Content-Adaptive Color Transform for HEVC

P. Bordes, P. Andrivon, P. Lopez
Plan

- Chroma representation used in HEVC
- Why introducing a Chroma Transformation
- PCA/ICA alternatives (Principal or Independent Component Analysis)
- Conclusions
HEVC and Color Space

HEVC profiles

- Main 10 profile supports up to 10 bit input video
- Note that even 8 bit input videos benefit from Main 10 profile since internal precision is 10 bits

Color Space

- Rec BT709 Y’CbCr (or YUV) is the « natural » color space at the HEVC input
- Objective: decorrelation of the RGB signal
- Y’CbCr components are derived from original RGB by:
  - Applying a gamma pre-correction $\gamma = 0.45$: $R' = R^\gamma$ (same for G and B)
  - Applying a 3x3 matrix to R’G’B’:
    - $Y' = \alpha_R R' + \alpha_G G' + \alpha_B B'$
    - $Cb = \beta_R (B' - Y')$
    - $Cr = \delta_R (R' - Y')$
- This transformation is content agnostic
- For broadcast applications, Cb and Cr are usually subsampled to form the YUV420 signal
Imperfection of YUV420

- YUV is an imperfect decorrelated version of the original RGB

- Chroma histogram of a sequence

- Objective of color transformation:
  - Increase the decorrelation between the chroma components
  - Constraint: no processing applied on the luminance (Y) component
  - Feature: content based transformation
Advantage of Color Transform
- The color transform processing is added outside the codec
- Neither the encoder nor the decoder needs to be modified

Limitation of color transform within the encoder
- The color transform must be consistent between a reference frame and all pictures using this reference frame ➔ coding efficiency
- Color transformation is thus applied on separate group of pictures
Implementation of Color Transform

Rotation and translation

- It is desirable to align one of the chroma axis to the main chroma axis of the sequence (red axis)

Rotation and translation model

\[
\begin{pmatrix}
u' \\
v'
\end{pmatrix} = \begin{bmatrix}
cos \theta & sin \theta \\
-sin \theta & cos \theta
\end{bmatrix} \begin{pmatrix}
u - T_u \\
v - T_v
\end{pmatrix}
\]

Note that the internal bitdepth of 10 bits allows to apply this rotation on 8 bit depth content without loss of quality.
Principal Component Analysis (PCA)

- Determination of the **orthogonal** transform of the chroma components
- Principal axis corresponds to the eigen-vector corresponding to the highest eigen-value
- Second axis is orthogonal to the principal axis
- To guarantee the inverse processing at the decoder, the rotation angle $\theta$ and the translation vector are transmitted as metadata
Principal Component Analysis (PCA)

- Bjontegaard gain vs basic HEVC in Random Access Main 10
  ➔ Gain for only half the sequences
Determination of a non-orthogonal transform

Minimization of a cost function defined from the oblique projections of each chroma space point to new $u'$ and $v'$ axis

This energy depends on the 4 unknown parameters: $T_u$, $T_v$, $\theta_1$ and $\theta_2$

$T_u$, $T_v$, $\theta_1$ are initialized by the values obtained by the PCA.

$\theta_2$ is set to $\theta_1 + \pi/2$

To guarantee the inverse processing at the decoder, the rotation angles $\theta_1$ and $\theta_2$ and the translation vector are transmitted as metadata
Bjontegaard gain vs basic HEVC in Random Access Main 10

Gain for most sequences
Conclusions

- A preprocessing/postprocessing content adaptive chroma transformation has been proposed
- Two implementations have been studied, the PCA and the ICA
- The non-orthogonal method (ICA) presents the best performance
- An Bjontegaard improvement versus HEVC is obtained
- Further improvement: adoption of different chroma QP-offset for the transformed chroma components

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