JCTVC-X0043
AHG 13: on Luma Adjustment

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Dolby Laboratories

Overview

- Luma Adjustment Background

- Problem statement
  - What problem luma adjustment tries to solve?
  - Why artifact is more visible in gamut boundary?

- Our study:
  - Impact on compression performance for anchor in BT. 2020 container
  - Mismatch of chroma upsampling filter in pre-/post- processing

- Conclusion

Background

- History

  - NCL Y'CbCr PQ 4:2:0 conversion process: source RGB->Y'CbCr420->reconstructed RGB

  - Technicolor: m35255, "About using a BT.2020 container for BT.709 content"
    - For Y'CbCr NCL 4:2:0 conversion process, when using BT. 709 container for some BT. 709 content (Market, FireEater, Tibul), chroma resampling can have some visible artifact.
      - Artifact most appears in color close to BT. 709 gamut boundary.
    - When following industrial practice by using BT. 2020 container for those BT. 709 content, artifact does not exist anymore.

  - Luma Adjustment
    - Ericsson: m35841, "Investigation of HDR Color Subsampling"
      - Solve artifact in BT. 709 container
    - Anchor uses BT. 2020 container, no artifact is shown in conversion process.
    - Anchor still employs algorithm mainly for two reasons
      - It can significantly improve a few objective metrics under the HDR CTC. For example, tPSNR-Y improves from 62.61dB to 69.77dB. => acknowledged subjectively hard to observe any improvement.
      - For future BT. 2020 content covering BT. 2020 gamut, hypothetically artifact may appear.
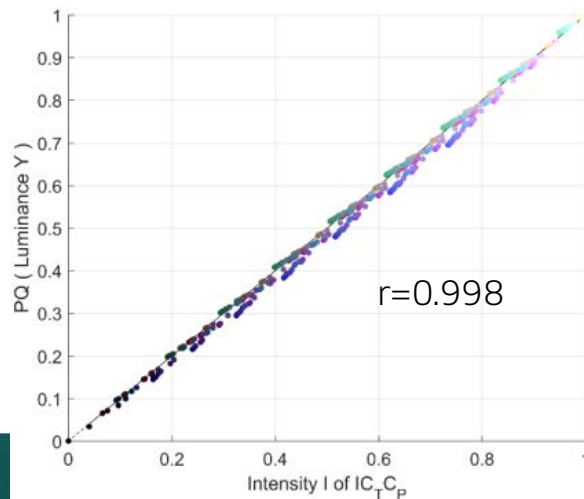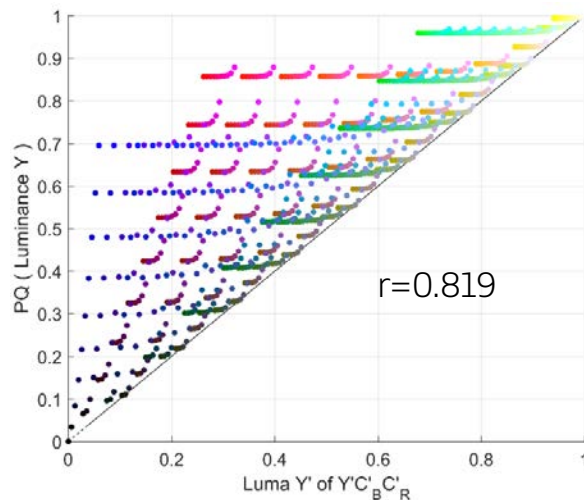
Luma Adjustment Overview

- Closed-loop conversion system
  - Basic idea: Modify Y' so the luminance value is closer to the source luminance.

- Algorithm employed in Anchor 3.2:
  - Substantial complexity increase: iterative process <= several contributions address this issue
  - Closed-loop: assuming upsampling filter is known at pre-processing chroma downsampling step.
  - Closed-loop ends before compression: after compression, benefit is diminished.

- Our contribution focuses on closed loop issue: compression and mismatched upsampling filter
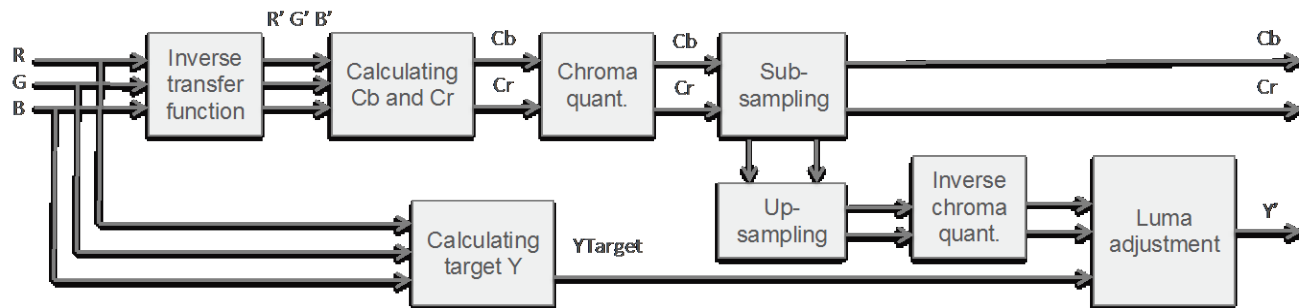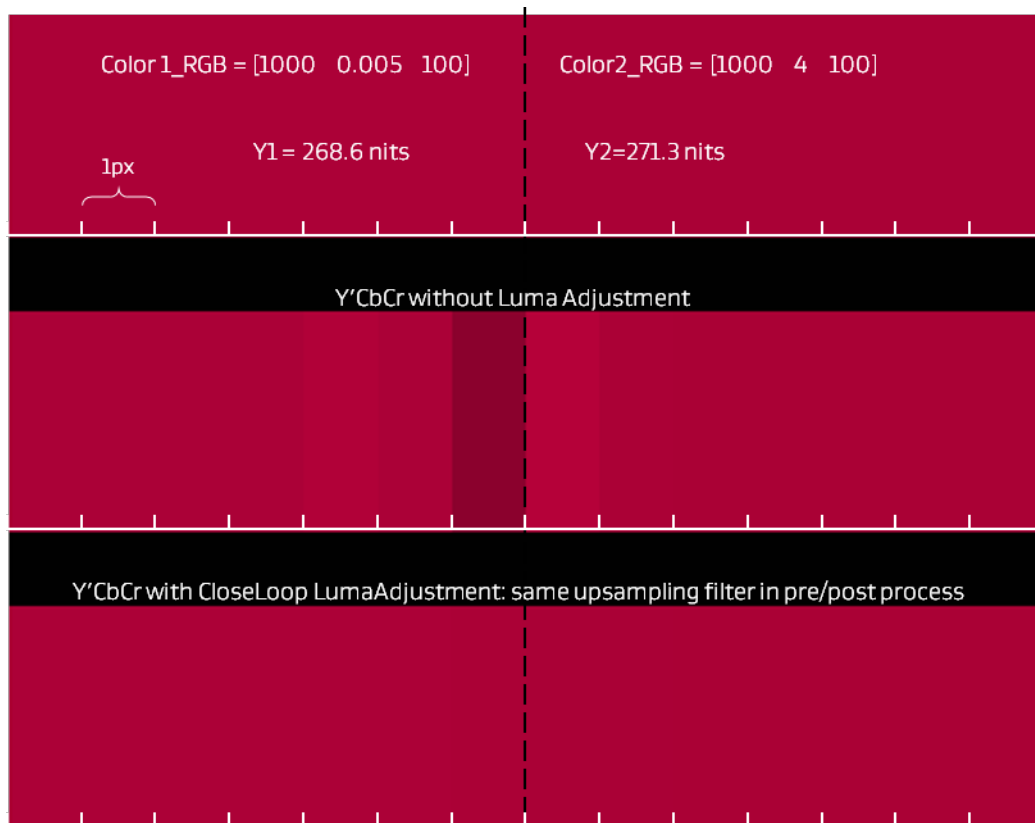
Problem Statement

- What problems luma adjustment tries to solve?
  - Non-constant luminance (NCL) representation of Y'CbCr
    - Poorly de-correlate luminance from color
    - When performing chroma subsampling, the distortion introduced in chroma channel can propagate to luminance to cause luminance shift.
      - Distortion tends to become large when color is more saturated.
      - It explains why chroma subsampling artifacts were mostly visible in colors close to gamut boundary where the color is more saturated.

- Luma Adjustment fixed the issue by modifying luma value to be closer to source luminance

- IC_TC_P has advantage dealing with this problem because I channel is more closer to PQ luminance than NCL Y'CbCr

r=0.819

r=0.998

Test Pattern Illustration of NCL Y'CbCr 4:2:0

Color1_RGB = [1000   0.005   100]   Color2_RGB = [1000   4   100]

Y1 = 268.6 nits   Y2=271.3 nits

1px

Y'CbCr without Luma Adjustment

Low complexity, one upsampling filter only in post process

Y'CbCr with CloseLoop LumaAdjustment: same upsampling filter in pre/post process

High complexity, close loop conversion; assuming identical upsampling filters are used in pre- and post- process

Test Pattern Illustration of IC_TC_P 4:2:0 vs. Y'CbCr NCL

Color 1_RGB = [1000   0.005   100]

Color2_RGB = [1000   4   100]

1px

Y1 = 268.6 nits

Y2=271.3 nits

Y'CbCr without Luma Adjustment

ICtCp (no Luma Adjustment)
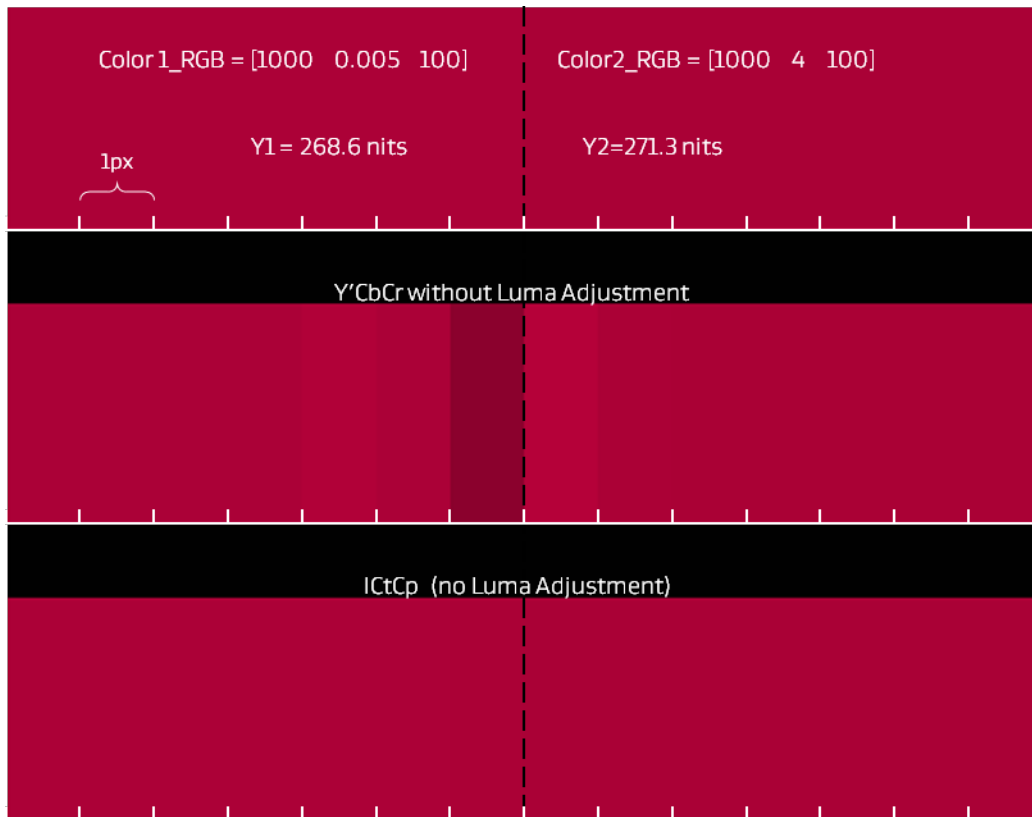
Same low complexity: one upsampling filter only in post process

r=0.819

r=0.998
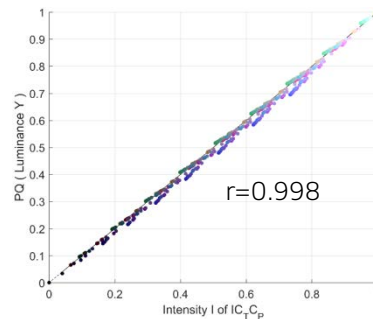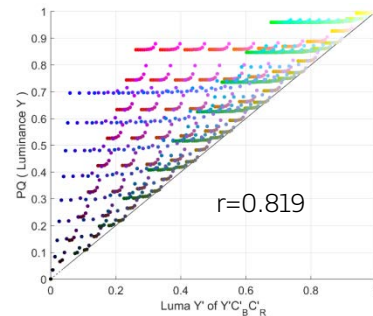
Impact: HDR/WCG CTC Conversion

- HDR/WCG CTC: HDR source is in BT. 2020 container

- Conversion
  - tPSNR-Y has gained about 7dB.
  - Since the tPSNR-Y value is above 60dB, subjectively no differences could be observed.

Conversion results of Y'CbCr with luma adjustment under HDR/WCG CTC

	tPSNR X	tPSNR Y	tPSNR Z	tPSNR XYZ	tOSNR-XYZ	DE100	MD100	PSNRL100
FireEaterClip4000r1	63.18	70.21	52.23	56.60	55.01	49.16	24.73	58.38
Market3Clip4000r2	55.60	69.61	45.96	50.27	49.89	36.79	21.87	47.89
SunRise	59.67	69.61	50.92	55.09	54.57	37.88	24.22	47.94
BikeSparklers cut 1	47.54	69.78	37.04	41.44	39.83	34.19	21.82	51.48
BikeSparklers cut 2	48.61	69.76	38.42	42.79	41.63	34.52	21.77	51.08
GarageExit	56.37	69.73	47.09	51.35	50.05	38.10	22.85	49.78
ShowGirl2Teaser	53.44	69.24	44.97	49.12	47.85	39.29	22.50	52.90
StEM_MagicHour cut 1	54.05	69.83	39.98	44.58	42.05	36.57	24.96	52.16
StEM_MagicHour cut 2	51.52	69.89	38.72	43.27	40.81	36.00	24.71	52.68
StEM_MagicHour cut 3	50.92	69.94	37.51	42.08	39.66	36.07	24.28	52.94
StEM_WarmNight cut 1	52.58	69.94	38.46	43.07	40.65	36.67	25.11	52.94
StEM_WarmNight cut 2	54.20	70.18	39.14	43.78	41.72	37.06	23.35	52.81
BalloonFestival	53.73	69.59	45.06	49.27	51.73	40.68	21.15	48.24
EBU_04_Hurdles	54.15	69.59	46.67	50.71	49.18	36.87	22.23	47.34
EBU_06_Start	51.23	69.60	44.07	48.07	47.75	36.12	21.28	47.71
Average	**53.79**	**69.77**	**43.08**	**47.43**	**46.16**	**37.73**	**23.12**	**51.08**

Conversion results of Y'CbCr without luma adjustment under HDR/WCG CTC

|	tPSNR X	tPSNR Y	tPSNR Z	tPSNR XYZ	tOSNR-XYZ	DE100	MD100	PSNRL100
FireEaterClip4000r1	58.73	64.38	53.39	56.78	54.86	48.42	24.69	55.05
Market3Clip4000r2	53.48	62.05	46.24	50.16	49.75	36.77	21.88	46.85
SunRise	58.60	67.76	51.34	55.28	54.62	37.87	24.21	47.70
BikeSparklers cut 1	46.39	58.98	37.27	41.52	39.81	34.17	21.82	48.20
BikeSparklers cut 2	47.57	59.92	38.65	42.87	41.60	34.51	21.77	48.46
GarageExit	55.21	65.61	47.08	51.17	49.89	38.08	22.85	48.77
ShowGirl2Teaser	52.11	62.98	44.86	48.81	47.49	39.23	22.50	50.84
StEM_MagicHour cut 1	52.66	63.91	40.06	44.59	42.01	36.55	24.95	50.33
StEM_MagicHour cut 2	50.22	62.70	38.62	43.08	40.59	35.97	24.70	50.27
StEM_MagicHour cut 3	49.48	61.22	37.39	41.88	39.46	36.03	24.28	50.10
StEM_WarmNight cut 1	51.10	61.83	38.65	43.16	40.73	36.64	25.11	50.59
StEM_WarmNight cut 2	52.05	61.07	39.45	43.96	41.81	37.00	23.35	49.76
BalloonFestival	52.78	62.06	45.61	49.54	51.91	40.62	21.15	46.98
EBU_04_Hurdles	52.12	62.75	46.85	50.41	48.82	36.84	22.23	45.36
EBU_06_Start	49.73	61.87	44.19	47.83	47.52	36.10	21.27	46.11
Average	**52.15**	**62.61**	**43.31**	**47.40**	**46.06**	**37.65**	**23.12**	**49.02**

Impact: HDR/WCG CTC Compression

- Compression
  - BDrate penalty for not using luma adjustment is only 0.5% for tPSNY, 0.5% for DE100, 0.3% for PSNRL100.
  - Subjectively not able to observe quality difference between Anchor v3.2 and Anchor v3.2 without luma adjustment

Compression results of Anchor 3.2 without luma adjustment against Anchor 3.2 (with luma adjustment) under HDR/WCG CTC

		X	Y	Z	XYZ	tOSNR-XYZ	DE100	MD100	PSNRL100
class A	FireEaterClip4000r1	3.8%	2.7%	-4.1%	1.2%	1.3%	2.5%	-2.5%	1.9%
	Market3Clip4000r2	1.1%	0.3%	-0.7%	0.1%	0.3%	0.5%	-66.9%	0.3%
	SunRise	1.3%	0.3%	-2.3%	-0.4%	-0.1%	1.0%	15.9%	0.3%
class B	BikeSparklers cut 1	2.0%	0.8%	-3.4%	-0.3%	0.2%	0.2%	-0.4%	0.6%
	BikeSparklers cut 2	1.8%	0.7%	-3.5%	-0.3%	-0.1%	0.2%	1.4%	0.4%
	GarageExit	0.9%	0.1%	0.3%	0.4%	0.3%	0.5%	1.8%	0.1%
class C	ShowGirl2Teaser	1.3%	0.4%	-0.2%	0.5%	3.7%	0.7%	22.2%	0.3%
class D	StEM_MagicHour cut 1	0.5%	0.2%	-0.6%	-0.1%	-0.1%	-0.3%	-8.5%	0.2%
	StEM_MagicHour cut 2	0.7%	0.3%	-0.2%	0.2%	0.0%	0.0%	-3.5%	0.3%
	StEM_MagicHour cut 3	0.7%	0.4%	0.0%	0.3%	0.1%	0.2%	2.6%	0.3%
	StEM_WarmNight cut 1	0.8%	0.1%	-0.8%	-0.1%	-0.2%	0.3%	1.6%	0.0%
	StEM_WarmNight cut 2	1.0%	0.2%	-1.3%	-0.3%	-0.1%	0.4%	37.6%	0.1%
class G	BalloonFestival	1.1%	0.6%	-2.5%	-0.6%	-0.2%	1.0%	1.0%	0.7%
class H	EBU_04_Hurdles	1.8%	0.0%	-1.0%	0.0%	0.0%	0.4%	13.4%	-0.1%
	EBU_06_Start	2.6%	0.1%	-1.1%	0.3%	0.3%	0.1%	4.2%	-0.1%
	Overall	1.4%	0.5%	-1.4%	0.1%	0.4%	0.5%	1.3%	0.3%

Luma Adjust Pre and Post Processing
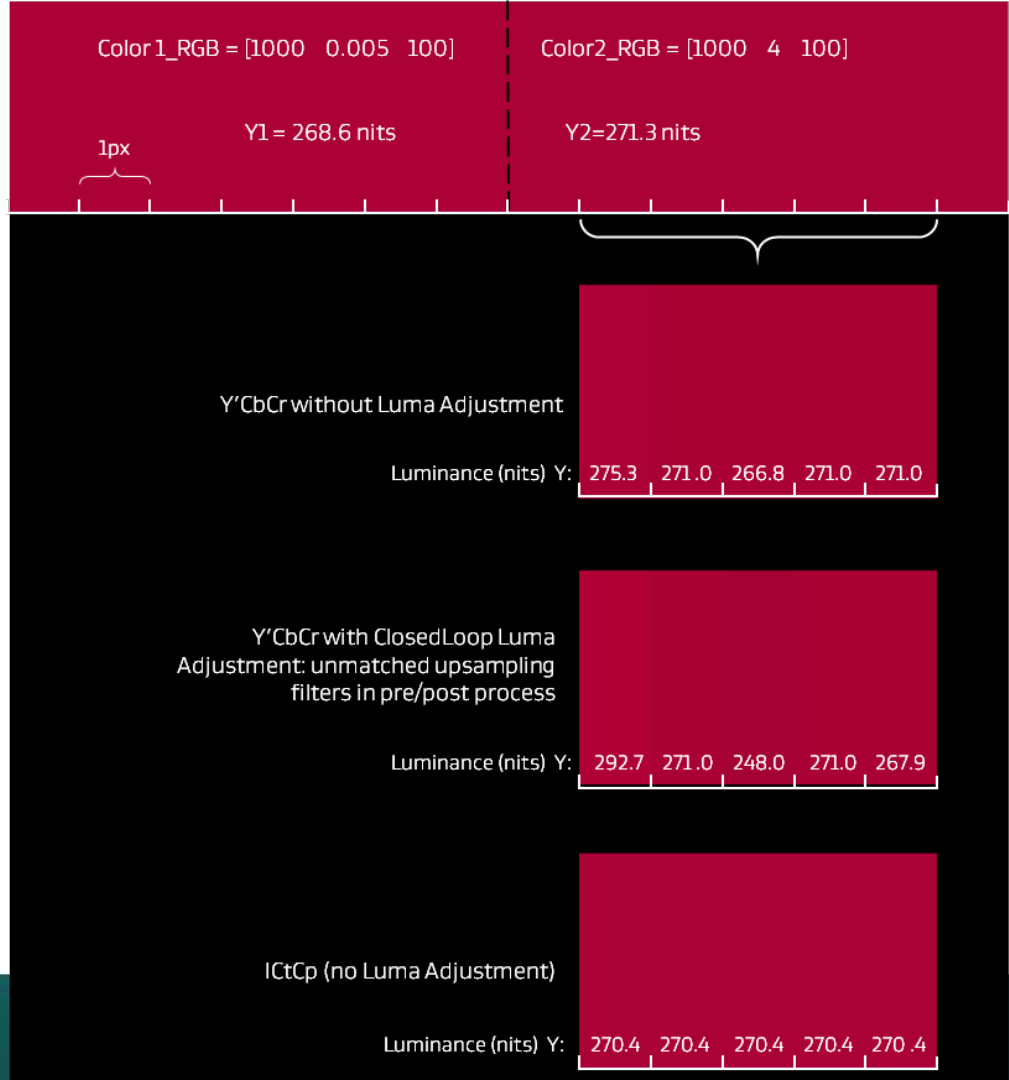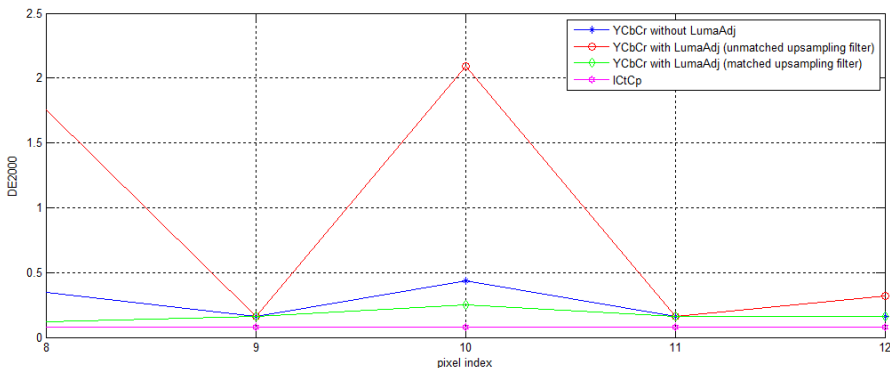

Pre-processing
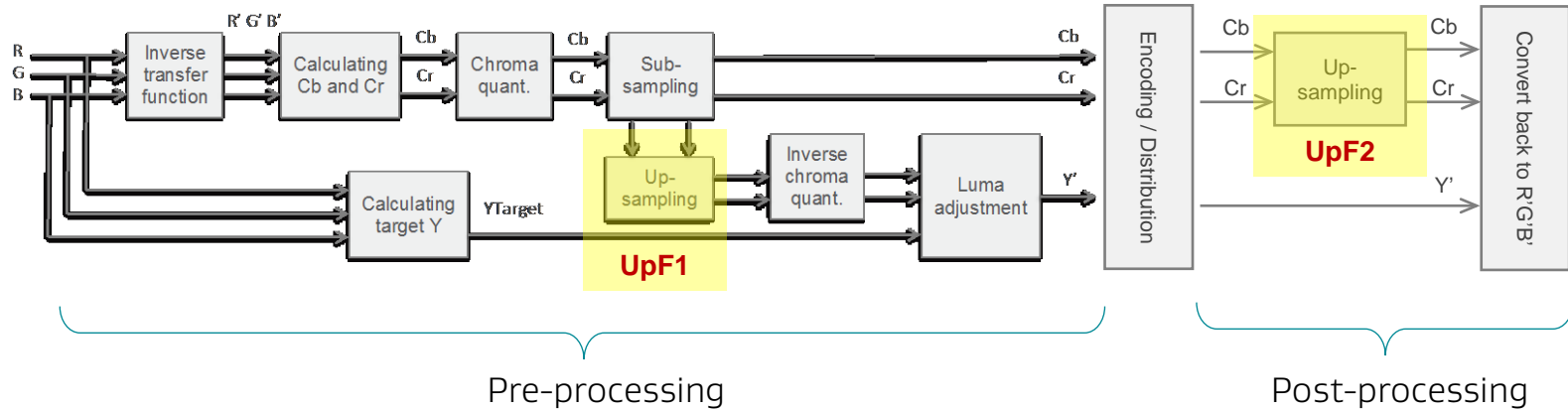
Post-processing

- **In Real Applications:** Decoder side post processing does not necessarily know what up-sampling filter was used to create the subsampled chroma components in pre-processing;

- What happens if UpF1 is different from UpF2?

Conversion: Un-matched Upsampling Filter

- HDR/WCG CTC Anchor 3.2 conversion:
  - Lanczos-2 chroma upsampling filter [-1 9 9 -1]/16 is used in both 4:4:4 to 4:2:0 pre-processing and 4:2:0 to 4:4:4 post-processing.

- In real application, hard to control upsampling filter in both ends.

- Study: what if different upsampling filter is used?
  - Un-matched upsampling filters may introduce new color artifacts
  - Example:
    - Pre-processing: TM filter [+21.0, -52.0, +159.0, +159.0, -52.0, +21.0]/256
    - Post-processing: Lanczos-2 chroma upsampling filter (default)
    - Observe luma adjustment introduce new rippling artifact
    - Same effect is observed if exchanging filters in pre-/post-processing.

Illustration: Un-matched Upfilter

- Observe new rippling artifact
  - No such artifact if up-filter is matched.

- IC_TC_P does not need to use luma adjustment.

Color 1_RGB = [1000 0.005 100]   Color2_RGB = [1000 4 100]

Y1 = 268.6 nits   Y2=271.3 nits

1px

Y'CbCr without Luma Adjustment

Luminance (nits) Y: | 275.3 | 271.0 | 266.8 | 271.0 | 271.0

Y'CbCr with ClosedLoop Luma Adjustment: unmatched upsampling filters in pre/post process

Luminance (nits) Y: | 292.7 | 271.0 | 248.0 | 271.0 | 267.9

ICtCp (no Luma Adjustment)

Luminance (nits) Y: | 270.4 | 270.4 | 270.4 | 270.4 | 270.4

Legend:
- YCbCr without LumaAdj
- YCbCr with LumaAdj (unmatched upsampling filter)
- YCbCr with LumaAdj (matched upsampling filter)
- ICtCp

Conclusion

- Luma Adjustment
  - In Anchor 3.2 dataset (BT.2020 container), the luma adjustment algorithm does not show any subjective benefits when no compression is applied.
  - Further, when compression is applied, there is hardly any benefit left both subjectively and objectively.
  - If there is a mismatch of upsampling filters in pre- and post- processing, applying luma adjustment may introduce new chroma sub-sampling artifact.

- IC_TC_P: a better iso-luminance color difference encoding space than NCL Y'CbCr
  - Achieve better quality than NCL Y'CbCr without the additional complexity associated with luma adjustment.
  - No need for closeloop luma adjustment ➔ no potential problem caused by mismatched upsampling filters in pre- and post-processing.

- Suggest more careful study to recommend luma adjustment in real applications.