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Perceptual Video Coding Optimization Techniques: Most Recent Trends and Future Directions

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SCTE CABLE-TEC EXPO® 22
SEPTEMBER 19-22 • PHILADELPHIA, PA

2022 Fall Technical Forum
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Contrast Sensitivity Function (CSF)

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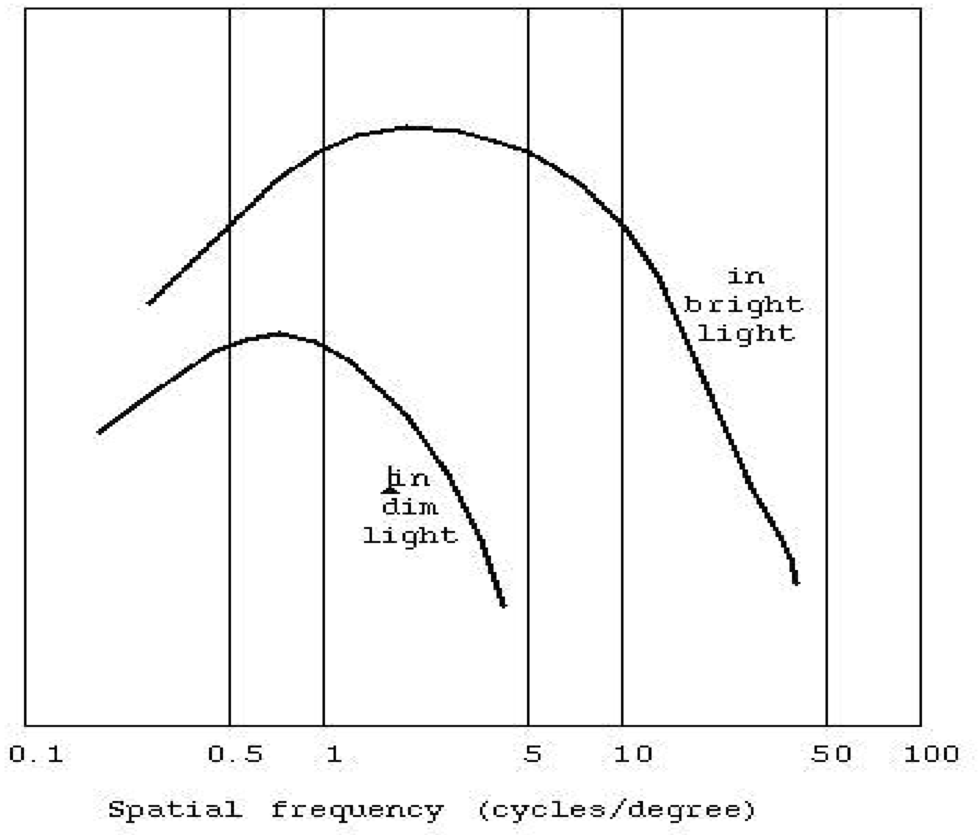
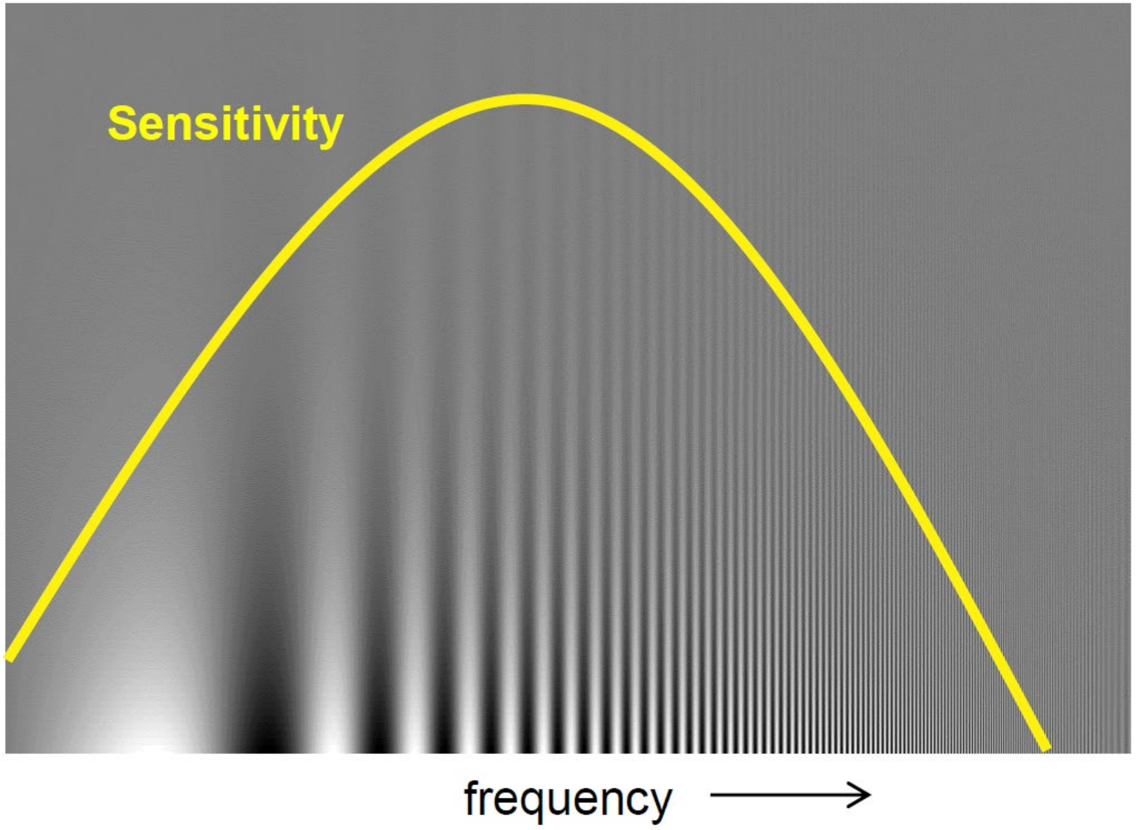
Relative Sensitivity of Human Visual System (Log Scale)





[Reinhard2016]

The contrast detection threshold depends on the spatial frequency of a stimulus.

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Contrast Sensitivity Function (CSF) – Cont.

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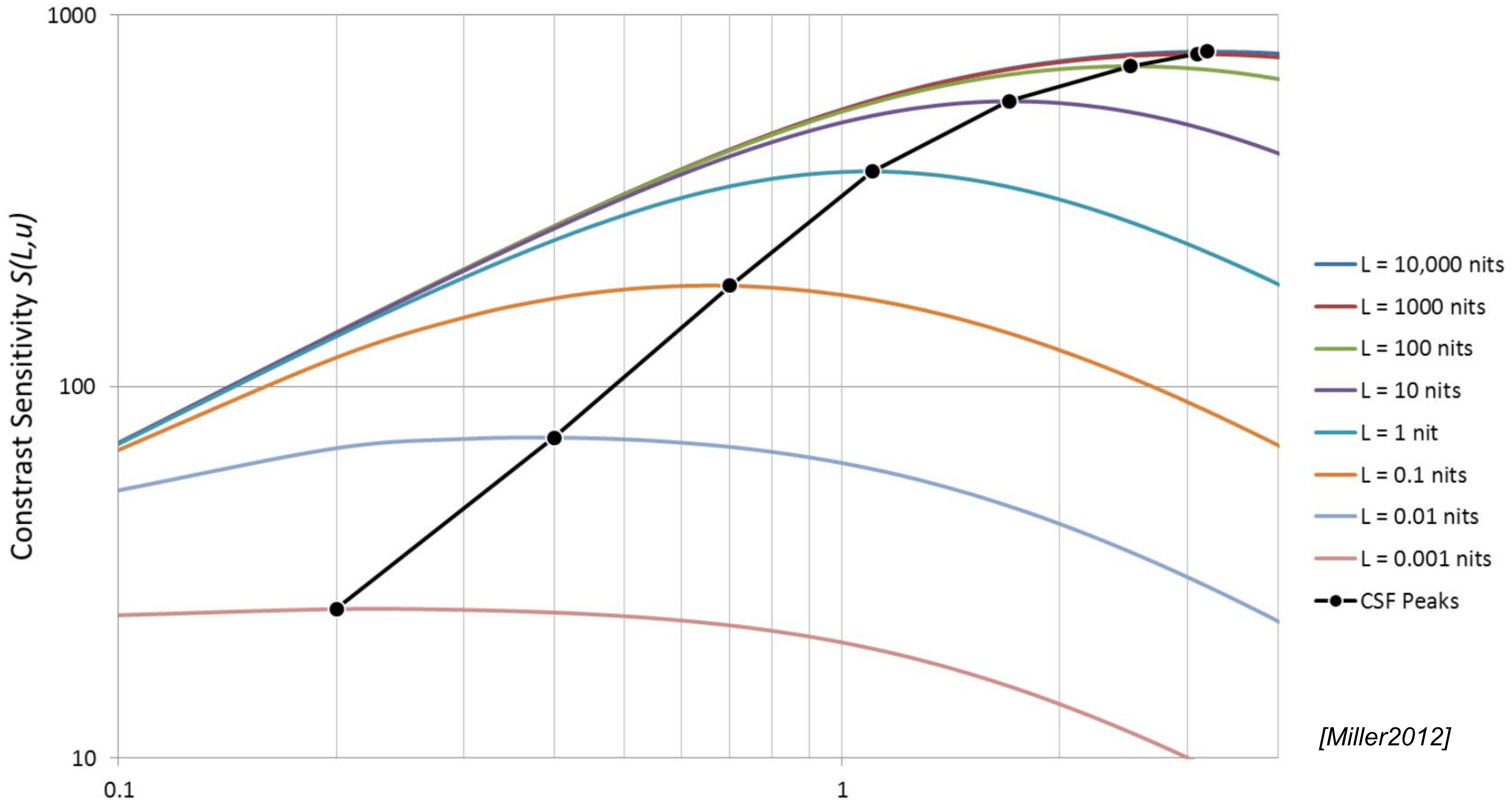
Tracking peaks of Contrast Sensitivity Functions



The peak of the CSF at a given luminance level refers to the lowest detection threshold at that luminance level.

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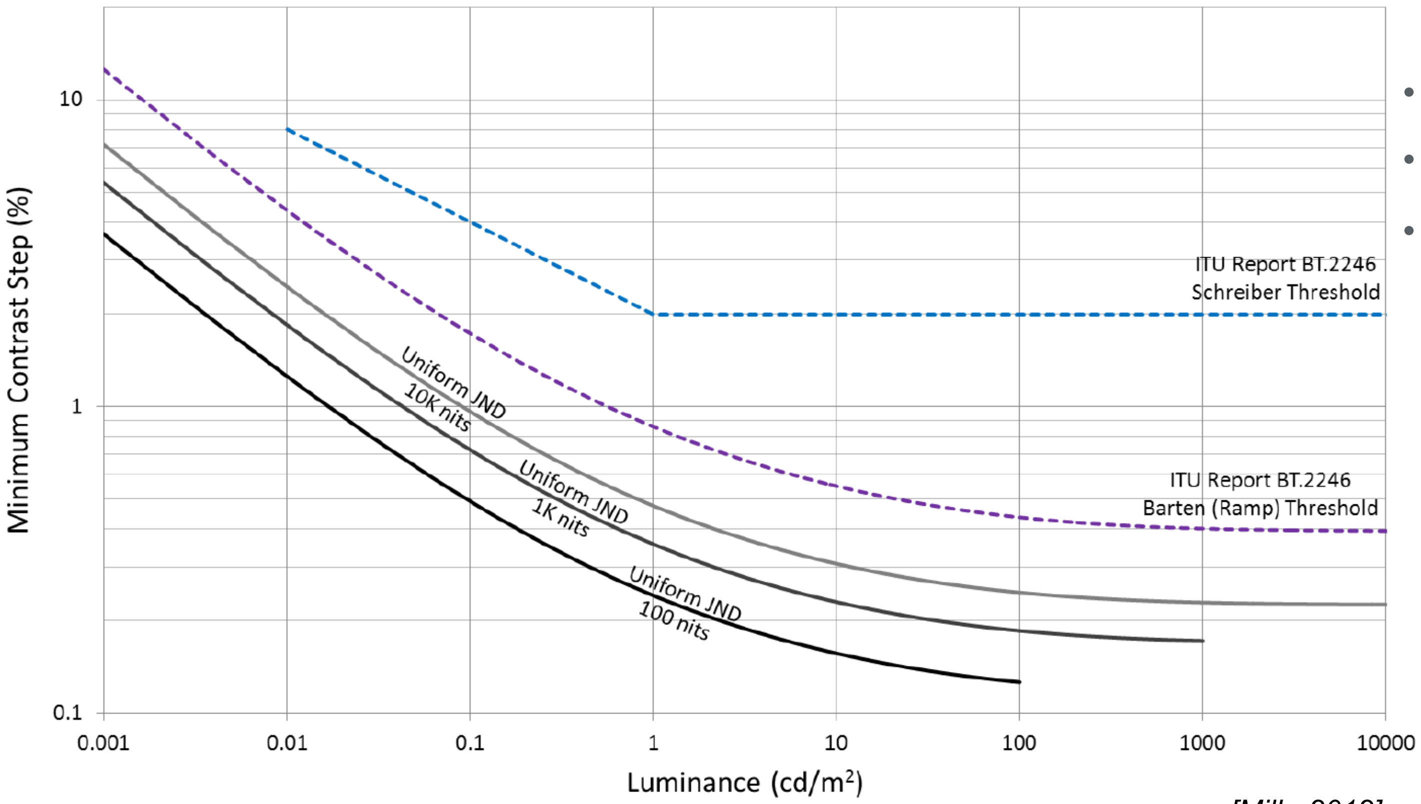
Just Noticeable Difference (JND) Curves

- **Converting CSF to Contrast Steps;**
- **Building Optimized Curves.**



[Miller2012]

Functional Approximation is Desired:

- Functional form instead of look-up table (LUT);
- Helpful for standardization;
- Simpler to document.

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Perceptual Quantizer (PQ) Electro-Optical Transfer Function (EOTF)

- Maximize the dynamic range of the signal by setting each quantization step to be **proportional to the Just Noticeable Difference (JND);**
- **Most efficient use of bits throughout entire range!**
- Iterative Electro-Optical Transfer Function (EOTF) computation;
- Exploiting the Barten CSF model in the range 0 to 10000 nits.

Defined in SMPTE ST 2084:

The linear color values proportional to the desired optical output Y are related to the non-linear color values proportional to an input signal V.

$$Y = L\left(\frac{V^{1/m} - c_1}{c_2 - c_3 V^{1/m}}\right)^{1/n}$$

$0 \leq V \leq 1$
$L = 10{,}000$
$m = 78.8438$
$n = 0.1593$
$c_1 = 0.8359$
$c_2 = 18.8516$
$c_3 = 18.6875$

[Reinhard2016; Miller2012]

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Contrast Sensitivity Function (CSF) – Cont.

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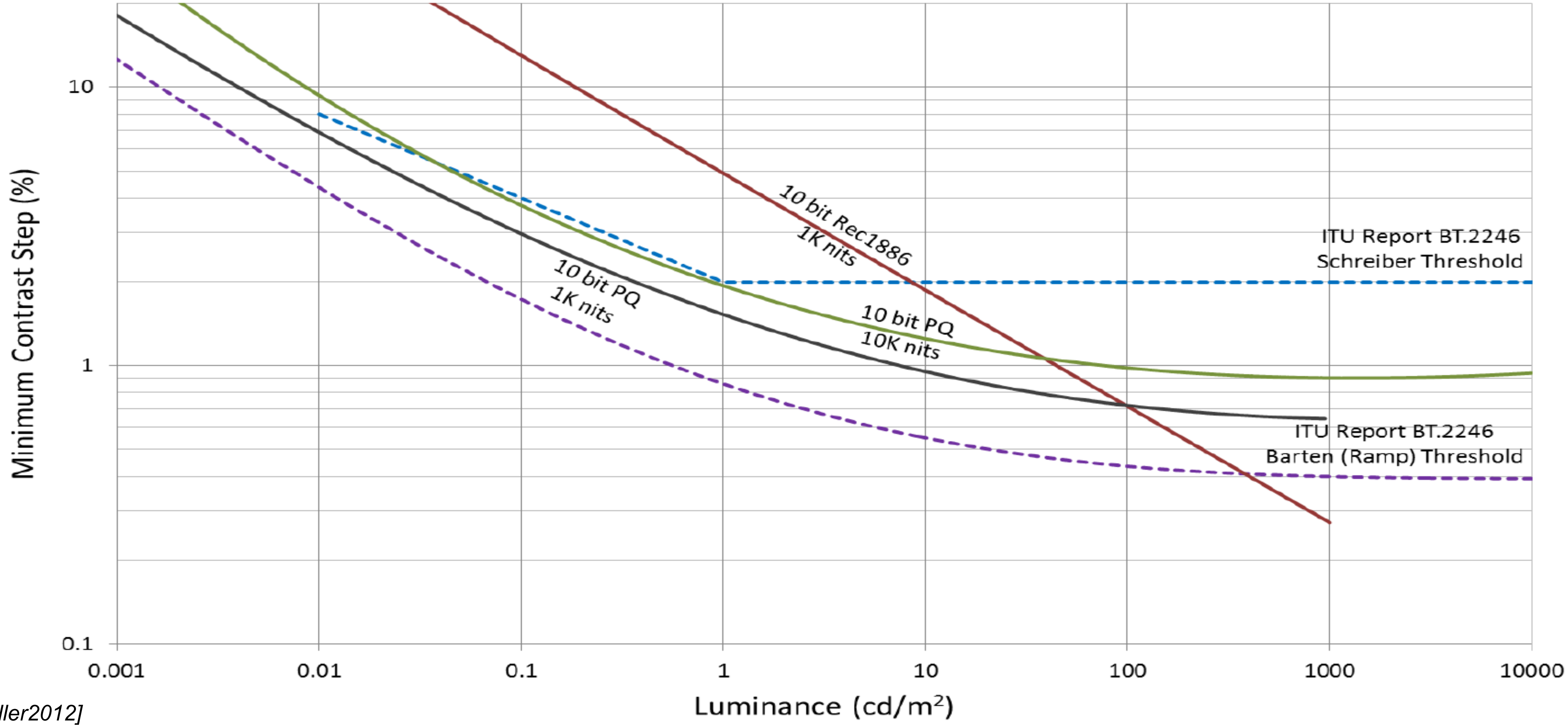
- **10-bit PQ still near or below perceptual thresholds.**

- **10 bit video is the norm;**
- **HEVC Main 10 profile is used for distribution.**



[Miller2012]

HEVC Video Coding Standard

- **The H.266/MPEG-HEVC standard was approved and published in 2013, as Recommendation ITU-T H.265 and ISO/IEC 23008-2;**

- **HEVC provides approximately twice compression efficiency of its predecessor H.264/MPEG-AVC;**

- **The deployment of the High-Efficiency Video Coding (HEVC) is constantly increasing.**

- ➢ **2013: HEVC version 1;**
- ➢ **2014: HEVC version 2 -** Range Extensions (RExt), Scalable Extensions (SHVC), Multiview Extensions (MV-HEVC);
- ➢ **2015: HEVC version 3 -** 3D Video Coding Extensions (3D-HEVC);
- ➢ **2016: HEVC version 4 -** Screen Content Coding Extensions (HEVC-SCC);
- ➢ **2018: HEVC version 5 -** additionally containing SEI messages that include omnidirectional video SEI messages, a Monochrome 10 profile, a Main 10 Still Picture profile;
- ➢ **2019: HEVC versions 6 and 7 -** additionally containing SEI messages for SEI manifest and SEI prefix, additionally containing the fisheye video information SEI message and the annotated regions SEI message, along with some corrections to the existing specification text.
- ➢ **2021: HEVC versions 8 -** additionally containing a shutter interval information SEI message.

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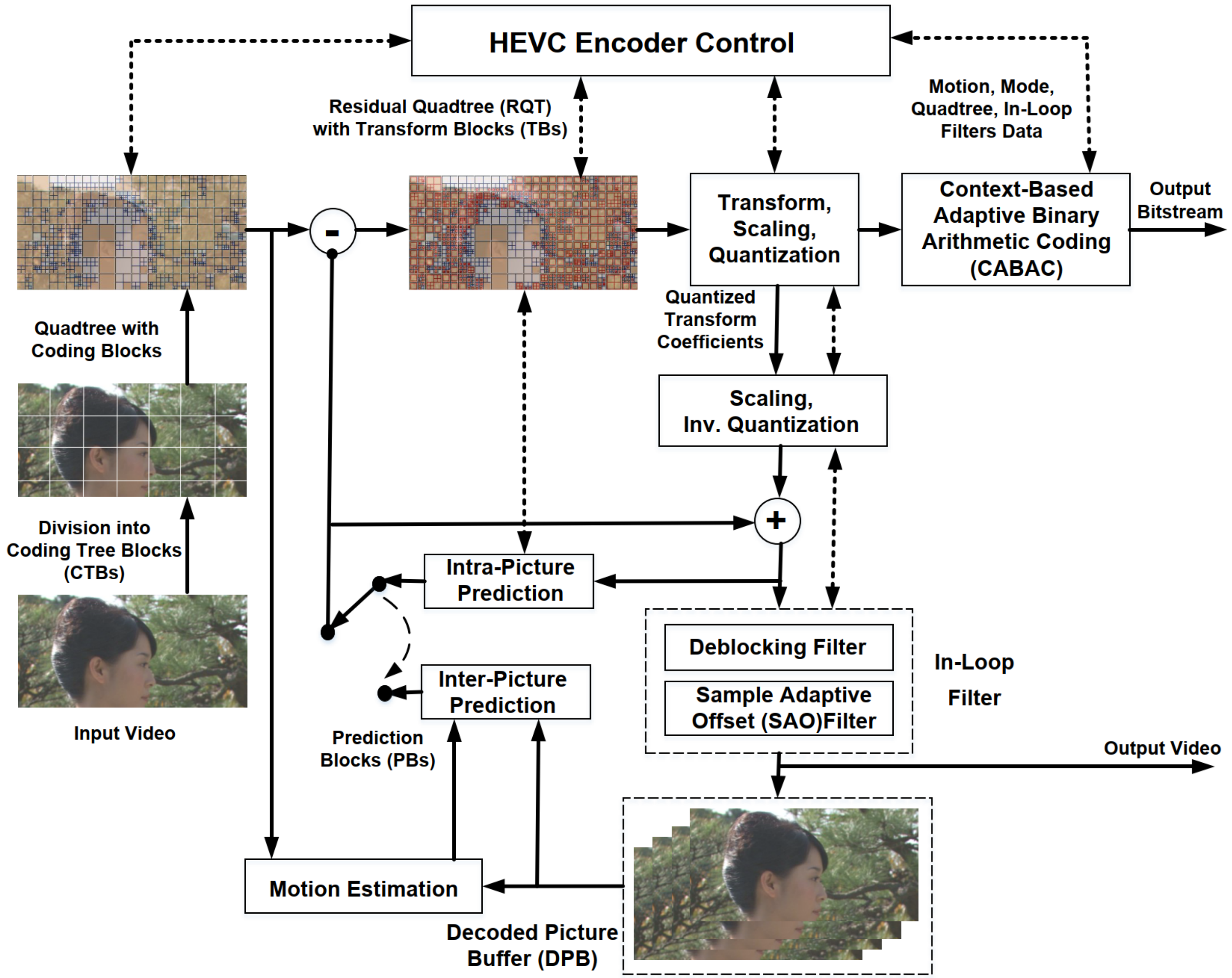
H.265/MPEG-HEVC Coding Loop



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HEVC Quantization Matrices

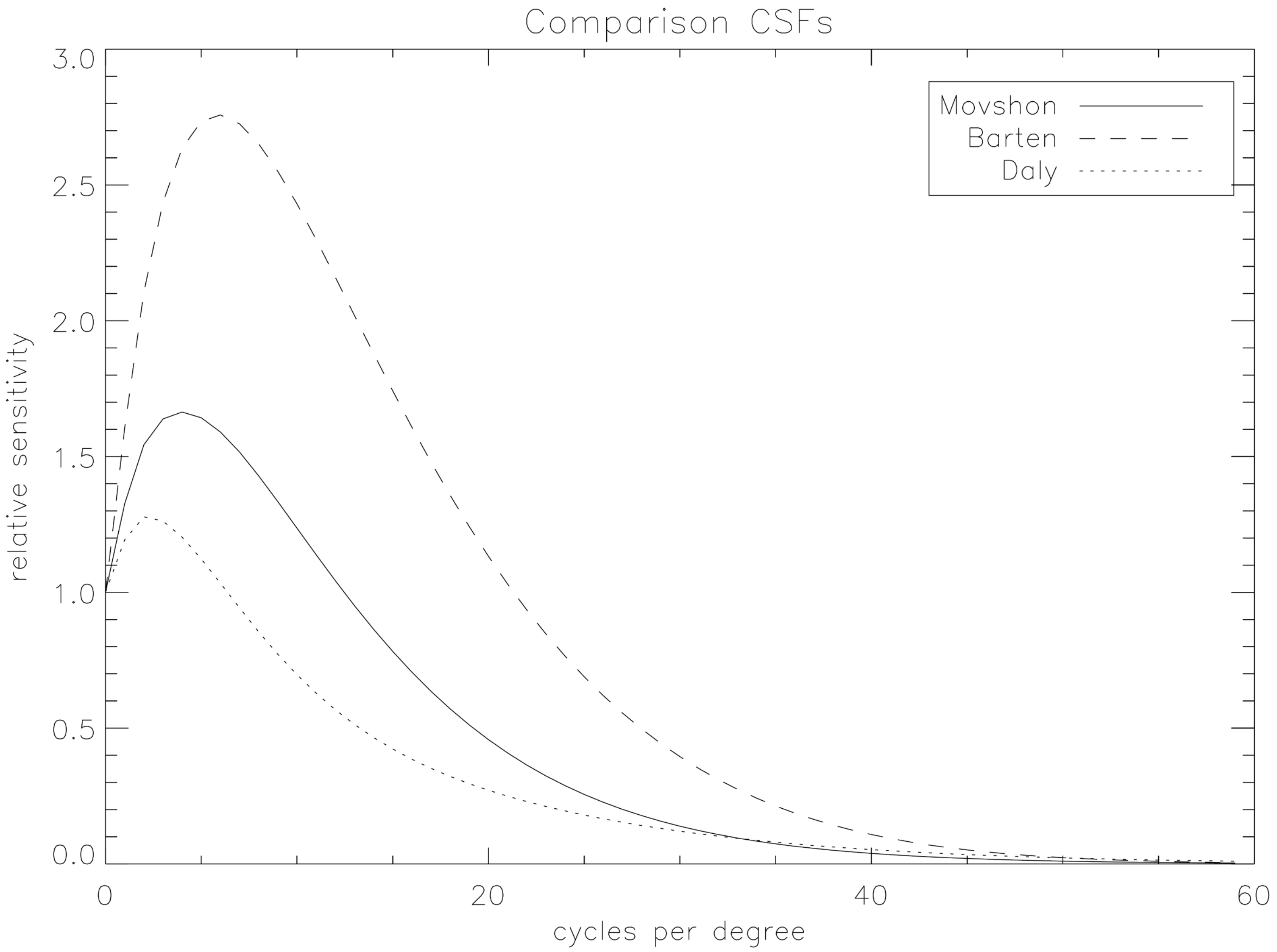
- The default quantization matrices of the HEVC video compression standard follow a **Daly CSF Model** developed for the **JPEG image compression standard** in 1993;

- However, initially the JPEG quantization matrices has been developed for **Standard Dynamic Range (SDR) low resolution images** (e.g., 512x512 images of "Lena" and "Barbara");

- So, the benefit of using **default HEVC quantization matrices for compressing HDR high resolution videos (e.g., 3840x2160) is very limited;**

- In addition, the **Daly CSF model does not consider as many Human Visual System (HVS) parameters as Barten model does**, and it follows the HVS CSF less accurately, thereby utilizing less accurate human visual frequency weighting matrix (FWM).

HEVC Quantization Matrices



[Johnson&Fairchild2002]

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Proposed Perceptual Quantization Matrices

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The following steps have been carried out for generating perceptual quantization matrices (QMs):

1. **Fitting a Daly CSF Model curve into the Barten CSF Model curve** to derive a human visual **Frequency Weighting Matrix (FWM)**;
2. **Optimizing the FWM coefficients**, which are in the range between 0 and 1, by

   raising them into a power of β: **FWM (i, j)= FWM (i, j)   where β > 1 ,** thereby:

   - Relatively small coefficients will become much smaller;
   - Relatively large coefficients will be insignificantly reduced.

Thereby, **high frequencies are attenuated much stronger than low frequencies.**

3. For **chroma FWM, raising each coefficient into a larger power** due to reduced sensitivity of Human Visual System (HVS) to chrominance.

4. **Deriving corresponding QM coefficients** for Intra and Inter-picture prediction as well as for Luma and Chroma components.

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Experimental Results

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The experiments were conducted with the following 4K HDR video sequences:

1) "Lucy" **(provided by NBCUniversal)** – action scenes, mixed motion;
2) "Everest" **(provided by NBCUniversal)** – mountains view, snow scenes, mostly slow motion;
3) "Warcraft" **(provided by NBCUniversal)** – various computer-generated content, mostly fast motion;
4) "Regatta" **(provided by UltraHD forum)** – water scenes, mostly fast motion.

Tested Video Sequences	No. of Frames	Frame Rate Per Second	Resolution	Dynamic Range
Lucy	8425	24	3840x2160	HDR
Everest	7202	23.98	3840x2160	HDR
Warcraft	8177	23.98	3840x2160	HDR
Regatta	5841	59.94	3840x2160	HDR

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Experimental Results (Cont.)

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For UltraHD Displays:

Target Bit-Rate Configuration

Tested Video Sequences	BD-BR SSIMPlus Proposed QMs vs. Default HEVC QMs	BD-BR SSIMPlus Proposed QMs vs. no QMs
Lucy	-13.5%	-15.5%
Everest	-3.8%	-5.9%
Warcraft	-6.1%	-6.0%
Regatta	-10.6%	-11.9%

Regatta Video Sequence – 5841 frames, 3840x2160, HDR, 59.94fps

Target Bit Rate	SSIMPlus (no QMs)	SSIMPlus (Default HEVC QMs)	SSIMPlus (Proposed QMs)	Minimal SSIMPlus (no QMs)	Minimal SSIMPlus (Default HEVC QMs)	Minimal SSIMPlus (Proposed QMs)
6,000	83.09	83.14	84.16	68	68	70
8,000	86.31	86.42	87.49	74	74	75
10,000	88.61	88.74	89.80	78	78	79
12,000	90.28	90.42	91.40	81	81	83
14,000	91.49	91.65	92.56	84	84	85

As it is seen, there are very significant SSIMPlus score improvements of more than 1 point, which is visually clearly noticeable.

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Experimental Results (Cont.)

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For Mobile Devices:

Target Bit-Rate Configuration

Tested Video Sequences	BD-BR SSIMPlus Proposed QMs vs. Default HEVC QMs	BD-BR SSIMPlus Proposed QMs vs. no QMs
Lucy	-15.5%	-16.8%
Everest	-21.4%	-22.2%
Warcraft	-5.9%	-7.8%
Regatta	-22.2%	-23.9%

Regatta Video Sequence – 5841 frames, 3840x2160, HDR, 59.94fps

Target Bit Rate	SSIMPlus (no QMs)	SSIMPlus (Default HEVC QMs)	SSIMPlus (Proposed QMs)	Minimal SSIMPlus (no QMs)	Minimal SSIMPlus (Default HEVC QMs)	Minimal SSIMPlus (Proposed QMs)
2,000	76.82	76.85	78.61	48	48	54
3,000	82.06	82.10	83.48	58	58	65
4,000	84.82	84.87	86.10	65	66	72
5,000	87.20	87.28	88.48	73	73	77

As it is seen, there are very significant SSIMPlus score improvements of up to about 2 point, which is visually clearly noticeable. In addition, the minimal SSIMPlus score in increased by a very significant number of up to 7 points.

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Introduction: Visual Masking

- ✓ **We transport more pixels**: vast majority of new TVs support UltraHD, more 4K linear content is available
- ✓ In 2021 OTT streaming accounted for 71% of Comcast broadband traffic ;
- ✓ **>97.5% time our players are playing highest-resolution representation**
- ✓ Aggregated **CDN storage and egress costs** are key components in the overall cost of delivery
- ✓ **Codec inertia:** changing codecs is expensive due to costs of replacing old CPE, multi-codec consumes more storage
- ✓ **Streaming-oriented HVS-based optimizations are the key target.**

- One of the promising approaches for increasing video coding gain is applying ***visual masking***:
  - **Reduced capacity of perceiving and fine detail around a scene cut**
  - **Scene cut locations are unique – optimizations there result in aggregate peak bandwidth reduction**

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Introduction: Visual Masking (Cont.)

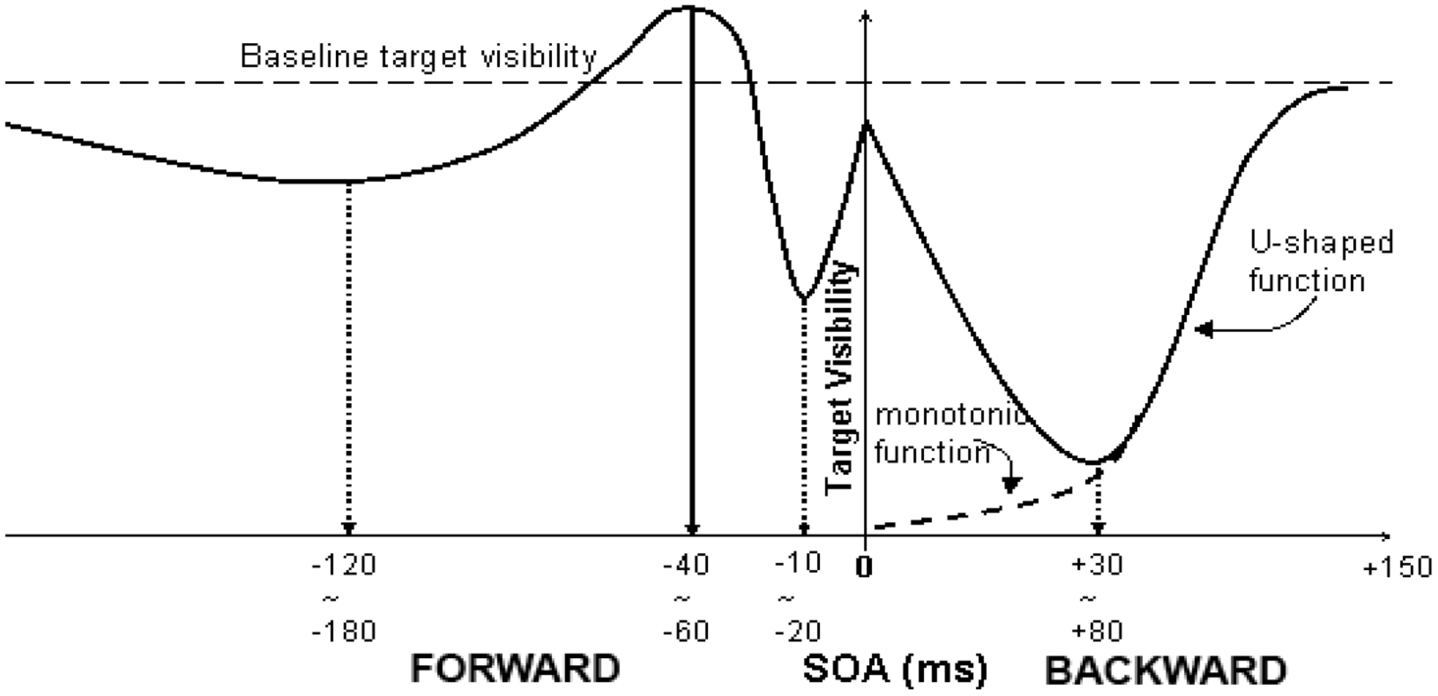
- Masking approach is based on so-called **interruption theory**: under certain conditions, **a pattern mask can erase the target data** (e.g., a video frame content) *[Adzic2014]*

- Generally, backward masking reduces visibility of the target stronger than forward

- **Low energy stimuli results in U-shaped** visibility over time, while **high energy stimuli results in a monotonic function**

- Many impairments introduced by **quantization prior to a scenecut would be masked by the new scene after the scenecut** *[Adzic2014]*

Human Visual System psychophysical model of visual masking: Visibility of a target (e.g., a scenecut), as a function of Time:



[Breitmeyer&Ogmen2007, Adzic2014]

The increase in quantization of frames with low visibility leads to an almost free bitrate reduction

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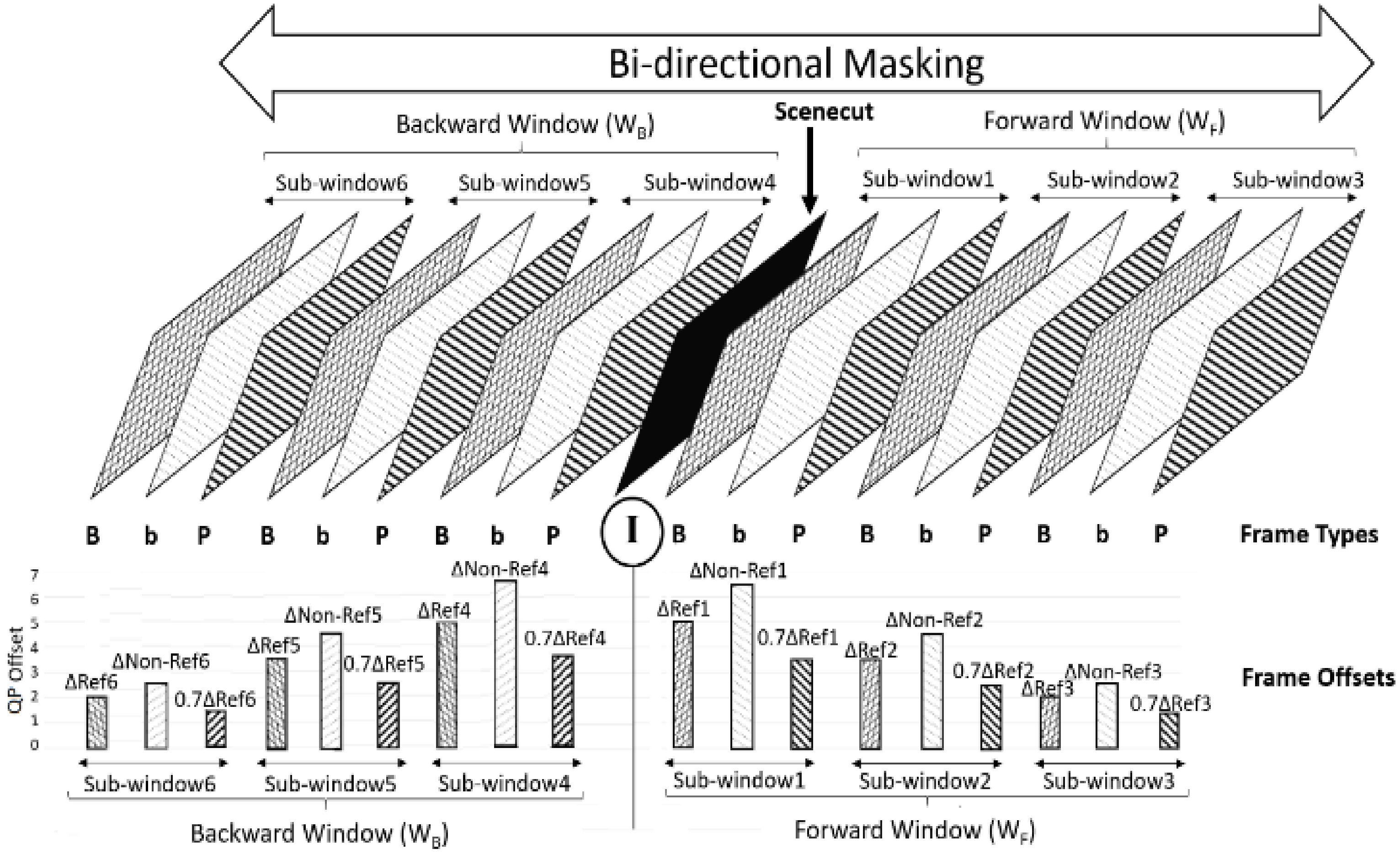
Joint Forward and Backward Masking Framework

- Three **forward sub-windows** *1* to *3*, and three **backward sub-windows** *4* to *6*.
- Each **masking window can have a different length** and for each window;
- A set of different QPs can be assigned by adding the **QP offsets;**
- Different QP offsets can be assigned **separately to reference frames and to non-reference frames** within each masking window.
- The QP offsets for *P-frames* are automatically **reduced by 30%** to improve their quality and to increase a coding gain.
- No QP offsets are applied to *I frames.*



Test Methodology and Evaluation Setup

Wide range of **cinematic content**, mostly in **10-bit UltraHD**, selected for testing *[IMDB, UHD_Forum]*:

(a) "Lucy" – includes many action scenes, **many fast motion scenes**, mixed natural and computer-generated content;

(b) "Warcraft" – includes various **computer-generated content**, mostly fast motion scenes;

(c) "Everest" – includes mountains views, snow scenes, **mostly slow motion scenes;**

(d) "Regatta" – includes mainly water sports, many **fast motion scenes**.

8-bit UltraHD **"El Fuente"** video sequence with **mixed content**: both fast and slow motion *[UHD_Forum]*.

No	Sequence name	Resolution	Frame count	Frame rate	Duration (sec.)	Bit depth
1	**El Fuente**	3840x2160	1500	60	25	8
2	**Lucy**	3840x2160	480	24	20	10
3	**Warcraft**	3840x2160	495	23.98	~20	10
4	**Everest**	3840x2160	480	23.98	~20	10
5	**Regatta**	3840x2160	1199	59.94	~20	10

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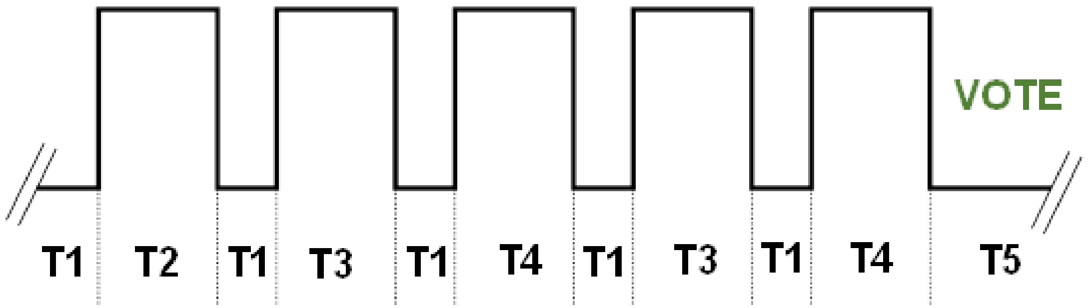
Test Methodology and Evaluation Setup (Cont.)

- The **Double Stimulus Impairment Scale (DSIS) Methodology of the Experimental Results Analysis *Variant II*** method was selected for conducting the subjective assessments.
- The original video sequence (substantially uncompressed) is presented once prior to displaying a pair of tested video sequences.

The exact order for displaying the presented video content:

T1	**3sec**	Mid-grey background with the text “Original”
T2	**20sec – 25sec**	Original uncompressed video sequence
T1	**3sec**	Mid-grey background with the text “A”
T3	**20sec – 25sec**	Compressed reference video sequence
T1	**3sec**	Mid-grey background with the text “B”
T4	**20sec – 25sec**	Compressed tested video sequence
T1	**3sec**	Mid-grey background with the text “A”
T3	**20sec – 25sec**	Compressed reference video sequence
T1	**3sec**	Mid-grey background with the text “B”
T4	**20sec – 25sec**	Compressed tested video sequence
T5	**10sec**	Mid-grey background with the text “Vote”



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Experimental Results

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Sequence Name	CRF	Without Masking (Reference)		With Masking (Tested)		BD-BR Savings
		Bitrate	MOS	Bitrate	MOS	
El-Fuente	20	23960.64	88	18266.86	89	-10.7%
	24	14701.49	85	11378.59	82	
	28	9013.59	80	7115.96	79	
	32	5629.3	73	4560.42	72	
	36	3616.78	64	3054.72	64	
Lucy	20	14074.81	89	11390.49	88	-5.6%
	24	8042.85	85	6677.24	84	
	28	5003.31	74	4210.82	75	
	32	3211.48	69	2737.33	62	
	36	2113.21	63	1832.32	55	
Warcraft	20	7092.24	88	6655.14	88	-2.3%
	24	4082.99	85	3852.15	85	
	28	2572.63	82	2436.43	83	
	32	1705.72	73	1621.98	71	
	36	1171.32	66	1121.69	58	
Everest	20	13420.24	85	11418.12	85	-14.8%
	24	5738.53	83	4943.96	82	
	28	2516.55	76	2224.67	78	
	32	1480.22	69	1335.23	70	
	36	1007.73	65	922.89	65	
Regatta	20	34769.29	83	26042.09	84	-26.3%
	24	21264.06	80	15836.46	82	
	28	13164.48	82	9791.08	79	
	32	8342.09	76	6249.4	72	
	36	5349.47	66	4192.14	61	
Average	-11.9%					

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Summary

- **Significant quality improvements based on both SSIMPlus and PSNR metrics.**
- **By utilizing Perceptual Quantization Matrices:**
  - **For UltraHD displays, the BD-BR SSIMPLus coding gain is up to 15.5%.**
  - **For mobile devices, the BD-BR SSIMPLus coding gain is up to about 24%.**
- **By utilizing Joint Backward And Forward Video Masking:**
  - **Up to 26% bitrate savings w/o substantial perceived visual quality degradation.**
  - Better performance for more challenging ***higher bitrates and frame rates,*** *as well as for* ***complex content with textures****, such as water and snow.*
  - Additionally, there is a substantial **decrease in the overall computational complexity** in terms of encoding times – **higher density and higher quality for software encoders**.

Future Directions: VVC Coding

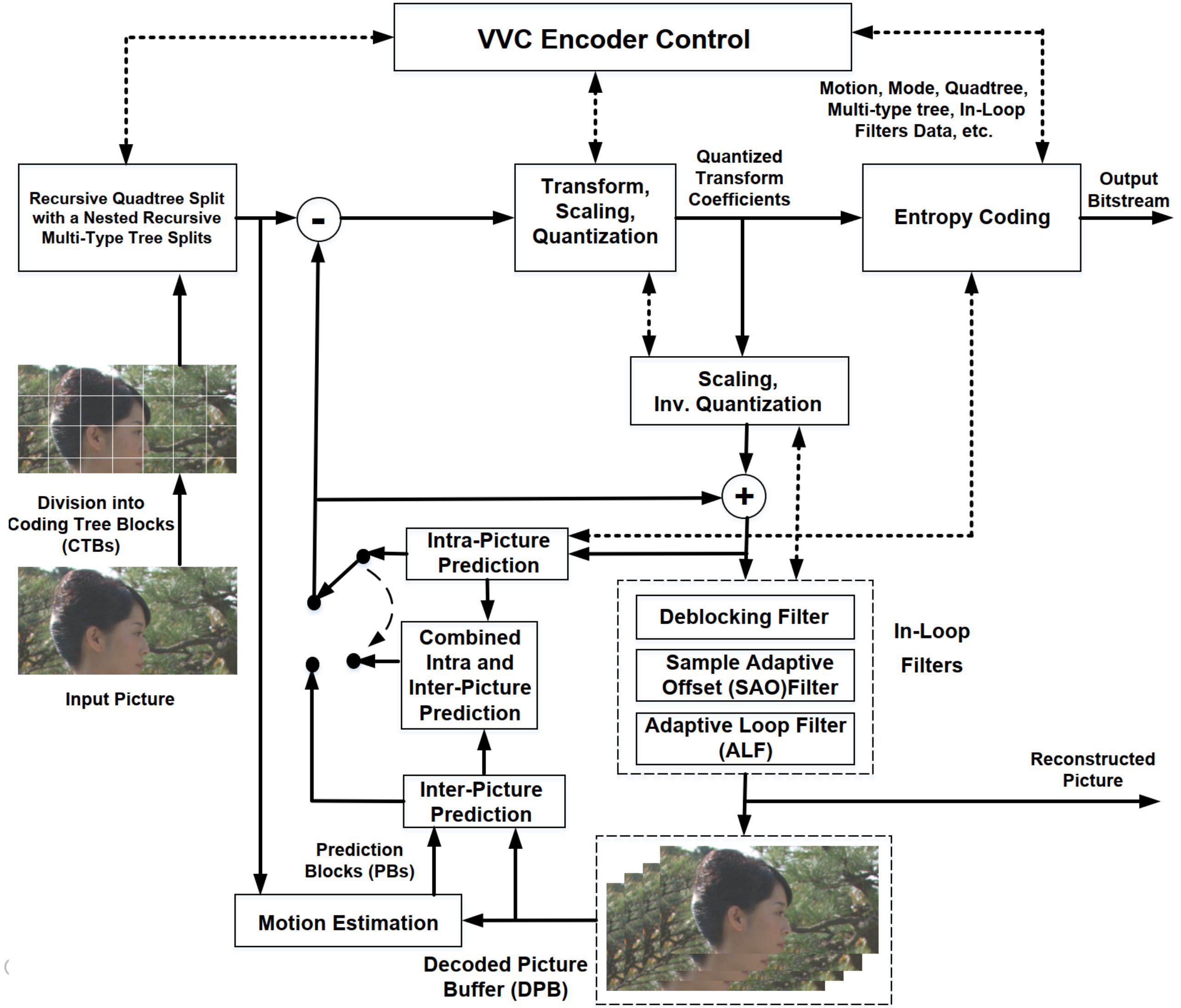
Incorporating the presented perceptual video coding optimizations techniques within the H.266/MPEG-VVC coding loop.

- The exploration phase of the video technology beyond HEVC started in Oct. 2015;
- Joint Video Experts Team (JVET) between ITU-T VCEG and ISO/IEC MPEG was established in Oct. 2017;

MPEG

ITU International Telecommunication Union

- Following the CfP responses in Apr. 2018, the development of the Versatile Video Codec (VVC) started;
- Just about 2 years later, **the 1st version of VVC was finalized in Jul. 2020;**



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Thank You!

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