Beyond Bjøntegaard – Limits of Video Compression Performance Comparisons

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Technische Fakultät

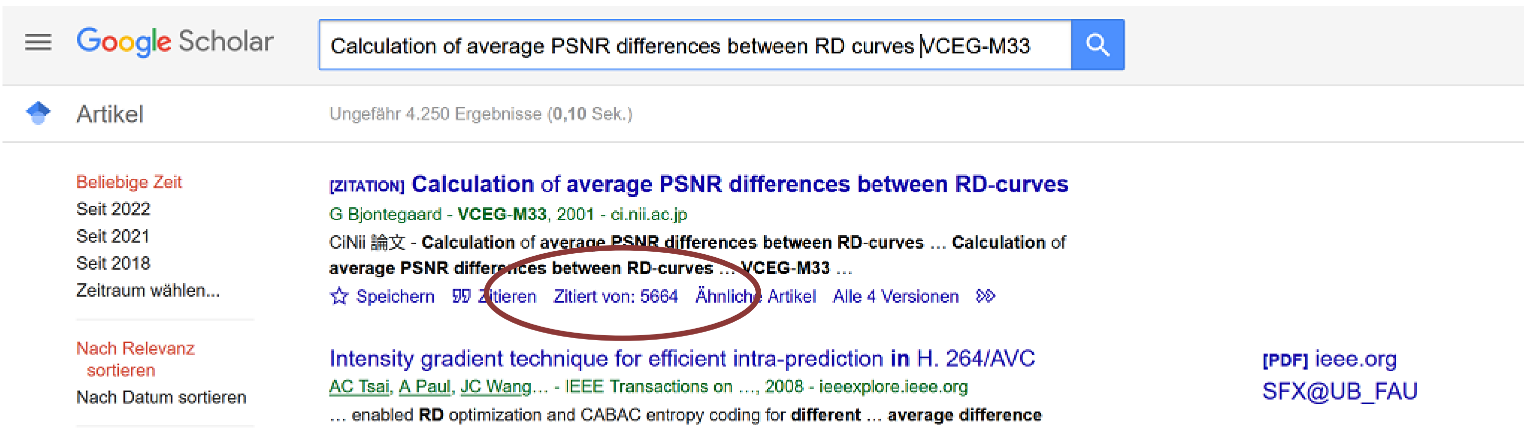
LMS

For 20 years…

…there is no video codec development without him

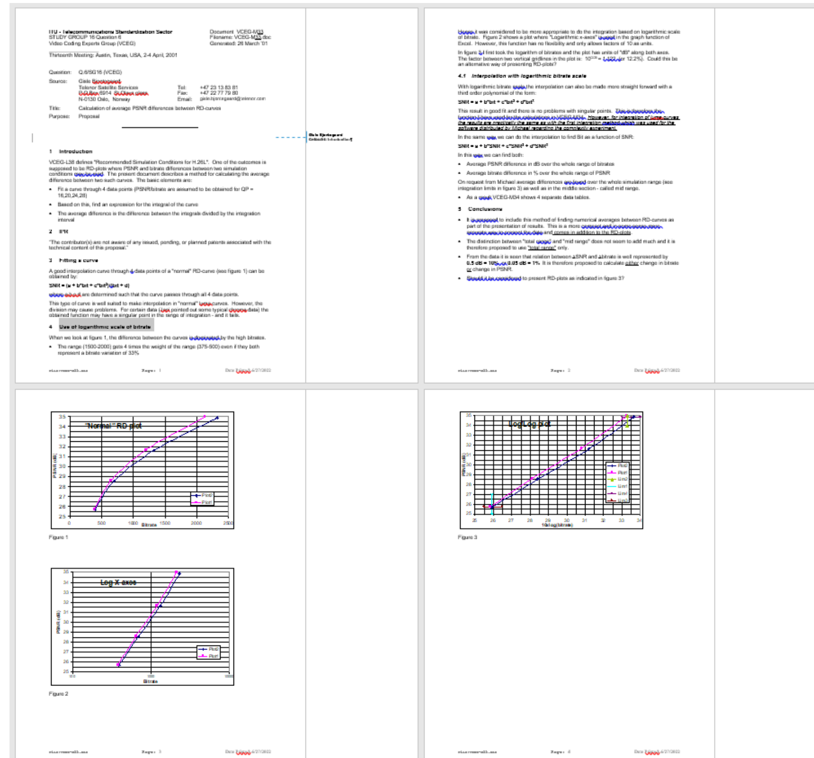
https://www.tu.no/artikler/dr-philos-gisle-bjontegaard-er-tildelt-norwegian-tech-awards-hederspris/412169

Probably the most cited standardization document ever



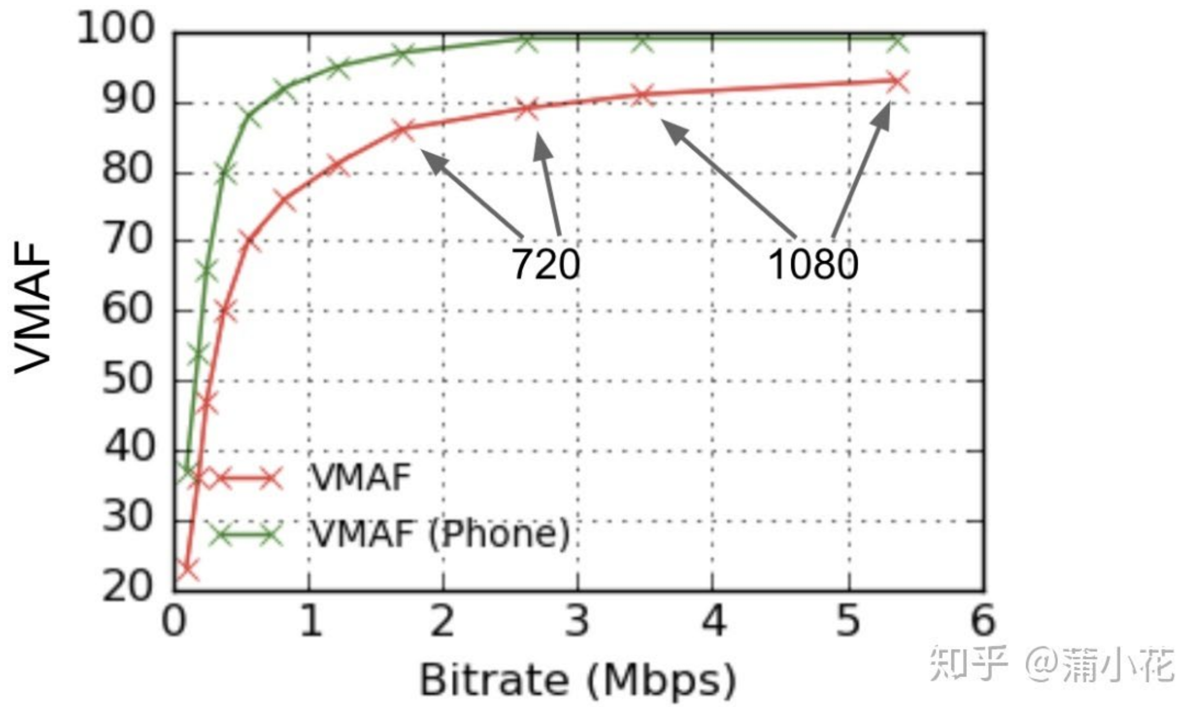
Four pages to calculate the difference between curves described by [1]

- **Rate (bps)**
- **PSNR (dB)**



Bjøntegaard, G.
Calculation of average PSNR differences between RD curves
VCEG-M33, VCEG-M33, **2001.**

But there is more than just rate-distortion (RD)



https://zhuanlan.zhihu.com/p/94223056

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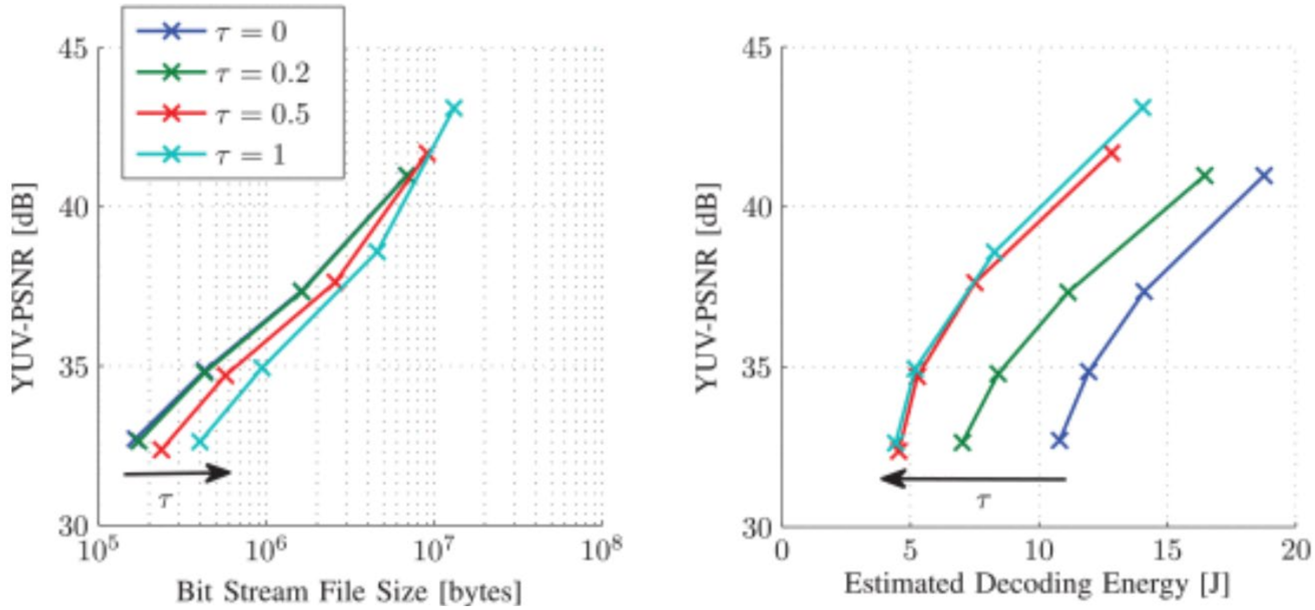


➔ **40% energy savings w.r.t. constant quality**

C. Herglotz, A. Heindel and A. Kaup, "Decoding-Energy-Rate-Distortion Optimization for Video Coding," in *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 29, no. 1, pp. 171-182, Jan. 2019.

Comparison of apples with pears

Startseite FAQ Impressum Unterstützen Der Postillon 1845-2021 Das Postillon-Archiv Postillon24 Shopillon

Postillon durchsuchen...

Der Postillon

Ehrliche Nachrichten - unabhängig, schnell, seit 1845

Politik Wirtschaft Sport Leute Medien Wissenschaft Panorama Ratgeber Newsticker Live-Tour

NEWSTICKER +++ Moorbuskron': Darmpatient wird Deutscher Meister der Feuchtgebietpersonenbeförderung +++

Donnerstag, 11. Mai 2017

Forscher vergleichen erstmals erfolgreich Äpfel mit Birnen

Berlin (dpo) - Berliner Wissenschaftler haben erstmals gewagt, was bislang als unmöglich galt: Sie haben Äpfel mit Birnen verglichen – und zwar erfolgreich. Die Ergebnisse der Pioniertat veröffentlicht das renommierte "Empiric Science Magazin" in seiner neuesten Ausgabe.

"Seit Jahrhunderten heißt es, man könne Äpfel nicht mit Birnen vergleichen", sagt

AUS DEM ARCHIV

REKLAME

FAKTILLON

Tweets by Faktillon

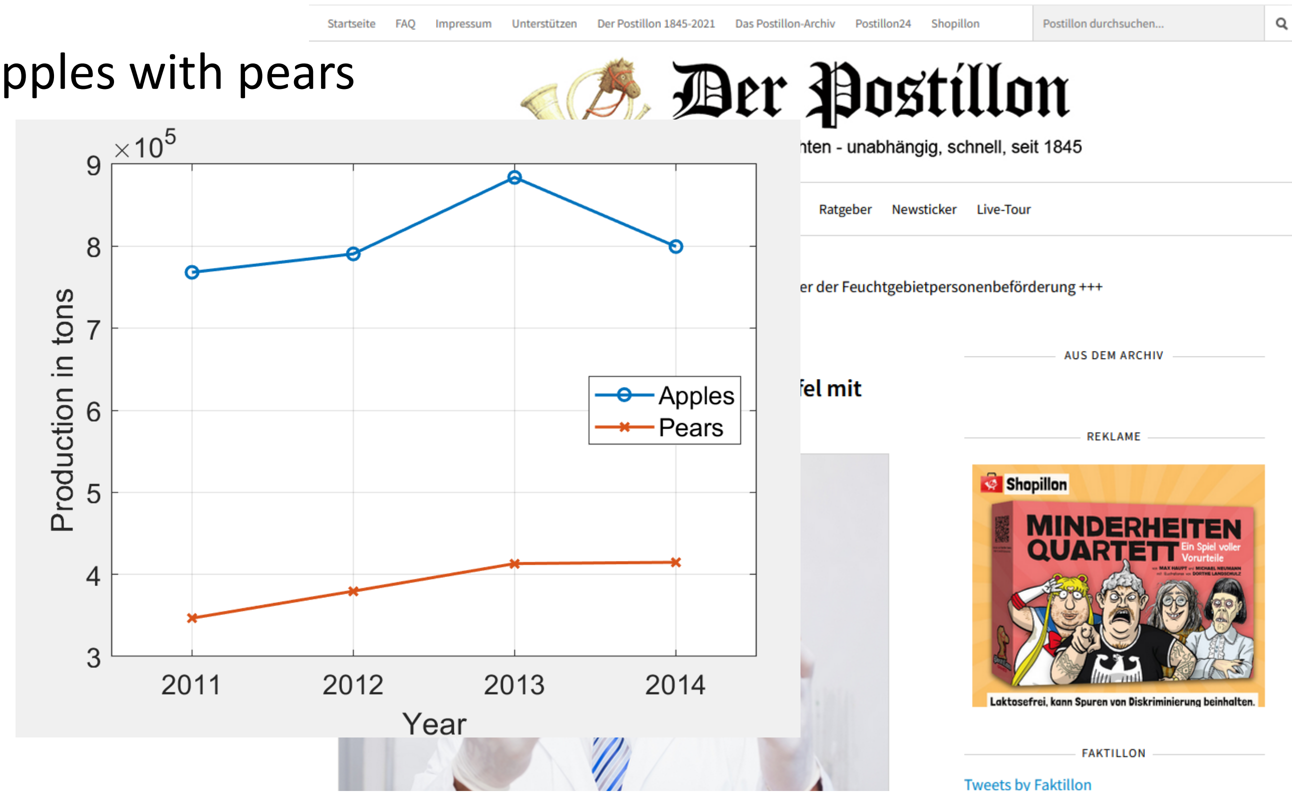
POSTILLON MINUS

Nur für Postillon-Minus-Abonnenten. Einloggen und den Postillon werbefrei genießen: LOGIN MIT STEADY

Hinweis: Aktuell leider nur auf Desktop

https://www.der-postillon.com/2017/05/aepfel-birnen.html

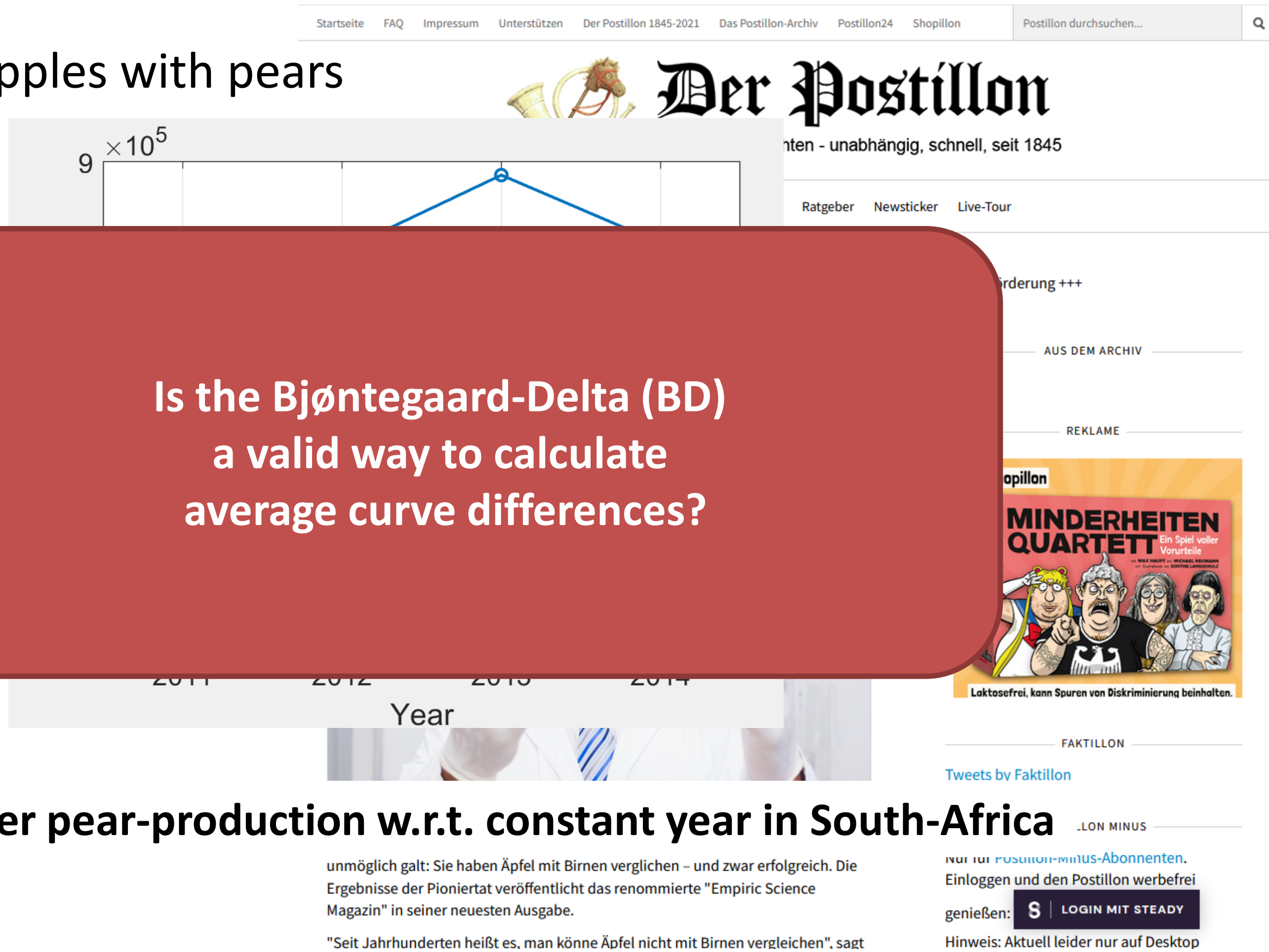
Comparison of apples with pears



➔ **52% lower pear-production w.r.t. constant year in South-Africa**

https://www.statista.com/

Comparison of apples with pears



Is the Bjøntegaard-Delta (BD) a valid way to calculate average curve differences?

➔ **52% lower pear-production w.r.t. constant year in South-Africa**

https://www.statista.com/

Outline

- The BD Calculus
- Interpolation Methods
- Evaluation
- Summary & Outlook

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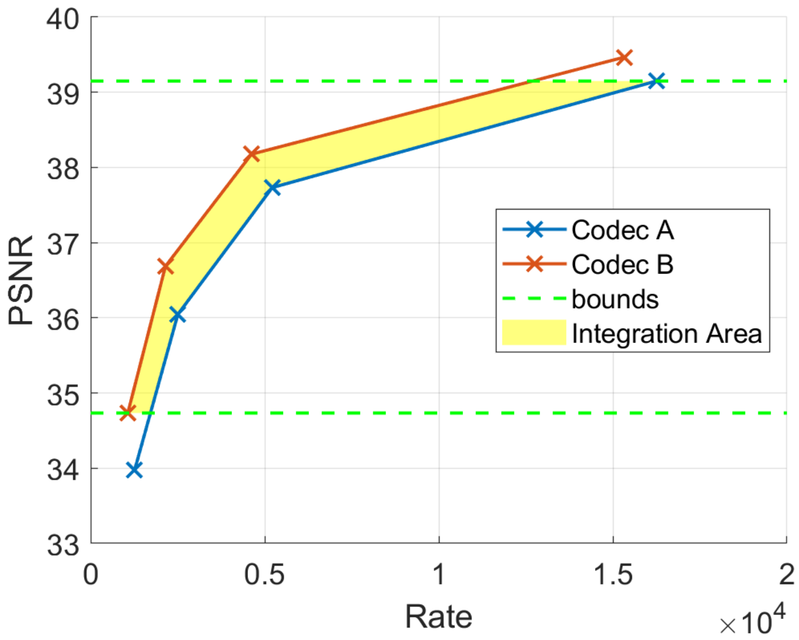
The BD Calculus

Visualization of the Calculus



➔ **33% lower rate of codec B w.r.t. codec A**

The BD Calculus

Mathematical Description of the Calculus

- For each codec, four RD points with **monotonic** values are given

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- Take the log of the rates
- Find piecewise cubic interpolants for the two codecs k as

$$\hat{r}_k(D) = a_k + b_k \cdot D + c_k \cdot D^2 + d_k \cdot D^3$$

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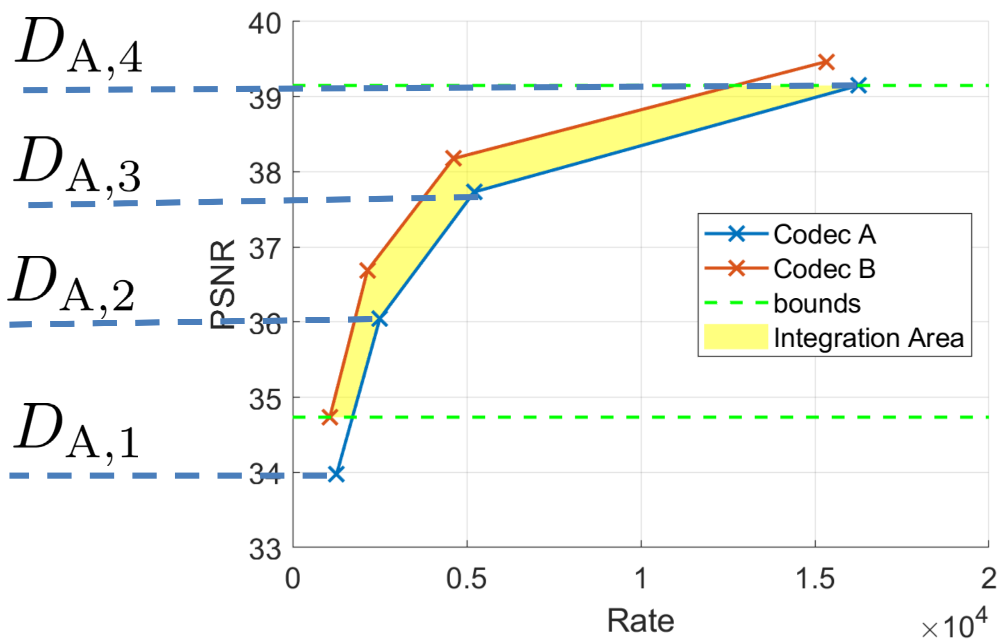
Rate in log-domain

Interpolation parameters

Distortion (PSNR)

The BD Calculus

Visualization of the Calculus



The BD Calculus

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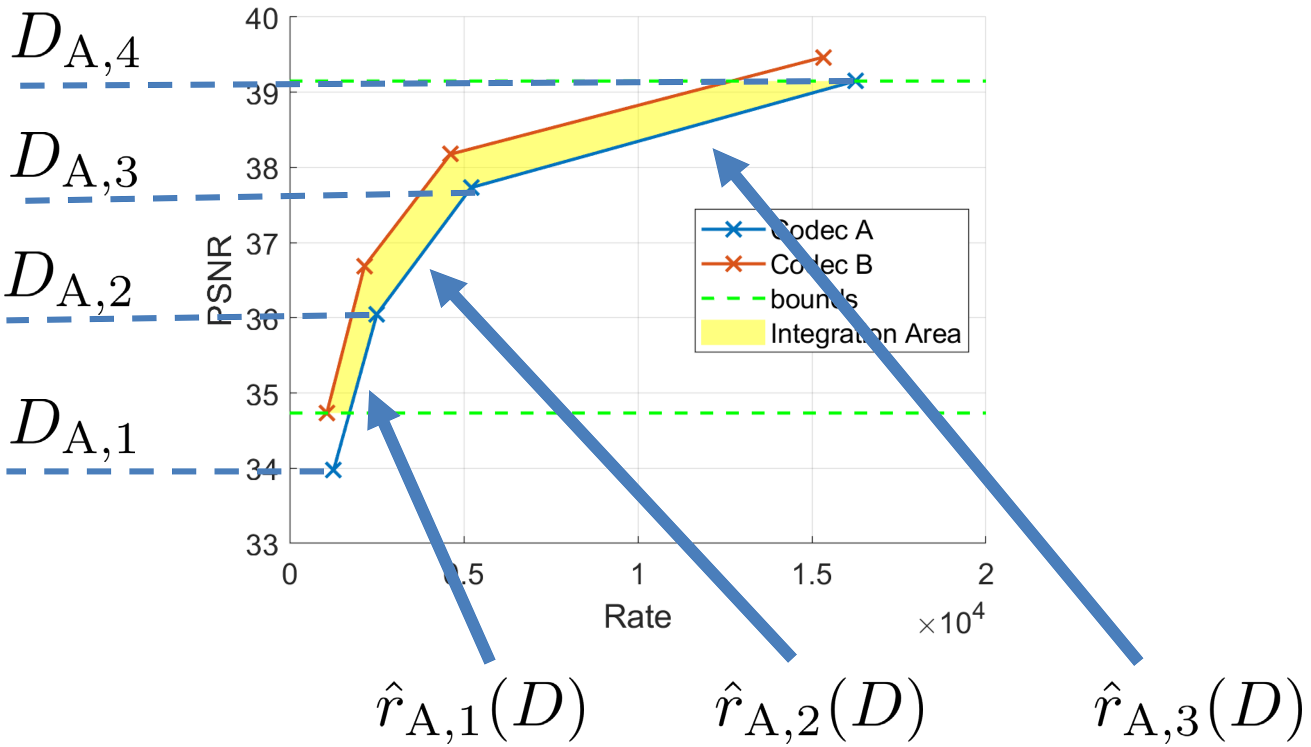

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- Determine integration bounds (minimum and maximum overlap of PSNR)

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- Determine integration bounds (minimum and maximum overlap of PSNR)
- Calculate the BD-rate by

$$\Delta R = 10^{\frac{1}{D_{\mathrm{high}} - D_{\mathrm{low}}} \int_{D_{\mathrm{low}}}^{D_{\mathrm{high}}} \hat{r}_{\mathrm{B}}(D) - \hat{r}_{\mathrm{A}}(D) \mathrm{d}D} - 1$$

The BD Calculus

Mathematical Description of the Calculus

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How to interpolate correctly?

- Determin p of PSNR)
- Calculate the BD-rate by

$$\Delta R = 10^{\frac{1}{D_\text{high} - D_\text{low}} \int_{D_\text{low}}^{D_\text{high}} \hat{r}_\text{B}(D) - \hat{r}_\text{A}(D) \text{d}D} - 1$$

Outline

- The BD Calculus
- **Interpolation Methods**
- Evaluation
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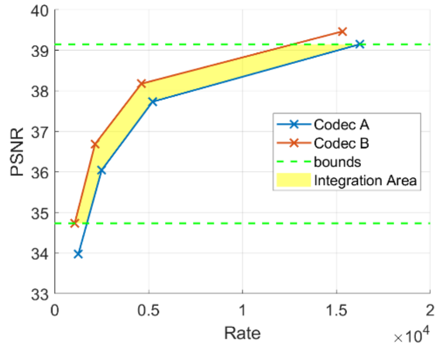
Interpolaton Methods



Cubic Spline Interpolation (CSI)

- Used in VCEG-M33 [1]

- Boundary constraints:

$$\hat{r}_{A,i}(D_{i+1}) = \hat{r}_{A,i+1}(D_{i+1})$$
$$\hat{r}'_{A,i}(D_{i+1}) = \hat{r}'_{A,i+1}(D_{i+1})$$
$$\hat{r}''_{A,i}(D_{i+1}) = \hat{r}''_{A,i+1}(D_{i+1})$$
$$\hat{r}'''_{A,i}(D_{i+1}) = \hat{r}'''_{A,i+1}(D_{i+1}) \quad \text{(not-a-knot)}$$

Interpolaton Methods

Relaxed interpolation methods

- Boundary constraints:

$$\hat{r}_{\mathrm{A},i}(D_{i+1}) = \hat{r}_{\mathrm{A},i+1}(D_{i+1})$$
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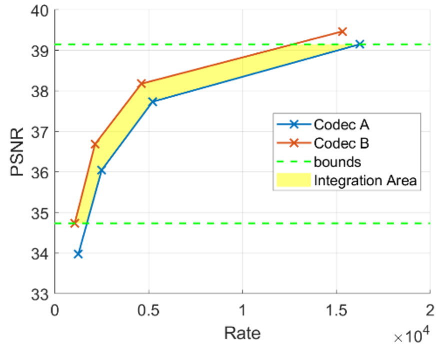

➔ **Further constraints needed**

Interpolaton Methods

Relaxed interpolation methods

- Boundary constraints:

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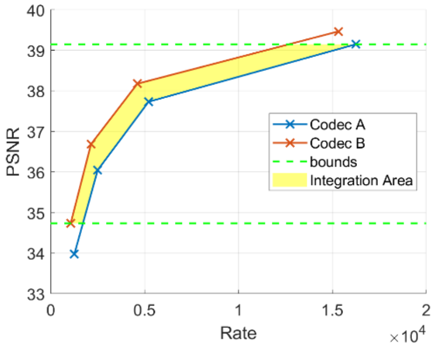
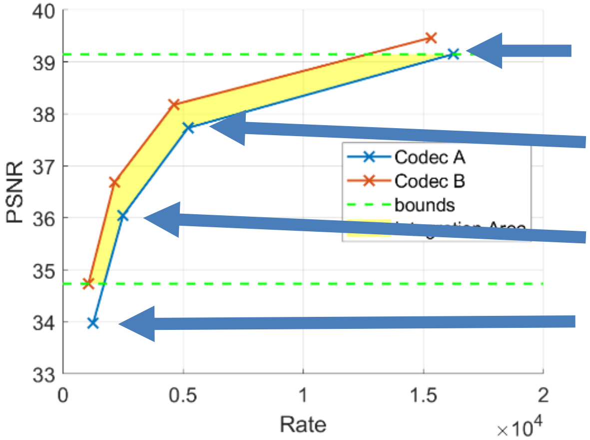


➔ **Further constraints needed**

➔ **Basis for PCHIP (used in JVET) and Akima (proposed)**

Interpolaton Methods

Idea: Smart choice of derivatives m_i in supporting points

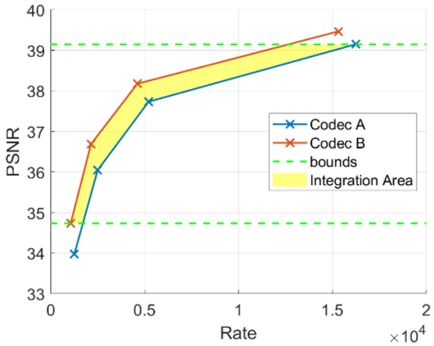


$\hat{r}'_{\mathrm{A},3}(D_{\mathrm{A},4}) = m_4$

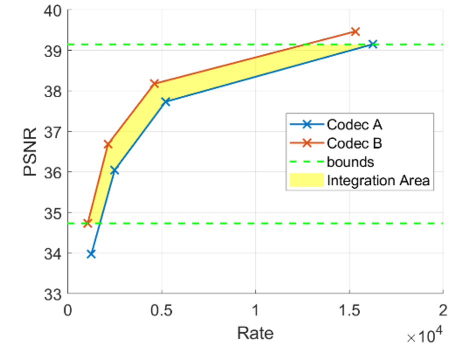
m_3

m_2

m_1



Interpolaton Methods



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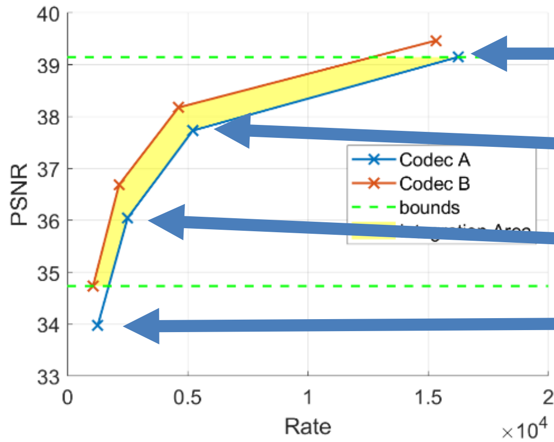


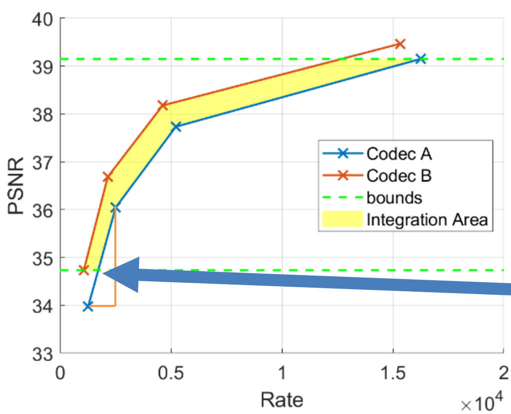
$$\hat{r}'_{\mathrm{A},3}(D_{\mathrm{A},4}) = m_4$$

m_3

m_2

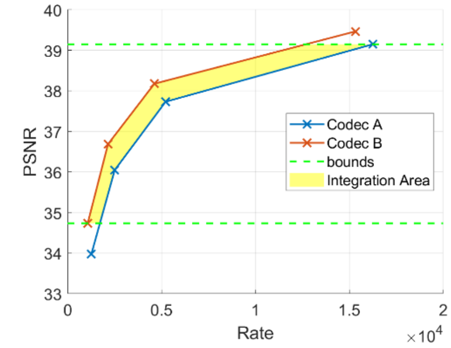
m_1

based on linear slopes between supporting points S_i



S_1

Interpolaton Methods



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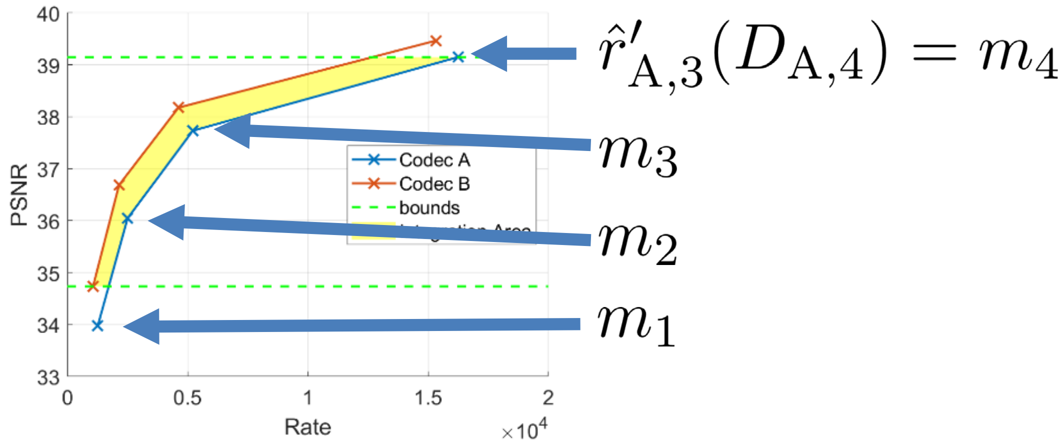

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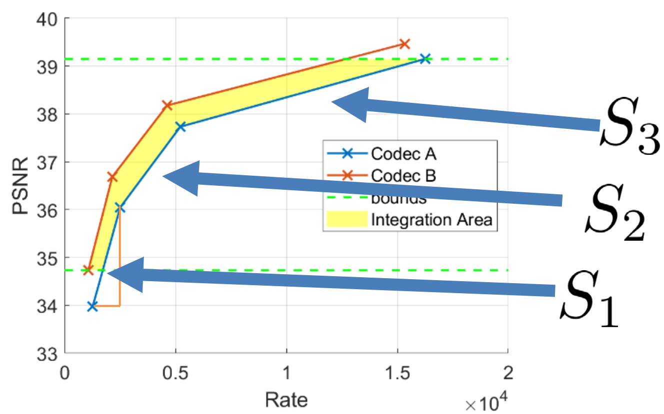
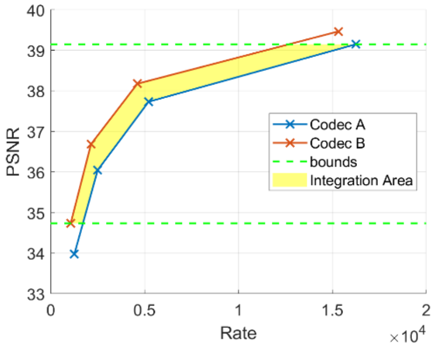


Interpolaton Methods



Piecewise cubic hermite interpolation polynomial (PCHIP) [2]

- Used in JVET [3]

- Inner supporting points

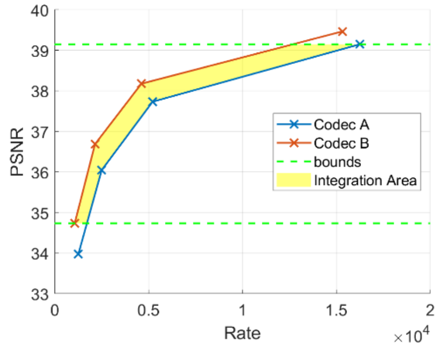
$$m_i = \frac{S_i S_{i+1}}{\alpha S_{i+1} + (1-\alpha) S_i}, \quad i = 2,3$$

$$\alpha = \text{complicated}$$

- Outer supporting points

$$m_i = \frac{(2\Delta D_1 + \Delta D_2) S_1 - \Delta D_1 S_2}{\Delta D_1 + \Delta D_2}, \quad i = 1,4$$

Interpolaton Methods



Piecewise cubic hermite interpolation polynomial (PCHIP)

- Used in JVET

- Inner supporting points

With constant $\Delta D = 1$ between supporting points

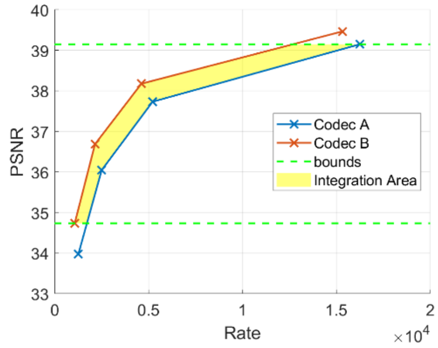
$$m_i = \frac{2S_i S_{i+1}}{S_{i+1} + S_i}, \qquad i = 2, 3$$

- Outer supporting points

$$m_i = \frac{3S_1 - S_2}{2}, \qquad i = 1, 4$$

➔ Bias towards smaller slopes

Interpolaton Methods



Akima Interpolation

- Proposed in [4]

- Derivatives calculated by

$$m_i = \frac{|S_{i+1} - S_i| S_{i-1} + |S_{i-1} - S_{i-2}| S_i}{|S_{i+1} - S_i| + |S_{i-1} - S_{i-2}|}$$

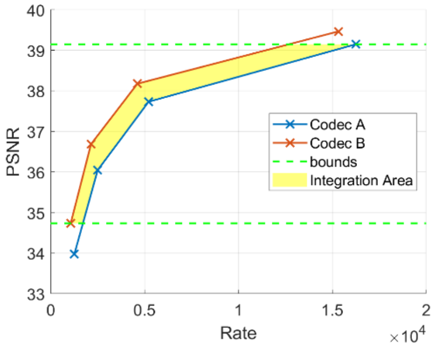
with additional slopes

$$S_0 = 2S_1 - S_2$$

$$S_{-1} = 2S_0 - S_1$$

[1] C. Herglotz, M. Kränzler, R. Mons, A. Kaup, „ Beyond Bjøntegaard – Limits of Video Compression Performance Comparisons“, accepted for IEEE International Conference on Image Processing (ICIP), Bordeaux, 2022.

Interpolaton Methods



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with ad

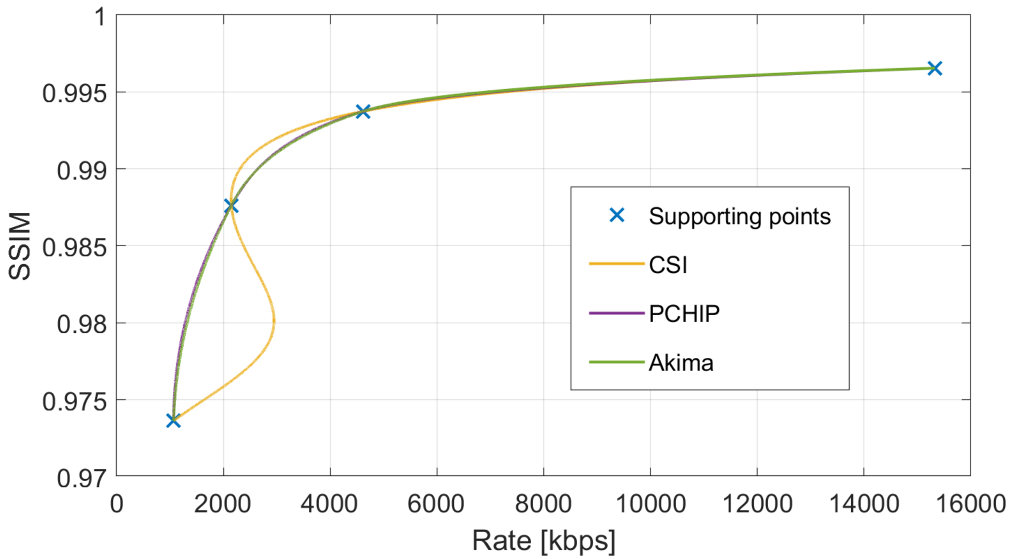
Emphasis on homogeneous slopes

➔ At borders, the local slope dominates

tegaard – Limits of
or IEEE International
Conference on Image Processing (ICIP), Bordeaux, 2022.

Interpolaton Methods

Visual Example



Outline

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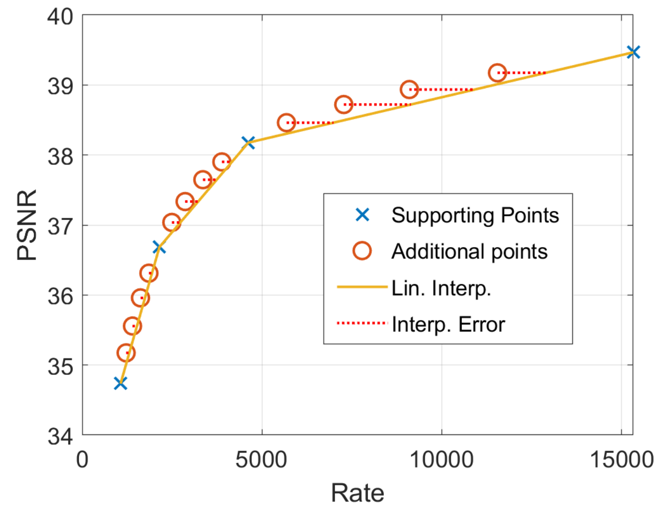
- Interpolation Methods
- **Evaluation**
- Summary & Outlook

Evaluation

Check the interpolation accuracy for intermediate points



Evaluation

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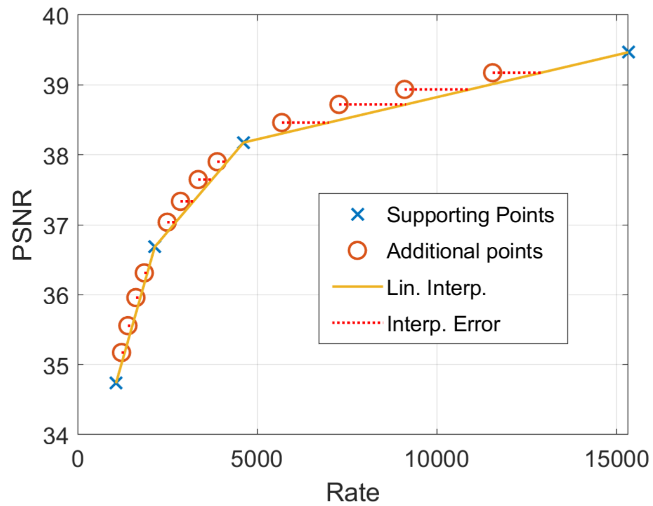

Calculate mean relative error over all points

$$e = \frac{1}{N} \sum_{n=1}^{N} \frac{\left|10^{\hat{r}(D_n)} - R_n\right|}{R_n}$$

n: Point index (QP)
N: Number of points
D_n: Distortion of n-th point
R_n: Rate of n-th point
$10^{\hat{r}(D_n)}$: Interpolated rate of n-th point

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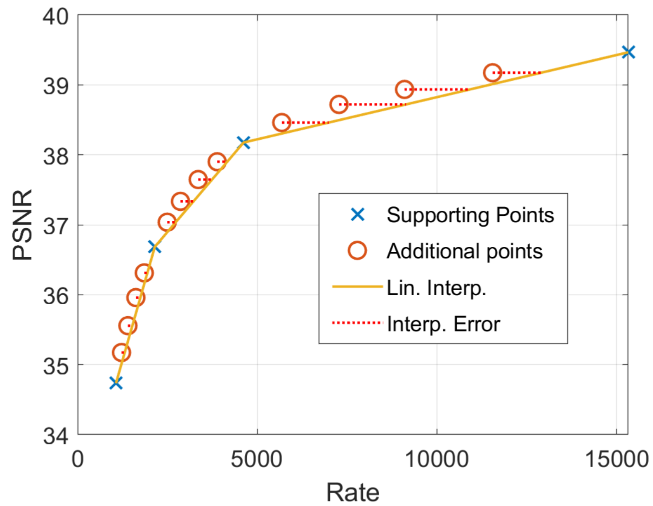

Maximum relative error over all points

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Evaluation

Evaluation setup

- Six sequences from JVET CTC
- QPs from 22 to 37, supporting points {22, 27, 32, 37}
- Encoding with VTM and HM
- 10 bit internal bit-depth (HM and VTM)

Performance metrics

- PSNR-Bitrate
- SSIM-Bitrate
- VMAF-Bitrate
- PSNR-Energy
- VMAF-Energy

Evaluation

Interpolation errors

PM pair	PSNR - Bitrate $\bar{e}$	PSNR - Bitrate $E_{\max}$
CSI	0.630%	5.151%
PHIP	0.420%	$\mathbf{4.103\%}$
Akima	$\mathbf{0.370\%}$	4.855%

Evaluation

Interpolation errors

PM pair	PSNR - Bitrate $\bar{e}$	PSNR - Bitrate $E_{\max}$	SSIM - Bitrate $\bar{e}$	SSIM - Bitrate $E_{\max}$
CSI	0.630%	5.151%	9.130%	110.446%
PHIP	0.420%	**4.103%**	1.709%	9.329%
Akima	**0.370%**	4.855%	**1.121%**	**7.439%**

Evaluation

Interpolation errors

PM pair	PSNR - Bitrate $\bar{e}$	PSNR - Bitrate $E_{\max}$	SSIM - Bitrate $\bar{e}$	SSIM - Bitrate $E_{\max}$	VMAF - Bitrate $\bar{e}$	VMAF - Bitrate $E_{\max}$
CSI	0.630%	5.151%	9.130%	110.446%	5.587%	29.093%
PHIP	0.420%	**4.103%**	1.709%	9.329%	2.010%	12.971%
Akima	**0.370%**	4.855%	**1.121%**	**7.439%**	**1.402%**	**10.576%**

Evaluation

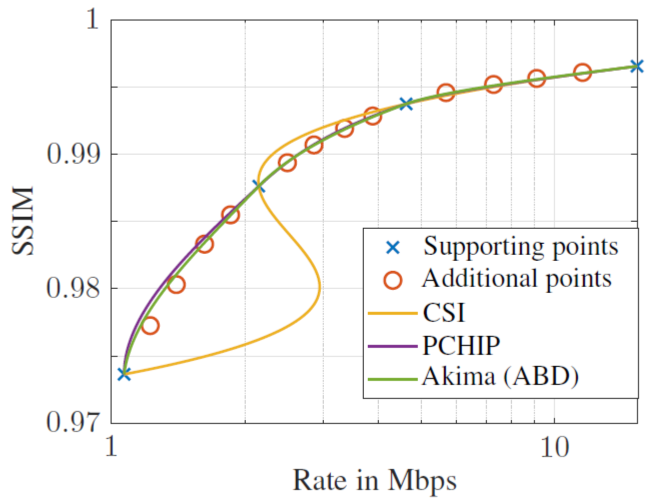
Interpolation errors

PM pair	PSNR - Bitrate $\bar{e}$	PSNR - Bitrate $E_{\max}$	SSIM - Bitrate $\bar{e}$	SSIM - Bitrate $E_{\max}$	VMAF - Bitrate $\bar{e}$	VMAF - Bitrate $E_{\max}$	PSNR - Energy $\bar{e}$	PSNR - Energy $E_{\max}$	VMAF - Energy $\bar{e}$	VMAF - Energy $E_{\max}$
CSI	0.630%	5.151%	9.130%	110.446%	5.587%	29.093%	0.992%	**7.060%**	2.588%	14.705%
PHIP	0.420%	**4.103%**	1.709%	9.329%	2.010%	12.971%	0.917%	7.093%	1.140%	**7.046%**
Akima	**0.370%**	4.855%	**1.121%**	**7.439%**	**1.402%**	**10.576%**	**0.904%**	7.066%	**1.064%**	7.053%

Evaluation

Interpolation errors

PM pair	PSNR - Bitrate $\bar{e}$	PSNR - Bitrate $E_{\max}$	SSIM - Bitrate $\bar{e}$	SSIM - Bitrate $E_{\max}$	VMAF - Bitrate $\bar{e}$	VMAF - Bitrate $E_{\max}$	PSNR - Energy $\bar{e}$	PSNR - Energy $E_{\max}$	VMAF - Energy $\bar{e}$	VMAF - Energy $E_{\max}$
CSI	0.630%	5.151%	9.130%	110.446%	5.587%	29.093%	0.992%	**7.060%**	2.588%	14.705%
PHIP	0.420%	**4.103%**	1.709%	9.329%	2.010%	12.971%	0.917%	7.093%	1.140%	**7.046%**
Akima	**0.370%**	4.855%	**1.121%**	**7.439%**	**1.402%**	**10.576%**	**0.904%**	7.066%	**1.064%**	7.053%



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Summary & Outlook

- **CSI should not be used for BD**
- **PCHIP and Akima return more accurate results**
- **Akima outperforms PCHIP**

- **Impact of these accuracies on BD-rate?**
- **Other questions?**

Python Implementation

https://github.com/FAU-LMS/bjontegaard

Bibliography

[1] G. Bjøntegaard, “Calculation of average PSNR differences between RD curves,” document, VCEG-M33, Austin, TX, USA, Apr. 2001.
[2] F. N. Fritsch, R. E. Carlson.,"Monotone piecewise cubic interpolation." *SIAM Journal on Numerical Analysis* 17.2 (1980): 238-246.
[3] F. Bossen, J. Boyce, X. Li, V. Seregin, and K. Sühring, “JVET common test conditions and software reference configurations for SDR video,” AHG Report, JVET-N1010, ITU/ISO/IEC Joint Video Exploration Team (JVET), Jan. 2017.
[4] H. Akima, “A new method of interpolation and smooth curve fitting based on local procedures,” Journal of the ACM (JACM), vol. 17, no. 4, pp. 589–602, 1970.
[5] C. Herglotz, M. Kränzler, R. Mons, A. Kaup, „ Beyond Bjøntegaard – Limits of Video Compression Performance Comparisons“, accepted for IEEE International Conference on Image Processing (ICIP), Bordeaux, 2022.