Luma Mapping with Chroma Scaling in Versatile Video Coding (VVC)

March 24-27, DCC 2020

Dolby Laboratories, Inc.

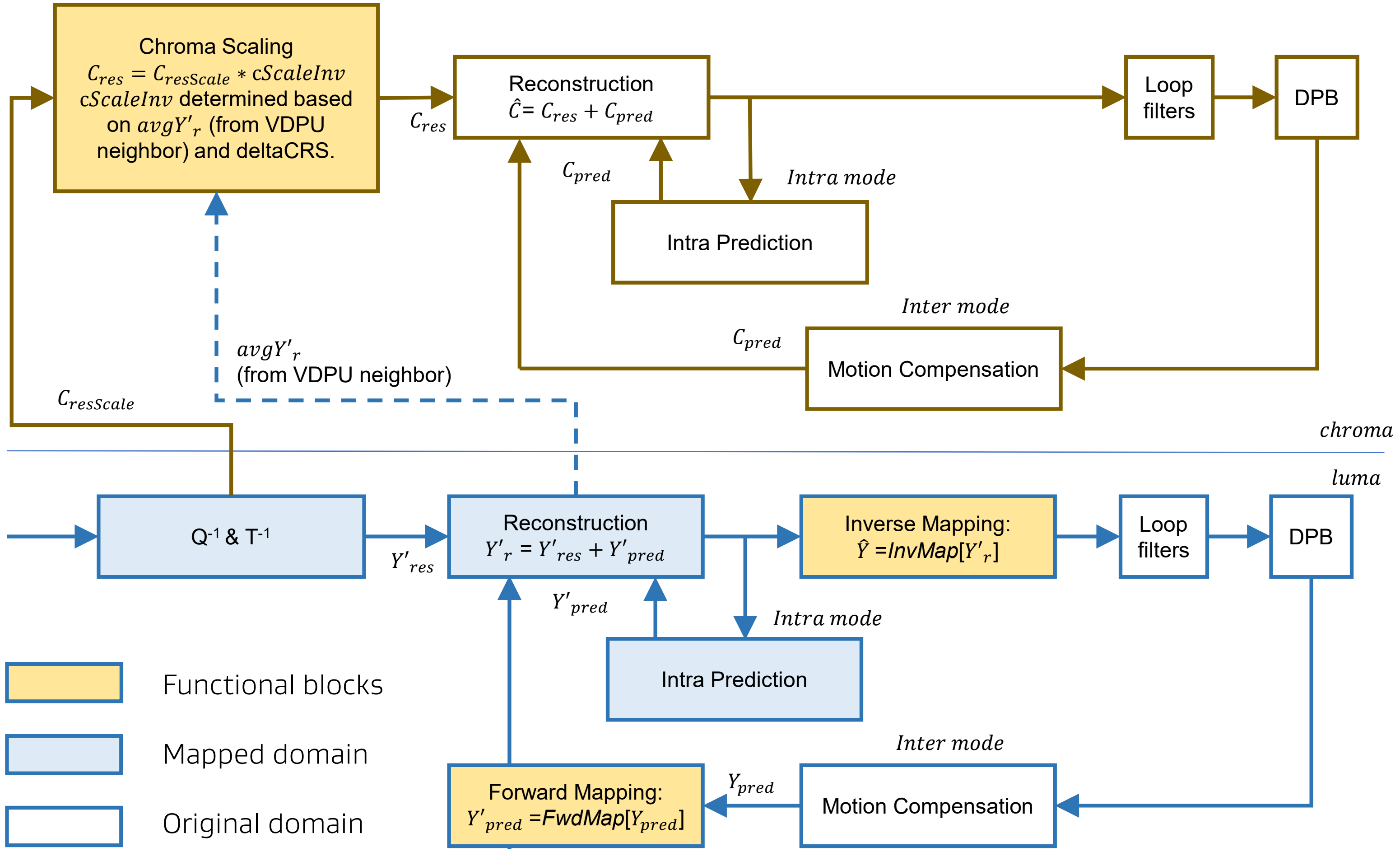
Introduction

- Versatile Video Coding (VVC): is being developed by Joint Video Experts Team (JVET)
  - To improve compression efficiency relative to High Efficiency Video Coding (HEVC).
  - To provide support for new video types such as HDR/WCG in addition to SDR.
- LMCS was proposed in response to CfP issued by MPEG and VCEG in Oct, 2017.
  - Originally focused on HDR content to improve the subjective coding performance.
- LMCS current design in VVC specification (draft 8)
  - Supports different video types including SDR, HLG and PQ signals.
  - Includes further refinement and simplification in implementation.
  - Improves subjective and objective performance for both SDR and HDR.

LMCS decoding architecture

Chroma Residual Scaling (CRS)

Luma Mapping (LM)



Luma mapping with piecewise linear model

- Basic idea: to make better use of the range of luma code values allowed at specific bit depth.
- It includes a forward mapping function and a corresponding inverse mapping function.
  - The forward mapping function (FwdMap) is signaled using piecewise linear model.

    The predicted luma sample Y_{pred}, belonging to i-th piece, is mapped as $FwdMap(Ypred)$:

    $$Y'_{pred} = \frac{\text{MappedPivot[i+1]} - \text{MappedPivot[i]}}{\text{InputPivot[i+1]} - \text{InputPivot[i]}} * (Y_{pred} - \text{InputPivot[i]}) + \text{MappedPivot[i]}$$

    the pivot point of each piece in original domain, is derived as InputPivot[i] = i * OrgCW.

    MappedPivot[i] denotes the mapped pivot points in the piecewise linear model.
  - The inverse mapping function (InvMap) is derived at the decoder from FwdMap.
- The parameters to determine the pivot points are signaled in the APS in VVC syntax structure.

Luma dependent chroma residue scaling (CRS)

- Designed to compensate for the interaction between luma and corresponding chroma signals.
- CRS applies <u>a constant scaling factor</u> to all chroma residue samples in a chroma coding block.
  - the forward scaling factor ($\boldsymbol{C_{Scale}}$) is applied at the encoder: $C_{ResScale} = C_{Res} * C_{Scale} = \frac{C_{Res}}{C_{ScaleInv}}$
  - the inverse scaling factor ($\boldsymbol{C_{ScaleInv}}$) is applied at the decoder: $C_{Res} = \frac{C_{ResScale}}{C_{Scale}} = C_{ResScale} * C_{ScaleInv}$
  - Derivation of the constant inverse scaling factor, $C_{ScaleInv}$, for each piece:
    - Compute the average value, $avgY'_r$, of top/left reconstructed neighbouring luma samples of current VPDU.
    - Determine the *i*-th piece $avgY'_r$ belongs to in the piecewise linear model.
    - Derive the value of $C_{ScaleInv}$ for the *i*-th piece as:

$$cScaleInv[i] = \frac{\text{InputPivot[i+1]}-\text{InputPivot[i]}}{(\text{MappedPivot[i+1]}-\text{MappedPivot[i]}) + \text{deltaCRS[i]}}$$

- deltaCRS is <u>a chroma scaling offset</u> introduced for chroma correction signaled in APS.

LMCS parameter estimation for SDR and HLG in VTM7

- Adaptive mapping to optimize coding performance measured with PSNR.
  - Step 1: Initially assign equal number of codewords to each valid piece.

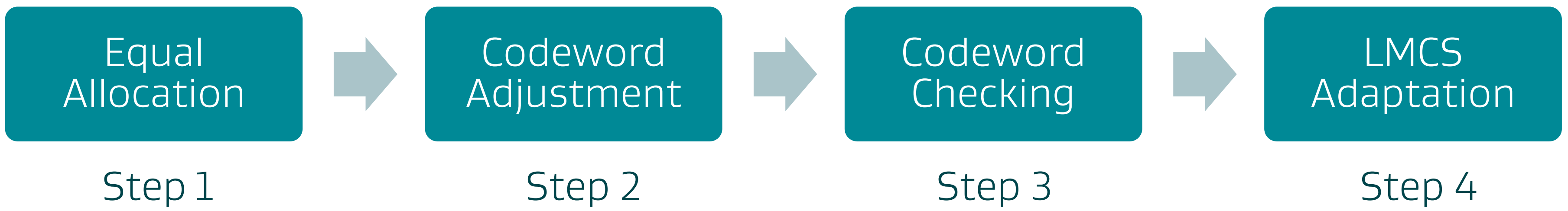
$$binCW[i] = round\left(\frac{totalCW}{endIdx - startIdx + 1}\right)$$

  - Step 2: Adjust codewords based on histogram and local spatial variance.

$$binVar[i] = \frac{\sum_{bin} \log_{10}(pxlVar + 1.0)}{binCnt[i]}$$

  - Step 3: Adjust the number of code words to the maximum allowed.
  - Step 4: Set rate, slice, and chroma adaptation parameters.

Codeword Allocation: more codewords for low variance pieces, less codewords for high variance pieces



LMCS parameter estimation for HDR PQ signals in VTM7

- Fixed mapping to optimize coding performance measured with wPSNR.
  - Step 1: Compute the slope of the mapping curve:

    $$slope[Y] = \mathrm{sqrt}(\mathrm{wSSE}(Y)) = 2\hat{}(dQP(Y)/6)$$

  - Step 2: Integrate the slope of the mapping curve for Y=0…$maxY$–1:

    $$F[Y+1] = F[Y] + slope[Y]$$

  - Step 3: Compute the look-up table, $FwdLUT[Y]$, by normalizing $F[Y]$ to [0 maxY]:

    $$FwdLUT[Y] = \mathrm{clip3}(0, \mathrm{maxY}, \mathrm{round}(F[Y] * maxY / F[maxY]))$$

  - Step 4: Calculate the number of code words, $binCW[i]$, to allocate to each piece:

    $$binCW[i] = FwdLUT[(i+1) * OrgCW] - FwdLUT[i * OrgCW]$$

Derive weighted PSNR: modeled on the luma-dependent quantization adaptation method (luma dQP)

The local delta QP (dQP) value per CTU: $\mathrm{dQP}(avgY) = max(-3, min(6, 0.015 * avgY - 1.5 - 6))$

where $avgY$ is the average luma value in current CTU.

The weighted sum square error, wSSE(Y): $\mathrm{wSSE}(Y) = 2\hat{}(dQP(Y)/3)$

Experimental Results on VTM7.0

Table 1: BD-rate performance of LMCS for SDR under RA

	Random access		
	Y	U	V
Class A1	-0.86%	0.01%	-0.19%
Class A2	-1.95%	2.33%	2.27%
Class B	-1.55%	-3.45%	-2.79%
Class C	-1.11%	-2.08%	-1.22%
Class E			
Overall	-1.37%	-1.24%	-0.84%
Class D	-0.78%	-1.64%	-1.00%
Class F	-0.82%	-1.86%	-1.29%

Table 2: BD-rate performance of LMCS for PQ under RA

	Random Access				
	DE100	PSNRL100	wPsnrY	wPsnrU	wPsnrV
Overall	-1.30%	-1.30%	-1.08%	1.45%	-1.49%

Table 3: BD-rate performance of LMCS for HLG under RA

	Random Access		
	Y	U	V
Overall	-0.93%	-1.29%	-0.89%

Table 4: LMCS encoder configuration parameter settings

Parameter Name	Description
LMCSEnable	0: disable; 1: enable
LMCSSignalType	0: SDR; 1: PQ; 2: HLG
LMCSUpdateCtrl	0: RA; 1: AI; 2: LDB/LDP
LMCSAdpOption	0: automatic model; 1: LMCS enabled for intra and inter, and 66 codewords allocated for each bin for QP<=22; 2: LMCS enabled only for Tid0 (for all QP); 3: LMCS enabled only for inter, and 66 codewords allocated for each bin for QP<=22; 4: LMCS enabled for inter (for all QP).
LMCSInitialCW	user-defined total number of codewords

Summary

- LMCS is currently part of VVC standard designed to provide significant coding efficiency compared to HEVC.
- LMCS is signaled as a piecewise linear model with a set of pivot points, allowing allocation of different number of code words to each piece to achieve particular target.
- In VTM software, current design applies adaptive mapping for SDR and HLG signals to improve PSNR, while uses fixed mapping for PQ content to improve weighted PSNR.
- In addition, luma-dependent chroma residue scaling (CRS) is introduced to achieve a good balance between luma and chroma.
- LMCS provides an additional level of video signal processing than is available in HEVC, AVC, or proprietary video coding specifications.