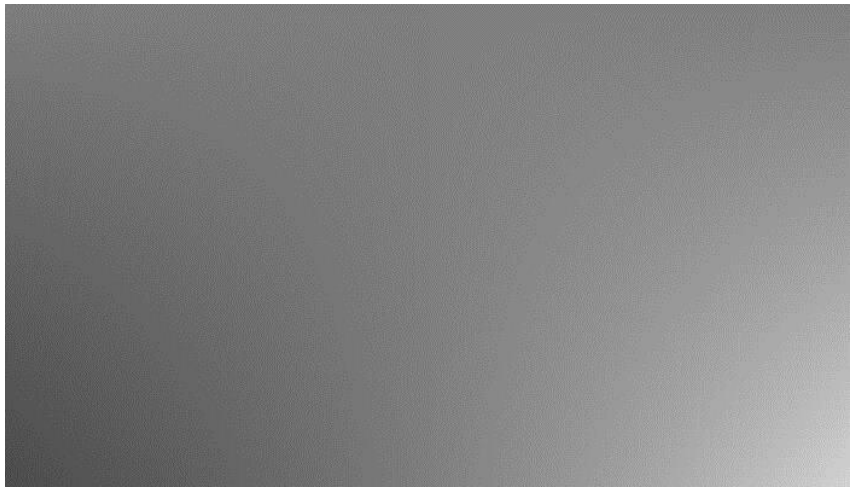
Test patch (700x400 in 1920x1080 picture)

- Average luminance varies from 0.05 to 150 cd/m²
  - Measurements above 150 cd/m² can be extrapolated as the CSF does not vary much above that level



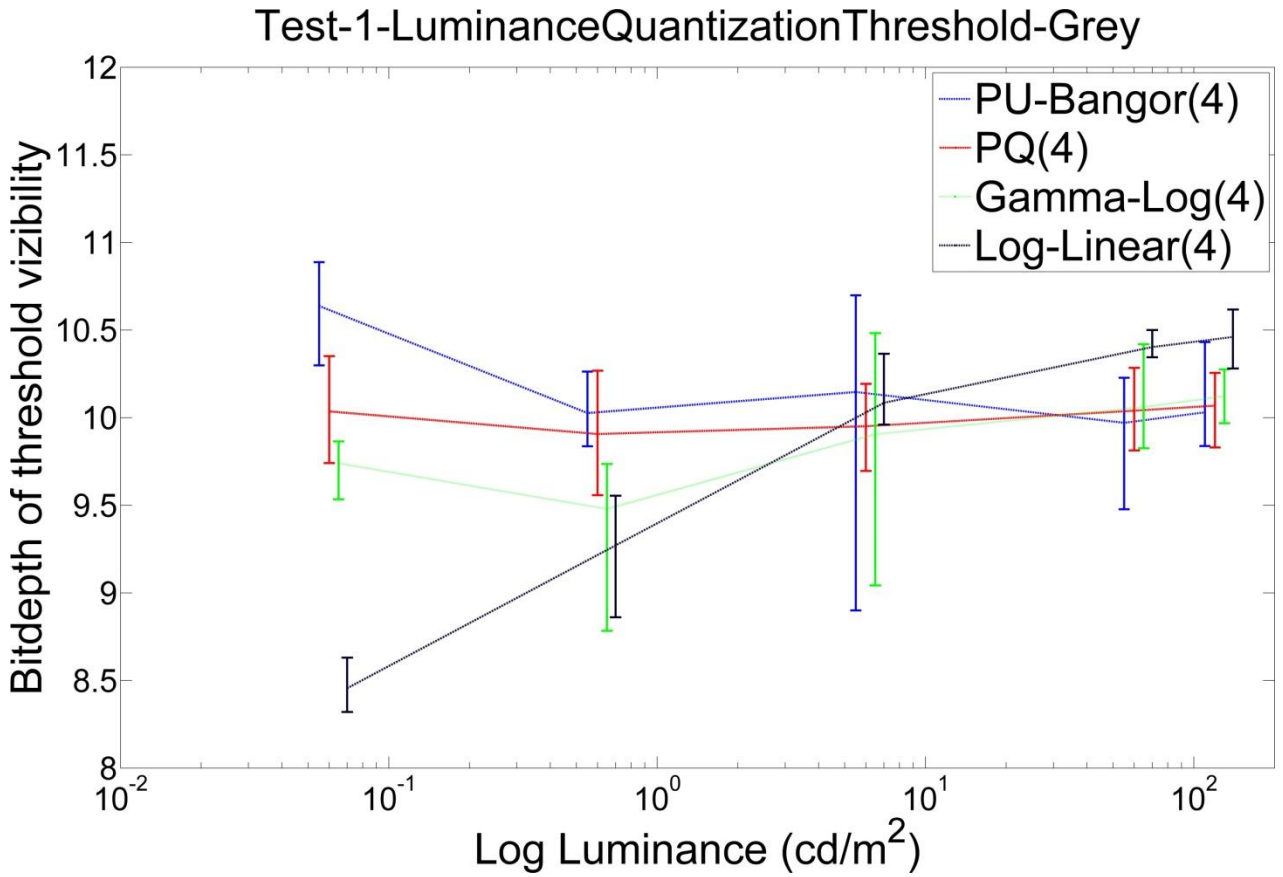
Perceptual Transfer Function

Experiment set-up. Which of the four is different?

Perceptual Transfer Function

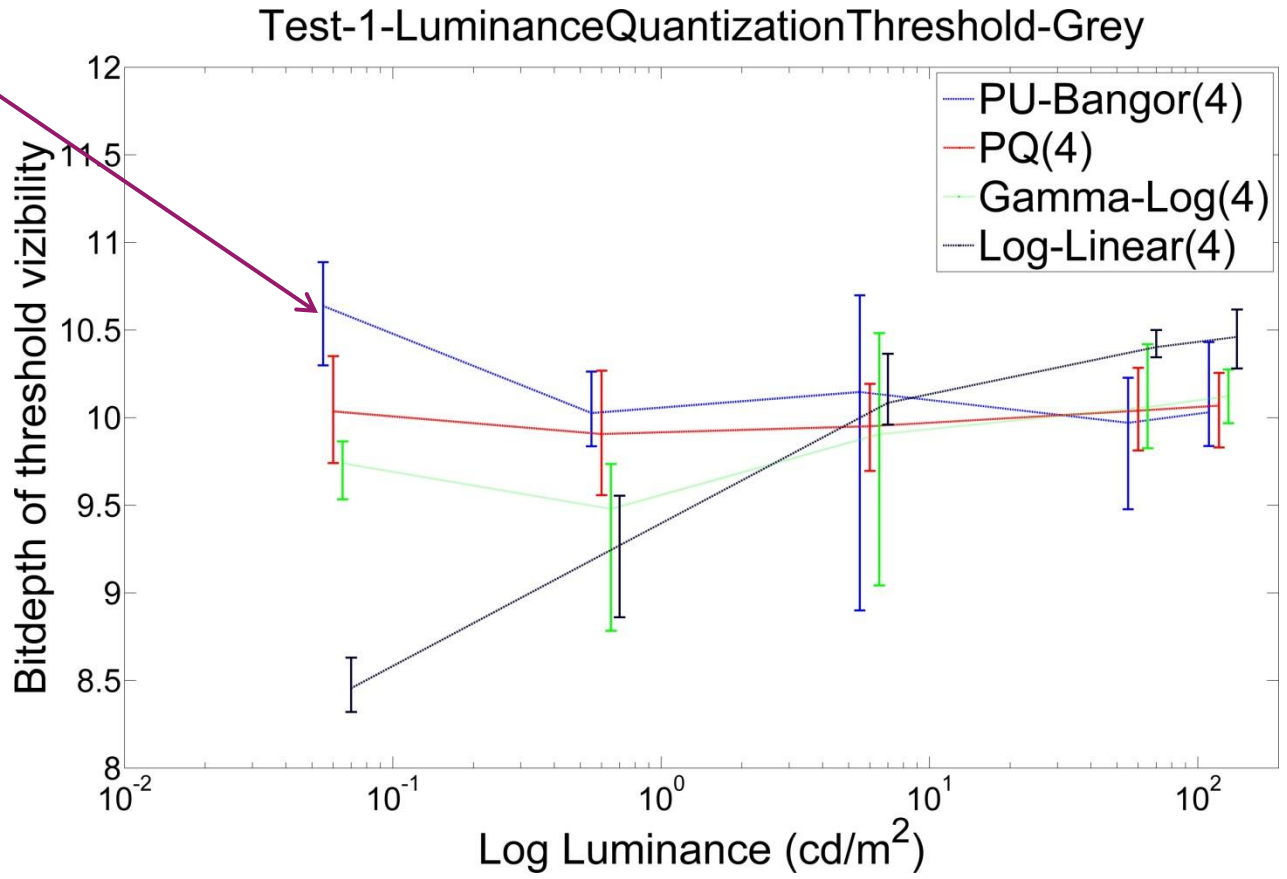
Experiment Results:



Perceptual Transfer Function

Experiment Results:

PU-Bangor requires more bits for low luminance

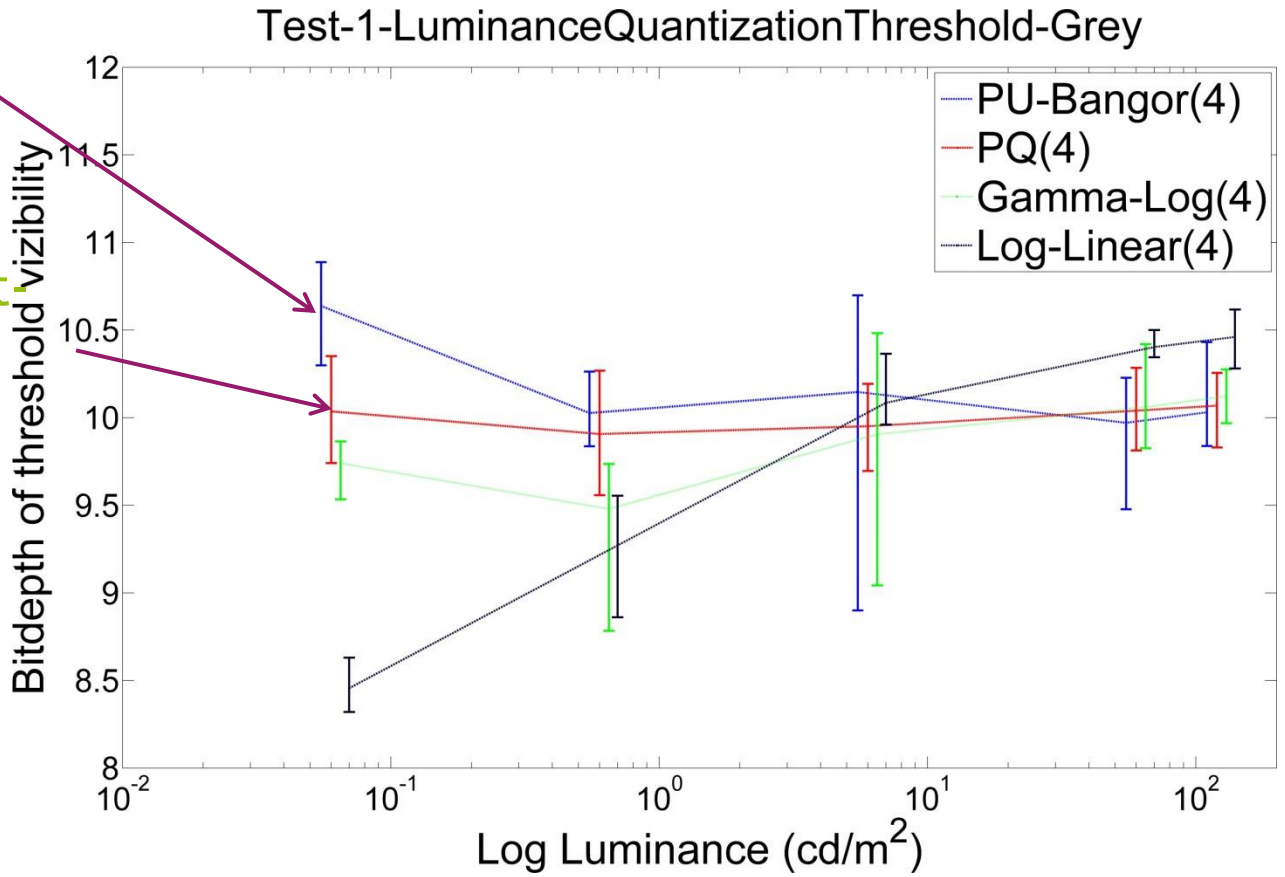


Perceptual Transfer Function

Experiment Results:

PU-Bangor requires more bits for low luminance

PQ requires the same bit-depth for every tested luminance



Perceptual Transfer Function

Experiment Results:

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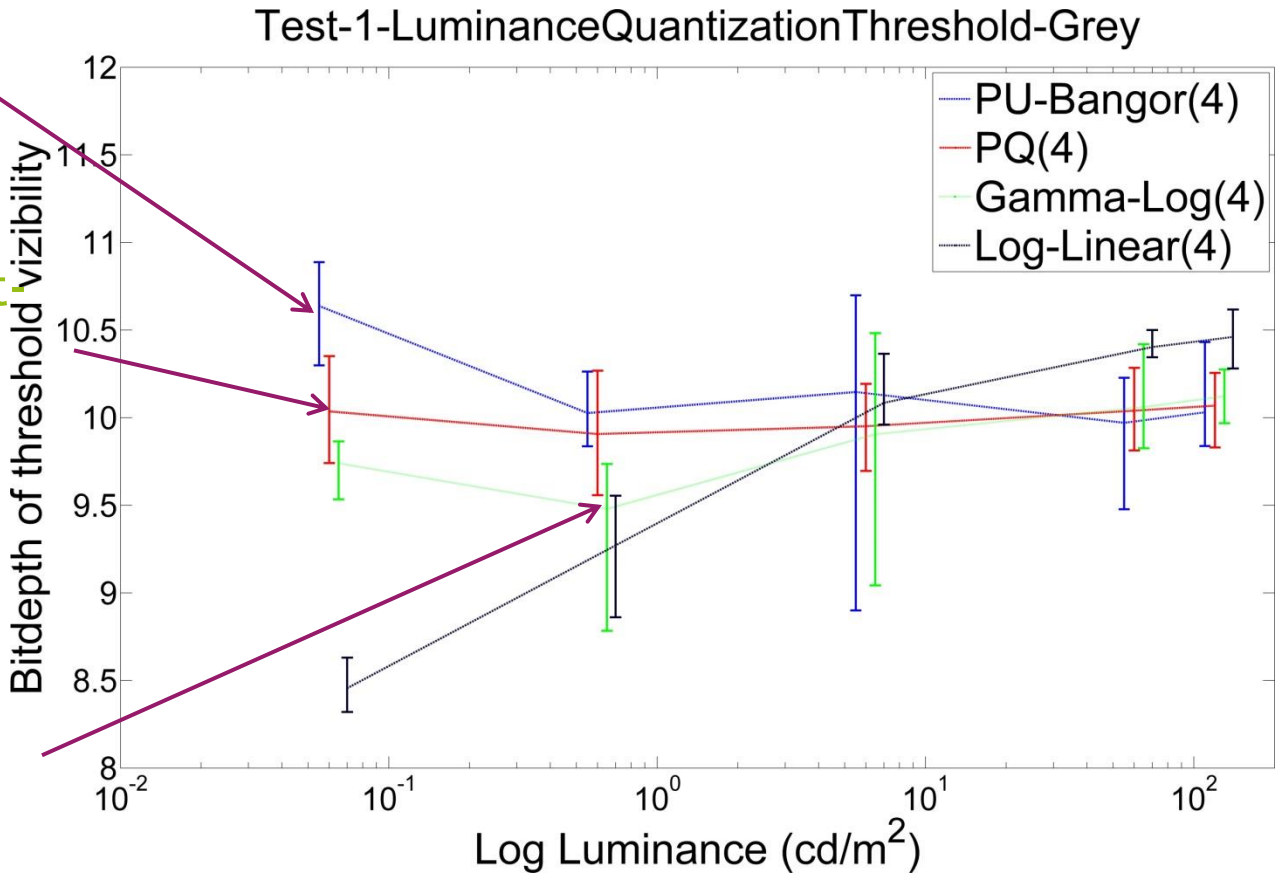
PQ requires the same bit-depth for every tested luminance

Gamma-log is below PQ but varies a bit more



Perceptual Transfer Function

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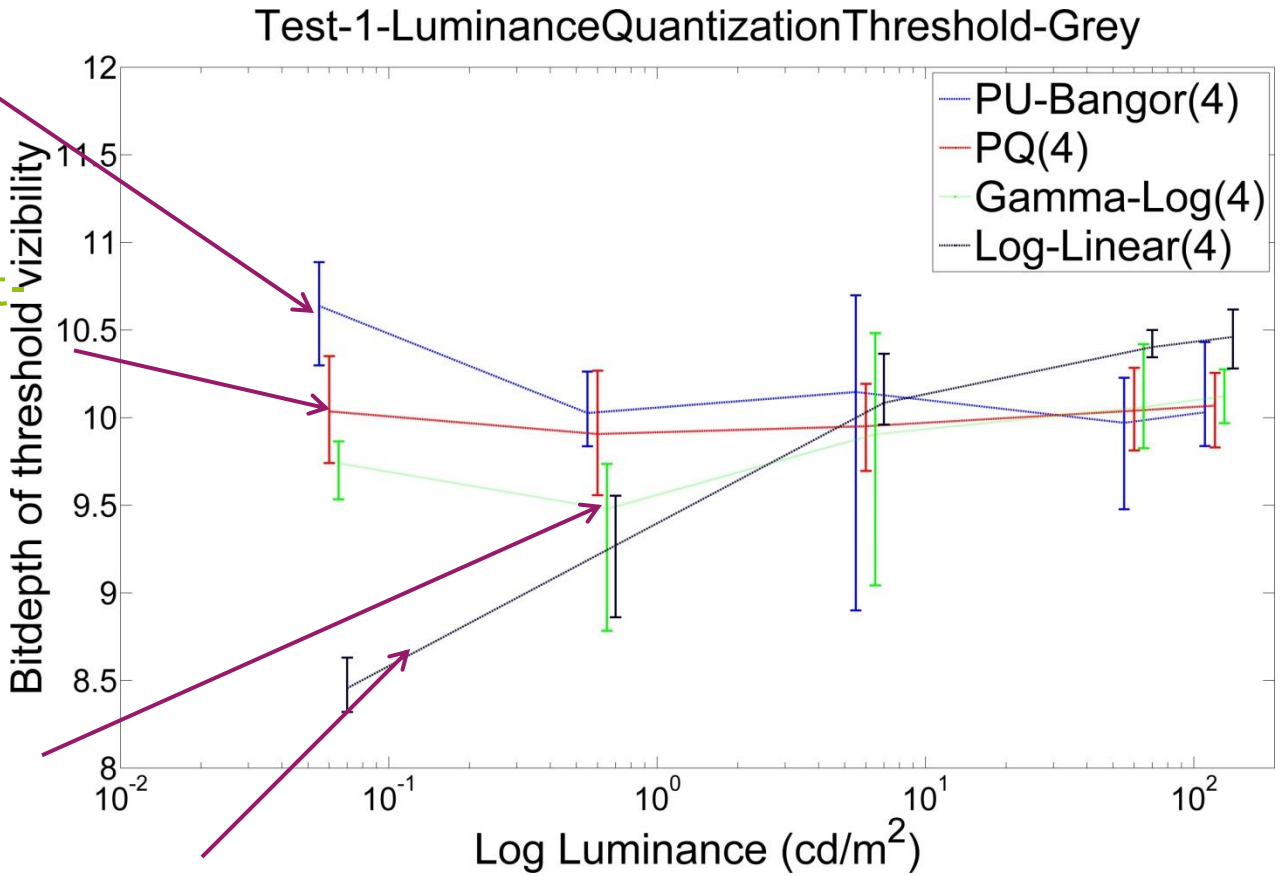


Log is more conservative for low luminances

Perceptual Transfer Function

Conclusions

- All encodings require less than 11 bits to quantize w/o introducing visible artifacts.
- Note: 11 bits when only the luminance alone is quantized
- For the PQ encoding, the minimum bit-depth is the same for every luminance tested
- Our experiment is more demanding than [Miller et al., 2013] which reported 9 to 10 bits for natural images

What happens when chrominance channels are also quantized in color difference encoding?

Overview

Perceptual Transfer Function (PTF)

Color Difference Encoding

Conclusion

Evaluation of channel decorrelation with color difference encoding:

- YCbCr associated with BT.709
- YDzDx
- YDuDv (modified LogLu'v' representation)

Representation	Input	$\mathbf{Y}$	$\mathbf{C_a}$	$\mathbf{C_b}$
YC_bC_r	RGB	$\mathbf{Y} = 0.2627\mathbf{R} + 0.6780\mathbf{G} + 0.0593\mathbf{B}$	$\mathbf{C_b} = \frac{\mathbf{B}-\mathbf{Y}}{1.8814}$	$\mathbf{C_r} = \frac{\mathbf{R}-\mathbf{Y}}{1.4746}$
YD_zD_x	CIE XYZ	$\mathbf{Y} = \mathbf{Y}$	$\mathbf{D_z} = \frac{\frac{2763}{2800}\mathbf{Z}-\mathbf{Y}}{2}$	$\mathbf{D_x} = \frac{\mathbf{X}-\frac{2741}{2763}\mathbf{Y}}{2}$
YD_uD_v	CIE L'u'v'	$\mathbf{Y} = \mathbf{L}$	$\mathbf{D_u} = \frac{\mathbf{u'}}{0.62} - 0.5$	$\mathbf{D_v} = \frac{\mathbf{v'}}{0.62} - 0.5$

- Test on MPEG HDR sequences (1st frame of Technicolor sequences)
- Pearson Correlation factor, Average Results with PQ-TF

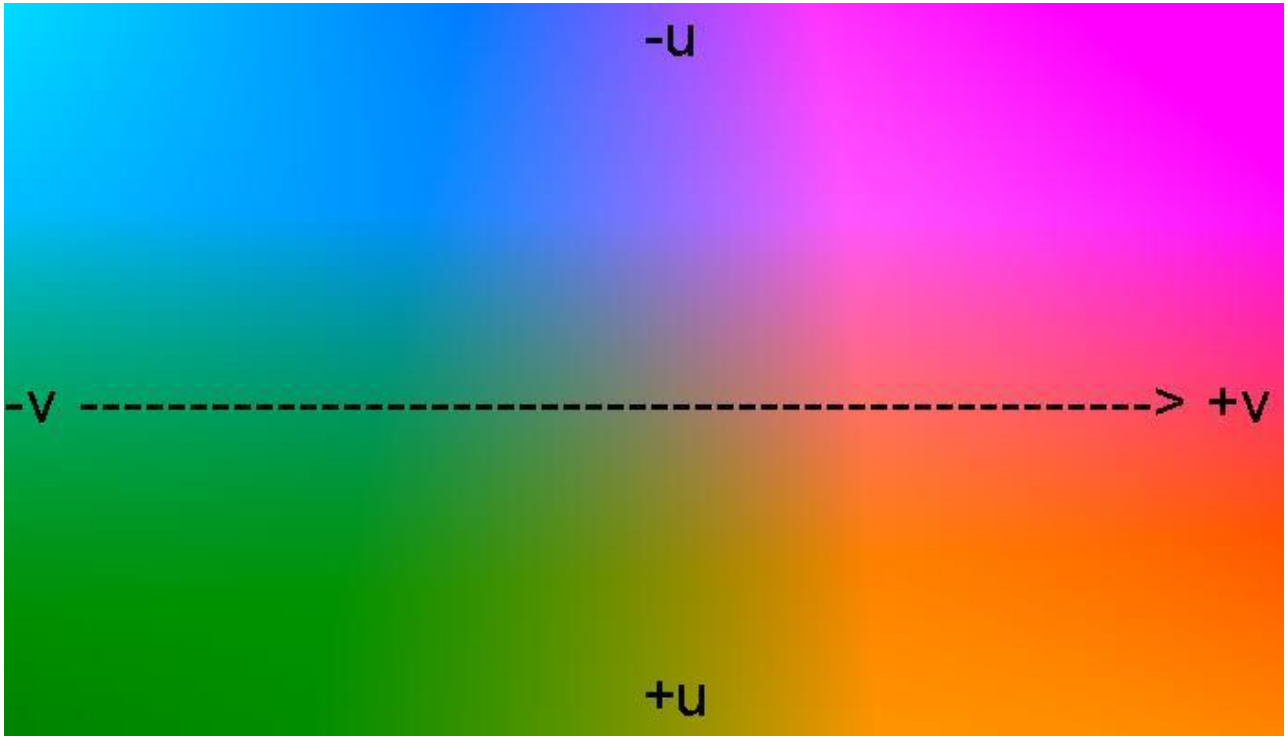
Chroma	YDzDx	YCbCr	YDuDv
Dz, Cb,Du	0.5106	0.4564	0.2231
Dx,Cr,Dv	0.5452	0.4119	0.2156

Color Difference Encoding

When quantizing value in these domains:

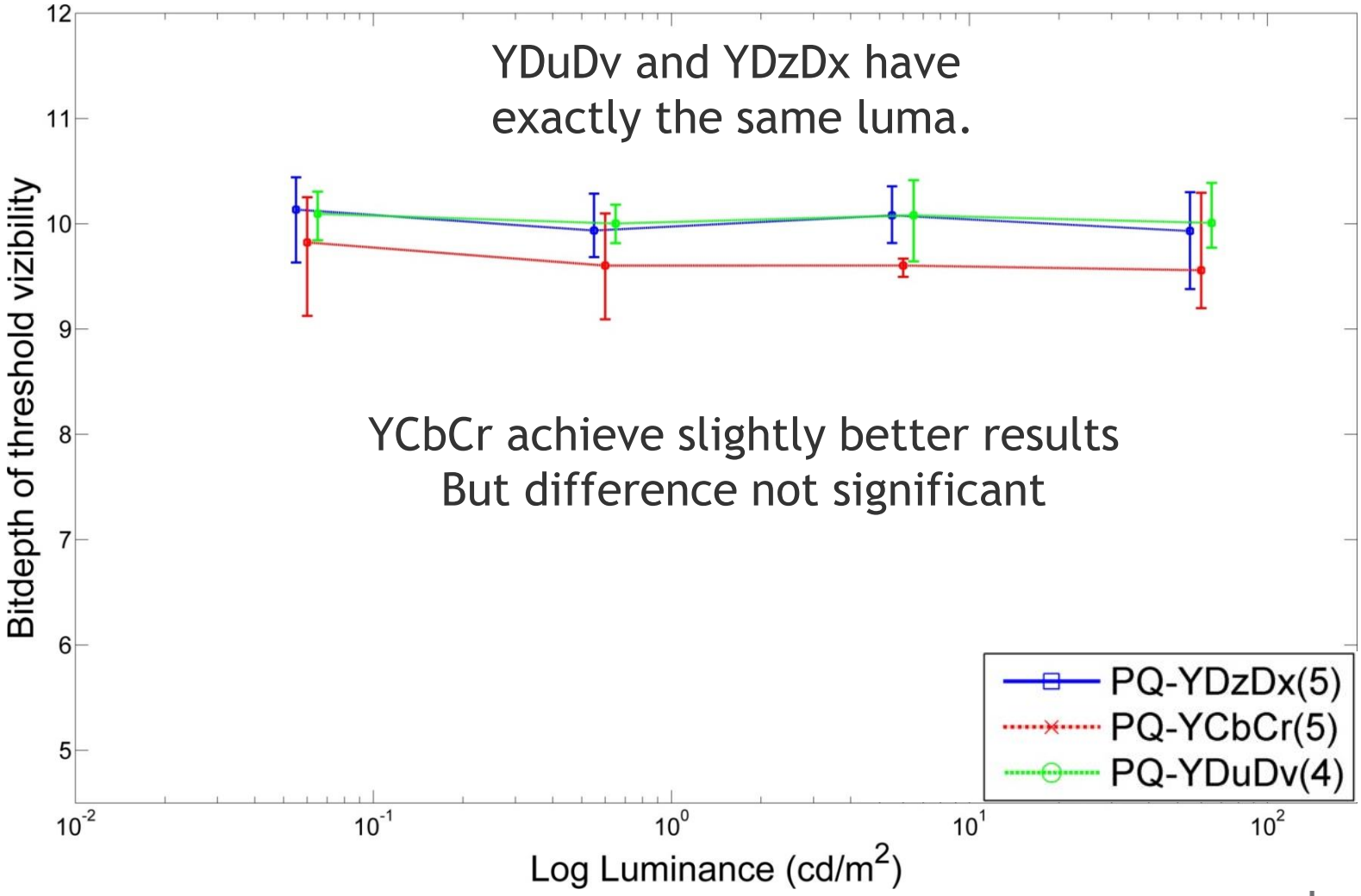
- What artifacts do we introduce?
- Which one is using the available dynamic range to the best?

Experiment: minimum bit-depth required in luma and chroma to avoid quantization artifacts in color difference encoding.



Color Difference Encoding

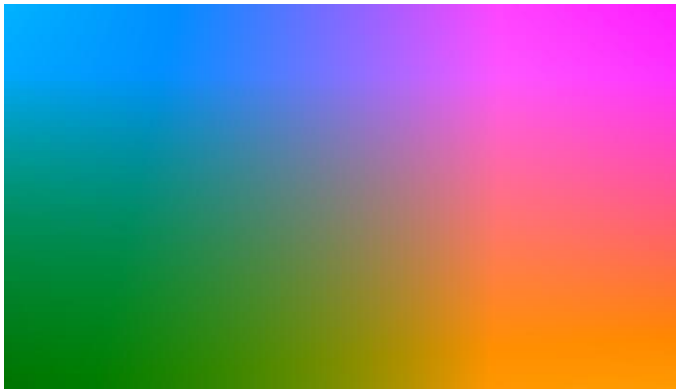
Experiment Results: Only luminance Quantized – PTF = PQ:



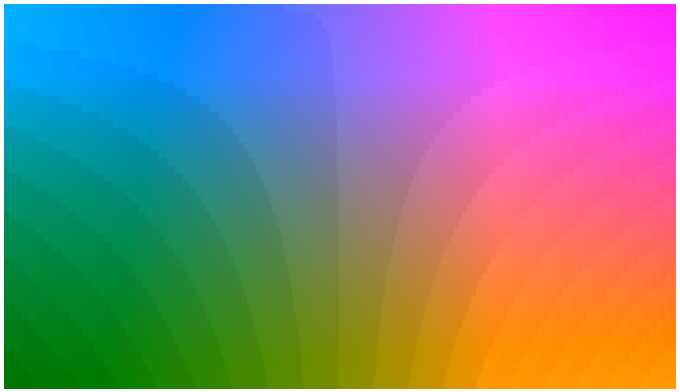
Color Difference Encoding

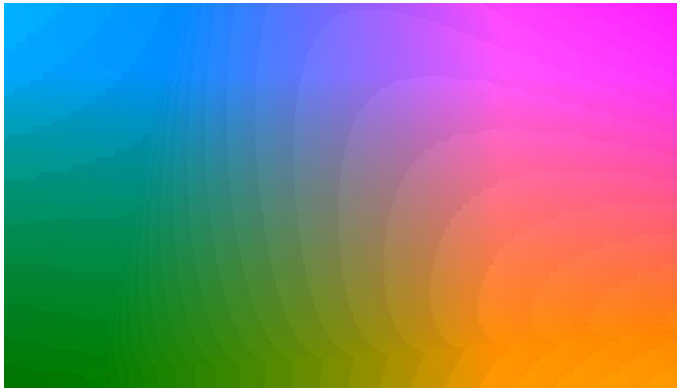
Luma quantization: Results at 9 bits for 0.5 cd/m², shown at mid-range luma level

Original

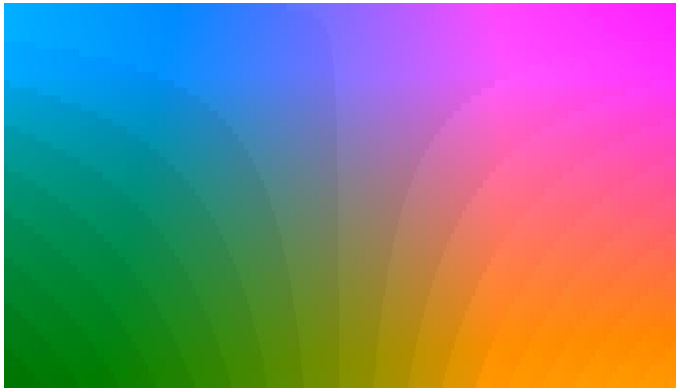


YDzDx





YCbCr



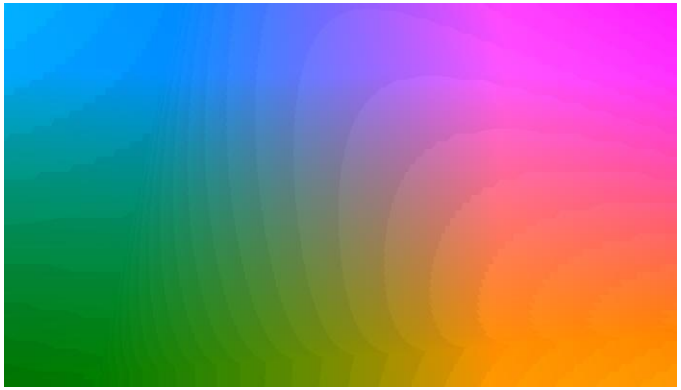
Luv

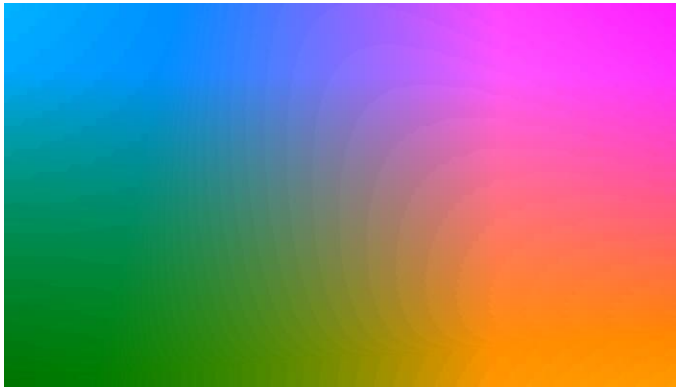
Color Difference Encoding

Luma quantization: YCbCr encoding for 9 bits at difference luminance level, shown at mid-range luma level

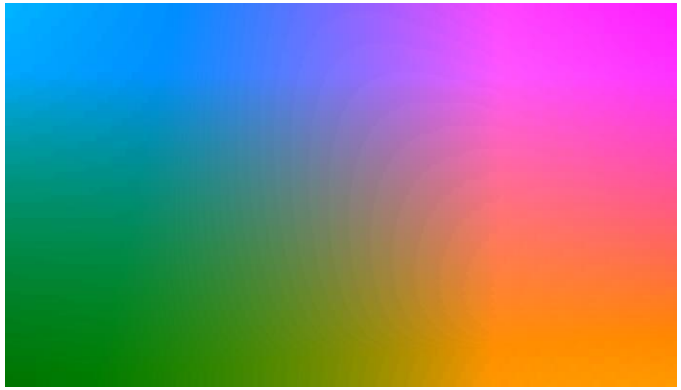
0.05 cd/m²

0.5 cd/m²





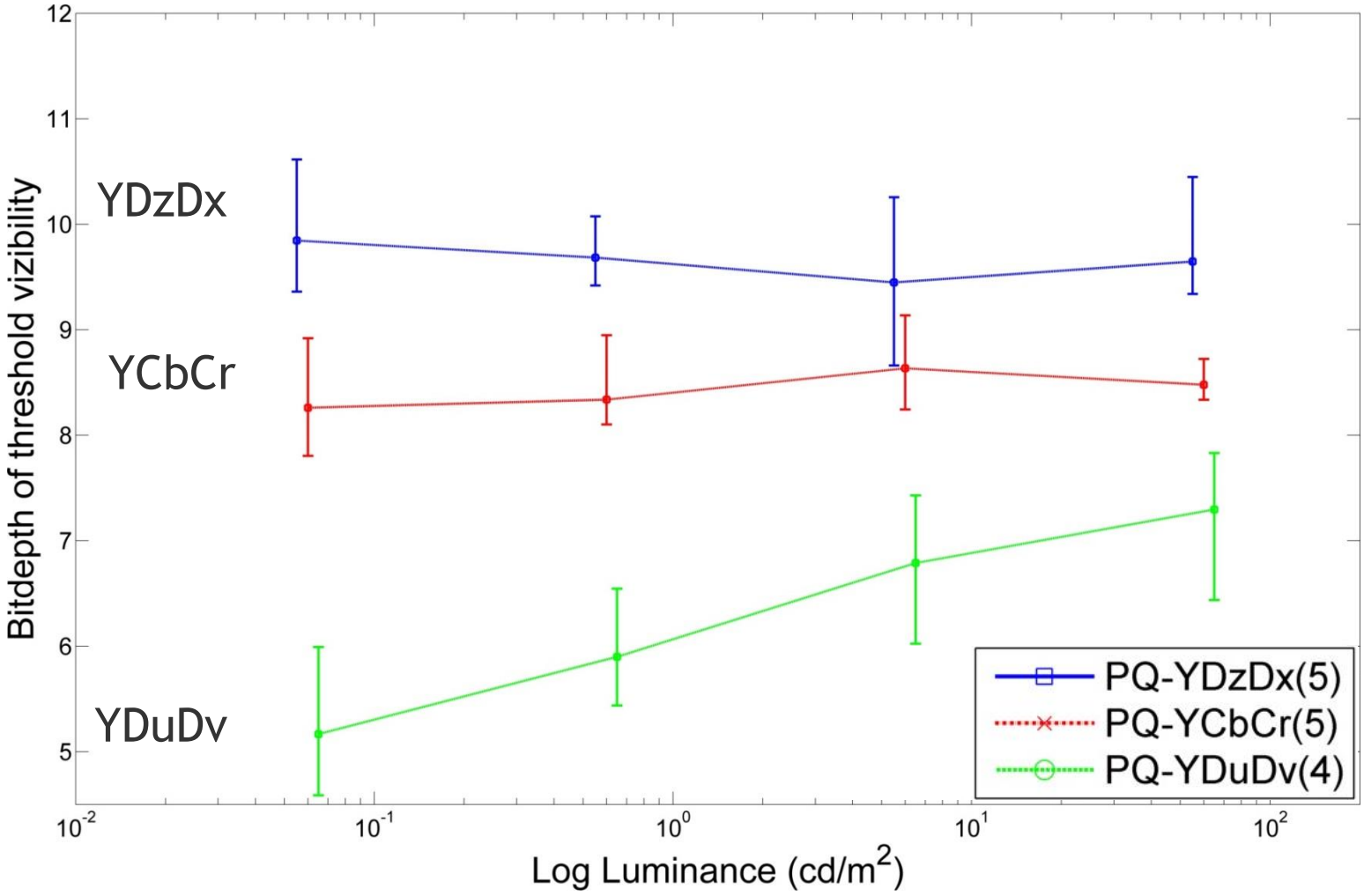
5 cd/m²



50 cd/m²

Color Difference Encoding

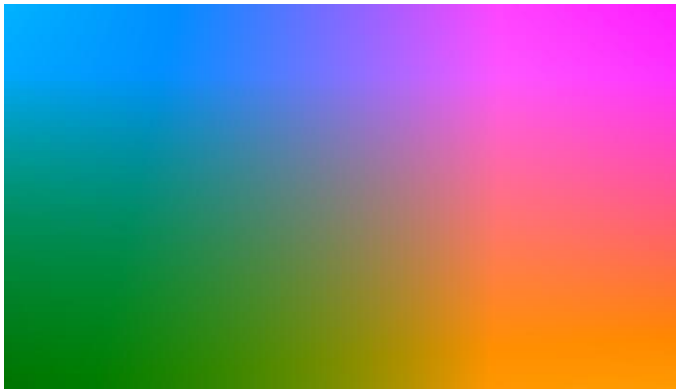
Experiment Results: Only Chroma Quantized – PTF = PQ:



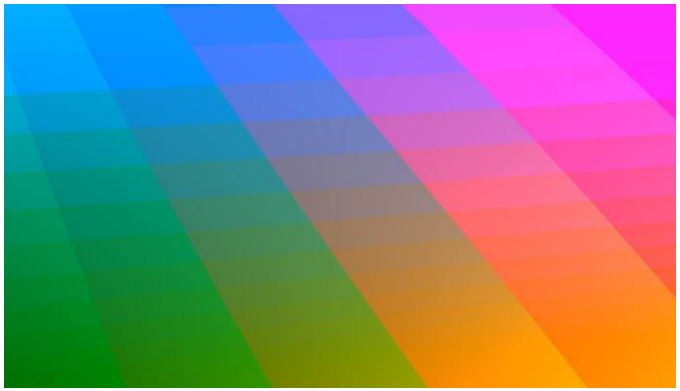
Color Difference Encoding

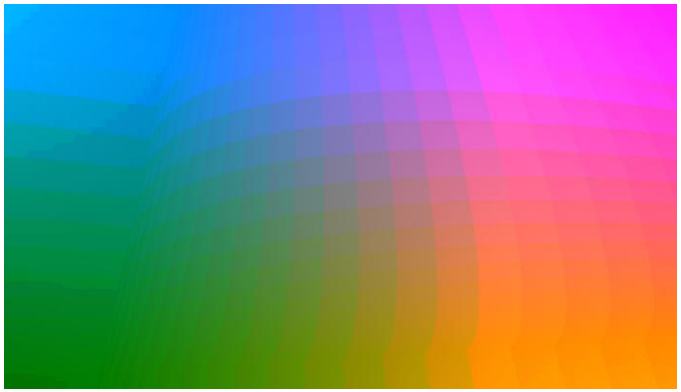
Chroma quantization: results at 8 bits for 0.5 cd/m^2, shown at mid-range luma level

Original

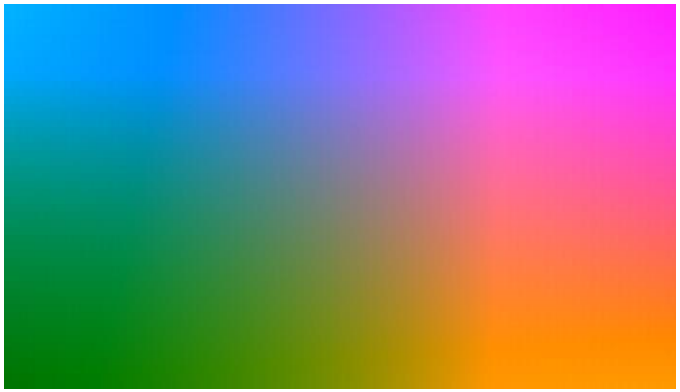


YDzDx





YCbCr



Luv

Color Difference Encoding

YCbCr encoding for 8 bits at difference luminance level, shown at mid-range luma level

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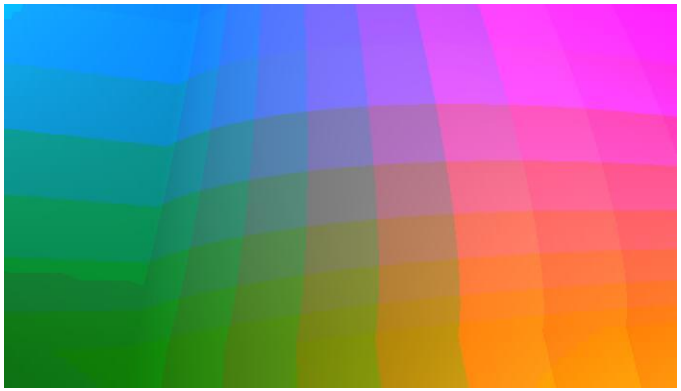
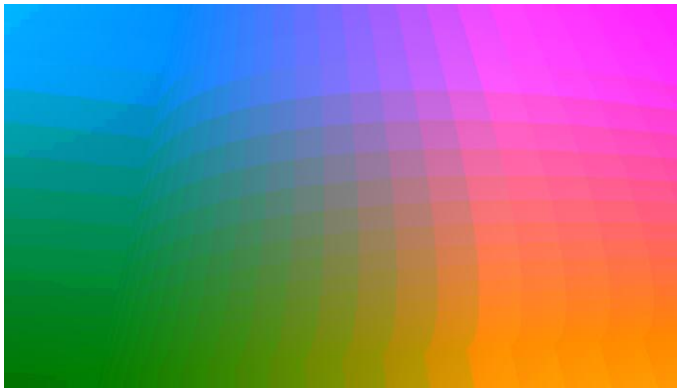


0.5 cd/m^2



5 cd/m^2

50 cd/m^2

Overview

Perceptual Transfer Function (PTF)

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Conclusion

Conclusion

Study on PTF:

- PQ seems to have the most consistent behavior with respect to quantization in the considered luminance range
- However the difference with the other TFs is rather moderate
- Log is not perceptually uniform but can be useful for non-calibrated HDR images

Study of color difference encoding:

- For HDR images YDuDv outperforms YCbCr and YDzDx in terms of required bits
- YDuDv is the less uniform encoding