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Synergies between in-loop and out-of-loop mapping for HDR-PQ content

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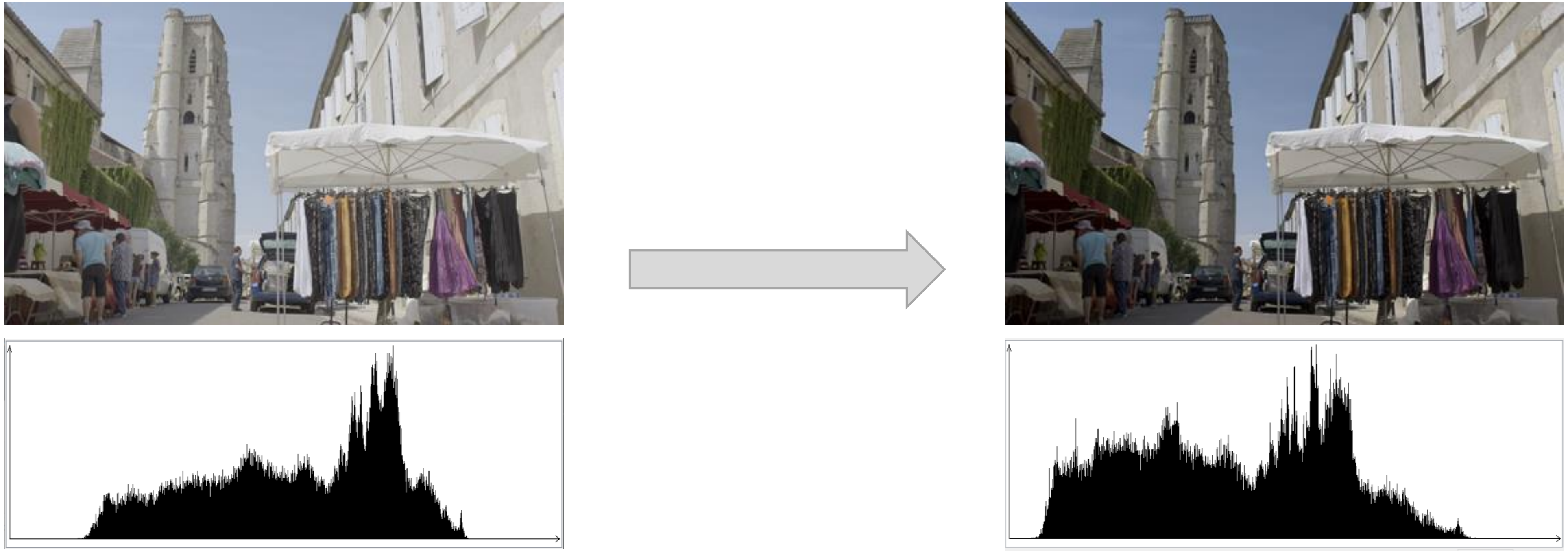
Context

- Adaptive video content mapping
  - Can bring significant compression gains for various types of content (SDR/HDR)
  - Adapt the video signal depending on its statistical properties in order to better exploit the signal codewords range



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Previous studies

- Out-of-loop mapping
  - Explored during MPEG work on HDR content coding [Lu et al 2016]
  - Proposed in response to the CfP for video compression beyond HEVC [Rusanovskyy et al 2016, JVET-J0022]
- In-loop mapping
  - Proposed in response to the CfP for video compression beyond HEVC [JVET-J0015]

- Further investigated in JVET Core Experiments – 2 versions studied
  1. Dynamic Range Adaptation (DRA): out-of-loop mapping [JVET-L0205]
  2. Luma mapping with chroma scaling (LMCS): in-loop mapping [JVET-M0427]

- In-loop LMCS finally adopted in VVC
  - More flexibility regarding temporal variations of the mapping function
  - No need for an additional buffer to the Decoded Picture Buffer (DPB)
  - Reference: [Lu et al 2020]

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Purpose of this study

- Compare In-Loop / Out-of-Loop mapping
- Evaluate synergies of In-Loop and Out-of-Loop mapping
- Specific focus on HDR-PQ content

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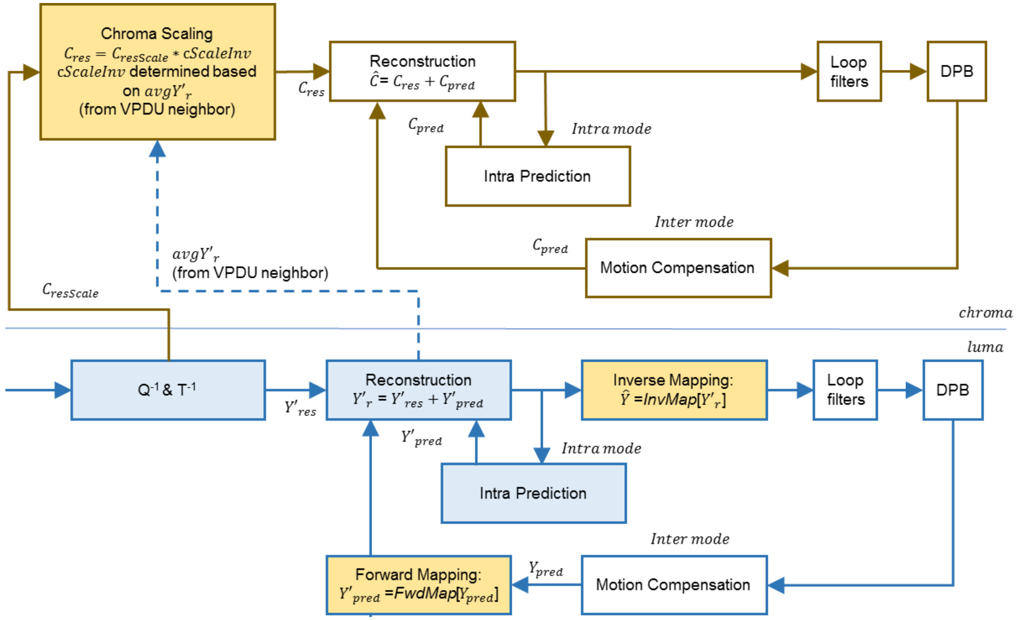
“Luma mapping with chroma scaling” (LMCS)

- In-loop solution
- Process (decoder)
  - Forward luma mapping applied to the inter-prediction blocks
  - Inverse luma mapping applied to reconstructed luma samples prior in-loop filtering
  - Inverse cross-component scaling applied to chroma residual



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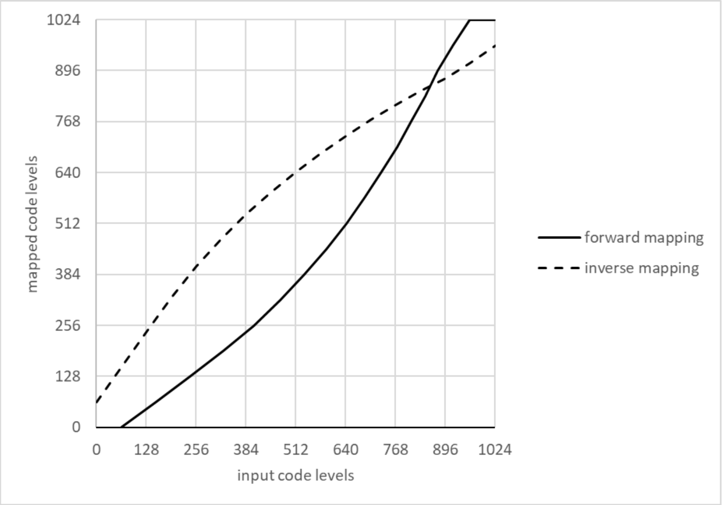
"Luma mapping with chroma scaling" (LMCS)

- Signalling
  - Forward luma mapping parameters signalled in APS
  - Inverse luma mapping function inferred from the Forward luma mapping parameters
  - Cross-component chroma scaling factors inferred from the Forward mapping parameters

- VTM implementation
  - HDR PQ
    - fixed mapping function used whatever the content
  - SDR and HLG
    - mapping function is content-adaptive
    - LMCS is adaptively enabled/disabled at picture level



HDR-PQ mapping functions

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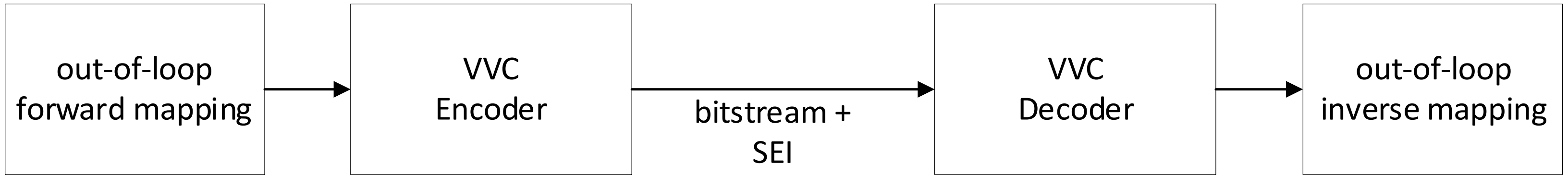
Out-of-loop mapping

- Out-of-loop solution
  - pre-encoding process and post-decoding inverse process



- Process
  - Luma – intra-component mapping
  - Chroma – intra- or inter-component mapping
- Signalling in SEI message
  - Luma – mapping function signalled as piecewise linear model
  - Chroma – mapping functions signalled as piecewise linear model, or inferred from luma mapping function

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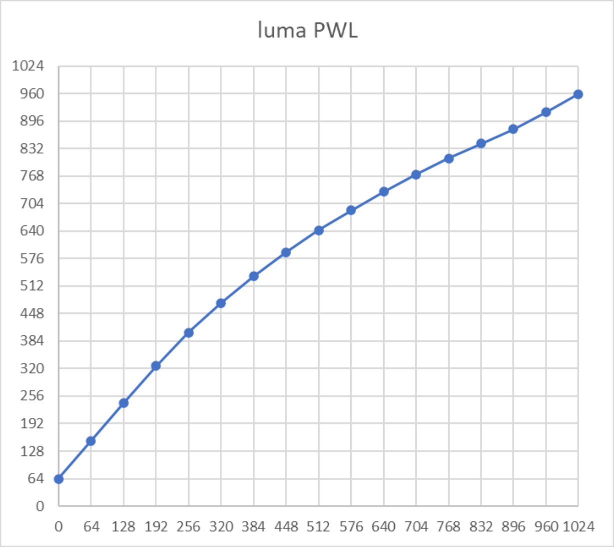
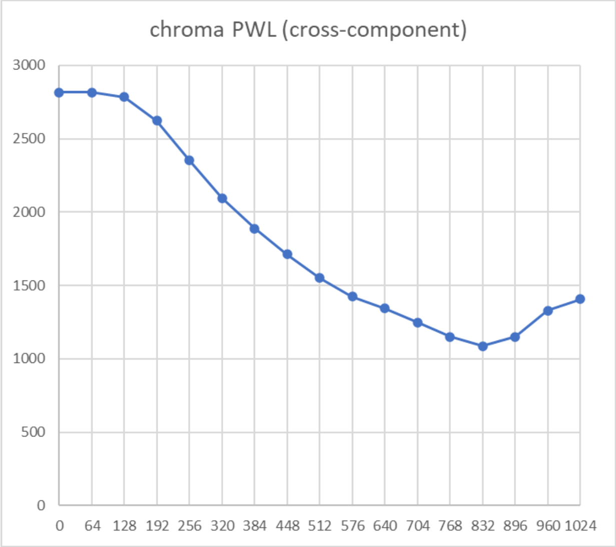
Out-of-loop mapping

• Luma	intra-plane process	$i = Y_{dec} >> K$	$Y_{post} = slope_Y[\,i\,] * (Y_{dec} - (i<<K)\,) + offset_Y[\,i\,]$
• Chroma	Mode 0 – intra-plane process	$i = C_{dec} >> K$	$C_{post} = slope_C[\,i\,] * (C_{dec} - (i<<K)\,) + offset_C[\,i\,]$
	Mode 1 – cross-plane process	$i = Y_{coloc} >> K$	$sc = slope_C[\,i\,] * (Y_{coloc} - (i<<K)\,) + offset_C[\,i\,]$ $C_{post} = offset + sc * (\,C_{dec} - offset\,)$

- Example of luma and chroma PWL functions (post-processing side)





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Complexity of out-of-loop post-process

- Per Luma sample
  - 1 mult, 2 adds, 2 right shifts, 1 left shift, 1 clipping
- Per Chroma sample (cross-comp mode)
  - 2 mults, 3 adds, 3 right shifts, 1 left shift, 1 clipping
- Note:
  - as a reference, ALF in VVC requires 15 multiplications per sample, and CC-ALF 16 multiplications per sample [JVET-P1008]

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Test conditions

- VTM12.0
- HDR-PQ test sequences

Sequence name	Frame count	Frame rate	Bit depth	Transfer Function
BalloonFestival	240	24 fps	10	PQ
Cosmos1	240	24 fps	10	PQ
EBU_Hurdles	500	50 fps	10	PQ
EBU_Starting	500	50 fps	10	PQ
Market	400	50 fps	10	PQ
ShowGirl	339	25 fps	10	PQ
SunRise	200	25 fps	10	PQ

- Reported configurations
  - AI – All Intra
  - RA – Random Access
  - LDB – Low Delay B
- Reported metrics
  - DE100 (also noted "DE"), PSNRL100 (also noted "PSNRL"), wPsnrY, wPsnrU, wPsnrV

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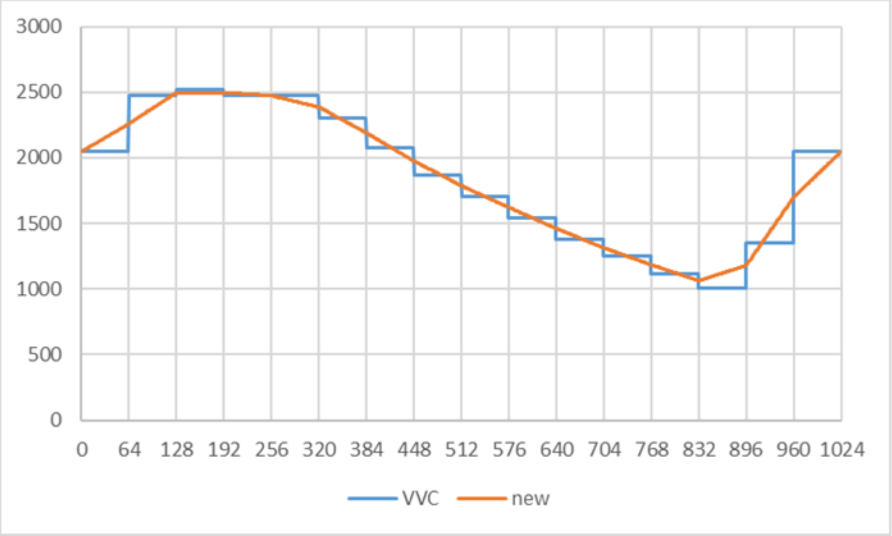
Implementation details

- Fwd and Inverse Luma mapping exactly same as in in-loop LMCS
- Cross-component Chroma scaling

In-loop	Out-of-loop
Residual chroma samples	Input (forward) and reconstructed (inverse) chroma samples
1 scaling factor per VPDU derived from co-located surrounding reconstructed luma samples	1 scaling factor per sample derived from co-located reconstructed luma sample
Chroma scaling function defined as successive fixed values per interval	Chroma scaling function defined as continuous Piece-wise linear function



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Experiments - Test 1

- Ref: LMCS enabled / OLF SEI disabled
- Test: LMCS disabled / OLF SEI enabled (cross-comp mode)

			wPSNR		
	DE	PSNRL	Y	U	V
AI	-1.15%	-0.76%	-0.50%	-5.43%	-7.24%
RA	-2.41%	-1.72%	-1.17%	-5.37%	-8.06%
LDB	-5.53%	-2.49%	-1.56%	-10.77%	-15.14%

- Coding gains observed for all metrics
- Highest gains observed in Low delay configurations

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Experiments - Test 2

- Ref: LMCS enabled / OLF SEI disabled
- Test: LMCS enabled / OLF SEI enabled (cross-comp mode)
  - OLF uses the fixed mapping function defined for HDR-PQ content
  - In-loop LMCS uses the adaptive tuning algorithm defined for SDR and HLG, which leads to a refinement of the HDR-PQ fixed mapping function used in OLF

			wPSNR		
	DE	PSNRL	Y	U	V
AI	-0.46%	-0.91%	-0.30%	-5.27%	-6.21%
RA	-2.30%	-3.31%	-1.74%	-5.65%	-7.35%
LDB	-5.85%	-3.96%	-2.57%	-9.52%	-14.06%

- Higher coding gains than Test 1 → Synergy between OLF and LMCS observed

- *Note: gains in luma (PSNRL100, wPSNRY) are, on balance, considered more significant than the corresponding slight loss in chroma*

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Conclusions

- Out-of-loop mapping can provide improved coding gain over in-loop LMCS for HDR-PQ content
- Additional gains can even be obtained when combining both tools
  - Out-of-loop mapping using static mapping function
  - In-loop LMCS using adaptive refinement mapping function
- Note: tests performed on SDR and HDR-HLG content do not show noticeable impacts on the overall performance
  - in VTM, LMCS coding gain for SDR and HDR-HLG comes from per-content and per-intra period mapping functions adaptation, and per-picture activation/de-activation
  - Temporal variations of the mapping function can jeopardize the temporal prediction when mapping is applied out-of-loop

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