# MSU Video-Codec Comparison 2019

*Part I: FullHD Content, Objective Evaluation*


| | |
|---|---|
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Free version

## Codecs:

**H.265**

- Bytedance
- HW265
- sz265
- Tencent V265 Encoder
- UC265
- x265
- xin265

**Non H.265**

- arowana xvc
- SIF Encoder
- VP9
- WZAurora
- x264


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# 1. REPORT VERSIONS

| | **Free version** | **Enterprise version** |
|---|---|---|
| Use cases | Universal (partially) | Fast, Universal, Ripping |
| Per-sequence-results | 2 of 100 sequences (only Universal use case) | All 100 sequences for all use cases (in interactive charts) |
| Relative quality analysis | ✗ | ✓ |
| Metric: YUV-SSIM | ✓ | ✓ |
| Other objective metrics (Y-VMAF(0.6.1), Y-VMAF(0.6.2), Y-VMAF(0.6.3), Y-VMAF(0.6.1, Phone), Y-VMAF(0.6.2, Phone), Y-VMAF(0.6.3, Phone), Y-SSIM, U-SSIM, V-SSIM, YUV-PSNR, Y-PSNR, U-PSNR, V-PSNR) | ✗ | ✓ |
| Per-frame metrics results (in HTML report) | ✗ | ✓ |
| Description of video sequences | ✓ | ✓ |
| Download links for video sequences | ✗ | ✓ |
| Codec info (developer, version number, website link) | ✓ | ✓ |
| Encoders presets description | ✗ | ✓ |
| PDF report | 58 pages | 83 pages |
| HTML report | 28 interactive charts | 14000+ interactive charts |

# Contents

## 2. ACKNOWLEDGMENTS

The Graphics & Media Lab Video Group would like to thank the following companies for providing the codecs and settings used in this report:

- ByteDance Inc.
- Divideon
- Huawei Technologies Co., Ltd.
- MulticoreWare, Inc.
- Nanjing Yunyan
- Peppa
- SIF Encoder Team
- Tencent
- Ucodec Inc.
- Visionular
- x264 Developer Team

We're also grateful to these companies for their help and technical support during the tests.

# 3. OVERVIEW

## 3.1. Sequences

| | Sequence | Number of frames | Frame rate | Resolution |
|---|---|---|---|---|
| 1. | African Village | 1524 | 24 | 1920×1080 |
| 2. | Airport Interview | 1016 | 24 | 1920×1080 |
| 3. | Animation Clip | 5450 | 30 | 1920×1080 |
| 4. | Ariadnes Thread | 902 | 30 | 1920×1080 |
| 5. | Bad Sleep | 1075 | 24 | 1920×1080 |
| 6. | Bagpipes | 1008 | 24 | 1920×1080 |
| 7. | Carnival | 1314 | 24 | 1920×1080 |
| 8. | Carpets | 801 | 25 | 1920×1080 |
| 9. | Castle | 324 | 24 | 1920×1080 |
| 10. | CG Figures | 1201 | 30 | 1920×1080 |
| 11. | Cherry Up | 877 | 30 | 1920×1080 |
| 12. | Christmas Cats | 1500 | 25 | 1920×1080 |
| 13. | Cion | 1540 | 24 | 1920×1080 |
| 14. | City Panorama | 751 | 24 | 1920×1080 |
| 15. | City Walk | 436 | 25 | 1920×1080 |
| 16. | Colliers Wood | 1341 | 25 | 1920×1080 |
| 17. | Controlled Burn | 570 | 30 | 1920×1080 |
| 18. | Cookie Jam | 600 | 30 | 1920×1080 |
| 19. | Craft Beer | 455 | 25 | 1920×1080 |
| 20. | Crazy Bar | 1116 | 25 | 1920×1080 |
| 21. | Creek Kooler | 1432 | 30 | 1920×1080 |
| 22. | Crowd Run | 500 | 50 | 1920×1080 |
| 23. | Dancing Party | 979 | 24 | 1920×1080 |
| 24. | Dancing People | 1463 | 24 | 1920×1080 |
| 25. | Desert | 750 | 24 | 1920×1080 |
| 26. | DJ Show | 993 | 60 | 1920×1080 |
| 27. | Drakenboot | 1010 | 25 | 1920×1080 |
| 28. | Field Milton Academy | 1080 | 30 | 1920×1080 |
| 29. | Film | 916 | 24 | 1920×1080 |
| 30. | Film Promo | 1042 | 25 | 1920×1080 |
| 31. | Final Cut Lesson | 750 | 25 | 1920×1080 |
| 32. | First Things First | 359 | 30 | 1920×1080 |

| | | | | |
|---|---|---|---|---|
| 33. | Flower Shop | 749 | 25 | 1920×1080 |
| 34. | Glass Production | 1126 | 30 | 1920×1080 |
| 35. | Golden Bear | 974 | 30 | 1920×1080 |
| 36. | Graduation | 850 | 30 | 1920×1080 |
| 37. | Greenscreen Talks | 978 | 24 | 1920×1080 |
| 38. | GTA5 | 3602 | 60 | 1920×1080 |
| 39. | Guitar Show | 1013 | 24 | 1920×1080 |
| 40. | Gun Stuff | 1364 | 30 | 1920×1080 |
| 41. | Gun Stuff Promo | 964 | 30 | 1920×1080 |
| 42. | Hallelujah | 974 | 30 | 1920×1080 |
| 43. | Historic Mansion | 958 | 30 | 1920×1080 |
| 44. | Hotel Advertisement | 1434 | 30 | 1920×1080 |
| 45. | Infinit | 258 | 25 | 1920×1080 |
| 46. | Interactive Newspaper | 1336 | 25 | 1920×1080 |
| 47. | Interview at the Expo | 1110 | 24 | 1920×1080 |
| 48. | Italy History | 989 | 24 | 1920×1080 |
| 49. | Judy Trailer | 754 | 24 | 1920×1080 |
| 50. | Kayak Trip | 1577 | 60 | 1920×1080 |
| 51. | Keeping Warm | 999 | 30 | 1920×1080 |
| 52. | Kobe Bryant | 891 | 25 | 1920×1080 |
| 53. | Laser Cutter | 1068 | 24 | 1920×1080 |
| 54. | Love Story | 1132 | 50 | 1920×1080 |
| 55. | Magazine Advertisement | 984 | 60 | 1920×1080 |
| 56. | Making Alcohol | 1575 | 24 | 1920×1080 |
| 57. | Manhattan Bridge Views | 1484 | 24 | 1920×1080 |
| 58. | Mercedes | 1016 | 25 | 1920×1080 |
| 59. | Music Clip | 989 | 24 | 1920×1080 |
| 60. | Music Fantasy | 1022 | 25 | 1920×1080 |
| 61. | Nancy | 1259 | 25 | 1920×1080 |
| 62. | New York Bakery | 429 | 25 | 1920×1080 |
| 63. | Newsy | 1005 | 30 | 1920×1080 |
| 64. | Night Pursuit | 1001 | 24 | 1920×1080 |
| 65. | Nina Music Video | 1001 | 24 | 1920×1080 |
| 66. | Nurse Interview | 1387 | 60 | 1920×1080 |
| 67. | Off the Wall | 394 | 25 | 1920×1080 |
| 68. | Old Message | 986 | 24 | 1920×1080 |
| 69. | Oman Museum | 532 | 25 | 1920×1080 |
| 70. | Pebble Beach | 930 | 24 | 1920×1080 |

| | | | | |
|---|---|---|---|---|
| 71. | Pet Photography | 925 | 30 | 1920×1080 |
| 72. | Preparation for the Celebration | 496 | 24 | 1920×1080 |
| 73. | Prism | 180 | 30 | 1920×1080 |
| 74. | Professor | 1439 | 24 | 1920×1080 |
| 75. | Psychotherapy | 1010 | 25 | 1920×1080 |
| 76. | Rugby | 901 | 60 | 1920×1080 |
| 77. | Rust | 3602 | 60 | 1920×1080 |
| 78. | Sad Day | 1039 | 24 | 1920×1080 |
| 79. | School Promo Video | 1006 | 24 | 1920×1080 |
| 80. | Sea Sunrise | 1021 | 25 | 1920×1080 |
| 81. | Simple Animation | 144 | 24 | 1920×1080 |
| 82. | Skiing Learning | 809 | 24 | 1920×1080 |
| 83. | Slow Motion Clip | 1021 | 24 | 1920×1080 |
| 84. | Snow Mount | 570 | 30 | 1920×1080 |
| 85. | Sports Team | 1007 | 25 | 1920×1080 |
| 86. | Street Show | 1058 | 24 | 1920×1080 |
| 87. | Surfing | 1156 | 30 | 1920×1080 |
| 88. | Terry Cage | 947 | 24 | 1920×1080 |
| 89. | Theater Show | 1307 | 25 | 1920×1080 |
| 90. | Tractor | 690 | 25 | 1920×1080 |
| 91. | Tribute | 1050 | 30 | 1920×1080 |
| 92. | Video in Video | 1537 | 24 | 1920×1080 |
| 93. | Walk with Children | 1032 | 30 | 1920×1080 |
| 94. | Wedding Party | 808 | 24 | 1920×1080 |
| 95. | Wedding Walk | 1031 | 24 | 1920×1080 |
| 96. | Will and Hannah | 965 | 30 | 1920×1080 |
| 97. | Work under the Microscope | 1129 | 25 | 1920×1080 |
| 98. | Wuyue | 1281 | 25 | 1920×1080 |
| 99. | Zombie Apocalypse | 900 | 60 | 1920×1080 |
| 100. | Zulu International | 914 | 24 | 1920×1080 |

**Table 1:** Summary of video sequences

Brief descriptions of the sequences used in our comparison appear in Table 1. Appendix B provides more-detailed descriptions of these sequences.

## 3.2. Codecs

| Codec | Developer | Version |
|---|---|---|
| arowana xvc | Divideon | 0.2.0.7 |
| Bytedance | ByteDance Inc. | v1.2.3 |
| HW265 | Huawei Technologies Co., Ltd. | V0.7.2 |
| SIF Encoder | SIF Encoder Team | v1.71.0 |
| sz265 | Nanjing Yunyan | |
| Tencent V265 Encoder | Tencent | 1.3.5.3 |
| UC265 | Ucodec Inc. | v1.0.7 |
| VP9 | The WebM Project | v1.8.0-424-ge50f4e411 |
| WZAurora | Visionular | v0.8 |
| x264 | x264 Developer Team | 0.157.2935 545de2f |
| x265 | MulticoreWare, Inc. | 3.0+1-ed72af837053 |
| xin265 | Peppa | v1.0 |

**Table 2:** Short codecs' descriptions

Brief descriptions of the codecs used in our comparison appear in Table 2. We used x264 as a good-quality AVC reference codec. Appendix C provides detailed descriptions of all codecs in our comparison.

# 4. OBJECTIVES AND TESTING RULES

This report presents the results of video codecs comparison, in which we used objective assessment methods to compare the encoding quality of recent HEVC encoders as well as encoders implementing other standards. This effort employed 100 video sequences at 1080p resolution to evaluate codec performance. The process of video sequences selection involved voting among the participants, organizers and an independent expert. To choose out test set, we analyzed 1,466,711 video sequences and selected representative examples (a detailed description of the selection process appears in Appendix D).

Our comparison consists of three parts, corresponding to various encoder use cases: fast encoding, universal encoding and ripping encoding. For each use case we offered the codec developers the option to provide encoding parameters for our tests. If they declined to provide any, we either used the same parameters from our prior study or, if none were available, did our best to choose good parameters ourselves. Nevertheless, the parameters had to satisfy a minimum speed requirements for their respective use case:

- Fast encoding—60fps

- Universal encoding—25fps

- Ripping encoding—1fps; We also imposed another requirement: the encoder had to produce a better SSIM quality score than x264 with the ”veryslow” preset. Due to low encoding speed requirements, only one encoder launch was made for measurements on this use case, encoders still were able to use multi-pass presets.

Our comparison used a computer with the following configuration: based on an Intel Core i7-8700K (Coffee Lake) processor @ 3.7GHz with 32 GB of RAM running Windows 10. For objective quality measurements we used the YUV-SSIM metric (see Appendix F.1).

## 5. FAST USE CASE

All the information about results for fast use case could be found in "MSU HEVC Codec Comparison Report 2019" (Enterprise version)

# 6. UNIVERSAL USE CASE

## 6.1. RD Curves

Judging from the mean quality scores (computed using the method described in Section E), first place in the quality competition goes to **HW265**, second place goes to **Tencent V265 Encoder**, and third place to **sz265**.

All the information about results for other video sequences could be found in "MSU HEVC Codec Comparison Report 2019" (Enterprise version)

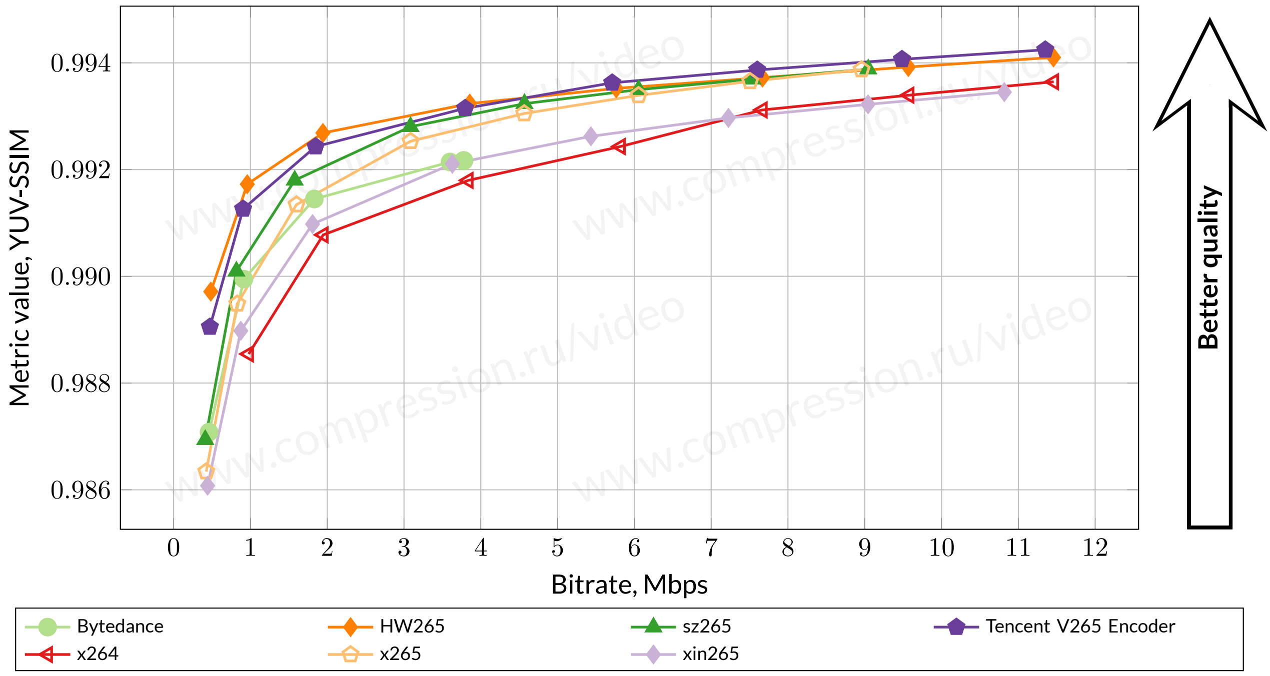



**Figure 1:** Bitrate/quality—use case "Universal Use Case," *Cion* sequence, YUV-SSIM metric.

The explanation of measuring on additional bitrates is presented in Section E.4.

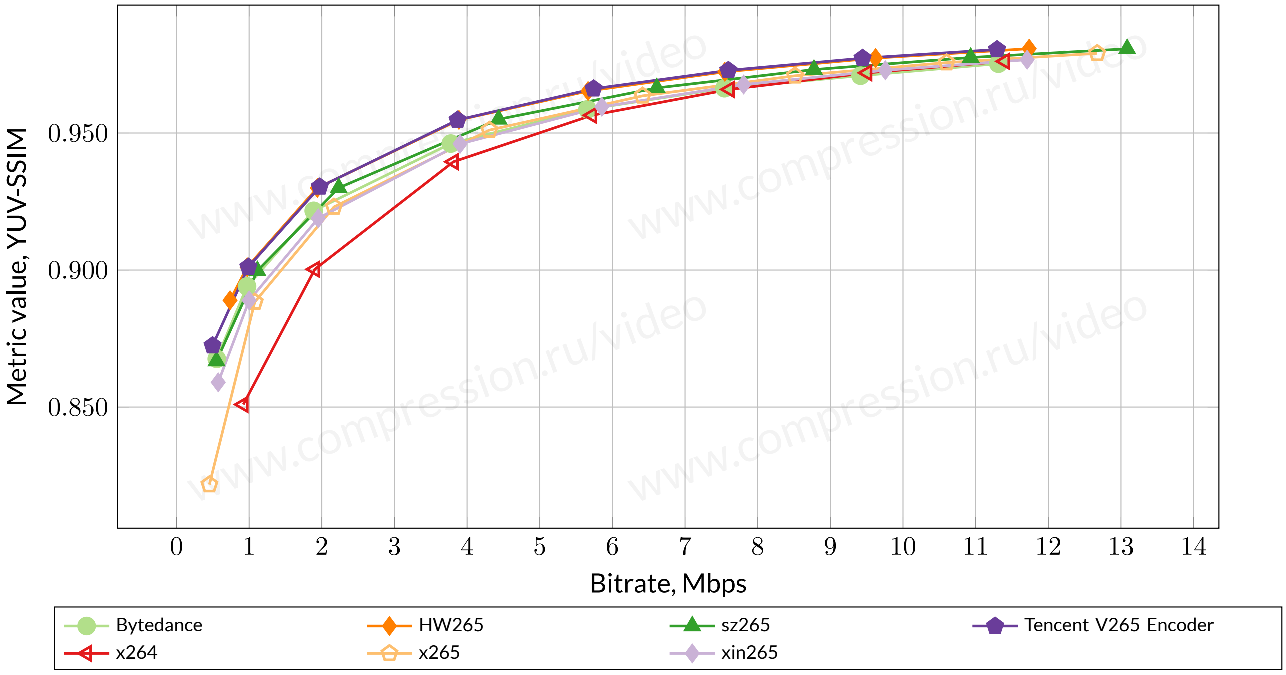



**Figure 2:** Bitrate/quality—use case “Universal Use Case,” *Kayak Trip* sequence, YUV-SSIM metric.

The explanation of measuring on additional bitrates is presented in Section E.4.

## 6.2. Encoding Speed

Judging from the mean speed scores (computed using the method described in Section E), first place in the speed competition goes to **Tencent V265 Encoder** and **sz265**, second place goes to **Bytedance** and **x264**, and third place to **x265**.

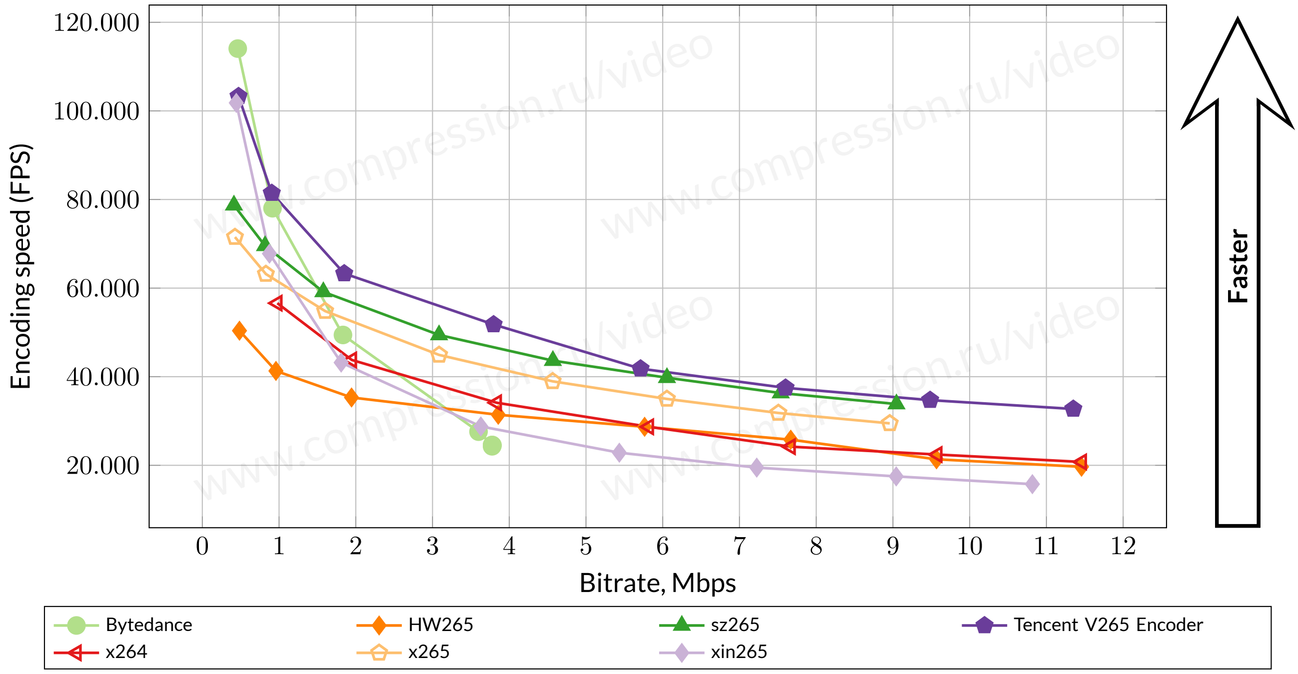



**Figure 3:** Encoding speed—use case "Universal Use Case," *Cion* sequence.

The explanation of measuring on additional bitrates is presented in Section E.4.

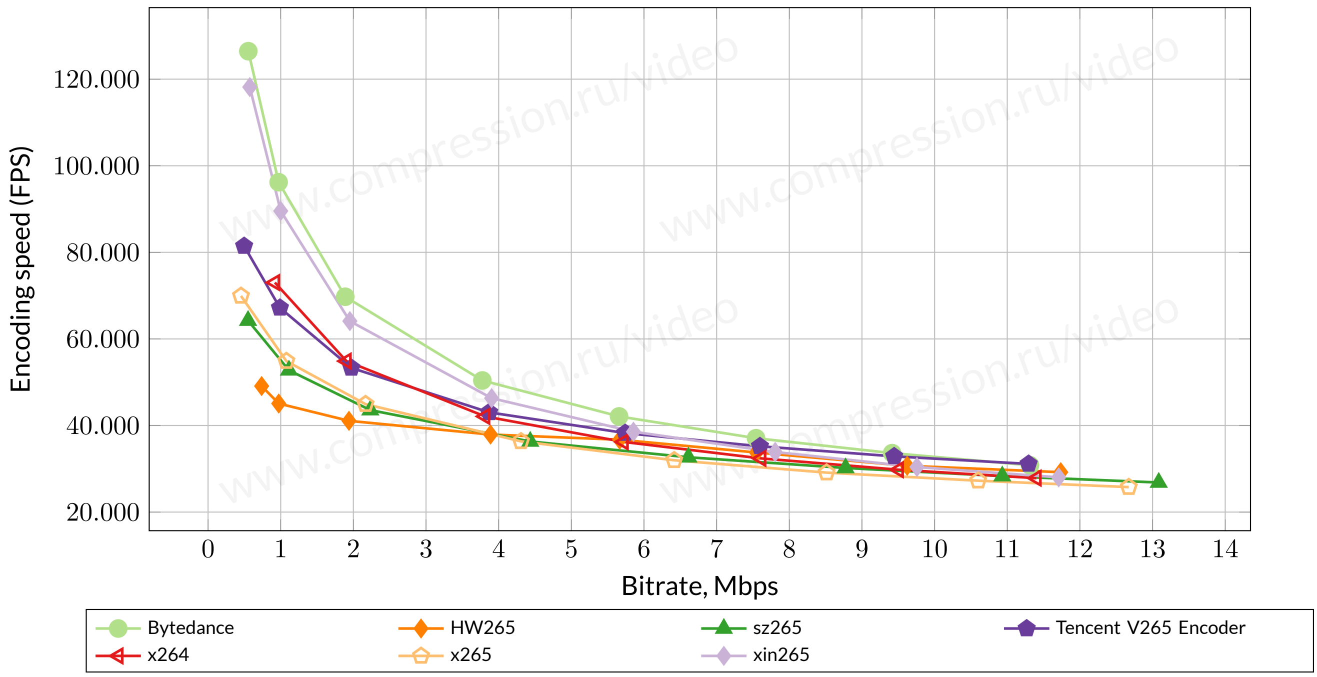



**Figure 4:** Encoding speed—use case "Universal Use Case," *Kayak Trip* sequence.

The explanation of measuring on additional bitrates is presented in Section E.4.

## 6.3. Speed/Quality Trade-Off

Detailed descriptions of the speed/quality trade-off graphs are in Appendix E. Some graphs omit the results for a particular codec owing to that codec's extremely poor performance (i.e., its RD curve fails to intersect with the reference RD curve).
The speed/quality trade-off graphs show both relative quality and speed scores for the encoders under comparison. Since we chose x264 as the reference codec, we normalized all scores to the x264 scores.

There are two Pareto-optimal encoders: **HW265** and **Tencent V265 Encoder**.

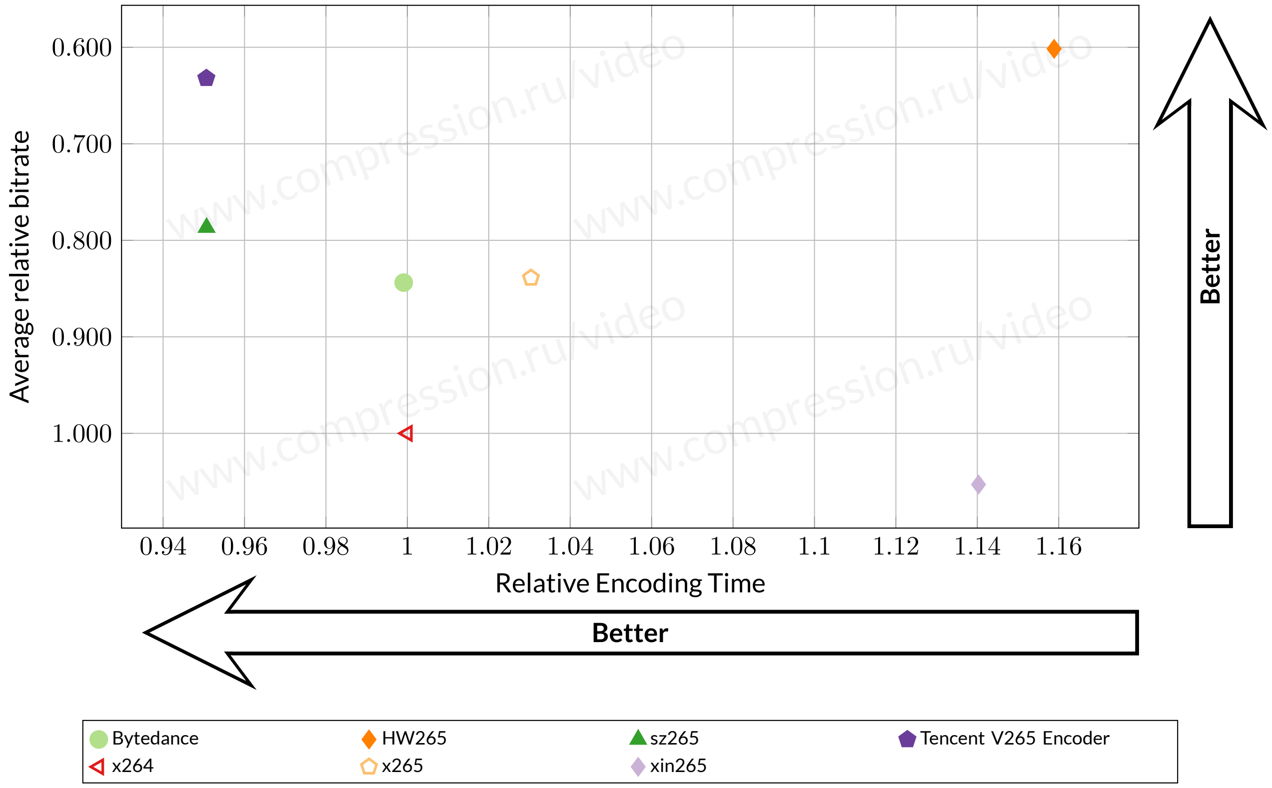



**Figure 5:** Speed/Quality Trade-Off—use case "Universal Use Case," all sequences, YUV-SSIM metric.

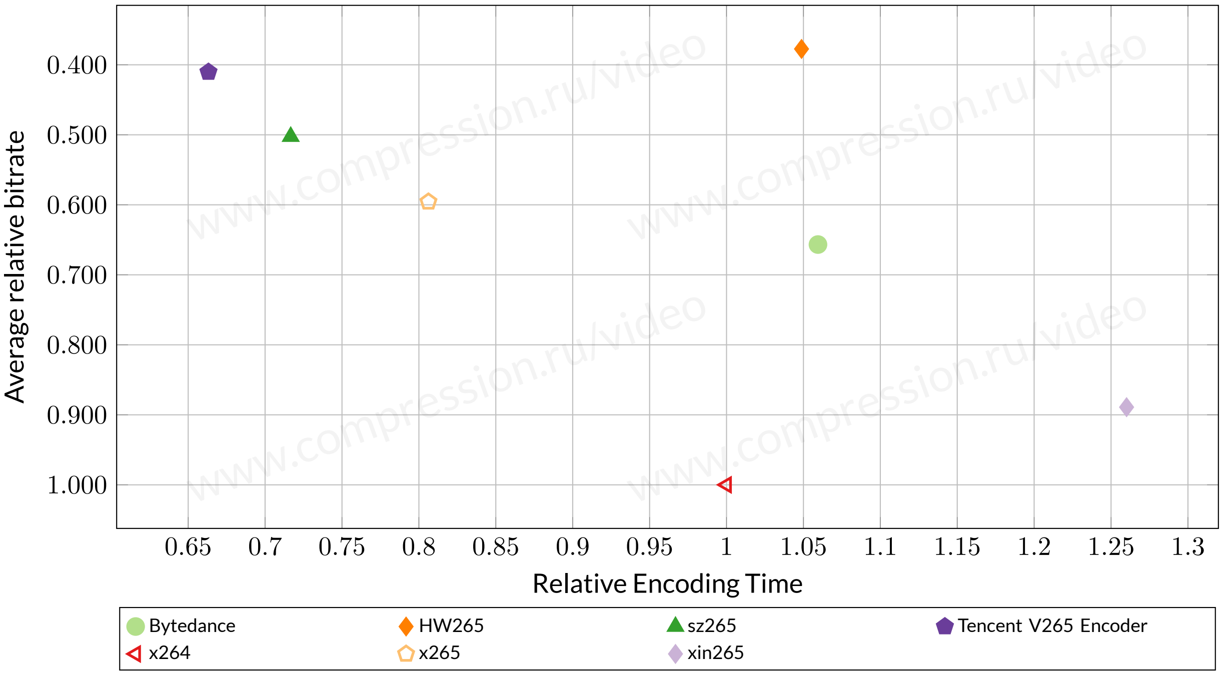



**Figure 6:** Speed/Quality Trade-Off—use case "Universal Use Case," *Cion* sequence, YUV-SSIM metric.

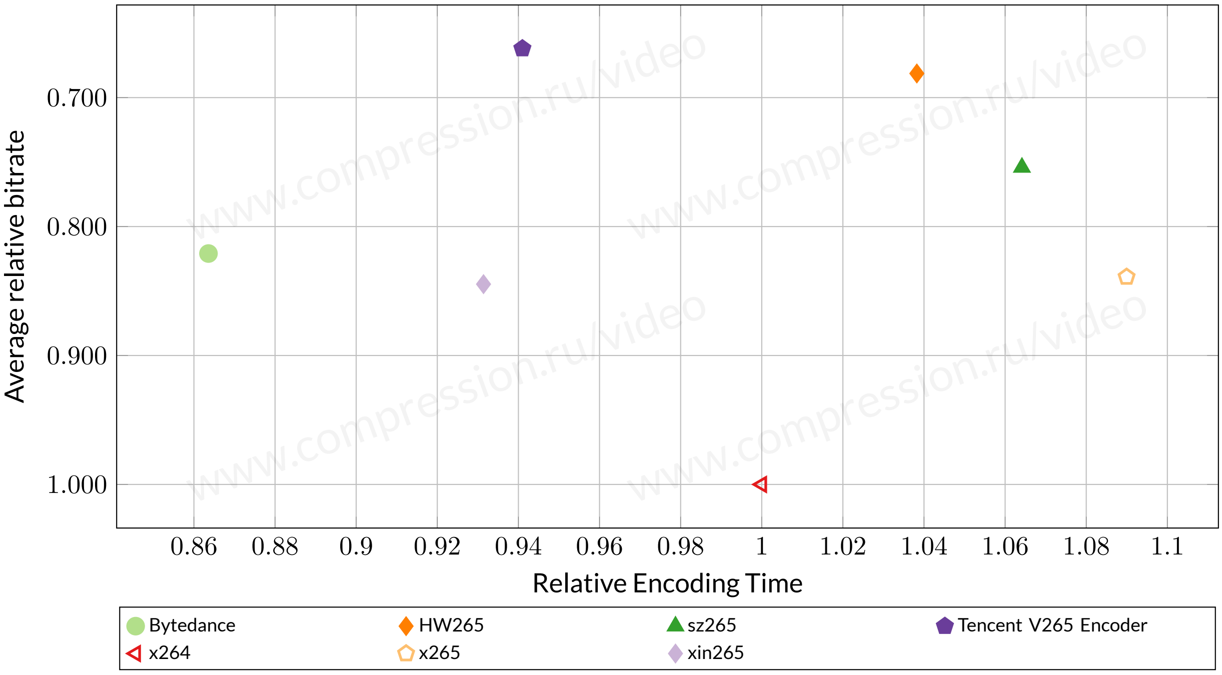



**Figure 7:** Speed/Quality Trade-Off—use case "Universal Use Case," *Kayak Trip* sequence, YUV-SSIM metric.

## 6.4. Bitrate Handling

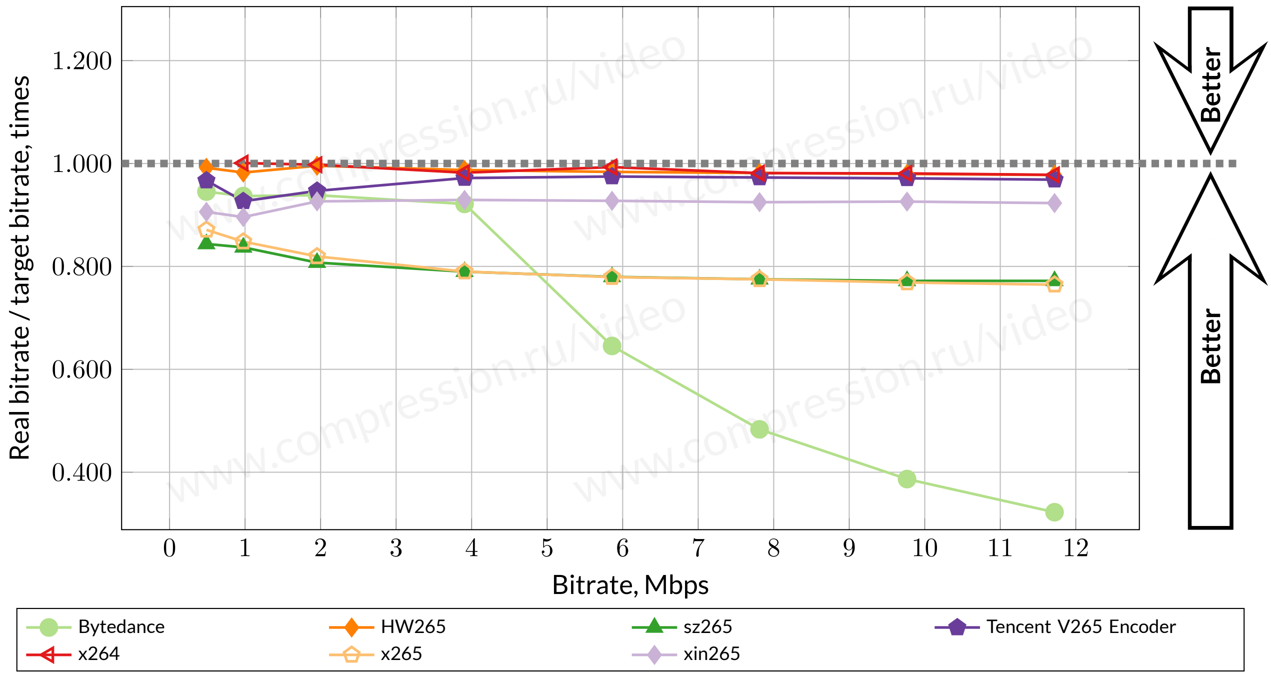



**Figure 8:** Bitrate handling—use case "Universal Use Case," *Cion* sequence.

The explanation of measuring on additional bitrates is presented in Section E.4.

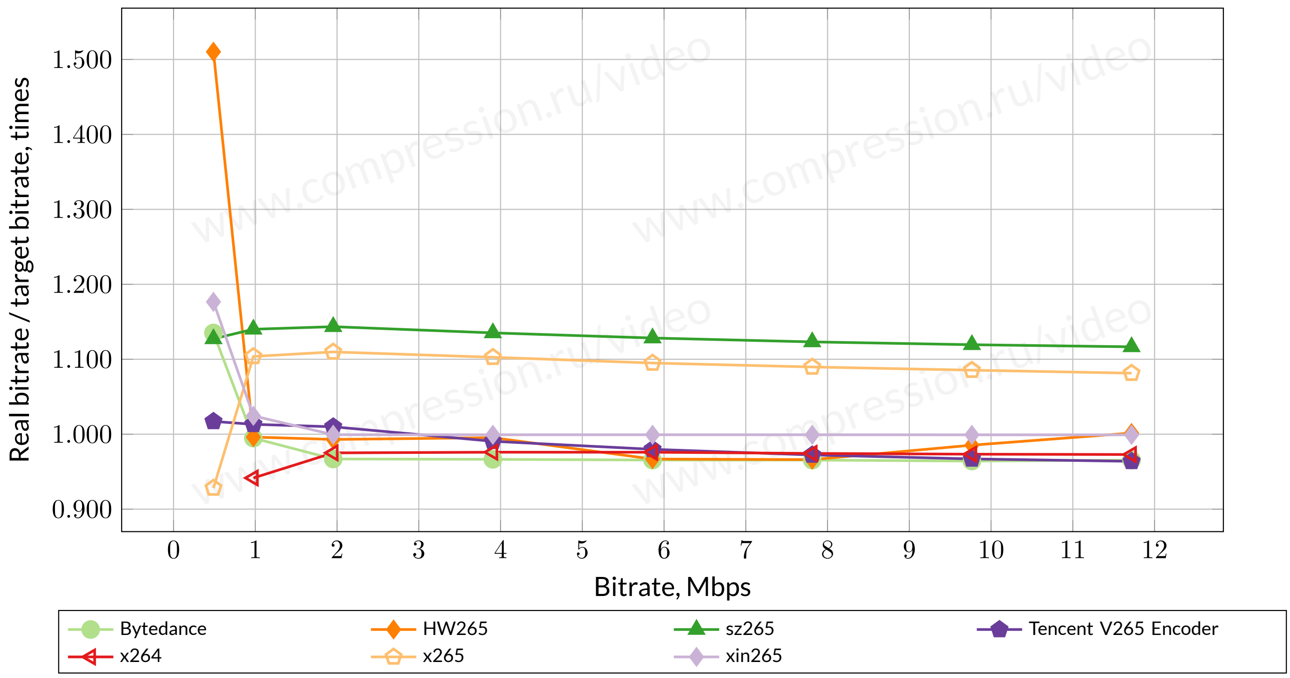



**Figure 9:** Bitrate handling—use case "Universal Use Case," *Kayak Trip* sequence.

The explanation of measuring on additional bitrates is presented in Section E.4.

## 6.5. Relative Quality Analysis

Note that each number in the tables below corresponds to some range of bitrates (see Appendix E.5). Unfortunately, these ranges can differ significantly because of differences in the quality of compared encoders. This situation can lead to some inadequate results when three or more codecs are compared.

All the information about Relative Quality Analysis could be found in "MSU HEVC Codec Comparison Report 2019" (Enterprise version)

# 7. RIPPING USE CASE

All the information about results for ripping use case could be found in "MSU HEVC Codec Comparison Report 2019" (Enterprise version)

# 8. CONCLUSION

## 8.1. Overall

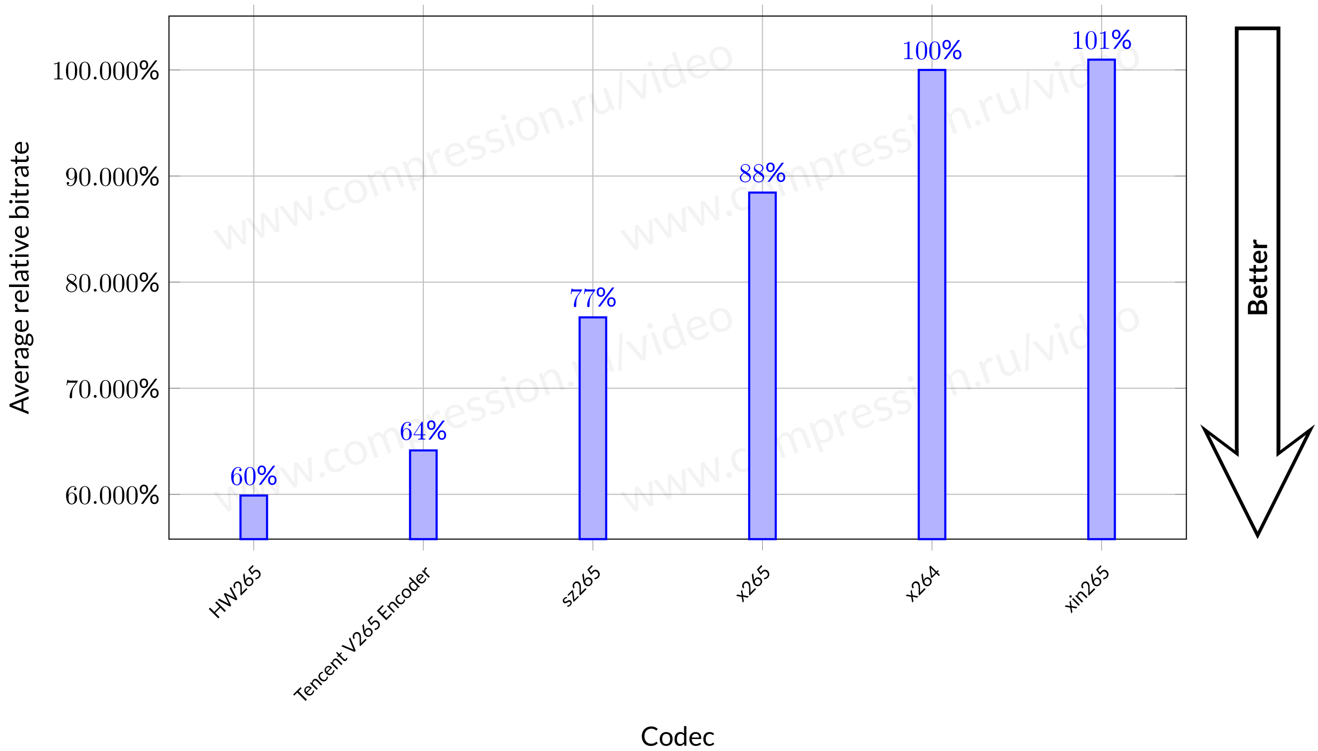



**Figure 10:** Average bitrate ratio for a fixed quality—all sequences, YUV-SSIM metric.

Separate overall results for each use case (fast, universal and ripping) and overall results for other metrics (PSNR, VMAF) could be found in "MSU HEVC Codec Comparison Report 2019" (Enterprise version)

# A. PARTICIPANTS' COMMENTS

## A.1. HW265

HW265 developed by Huawei, applied the rate-control technique provided by Prof. Zhenyu Liu and Prof. Xiangyang Ji of Tsinghua University.

## A.2. SIF Encoder

SIF Codec results differ from group of 264 / 265 codecs particularly because pre-compressed samples were used for test. Since pre-compression was made by 264 codec it gave advance to 264 / 265 codecs over the codecs with different architecture.

## A.3. xin265

Xin265 is a private project. It is written to my beautiful child. It is target to zero-latency real time communication. So far, it has no lookahead algorithm and it is only optimized for PSNR metric.

# B. SEQUENCES

Full descriptions of all videos used in this comparison are presented on a project page and in separate PDF, provided with this report.

# C. CODECS

All tested encoders presets can be found in “MSU HEVC Codec Comparison Report 2019” (Enterprise version)

## D. SEQUENCE SELECTION

In "MSU Video Codecs Comparison 2016" we introduced a technique for selecting test video sequences. This technique allows for creating a set containing representative sequences. For this report, we used the same method and updated the video database from which we sample videos.

We analyzed 384,946 videos at Vimeo, looking for 4K and FullHD examples with high bitrates (we chose 50 Mbps as our minimum) and downloaded 145 new 4K videos and 603 new FullHD videos. Figure 11 shows the bitrate distributions for last year data set and for the updated data set. Table Table 3 shows

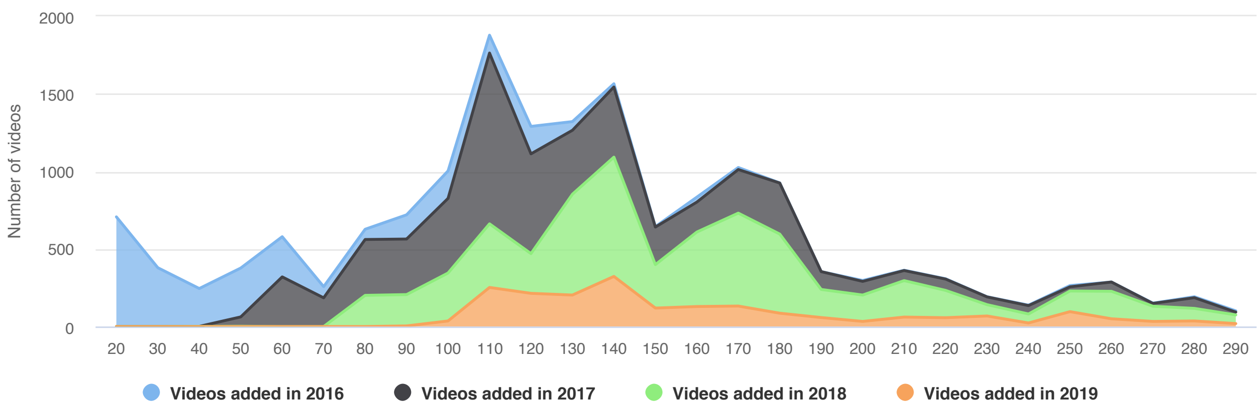



**Figure 11:** Bitrate distributions for comparison video set.

| Year | FullHD videos | FullHD samples | 4K videos | 4K samples | Total (videos) | **Total (samples)** |
|---|---|---|---|---|---|---|
| 2016 | 3 | 7 | 882 | 2902 | 885 | 2909 |
| 2017 | 1996 | 4638 | 1544 | 4561 | 3540 | 9299 |
| 2018 | 4342 | 10330 | 1946 | 5503 | 6288 | 15833 |
| 2019 | 4945 | 12402 | 2091 | 6016 | 7036 | **18418** |

**Table 3:** Number of videos in MSU video collection.

We resized and cropped 4K videos to FullHD resolution in order to avoid compression artefacts, and at scene changes, we cut all videos to samples using an approximate length of 1,000 frames. Besides 2,585 samples from 748 newly downloaded videos, we used 15,833 samples from our collection, which was used in our previous comparisons. Thus, our sample database for this year consisted of 18,418 items.

To evaluate spatial and temporal complexity, we encoded all samples using x264 with a constant quantization parameter (QP). We calculated the temporal and spatial complexity for each scene, defining spatial complexity as the average size of the I-frame normalized to the sample's uncompressed frame size. Temporal complexity in our definition is the average size of the P-frame divided by the average size of I-frame. [1] Also, an additional preprocessing step was added to unify chroma subsampling of videos which affects evaluating complexity. All

[1] C. Chen et. al., "A Subjective Study for the Design of Multi-resolution ABR Video Streams with the VP9 Codec," 2016.

videos were converted to YUV 4:2:0 chroma subsample. Distribution of obtained samples compared to samples from previous codec comparisons is shown in Figure 12.

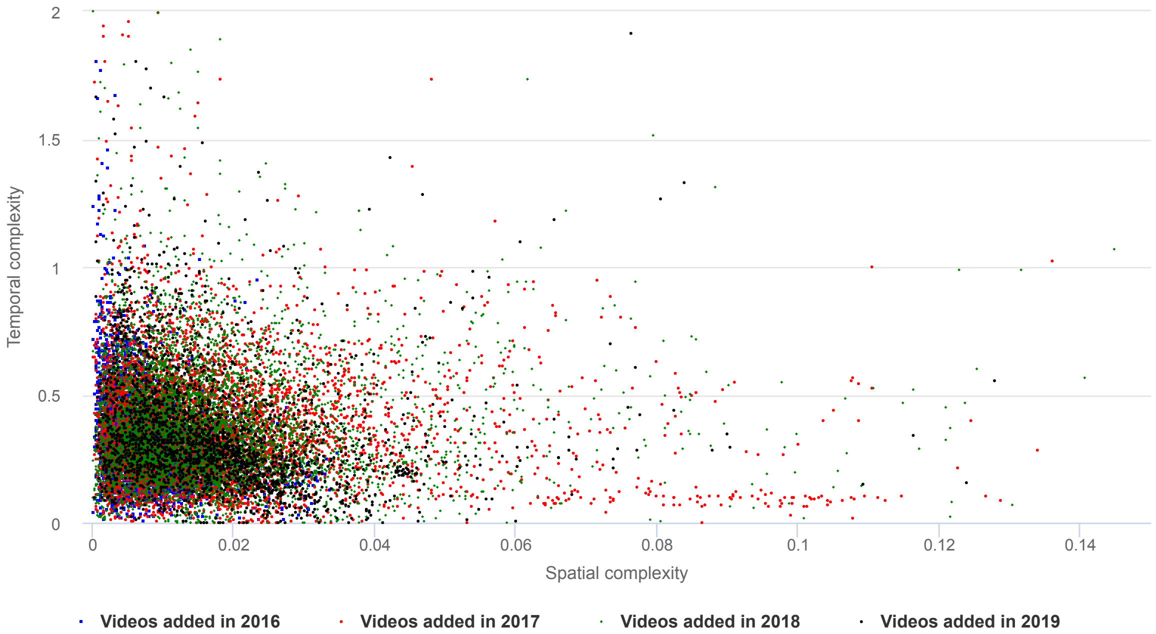



**Figure 12:** Distribution of obtained samples.

This year, we conducted a voting to choose final set of 100 videos for the comparison. Participation in video selection was optional. We divided the video collection into 100 clusters. For each cluster, we randomly selected from 2 to 6 candidate videos that were close to the cluster centre and that had a license enabling derivatives and commercial use. Figure 13 shows the cluster boundaries and constituent sequences.

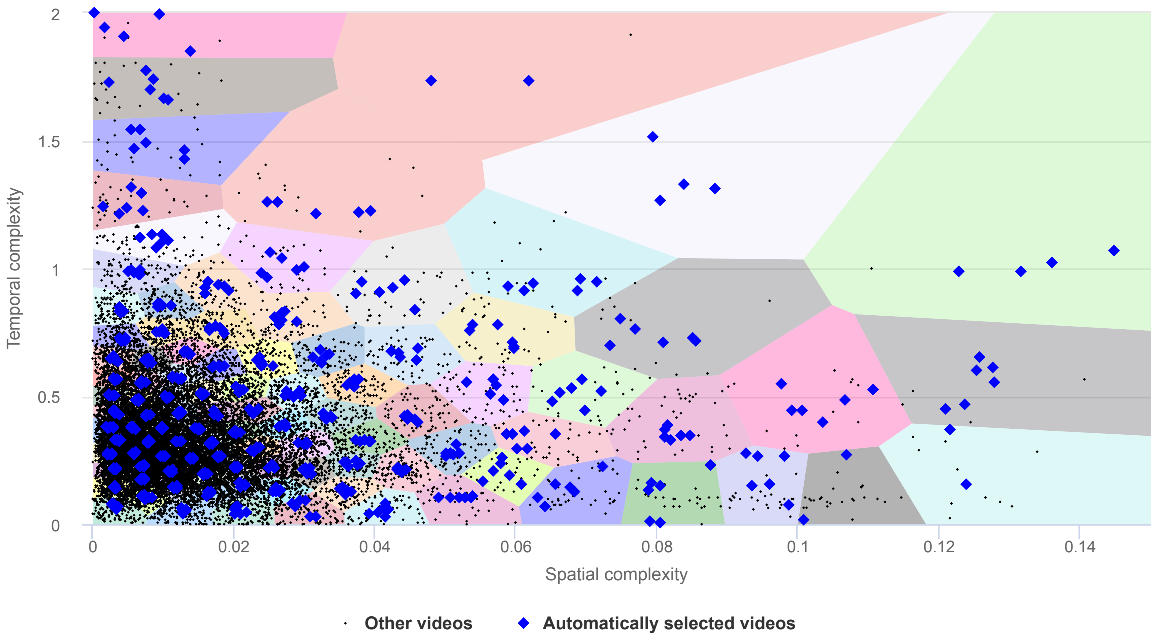



**Figure 13:** Segmentation of samples.

All comparison participants were invited to participate in video selection, and seven took part in it. Also, two organizers of comparison (Dr Dmitriy Vatolin and Dr Dmitriy Kulikov) and independent industry expert (Jan Ozer https://streaminglearningcenter.com/about-jan-ozer) took part in voting for final video set. Table 4 contains information about video selection participants.

| Voter | Number of clusters to vote | Number of received votes | Vote weight |
|---|---|---|---|
| Dr. D. Vatolin | 100 | 100 | 1 |
| Dr. D. Kulikov | 100 | 100 | 1 |
| Jan Ozer | 70 | 70 | 2 |
| Participant #1 | 25 | 25 | 1 |
| Participant #2 | 25 | 25 | 1 |
| Participant #3 | 25 | 25 | 1 |
| Participant #4 | 25 | 25 | 1 |
| Participant #5 | 25 | 15 | 1 |
| Participant #6 | 25 | 8 | 1 |
| Participant #7 | 25 | 7 | 1 |

**Table 4:** Voted members of video selection.

For every participant, only a subset of clusters is available for voting. Each participant was suggested to choose one video in each of 25 given clusters. These clusters were chosen randomly, overlapped for differents voters and equally covered all 100 clusters. A participant could change a vote until the end of voting. Fig. 14 shows the interface of video selection platform.

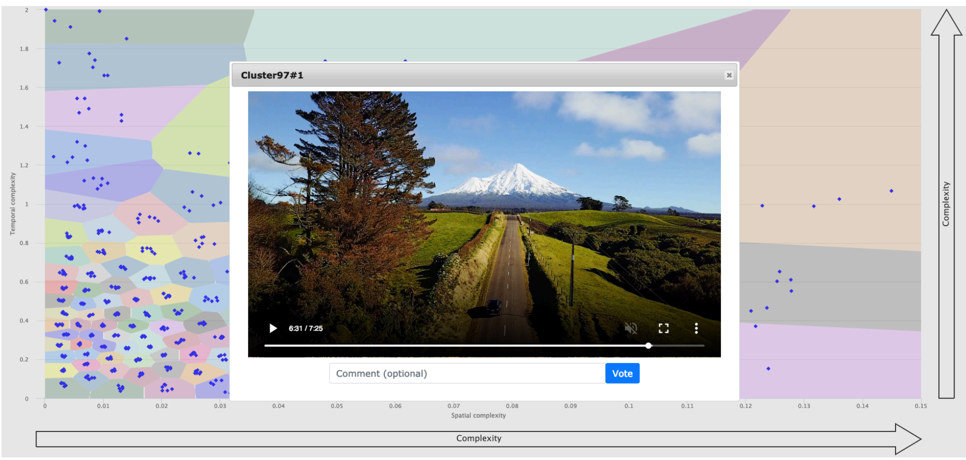



**Figure 14:** Video selection platform interface.

At the end of voting, videos with the highest number of votes were selected for the final comparison set. List of final videos and votes for them is presented in separate PDF with videos descriptions, and their distribution in SI/TI space among all videos from collection is shown in Fig. 15.

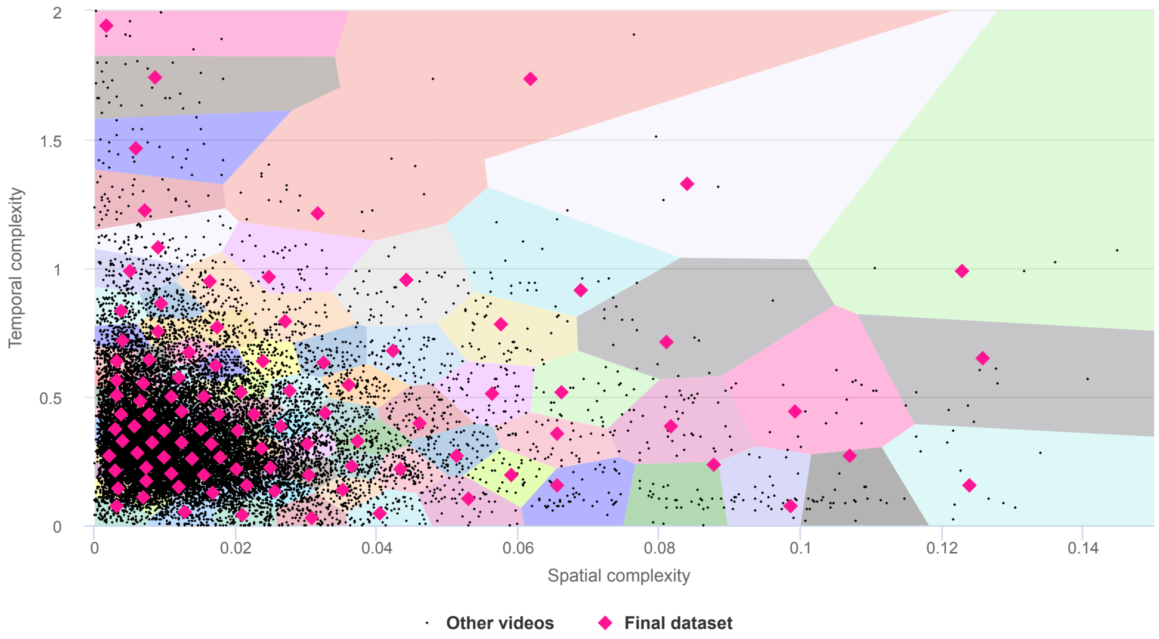



**Figure 15:** Distribution of sequences in final set.

The new data set consists of 100 sequences: 8 from the old data set and 92 new ones from Vimeo and xiph.org. The average bitrate for all sequences in the final set is 218.9 Mbps, median – 143.2 Mbps. "City walk" (61.5 Mbps), "Nancy" (67.6 Mbps) and "Oman museum" (69.7 Mbps) sequences have minimal bitrates. The complete list of sequences for new data set appears in Appendix B.

We also compared the distribution of videos from xiph.org with clusters obtained from our data set from Vimeo. The result is presented on Figure 16. It shows that most of the videos from xiph.org database have high spatial and temporal complexity with which codecs rarely face in everyday life.

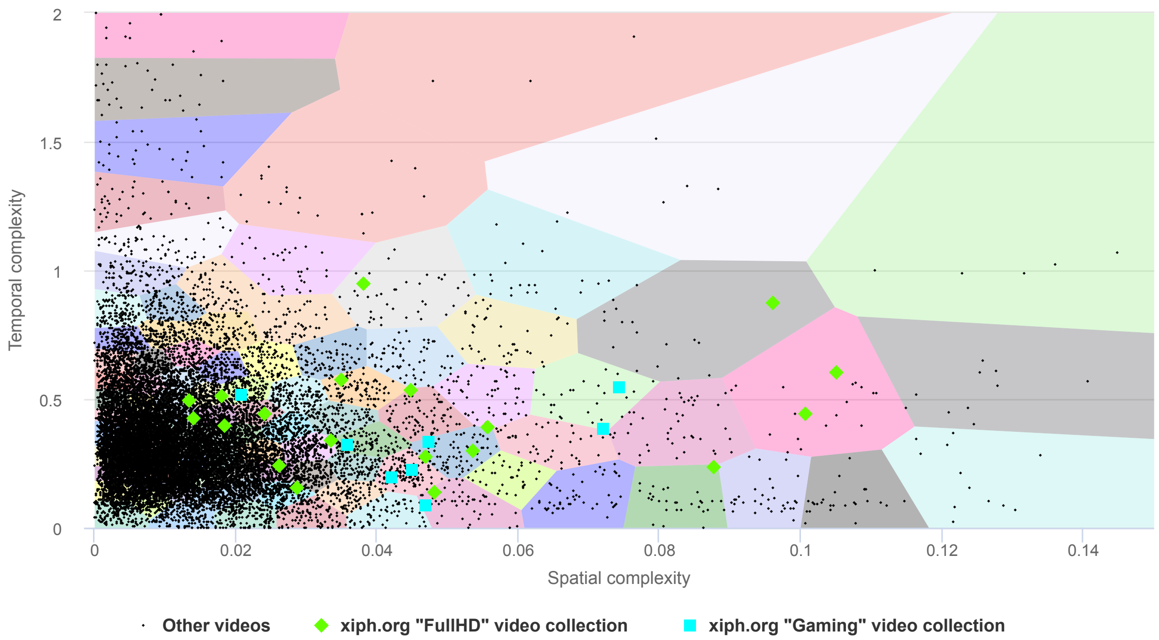



**Figure 16:** Comparison with xiph.org

# E. FIGURE EXPLANATION

The main charts in this comparison are classic RD curves (quality/bitrate graphs) and relative-bitrate/relative-time charts. Additionally, we also used bitrate-handling charts (the ratio of real to target bitrates) and per-frame quality charts.

## E.1. RD Curves

The RD charts show variation in codec quality by bitrate or file size. For this metric, a higher value presumably indicates better quality.

## E.2. Relative-Bitrate/Relative-Time Charts

Relative-bitrate/relative-time charts show the average bitrate's dependence on relative encoding time for a fixed-quality output. The y-axis shows the ratio of a codec's bitrate under test to the reference codec's bitrate for a fixed quality. A lower value (that is, a higher the value on the graph) indicates a better-performing codec. For example, a value of 0.7 means the codec can encode the sequence in a file that's 30% smaller what the reference codec produces.

The x-axis shows the relative encoding time. Larger values indicate a slower codec. For example, a value of 2.5 means the codec works 2.5 times slower, on average, than the reference codec.

## E.3. Graph Example

Figure 17 shows a situation where these graphs can be useful. In the top-left graph, the “Green” codec clearly produces better quality than the “Black” codec. On the other hand, the top-right graph shows that the “Green” codec is slightly slower. Relative-bitrate/relative-time graphs can be useful in precisely these situations: the bottom graph clearly shows that one codec is slower but yields higher visual quality, whereas the other codec is faster but yields lower visual quality.

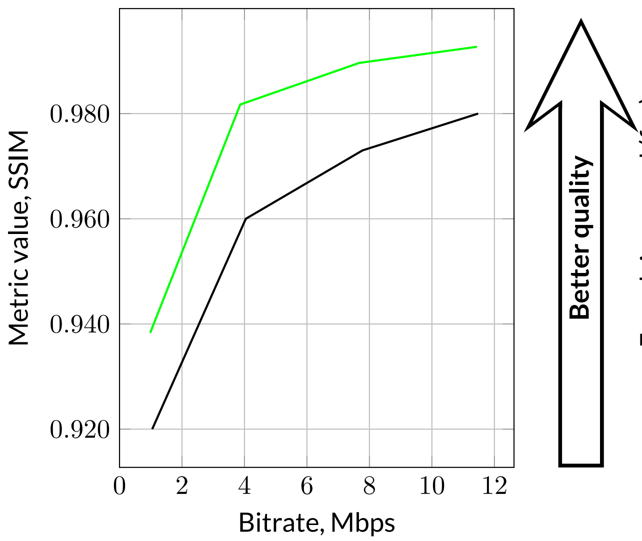
Owing to these advantages, we frequently use relative-bitrate/relative-time graphs in this report because they assist in evaluating the codecs in the test set, especially when the number of codecs is large.

A more detailed description of how we prepared these graphs appears below.

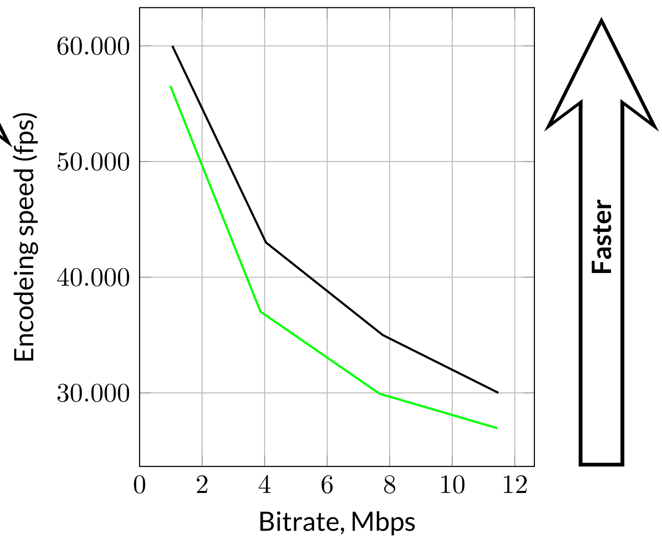
## E.4. Bitrate Ratio for the Same Quality

The first step in computing the average bitrate ratio for a fixed quality is to invert the axes of the bitrate/quality graph (see Figure 18b). All further computations use the inverted graph.

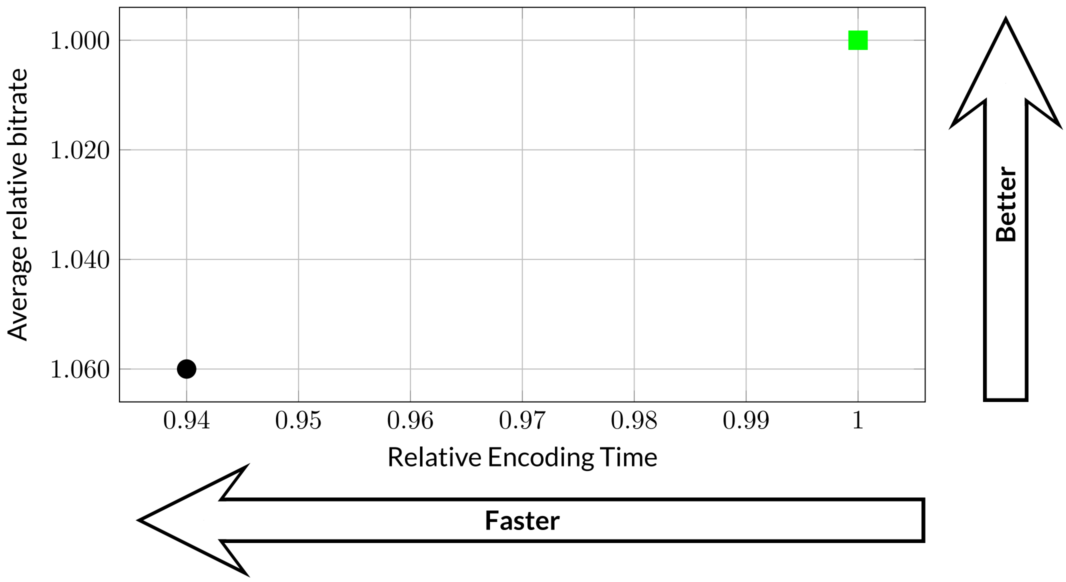
The second step involves averaging the interval over which the quality axis is chosen. The averaging is only over those segments for which both codecs yield results. This limitation is due to the difficulty of developing extrap-




**(a)** RD curve. "Green" codec is better!

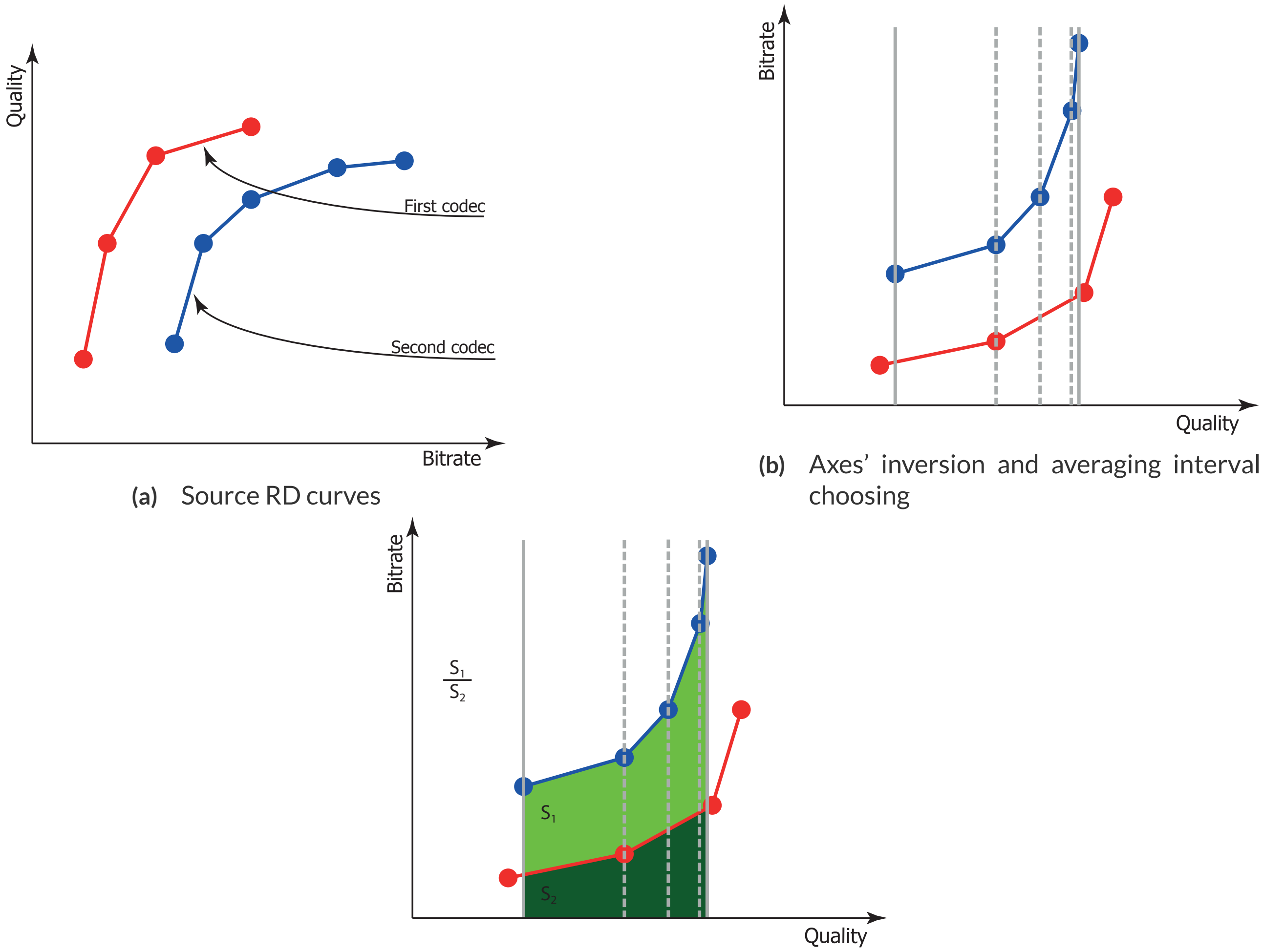



**(b)** Encoding speed (frames per second). "Green" codec is slower!




**(c)** Integral situation with codecs. This plot shows the situation more clearly

**Figure 17:** Speed/Quality trade-off example




(a) Source RD curves

(b) Axes' inversion and averaging interval choosing

(c) Areas under curves ratio

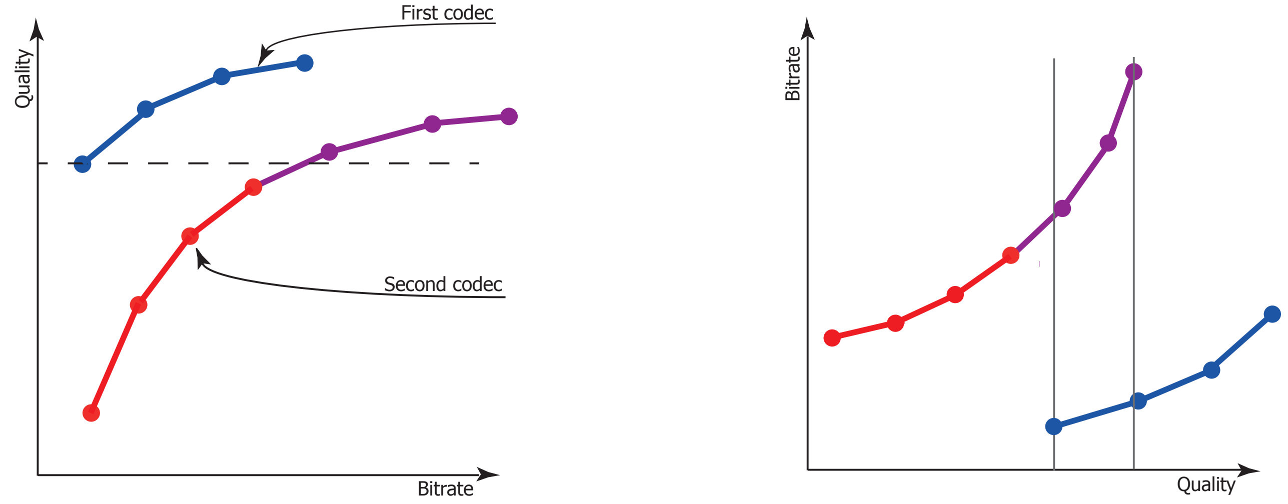
**Figure 18:** Average bitrate ratio computation

olation methods for classic RD curves; nevertheless, even linear methods are acceptable when interpolating RD curves.

The final step is calculation of the area under the curves in the chosen interpolation segment and determination of their ratio (see Figure 18c). This result is an average bitrate ratio at a fixed quality for the two codecs. When considering more than two codecs, one of is defined as a reference codec, and the quality of the others is compared with that of the reference.

### E.4.1. When RD Curves Fail to Cross the Quality Axis

If no segment exists for which two codecs both produce encoding results, we measured the results for additional higher and/or lower bitrates. The schematic example (Figure 19) shows that the results for these extra bitrates (purple) cross with codec two and enable a comparison with codec one.



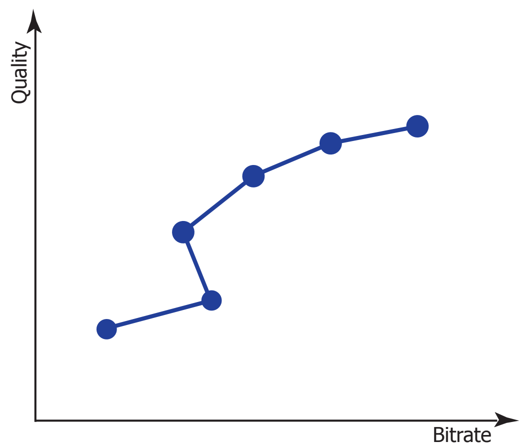

**(a)** Source RD curves, purple color indicates results for extra bitrates

**(b)** Axes' inversion and averaging interval choosing

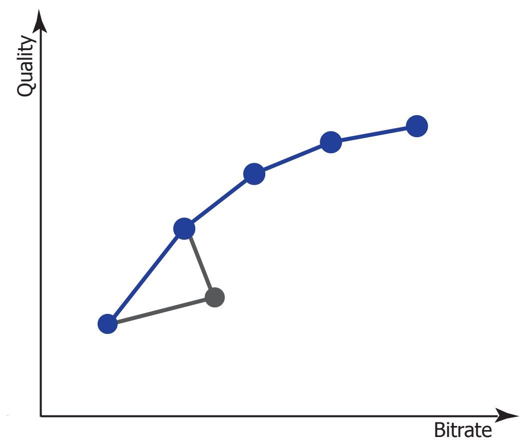
**Figure 19:** Measuring codec on additional bitrates to make it cross with other codecs over the quality axis.

### E.4.2. When RD Curves Are Non-monotonic

Sometimes, especially on complex videos, the encoding results for neighboring bitrates vary greatly owing to the codec's operating characteristics. This situation leads to a non-monotone RD curve, which we process as follows: for each point, use the next point at the target bitrate that has greater or equal quality. This technique yields the reduced monotonic curve, which appears in the example of Figure 20.




**(a)** Non-monotonic RD-curve.




**(b)** Points that were used to calculate integral.

**Figure 20:** Processing non-monotonic RD-curves.

## E.5. Relative Quality Analysis

Although most figures in this report provide codec scores relative to a reference encoder (i.e., x264), the "Relative Quality Analysis" sections provide the bitrate ratio at a fixed quality score (see Section E.4) for each codec pair.

This approach may be useful when comparing codec A relative with codec B only.

Below is a simplified example table showing the average bitrate ratio, given a fixed quality, for just two codecs.

| | A | B |
|---|---|---|
| A | 100% ☺ | 75% ☹ |
| B | 134% ☹ | 100% ☺ |


**Table 5:** Example of average bitrate ratio for a fixed quality table

Consider column "B", row "A" of the table, which contains the value 75%. This number should be interpreted in the following way: the average bitrate for Codec B at a fixed quality is 75% less than that for codec A. The icon in the cell depicts the confidence of this estimate. If projections of RD curves on the quality axis (see Figure 18) have large common areas, the cell contains a happy icon. If this overlapping area is small, and thus the bitrate-score calculation is unreliable, the cell contains a sad icon.

Plots of the average bitrate ratio for a fixed quality are visualizations of these tables. Each line in the plot depicts values from one column of the corresponding table.

# F. OBJECTIVE-QUALITY METRIC DESCRIPTION

## F.1. SSIM (Structural Similarity)

We used the YUV-SSIM objective-quality metric in this report to assess the quality of encoded video sequences. We compute YUV-SSIM as the weighted average of SSIM values for each channel individually (Y-SSIM, U-SSIM and V-SSIM):

$$\text{YUV-SSIM} = \frac{4\,\text{Y-SSIM} + \text{U-SSIM} + \text{V-SSIM}}{6}. \tag{1}$$

Below is a brief description of SSIM computation.

### F.1.1. Brief Description

Wang, et al.[2] published the original paper on SSIM. This paper available at http://ieeexplore.ieee.org/iel5/83/28667/01284395.pdf. The SSIM author homepage is http://www.cns.nyu.edu/~lcv/ssim/

The main idea that underlies the structural-similarity (SSIM) index is comparison of the distortion of three image components:

- Luminance
- Contrast
- Structure

The final formula, after combining these comparisons, is

$$\mathbf{SSIM}(x, y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x + \mu_y + C_1)(\sigma_x + \sigma_y + C_2)}, \tag{2}$$

where

$$\mu_x = \sum_{i=1}^{N} \omega_i x_i, \tag{3}$$

$$\sigma_x = \sqrt{\sum_{i=1}^{N} \omega_i (x_i - \mu_x)}, \tag{4}$$

$$\sigma_{xy} = \sum_{i=1}^{N} \omega_i (x_i - \mu_x)(y_i - \mu_y). \tag{5}$$

Finally, $C_1 = (K_1 L)^2$ and $C_2 = (K_2 L)^2$, where $L$ is the dynamic range of the pixel values (e.g. 255 for 8-bit greyscale images), and $K1, K2 \ll 1$.

We used $K_1 = 0.01$ and $K_2 = 0.03$ were used for the comparison presented in this report, and we filled the matrix with a value “1” in each position to form a filter for the results map.

[2] Zhou Wang, Alan Conrad Bovik, Hamid Rahim Sheikh and Eero P. Simoncelli, “Image Quality Assessment: From Error Visibility to Structural Similarity,” IEEE Transactions on Image Processing, Vol. 13, No. 4, April 2004.

For our implementation, one SSIM value corresponds to two sequences. The value is in the range $[-1, 1]$, with higher values being more desirable (a value of 1 corresponds to identical frames). One advantage of the SSIM metric is that it better represents human visual perception than does PSNR. SSIM is more complex, however, and takes longer to calculate.

#### F.1.2. Examples

Figure 21 shows an example SSIM result for an original and processed (compressed with lossy compression) image. The value of 0.9 demonstrates that the two images are very similar.


(a) Original (b) Compressed (c) SSIM

**Figure 21:** SSIM example for compressed image

Figure 22 depicts various distortions applied to the original image, and Figure 23 shows SSIM values for these distortions.


(a) Original image


(b) Image with added noise

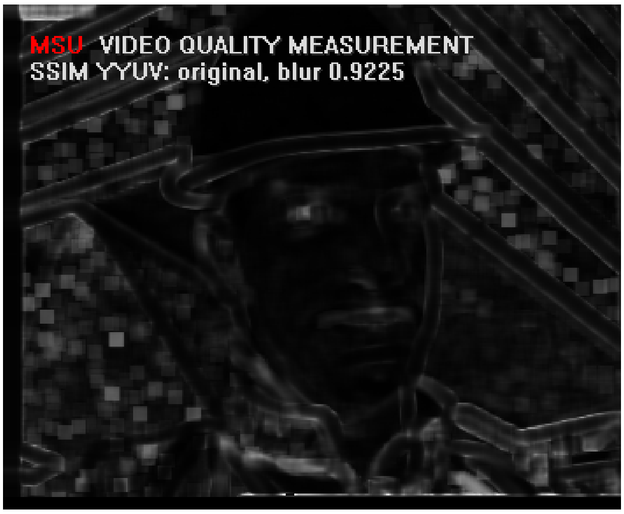
(c) Blurred image


(d) Sharpen image

**Figure 22:** Examples of processed images


(a) SSIM map for original image, SSIM $= 1$


(b) SSIM map for noisy image, SSIM $= 0.552119$




(c) SSIM map for blurred image, SSIM $= 0.9225$


(d) SSIM map for sharpen image, SSIM $= 0.958917$

**Figure 23:** SSIM values for original and processed images

### F.1.3. Measurement method

We used the MSU Video Quality Measurement Tool (VQMT) to calculate objective metrics for the encoded streams. The tool can be downloaded or purchased at `http://compression.ru/video/quality_measure/vqmt_download.html#start`.

Run the command

```
vqmt -in "{original_yuv}" IYUV {width}×{height} -in "decoded_yuv" IYUV
{width}×{height} metrics_list -subsampling -json -json_file "{json_filename}" -threads
3
```

where `input_yuv` is the encoded stream name, `width` and `height` are the size of encoded stream in pixels, `metrics_list` is a list of metrics to measure (e.g., "-metr ssim_precise YYUV -metr ssim_precise UYUV -metr ssim_precise VYUV"), and `json_filename` is the name of the output file containing the metric results.

## G. ABOUT THE GRAPHICS & MEDIA LAB VIDEO GROUP

The Graphics & Media Lab Video Group is part of the Computer Science Department of Lomonosov Moscow State University. The Graphics Group began at the end of 1980's, and the Graphics & Media Lab was officially founded in 1998. The main research avenues of the lab include areas of computer graphics, computer vision and media processing (audio, image and video). A number of patents have been acquired based on the lab's research, and other results have been presented in various publications.

The main research avenues of the Graphics & Media Lab Video Group are video processing (pre- and post-, as well as video analysis filters) and video compression (codec testing and tuning, quality metric research and codec development).

The main achievements of the Video Group in the area of video processing include:

- High-quality industrial filters for format conversion, including high-quality deinterlacing, high-quality frame rate conversion, new, fast practical super resolution and other processing tools.
- Methods for modern television sets, such as a large family of up-sampling methods, smart brightness and contrast control, smart sharpening and more.
- Artifact removal methods, including a family of denoising methods, flicking removal, video stabilization with frame edge restoration, and scratch, spot and drop-out removal.
- Application-specific methods such as subtitle removal, construction of panorama images from video, video to high-quality photo conversion, video watermarking, video segmentation and practical fast video deblur.

The main achievements of the Video Group in the area of video compression include:

- Well-known public comparisons of JPEG, JPEG-2000 and MPEG-2 decoders, as well as MPEG-4 and annual H.264 codec testing; codec testing for weak and strong points, along with bug reports and codec tuning recommendations.
- Video quality metric research; the MSU Video Quality Measurement Tool and MSU Perceptual Video Quality Tool are publicly available.
- Internal research and contracts for modern video compression and publication of MSU Lossless Video Codec and MSU Screen Capture Video Codec; these codecs have one of the highest available compression ratios.

The Video Group has also worked for many years with companies like Intel, Samsung and RealNetworks.

In addition, the Video Group is continually seeking collaboration with other companies in the areas of video processing and video compression.

E-mail: video@graphics.cs.msu.ru

# MSU Video Quality Measurement Tool

Speedup of your video quality measurement up to 12 times

GRAPHICS & MEDIA LAB

**3 reasons to use VQMT:**

- Fastest implementation of VMAF
- Fastest SSIM/MS-SSIM speed on 4K/8K video
- Professional analysis with NIQE and artifact metrics

video-measure@compression.ru

## Widest Range of Metrics & Formats

### 20+ Objective Metrics

| | |
|---|---|
| PSNR several versions | Spatio-Temporal SSIM |
| MSAD | MSU Blurring Metric |
| Delta | MSU Brightness Flicking Metric |
| MSE | MSU Brightness Independent PSNR |
| VQM | MSU Drop Frame Metric |
| SSIM | MSU Noise Estimation Metric |
| MS-SSIM | MSU Scene Change Detector |
| 3-SSIM | MSU Blocking Metric |
| VMAF | NIQE (no-reference comparison) |

### HDR support

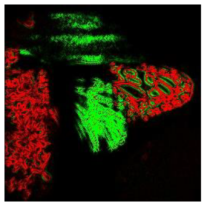
### Hundreds Video and 30+ Image Formats

All popular video codecs, including H264 and HEVC.
Special support for: RAW, Y4M, AviSynth, PXM.
All popular image formats: PNG, JPEG, TIFF (with HDR support), EXR, BMP, PSD, and others

### 2k, 4k, 8k support

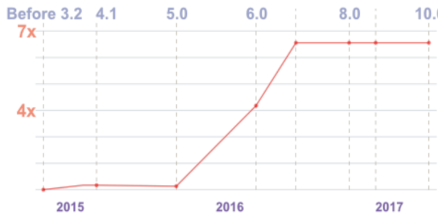
## Visualization Examples

Allows easily detect where codec/filter fails



MSU Blurring Metric

MSU Blocking Metric




VQMT average Speedup

## Fastest Video Quality Measurement

### Up to 11.7x faster calculation of metrics with GPU (CUDA & OpenGL support)

### Multi-core Processors Support

## Easy Integration

### Linux Support

DEB & RPM packages

### Batch Processing with JSON and CSV output

### Plugins SDK

## Professional Analysis

### Comparative Analysis

### Metric Visualization

## MSU VQMT Official Page

**compression.ru/video/quality_measure/video_measurement_tool.html**

Tool was downloaded more than 200 000 times!
Free and Professional versions are available

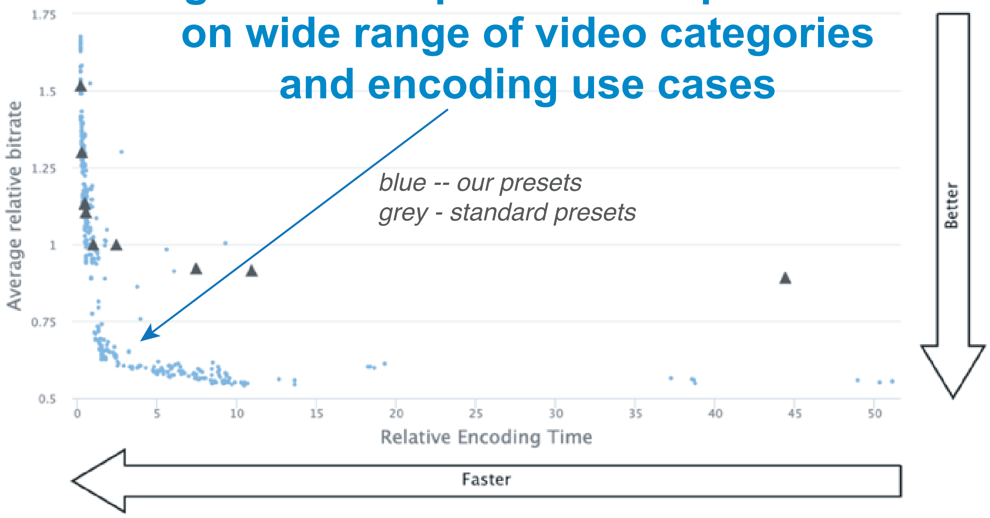
## Big thanks to our contributors:

# Video-Codec Advanced Tuning

Boost up your codec without changing code!

Video Group of Lomonosov MSU Graphics&Media Lab has **15-years experience** in video codecs analysis and optimization. We know that almost always it is possible to find efficient encoding options for every video which increase encoding performance

## Our goal is to improve codec performance on wide range of video categories and encoding use cases




## Why is codec tuning difficult?

Example of x264 tuning for one 20-second video:

- 49 encoding options
- many options make unexpected influence on encoding performance
- exhaustive search for 500-frames video sequence will last ~2.2*10^13 computing centuries (~488 000 Earth ages)

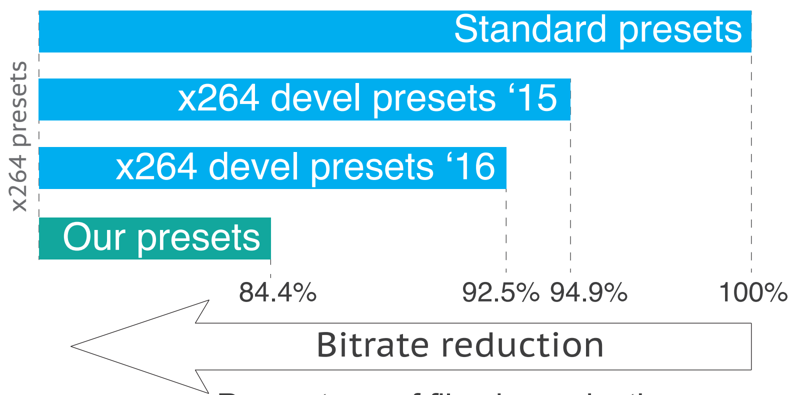
## 15% bitrate savings in average

Encoding presets determined by our method beats x264 developers' presets with keeping encoding time and encoded video quality

We find presets that **do not reduce encoding speed and objective quality of encoded video** compared to your given reference

You give limitations, and we guarantee the same or higher objective quality and encoding speed

You use standard presets and don't believe it will work for your videos? Give us a chance — request a free demo!




Percentage of file size reduction in average for a set of 77 UGC-videos

## We can find best encoding presets for your videos

1. **Your video** — send us uncompressed video and your preset
2. **Report** — get a report with optimal presets for your video and their gain
3. **Choose and pay** — we offer additional options for better compression and analysis
4. **Get preset** — and encode similar videos with it — or — **Get video** — compressed with chosen preset

Our project page: compression.ru/video/video_codec_optimization/


evt@compression.ru

In cooperation with Lomonosov MSU Graphics&Media Lab