HVS-BASED PERCEPTUAL COLOR COMPRESSION OF IMAGE DATA

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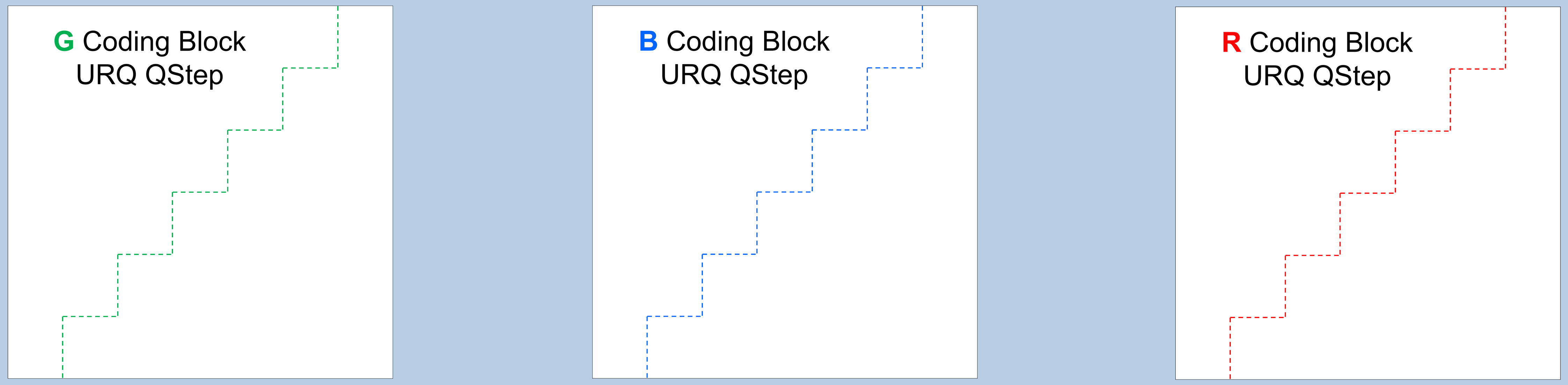
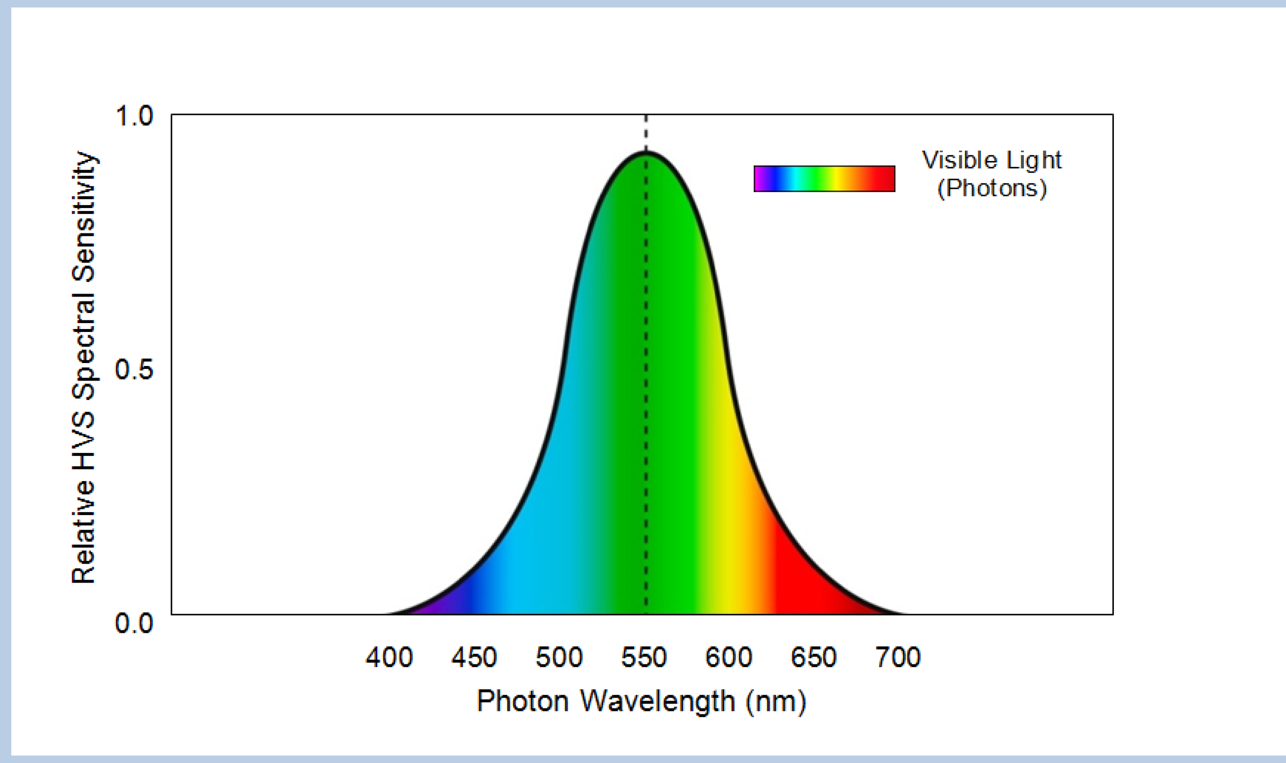
CB-Level Uniform Reconstruction Quantization (URQ)

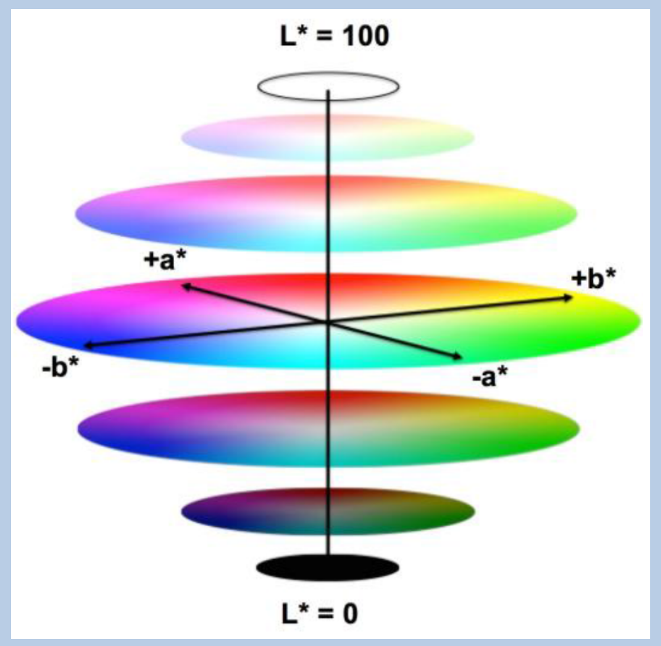


- URQ quantizes coefficients at the CB level according to a uniform Quantization Step Size (QStep) [1, 2]; see above.
- With URQ, perceptually significant data is quantized in the same manner as perceptually insignificant data (i.e., uniformly).
- The lack of perceptually adaptive quantization in URQ equates to a waste of bits spent on perceptually insignificant data.
- PCC perceptually adjusts the QStep at the CB level.
- In PCC, the perceptually adaptive QStep design is based on HVS spectral sensitivity and JNCD-based modeling.

HVS Spectral Sensitivity and JNCD Modeling in PCC



- PCC performs CB-level perceptual quantization by virtue of Human Visual System (HVS) spectral sensitivity modeling.
- The HVS is vastly more sensitive to the brightness of photons in the range 500-585 nm, which are perceived as green [3].
- In PCC, we base the ordering of CB-level perceptual quantization increments and decrements on spectral sensitivity.
- Our approach is effective in terms of adaptively modifying the QStep, so that it is no longer uniform for each color channel.



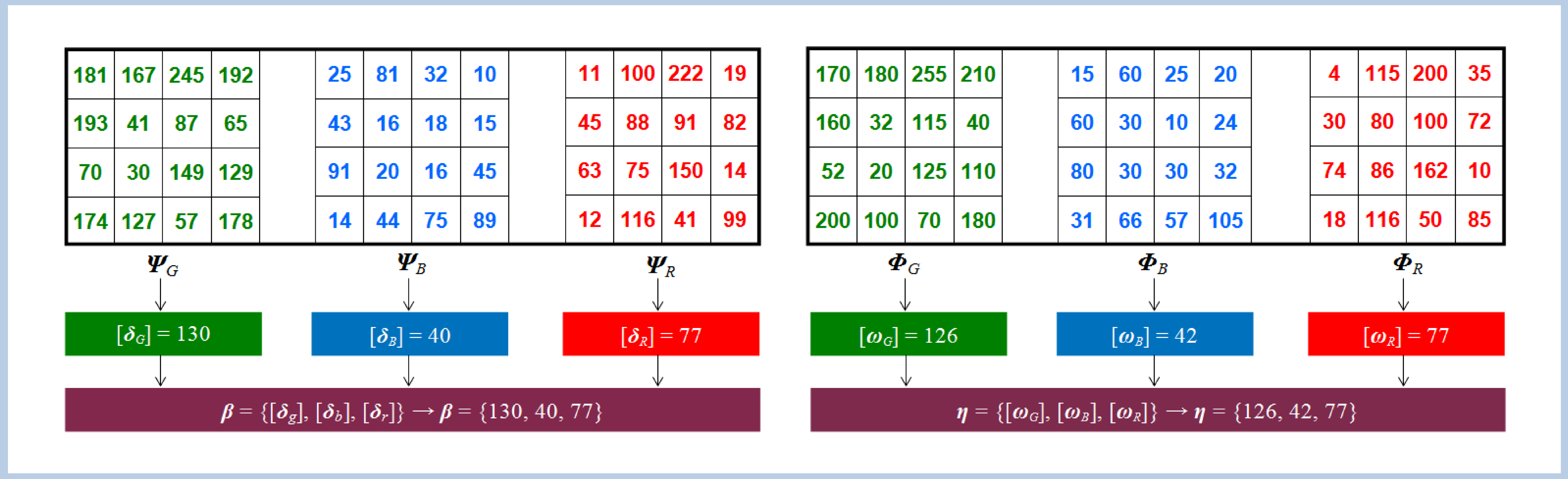
$$\Delta E_{ab} = \sqrt{\left(L_2 - L_1\right)^2 + \left(a_2 - a_1\right)^2 + \left(b_2 - b_1\right)^2} \quad (1)$$

Just Noticeable Color Difference (JNCD) modeling is utilized at the Coding Unit (CU) level in PCC. For this, we employ the CIELAB color difference formula, denoted as ΔE_{ab} in (1) [4], for measuring acceptable levels of color distortion in the perceptually coded image. The Cartesian coordinates, L, a and b, in CIELAB ΔE_{ab} are defined as follows:

L : Lightness in CIELAB. Note that $L \in [0,100]$, where 0 is black and 100 is white.
a : Chroma axis from green to red; (−a) for green and (+a) for red (see left image).
b : Chroma axis from blue to yellow; (−a) for blue and (+a) for yellow (see left image).

- The CIELAB JNCD threshold is quantified as $\Delta E_{ab} \approx 2.3$ [5].
- When $\Delta E_{ab} \approx 2.3$ (i.e., the JNCD threshold), this means that the perceptual difference between two colors is indiscernible.
- CIELAB JNCD is therefore very useful for RGB-based perceptual image coding applications.

Proposed Perceptual Color Compression (PCC) Technique



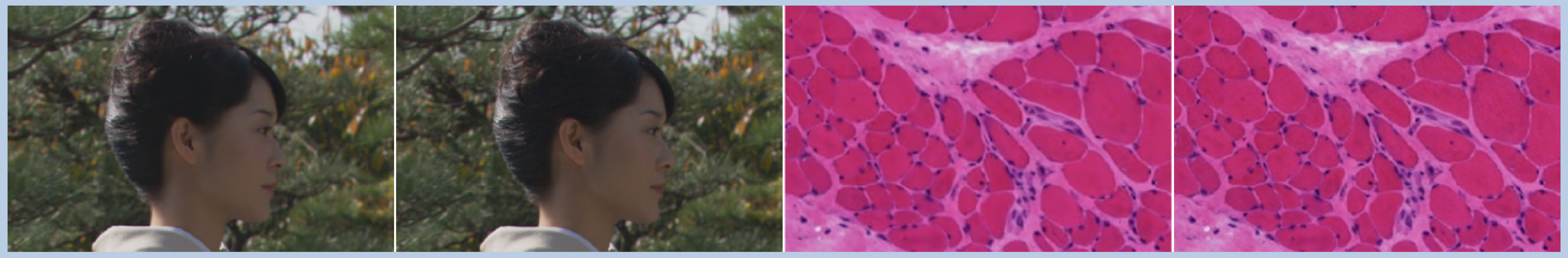
Ψ_G : Raw G CB
Ψ_B : Raw B CB
Ψ_R : Raw R CB

Φ_G : Reconstructed G CB
Φ_B : Reconstructed B CB
Φ_R : Reconstructed R CB

δ_G : Mean Raw G Sample
δ_B : Mean Raw B Sample
δ_R : Mean Raw B Sample

ω_G : Mean Reconstructed G Sample
ω_B : Mean Reconstructed B Sample
ω_R : Mean Reconstructed B Sample

- β denotes a mean raw pixel. It is a set consisting of $[\delta_G]$,$[\delta_B]$ and $[\delta_R]$. Therefore, $\beta = \{[\delta_G],[\delta_B],[\delta_R]\}$.
- η denotes a mean reconstructed pixel. It is a set consisting of $[\omega_G]$,$[\omega_B]$ and $[\omega_R]$. Therefore, $\eta = \{[\omega_G],[\omega_B],[\omega_R]\}$.
- As per the JNCD modeling of the proposed PCC technique, we use the CIELAB ΔE_{ab} formula to compare β with η.
- If $\Delta E_{ab} \approx 2.3$ when comparing β with η, then the reconstructed color is visually lossless.
- If $\Delta E_{ab} < 2.3$ when comparing β with η, then the CB-level QPs are incremented until $\Delta E_{ab} \approx 2.3$ (spectral sensitivity modelling).
- If $\Delta E_{ab} > 2.3$ when comparing β with η, then the CB-level QPs are decrement until $\Delta E_{ab} \approx 2.3$ (spectral sensitivity modelling).



(a) (b) (c) (d)

- **Kimono Evaluation:** PCC (a) versus Raw Data (b). PCC attains visually lossless quality (i.e., MOS = 5 and SSIM ≥ 0.99).
- **WSI Evaluation:** PCC (c) versus Raw Data (d). PCC achieves visually lossless quality (i.e., MOS = 5 and SSIM ≥ 0.99).

Bits Per Pixel (BPP), SSIM and MS-SSIM Scores and MOS for Proposed PCC Method versus Reference Techniques

	Bits Per Pixel (BPP)					SSIM					MS-SSIM					MOS (Rounded)				
RGB Data	PCC	SPAQ	FDPQ	VVC	HEVC	PCC	SPAQ	FDPQ	VVC	HEVC	PCC	SPAQ	FDPQ	VVC	HEVC	PCC	SPAQ	FDPQ	VVC	HEVC
BirdsInCage	0.40	0.60	1.00	1.05	1.10	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	5	5	5	5	5
Bubbles	0.51	0.82	1.17	1.04	1.11	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	5	5	5	5	5
CrowdRun	2.16	3.92	5.03	5.57	5.85	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	5	5	5	5	5
CT	0.32	0.36	0.59	0.44	0.47	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	5	5	5	5	5
DucksAndLegs	2.21	3.79	4.69	5.38	5.55	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	5	5	5	5	5
Kimono	0.50	1.01	1.87	1.82	1.90	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	5	5	5	5	4
OldTownCross	1.30	3.33	4.57	5.26	5.49	0.99	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.99	5	5	5	5	5
ParkScene	1.10	2.35	3.33	3.58	3.78	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	4	5	5	5	5
Seeking	1.71	3.74	4.81	5.53	5.80	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	4	5	5	5	5
Traffic	1.14	1.35	1.95	1.83	2.03	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	5	5	5	5	5
VenueVu	0.64	0.73	1.07	0.92	1.01	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	4	4	4	4	4
WSI (4K)	0.53	0.52	0.78	0.63	0.66	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	5	5	5	5	5

- **BPP Reductions (Kimono):** Compared with VVC, PCC attains a 72.50% BPP reduction on the Kimono image.
- **BPP Reductions (WSI):** Compared with FDPQ, PCC attains a 32.05% BPP reduction on the WSI image.
- **Discussion:** Spectral sensitivity and JNCD modeling facilitate visually lossless compression with high BPP reductions.
- **Future Work:** Potential applications for spatiotemporal RGB, YCbCr and HDR video data and medical imaging.

[1] G. Sullivan et al., "Overview of the High Efficiency Video Coding (HEVC) Standard," *IEEE Trans. Circuits Syst. Video Techn.*, vol. 22, no. 12, pp. 1649-1668, 2012.
[2] D. Flynn et al., "Overview of the Range Extensions for the HEVC Standard: Tools, Profiles, and Performance," *IEEE Trans. Circuits Syst. Video Techn.*, vol. 26, no. 1, pp. 4-19, 2016.
[3] H-J. Lewerenz, "Photons in Natural and Life Sciences," Berlin, Germany: Springer, 2012.
[4] A. R. Robertson, "Historical development of CIE recommended color difference equations," *Color Research and Application*, vol. 15, no. 3, pp. 167-170, 1990.
[5] G. Sharma and R. Bala, "Color Fundamentals for Digital Imaging," in *Digital Color Imaging Handbook*, CRC Press, 2002, pp. 31.