



Sample Adaptive Offset with Zero Pixel Line Buffers for LCU-based Decoding

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Overall Summary

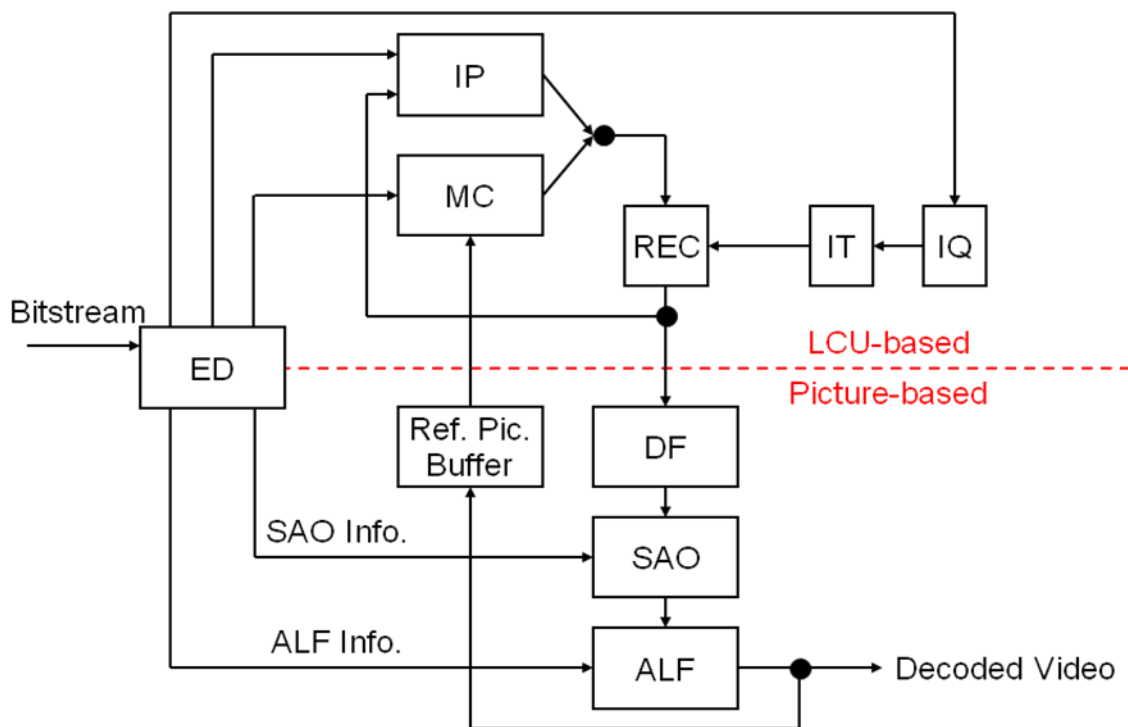
- Padding at virtual boundaries to remove pixel line buffers of sample adaptive offset (SAO)
 - To filter a pixel right below a virtual boundary, pixels on the upper side of the virtual boundary (VB) cannot be used in the SAO process.
 - Padding to replace pixels on the upper side of the VB is subjectively better than skipping to-be-filtered pixels right below the VB
- Performance
 - Removed all SAO line buffers (1 luma line in HM-3.0) for LCU-based decoding, as well as for picture-based decoding
 - No BD-rate changes
 - No run time changes
 - Improved subjective quality in comparison with the HM anchor
- “Padding better than skipping” is also shown in another proposal, JCTVC-F093

Outline

- Picture-based and LCU-based decoding
- Analysis of line buffers for in-loop filtering in HM-3.0
- Proposed virtual boundaries
- Simulation results
- Conclusion

Current Implementation in HM-3.0

- LCU-based processing is used for intra prediction, motion compensation, inverse quantization, inverse transform, and reconstruction.
- Picture-based processing is used for deblocking filter (DF), sample adaptive offset (SAO), and adaptive loop filter (ALF).

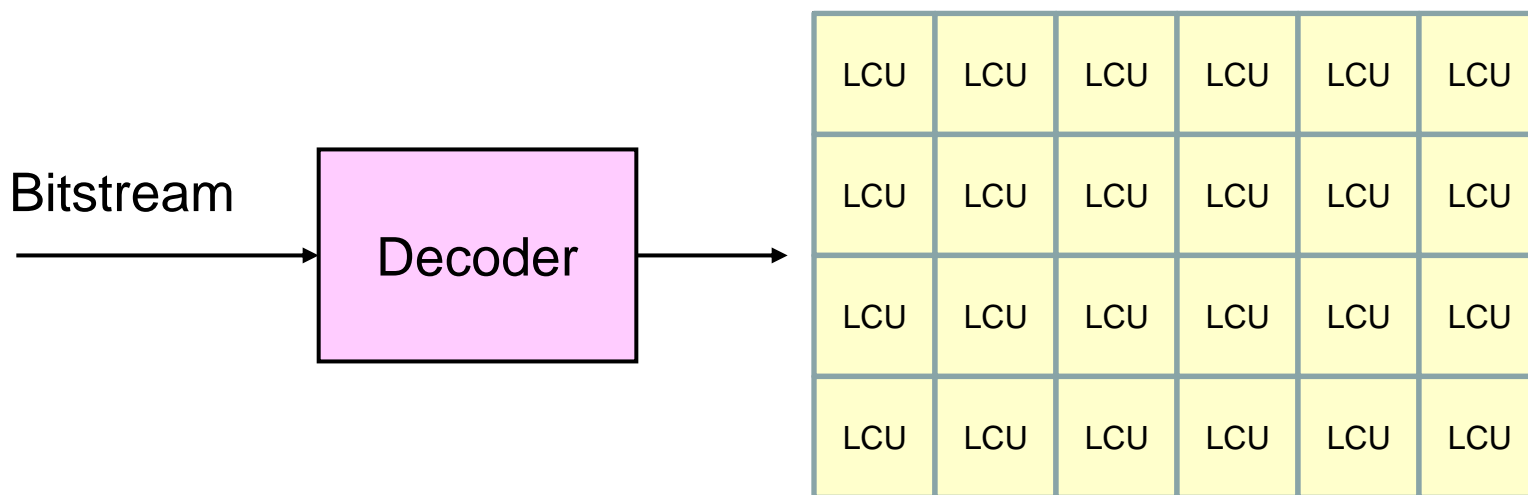


Picture-based Decoding

- Store the entire picture after REC
- Access the REC picture buffer to perform DF and store the entire picture after DF
- Access the DF picture buffer to perform SAO and store the entire picture after SAO
- Access the SAO picture buffer to perform ALF and store the entire picture after ALF
- Need additional picture buffers
- May be okay for PC-based software but very bad for embedded software and hardware
 - On-chip picture buffers usually require unacceptable area cost.
 - Off-chip picture buffers require significantly longer access time and higher power consumption in comparison with on-chip buffers and consumes a lot of precious external memory bandwidth

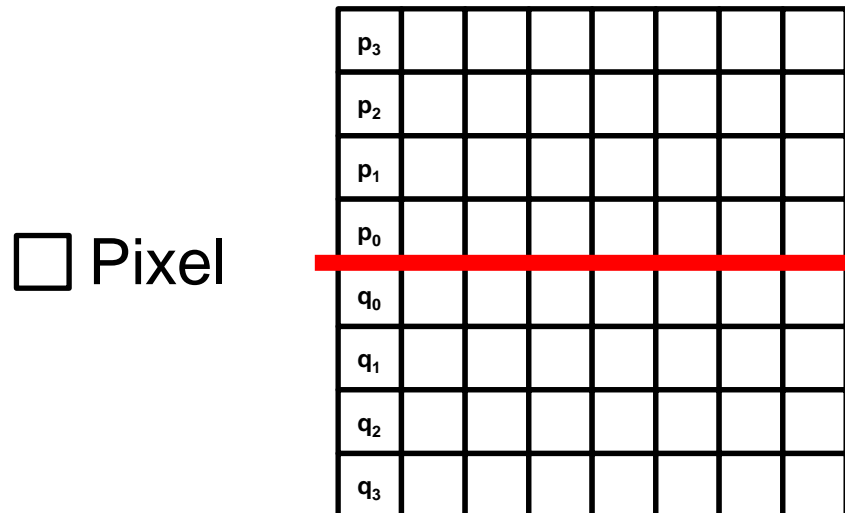
LCU-based Decoding

- Input bitstream
- Output decoded results LCU by LCU
- No picture buffers except for reference pictures
 - To minimize the external memory storage size and data access
- Mainstream for embedded software and hardware



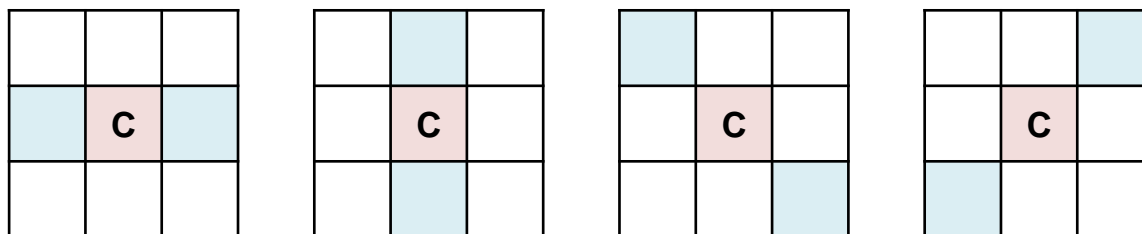
Deblocking Filter (DF)

- Luma vertical edges are first processed, and the results are DF intermediate pixels.
- Luma horizontal edges are then processed.
 - Use **reconstructed pixels** for filtering decisions (on/off & strong/weak)
 - Use **DF intermediate pixels** for filtering operations to generate **DF output pixels**
 - May change rows p_0 - p_2 & q_0 - q_2 for luma
- For chroma horizontal edges, only p_0 & q_0 may be changed, and only DF intermediate pixels are used in filtering decisions and filtering operations.



Sample Adaptive Offset (SAO)

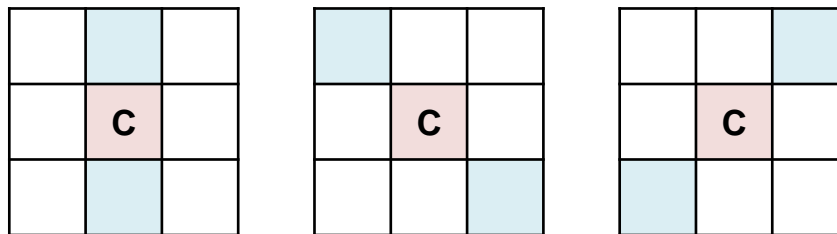
- Applied only for luma in HM-3.0
- Each LCU belongs to one of the following SAO types
 - Central group band offset (BO), side group BO, 0-degree edge offset (EO), 45-degree EO, 90-degree EO, 135-degree EO, no processing
- BO uses the DF output pixel intensity for each pixel to perform pixel classification
- EO uses two neighboring DF output pixels for each pixel to perform pixel classification



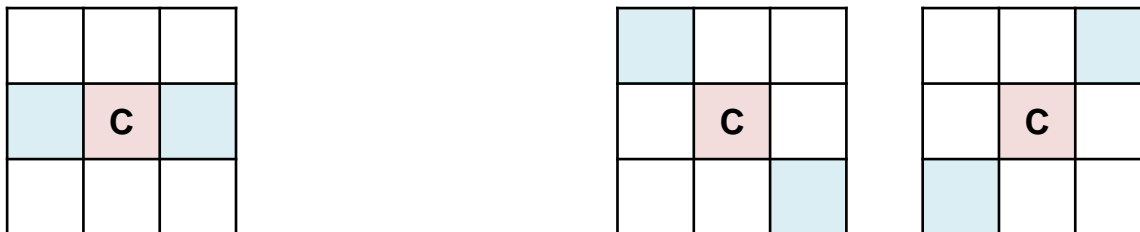
- After pixel classification, one offset is added for each DF output pixel to generate SAO output pixels

LCU-Independent SAO Decoding in HM-3.0

- SAO is skipped for the upmost and lowest pixel rows of each LCU belonging to 45-degree, 90-degree, and 135-degree EO.



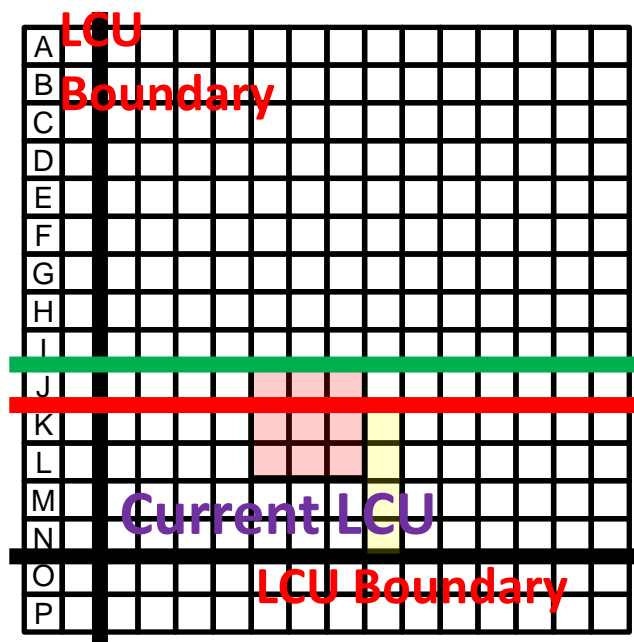
- SAO is skipped for the leftmost and rightmost pixel columns of each LCU belonging to 0-degree, 45-degree, and 135-degree EO.



- No decoder line buffer is required for picture-based SAO decoding
 - Not true for LCU-based decoding**

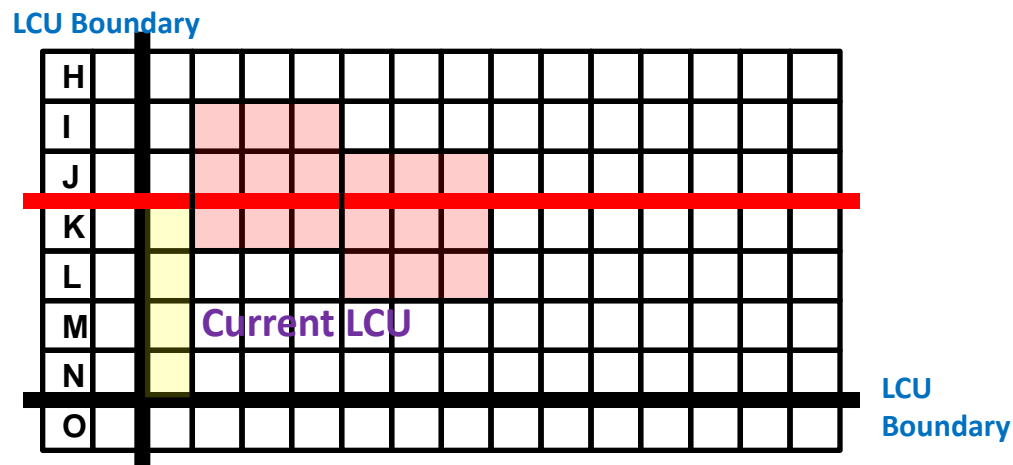
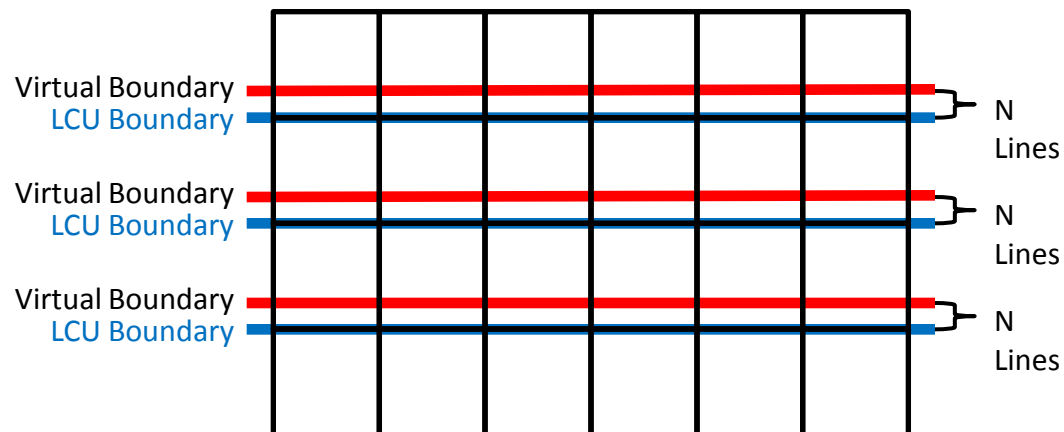
Luma Pixel Line Buffers in HM-3.0

- Reconstructed pixels and DF intermediate pixels of lines K-N have to be stored for DF.
- Lines ...A-J can be processed by SAO because only lines L..N will be changed by vertical filter in DF
- When the lower LCU comes, lines K-P... can be processed by DF and SAO; however, **DF output pixels of line J need to be stored for SAO** for processing line K.



Proposed Virtual Boundaries for SAO

- Virtual boundaries (VBs) are upward shifted horizontal LCU boundaries by N pixels
 - N=4 for luma
- For each to-be-filtered pixel below a virtual boundary, use padding to replace pixels on the other side of the virtual boundary
- Release HM-3.0 constraints at vertical LCU boundaries
- No line buffer is required.**
 - Save 1 luma line buffer



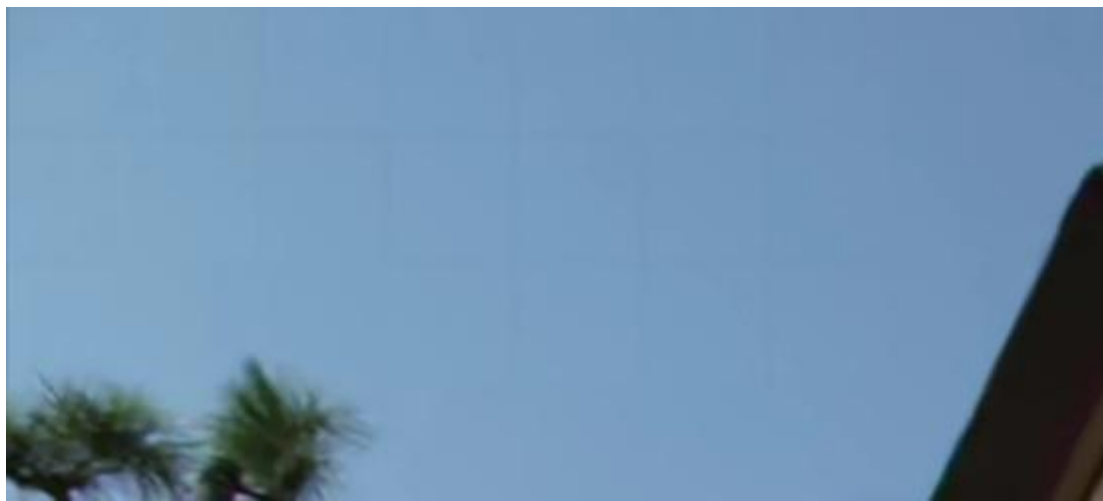
Simulation Results

- JCTVC-E700 anchor
- No significant BD-rate changes
- No significant run time changes

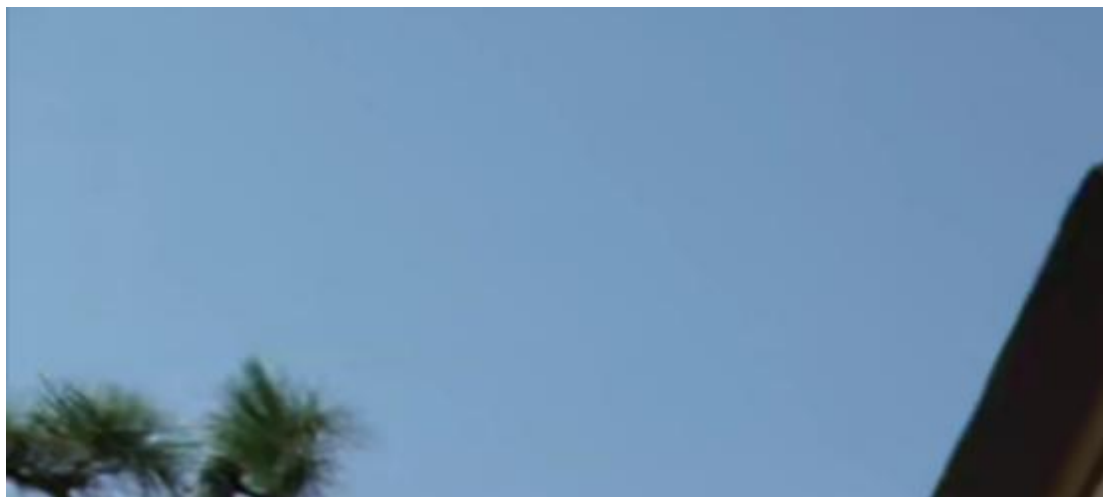
	Intra			Intra LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	0.0	0.0	0.0	0.0	0.0	0.0
Class B	0.0	0.0	0.0	0.0	0.0	0.0
Class C	0.0	0.0	0.0	0.0	0.0	0.0
Class D	0.0	0.0	0.0	0.0	0.0	0.0
Class E	0.0	0.0	0.0	0.0	0.0	0.0
All	0.0	0.0	0.0	0.0	0.0	0.0
Enc Time	100%			101%		
Dec Time	100%			100%		
	Random access			Random access LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	0.0	-0.1	0.1	-0.1	-0.2	0.1
Class B	0.0	-0.1	-0.1	0.0	0.0	0.0
Class C	0.0	0.1	0.0	0.0	0.0	0.0
Class D	0.0	-0.1	-0.1	0.0	-0.1	0.0
Class E						
All	0.0	-0.1	0.0	0.0	-0.1	0.0
Enc Time	101%			100%		
Dec Time	100%			99%		
	Low delay			Low delay LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A						
Class B	0.0	0.0	0.0	0.1	-0.1	-0.1
Class C	0.0	0.1	0.0	0.0	-0.1	-0.3
Class D	-0.1	-0.3	0.4	0.0	-0.2	-0.1
Class E	0.0	-0.2	-0.3	0.1	0.0	-0.1
All	0.0	-0.1	0.1	0.0	-0.1	-0.2
Enc Time	100%			100%		
Dec Time	99%			100%		

Improved Visual Quality

- Kimono
- POC=17
- QP=32
- HE-LD



HM-3.0



Proposed

Subjective Quality Evaluation

- Blind tests
 - Not knowing which one is the anchor and which one is the proposed method
 - All tested videos with 4 QP values were evaluated by 5 people.
 - 4 tested videos were evaluated by more than 20 people including video experts and non-experts.
 - All bitstreams and decoders can be downloaded, and requests of the FTP site information can be sent to chihming.fu@mediatek.com
- The proposed method clearly showed better quality for the sky regions of Kimono
- For textured regions, it is difficult to tell differences between the anchor and the proposed method.

Crosscheck

- We thank Qualcomm for crosscheck (JCTVC-F366).
- All objective and subjective results were confirmed.

Conclusions

- Proposed to apply padding at virtual boundaries to remove all SAO line buffers for both LCU-based decoding and picture-based decoding
- Performance
 - Saved 1 luma line buffer
 - No noticeable changes in BD-rates
 - No noticeable run time differences
 - Achieved better subjective quality than the HM anchor