MPEG-4 AVC/H.264 Video Codecs Comparison

Enterprise Pro Edition

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Codecs:

- XviD (MPEG-4 ASP codec)
- MainConcept H.264
- Intel H.264
- x264
- AMD H.264
- Artemis H.264

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http://www.compression.ru/video/codec_comparison/index_en.html

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1 Acknowledgments

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

- **Advanced Micro Devices, Inc.**
- **Intel Corporation**
- **MainConcept AG**
- **x264 Development Team**
- **XviD**

The Video Group would also like to thank these companies for their help and technical support during the tests.

2 Overview

2.1 Sequences

Table 1. Summary of video sequences.

	Sequence	Number of frames	Frame rate	Resolution and color space
1.	Salesman	449	30	176x144(YV12)
2.	Foreman	300	30	352x288(YV12)
3.	News	300	30	352x288(YV12)
4.	Battle	1599	24	704x288(YV12)
5.	Smith	772	24	720x432(YV12)
6.	Iceage	491	24	720x576(YV12)
7.	Lord of the Rings	292	24	720x416(YV12)
8.	Troy	300	24	1920x1072(YV12)
9.	Matrix (HDTV)	250	30	1920x1072(YV12)

Brief descriptions of the sequences used in our comparison are given in Table 1. More detailed descriptions of these sequences can be found in Appendix 4. Test Set of Video Sequences.

2.2 Codecs

Table 2. Short codec descriptions

	Codec	Developer	Version
1.	MainConcept H.264/AVC encoder	MainConcept AG	build 7.3.0 at 2007/07/25 rev. 18090
2.	AMD H.264/AVC encoder	Advanced Micro Devices, Inc.	
3.	Intel H.264 Encoder	Intel Corp.	dev. version for 07.09.2007
4.	Raw H.264 XArt	Artemis	07.2007
5.	x264	x264 Development Team	x264 core:56 svn-671
6.	Xvid raw mpeg4 bitstream encoder	Xvid	version for 24.08.2007

Brief descriptions of the codecs used in our comparison are given in Table 2. XviD was used as a good quality MPEG-4 ASP reference codec for comparison purposes. Detailed descriptions of all codecs used in our comparison can be found in Appendix 5. Tested Codecs.

2.3 Table of Noteworthy Points in Codec Comparison

The following table lists the bugs, errors and other interesting points regarding the codecs tested in this comparison.

Codec and Preset	Point Description	Reference
Videoconferences, x264, High Quality	"Foreman" sequence is the only case where x264 performs better than MainConcept	Figure 1
Videoconferences, Artemis x264, High Speed	Unstable PSNR results for all sequences	Figure 7 – Figure 9
Videoconferences, AMD, High Speed	For the "Salesman" and "News" sequences, AMD has no strong correlation between encoding speed and bitrate	Figure 19, Figure 23
Videoconferences, XviD, High Speed	For the "Salesman" sequence, XviD has no strong dependency of encoding speed on bitrate	Figure 20
Videoconferences, AMD and XviD	Bad bitrate handling algorithm	Figure 41 – Figure 47
Movies, MainConcept, High Quality	The "Lord of the Rings" sequence is the only case where MainConcept performs better than x264	Figure 53, Figure 57
Movies, Artemis x264, High Speed	Unstable PSNR results for all sequences	Figure 60 – Figure 63
Movies, Artemis x264, High Speed	Considerable difference between PSNR and SSIM results; see Appendix 3. Artemis x264 and x264 PNSR and SSIM Comparative Analysis for more details	Figure 60, Figure 64 (for example)
Movies, XviD	Unstable encoding time	Figure 68 – Figure 83
Movies, MainConcept, High Quality	Both speed and quality are better than x264 for the "Lord of the Rings" sequence	Figure 85
Movies, Intel IPP, High Speed	Considerable difference between results for PSNR and SSIM	Figure 96, Figure 100
Movies, AMD	Bad bitrate handling algorithm	Figure 104 – Figure 111
HDTV, XviD, High Quality	XviD results at high bitrates for the "Troy" sequence are among the best	Figure 116, Figure 118
HDTV, Artemis x264, High Speed	Artemis x264 PSNR results for "Troy" sequence are unstable	Figure 120
HDTV, XviD, High-Quality	Unusual dependence of encoding speed on bitrate	Figure 127
HDTV, High-Quality, "The Matrix"	AMD and Artemis x264 demonstrate unstable encoding speed	Figure 128, Figure 129
HDTV, AMD	Bad bitrate handling algorithm	Figure 144 – Figure 147

3 Objectives and Testing Rules

3.1 H.264 Codec Testing Objectives

The main goal of this report is the presentation of a comparative evaluation of the quality of new H.264 codecs using objective measures of assessment. The comparison was done using settings provided by the developers of each codec.

3.2 Testing Rules

- The entire test set was divided into three primary types of applications. These applications differ by resolution, bitrate and encoding speed requirements:
    - Videoconferences (bitrates of 50-400 kbps)
    - Movies (bitrates of 500-1500 kbps)
    - High-definition television (“HDTV”; bitrates of 1-10 Mbps)
- There are special presets and speed limitations for every type of application:
    - Videoconferences (speed requirements for 200 kbps CIF sequences):
        - Minimum 60 fps for "High Speed" preset
        - Minimum 30 fps for "High Quality" preset
    - Movies (speed requirements for 750 kbps 4CIF sequences):
        - Minimum 15 fps for "High Speed" preset
        - Minimum 4 fps for "High Quality" preset
    - HDTV (speed requirements for 3 Mbps 1280x720 sequences):
        - Minimum 4 fps for "High Speed" preset
        - Minimum 1 fps for "High Quality" preset
- The developer of each codec provided settings for each type of application
- Each codec was tested for speed three times; the median score (the middle value of the three measurements) was then used as the representative time.
- During the testing process, source video sequences were in the YV12 format (.yuv file extension)
- For all measurements the PRO version of the MSU Video Quality Measurement Tool was used (http://www.compression.ru/video/quality_measure/vqmt_pro_en.html#start).
- The following computer configuration was used for the main tests, except for multi-core encoding:

OS Name	Microsoft Windows XP Professional
Version	5.1.2600 Service Pack 2 Build 2600

Processor	x86 Family 15 Model 4 Stepping 10 AuthenticAMD ~2009 MHz
BIOS Version/Date	Phoenix Technologies, LTD 6.00 PG, 01.07.2005
Total Physical Memory	1024.00 MB
Video Adapter Type	NVIDIA GeForce 6600

- The following computer configuration was used for multi-core tests:

OS Name	Microsoft Windows XP Professional x64 Edition
Version	5.2.3790 Service Pack 1 Build 3790
Processor	4xEM64T Family 6 Model 15 Stepping 11 GenuineIntel ~2400 MHz
BIOS Version/Date	Intel Corporation BX97520J.86A.2802.2007.1024.1947
Total Physical Memory	4093.42 MB
Video Adapter Type	NVIDIA GeForce 8500 GT

During the evaluation the following measures were used:

- PSNR (Y, U, V components)
- SSIM (Y, U, V components)

More detailed information about these measures may be found on the Internet at the following URL:

http://www.compression.ru/video/quality_measure/info.html

4 Comparison Results

4.1 Video conferences

4.1.1 RD Curves

4.1.1.1 High Speed Preset

High Quality preset results for each sequence are presented in Figure 1 through Figure 6. The first three figures depict the PSNR results and the last three depict the SSIM results. MainConcept yields the best results for all sequences except “Foreman”; the x264 encoder demonstrates the best results for this sequence according to the Y-PSNR metric, and it yields almost the same quality according to the Y-SSIM metric. Intel IPP shows slightly lower quality than x264, but all three codecs (MainConcept, x264 and Intel IPP) are very close according to objective quality metrics. The AMD encoder yields the lowest quality results, and the XviD encoder stands in a strong fourth place.

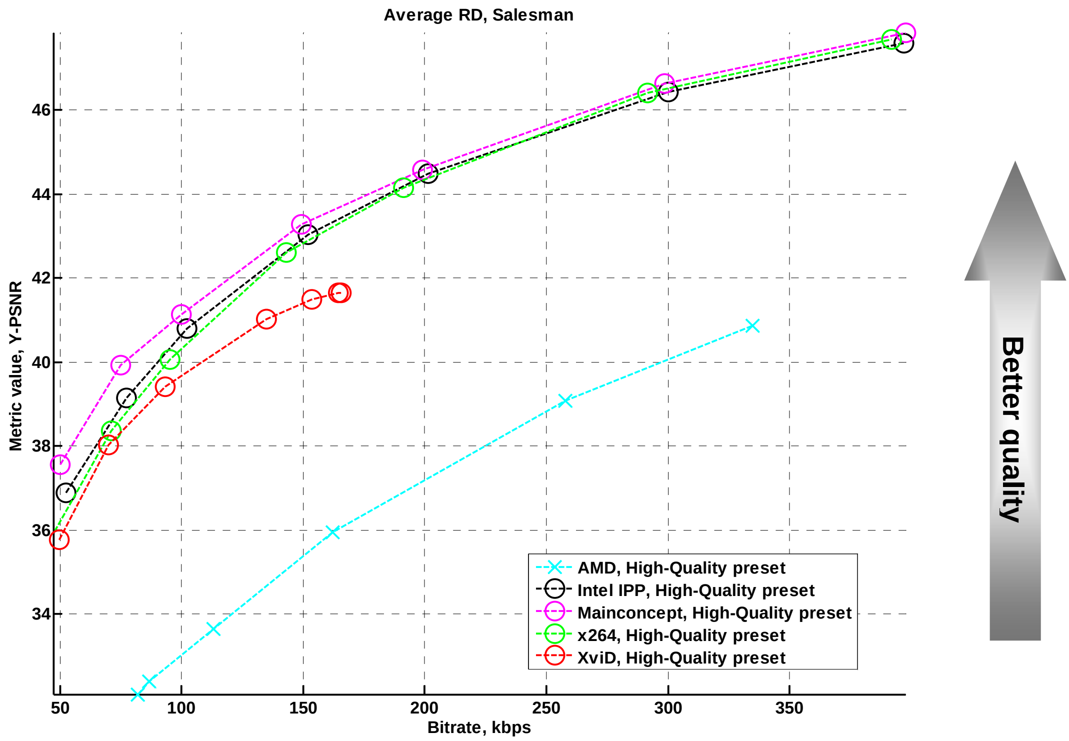


Figure 1. Bitrate/Quality. Usage area “Video Conferences”, “Salesman” sequence, “High Quality” preset, Y-PSNR

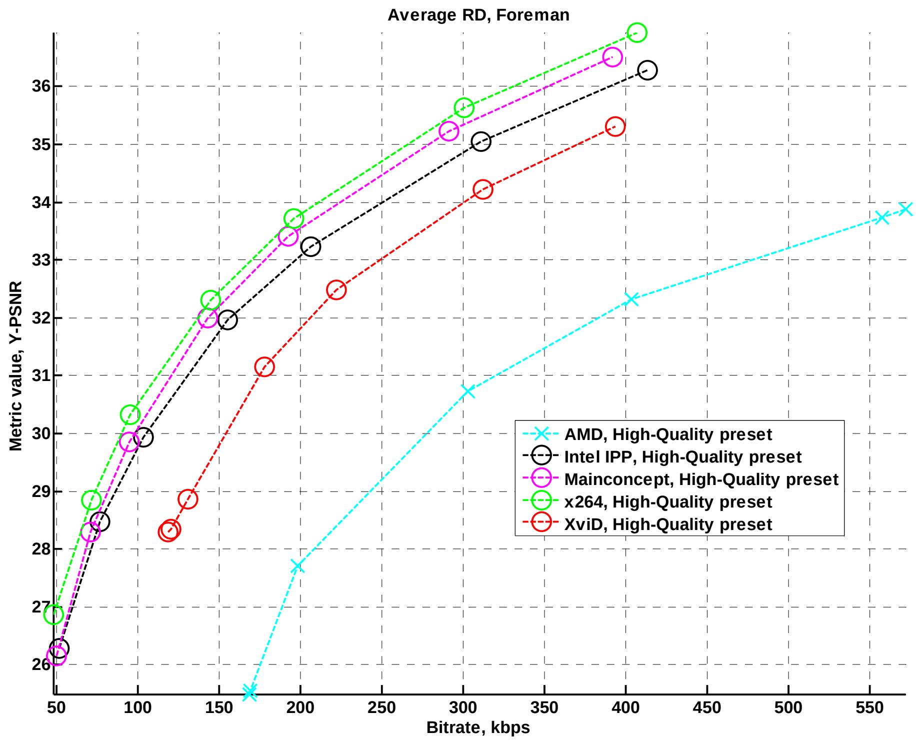


Figure 2. Bitrate/Quality. Usage area "Video Conferences", "Foreman" sequence, "High Quality" preset, Y-PSNR

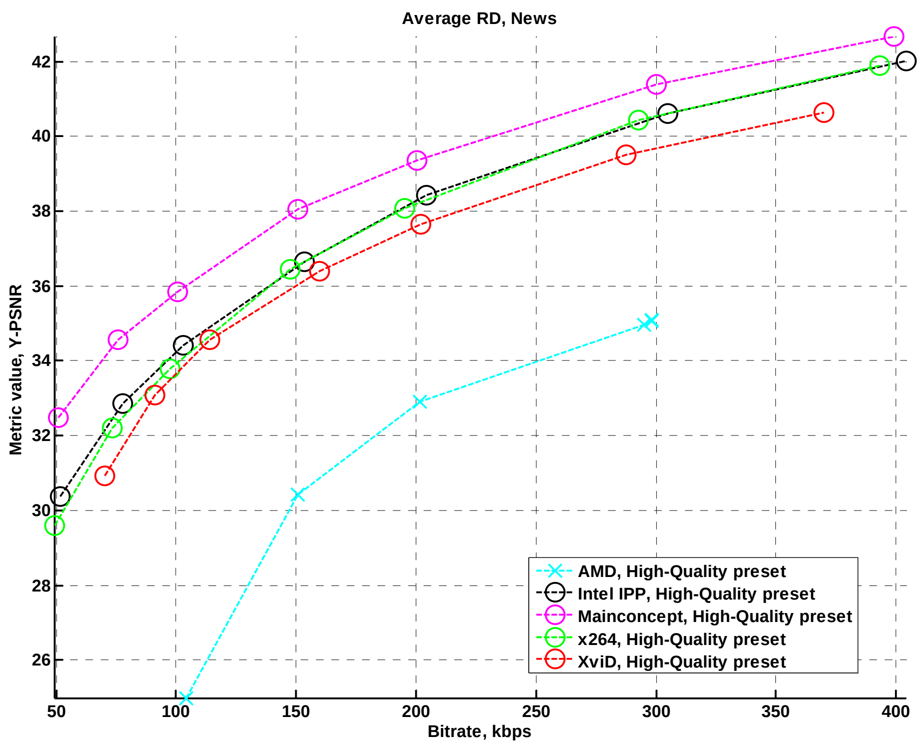


Figure 3. Bitrate/Quality. Usage area "Video Conferences", "News" sequence, "High Quality" preset, Y-PSNR

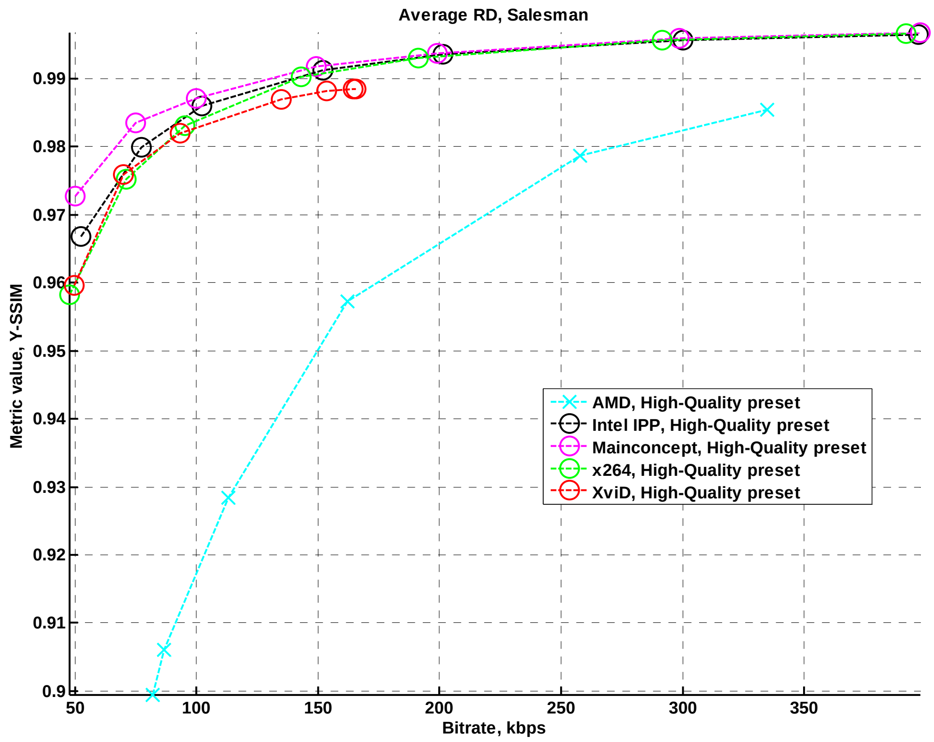


Figure 4. Bitrate/Quality. Usage area "Video Conferences", "Salesman" sequence, "High Quality" preset, Y-SSIM

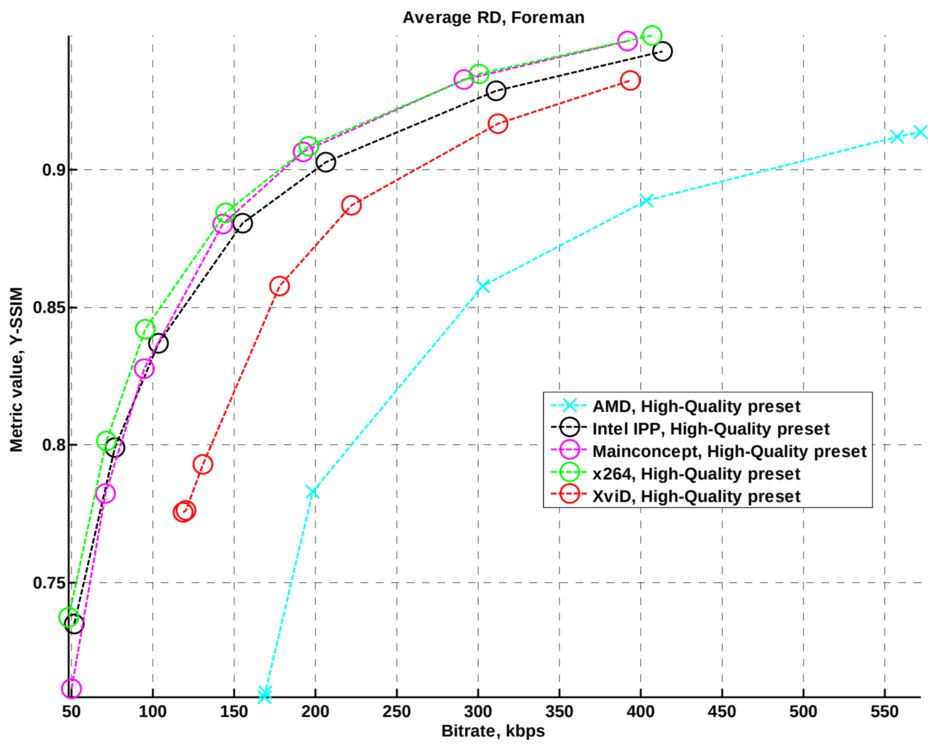


Figure 5. Bitrate/Quality. Usage area "Video Conferences", "Foreman" sequence, "High Quality" preset, Y-SSIM

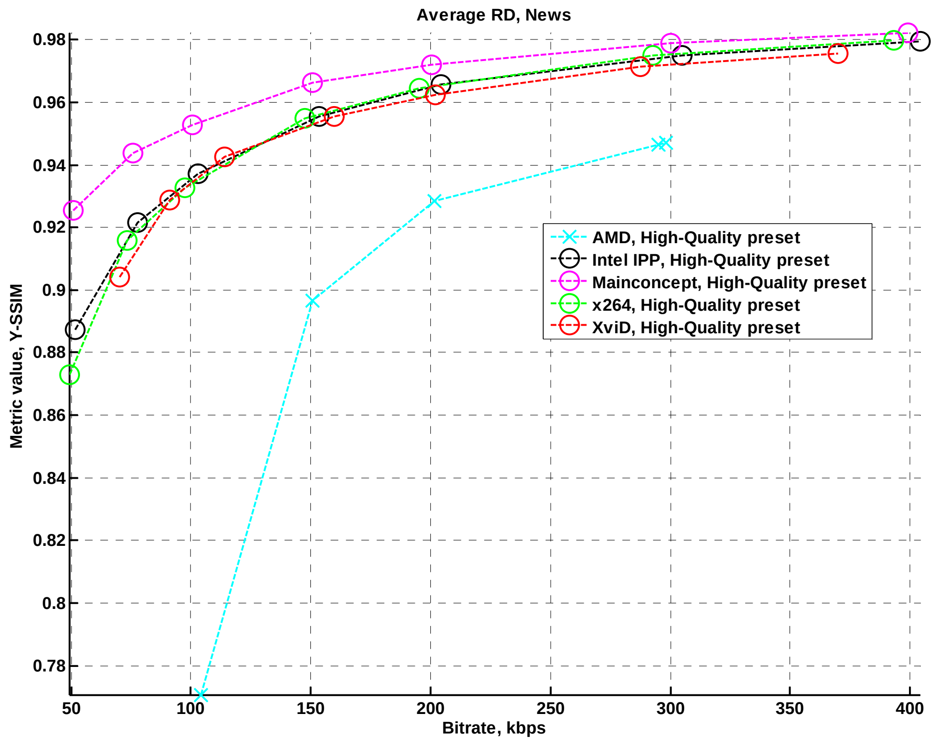


Figure 6. Bitrate/Quality. Usage area “Video Conferences”, “News” sequence, “High Quality” preset, Y-SSIM

4.1.1.2 High Speed Preset

The RD curves for the High Speed preset are shown in Figure 7 through Figure 12. The extremely unstable Artemis x264 encoder results should be noted first. PSNR results for this codec for the "Salesman" sequence are not monotonic (over an increasing bitrate). SSIM results for this codec are relatively more stable, but still fall short of those of the leaders. The RD curves for other sequences are also less than ideal, having a number of increases and decreases. According to the Y-SSIM metric for the "News" and "Foreman" sequences, the results of the Artemis x264 modification are quite comparable with those of the other codecs.

The leading codecs for this preset are the x264, MainConcept and Intel IPP encoders. MainConcept provides better results for the "News" sequence, but x264 provides better results for the "Foreman" sequence. The Intel IPP results are very close to those of x264 and MainConcept. The worst results (with the exception of those of Artemis x264) are produced by the AMD encoder.

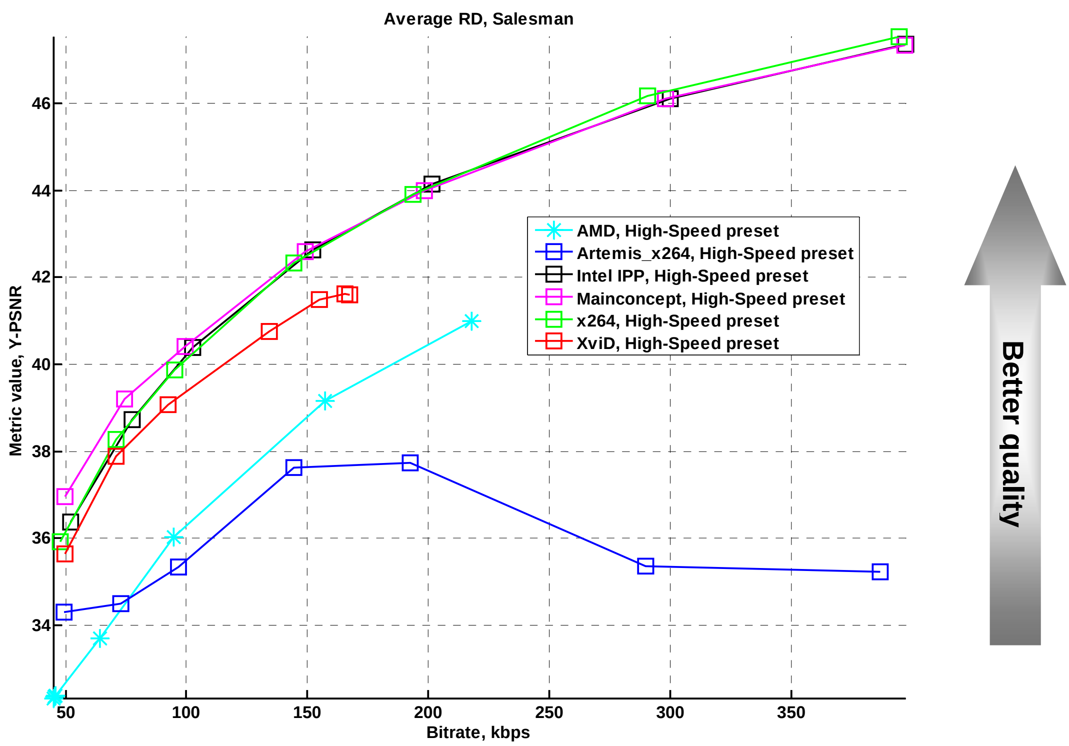


Figure 7. Bitrate/Quality. Usage area "Video Conferences", "Salesman" sequence, "High Speed" preset, Y-PSNR

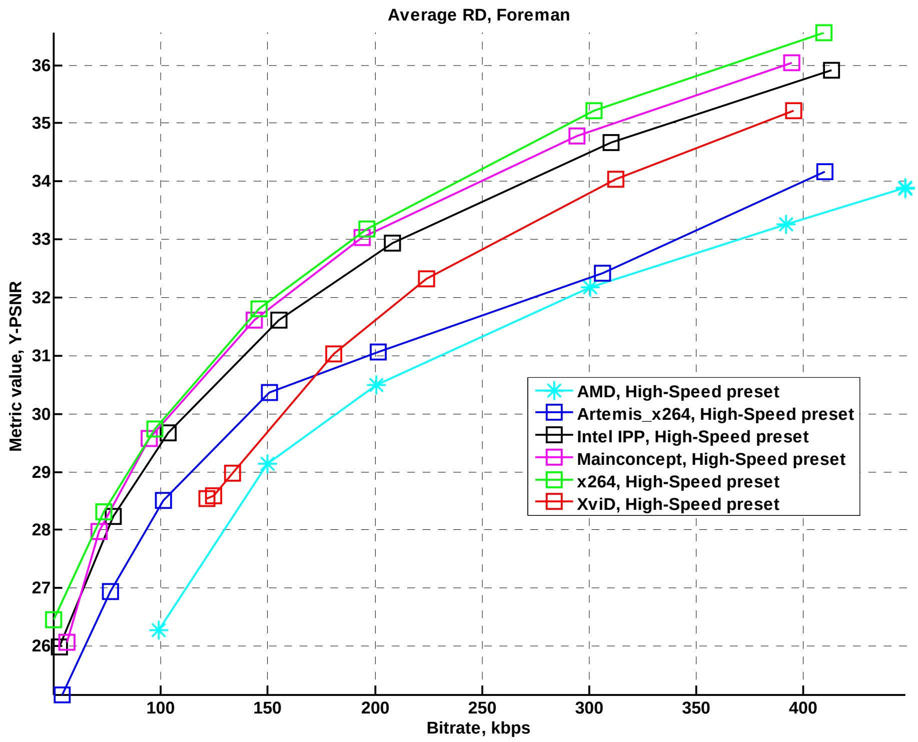


Figure 8. Bitrate/Quality. Usage area "Video Conferences", "Foreman" sequence, "High Speed" preset, Y-PSNR

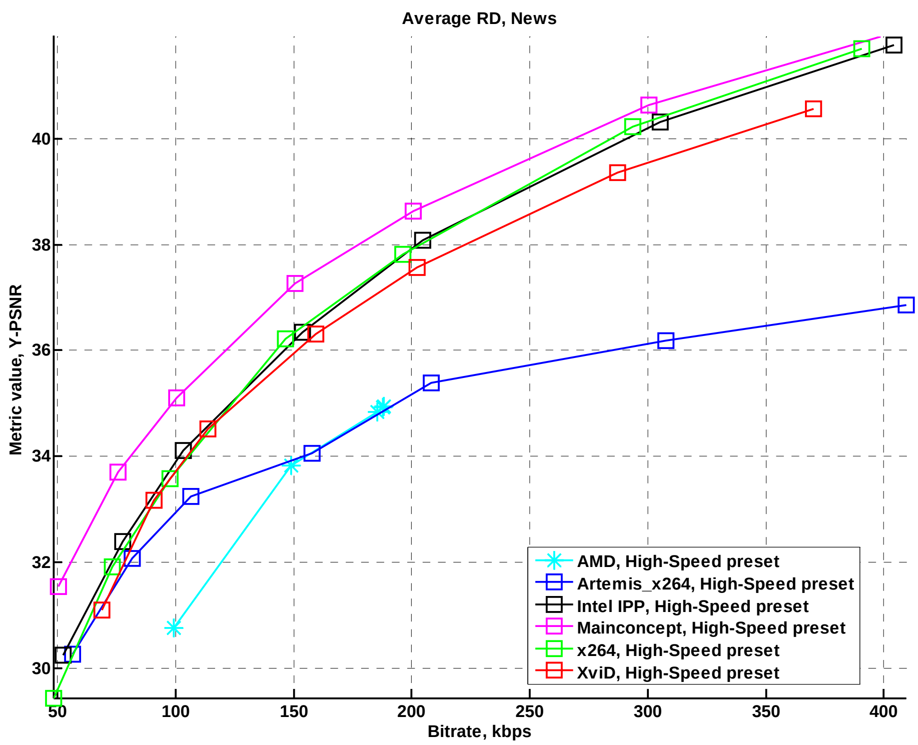


Figure 9. Bitrate/Quality. Usage area "Video Conferences", "News" sequence, "High Speed" preset, Y-PSNR

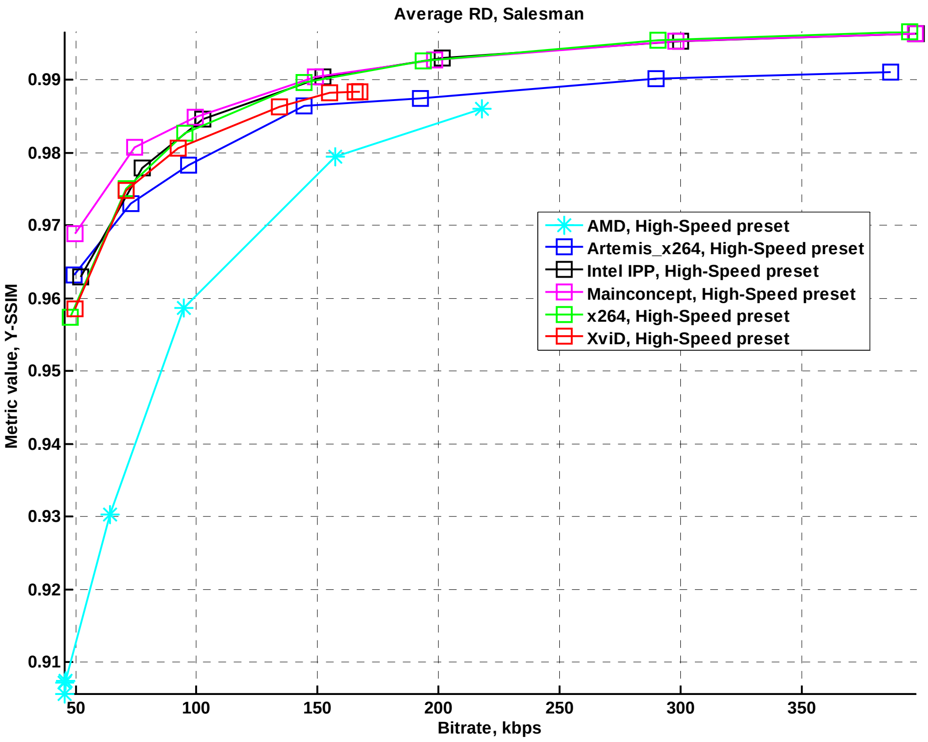


Figure 10. Bitrate/Quality. Usage area "Video Conferences", "Salesman" sequence, "High Speed" preset, Y-SSIM

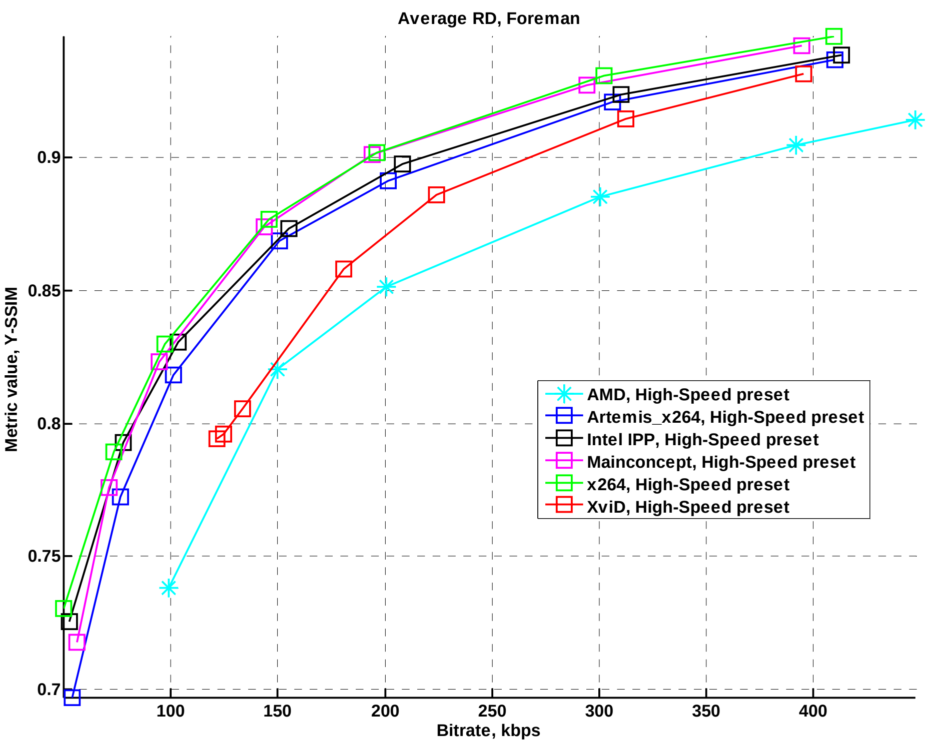


Figure 11. Bitrate/Quality. Usage area "Video Conferences", "Foreman" sequence, "High Speed" preset, Y-SSIM

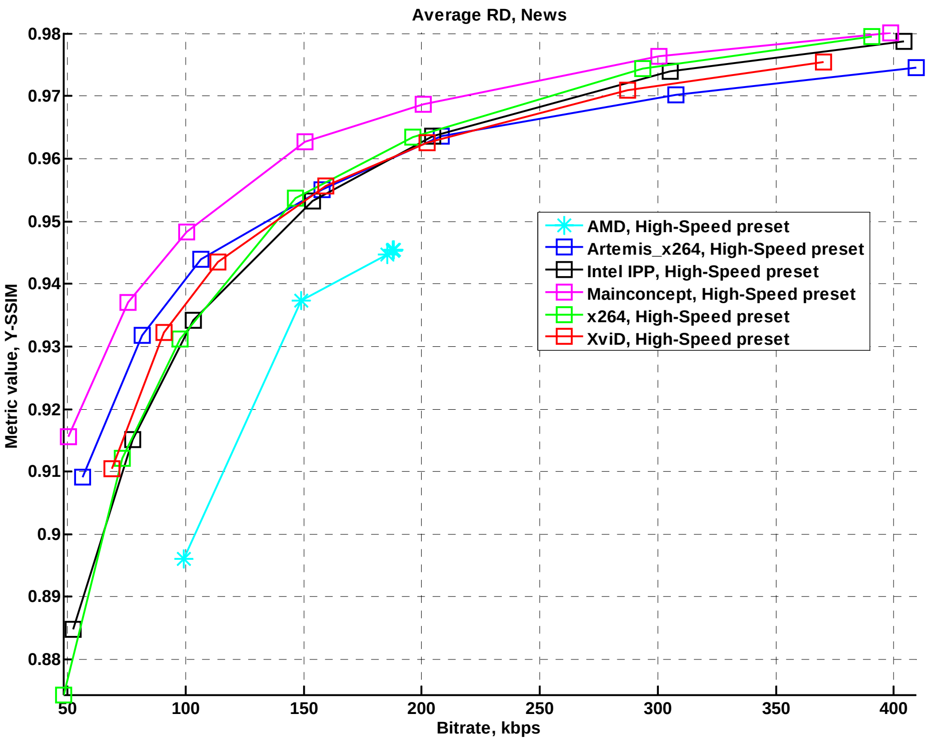


Figure 12. Bitrate/Quality. Usage area “Video Conferences”, “News” sequence, “High Speed” preset, Y-SSIM

4.1.2 Encoding Speed

Absolute speed results are presented in Figure 13 through Figure 24. Note the differing dependence of encoding time on bitrate. The Intel IPP H.264, MainConcept and x264 encoders all have a similar growth rate for the encoding time as the bitrate is increased, but the Intel IPP growth rate is slightly higher. Results for XviD are not stable. Among all the encoders, AMD is the fastest and it has the lowest dependency of encoding speed on bitrate. AMD is 5 to 10 times faster, on average, than the other codecs.

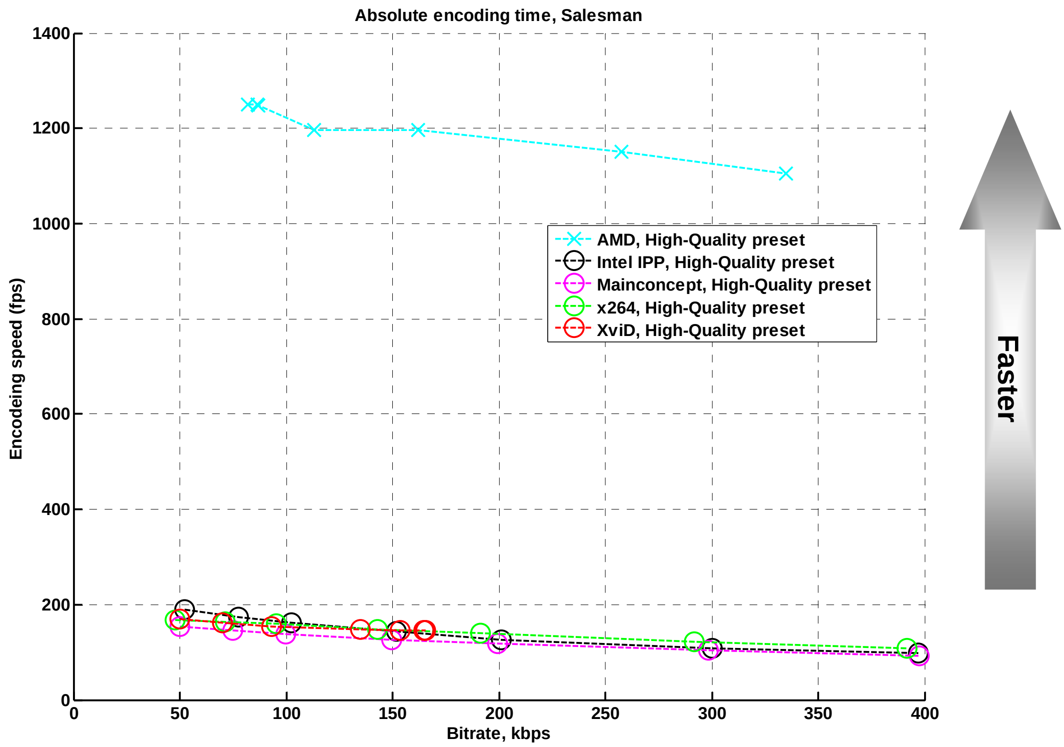


Figure 13. Encoding speed. Usage area “Video Conferences”, “Salesman” sequence, “High Quality” preset

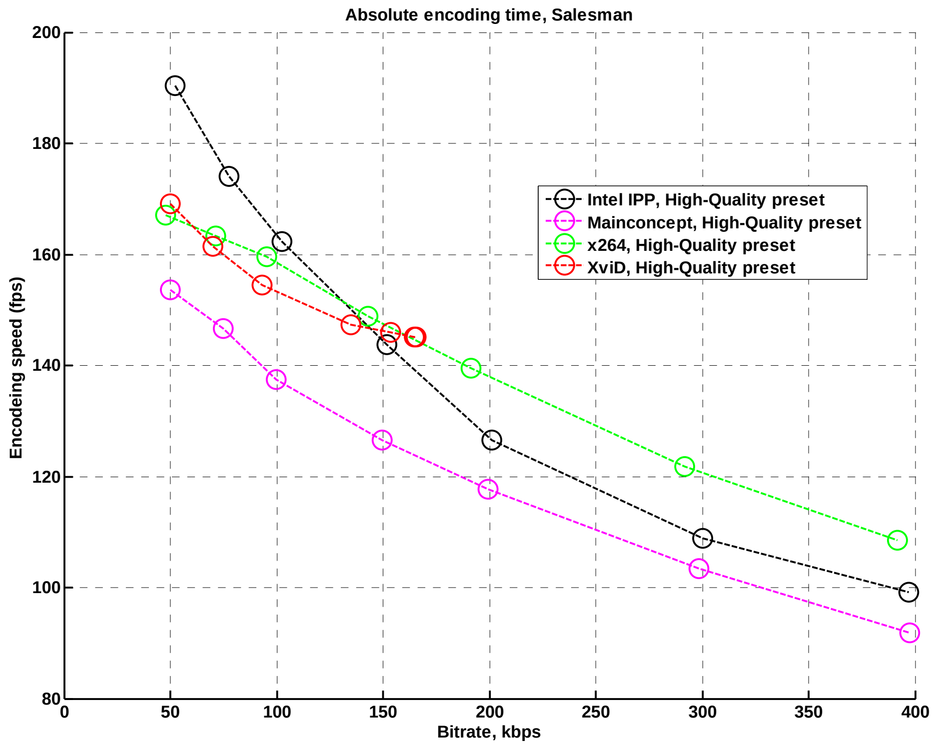


Figure 14. Encoding speed. Usage area "Video Conferences", "Salesman" sequence, "High Quality" preset. All encoders except AMD

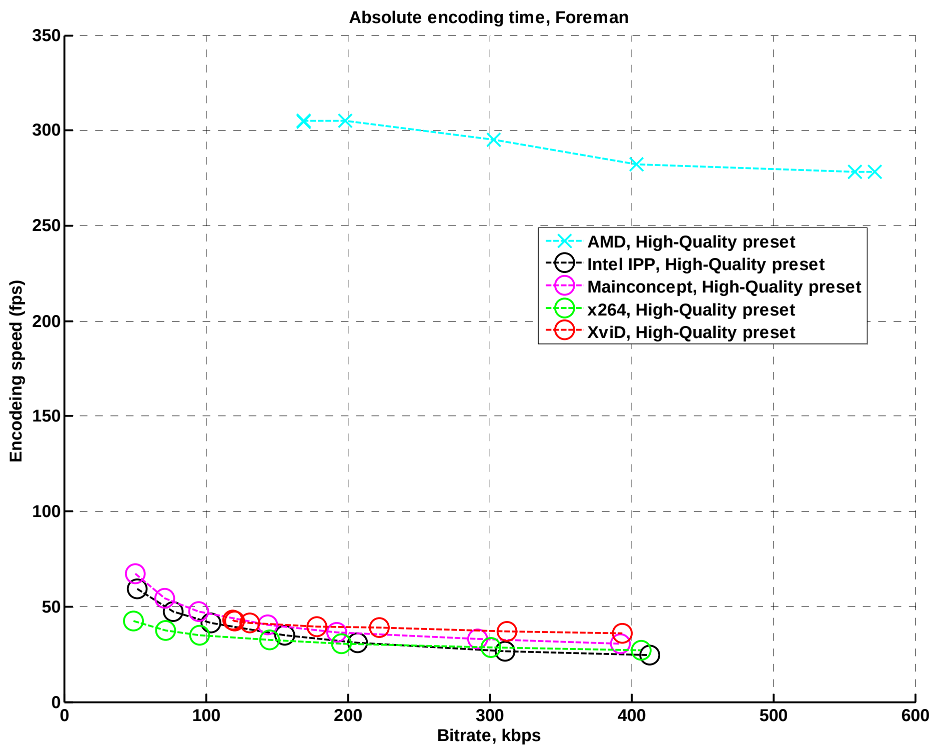


Figure 15. Encoding speed. Usage area "Video Conferences", "Foreman" sequence, "High Quality" preset

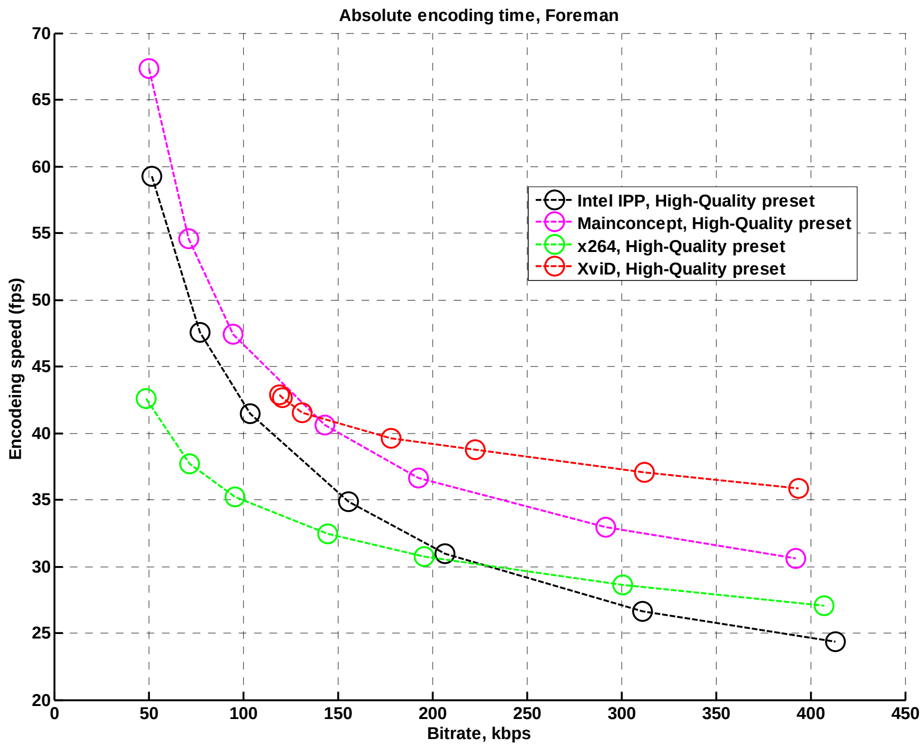


Figure 16. Encoding speed. Usage area "Video Conferences", "Foreman" sequence, "High Quality" preset. All encoders except AMD

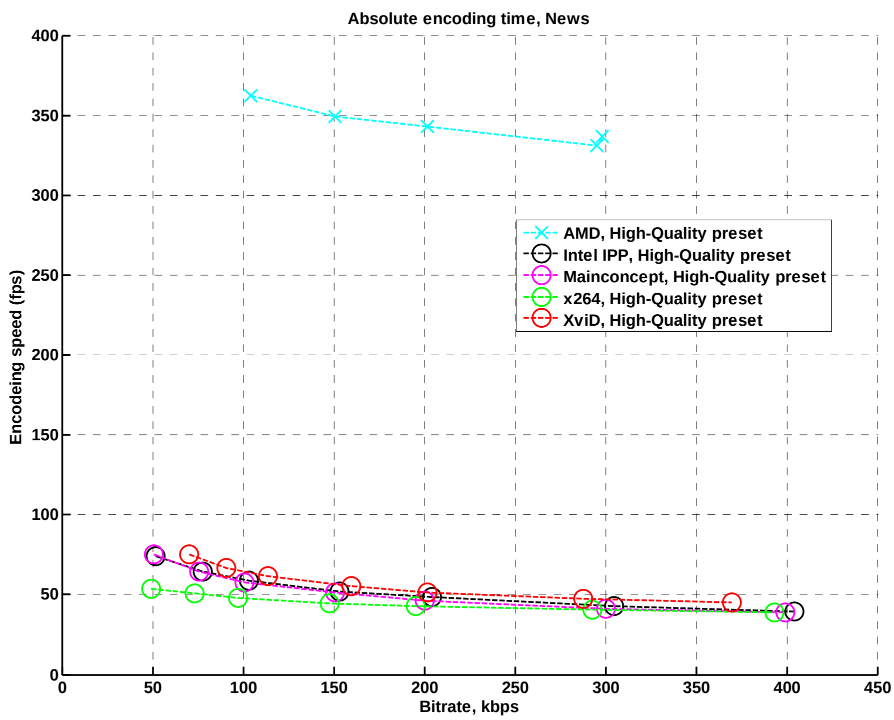


Figure 17. Encoding speed. Usage area "Video Conferences", "News" sequence, "High Quality" preset

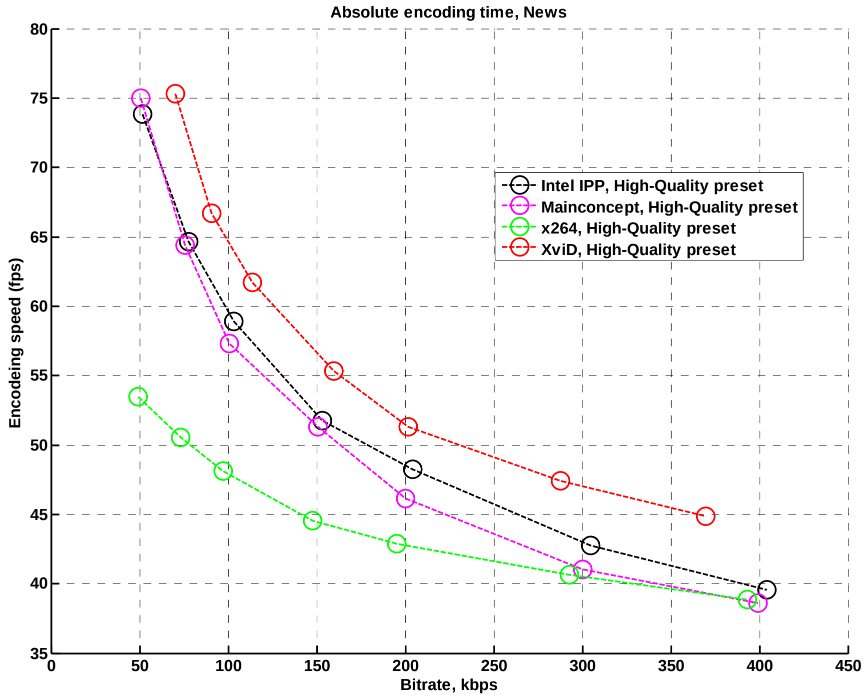


Figure 18. Encoding speed. Usage area "Video Conferences", "News" sequence, "High Quality" preset. All encoders except AMD

4.1.2.1 High Speed Preset

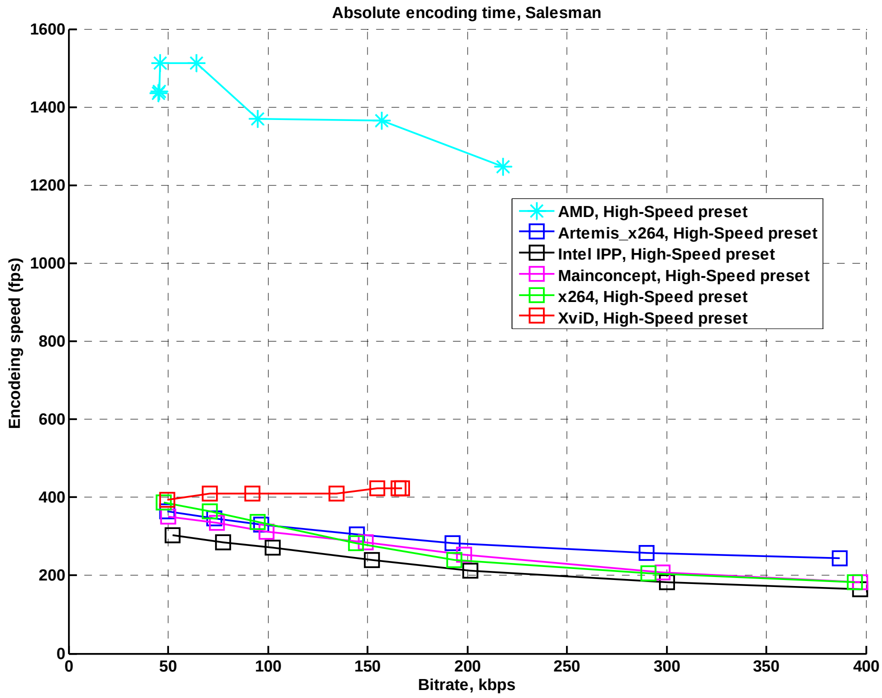


Figure 19. Encoding speed. Usage area "Video Conferences", "Salesman" sequence, "High Speed" preset

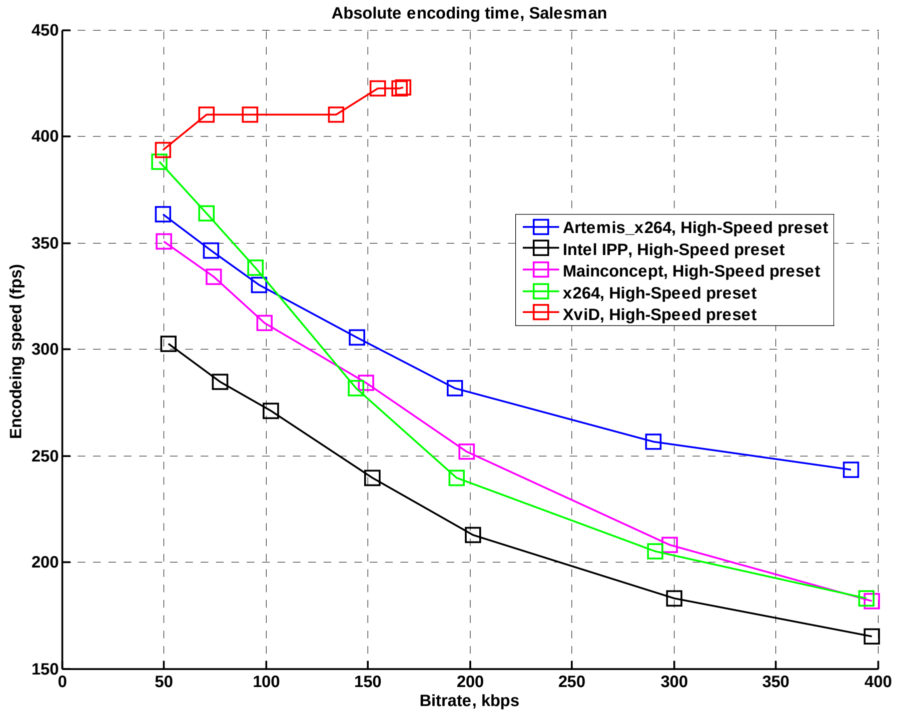


Figure 20. Encoding speed. Usage area “Video Conferences”, “Salesman” sequence, “High Speed” preset. All encoders except AMD

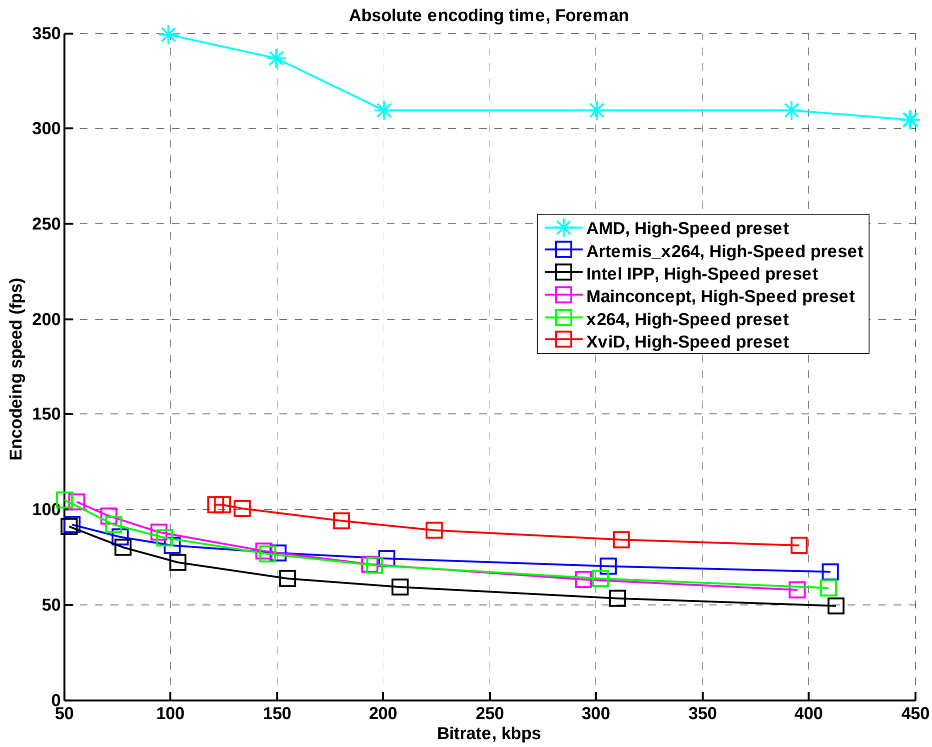


Figure 21. Encoding speed. Usage area “Video Conferences”, “Foreman” sequence, “High Speed” preset

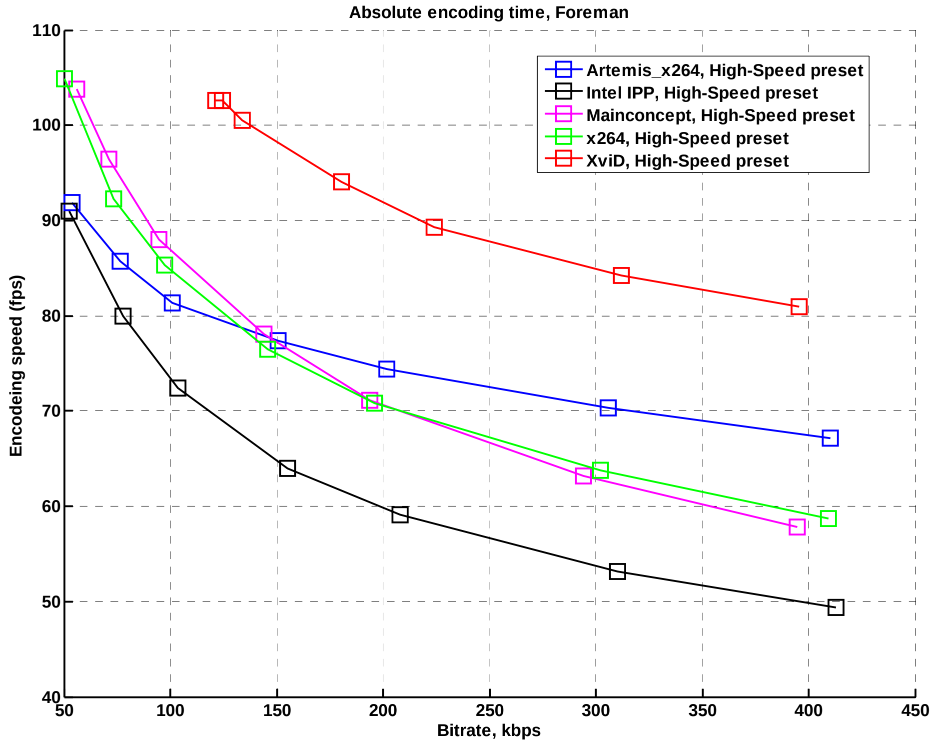


Figure 22. Encoding speed. Usage area "Video Conferences", "Foreman" sequence, "High Speed" preset. All encoders except AMD

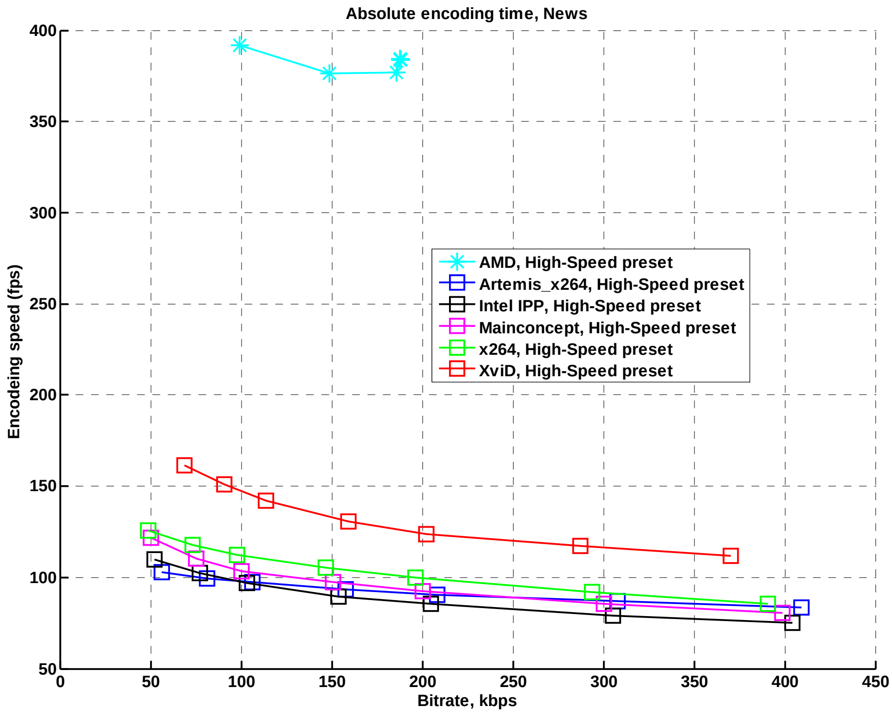


Figure 23. Encoding speed. Usage area "Video Conferences", "News" sequence, "High Speed" preset

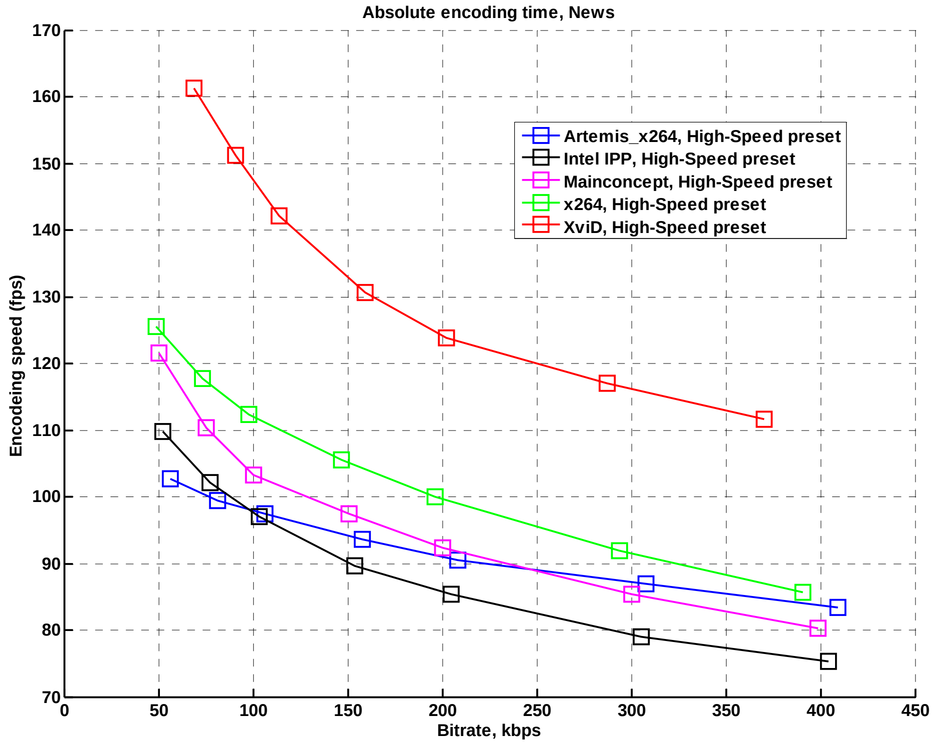


Figure 24. Encoding speed. Usage area "Video Conferences", "News" sequence, "High Speed" preset. All encoders except AMD

4.1.3 Speed/Quality Trade-Off

Speed/quality trade-off charts simultaneously show the relative quality and encoding speed of the encoders tested in this comparison. The reference codec is XviD, which has a quality and a speed both equal to unity in all of the below charts. The comparative terms "better" and "worse" are used at times for comparing the codecs in these charts; these terms simply mean that one codec is of higher speed and better quality (or lower speed and lower quality) than is another codec.

Detailed descriptions of the speed/quality trade-off graphs can be found in Appendix 6. Figures Explanation. Sometimes codec results are not present in the particular graph. The reason for that are extremely poor results of the codec. Its RD curve has no intersection with reference's RD curve.

Figure 25 through Figure 32 show the results of the tests for the High Quality preset. The MainConcept codec is better than the Intel IPP and XviD codecs for the "Foreman" sequence. Additionally, MainConcept is better than x264 in the case of the "News" sequence. The PSNR and SSIM results do not differ greatly. MainConcept is better than x264 and Intel IPP, on average, for three sequences.

Please note that the averaging method among all sequences suppose that all codecs have the results for each sequence. When it's not the case, then only existing results are taking into account.

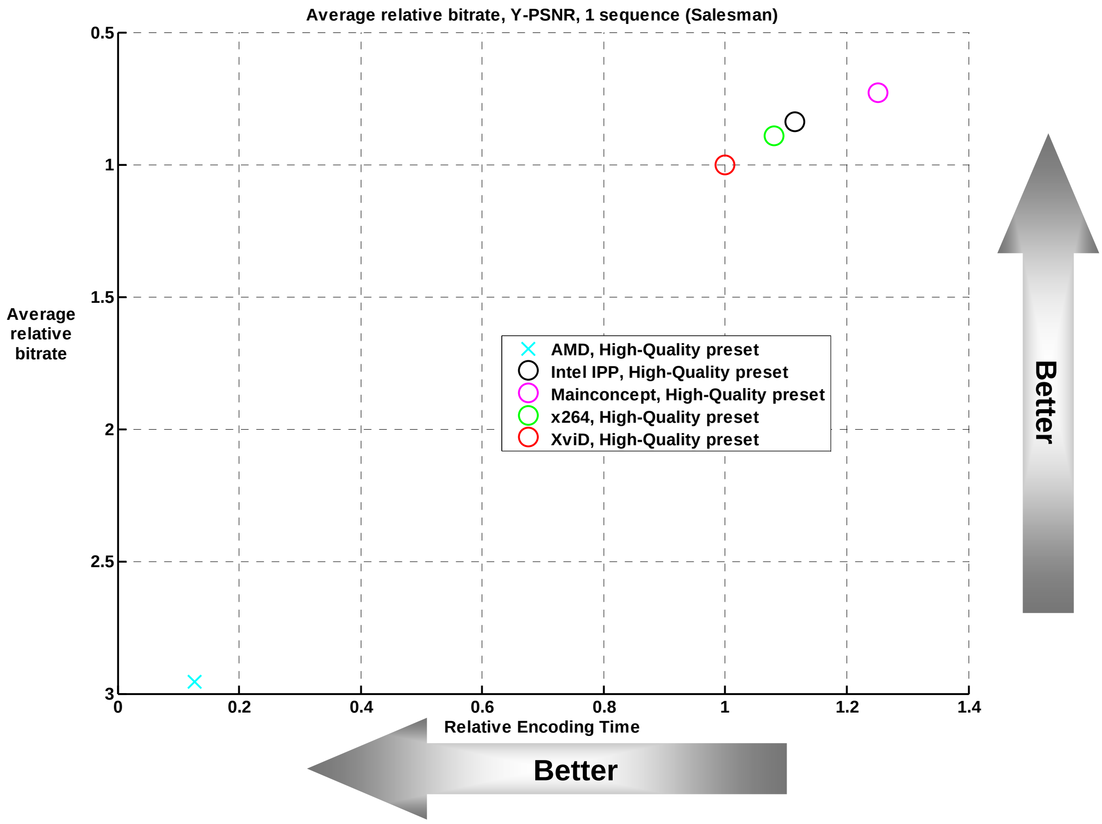


Figure 25. Speed/Quality tradeoff. Usage area "Video Conferences", "Salesman" sequence, "High Quality" preset, Y-PSNR

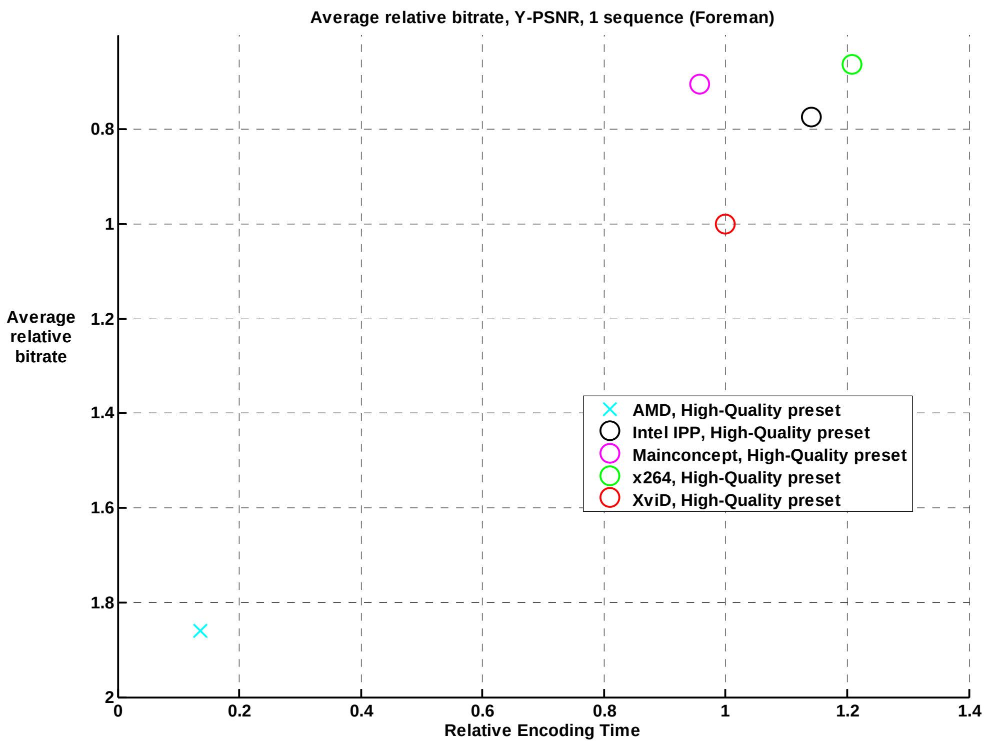


Figure 26. Speed/Quality tradeoff. Usage area "Video Conferences", "Foreman" sequence, "High Quality" preset, Y-PSNR

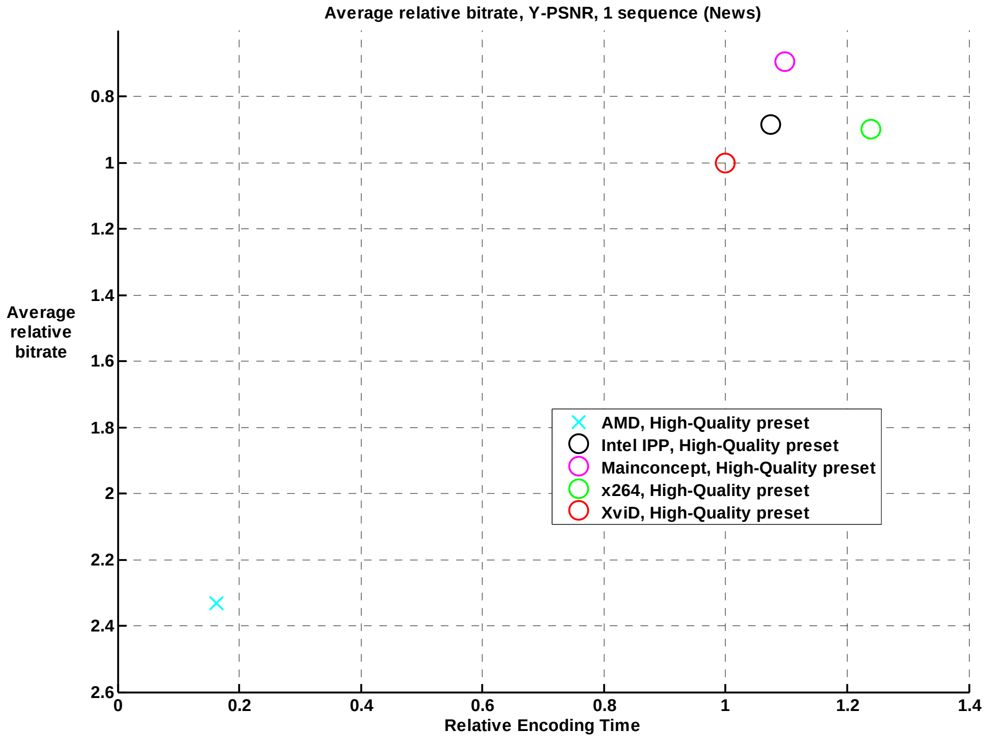


Figure 27. Speed/Quality tradeoff. Usage area "Video Conferences", "News" sequence, "High Quality" preset, Y-PSNR

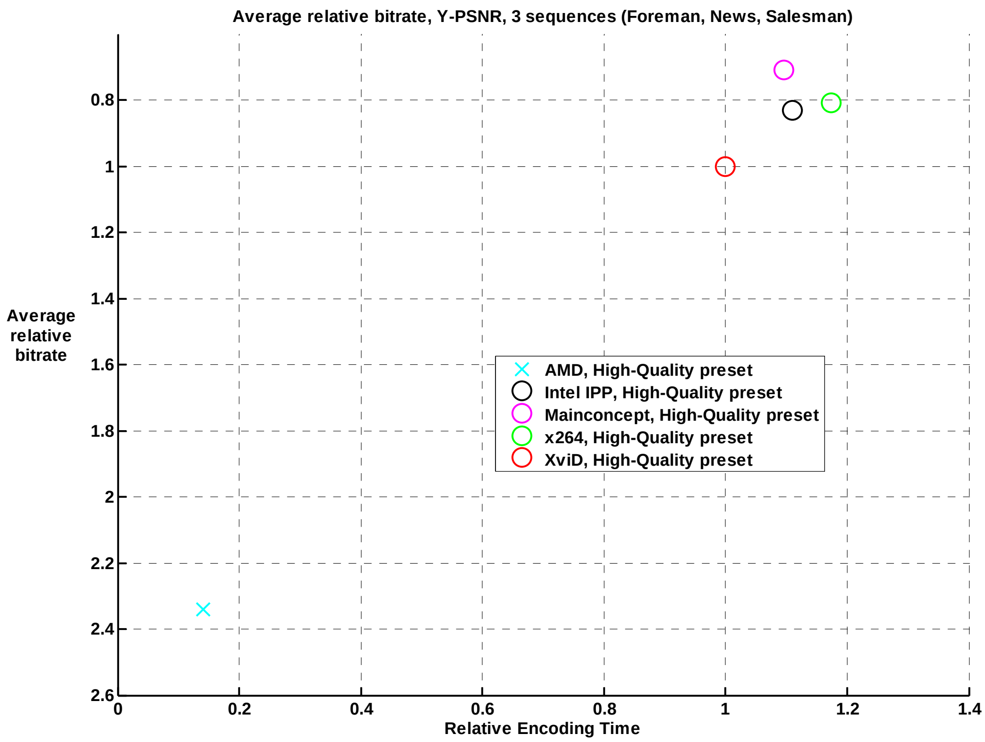


Figure 28. Speed/Quality tradeoff. Usage area "Video Conferences", all sequences, "High Quality" preset, Y-PSNR

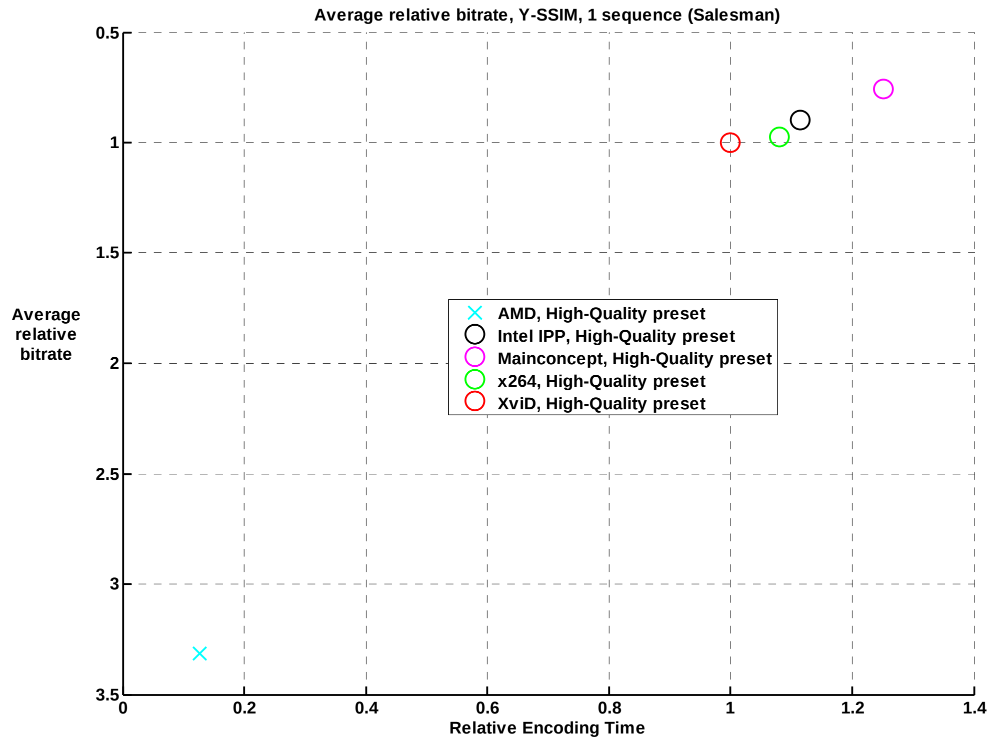


Figure 29. Speed/Quality tradeoff. Usage area "Video Conferences", "Salesman" sequence, "High Quality" preset, Y-SSIM

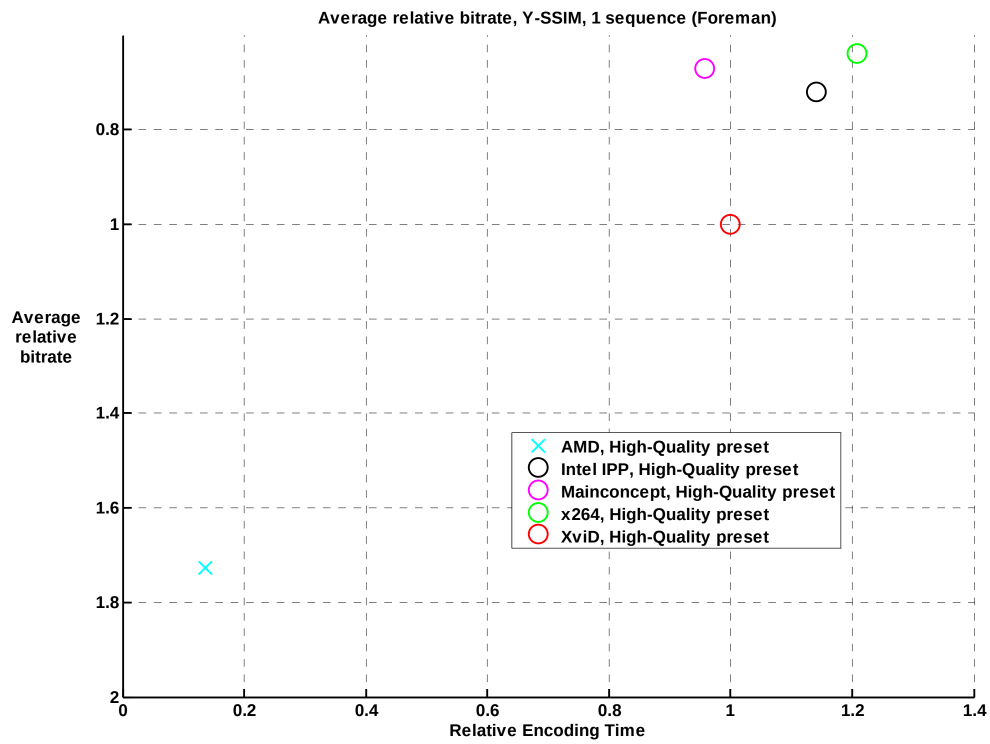


Figure 30. Speed/Quality tradeoff. Usage area "Video Conferences", "Foreman" sequence, "High Quality" preset, Y-SSIM

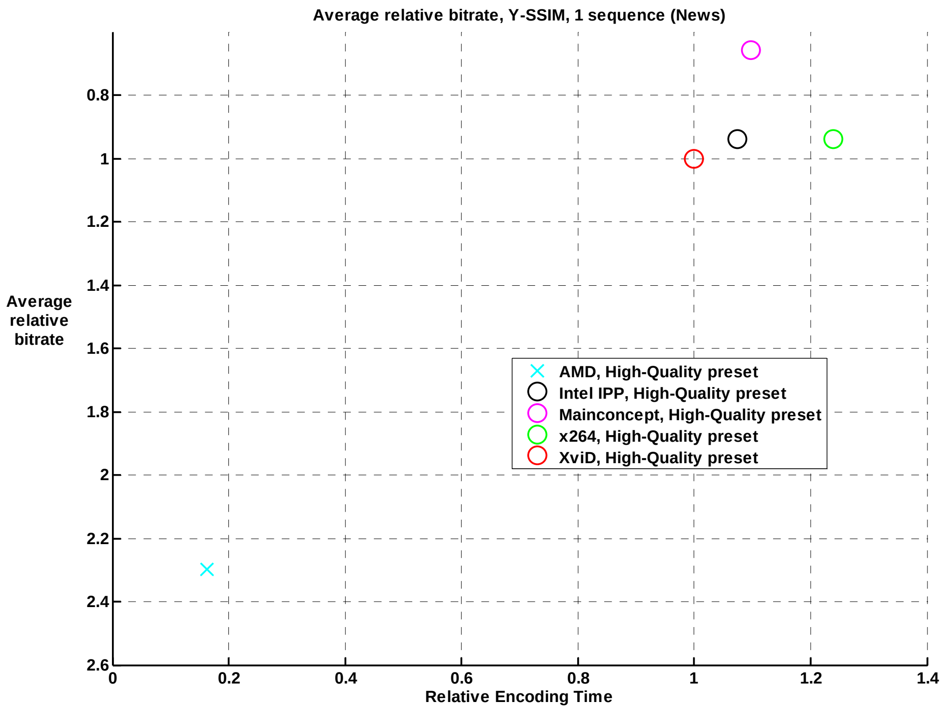


Figure 31. Speed/Quality tradeoff. Usage area "Video Conferences", "News" sequence, "High Quality" preset, Y-SSIM

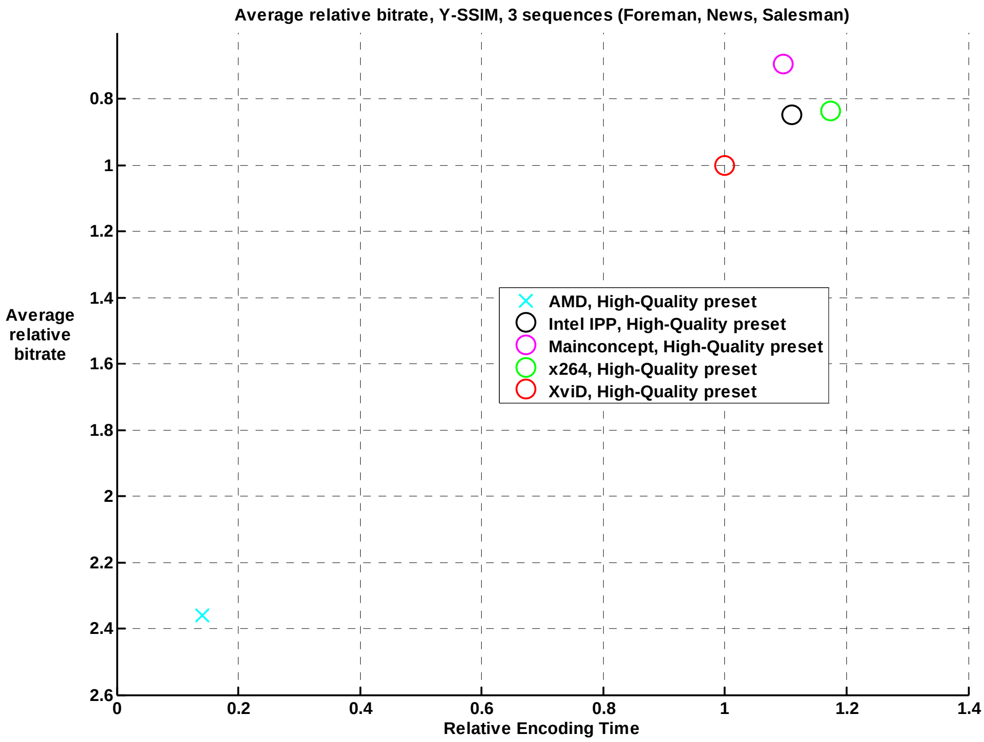


Figure 32. Speed/Quality tradeoff. Usage area "Video Conferences", all sequences, "High Quality" preset, Y-SSIM

4.1.3.1 High Speed Preset

Figure 33 through Figure 40 show the results of the tests for the High Speed preset. The MainConcept codec is better than the Intel IPP codec, and XviD is better than Artemis x264 for all sequences according to the Y-PSNR metric. If Y-SSIM is used, however, Artemis x264 produces better quality. For example, using the Y-SSIM metric, Artemis x264 is comparable to XviD for the “Foreman” sequence, and it is also comparable, on average, to XviD.

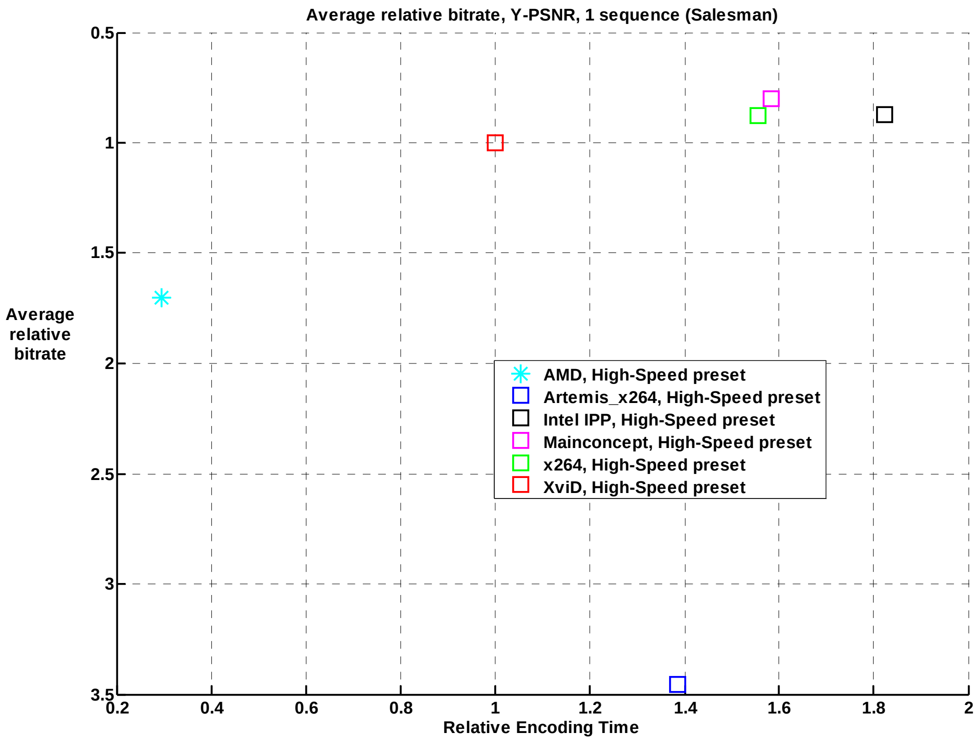


Figure 33. Speed/Quality tradeoff. Usage area “Video Conferences”, “Salesman” sequence, “High Speed” preset, Y-PSNR

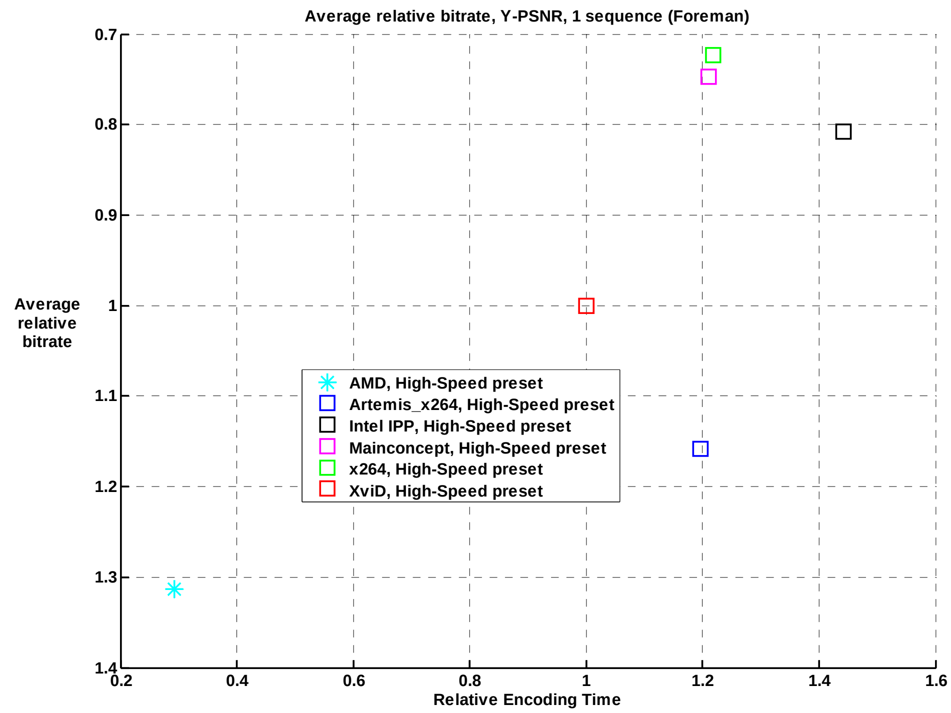


Figure 34. Speed/Quality tradeoff. Usage area “Video Conferences”, “Foreman” sequence, “High Speed” preset, Y-PSNR

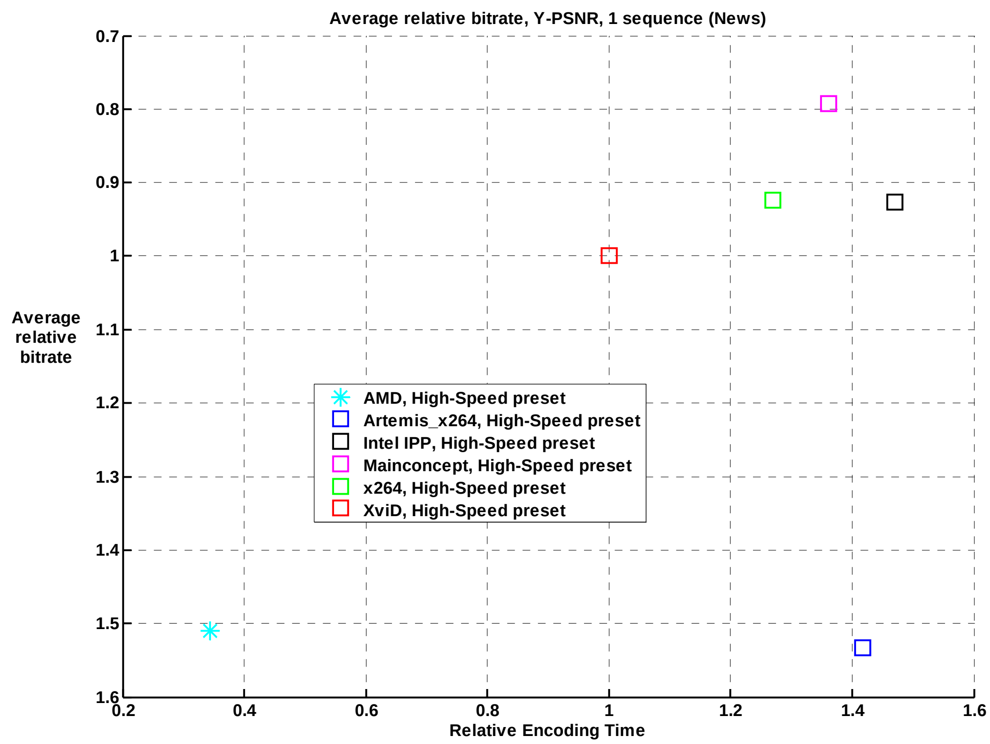


Figure 35. Speed/Quality tradeoff. Usage area “Video Conferences”, “News” sequence, “High Speed” preset, Y-PSNR

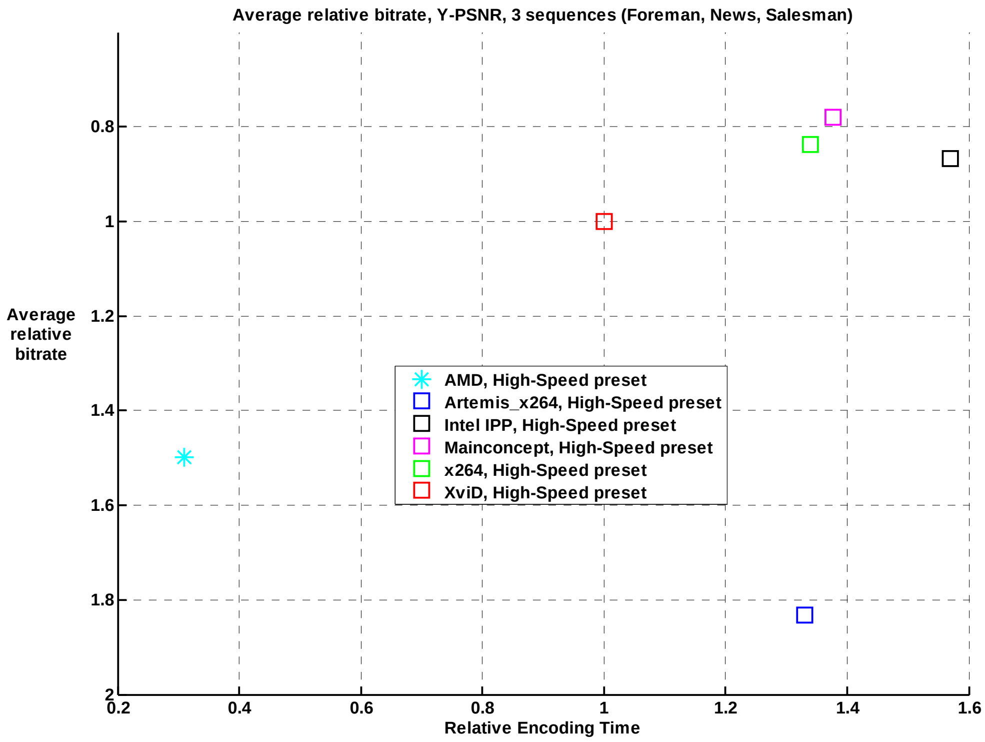


Figure 36. Speed/Quality tradeoff. Usage area “Video Conferences”, all sequences, “High Speed” preset, Y-PSNR

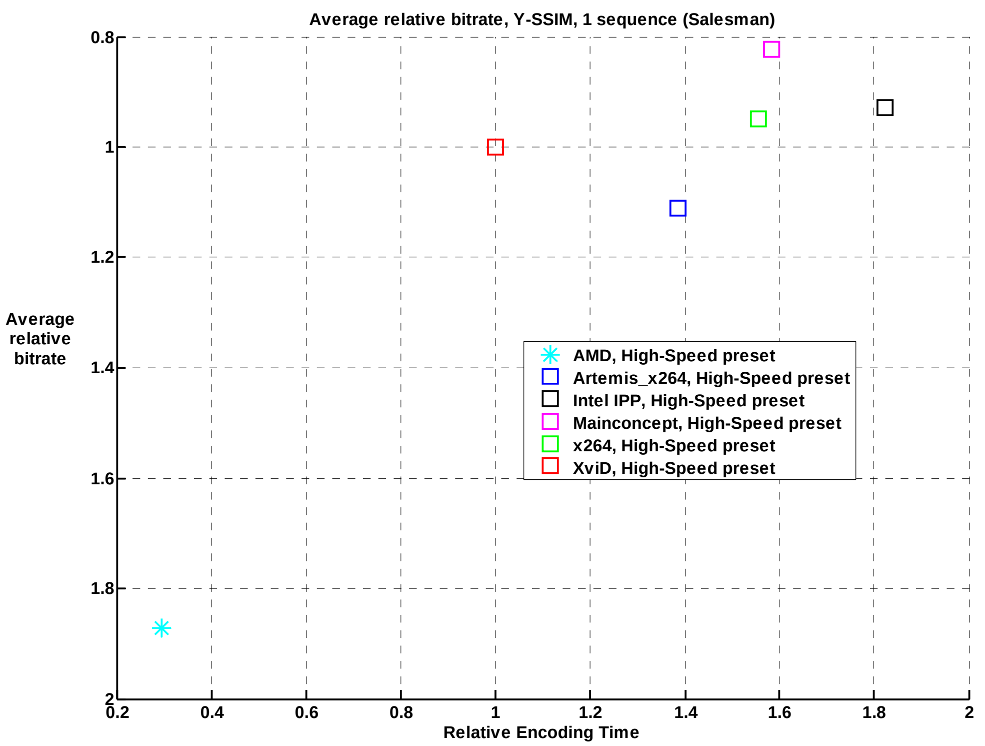


Figure 37. Speed/Quality tradeoff. Usage area “Video Conferences”, “Salesman” sequence, “High Speed” preset, Y-SSIM

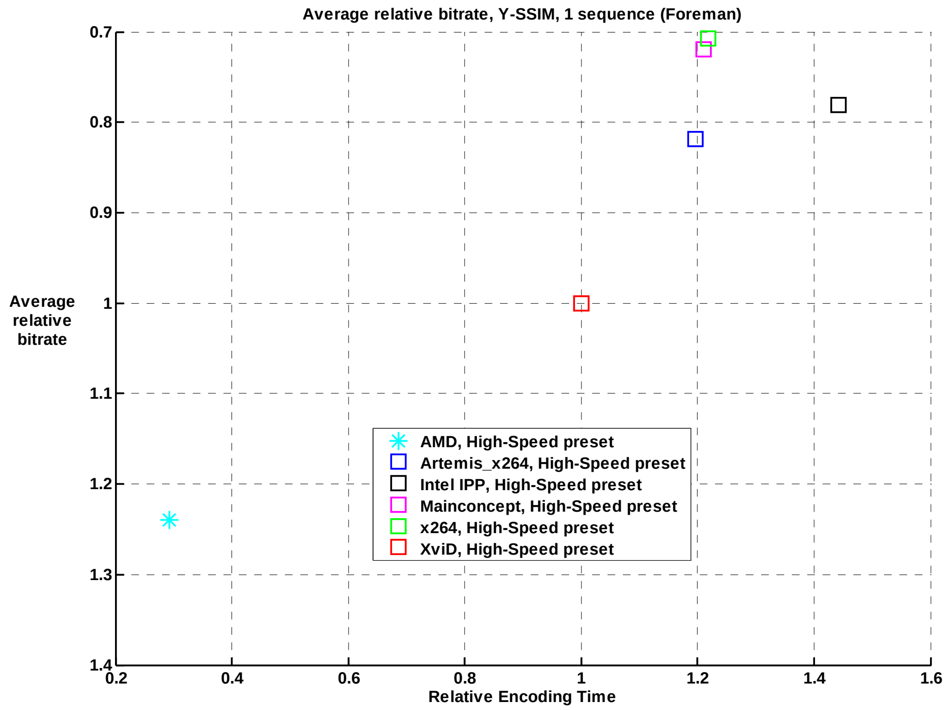


Figure 38. Speed/Quality tradeoff. Usage area "Video Conferences", "Foreman" sequence, "High Speed" preset, Y-SSIM

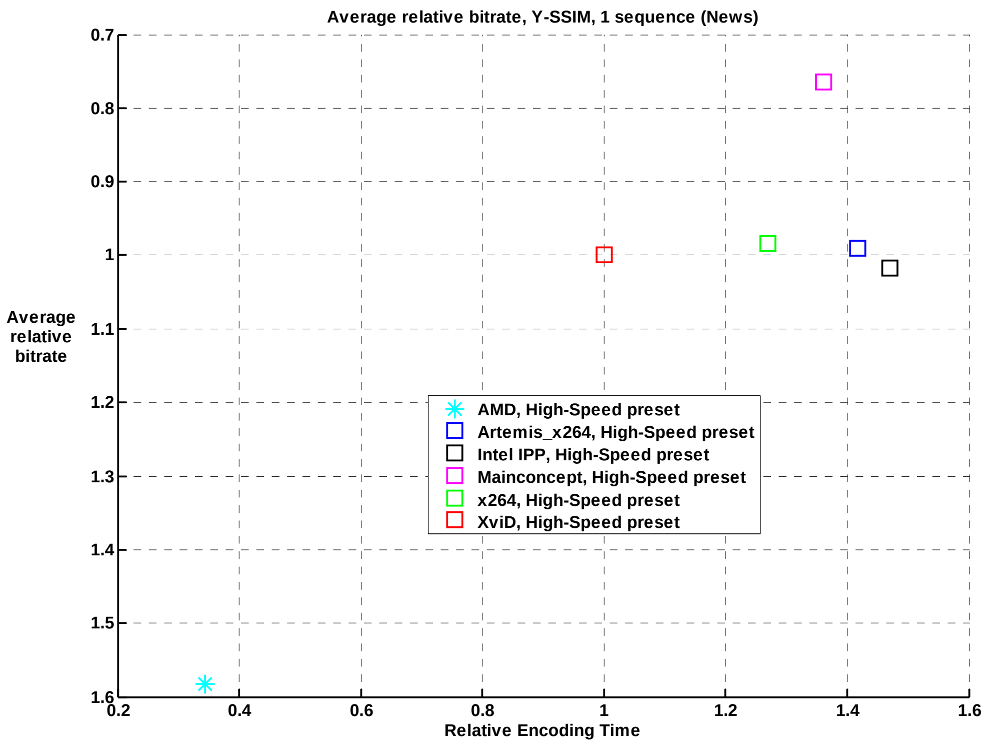


Figure 39. Speed/Quality tradeoff. Usage area "Video Conferences", "News" sequence, "High Speed" preset, Y-SSIM

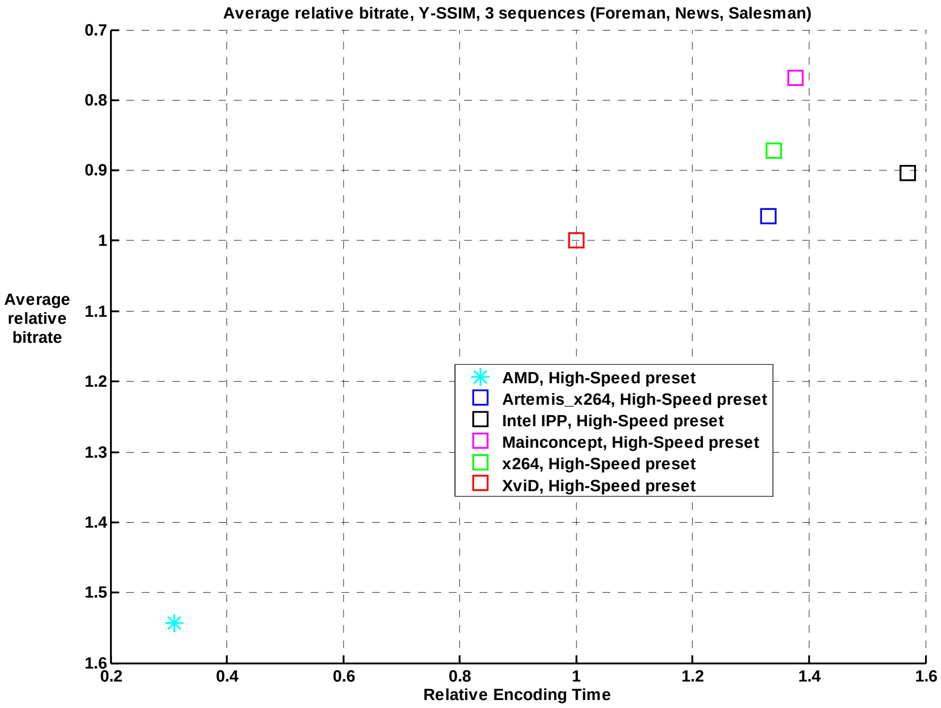


Figure 40. Speed/Quality tradeoff. Usage area "Video Conferences", all sequences, "High Speed" preset, Y-SSIM

4.1.4 Bitrate Handling

There are two codecs that have difficulties with bitrate handling: XviD and AMD. For the High Quality preset and the "Salesman" sequence, XviD and AMD yield lower output bitrates for all input bitrates. The only exception to this trend is for AMD at low bitrates: AMD increases the output bitrate. For the "Foreman" and "News" sequences, XviD and AMD increase the bitrate on average, and AMD decreases high bitrates.

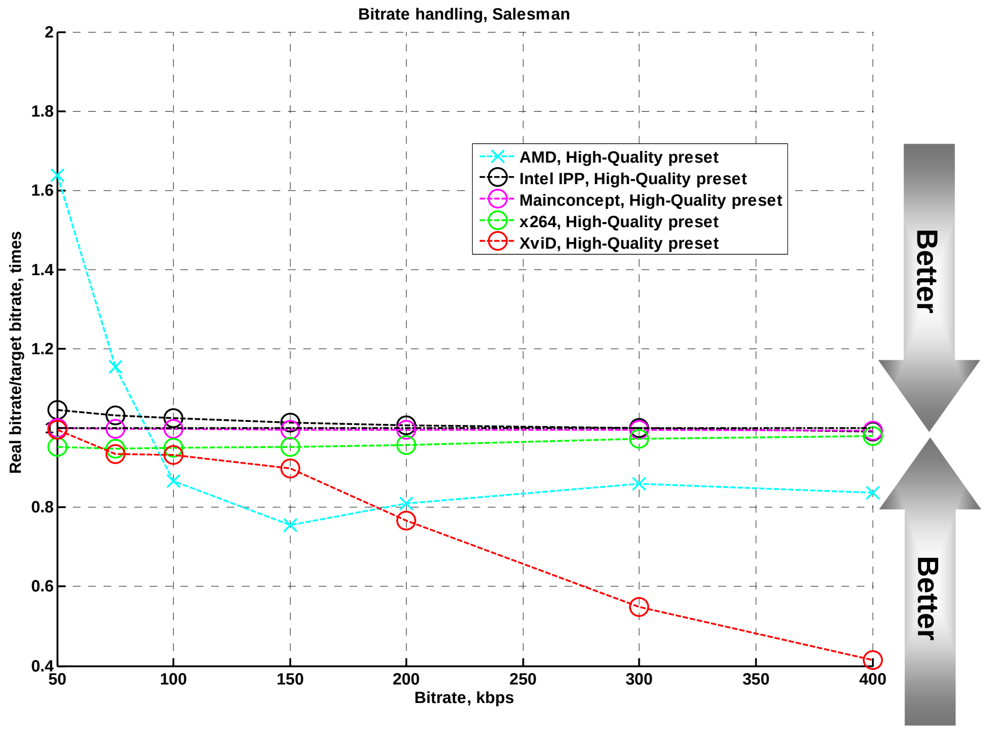


Figure 41. Bitrate Handling. Usage area "Video Conferences", "Salesman" sequence, "High Quality" preset

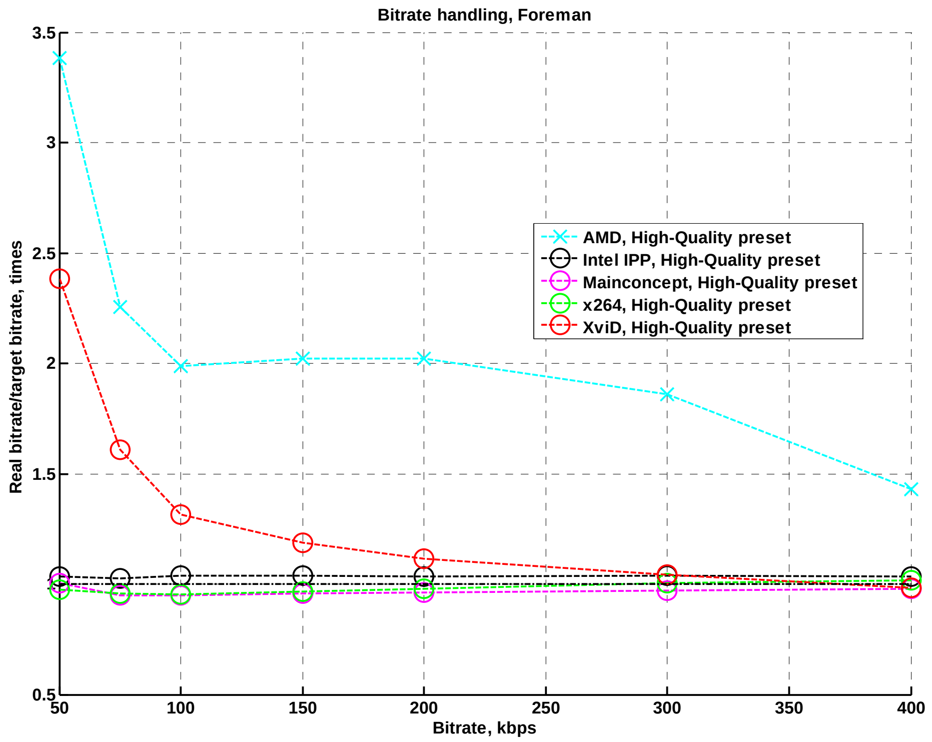


Figure 42. Bitrate Handling. Usage area "Video Conferences", "Foreman" sequence, "High Quality" preset

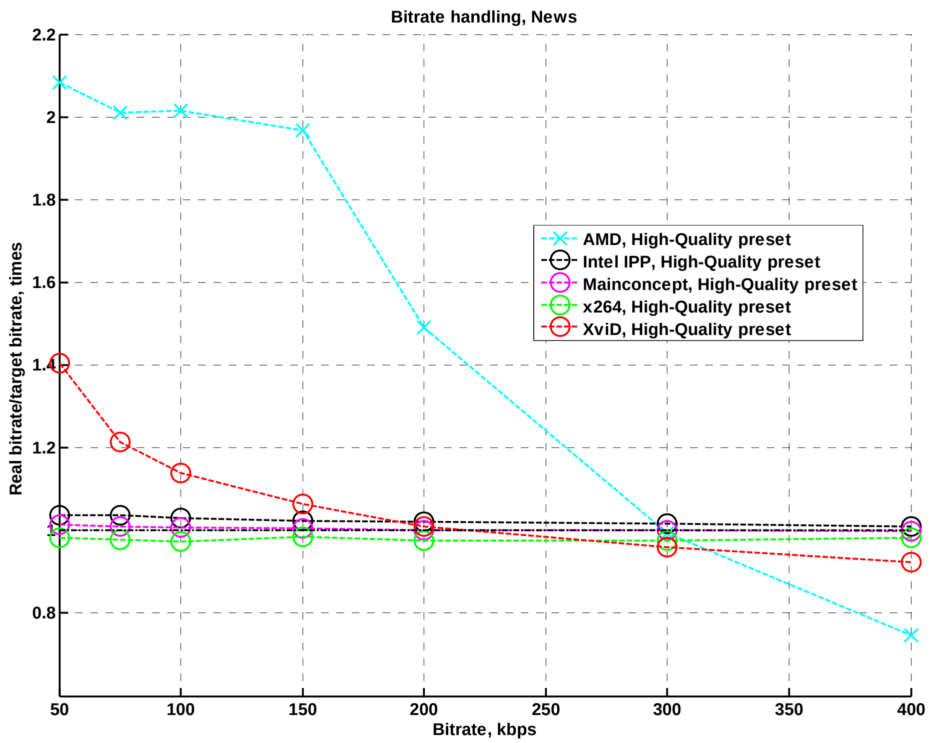


Figure 43. Bitrate Handling. Usage area "Video Conferences", "News" sequence, "High Quality" preset

4.1.4.1 High Speed Preset

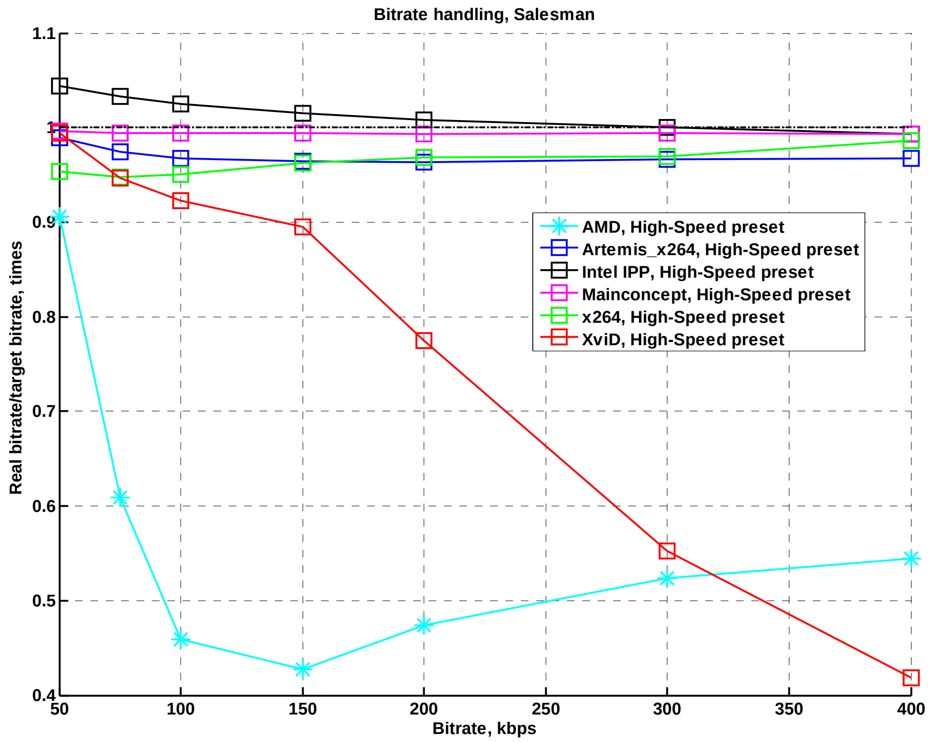


Figure 44. Bitrate Handling. Usage area “Video Conferences”, “Salesman” sequence, “High Speed” preset

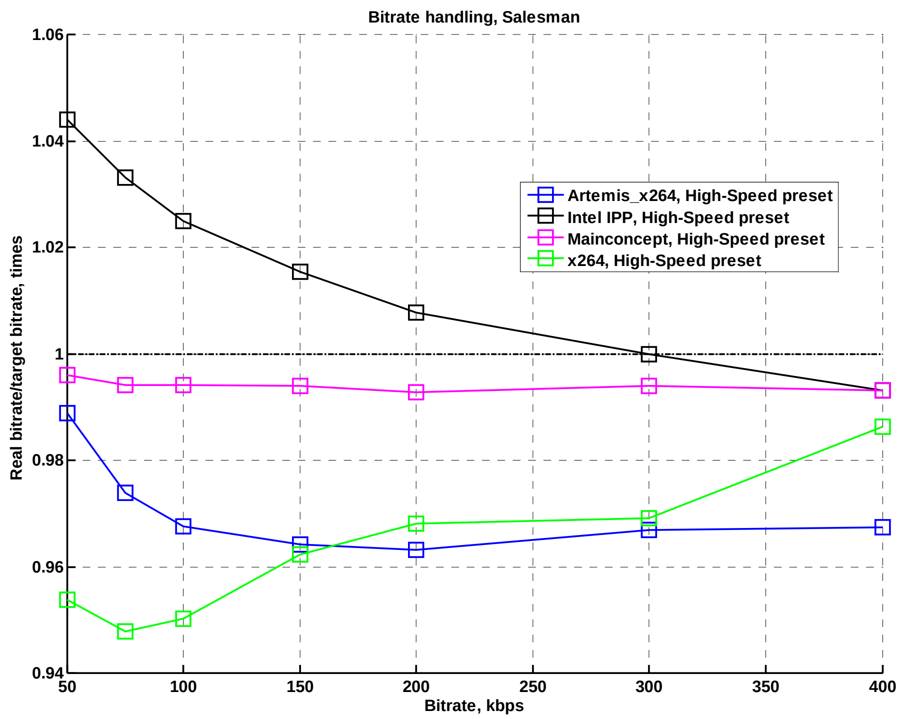


Figure 45. Bitrate Handling. Usage area “Video Conferences”, “Salesman” sequence, “High Speed” preset, without AMD and XviD

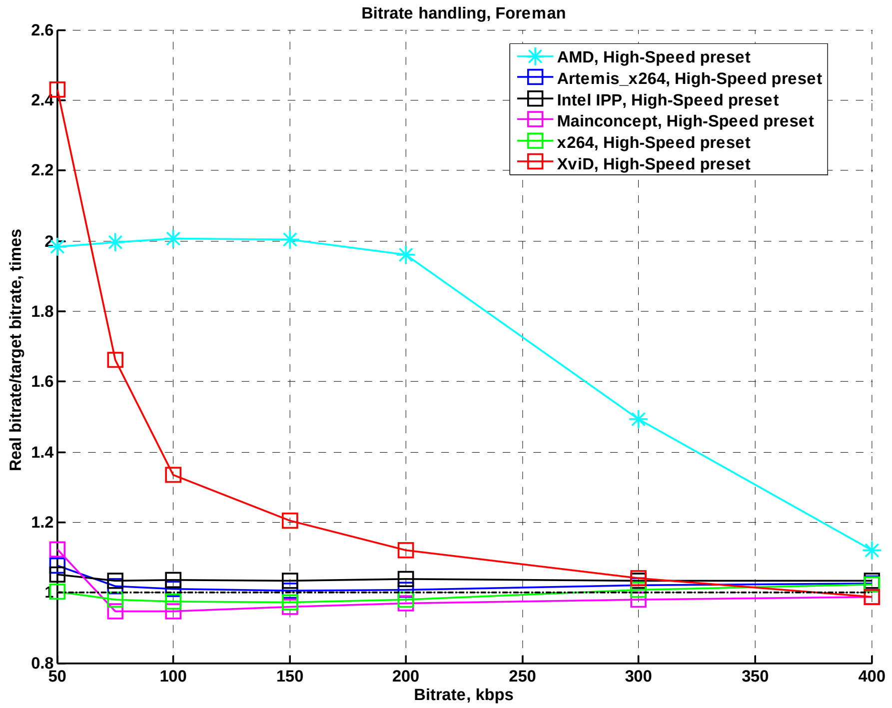


Figure 46. Bitrate Handling. Usage area "Video Conferences", "Foreman" sequence, "High Speed" preset

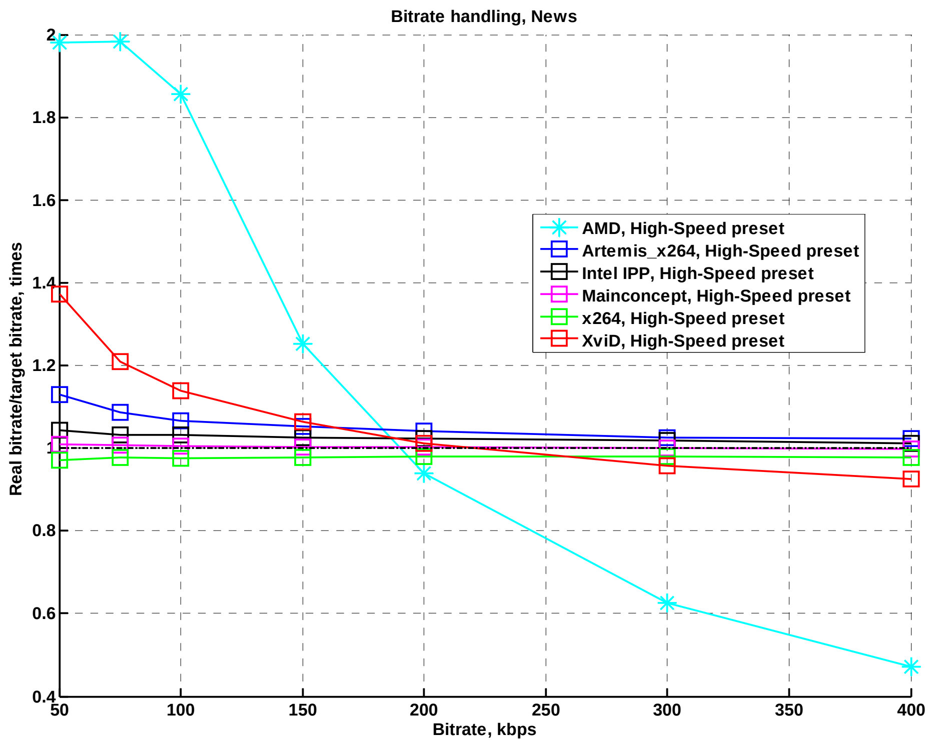


Figure 47. Bitrate Handling. Usage area "Video Conferences", "News" sequence, "High Speed" preset

4.1.5 Relative Quality Analysis

Table 3 through Table 6 contain relative bitrate for the same quality for all the encoders.

The MainConcept codec is the leader for all presets according to all objective quality metrics, and it is followed by the x264 codec. The Intel IPP encoder holds third place. The quantitative difference between these three codecs is not overly tremendous. AMD is the only codec that is worse than the XviD reference codec. The Artemis x264 codec falls short of XviD according to the Y-PSNR metric, but it is better than XviD according to the Y-SSIM metric.

Note, that each the number in tables below corresponds to some segment of bitrates (see Appendix 6. Figures Explanation for more details). Unfortunately, those segments can be rather different because of different quality of compared encoders. This fact can lead to some inadequate results in case of three and more codecs comparisons. This comparison technique will be improved in the future.

Table 3. Average bitrate ratio for a fixed output quality using videoconference sequences and the High Speed preset (Y-PSNR metric).

	AMD	Artemis x264	Intel IPP	MainConcept	x264	XviD
AMD	100,00%	114,61%	58,00%	50,89%	56,70%	66,70%
Artemis x264	87,25%	100,00%	52,53%	47,12%	48,89%	54,60%
Intel IPP	172,42%	190,37%	100,00%	92,81%	95,57%	115,30%
MainConcept	196,49%	212,20%	107,75%	100,00%	102,95%	128,19%
x264	176,37%	204,55%	104,63%	97,13%	100,00%	119,53%
XviD	149,93%	183,13%	86,73%	78,01%	83,66%	100,00%

Table 4. Average bitrate ratio for a fixed output quality using videoconference sequences and the High Speed preset (Y-SSIM metric).

	AMD	Artemis x264	Intel IPP	MainConcept	x264	XviD
AMD	100,00%	59,53%	59,01%	49,55%	57,60%	64,82%
Artemis x264	167,98%	100,00%	90,52%	76,70%	87,22%	103,58%
Intel IPP	169,46%	110,47%	100,00%	87,82%	95,90%	110,65%
MainConcept	201,81%	130,37%	113,87%	100,00%	108,64%	130,22%
x264	173,62%	114,66%	104,28%	92,05%	100,00%	114,80%
XviD	154,29%	96,54%	90,37%	76,79%	87,11%	100,00%

Table 5. Average bitrate ratio for a fixed output quality using videoconference sequences and the High Quality preset (Y-PSNR metric).

	AMD	Intel IPP	MainConcept	x264	XviD
AMD	100,00%	35,17%	29,36%	34,53%	42,73%
Intel IPP	284,30%	100,00%	88,08%	95,52%	120,20%
MainConcept	340,60%	113,53%	100,00%	108,39%	140,98%
x264	289,60%	104,69%	92,26%	100,00%	123,56%
XviD	234,05%	83,19%	70,93%	80,93%	100,00%

Table 6. Average bitrate ratio for a fixed output quality using videoconference sequences and the High Quality preset (Y-SSIM metric).

	AMD	Intel IPP	MainConcept	x264	XviD
AMD	100,00%	35,54%	28,83%	35,13%	42,35%
Intel IPP	281,35%	100,00%	84,22%	97,45%	118,08%
MainConcept	346,91%	118,73%	100,00%	115,08%	144,04%
x264	284,63%	102,62%	86,89%	100,00%	119,56%
XviD	236,14%	84,69%	69,42%	83,64%	100,00%

Figure 48 through Figure 51 visualize data in the tables above. Each line in those figures corresponds to one codec. Values in vertical axis are average relative bitrate comparing to the codecs in horizontal axis. The lower bitrate is the better relative results have the codec.

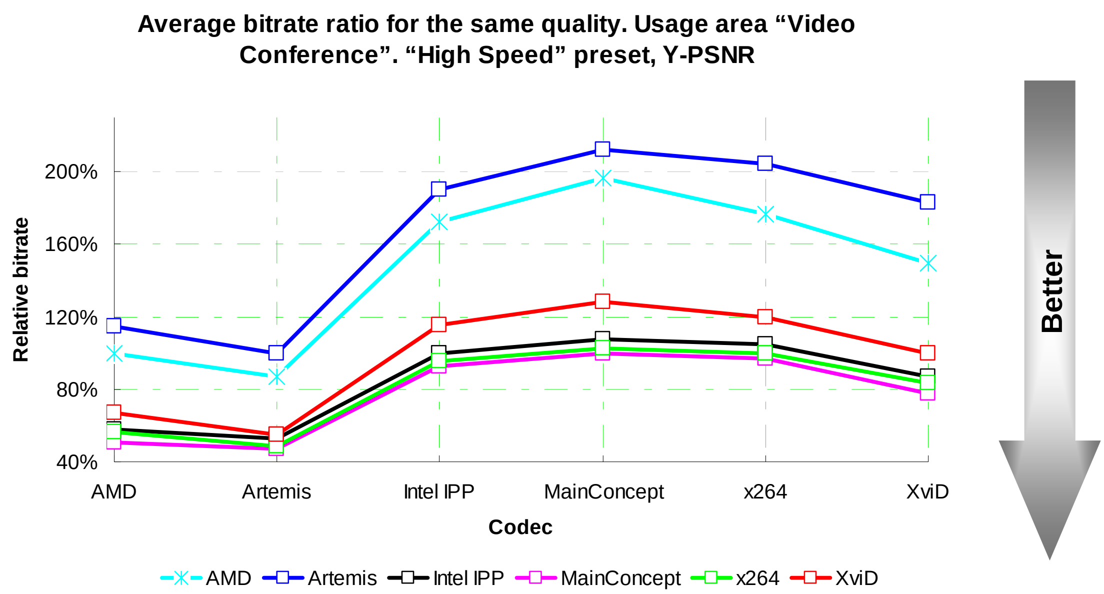


Figure 48. Average bitrate ratio for a fixed output quality using videoconference sequences and the High Speed preset (Y-PSNR metric).

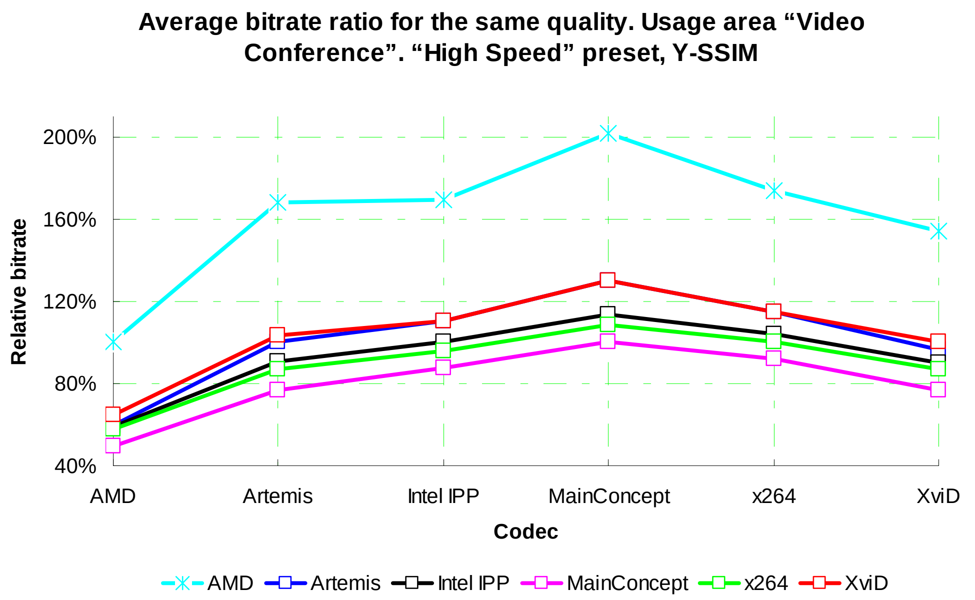


Figure 49. Average bitrate ratio for the same quality. Usage area "Video Conferences". "High Speed" preset, Y-SSIM.

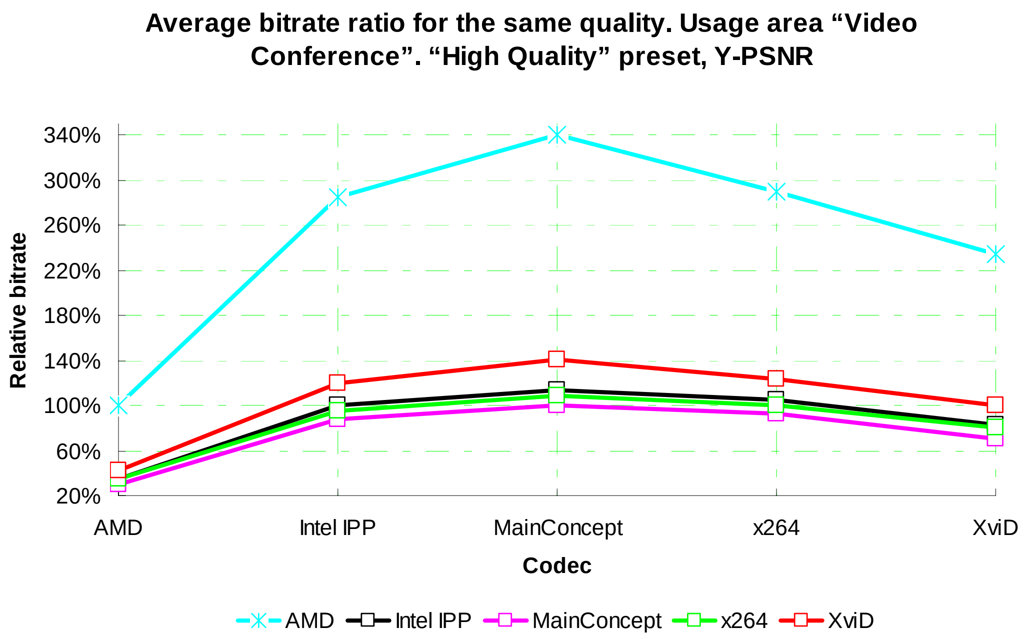


Figure 50. Average bitrate ratio for the same quality. Usage area "Video Conferences". "High Quality" preset, Y-PSNR.

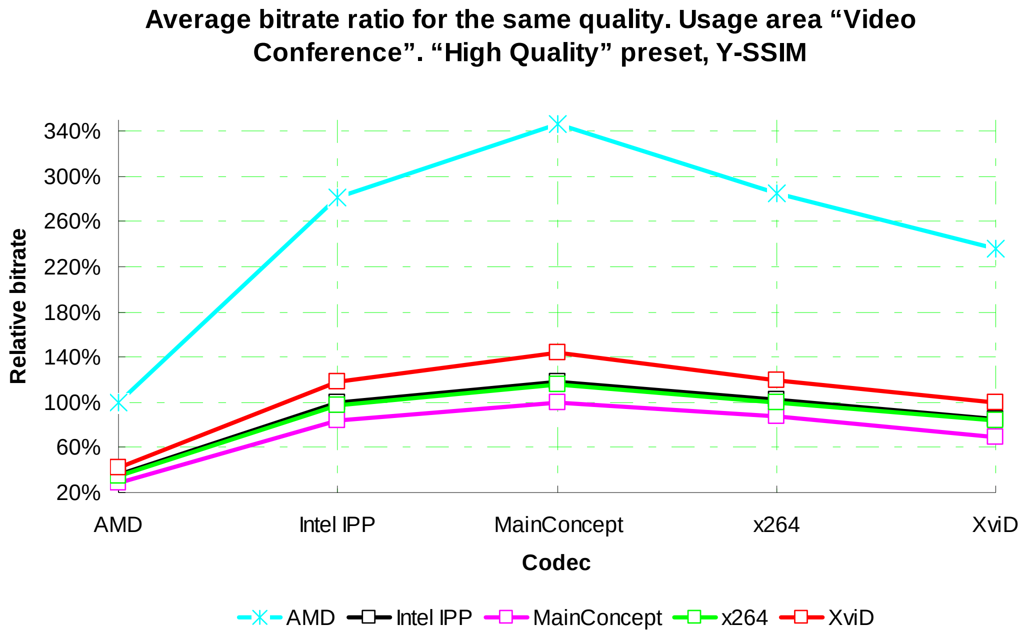


Figure 51. Average bitrate ratio for the same quality. Usage area "Video Conferences". "High Quality" preset, Y-SSIM.

4.2 Movies

4.2.1 RD Curves

The High Quality preset results for each sequence are presented in Figure 52 through Figure 59. The first four pictures show the Y-PSNR results and the last four pictures show the Y-SSIM results. The x264 codec is the leader for all sequences except "Lord of the Rings," where the MainConcept encoder yields the best results. The AMD encoder yields lowest-quality results, and the Intel IPP encoder takes a strong third place.

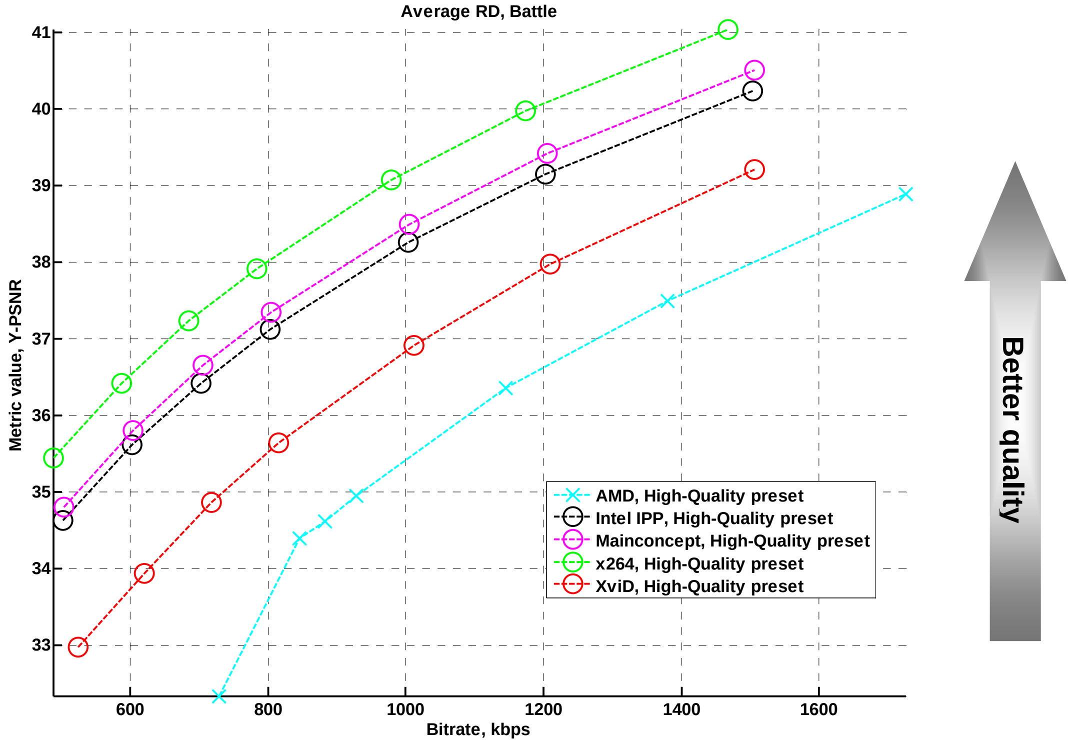


Figure 52. Bitrate/Quality. Usage area "Movies", "Battle" sequence, "High Quality" preset, Y-PSNR

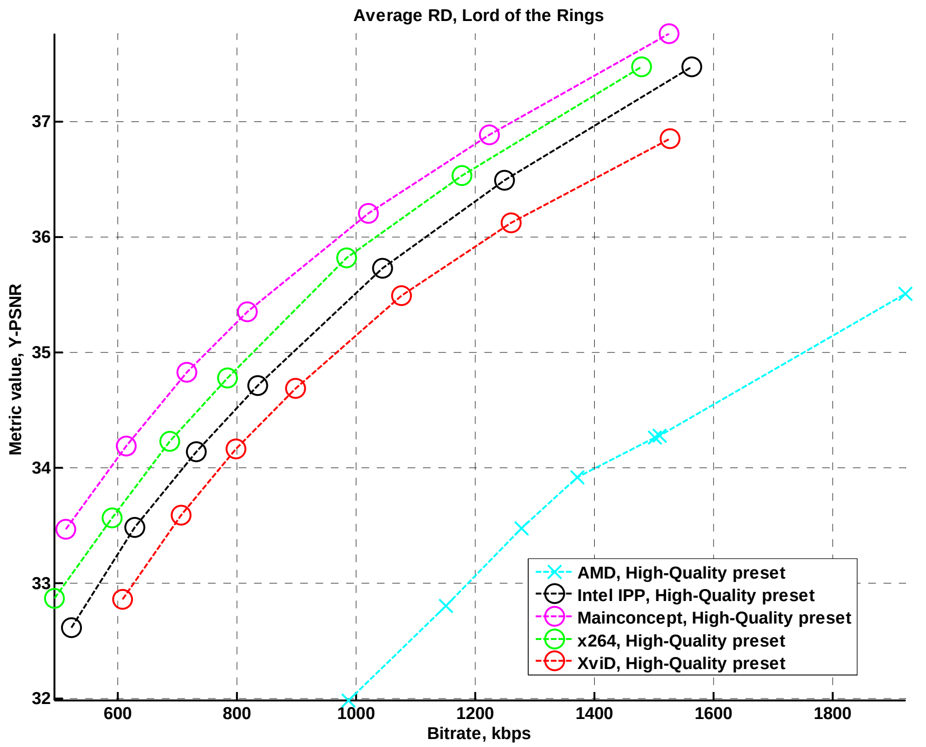


Figure 53. Bitrate/Quality. Usage area “Movies”, “Lord of the Rings” sequence, “High Quality” preset, Y-PSNR

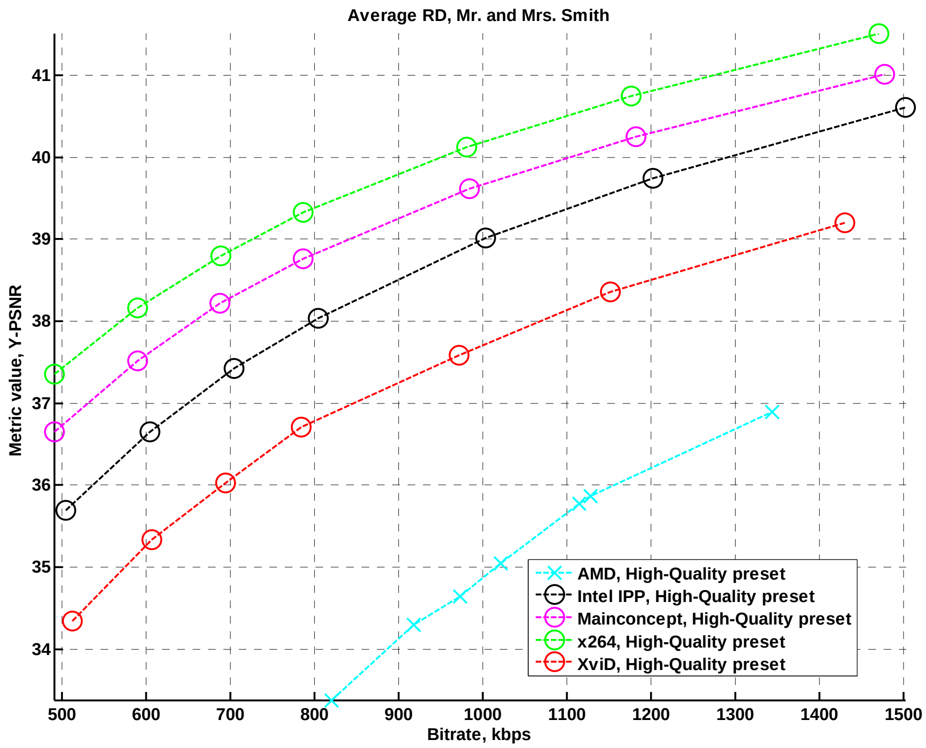


Figure 54. Bitrate/Quality. Usage area “Movies”, “Mr. And Mrs. Smith” sequence, “High Quality” preset, Y-PSNR

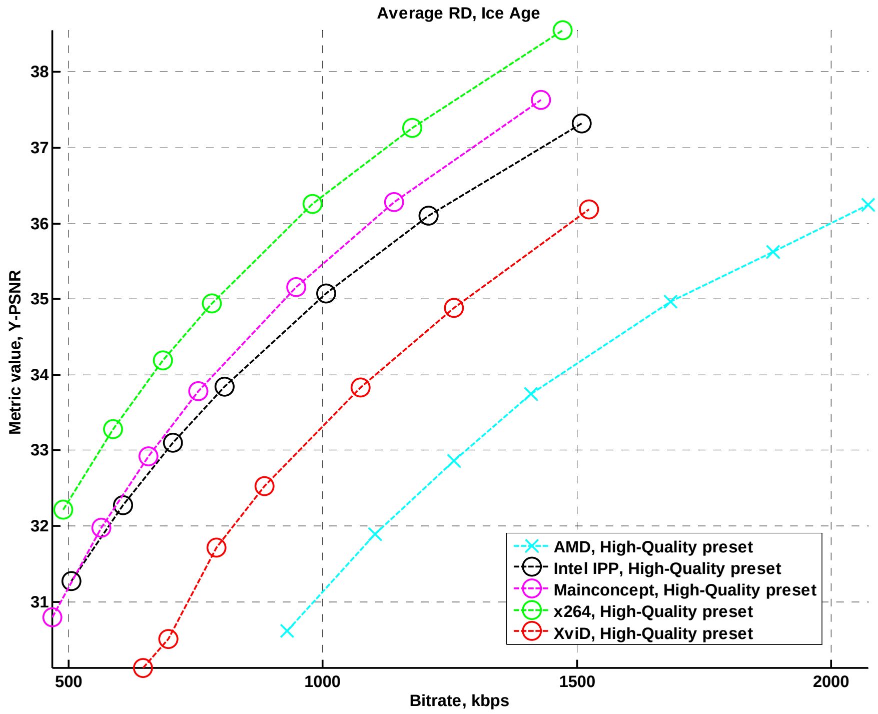


Figure 55. Bitrate/Quality. Usage area “Movies”, “Ice Age” sequence, “High Quality” preset, Y-PSNR

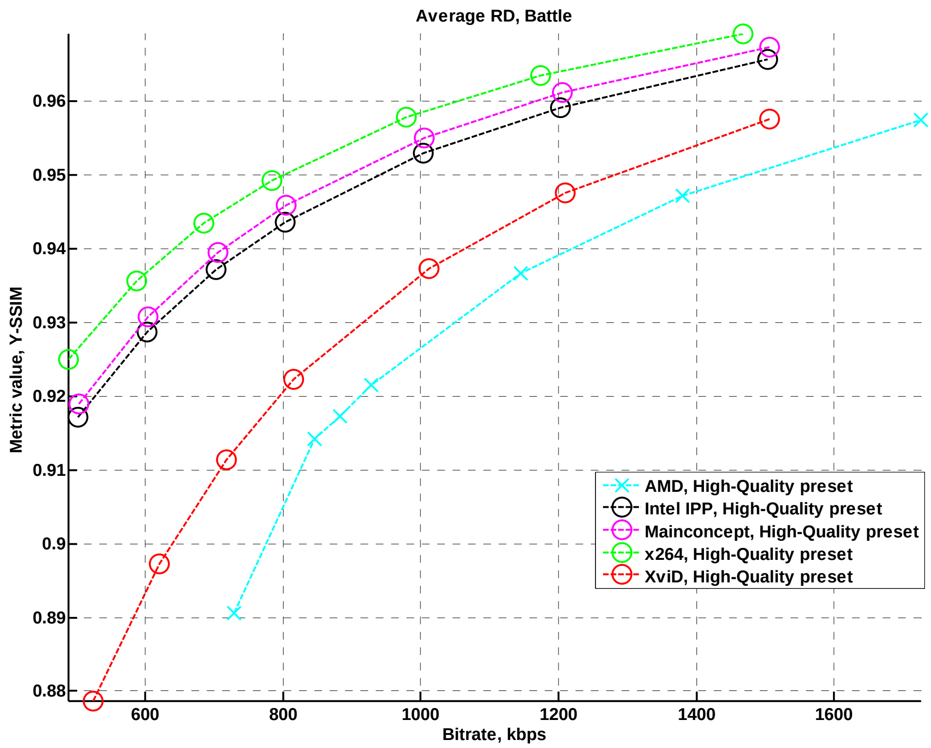


Figure 56. Bitrate/Quality. Usage area “Movies”, “Battle” sequence, “High Quality” preset, Y-SSIM

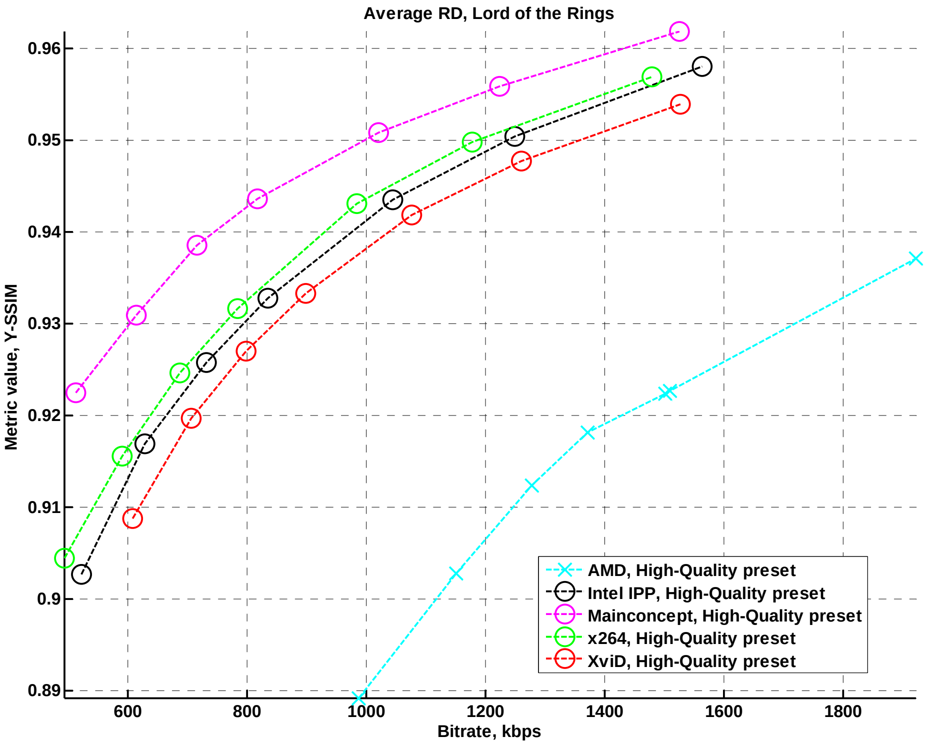


Figure 57. Bitrate/Quality. Usage area “Movies”, “Lord of the Rings” sequence, “High Quality” preset, Y-SSIM

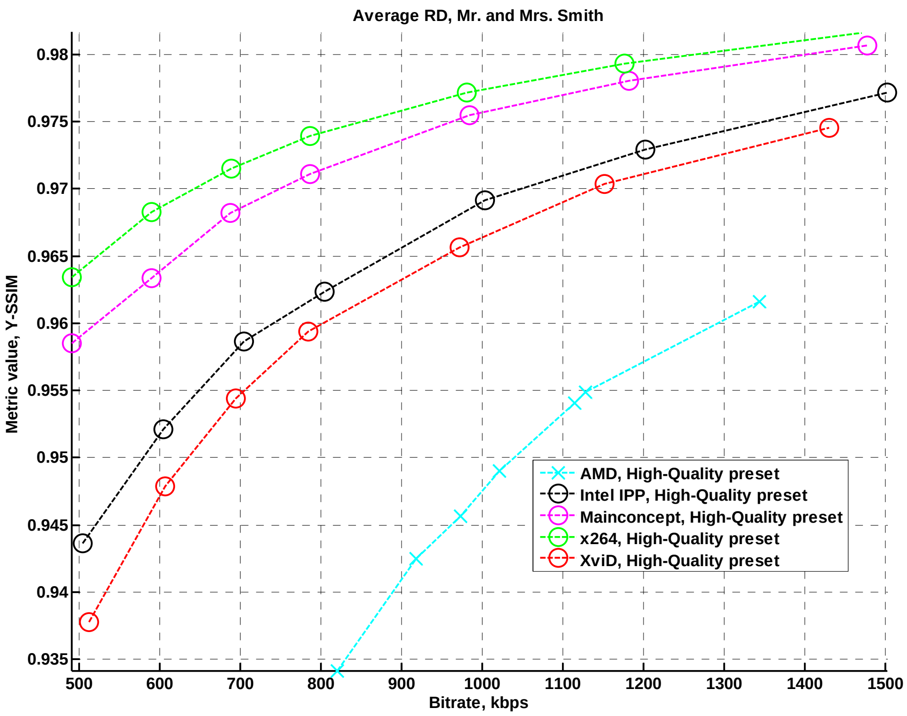


Figure 58. Bitrate/Quality. Usage area “Movies”, “Mr. And Mrs. Smith” sequence, “High Quality” preset, Y-SSIM

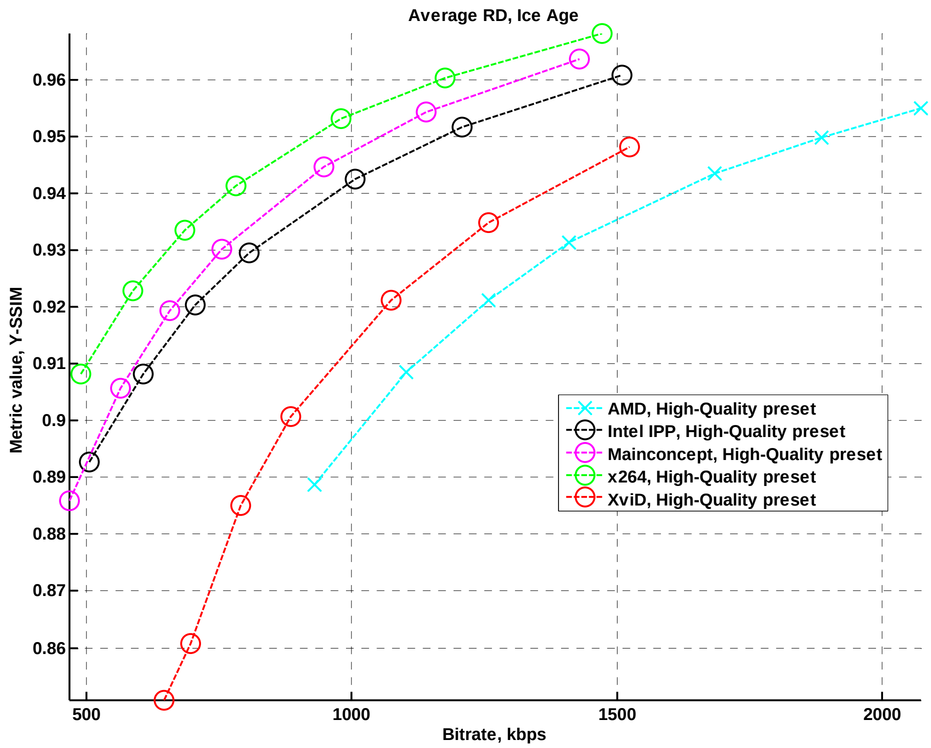


Figure 59. Bitrate/Quality. Usage area "Movies", "Ice Age" sequence, "High Quality" preset, Y-SSIM

4.2.1.1 High Speed Preset

The RD curves for the High Speed preset are shown in Figure 60 through Figure 67. The extremely unstable results from the Artemis x264 encoder should be noted first; the Y-PSNR results for this codec are very low for all sequences. Moreover, the results are not monotonic for an increasing bitrate. The Y-SSIM results for the codec are relatively more stable, but are still far from those of the leading codecs. Only for the "Ice Age" sequence are the results of Artemis x264 processing comparable to those of the other codecs.

The leading codecs in this case are the x264 and MainConcept encoders. MainConcept is better for the "Lord of the Rings" sequence as before, and its results are very close to those of the x264 encoder for other sequences. The AMD encoder shows the fastest results, but, unfortunately, with less-than-stellar quality optimization. Several problems in the rate control of the Artemis x264 encoder are clearly apparent.

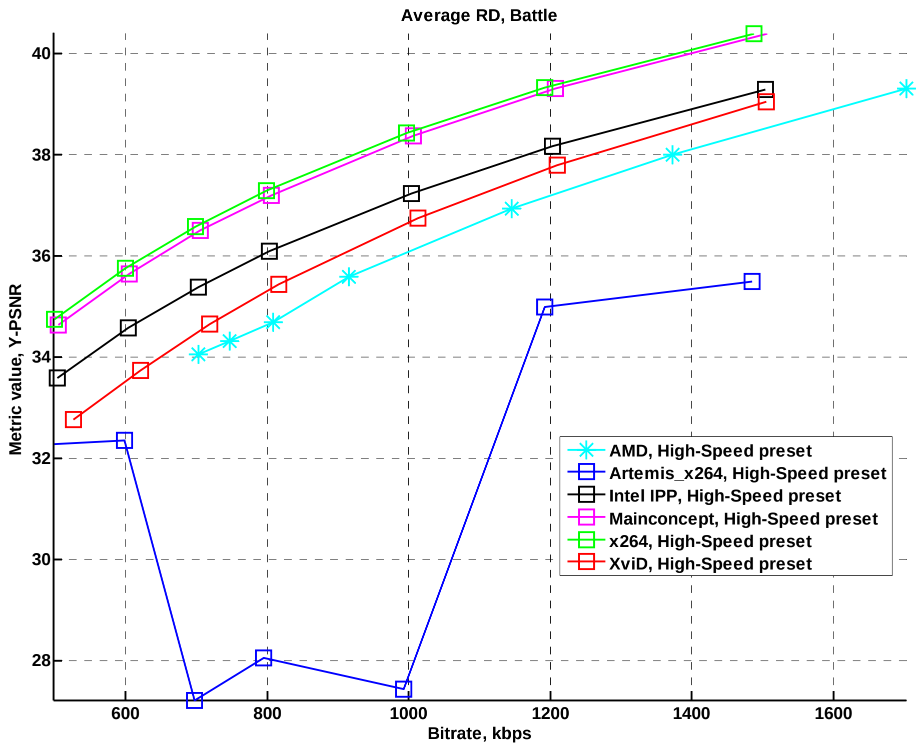


Figure 60. Bitrate/Quality. Usage area "Movies", "Battle" sequence, "High Speed" preset, Y-PSNR

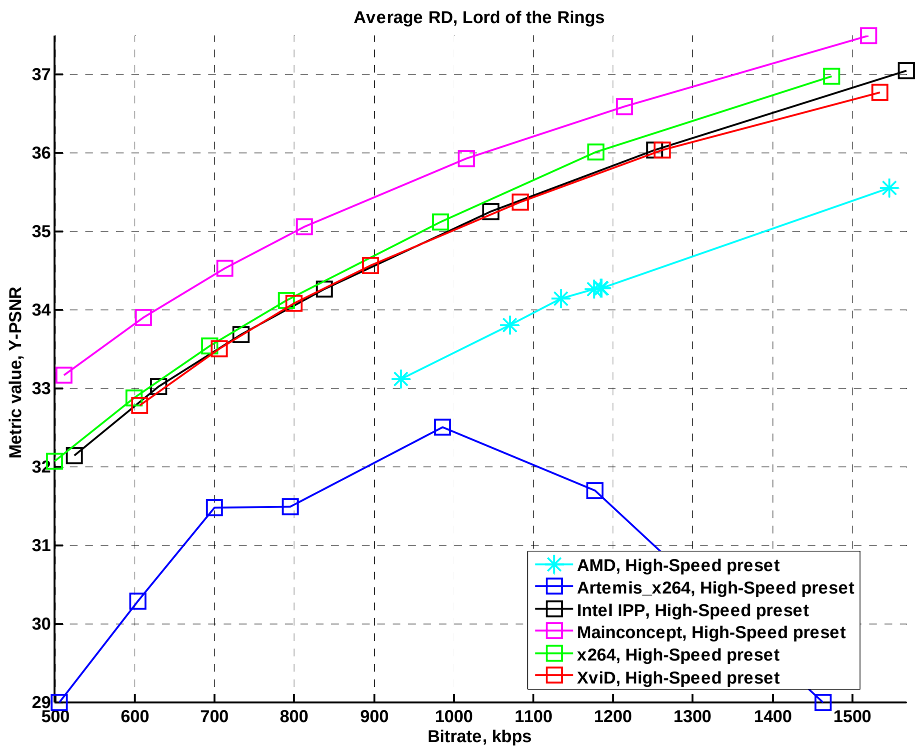


Figure 61. Bitrate/Quality. Usage area "Movies", "Lord of the Rings" sequence, "High Speed" preset, Y-PSNR

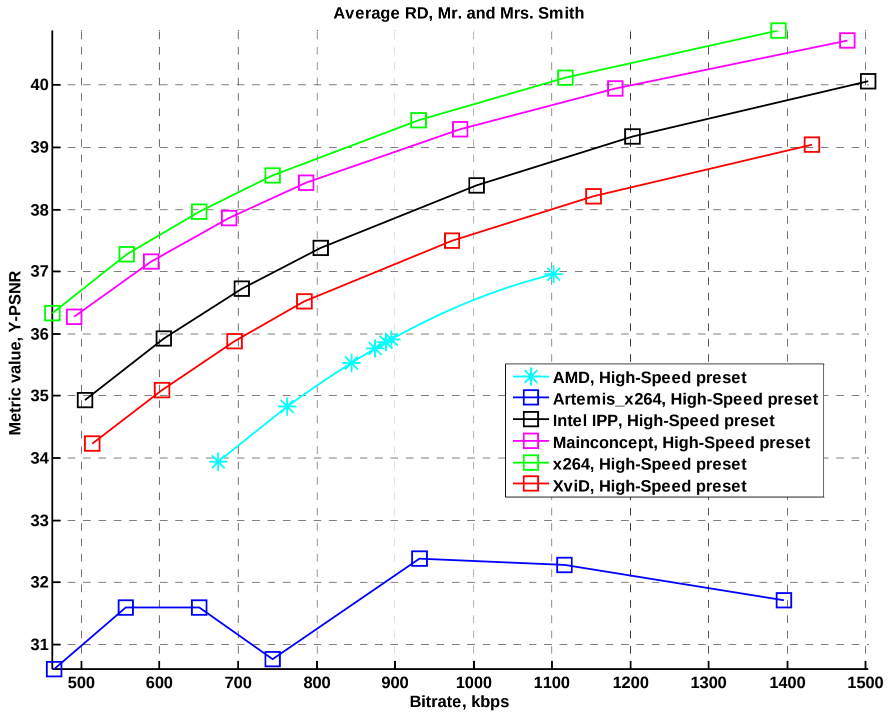


Figure 62. Bitrate/Quality. Usage area “Movies”, “Mr. And Mrs. Smith” sequence, “High Speed” preset, Y-PSNR

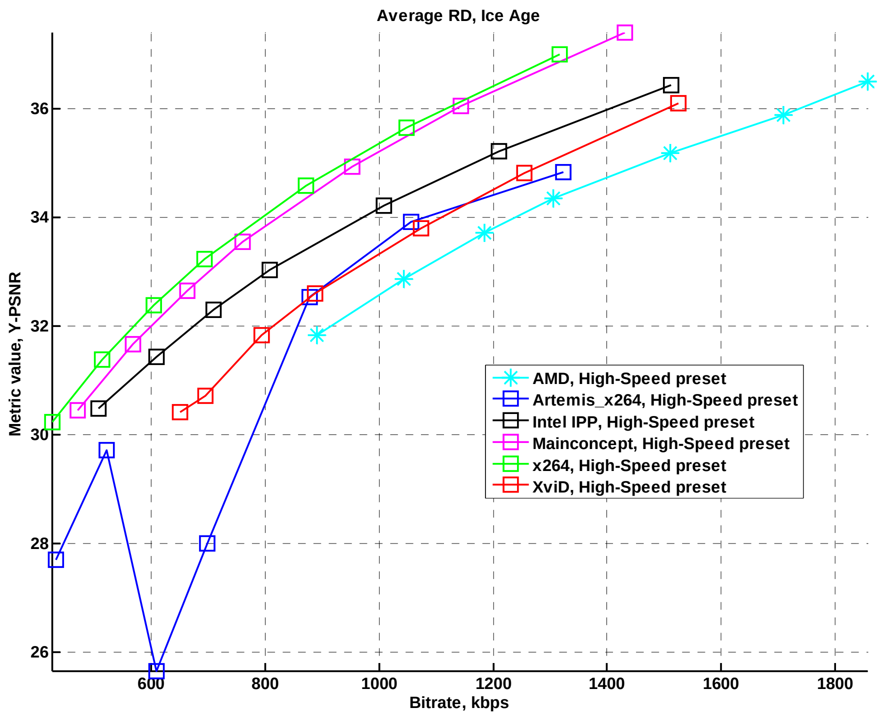


Figure 63. Bitrate/Quality. Usage area “Movies”, “Ice Age” sequence, “High Speed” preset, Y-PSNR

SSIM Results

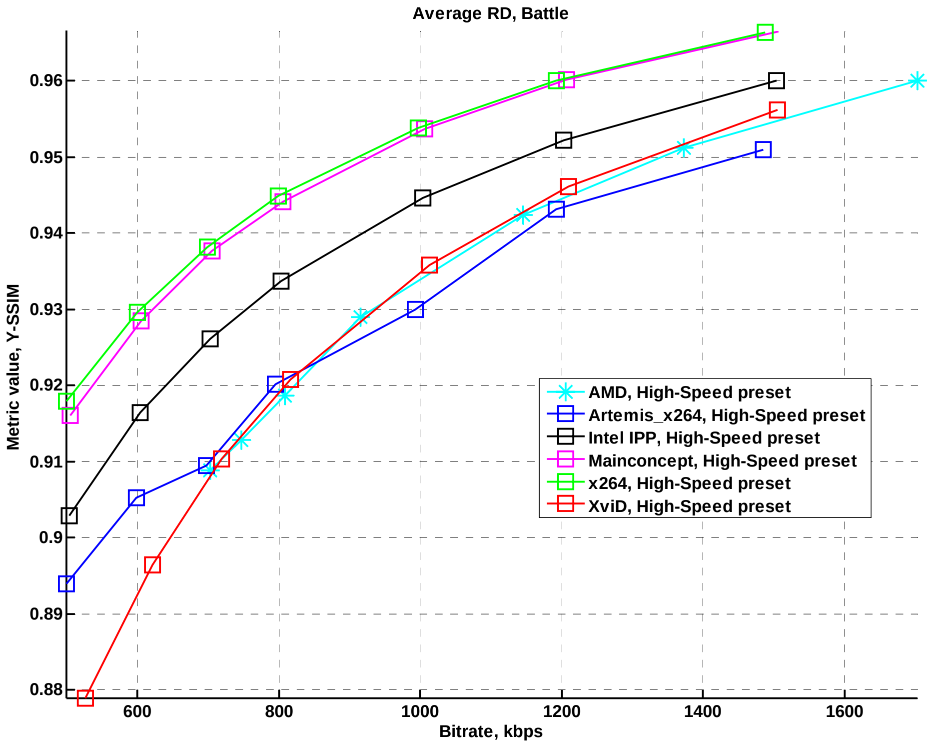


Figure 64. Bitrate/Quality. Usage area "Movies", "Battle" sequence, "High Speed" preset, Y-SSIM

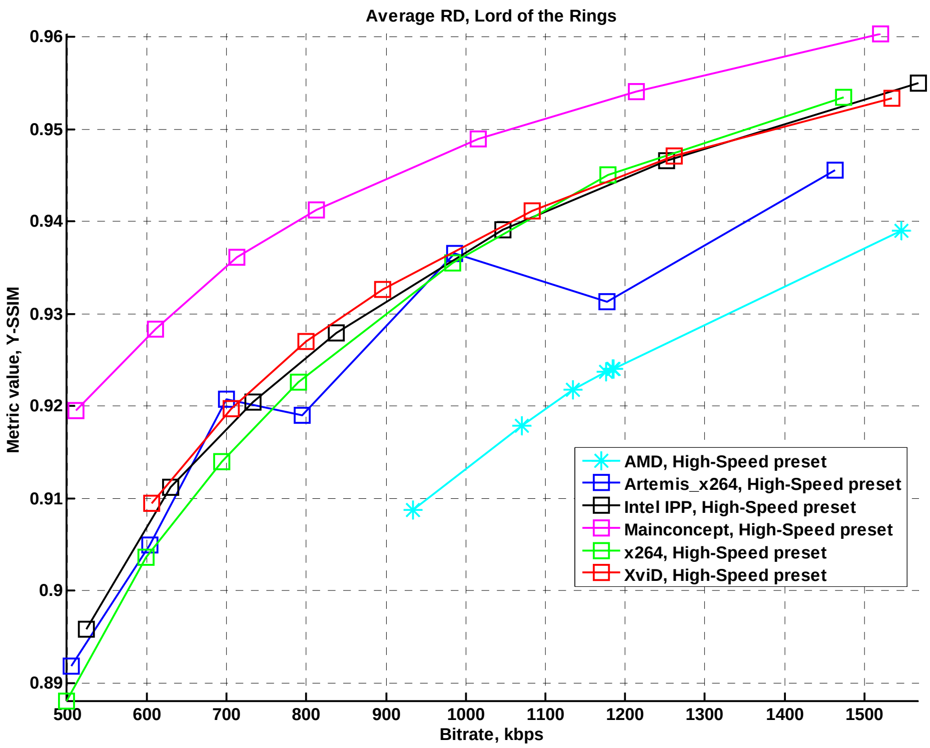


Figure 65. Bitrate/Quality. Usage area "Movies", "Lord of the Rings" sequence, "High Speed"

preset, Y-SSIM

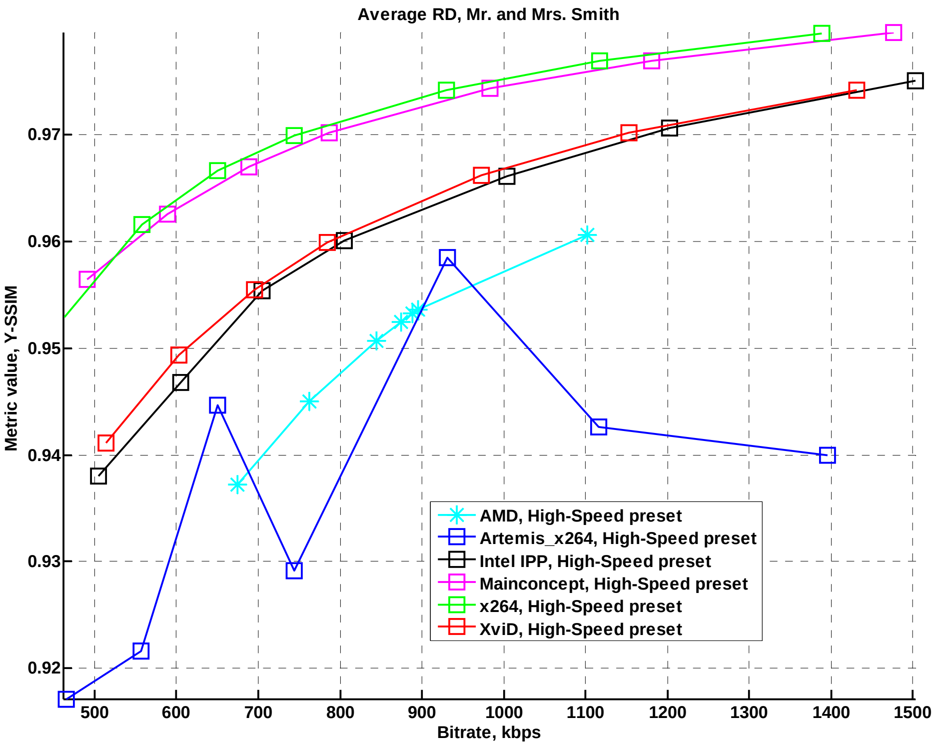


Figure 66. Bitrate/Quality. Usage area "Movies", "Mr. And Mrs. Smith" sequence, "High Speed" preset, Y-SSIM

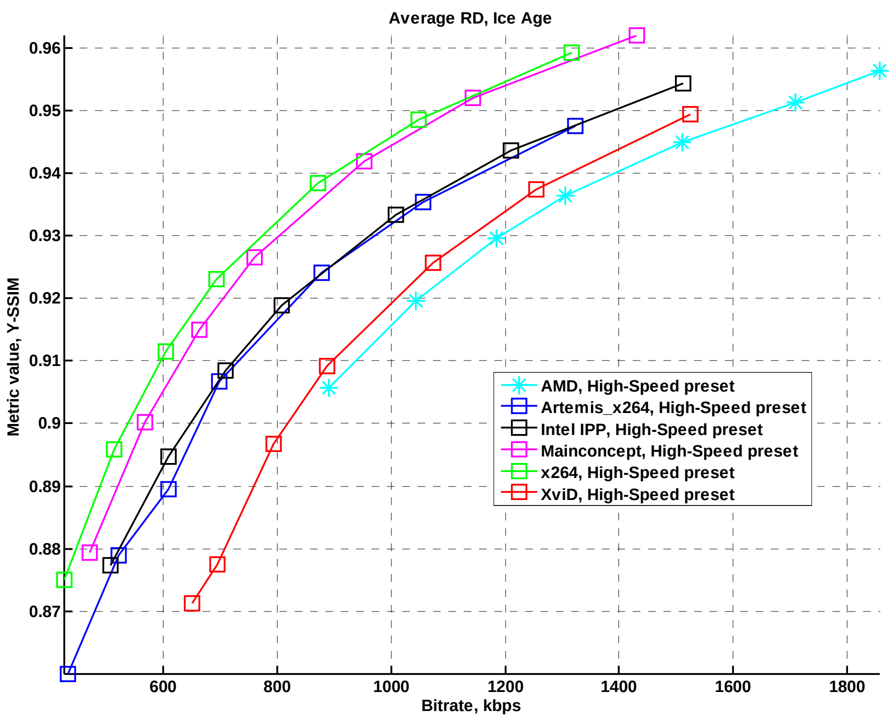


Figure 67. Bitrate/Quality. Usage area "Movies", "Ice Age" sequence, "High Speed" preset, Y-

SSIM

4.2.2 Encoding Speed

Absolute speed results are presented in Figure 68 through Figure 83. Note the differing dependence of encoding time on bitrate. The Intel IPP H.264 encoder displays the fastest rise in encoding time with increasing bitrate. Results for the XviD encoder are unstable. The AMD encoder shows rather high speed due to specific encoder settings that are oriented toward speed maximization.

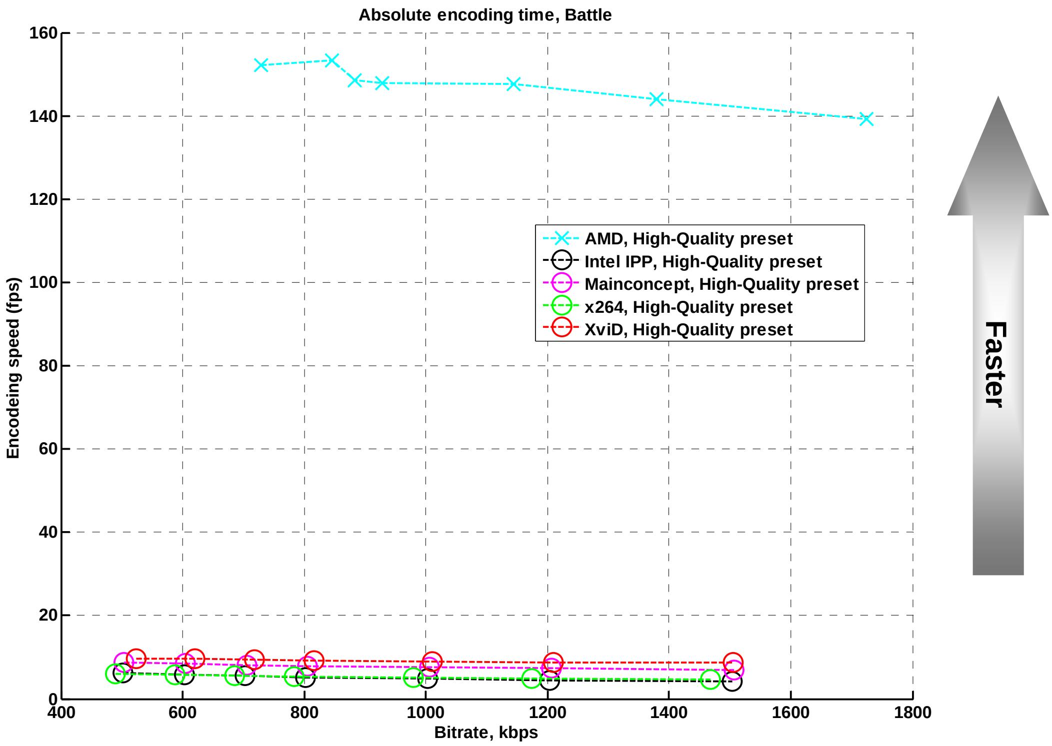


Figure 68. Encoding speed. Usage area “Movies”, “Battle” sequence, “High Quality” preset

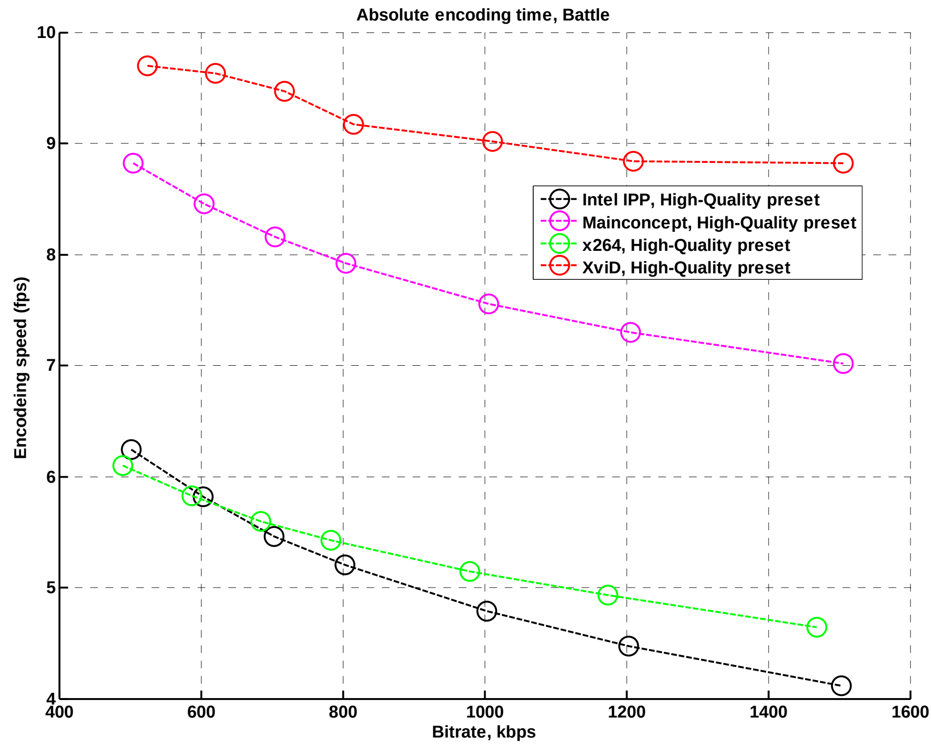


Figure 69. Encoding speed. Usage area "Movies", "Battle" sequence, "High Quality" preset. All encoders except AMD

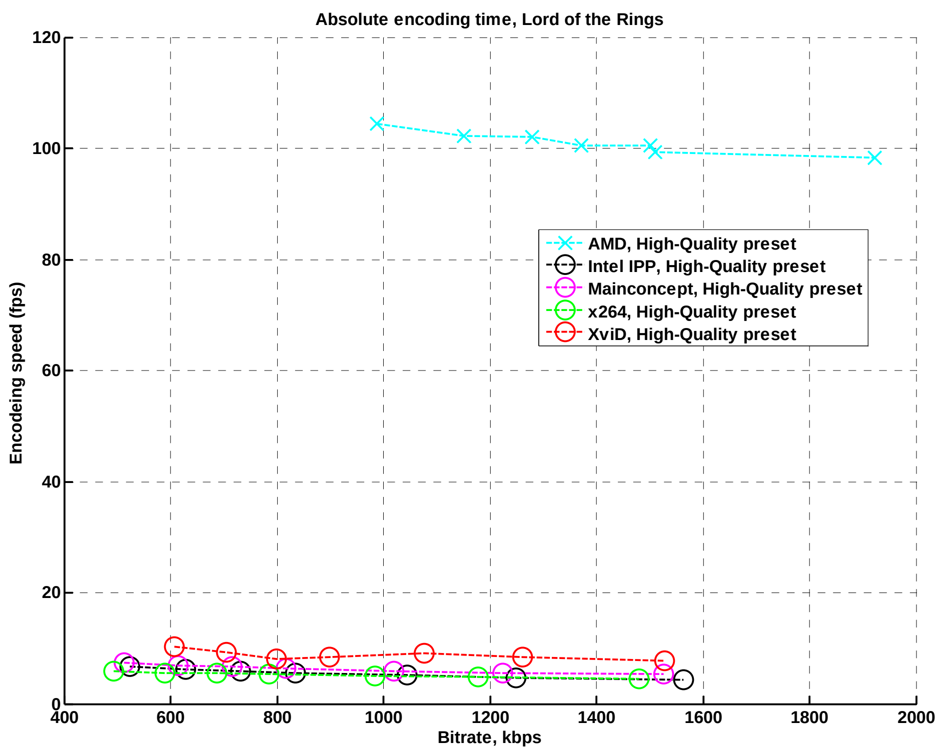


Figure 70. Encoding speed. Usage area "Movies", "Lord of the Rings" sequence, "High Quality" preset

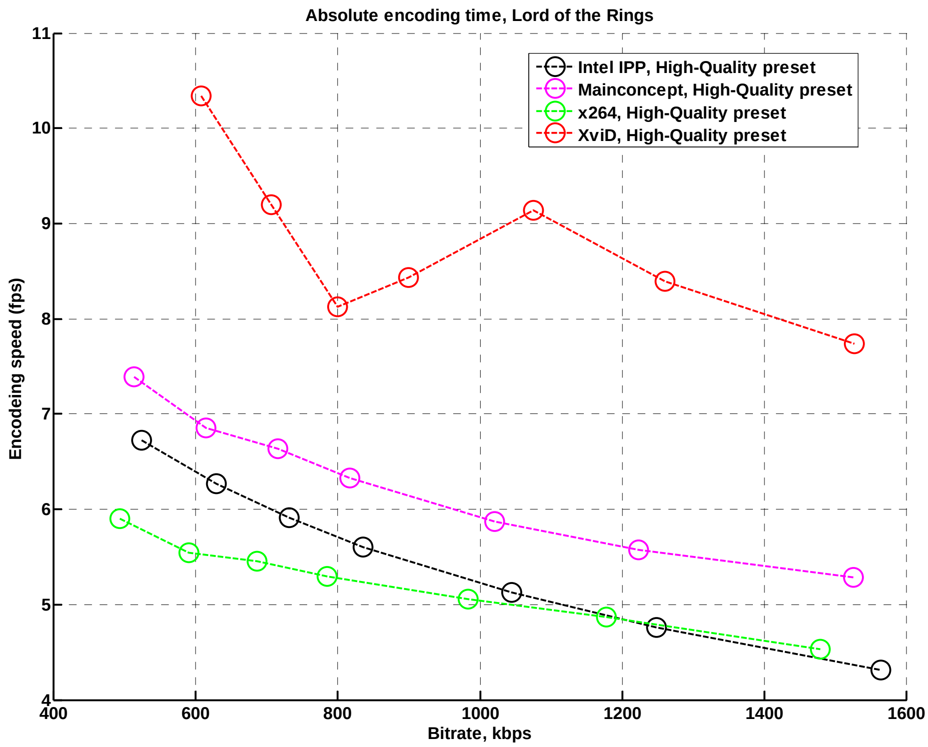


Figure 71. Encoding speed. Usage area "Movies", "Lord of the Rings" sequence, "High Quality" preset. All encoders except AMD

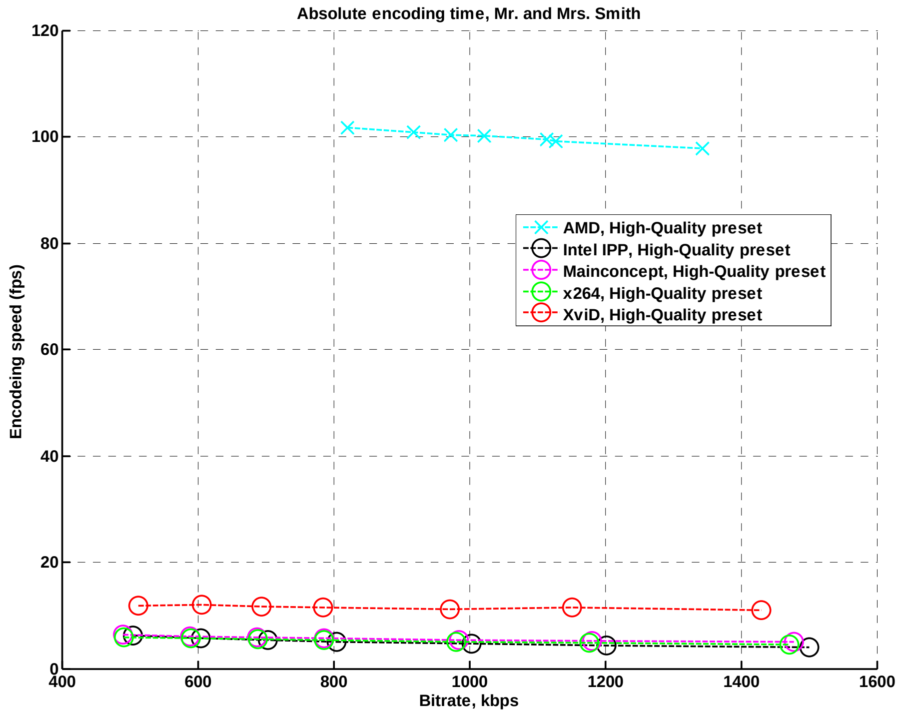


Figure 72. Encoding speed. Usage area "Movies", "Mr. And Mrs. Smith" sequence, "High Quality" preset

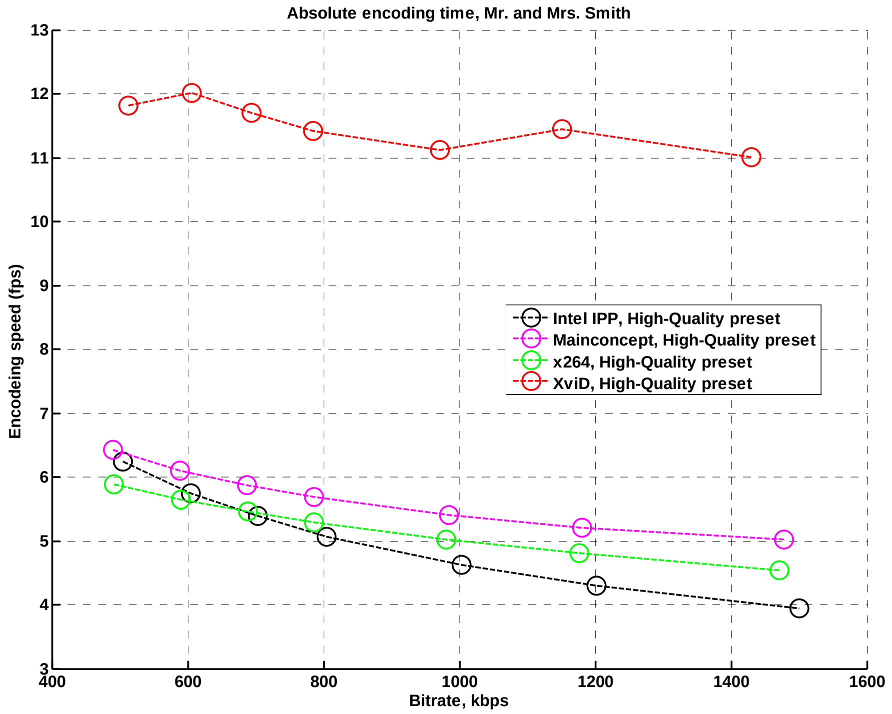


Figure 73. Encoding speed. Usage area “Movies”, “Mr. And Mrs. Smith” sequence, “High Quality” preset. All encoders except AMD

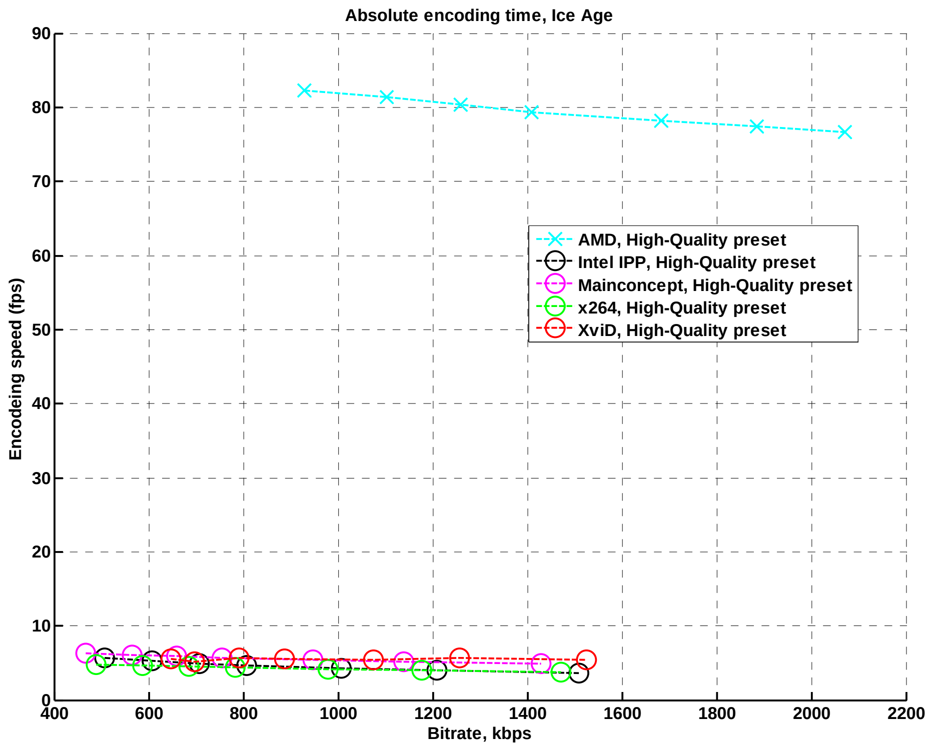


Figure 74. Encoding speed. Usage area “Movies”, “Ice Age” sequence, “High Quality” preset

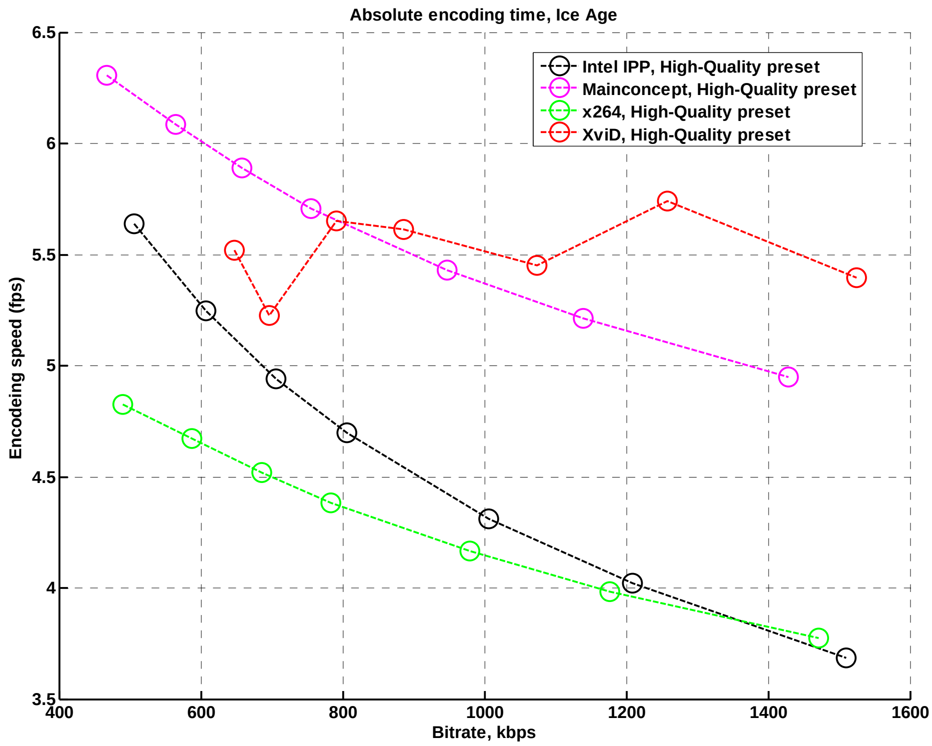


Figure 75. Encoding speed. Usage area "Movies", "Ice Age" sequence, "High Quality" preset. All encoders except AMD

4.2.2.1 High Speed Preset

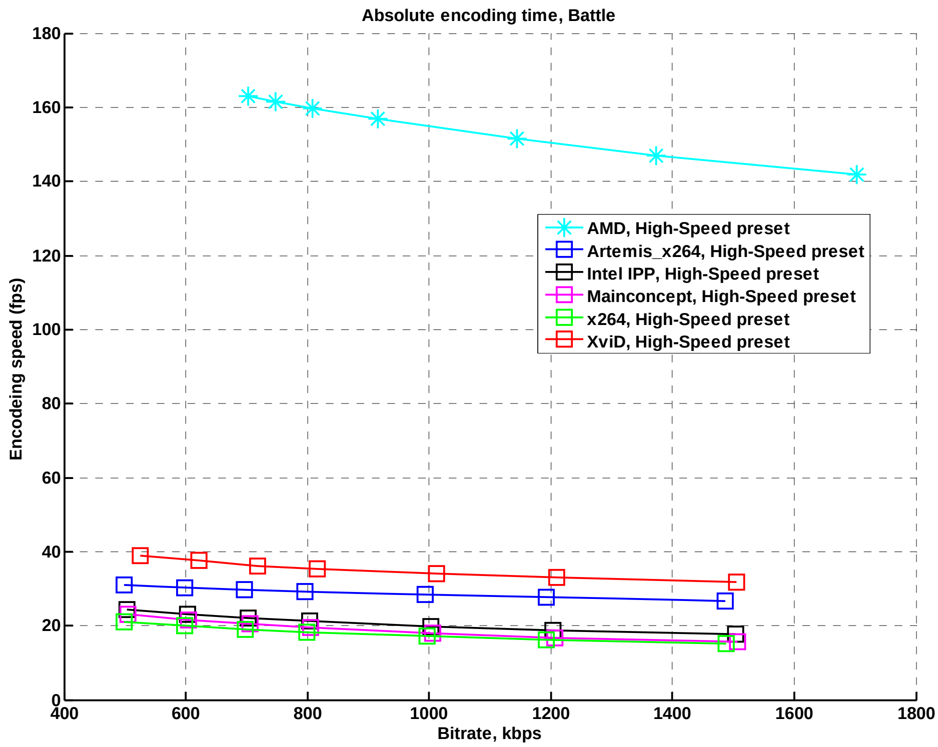


Figure 76. Encoding speed. Usage area "Movies", "Battle" sequence, "High Speed" preset

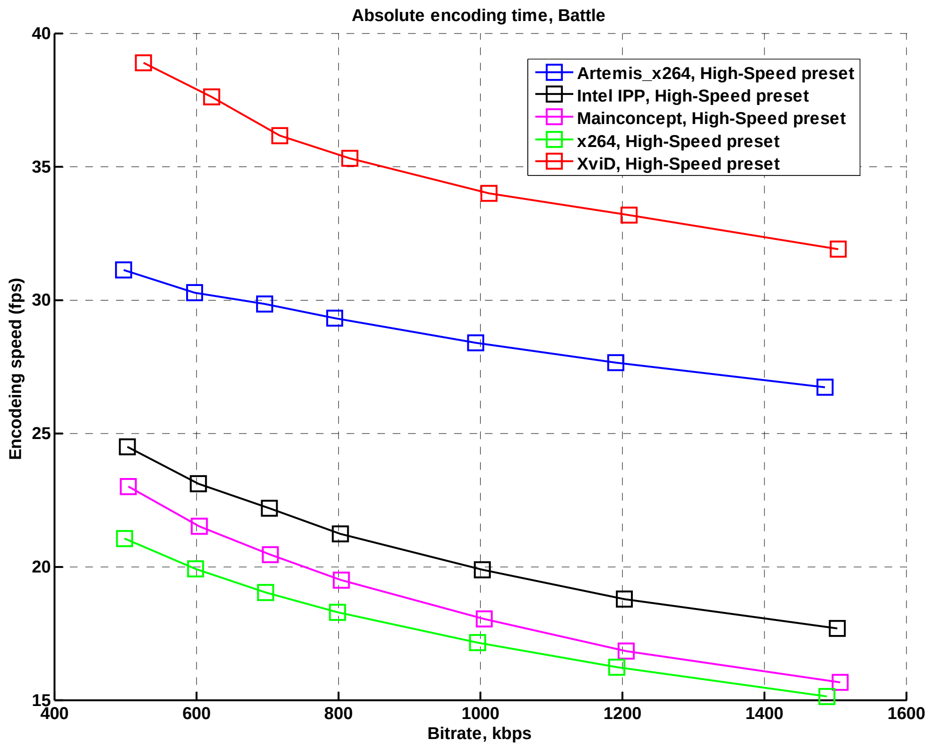


Figure 77. Encoding speed. Usage area “Movies”, “Battle” sequence, “High Speed” preset. All encoders except AMD

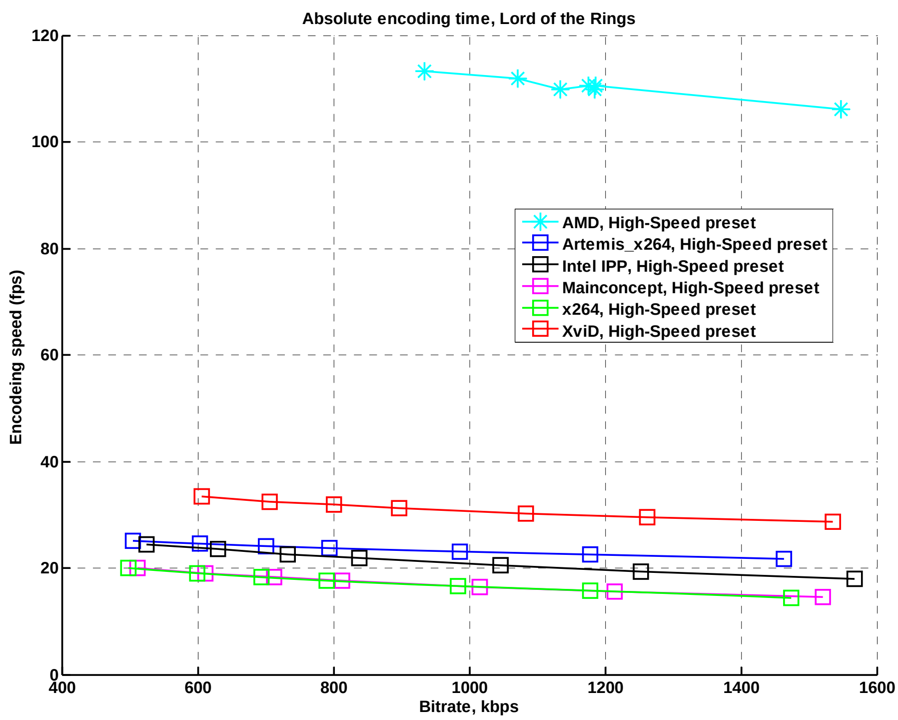


Figure 78. Encoding speed. Usage area “Movies”, “Lord of the Rings” sequence, “High Speed” preset

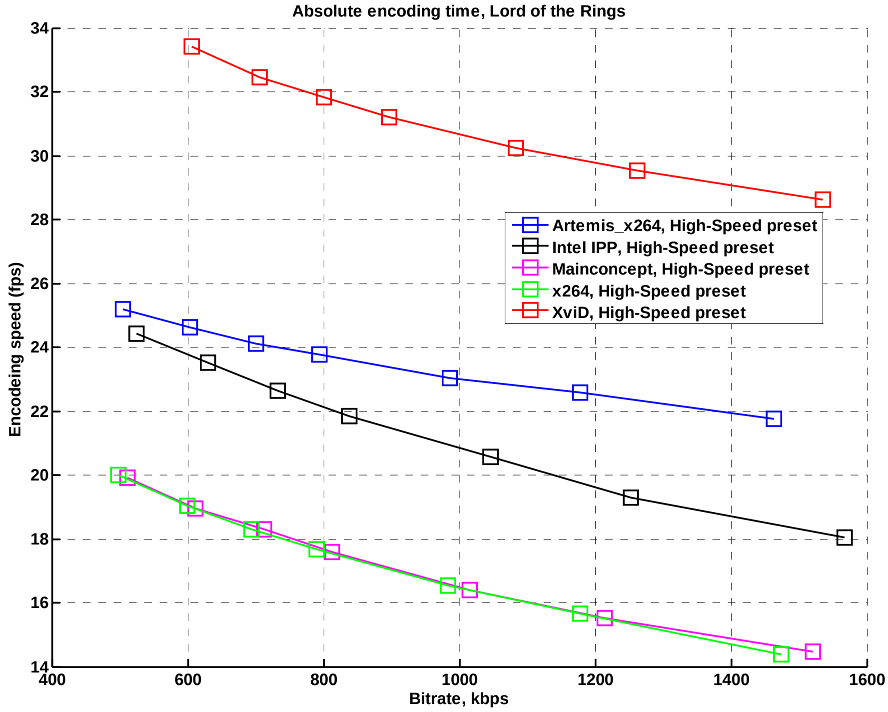


Figure 79. Encoding speed. Usage area “Movies”, “Lord of the Rings” sequence, “High Speed” preset. All encoders except AMD

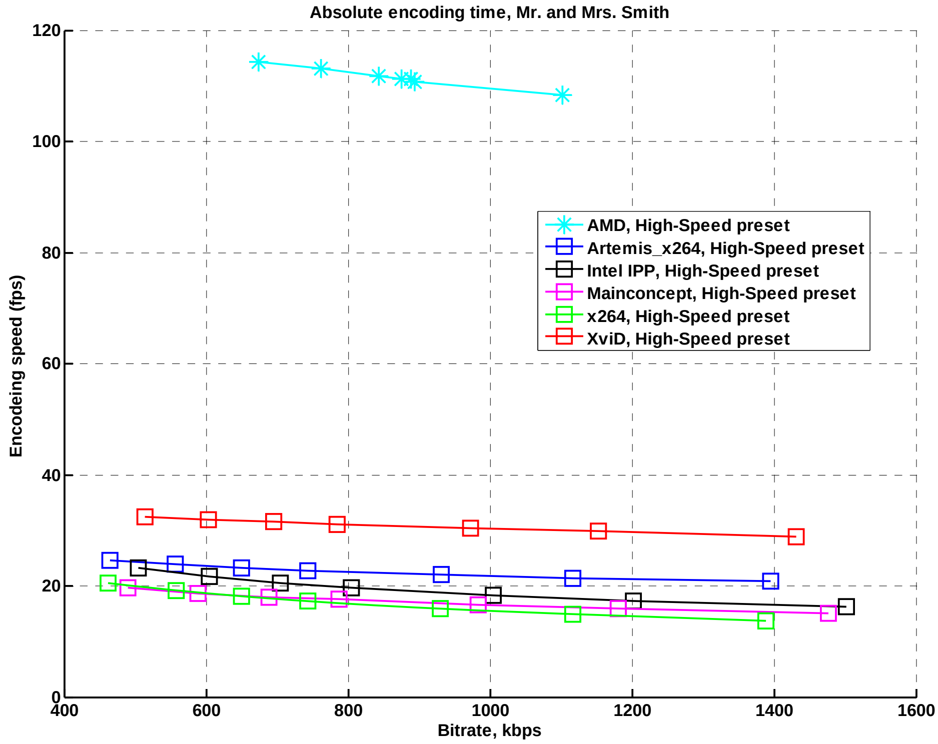


Figure 80. Encoding speed. Usage area “Movies”, “Mr. And Mrs. Smith” sequence, “High Speed” preset

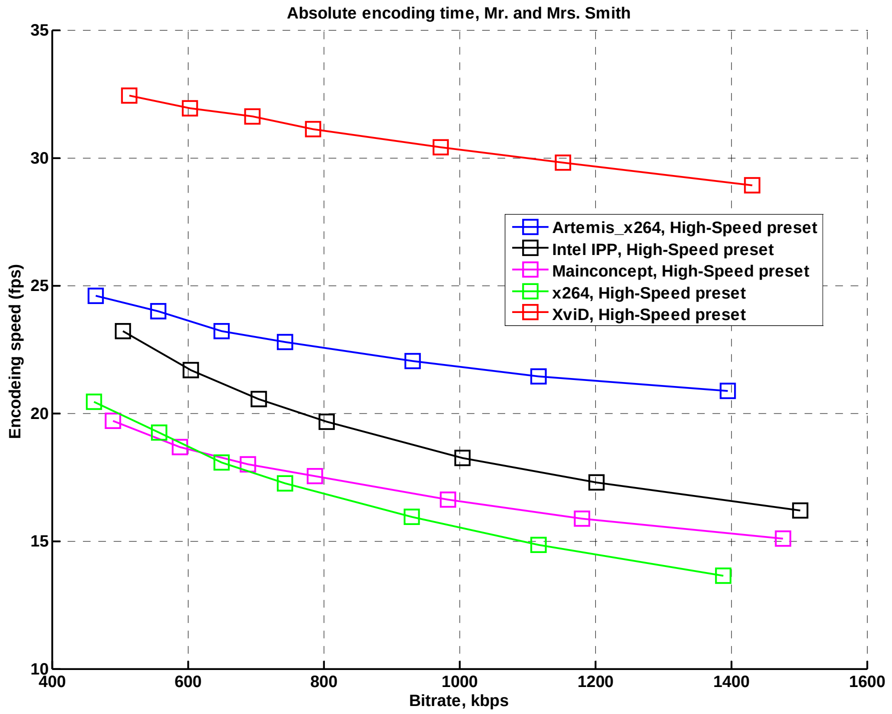


Figure 81. Encoding speed. Usage area "Movies", "Mr. And Mrs. Smith" sequence, "High Speed" preset. All encoders except AMD

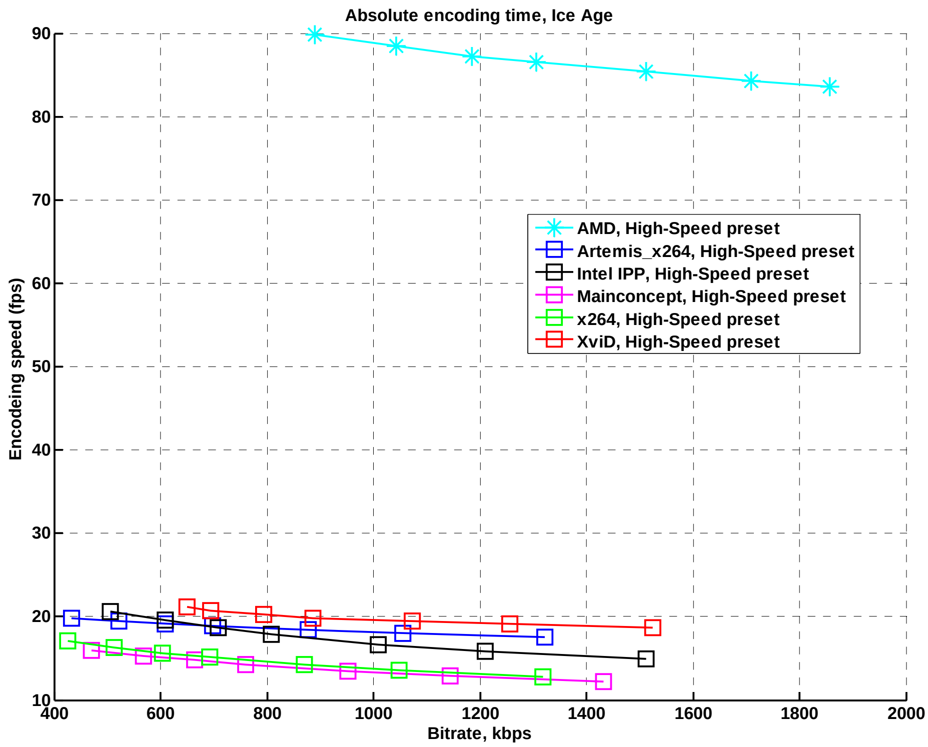


Figure 82. Encoding speed. Usage area "Movies", "Ice Age" sequence, "High Speed" preset

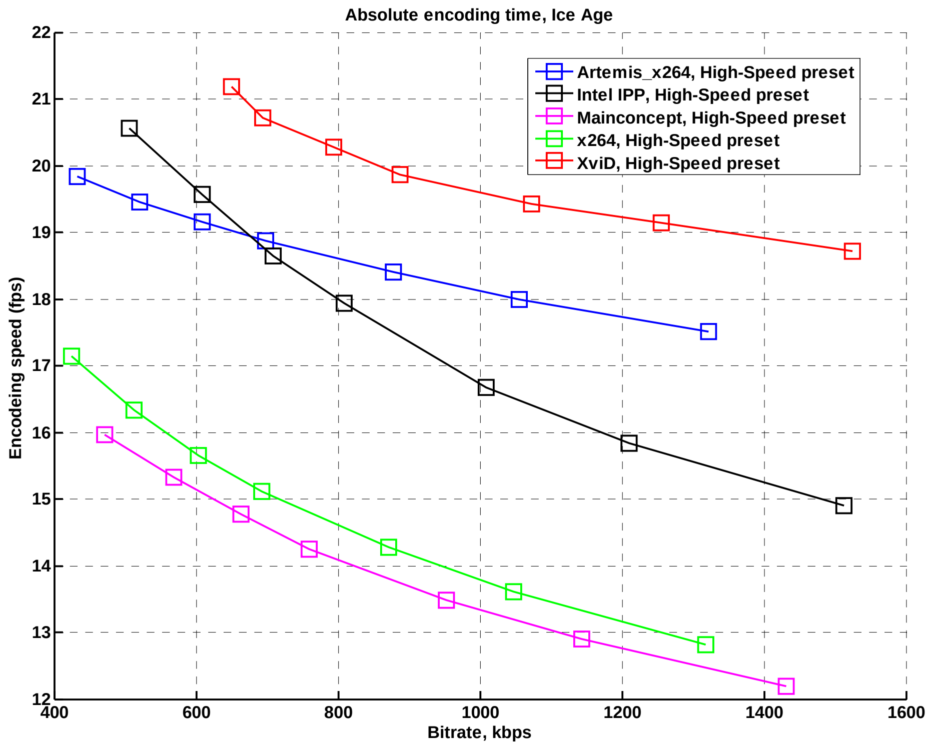


Figure 83. Encoding speed. Usage area "Movies", "Ice Age" sequence, "High Speed" preset. All encoders except AMD

4.2.3 Speed/Quality Tradeoff

Detailed descriptions of the speed/quality trade-off graphs can be found in Appendix 6. Figures Explanation. Sometimes codec results are not present in the particular graph. The reason for that are extremely poor results of the codec. Its RD curve has no intersection with reference's RD curve.

The speed/quality trade-off graphs simultaneously show relative quality and encoding speed for the encoders tested in this comparison. Again, XviD is the reference codec with both quality and speed normalized to unity for all of the below graphs. The terms "better" and "worse" are used to compare codecs in the same manner as in previous portions of this comparison.

Please note that the averaging method among all sequences suppose that all codecs have the results for each sequence. When it's not the case, then only existing results are taking into account.

Figure 84 through Figure 93 show results for the High Quality preset. The MainConcept codec yields better results than the Intel IPP codec for all sequences. Additionally, MainConcept is better than x264 for the "Lord of the Rings" sequence. The Y-PSNR and Y-SSIM results are very similar.

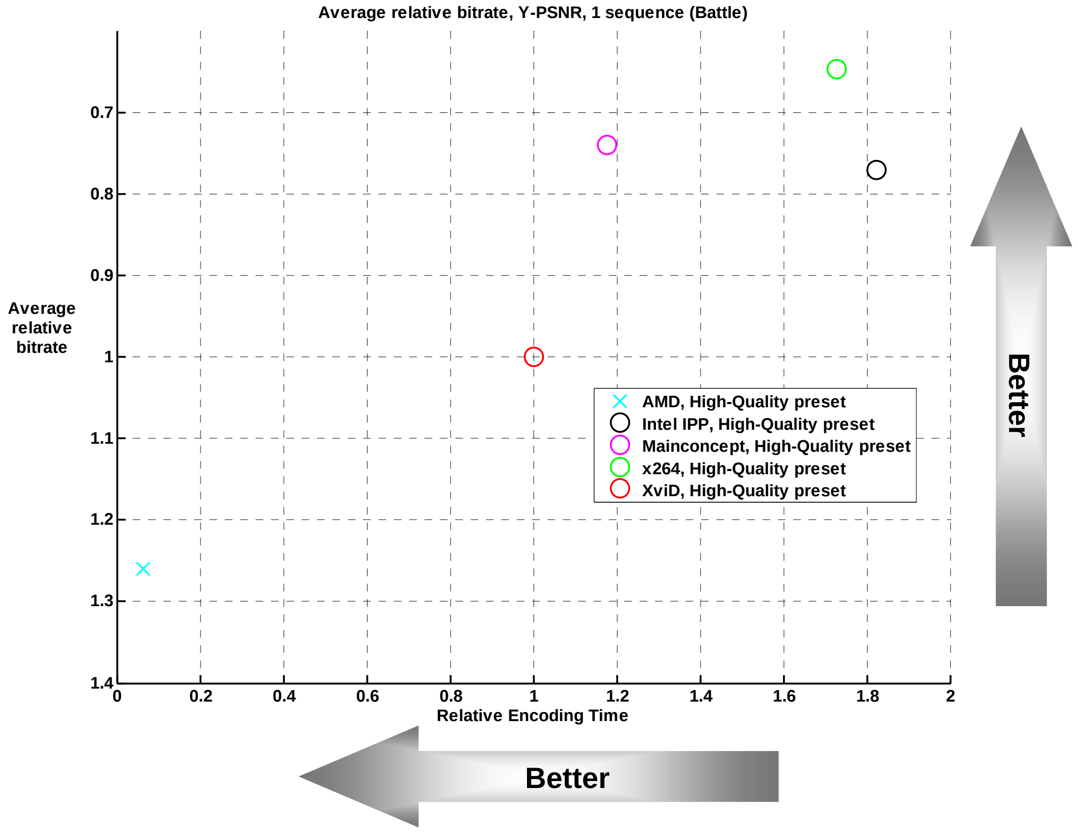


Figure 84. Speed/Quality tradeoff. Usage area "Movies", "Battle" sequence, "High Quality" preset, Y-PSNR

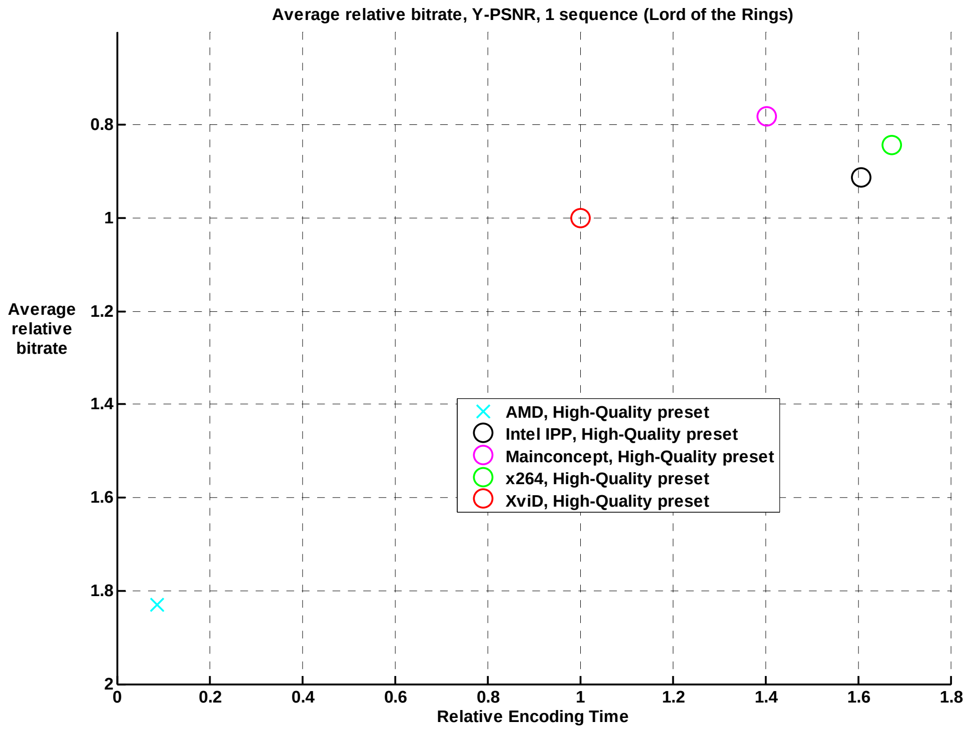


Figure 85. Speed/Quality tradeoff. Usage area "Movies", "Lord of the Rings" sequence, "High Quality" preset, Y-PSNR

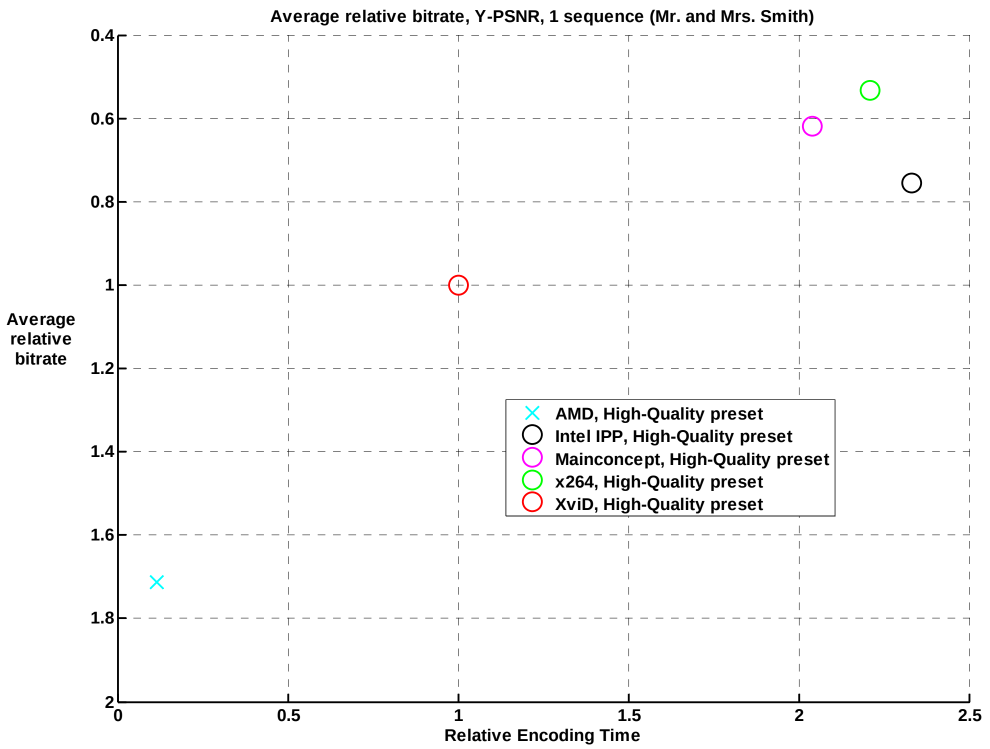


Figure 86. Speed/Quality tradeoff. Usage area "Movies", "Mr. And Mrs. Smith" sequence, "High Quality" preset, Y-PSNR

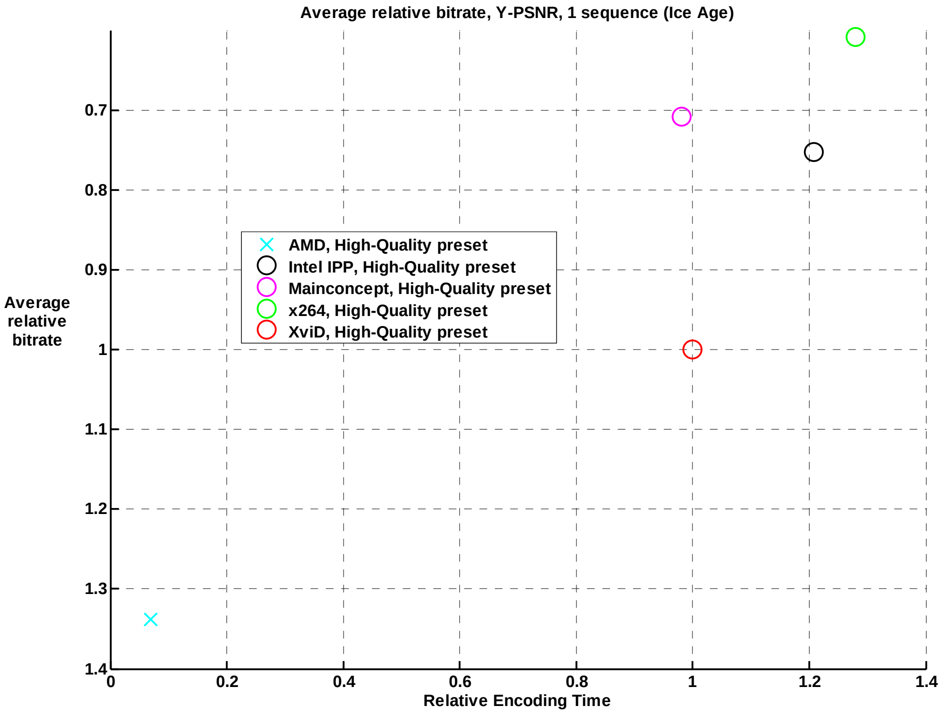


Figure 87. Speed/Quality tradeoff. Usage area “Movies”, “Ice Age” sequence, “High Quality” preset, Y-PSNR

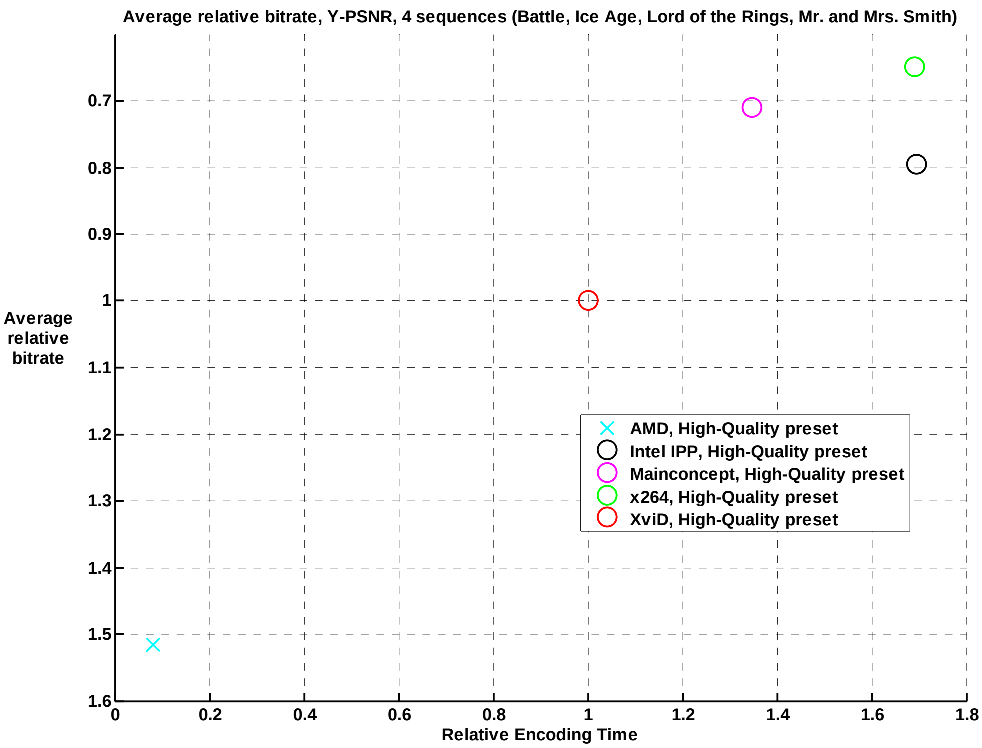


Figure 88. Speed/Quality tradeoff. Usage area “Movies”, all sequences, “High Quality” preset, Y-PSNR

SSIM

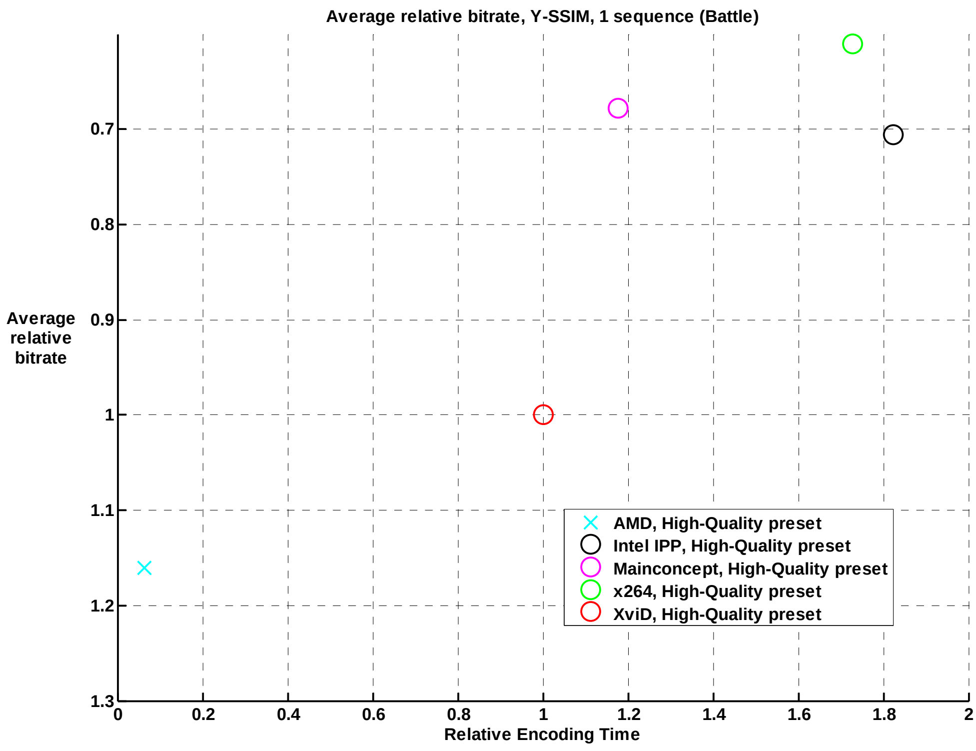


Figure 89. Speed/Quality tradeoff. Usage area "Movies", "Battle" sequence, "High Quality" preset, Y-SSIM

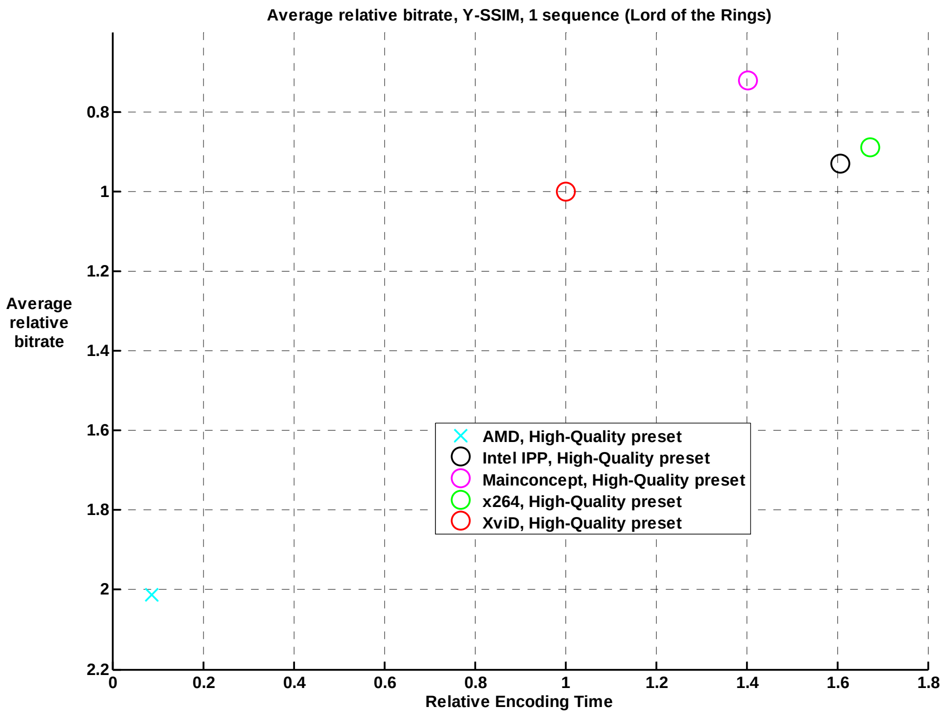


Figure 90. Speed/Quality tradeoff. Usage area "Movies", "Lord of the Rings" sequence, "High Quality" preset, Y-SSIM

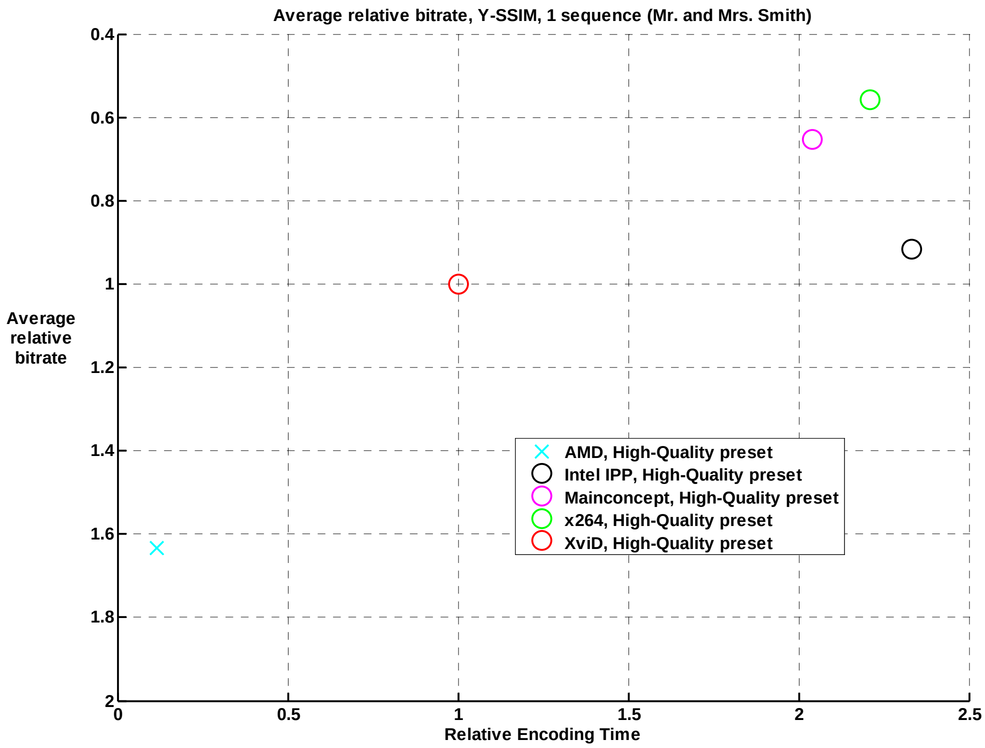


Figure 91. Speed/Quality tradeoff. Usage area "Movies", "Mr. And Mrs. Smith" sequence, "High Quality" preset, Y-SSIM

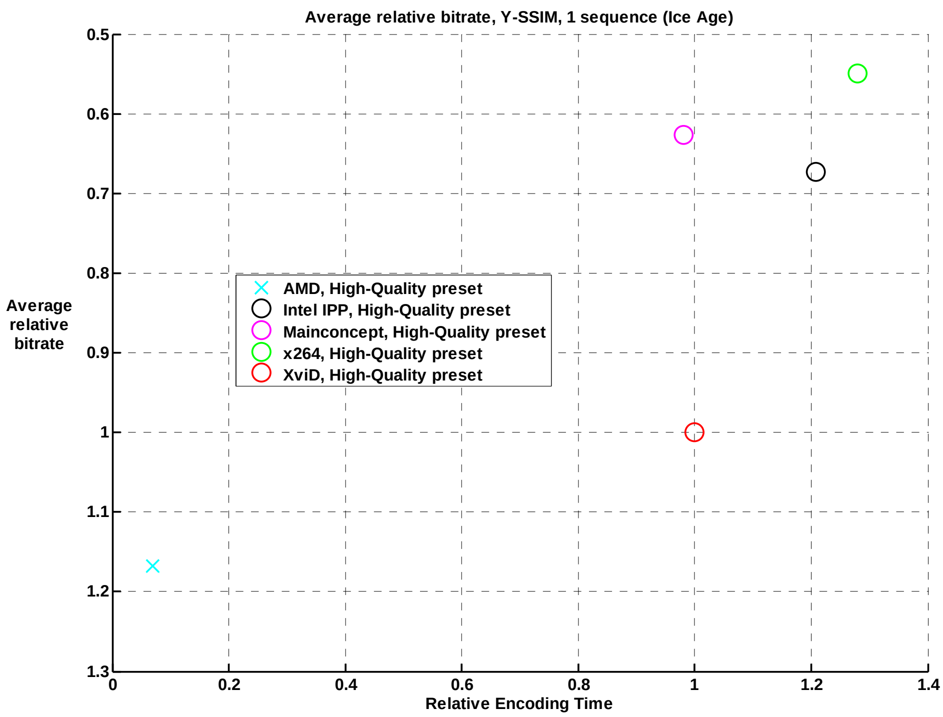


Figure 92. Speed/Quality tradeoff. Usage area "Movies", "Ice Age" sequence, "High Quality" preset, Y-SSIM

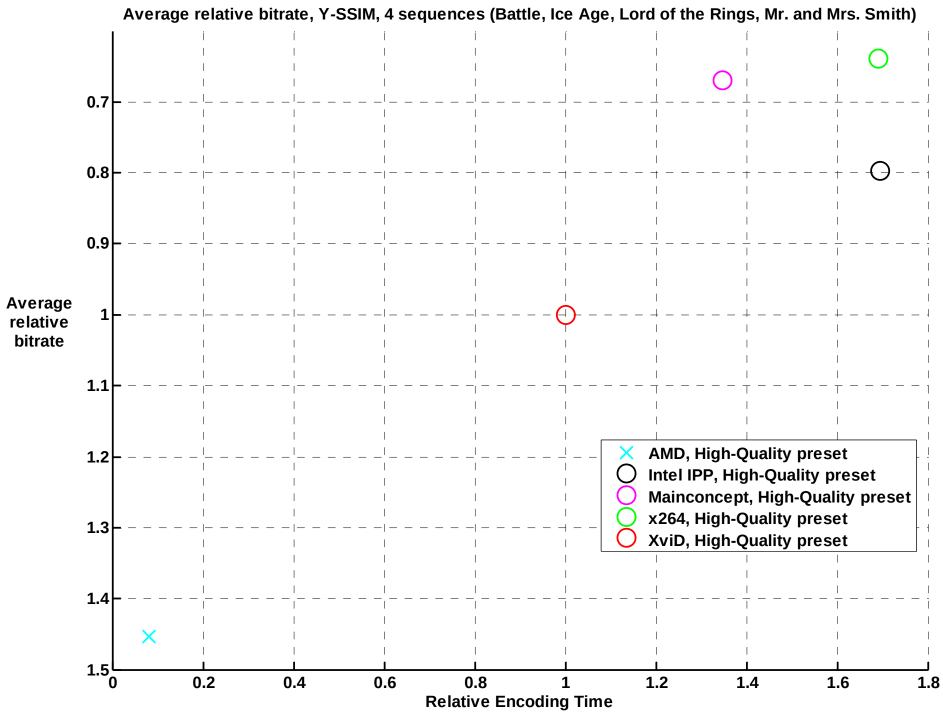


Figure 93. Speed/Quality tradeoff. Usage area “Movies”, all sequences, “High Quality” preset, Y-SSIM

4.2.3.1 High Speed Preset

Figure 94 through Figure 103 show results for the High Speed preset. In considering the cumulative results for all sequences, it becomes apparent that the XviD codec is better than the Artemis modification of x264 for all sequences. The x264 and MainConcept encoders yield very similar results. Per-sequence results demonstrate significant variation. For example, MainConcept is better than x264 for the “Lord of the Rings” sequence, but it is worse than x264 for the “Ice Age” sequence. The Intel IPP encoder results for the “Mr. and Mrs. Smith” sequence strongly depend on the metric used.

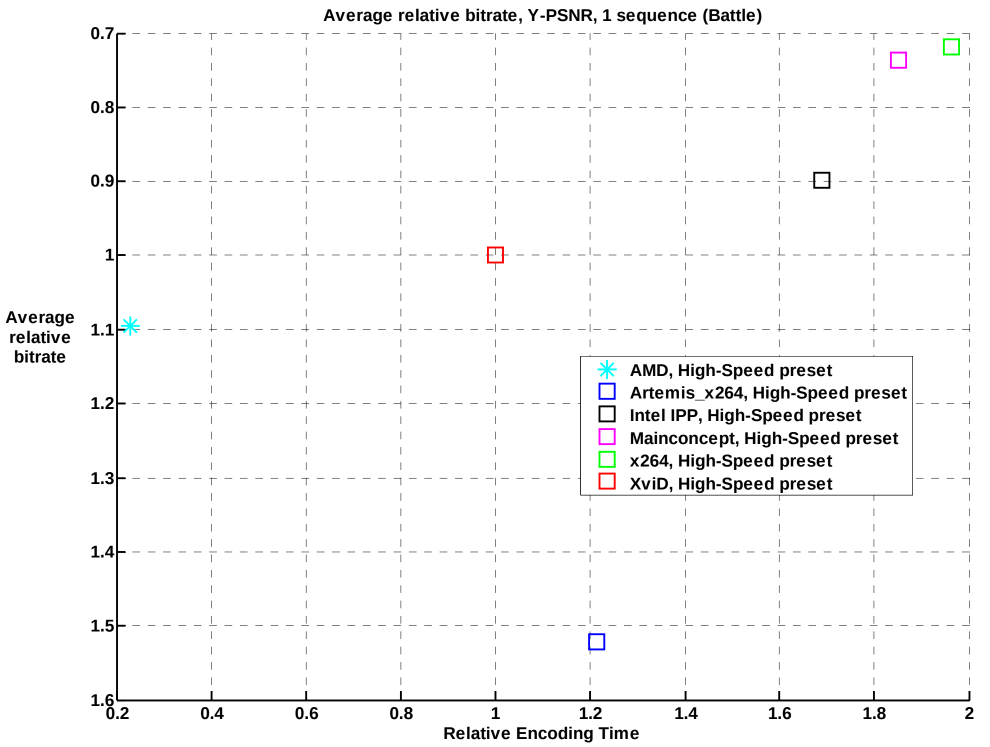


Figure 94. Speed/Quality tradeoff. Usage area “Movies”, “Battle” sequence, “High Speed” preset, Y-PSNR

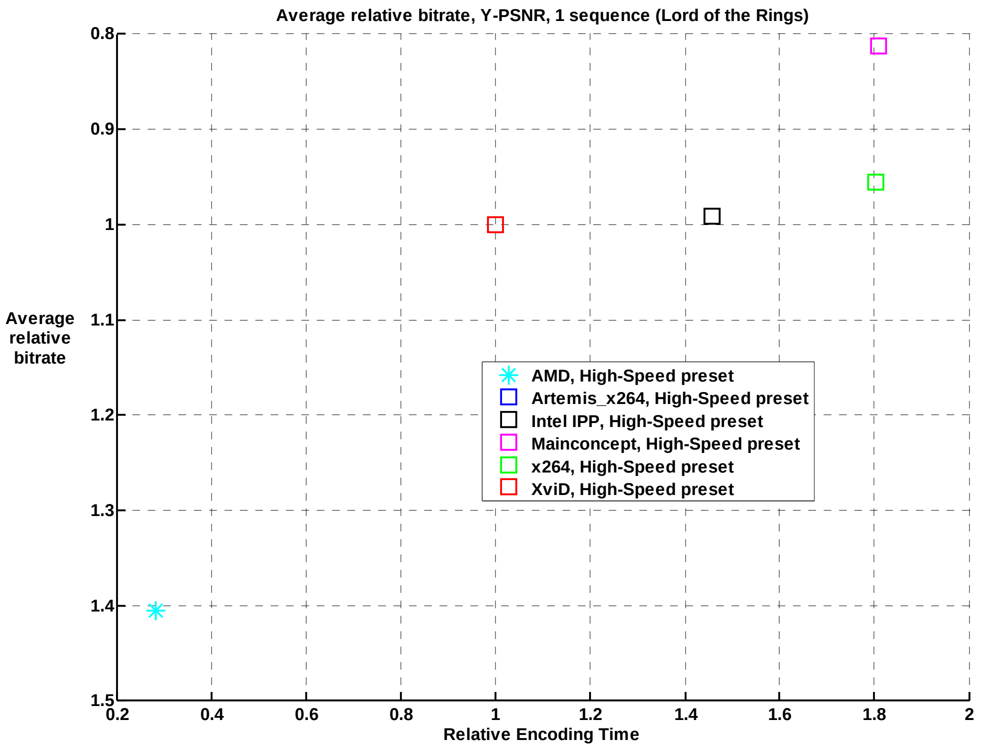


Figure 95. Speed/Quality tradeoff. Usage area “Movies”, “Lord of the Rings” sequence, “High Speed” preset, Y-PSNR

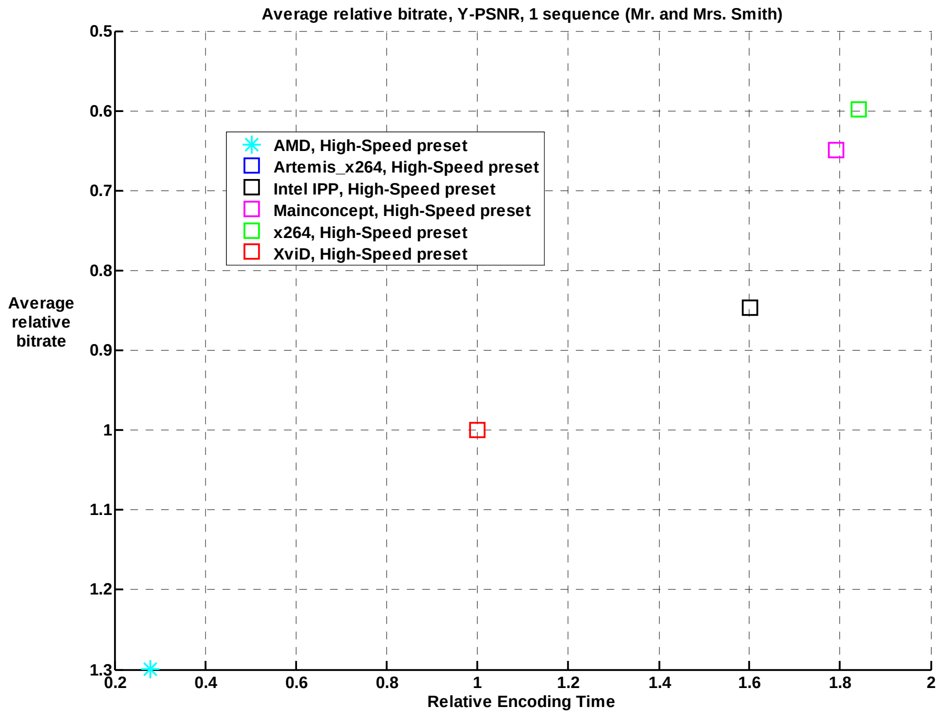


Figure 96. Speed/Quality tradeoff. Usage area "Movies", "Mr. And Mrs. Smith" sequence, "High Speed" preset, Y-PSNR

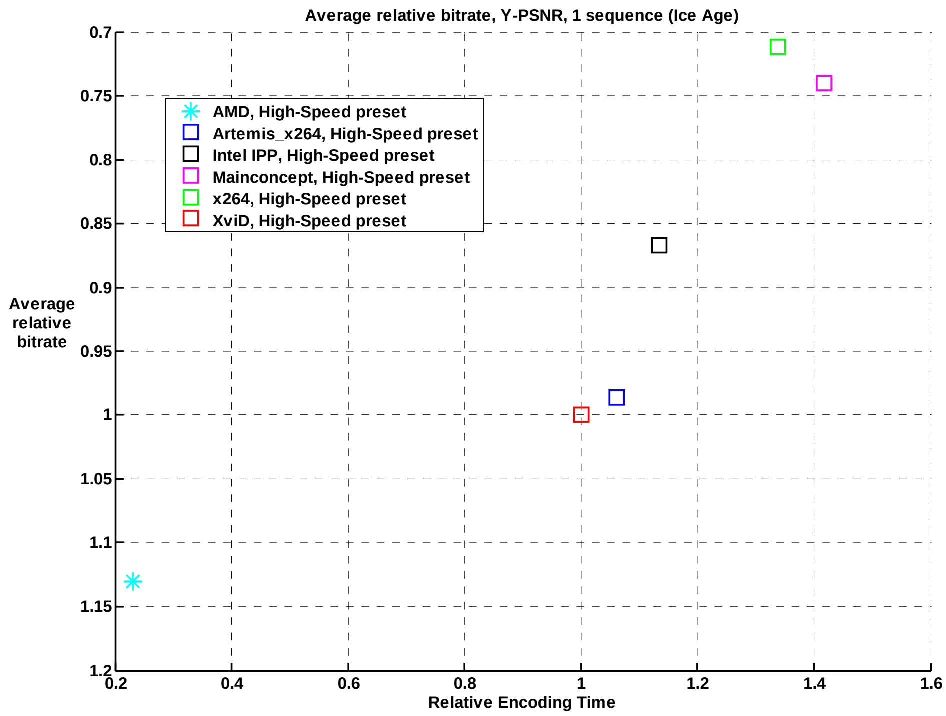


Figure 97. Speed/Quality tradeoff. Usage area "Movies", "Ice Age" sequence, "High Speed" preset, Y-PSNR

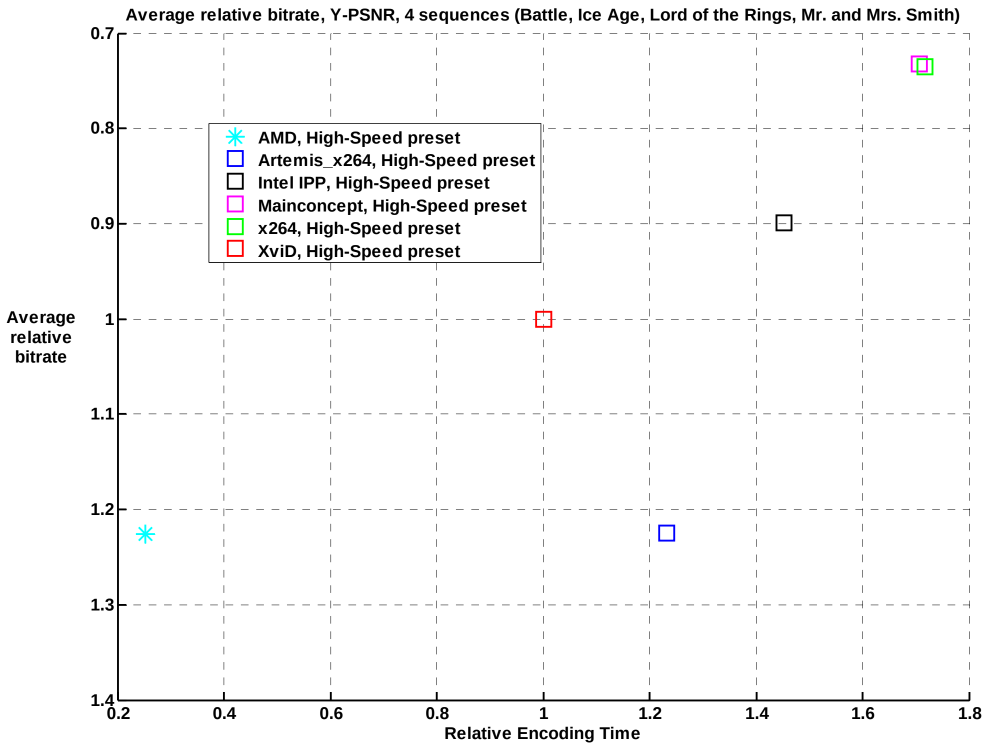


Figure 98. Speed/Quality tradeoff. Usage area “Movies”, all the sequences, “High Speed” preset, Y-PSNR

SSIM

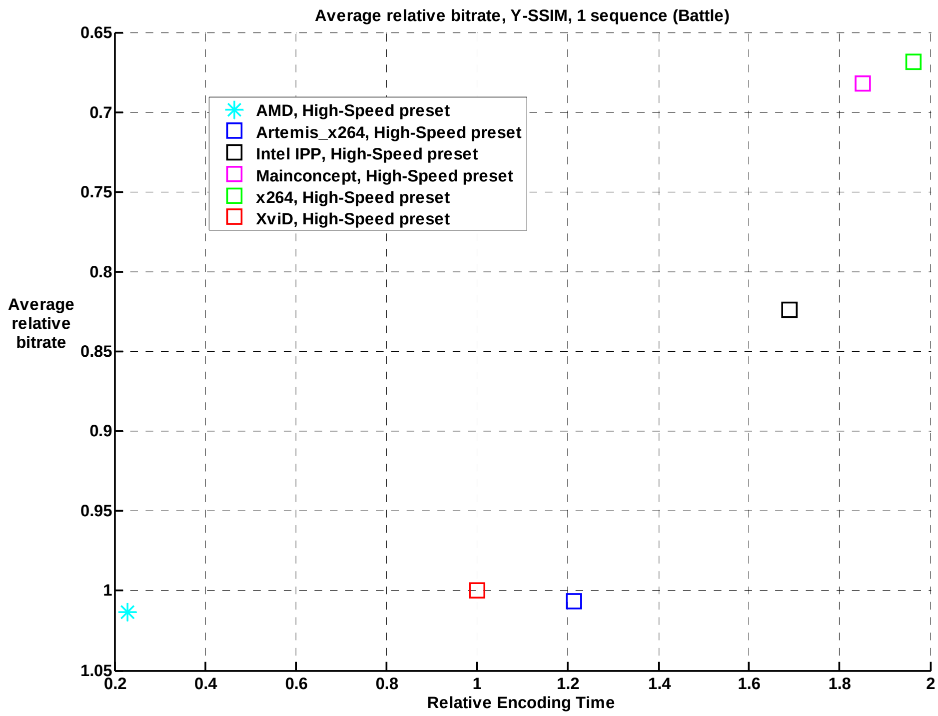


Figure 99. Speed/Quality tradeoff. Usage area “Movies”, “Battle” sequence, “High Speed” preset, Y-SSIM

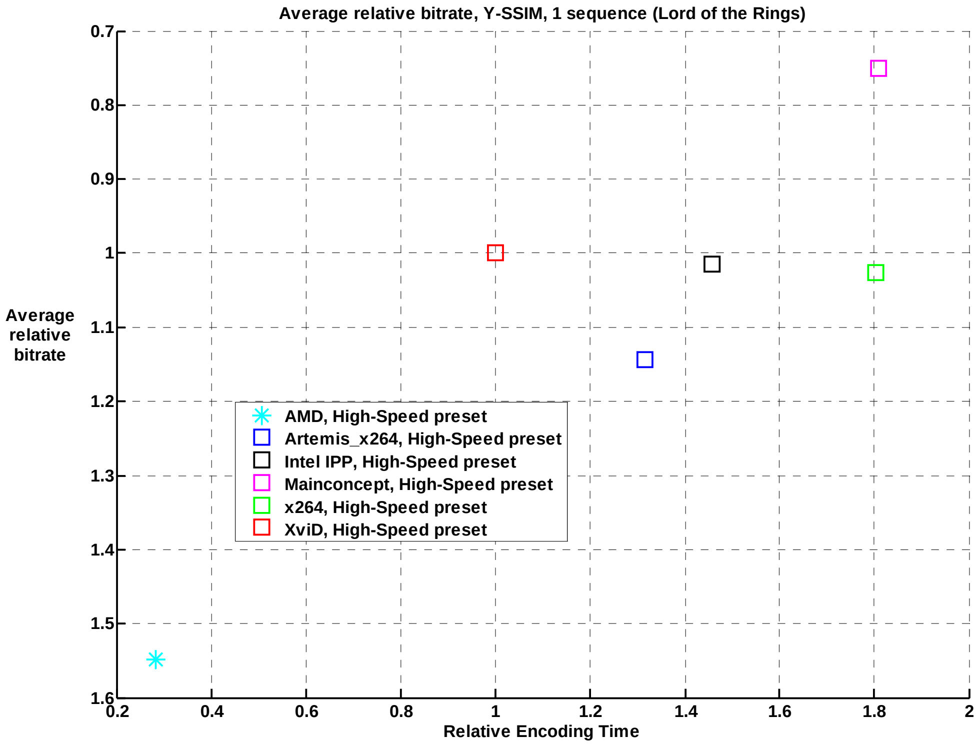


Figure 100. Speed/Quality tradeoff. Usage area “Movies”, “Lord of the Rings” sequence, “High Speed” preset, Y-SSIM

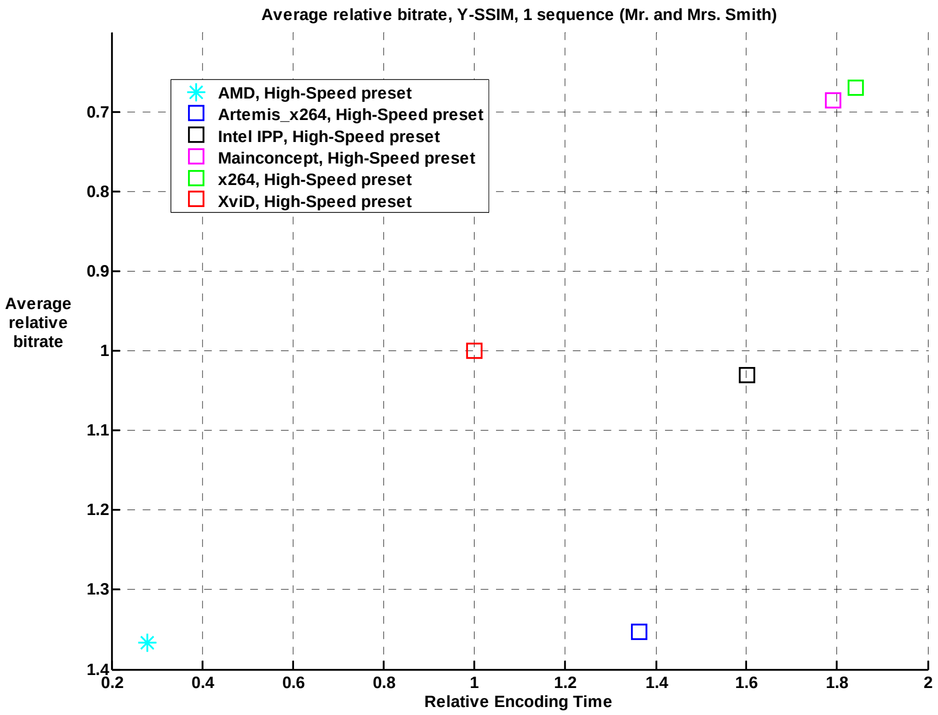


Figure 101. Speed/Quality tradeoff. Usage area “Movies”, “Mr. And Mrs. Smith” sequence, “High Speed” preset, Y-SSIM

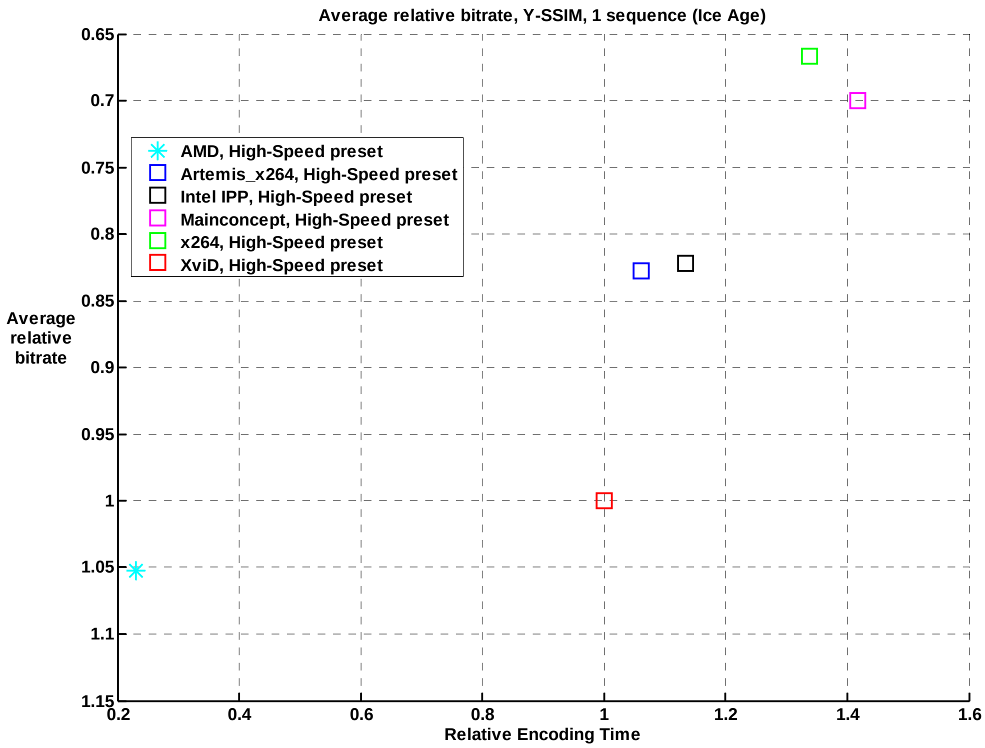


Figure 102. Speed/Quality tradeoff. Usage area “Movies”, “Ice Age” sequence, “High Speed” preset, Y-SSIM

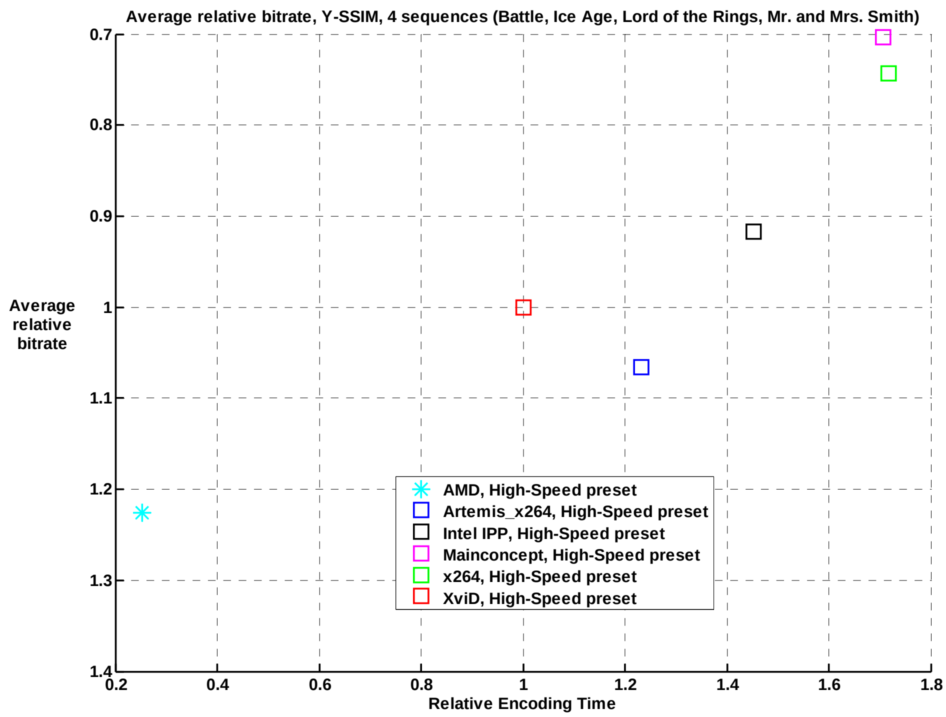


Figure 103. Speed/Quality tradeoff. Usage area “Movies”, all sequences, “High Speed” preset, Y-SSIM

4.2.4 Bitrate Handling

The AMD encoder shows less-than-optimal results for bitrate handling: it increases the bitrate up to two times (for the "Lord of the Rings" sequence, for example). The XviD encoder also increases low bitrates, for other bitrates the bitrate handling is good, but not so perfect as for MainConcept, x264 and Intel IPP.

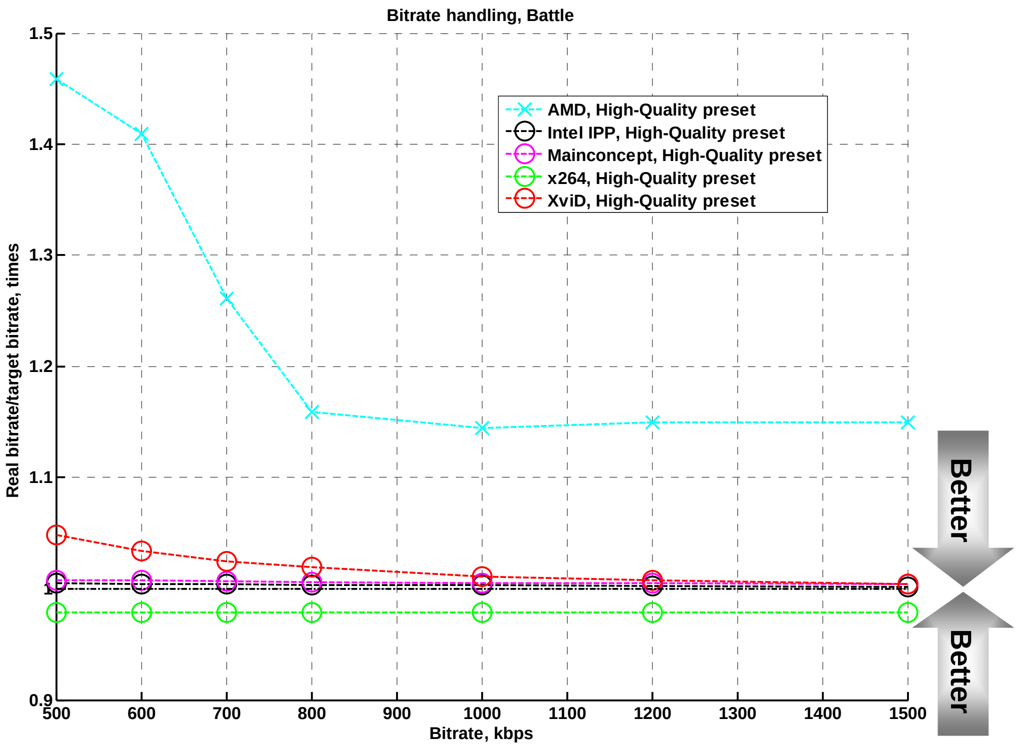


Figure 104. Bitrate Handling. Usage area "Movies", "Battle" sequence, "High Quality" preset

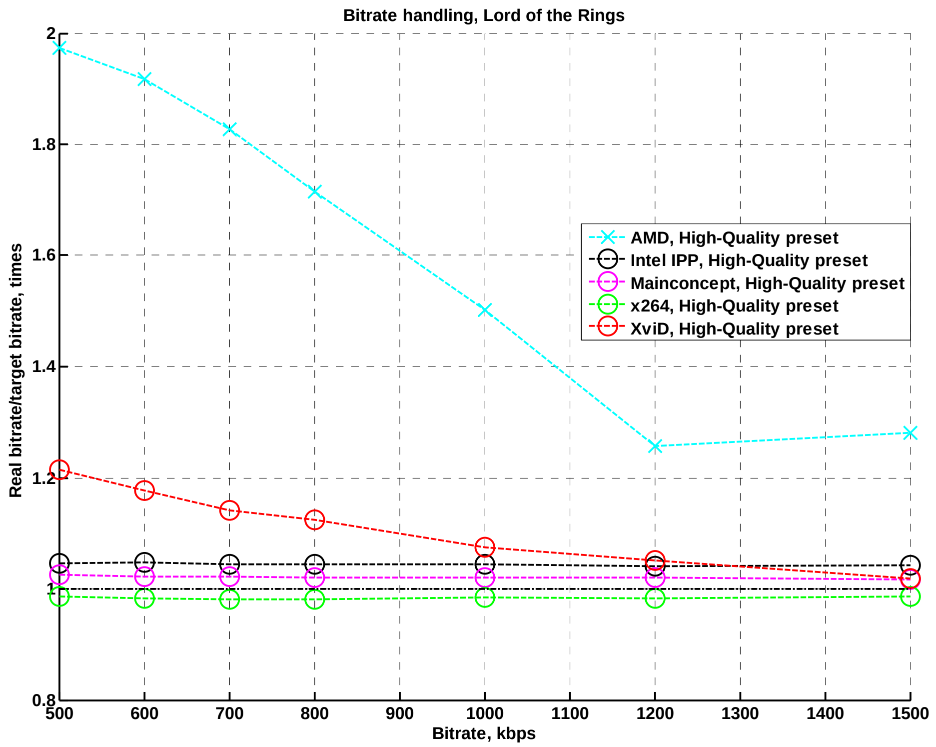


Figure 105. Bitrate Handling. Usage area “Movies”, “Lord of the Rings” sequence, “High Quality” preset

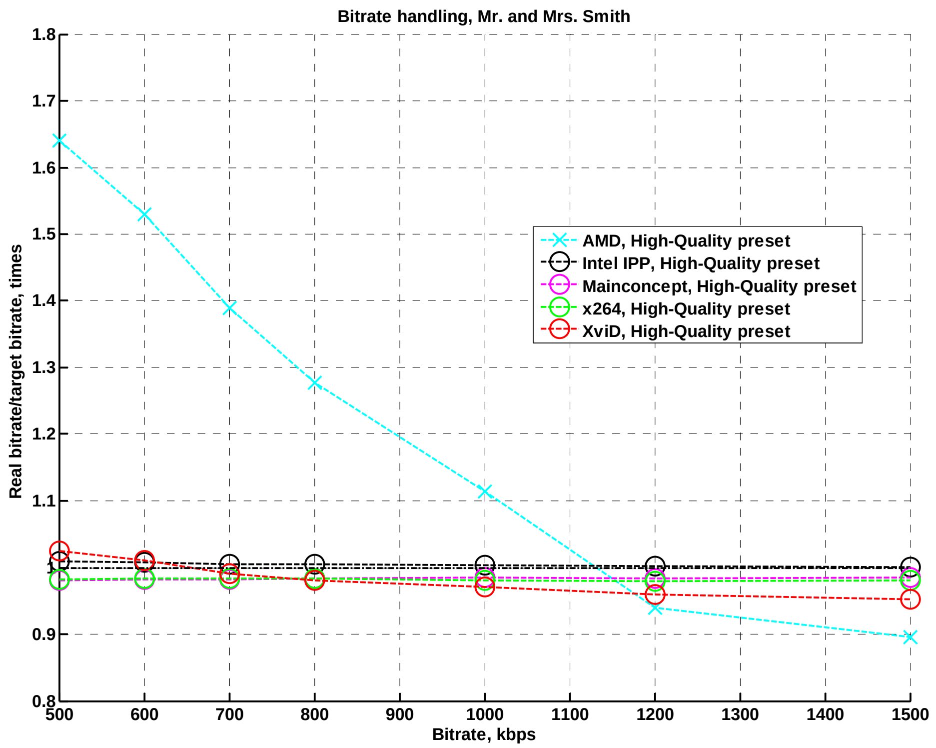


Figure 106. Bitrate Handling. Usage area “Movies”, “Mr. And Mrs. Smith” sequence, “High Quality” preset

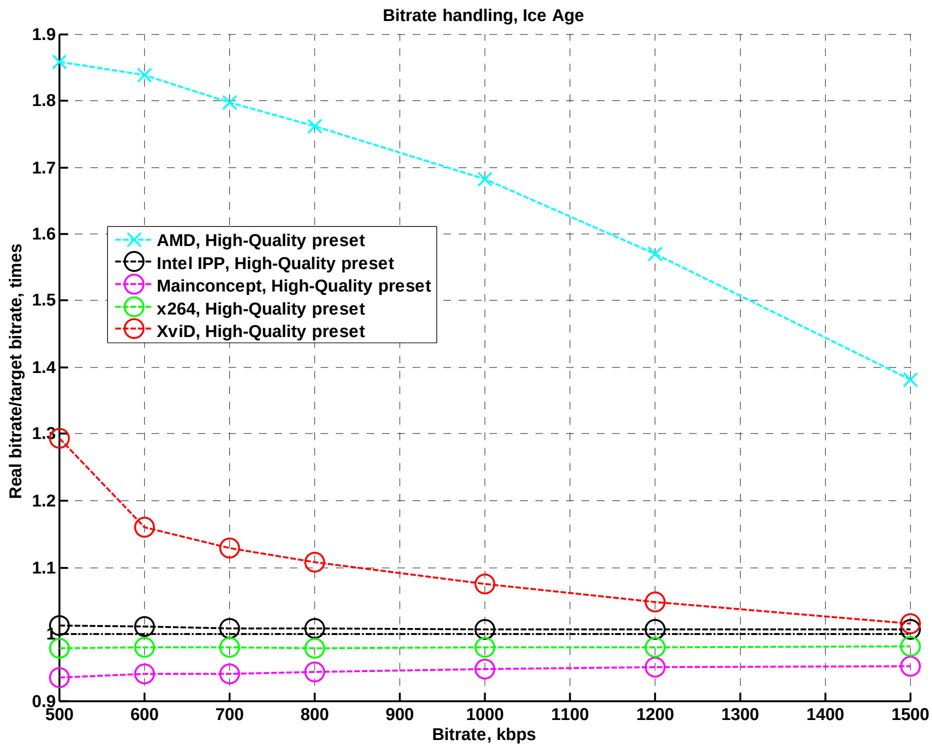


Figure 107. Bitrate Handling. Usage area "Movies", "Ice Age" sequence, "High Quality" preset

4.2.4.1 High Speed Preset

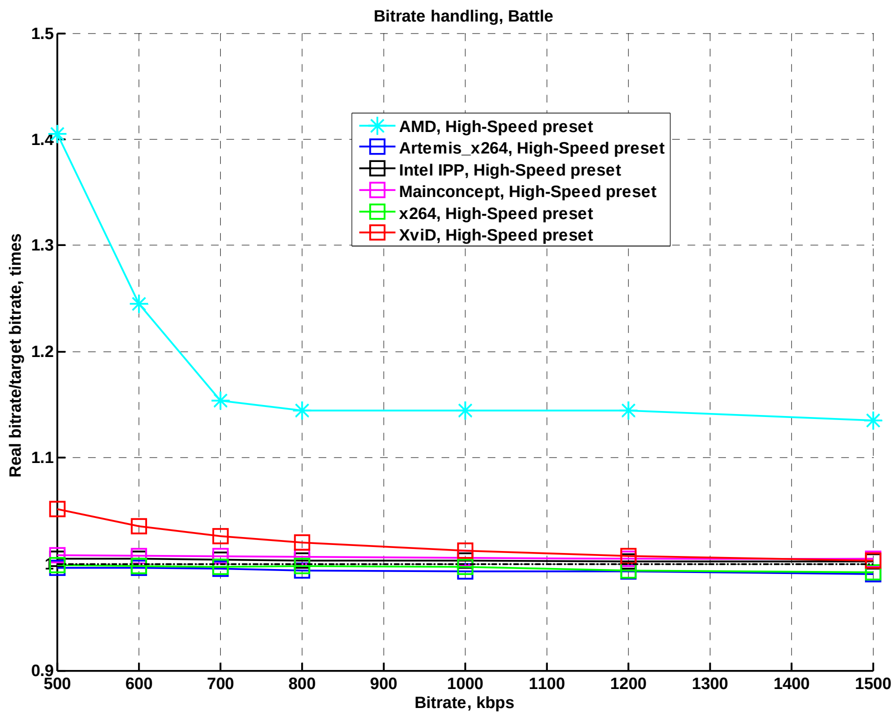


Figure 108. Bitrate Handling. Usage area "Movies", "Battle" sequence, "High Speed" preset

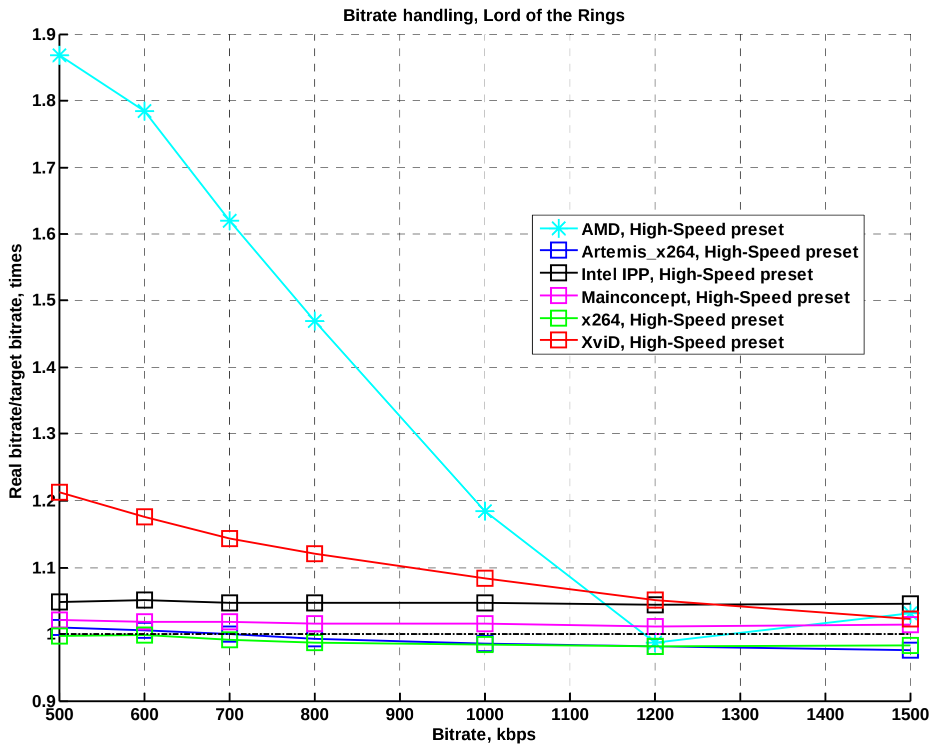


Figure 109. Bitrate Handling. Usage area “Movies”, “Lord of the Rings” sequence, “High Speed” preset

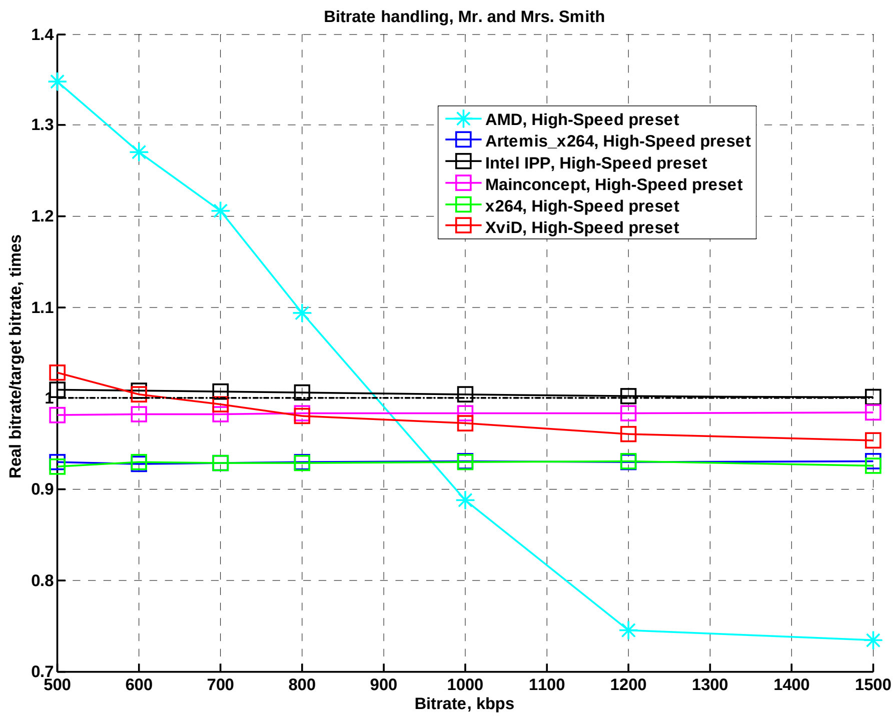


Figure 110. Bitrate Handling. Usage area “Movies”, “Mr. And Mrs. Smith” sequence, “High Speed” preset

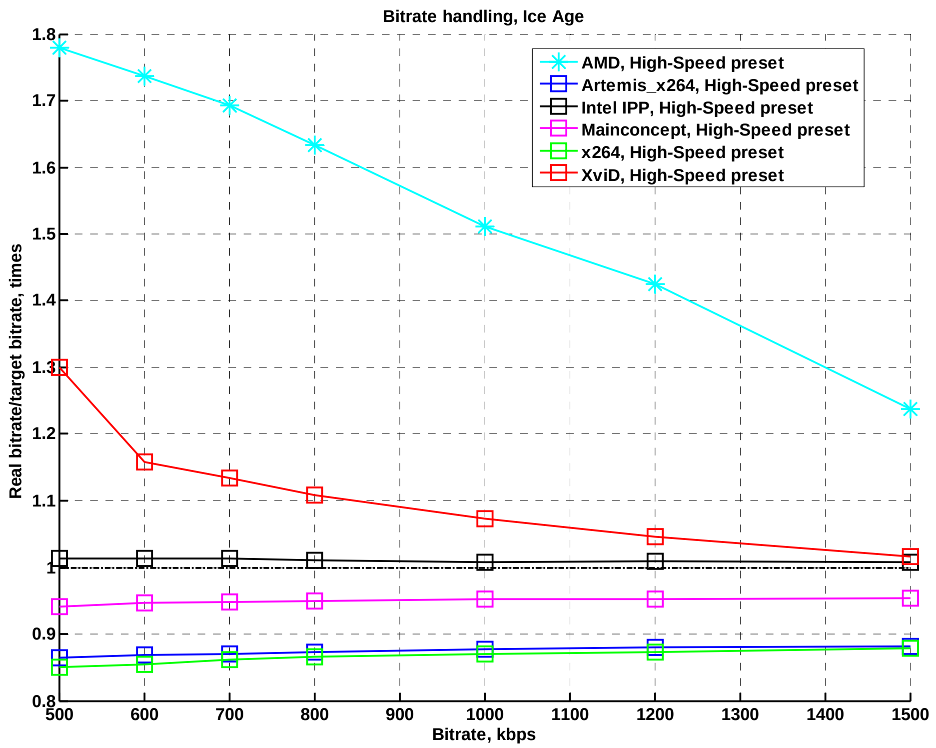


Figure 111. Bitrate Handling. Usage area "Movies", "Ice Age" sequence, "High Speed" preset

4.2.5 Relative Quality Analysis

Table 7 through Table 10 show relative bitrates for a fixed quality output for all codecs and presets. Note that these tables do not include information about the speed of the encoder.

Note, that each the number in tables below corresponds to some segment of bitrates (see Appendix 6. Figures Explanation for more details). Unfortunately, those segments can be rather different because of different quality of compared encoders. This fact can lead to some inadequate results in case of three and more codecs comparisons. This comparison technique will be improved in the future.

Consider the High Speed preset (Y-PSNR results in Table 7, Y-SSIM results in Table 8). Interestingly, the results of the Artemis x264 encoder strongly depend on the quality metric that is used (the Y-SSIM results are better than the Y-PSNR results). Regardless of this fact, the quality of the Artemis x264 encoder is lower than that of the XviD MPEG-4 reference. Another encoder that performs more poorly than XviD is AMD. The best codecs for the High Speed preset are MainConcept and x264 (the former is slightly better). The Intel IPP codec yields results just short of those of the leading codecs.

Table 9 and Table 10 present the High Quality preset results for the Y-PSNR and Y-SSIM quality metrics, respectively. The leading codecs are, again, x264 and MainConcept, with a small advantage going to x264. The Intel IPP encoder places just after these two leading codecs. The list of H.264 codecs, according to quality, concludes with the AMD encoder.

Table 7. Average bitrate ratio for the same quality. Usage area “Movie”. “High Speed” preset, Y-PSNR.

	AMD	Artemis x264	Intel IPP	MainConcept	x264	XviD
AMD	100.0%	113.4%	74.5%	60.0%	61.0%	81.6%
Artemis x264	88.2%	100.0%	62.7%	56.9%	53.2%	81.6%
Intel IPP	134.1%	159.6%	100.0%	81.6%	81.8%	111.2%
MainConcept	166.7%	175.7%	122.5%	100.0%	100.3%	136.6%
x264	164.1%	188.0%	122.2%	99.8%	100.0%	136.0%
XviD	122.6%	122.5%	89.9%	73.2%	73.5%	100.0%

Table 8. Average bitrate ratio for the same quality. Usage area “Movie”. “High Speed” preset, Y-SSIM.

	AMD	Artemis x264	Intel IPP	MainConcept	x264	XviD
AMD	100.0%	91.2%	76.0%	57.5%	62.2%	81.6%
Artemis x264	109.6%	100.0%	83.4%	66.4%	71.8%	93.8%
Intel IPP	131.7%	119.9%	100.0%	76.5%	80.9%	109.0%
MainConcept	174.0%	150.6%	130.7%	100.0%	105.4%	142.1%
x264	160.8%	139.3%	123.6%	94.9%	100.0%	134.5%
XviD	122.5%	106.6%	91.7%	70.4%	74.4%	100.0%

Table 9. Average bitrate ratio for the same quality. Usage area “Movie”. “High Quality” preset, Y-PSNR.

	AMD	Intel IPP	MainConcept	x264	XviD
AMD	100.0%	53.3%	47.5%	47.9%	66.0%
Intel IPP	187.5%	100.0%	89.7%	81.7%	125.7%
MainConcept	210.6%	111.5%	100.0%	91.2%	141.0%
x264	208.7%	122.4%	109.6%	100.0%	154.1%
XviD	151.6%	79.5%	70.9%	64.9%	100.0%

Table 10. Average bitrate ratio for the same quality. Usage area “Movie”. “High Quality” preset, Y-SSIM.

	AMD	Intel IPP	MainConcept	x264	XviD
AMD	100.0%	55.3%	46.1%	48.1%	68.8%
Intel IPP	180.9%	100.0%	83.8%	79.5%	125.4%
MainConcept	216.7%	119.3%	100.0%	95.6%	149.5%
x264	207.9%	125.8%	104.6%	100.0%	156.5%
XviD	145.3%	79.8%	66.9%	63.9%	100.0%

Figure 112 through Figure 115 visualize data in the tables above. Each line in those figures corresponds to one codec. Values in vertical axis are average relative bitrate comparing to the codecs in horizontal axis. The lower bitrate is the better relative results have the codec.

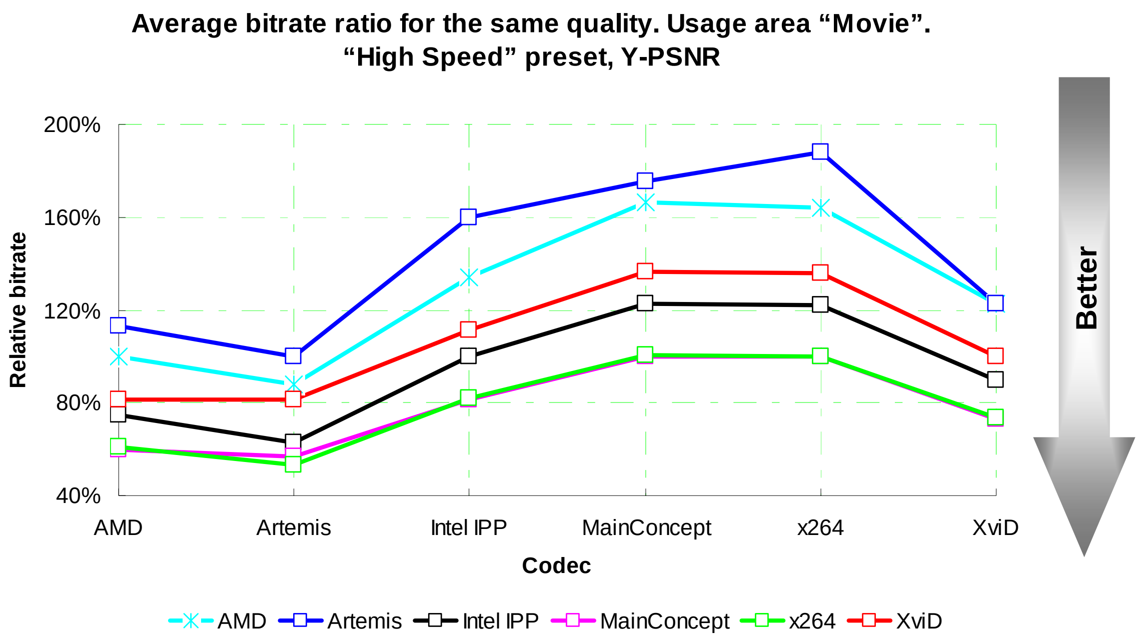


Figure 112. Average bitrate ratio for the same quality. Usage area “Movie”. “High Speed” preset, Y-PSNR.

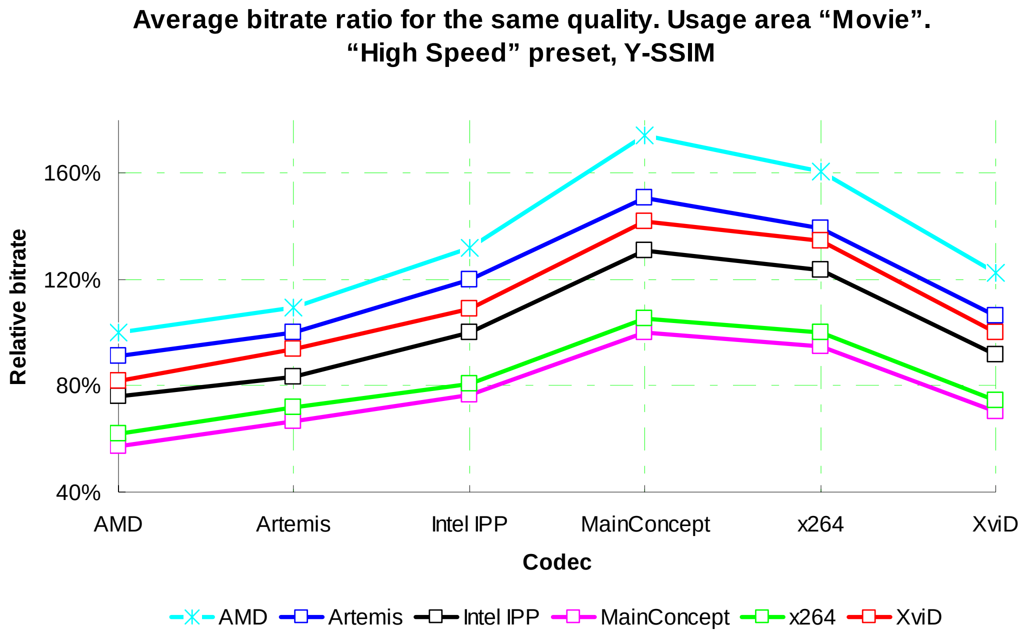


Figure 113. Average bitrate ratio for the same quality. Usage area “Movie”. “High Speed” preset, Y-SSIM.

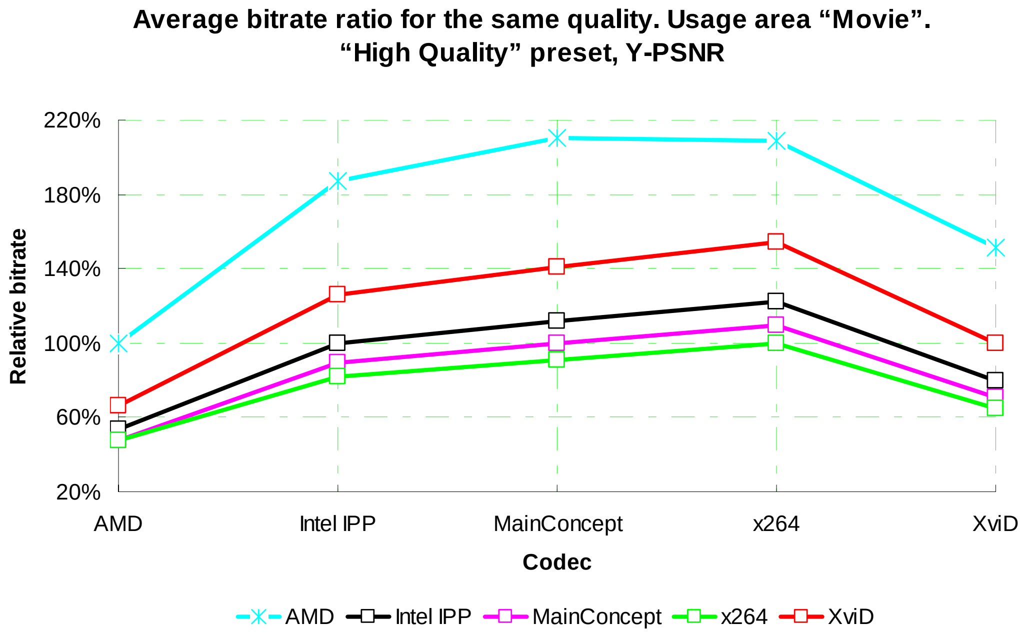


Figure 114. Average bitrate ratio for the same quality. Usage area “Movie”. “High Quality” preset, Y-PSNR.

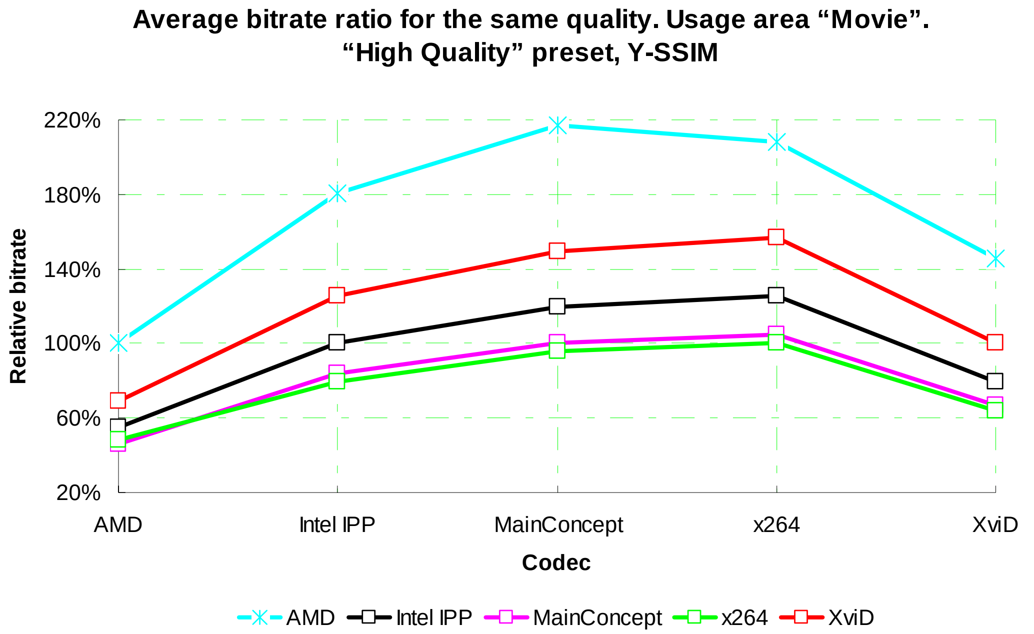


Figure 115. Average bitrate ratio for the same quality. Usage area "Movie". "High Quality" preset, Y-SSIM.

4.3 HDTV

4.3.1 RD Curves

Figure 116 through Figure 119 depict the RD curves for the High Quality preset in the case of HDTV. The results for this category are similar to those of the other categories. The AMD encoder, as it did previously, demonstrates good speed optimization but not-so-good quality. The RD curve for this encoder is far below that of other codecs. The XviD encoder performs rather well for the “Troy” sequence, but performs more poorly than other codecs for the “Matrix” sequence. The x264 codec is the leading encoder in this category, but only by a narrow margin.

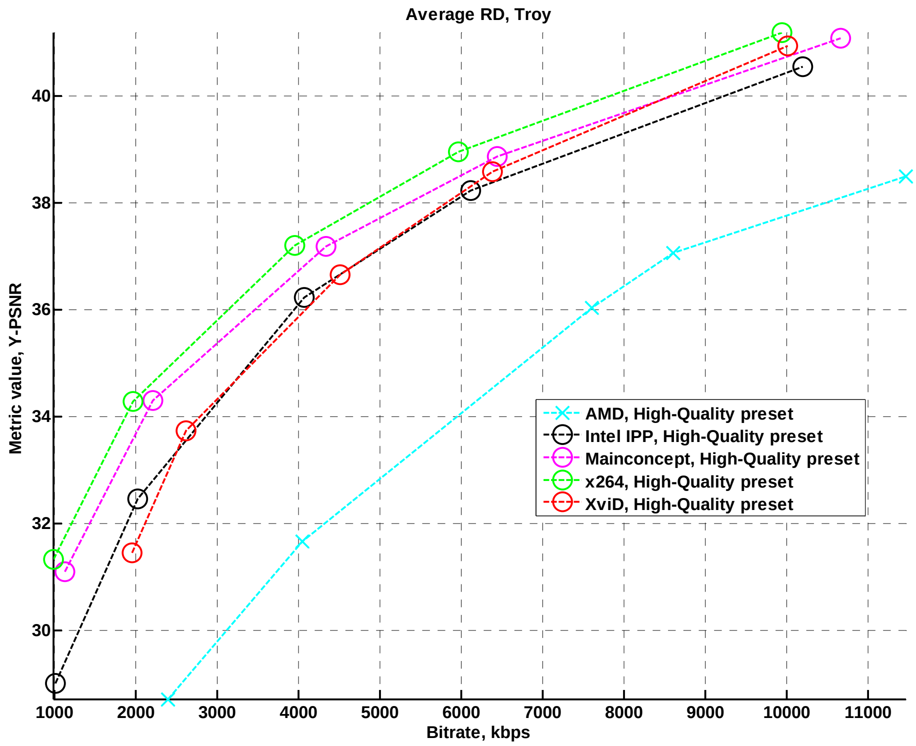


Figure 116. Bitrate/Quality. Usage area “HDTV”, “Troy” sequence, “High Quality” preset, Y-PSNR

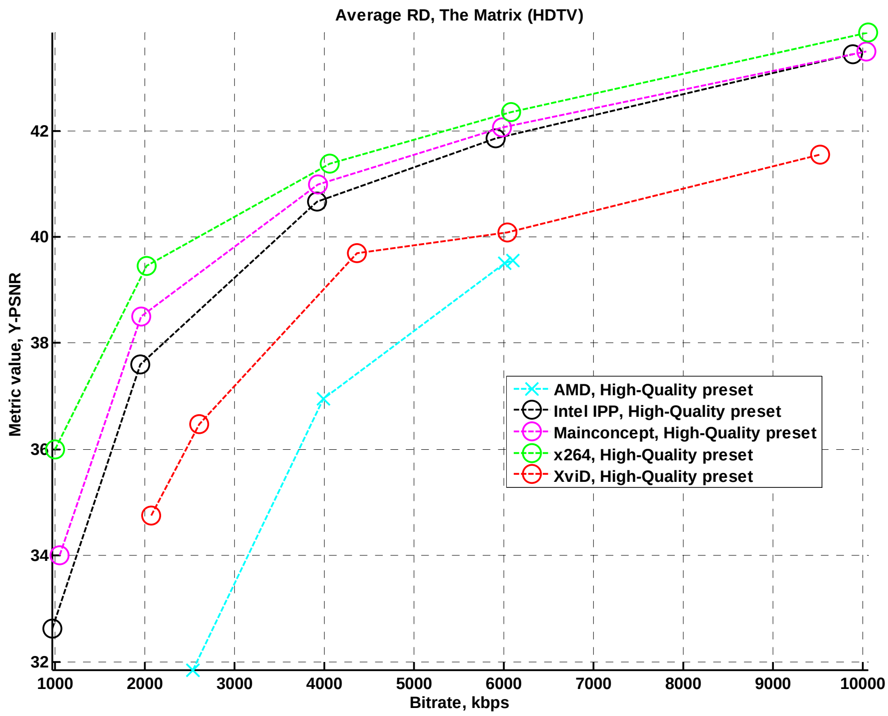


Figure 117. Bitrate/Quality. Usage area "HDTV", "The Matrix" sequence, "High Quality" preset, Y-PSNR

SSIM

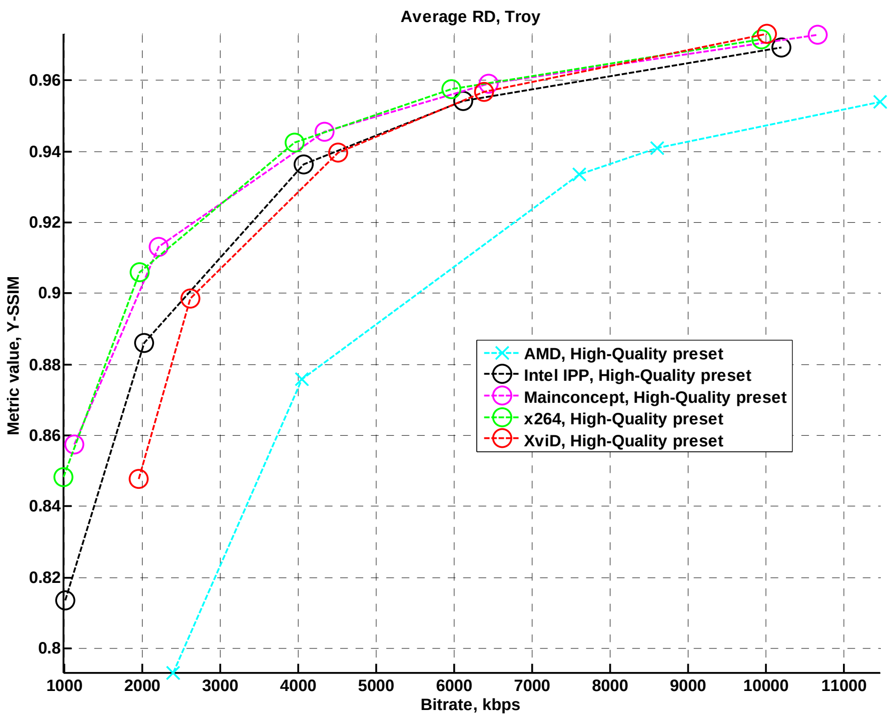


Figure 118. Bitrate/Quality. Usage area "Movies", "Troy" sequence, "High Quality" preset, Y-SSIM

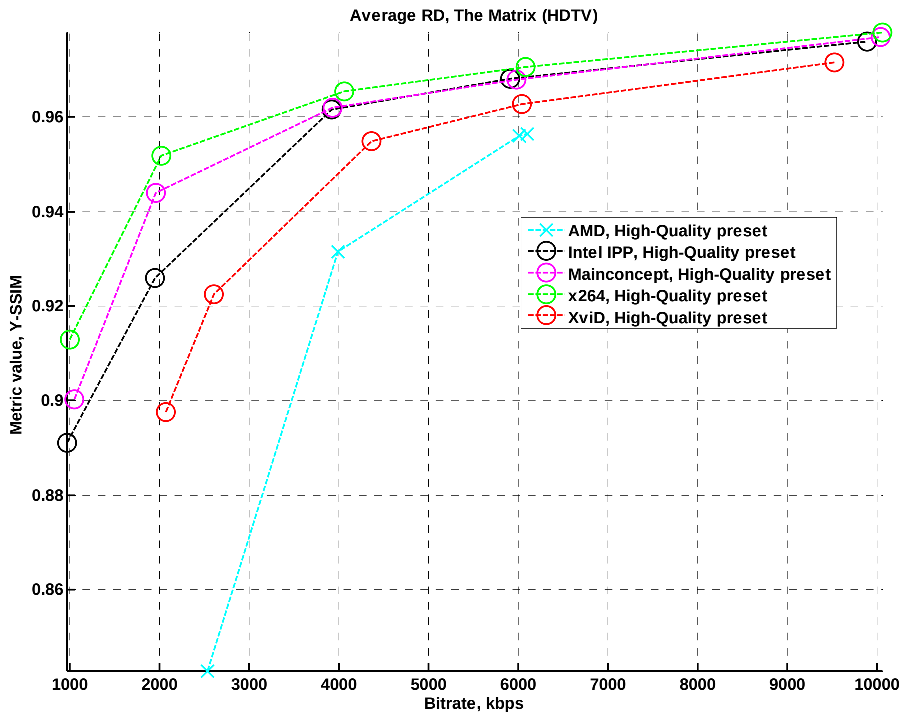


Figure 119. Bitrate/Quality. Usage area “Movies”, “The Matrix” sequence, “High Quality” preset, Y-SSIM

4.3.1.1 High Speed Preset

Figure 120 through Figure 123 depict the RD curves for encoders using the High Speed preset.

For the “Troy” sequence, the Artemis x264 encoder yields a low value according to the Y-PSNR metric. It is interesting, however, that the Y-SSIM results for the Artemis x264 codec show significant improvement and stability (see Appendix 3. Artemis x264 and x264 PNSR and SSIM Comparative Analysis for a detailed analysis).

The leading codecs for this preset are x264 and MainConcept. The Y-PSNR results are very similar in both cases, but the MainConcept encoder demonstrates a slight superiority according to the Y-SSIM metric. The Intel IPP codec closely follows the leading encoders for both the “Troy” and “Matrix” sequences. XviD demonstrates good quality for the “Troy” sequence, but is much slower for the “Matrix” sequence. The AMD encoder leads in terms of encoding speed, but it demonstrates lower quality for both sequences.

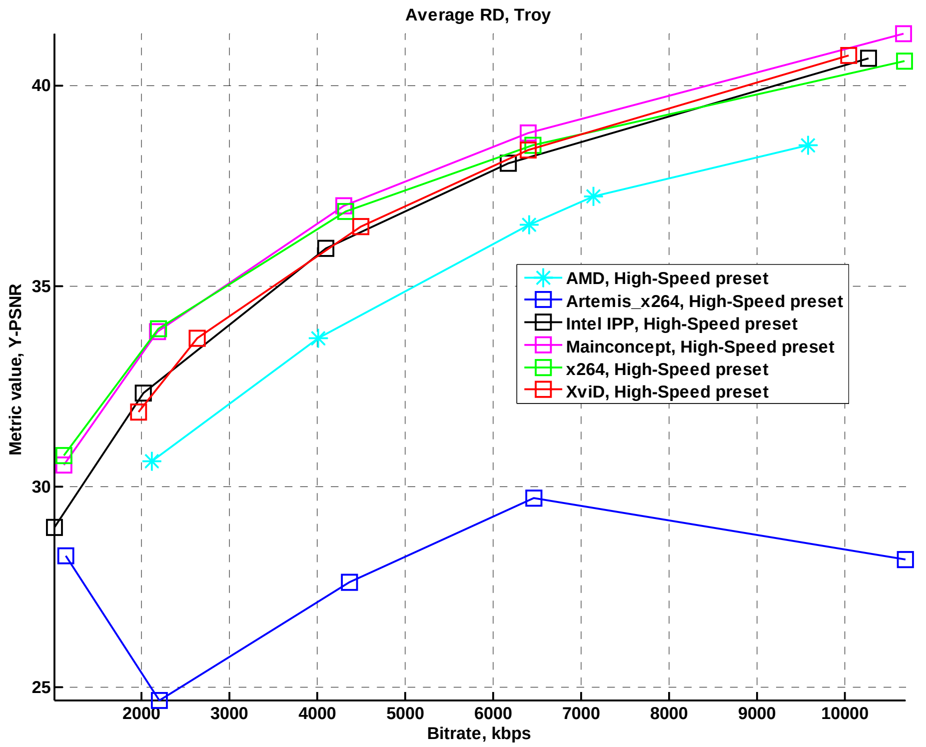


Figure 120. Bitrate/Quality. Usage area “HDTV”, “Troy” sequence, “High Speed” preset, Y-PSNR

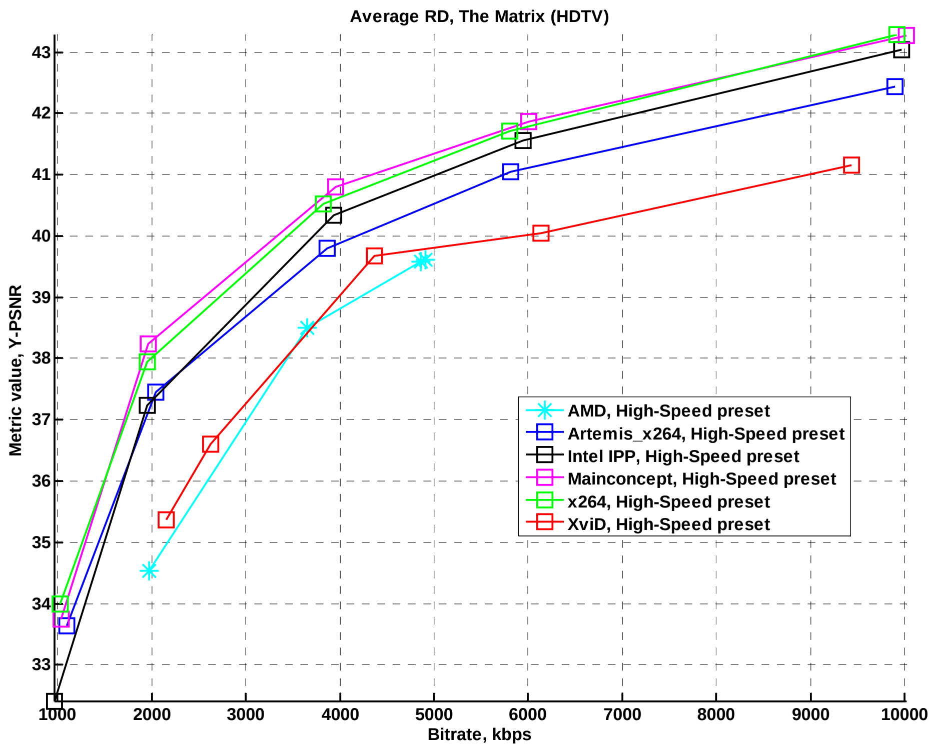


Figure 121. Bitrate/Quality. Usage area “HDTV”, “The Matrix” sequence, “High Speed” preset, Y-PSNR

SSIM

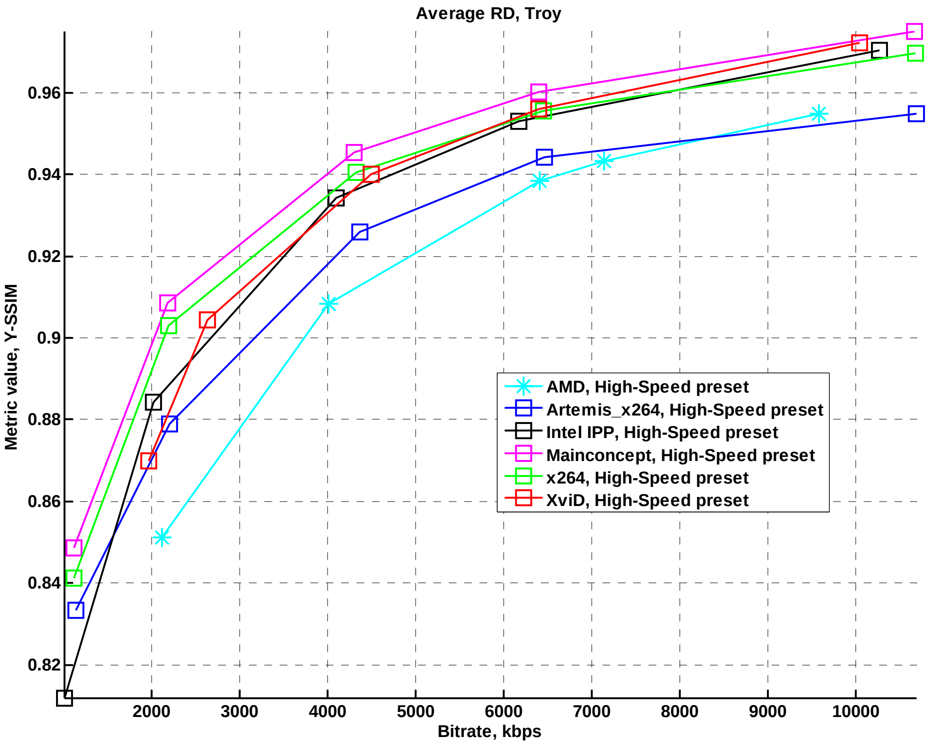


Figure 122. Bitrate/Quality. Usage area "Movies", "Troy" sequence, "High Speed" preset, Y-SSIM

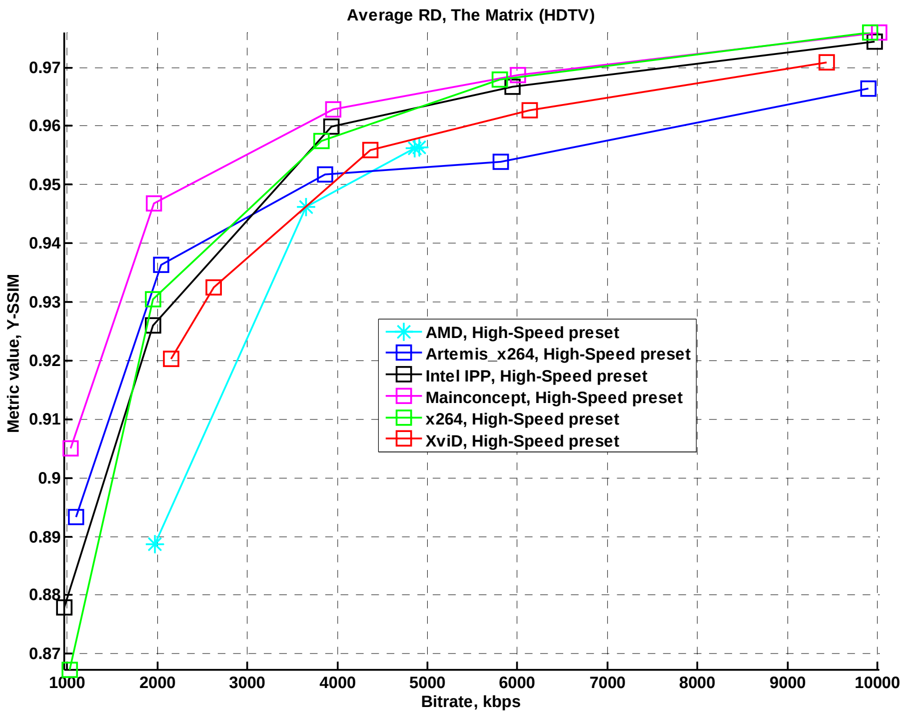


Figure 123. Bitrate/Quality. Usage area "Movies", "The Matrix" sequence, "High Speed" preset, Y-SSIM

4.3.2 Encoding Speed

Figure 124 through Figure 131 are visualizations of codec encoding speed. The slowest codec is x264; the fastest is AMD. It is interesting to note the strange encoding complexity of the Artemis x264 modification for the "Matrix" sequence.

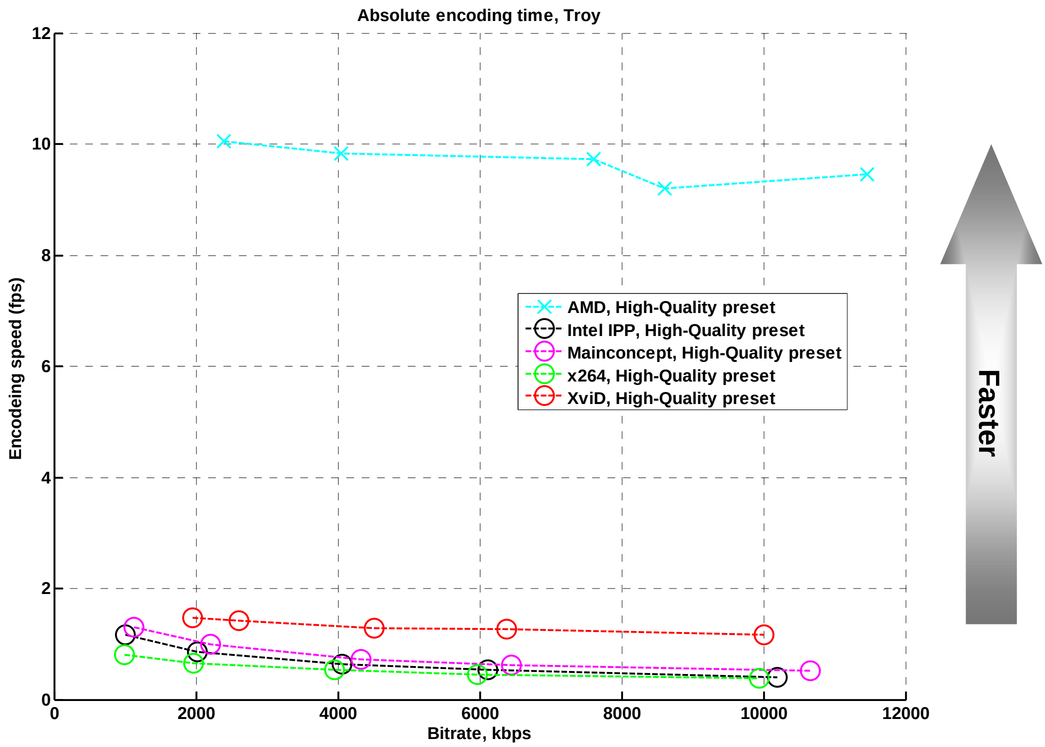


Figure 124. Encoding speed. Usage area "HDTV", "Troy" sequence, "High Quality" preset

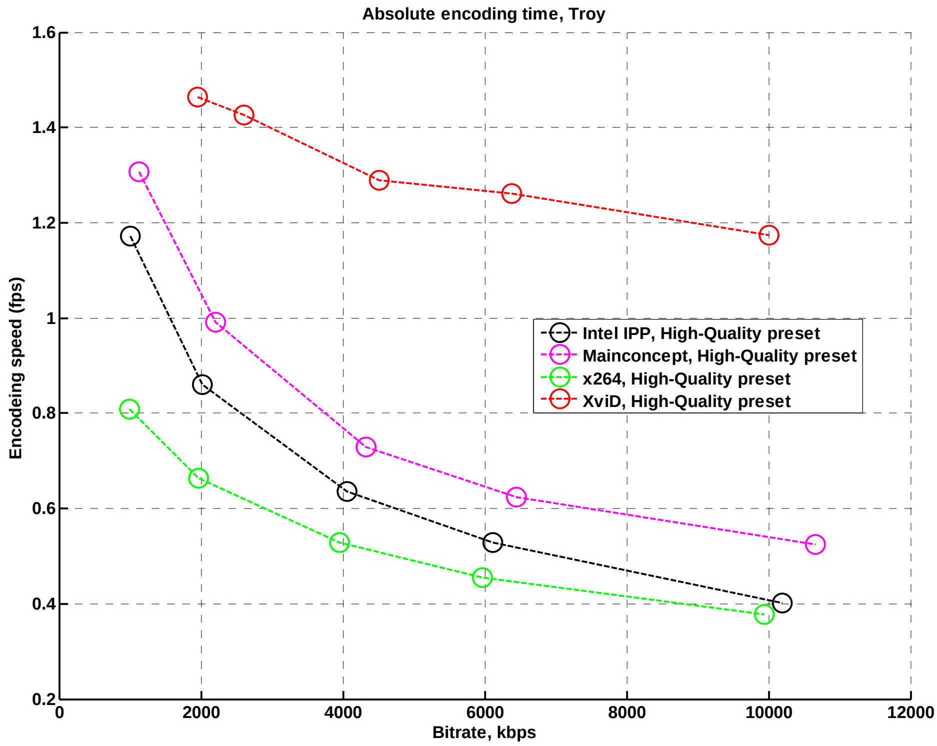


Figure 125. Encoding speed. Usage area “HDTV”, “Troy” sequence, “High Quality” preset. All encoders except AMD

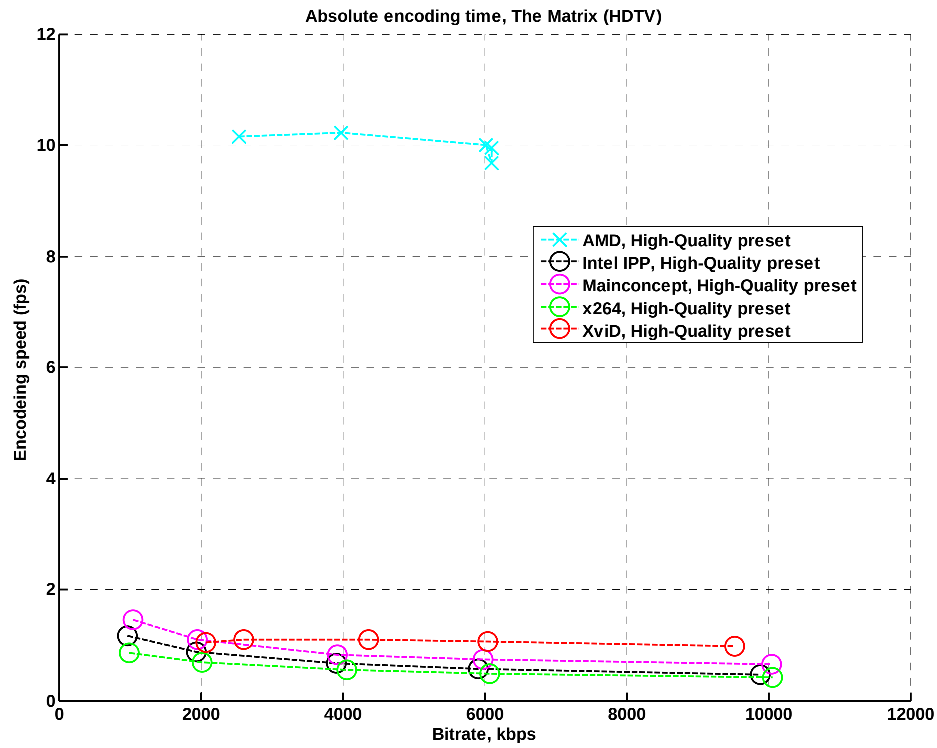


Figure 126. Encoding speed. Usage area “HDTV”, “The Matrix” sequence, “High Quality” preset

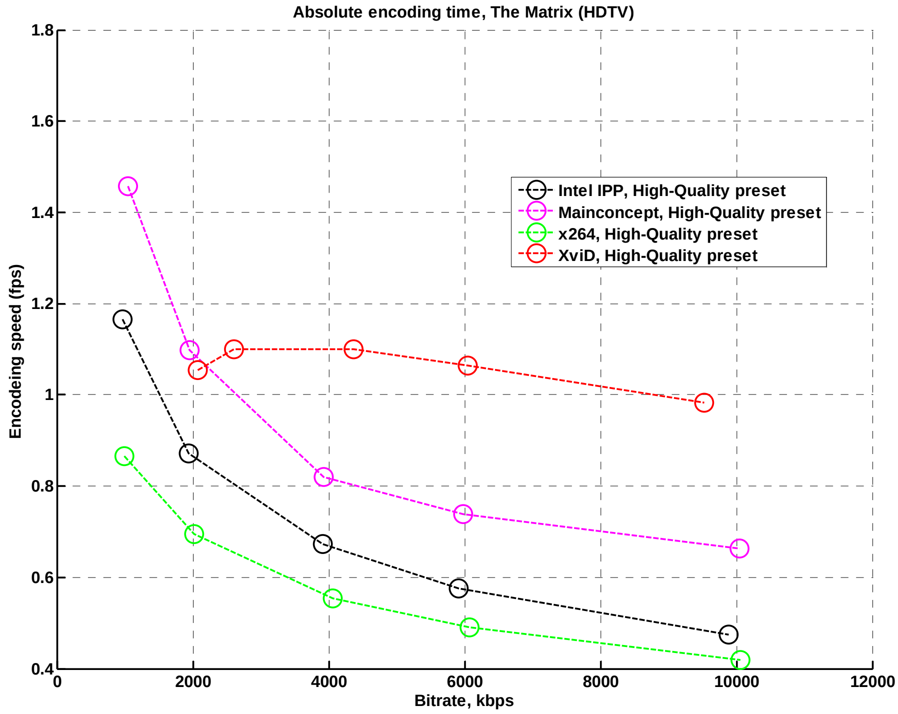


Figure 127. Encoding speed. Usage area “HDTV”, “The Matrix” sequence, “High Quality” preset. All encoders except AMD

4.3.2.1 High Speed Preset

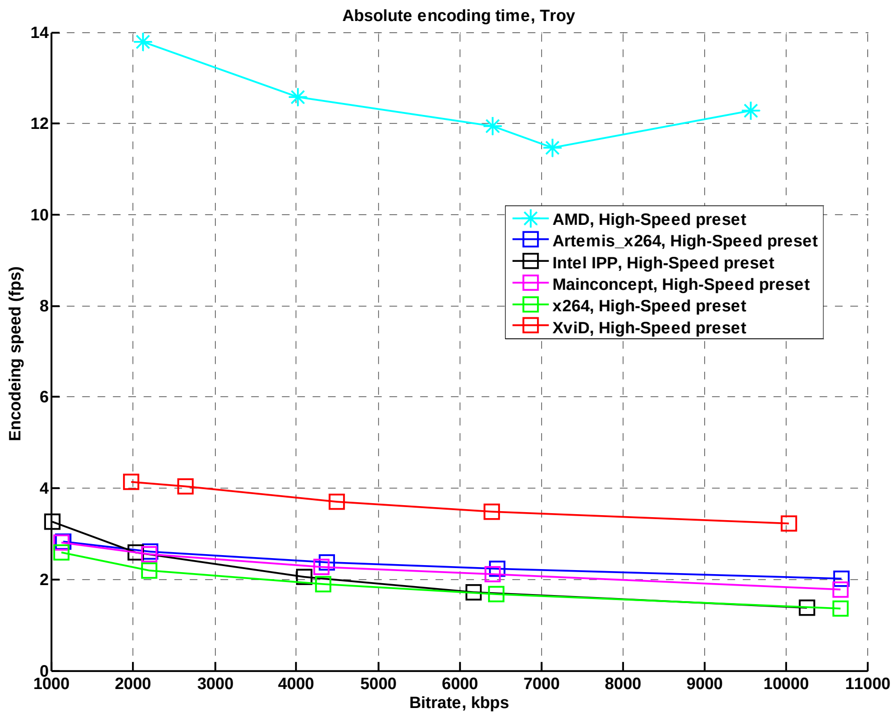


Figure 128. Encoding speed. Usage area “HDTV”, “Troy” sequence, “High Speed” preset

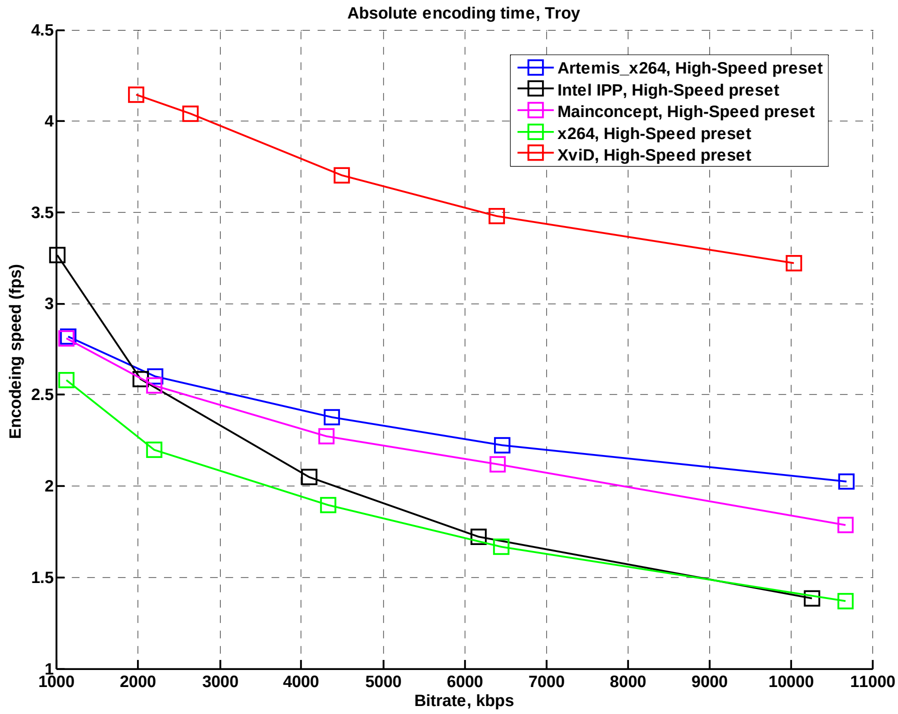


Figure 129. Encoding speed. Usage area “HDTV”, “Troy” sequence, “High Speed” preset. All encoders except AMD

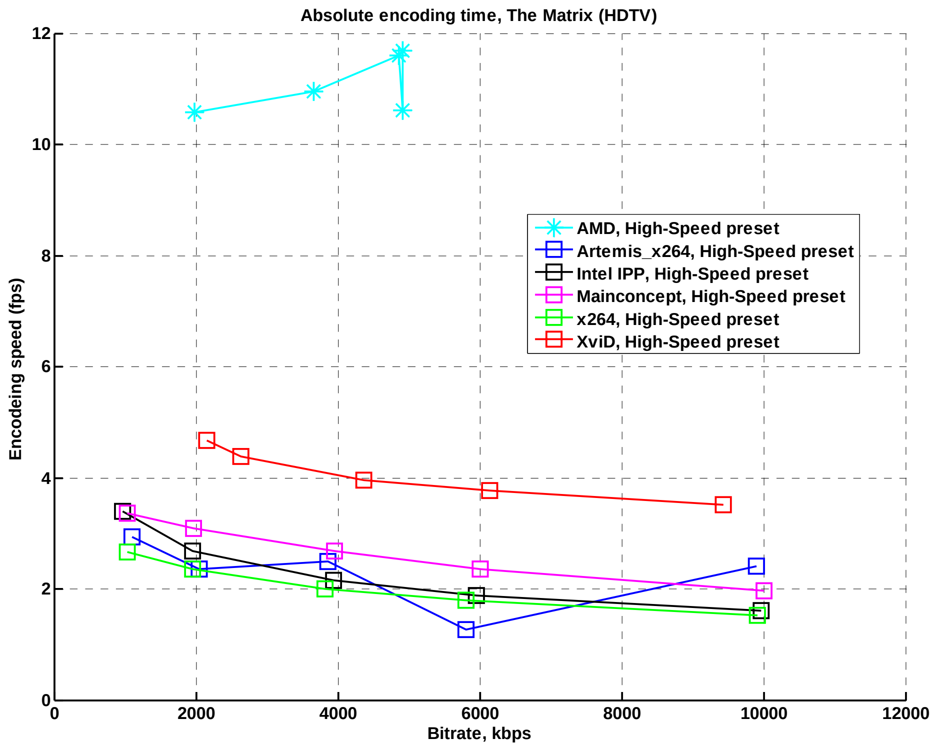


Figure 130. Encoding speed. Usage area “HDTV”, “The Matrix” sequence, “High Speed” preset

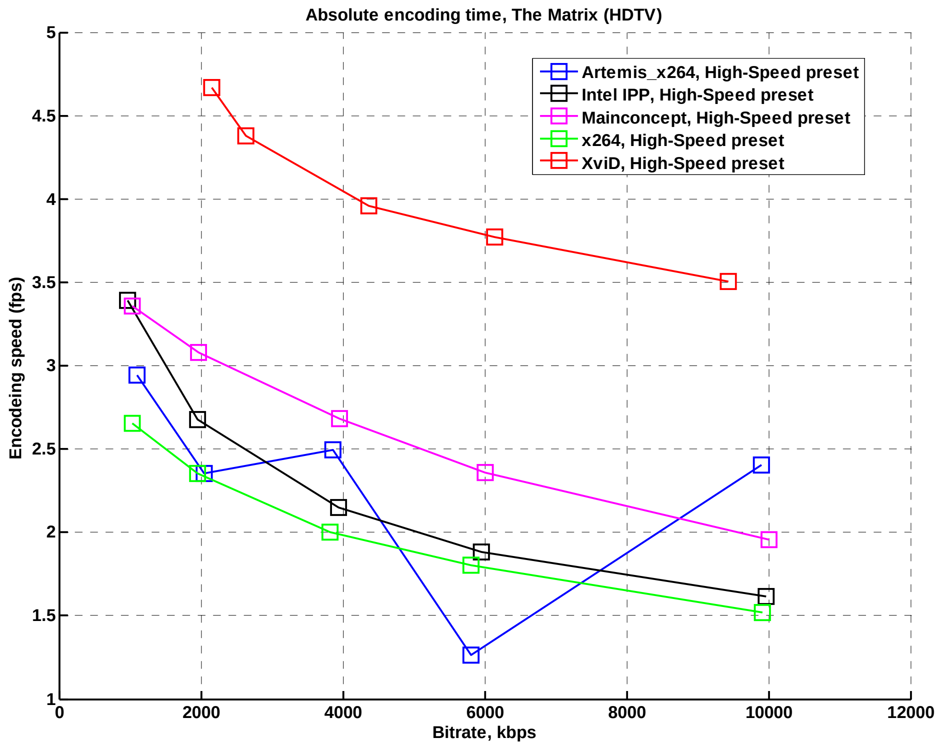


Figure 131. Encoding speed. Usage area "HDTV", "The Matrix" sequence, "High Speed" preset. All encoders except AMD

4.3.3 Speed\Quality Tradeoff

Detailed descriptions of speed/quality trade-off graphs can be found in Appendix 6. Figures Explanation. Sometimes codec results are not present in the particular graph. The reason for that are extremely poor results of the codec. Its RD curve has no intersection with reference's RD curve.

Please note that the averaging method among all sequences suppose that all codecs have the results for each sequence. When it's not the case, then only existing results are taking into account.

The High Quality preset results are presented in Figure 132 through Figure 137. All encoders, except Intel IPP, are sub-optimal in terms of the speed/quality trade-off (there are no codec, which is faster and better than others). The Intel IPP codec yields poorer results than does the MainConcept codec for all sequences and metrics.

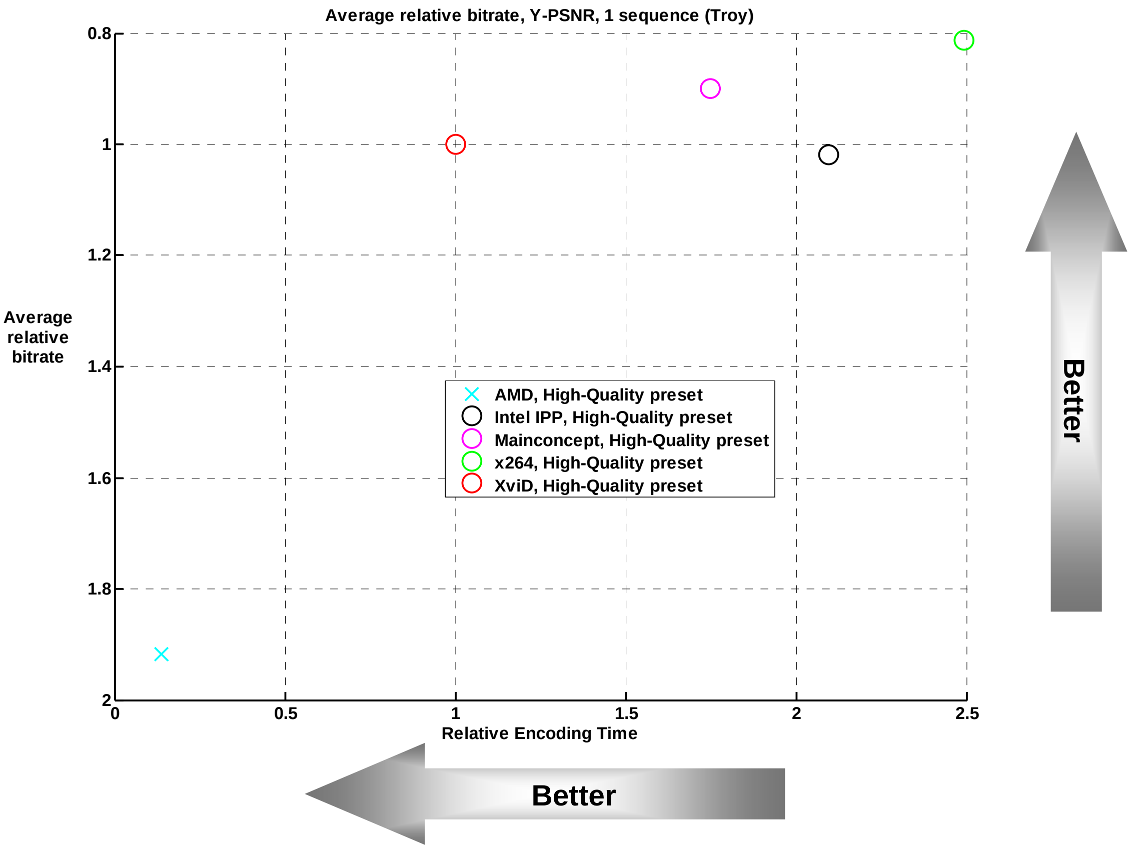


Figure 132. Speed/Quality tradeoff. Usage area “HDTV”, “Troy” sequence, “High Quality” preset, Y-PSNR

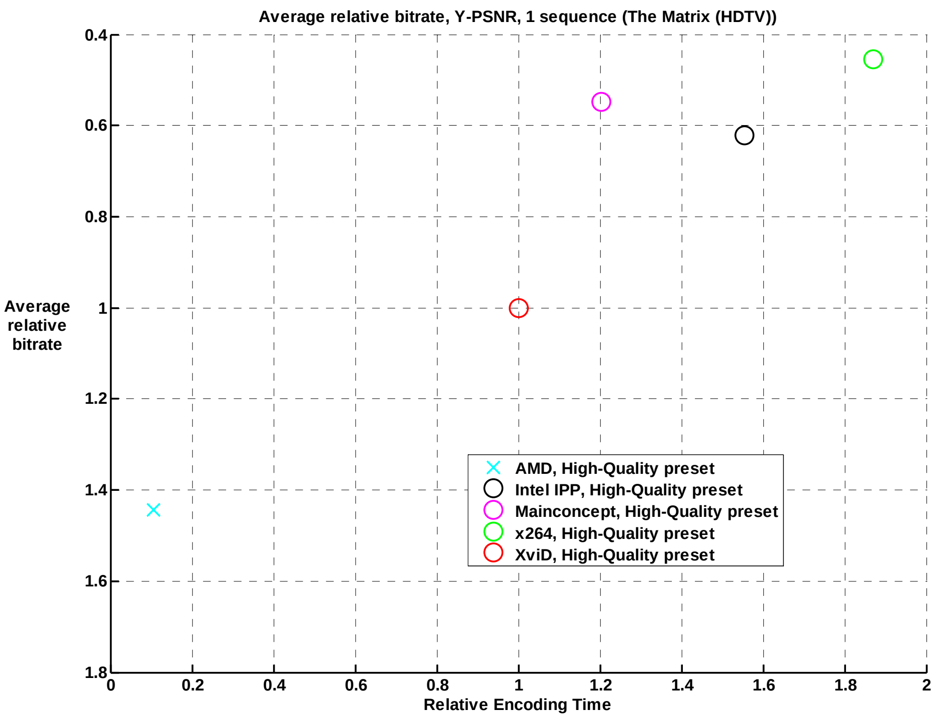


Figure 133. Speed/Quality tradeoff. Usage area “HDTV”, “The Matrix” sequence, “High Quality” preset, Y-PSNR

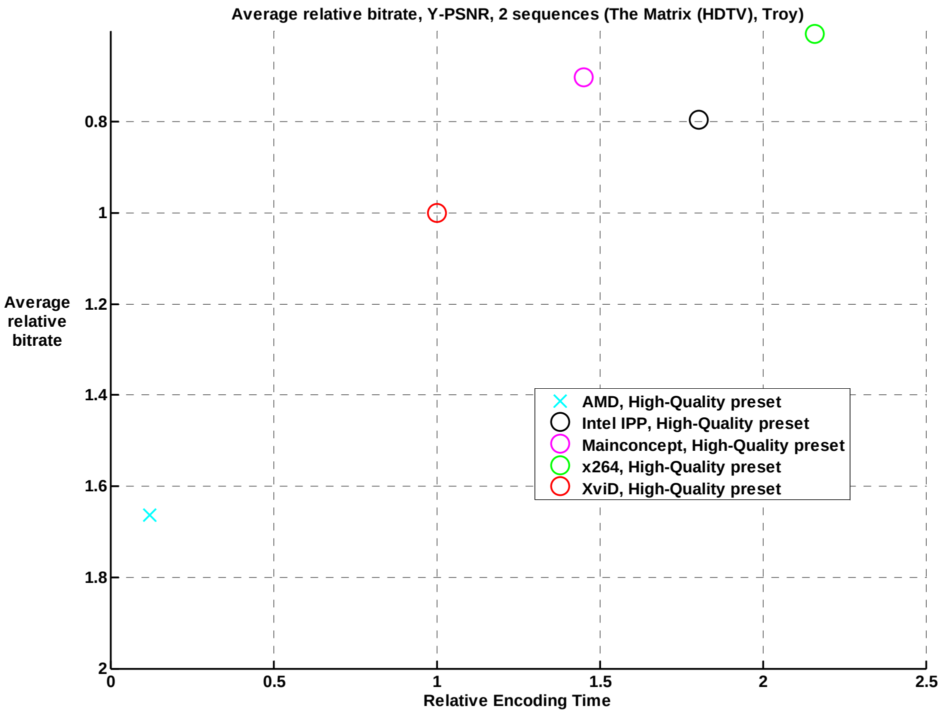


Figure 134. Speed/Quality tradeoff. Usage area "HDTV", all sequences, "High Quality" preset, Y-PSNR

SSIM

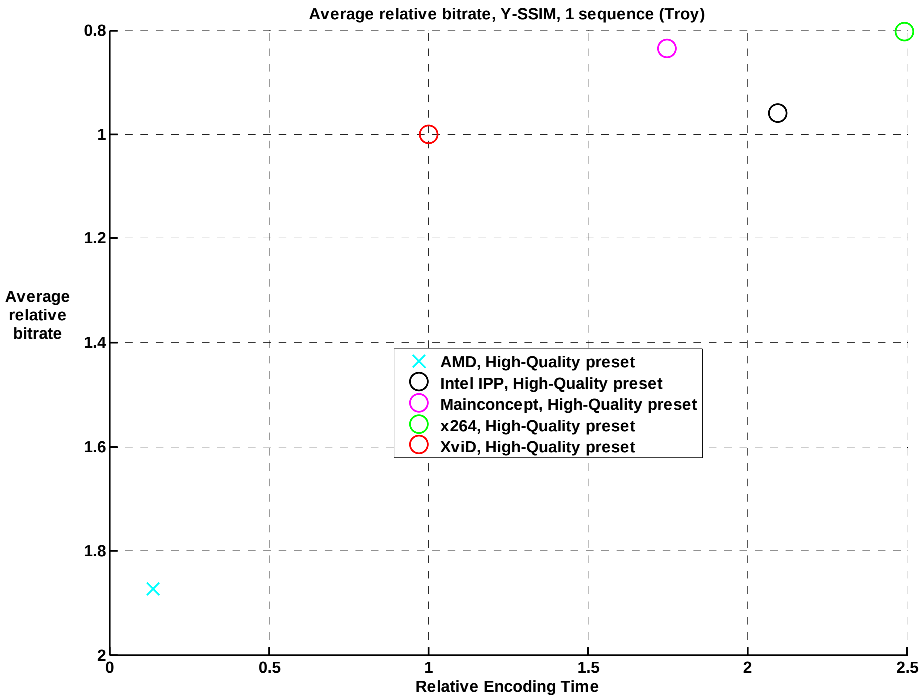


Figure 135. Speed/Quality tradeoff. Usage area "HDTV", "Troy" sequence, "High Quality" preset, Y-SSIM

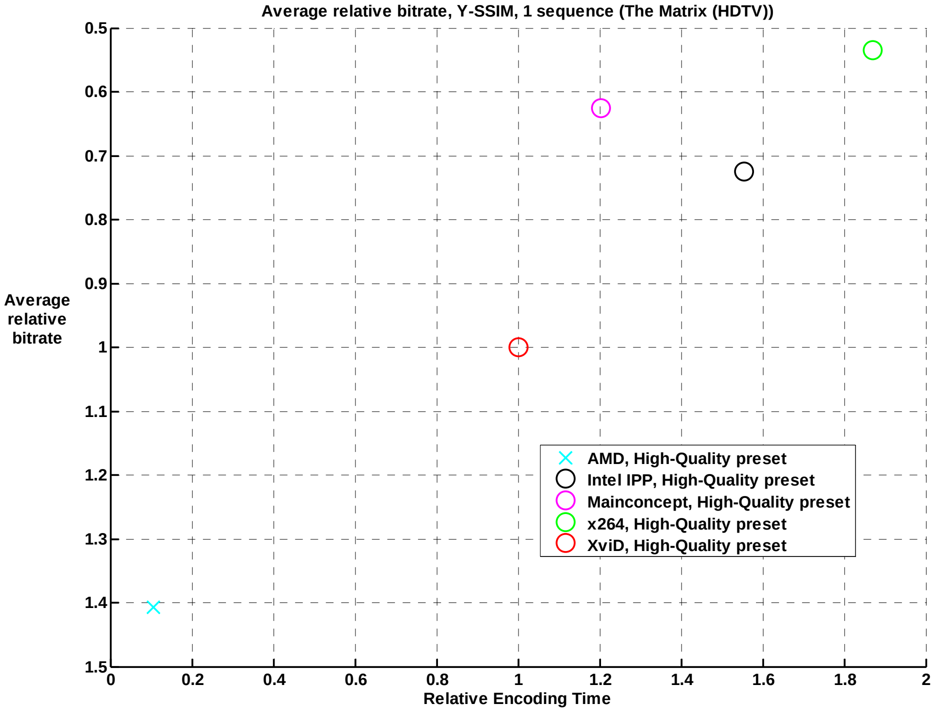


Figure 136. Speed/Quality tradeoff. Usage area "Movies", "The Matrix" sequence, "High Quality" preset, Y-SSIM

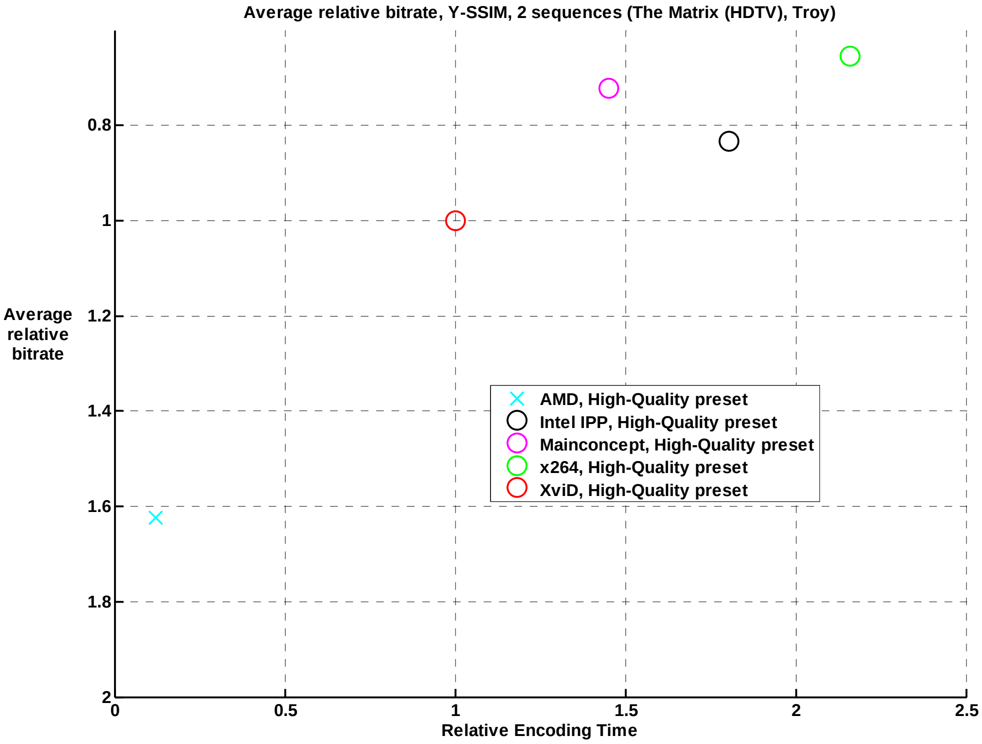


Figure 137. Speed/Quality tradeoff. Usage area "HDTV", all sequences, "High Quality" preset, Y-SSIM

4.3.3.1 High Speed Preset

Figure 138 through Figure 143 are visualizations of the speed/quality trade-off for the High Quality preset. The MainConcept encoder yields universally better results than the x264, IPP and (in most cases) Artemis x264 codecs.

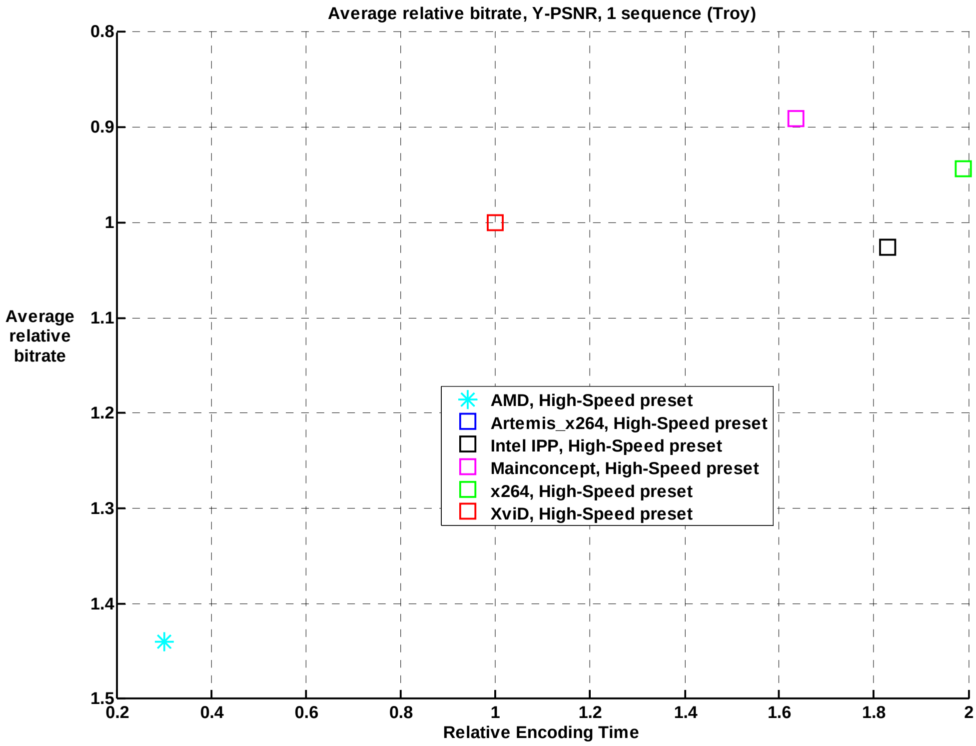


Figure 138. Speed/Quality tradeoff. Usage area "HDTV", "Troy" sequence, "High Speed" preset, Y-PSNR

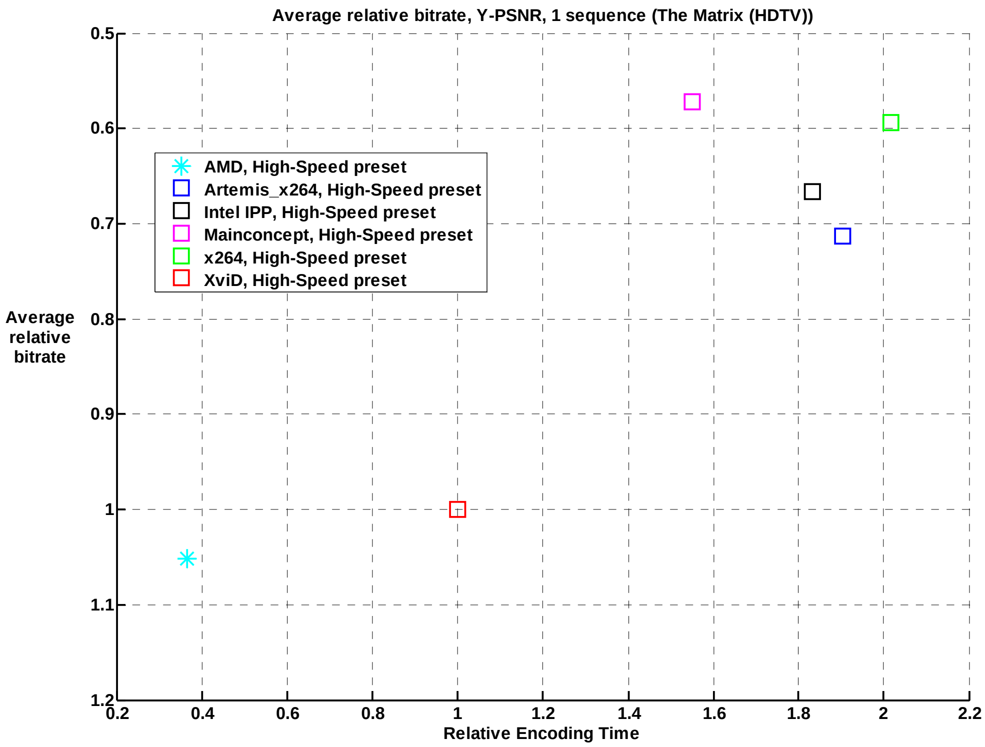


Figure 139. Speed/Quality tradeoff. Usage area "HDTV", "The Matrix" sequence, "High Speed" preset, Y-PSNR

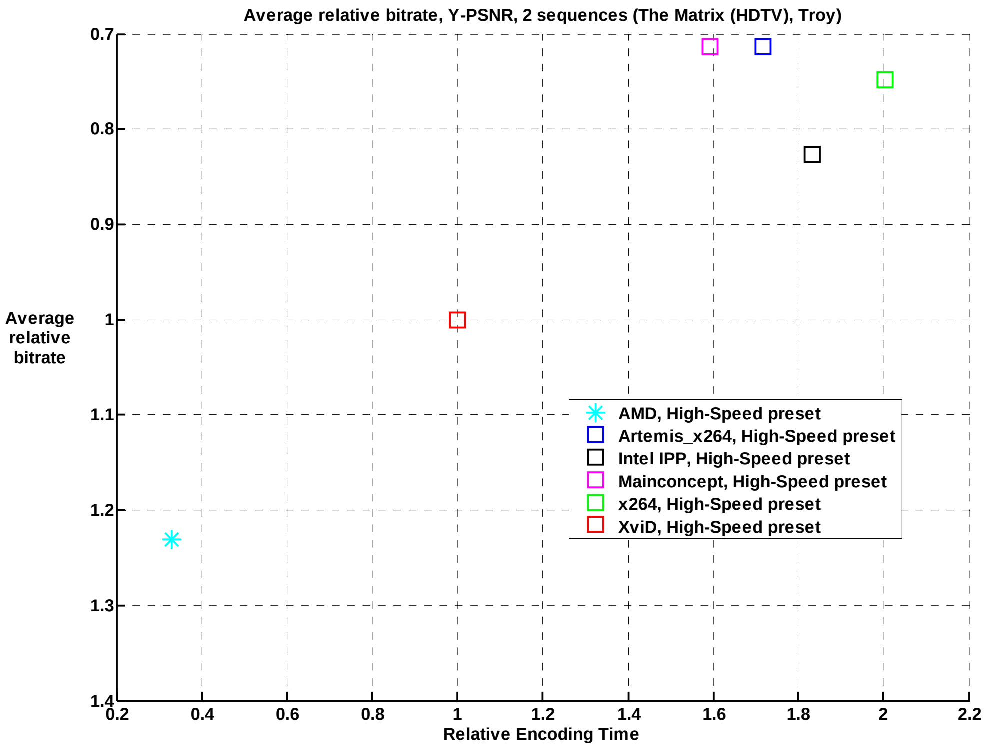


Figure 140. Speed/Quality tradeoff. Usage area "HDTV", all sequences, "High Speed" preset, Y-PSNR

SSIM Results

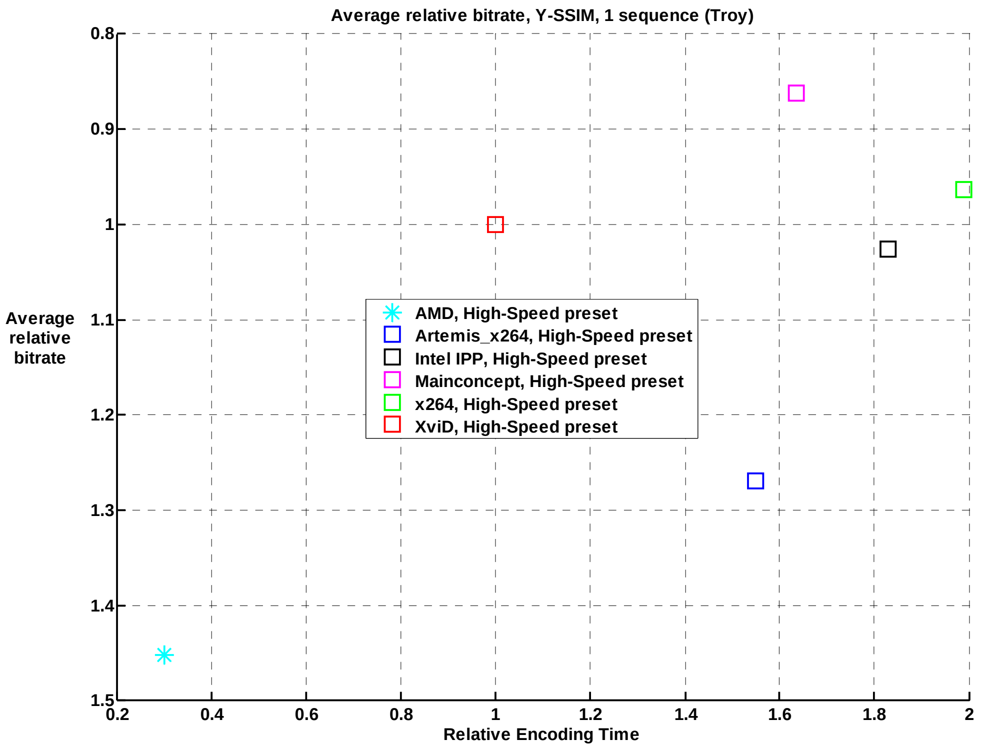


Figure 141. Speed/Quality tradeoff. Usage area “HDTV”, “Troy” sequence, “High Speed” preset, Y-SSIM

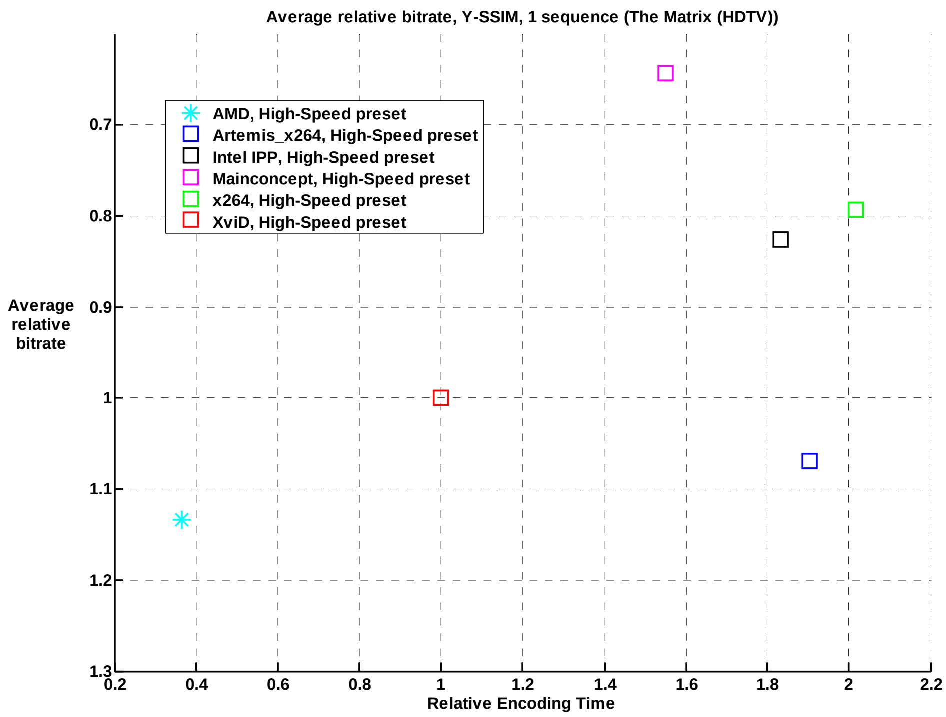


Figure 142. Speed/Quality tradeoff. Usage area “Movies”, “The Matrix” sequence, “High Speed” preset, Y-SSIM

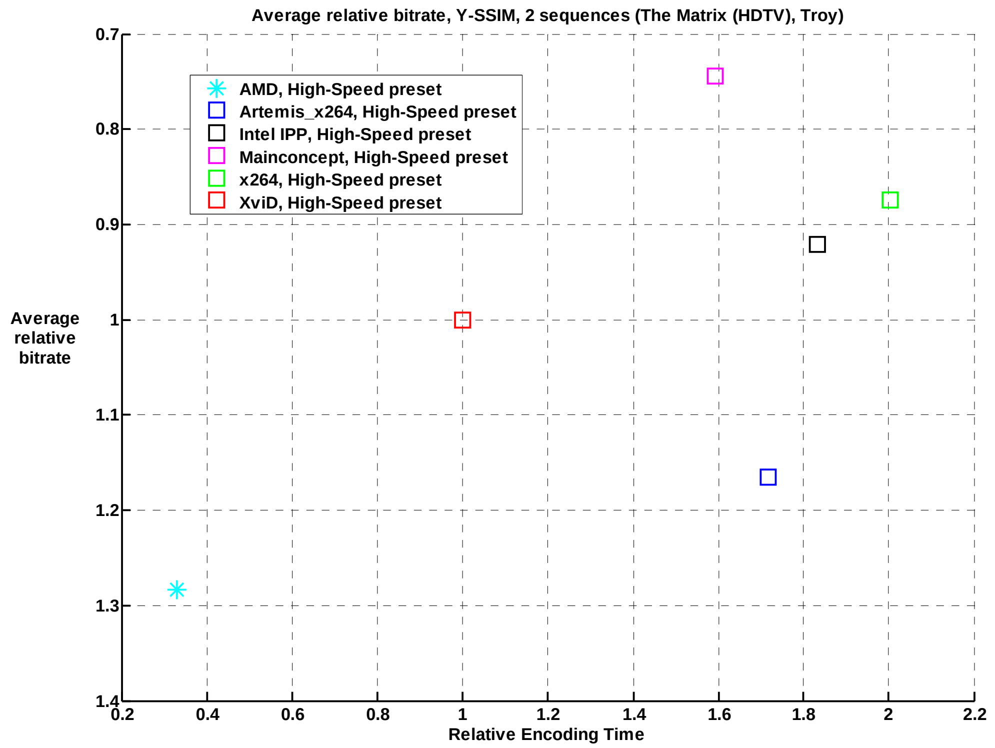


Figure 143. Speed/Quality tradeoff. Usage area "HDTV", all sequences, "High Speed" preset, Y-SSIM

4.3.4 Bitrate Handling

Bitrate handling results are presented in Figure 144 through Figure 147. The XviD codec has problems at low bitrates, for which it increases the bitrate up to two times. The best bitrate handling results are demonstrated in this category by Intel IPP. AMD, as in other cases, yields poor results.

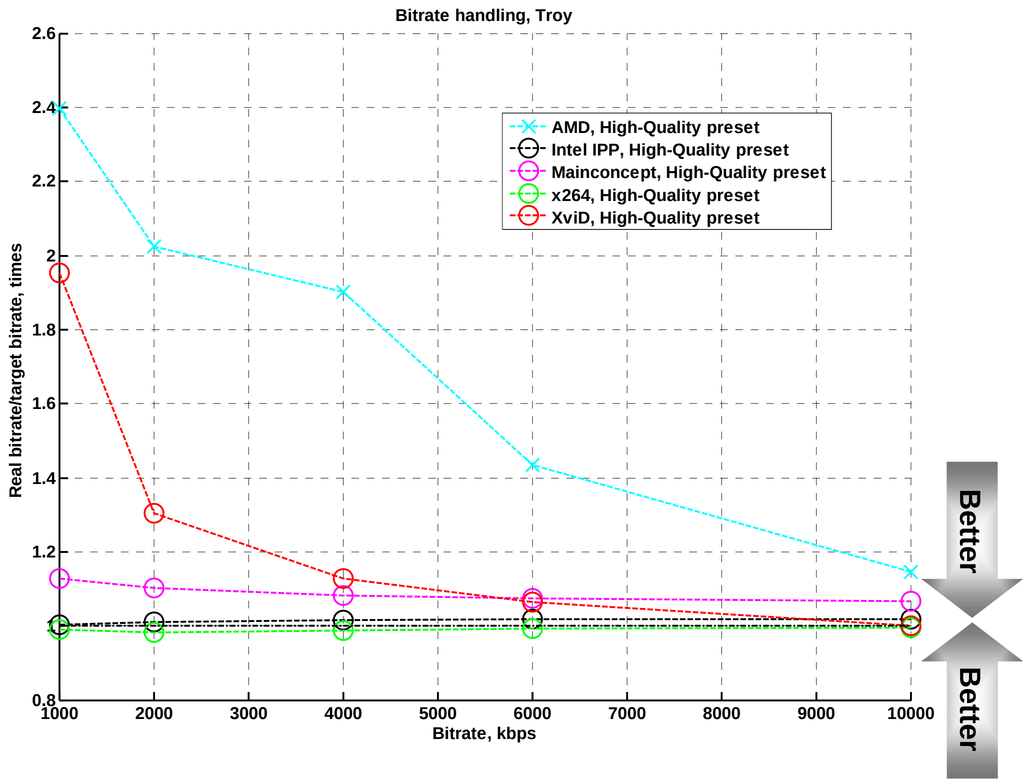


Figure 144. Bitrate Handling. Usage area "HDTV", "Troy" sequence, "High Quality" preset

Figure 145. Bitrate Handling. Usage area "HDTV", "The Matrix" sequence, "High Quality" preset

4.3.4.1 High Speed Preset

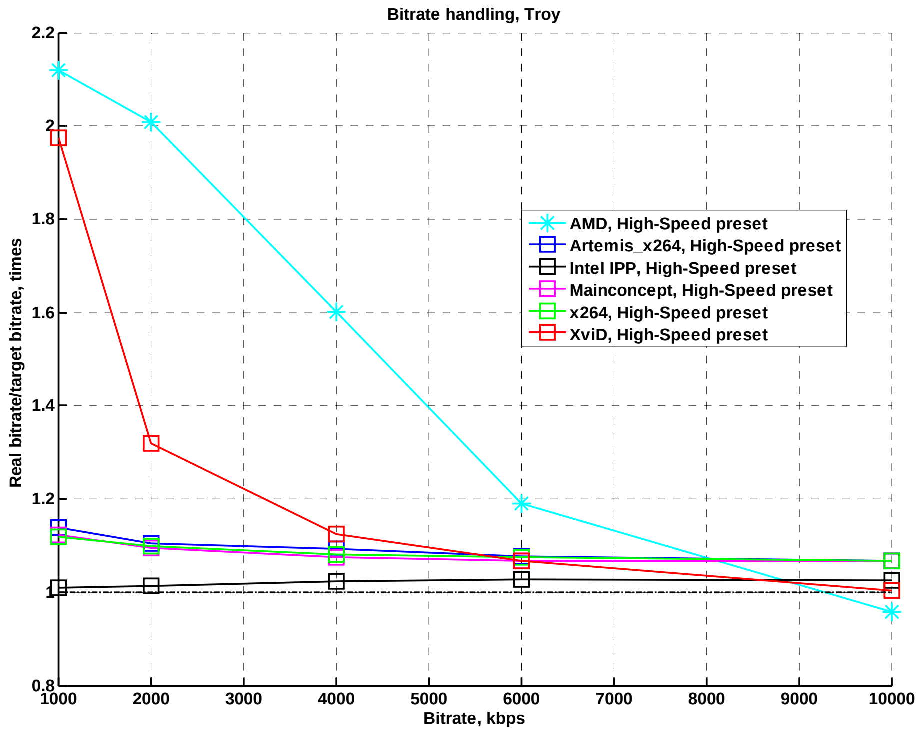


Figure 146. Bitrate Handling. Usage area “HDTV”, “Troy” sequence, “High Speed” preset

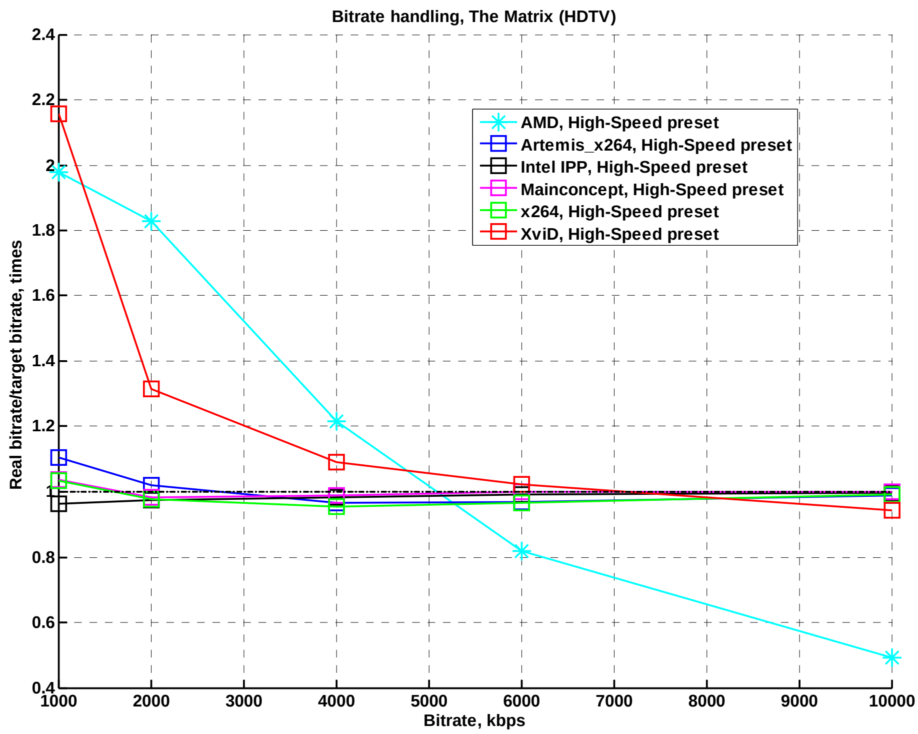


Figure 147. Bitrate Handling. Usage area “HDTV”, “The Matrix” sequence, “High Speed” preset

4.3.5 Relative Quality Analysis

Table 11 through Table 14 contain relative bitrate data for a fixed quality output for all the encoders.

Note, that each number in tables below corresponds to some segment of bitrates (see Appendix 6. Figures Explanation for more details). Unfortunately, those segments can be rather different because of different quality of compared encoders. This fact can lead to some inadequate results in case of three and more codecs comparisons. This comparison technique will be improved in the future.

MainConcept is the leader for the High Speed preset, followed by x264. Differences between these codecs depend strongly on the quality metric that is used: a 3% difference according to the Y-PSNR metric and a 16% difference according to the Y-SSIM metric. AMD is the only codec that has lower results than XviD MPEG-4; this outcome is due to its specifically designed speed optimization.

The situation for the High Quality preset is reversed from that of the High Speed preset: x264 performs better than MainConcept.

Table 11. Average bitrate ratio for the same quality. Usage area “HDTV”. “High Speed” preset, Y-PSNR.

	AMD	Artemis x264	Intel IPP	MainConcept	x264	XviD
AMD	100.0%	69.9%	69.7%	58.7%	60.1%	81.3%
Artemis x264	143.0%	100.0%	44.6%	79.1%	81.3%	140.2%
Intel IPP	143.6%	224.0%	100.0%	87.2%	90.7%	120.9%
MainConcept	170.3%	126.5%	114.7%	100.0%	103.9%	140.1%
x264	166.4%	123.0%	110.2%	96.3%	100.0%	133.6%
XviD	123.1%	71.3%	82.7%	71.4%	74.8%	100.0%

Table 12. Average bitrate ratio for the same quality. Usage area “HDTV”. “High Speed” preset, Y-SSIM.

	AMD	Artemis x264	Intel IPP	MainConcept	x264	XviD
AMD	100.0%	78.1%	70.0%	54.2%	66.0%	77.9%
Artemis x264	128.0%	100.0%	82.7%	63.6%	77.6%	85.8%
Intel IPP	142.9%	120.9%	100.0%	81.0%	95.4%	108.6%
MainConcept	184.7%	157.3%	123.5%	100.0%	116.1%	134.4%
x264	151.6%	128.9%	104.9%	86.1%	100.0%	114.4%
XviD	128.3%	116.5%	92.1%	74.4%	87.4%	100.0%

Table 13. Average bitrate ratio for the same quality. Usage area “HDTV”. “High Quality” preset, Y-PSNR.

	AMD	Intel IPP	MainConcept	x264	XviD
AMD	100.0%	47.1%	40.9%	35.3%	60.1%
Intel IPP	212.4%	100.0%	89.3%	79.2%	125.7%
MainConcept	244.5%	112.0%	100.0%	88.6%	142.4%
x264	283.6%	126.2%	112.9%	100.0%	164.5%
XviD	166.4%	79.6%	70.2%	60.8%	100.0%

Table 14. Average bitrate ratio for the same quality. Usage area "HDTV". "High Quality" preset, Y-SSIM.

	AMD	Intel IPP	MainConcept	x264	XviD
AMD	100.0%	48.6%	40.4%	37.2%	61.6%
Intel IPP	205.7%	100.0%	86.2%	78.8%	119.9%
MainConcept	247.2%	116.1%	100.0%	91.7%	138.4%
x264	268.7%	127.0%	109.1%	100.0%	152.6%
XviD	162.3%	83.4%	72.3%	65.5%	100.0%

Figure 148 through Figure 151 visualize data in the tables above. Each line in those figures corresponds to one codec. Values in vertical axis are average relative bitrate comparing to the codecs in horizontal axis. The lower bitrate is the better relative results have the codec.

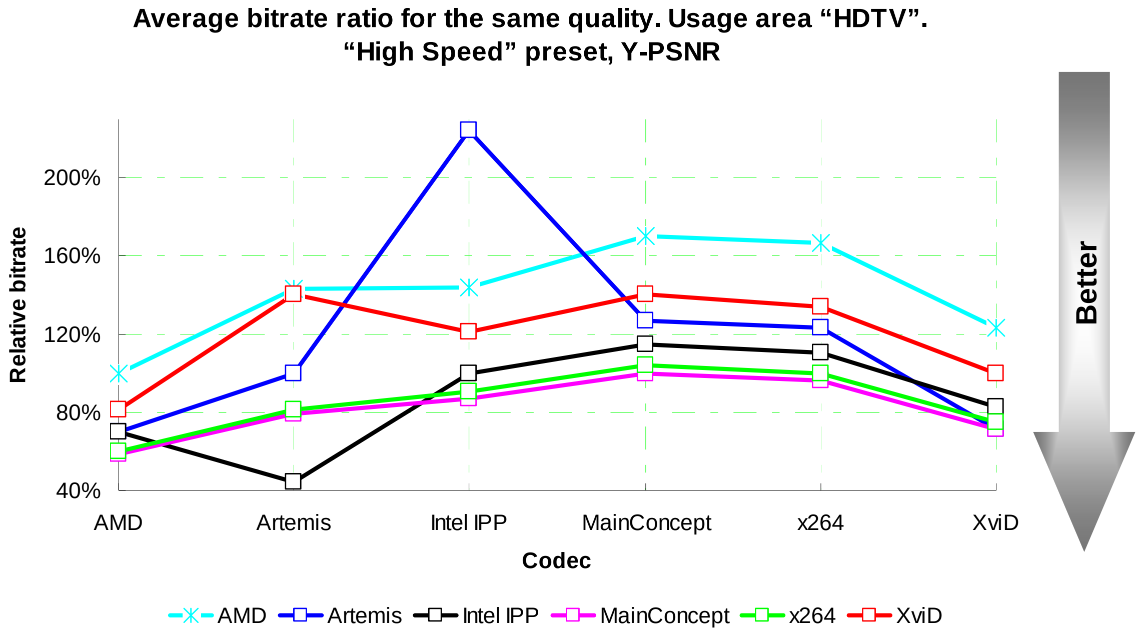


Figure 148. Average bitrate ratio for the same quality. Usage area "HDTV". "High Speed" preset, Y-PSNR.

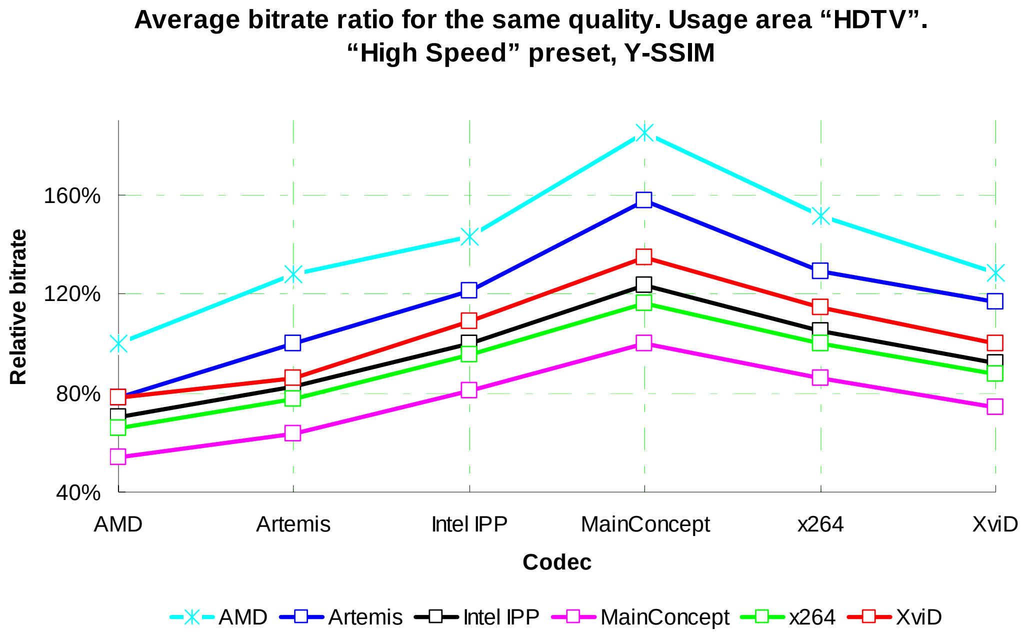


Figure 149. Average bitrate ratio for the same quality. Usage area "HDTV". "High Speed" preset, Y-SSIM.

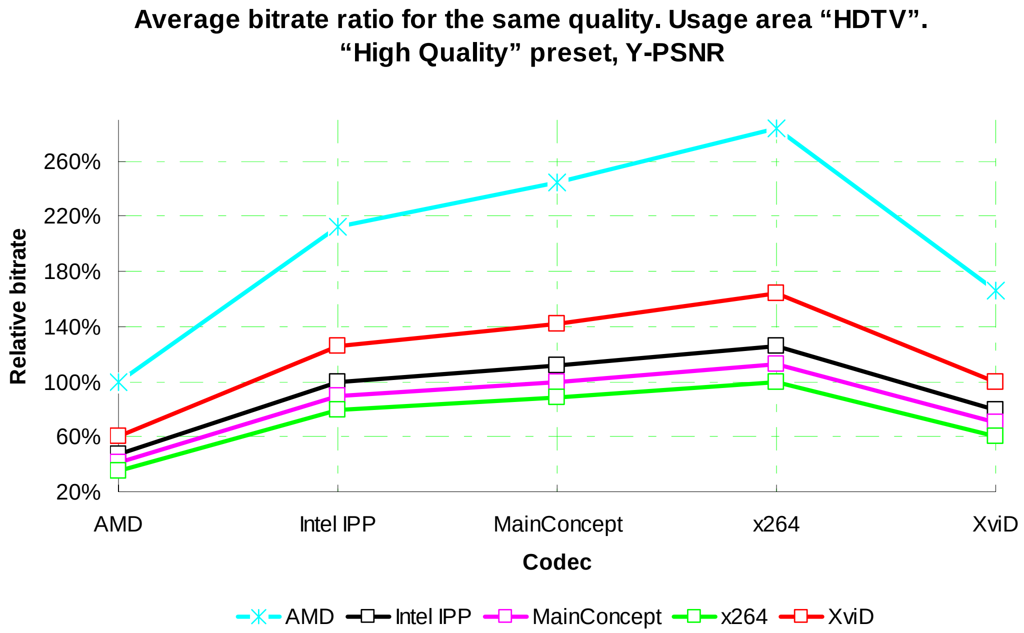


Figure 150. Average bitrate ratio for the same quality. Usage area "HDTV". "High Quality" preset, Y-PSNR.

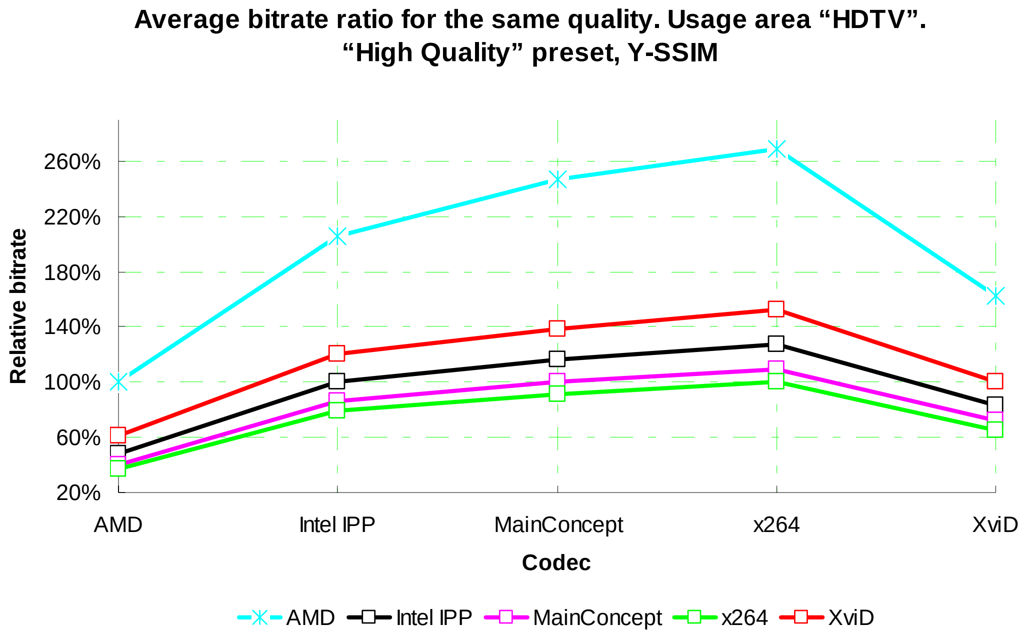


Figure 151. Average bitrate ratio for the same quality. Usage area "HDTV". "High Quality" preset, Y-SSIM.

4.4 Conclusions

4.4.1 Video conferences

Leaders in the videoconference area are the x264 and MainConcept codecs, with MainConcept being the slightly better alternative. The worst quality is demonstrated by the AMD encoder. The main reason of that result is extremely fast preset of the encoder (5 times faster than XviD).

4.4.1.1 High Quality preset

MainConcept demonstrates the best quality for all sequences. The top three codecs for this preset are the following:

1. MainConcept
2. x264
3. Intel IPP

The top three codecs also demonstrate acceptable bitrate handling.

4.4.1.2 High Speed preset

MainConcept demonstrates the best quality for all sequences. The top three codecs for this preset are the following:

1. MainConcept
2. x264
3. Intel IPP
4. XviD

5,6 AMD, Artemis x264 (the places depends on Y-PSNR or Y-SSIM as quality metric)

The first three codecs also demonstrate acceptable bitrate handling.

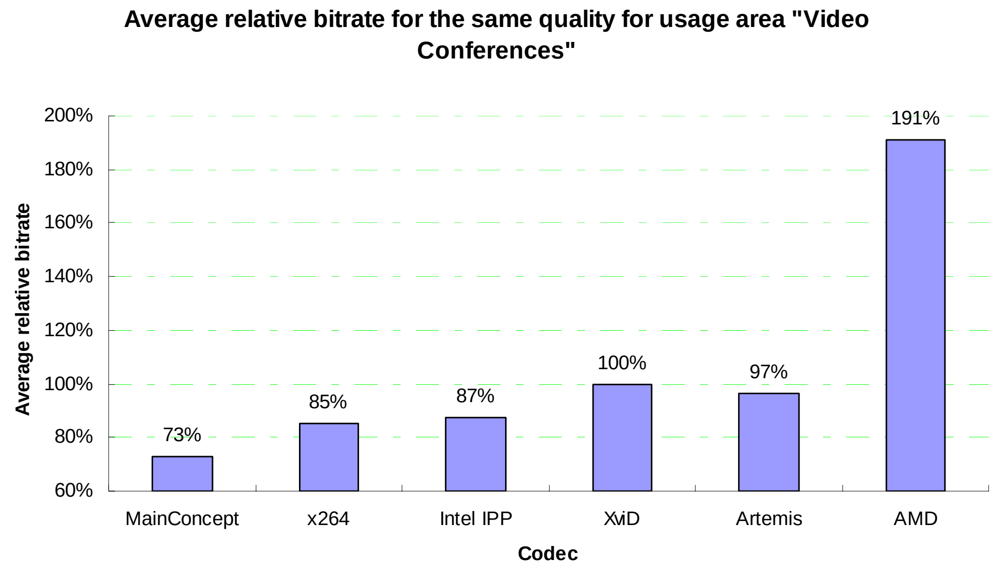


Figure 152. Average bitrate ratio for the same quality. Usage area "Video Conferences". All presets, Y-SSIM.

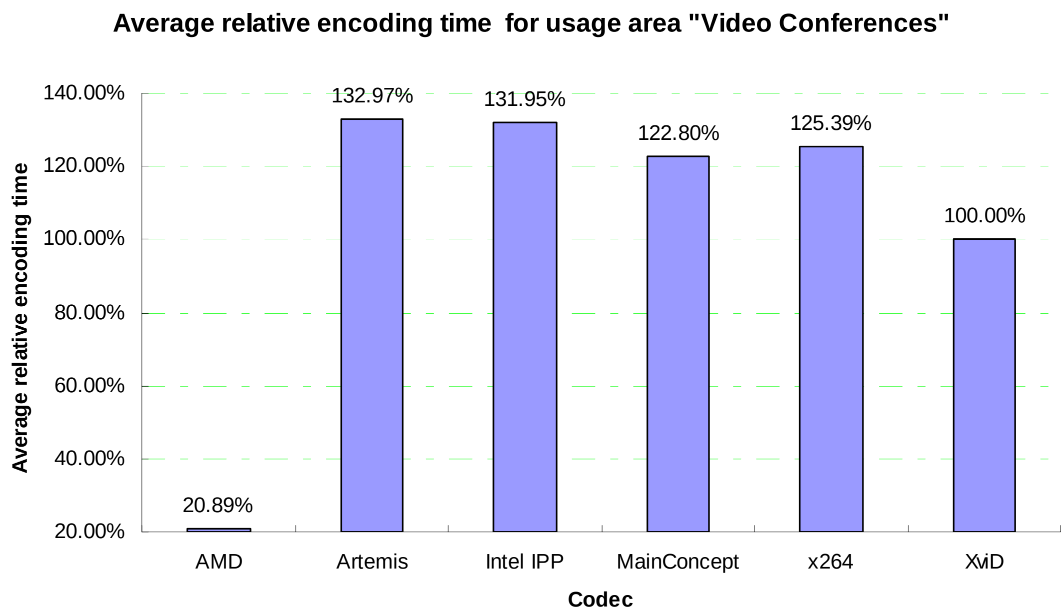


Figure 153. Average relative encoding time. Usage area "Video Conferences". All presets.

4.4.2 Movies

The leading encoders in this category are x264 and MainConcept. The quality of the AMD encoder is again rather low.

4.4.2.1 High Quality Preset

The x264 encoder demonstrates better quality for all sequences except the "Lord of the Rings" sequence (for approximately 10% of the bitrate and for a fixed quality), but it yields slower performance at the same bitrate for 30%. For the "Lord of the Rings" sequence, the MainConcept encoder is faster and yields better quality. The bitrate handling algorithm of these codecs is acceptable for this category. The Intel IPP codec once again holds third place. In some cases the Intel IPP encoder performs more poorly than the MainConcept encoder, but it still provides rather stable performance. Comparison of the XviD and AMD codecs with other codecs is difficult, as they are faster and show lower quality for a fixed bitrate. The objective quality of the AMD encoder is lower than that of XviD, but the AMD encoder is approximately 10 times faster. Also, the AMD encoder has problems with bitrate handling (for some sequences the bitrate exceeds the target rate by 100%).

4.4.2.2 High Speed Preset

The results for this preset are similar to those of the High Quality preset. The leaders are the x264 and MainConcept codecs. In third place, once again, is the Intel IPP encoder. The speed/quality trade-off results for the Intel IPP encoder for this preset are improved, as it is faster than the MainConcept encoder. The Artemis modification of x264 is very unstable. The speed of this codec is only 20% faster than that of the Intel IPP encoder, but its overall quality is lower than that of the XviD encoder. The AMD encoder is again very fast, but still demonstrates low quality.

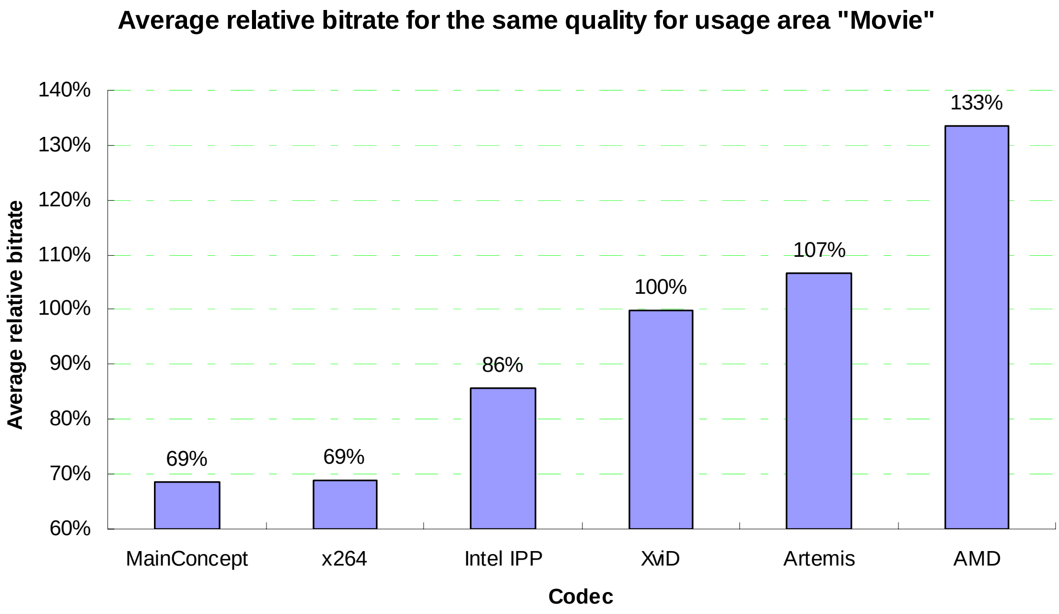


Figure 154. Average bitrate ratio for the same quality. Usage area "Movie". All presets, Y-SSIM.

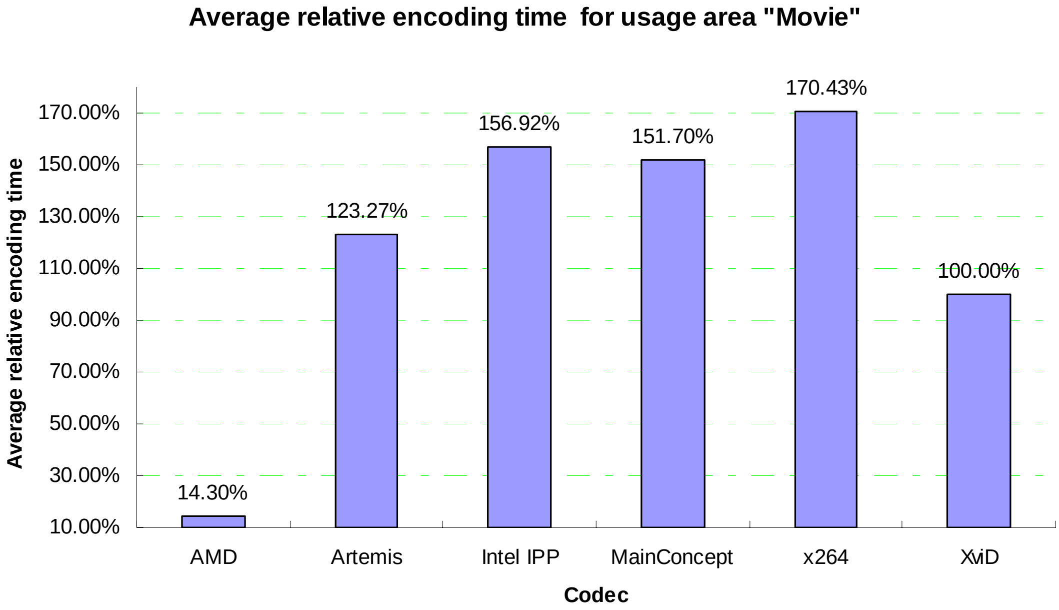


Figure 155. Average relative encoding time. Usage area “Movie”. All presets.

4.4.3 HDTV

4.4.3.1 High Quality Preset

The x264 and MainConcept codecs demonstrate the highest quality among all the codecs tested in this comparison. The encoding quality of the x264 codec is greater than quality the MainConcept encoder, the speed is slower. The third-place encoder, rated by quality, is the Intel IPP codec. Nevertheless, it is slower than MainConcept. The AMD and XviD codecs, as usual, are faster than all the competitors.

4.4.3.2 High Speed Preset

The leader for this preset is the MainConcept codec, which is better (both in speed and quality) than the x264, Intel IPP and Artemis x264 codecs. The output quality of the Artemis x264 codec is very unstable. It is likely that this is the worst-performing codec for this preset.

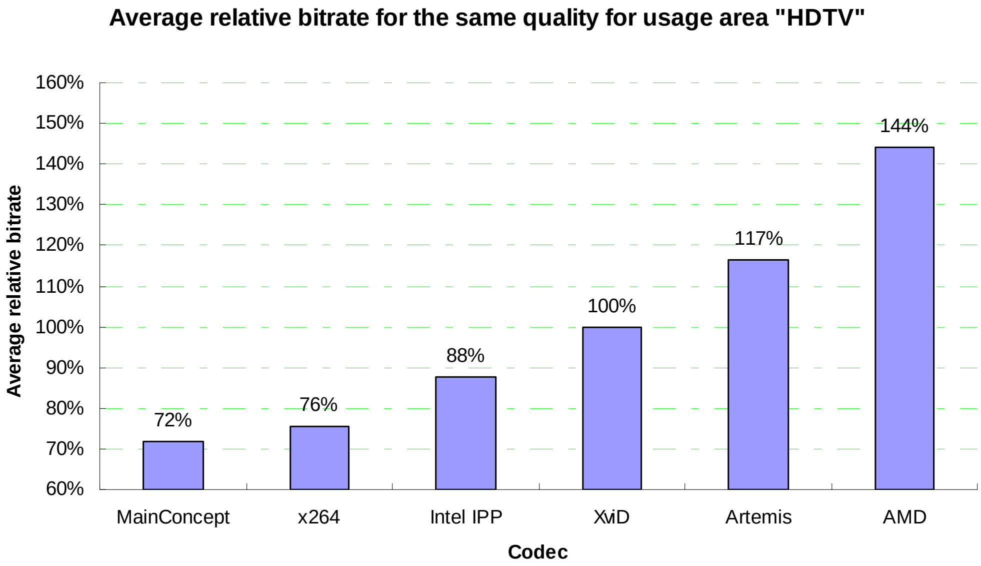


Figure 156. Average bitrate ratio for the same quality. Usage area “HDTV”. All presets, Y-SSIM.

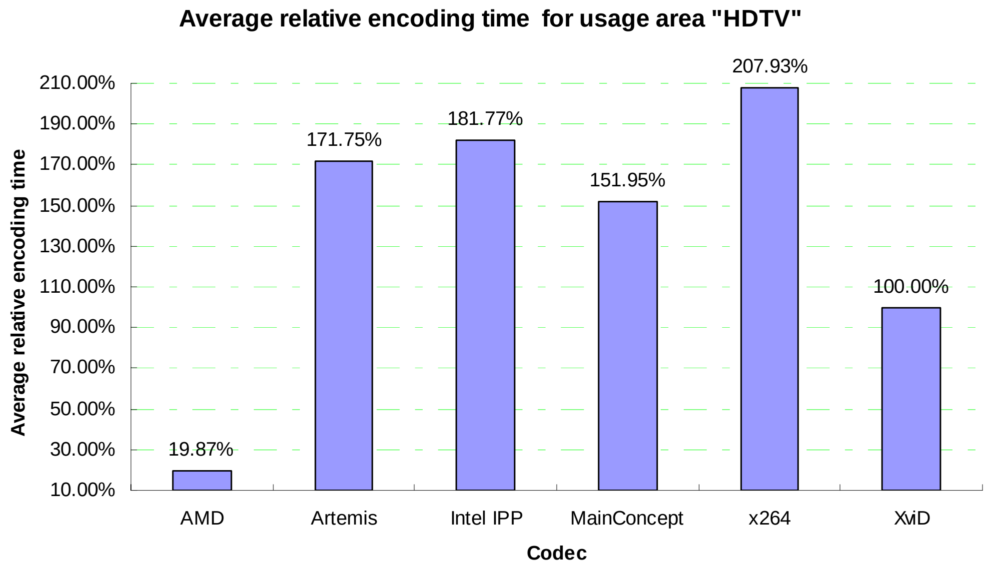


Figure 157. Average relative encoding time. Usage area "HDTV". All presets.

4.4.4 Overall Conclusions

Overall, the leaders in this comparison are the MainConcept and x264 encoders, with the Intel IPP encoder taking a strong third place. The XviD (MPEG-4 ASP) codec is, on average, better than the AMD and Artemis x264 codecs, which proves that the AMD and Artemis x264 encoders did not use all of the features of the H.264 standard. The main reason of AMD encoder low quality is very high speed of the encoder. The XviD codec demonstrates difficulties with bitrate handling algorithms, so does the AMD encoder as well.

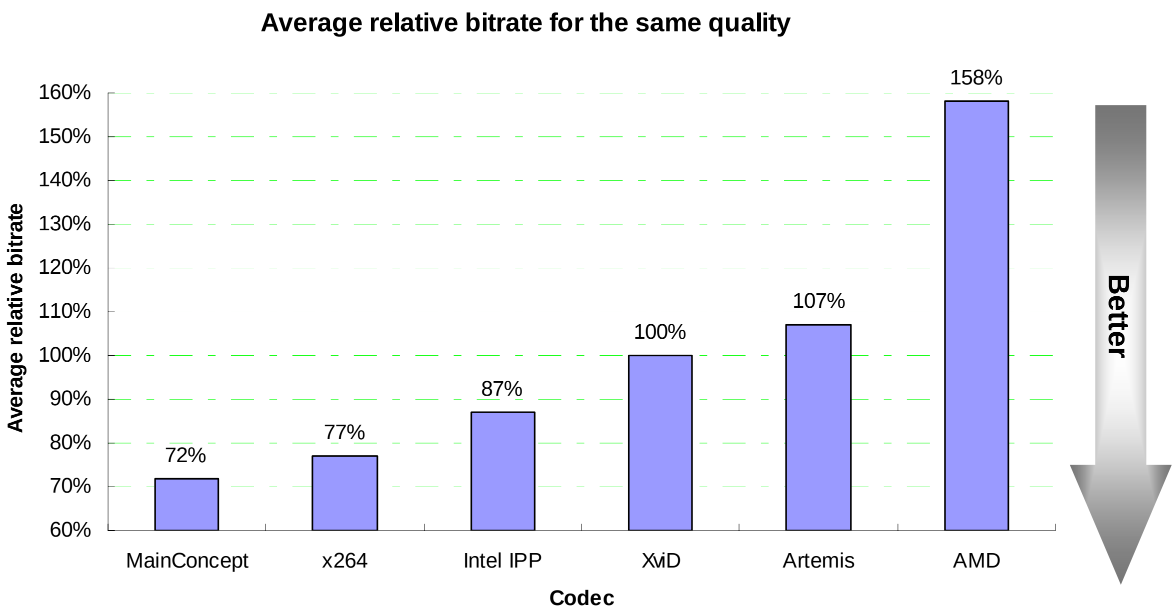


Figure 158. Average bitrate ratio for a fixed quality for all categories and all presets (Y-SSIM).

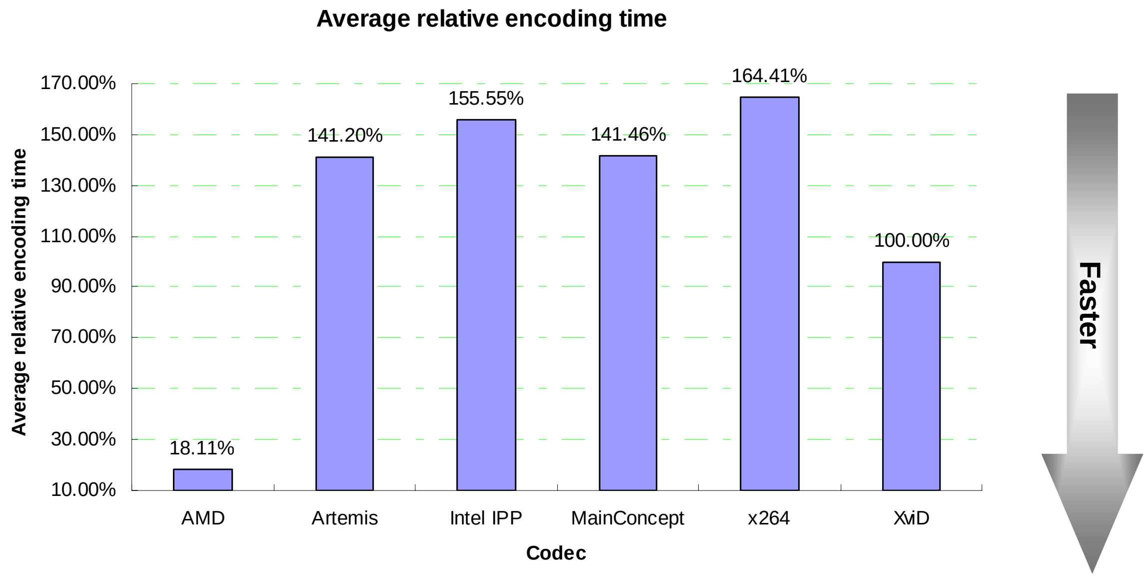


Figure 159. Average relative encoding time for all categories and all presets.

The overall ranking of the codecs tested in this comparison is as follows:

1. MainConcept
2. x264
3. Intel IPP
4. XviD
5. Artemis x264
6. AMD

This rank based only on quality results of encoders (see Figure 158). Encoding speed is not considered here.

The difference between the MainConcept and x264 encoders is not overly significant, so these two encoders are both the clear leaders in this comparison. The developers of the Artemis x264 encoder do not provide a High Quality preset, so its ranking is based solely on the results for the High Speed preset. The quality of the Artemis x264 (H.264) codec is lower than that of XviD (MPEG-4 ASP), which means that the developers of Artemis x264 did not employ the x264 encoder, which they modified, to its fullest potential. The low quality of AMD could be explained by its high encoding speed; the developers of the AMD codec did not provide a "slow" preset for use in this comparison, so tests of the AMD codec only used a *very fast preset* (5 to 10 times faster than that of its competitors).

5 Per-Frame Comparison

Per-frame quality graphs can be used to provide a better analysis of codec behavior at certain points in the video sequences. For this part of the comparison, consider some specific graphs.

5.1 Videoconferences

Consider the “Salesman” sequence at 50 kbps with the High Speed preset (at this bitrate all codecs demonstrate good bitrate handling).

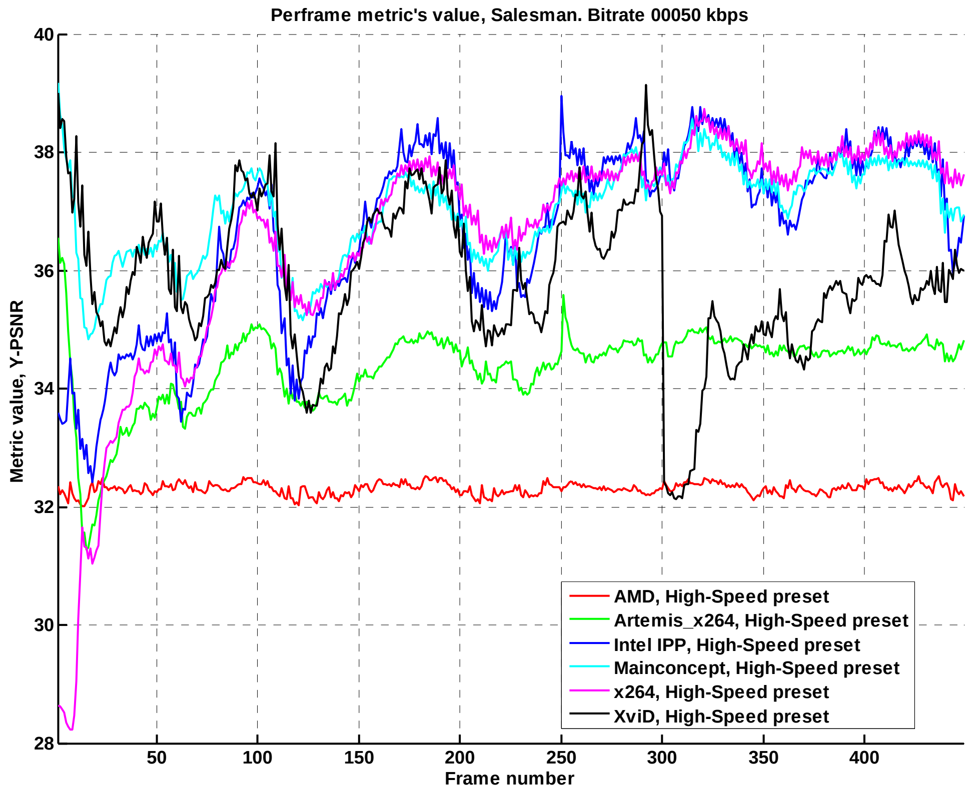


Figure 160. Per-frame quality. Usage area “Video Conferences”, “Salesman” sequence, “High Speed” preset, 50 kbps

This graph shows that all codecs, except AMD and XviD, have very similar per-frame quality characteristics, but there are several interesting points:

- x264 has very low quality at the beginning of the sequence, after which point this codec encodes with better quality
- AMD has approximately the same quality over the entire sequence
- XviD shows a drop in quality at the 300th frame

Consider the "News" sequence at 200 kbps with the High Speed preset (at this bitrate all codecs demonstrate good bitrate handling).

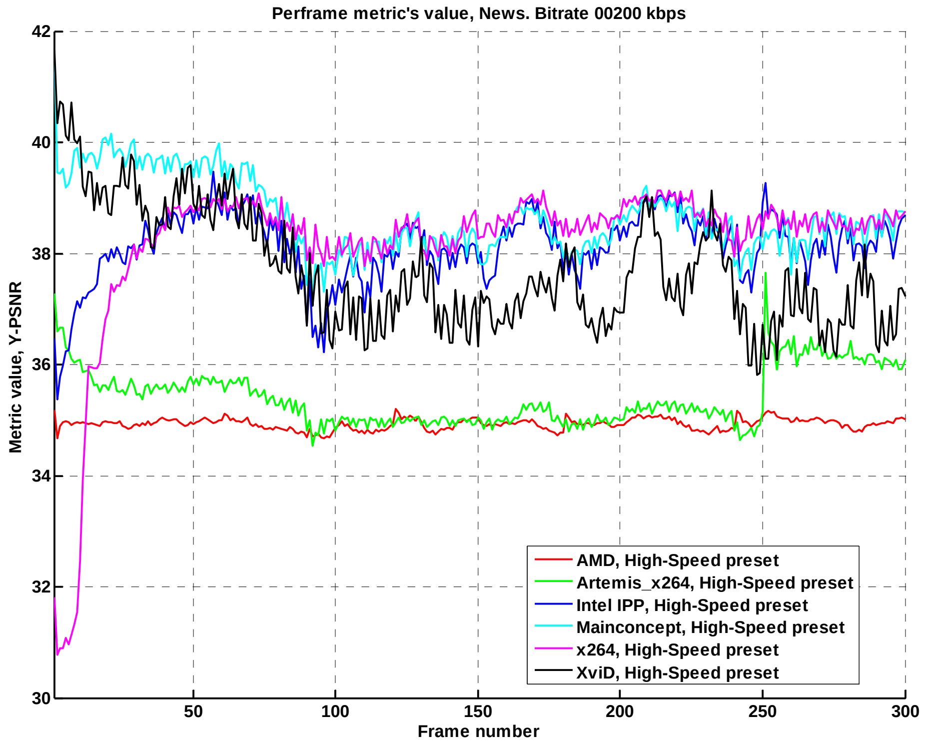


Figure 161. Per-frame quality. Usage area "Video Conferences", "News" sequence, "High Speed" preset, 200 kbps

This case is similar to that shown in the previous graph:

- AMD has nearly constant quality
- x264 has low quality at the beginning of the sequence
- Artemis x264 has the same quality before the I-frame at the 250th frame

5.2 Movies

Consider the "Lord of the Rings" sequence at 1200 kbps with the High Speed preset (at this bitrate all codecs demonstrate good bitrate handling).

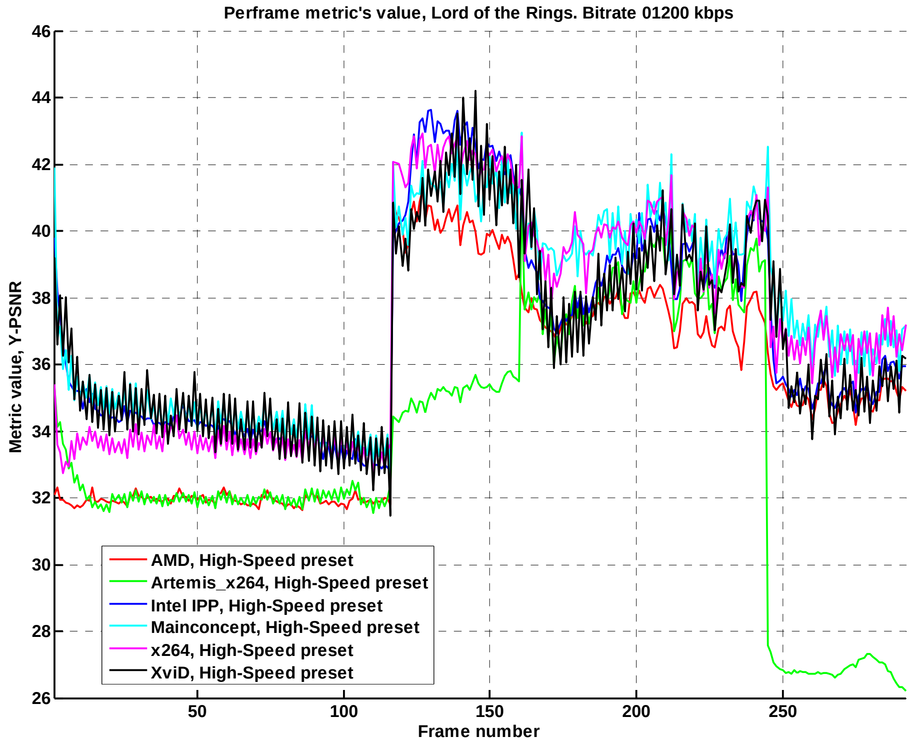


Figure 162. Per-frame quality. Usage area “Movies”, “Lord of the Rings” sequence, “High Speed” preset, 1200 kbps

This graph shows that all of the codecs, except Artemis x264, have very similar per-frame quality graphs, but there are some interesting points that apply to all of the codecs:

- Frame-to-frame quality fluctuation
- Quality increase at the 117th frame (I-frame, scene change)

Artemis x264 has difficulties with quality at the 245th frame (I-frame, difficulties with brightness)

Consider the "Mr. and Mrs. Smith" sequence at 1000 kbps with the High Speed preset (at this bitrate all codecs demonstrate good bitrate handling).

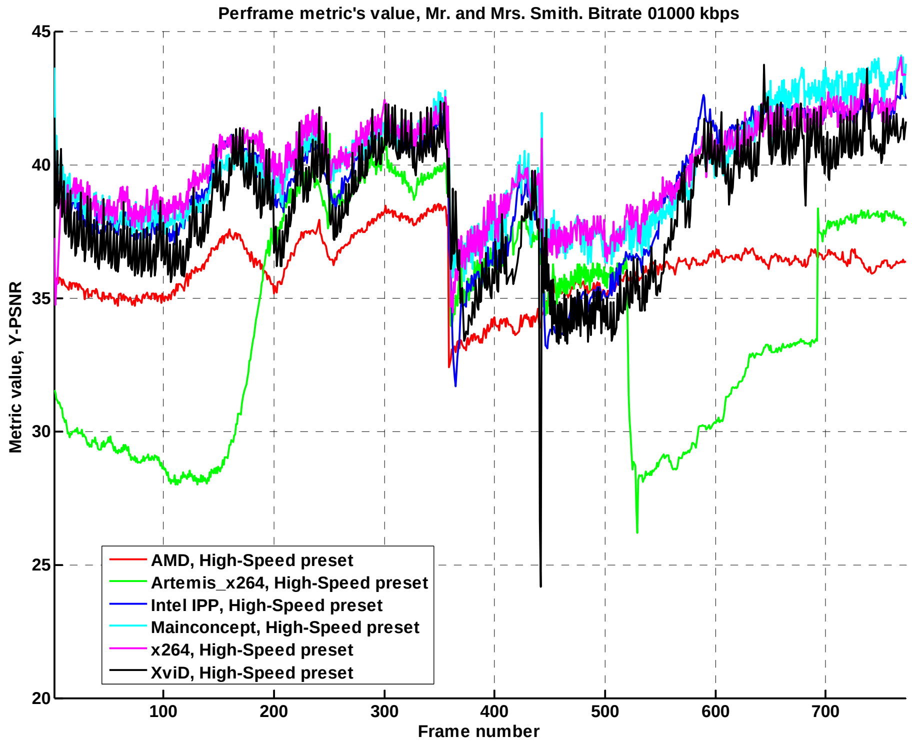


Figure 163. Per-frame quality. Usage area "Movies", "Mr. and Mrs. Smith" sequence, "High Speed" preset, 1000 kbps

This graph shows that all codecs, except Artemis x264, have very similar per-frame quality graphs, but there is one interesting point: XviD demonstrates a significant quality decrease at the 442nd frame.

5.3 HDTV

Consider the “Matrix (HDTV)” sequence at 6000 kbps with the High Quality preset (at this bitrate all codecs demonstrate good bitrate handling).

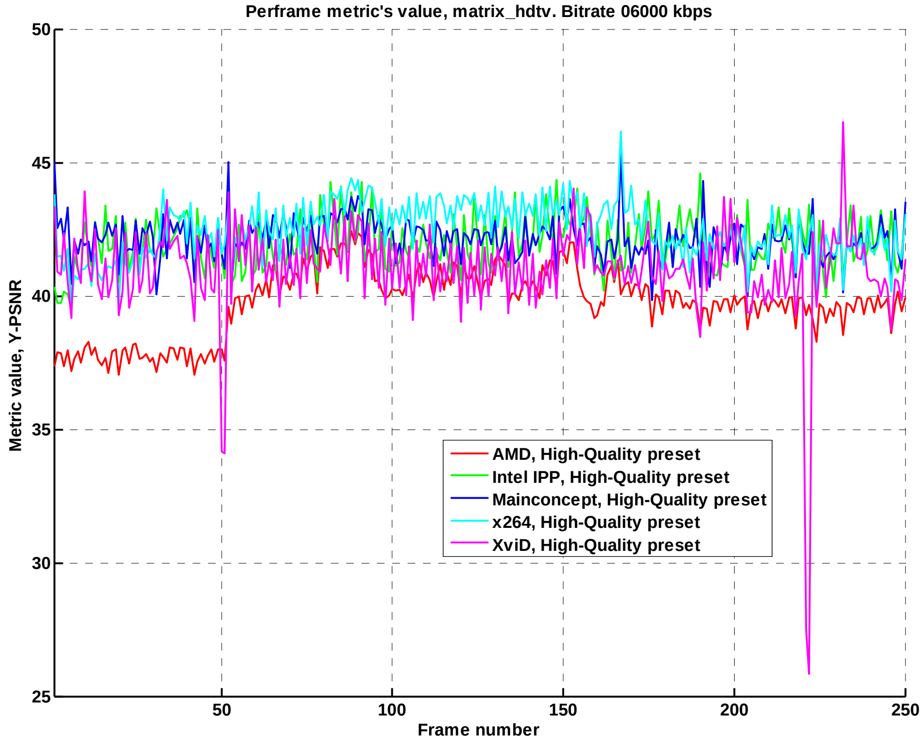


Figure 164. Per-frame quality. Usage area “HDTV”, “Matrix (HDTV)” sequence, “High Speed” preset, 6000 kbps

This graph shows that XviD has problems with quality at the 50th and 51st frames as well as at the 221st and 222nd frames.

Consider the “Troy” sequence at 6000 kbps with the High Speed preset (at this bitrate all codecs demonstrate good bitrate handling).

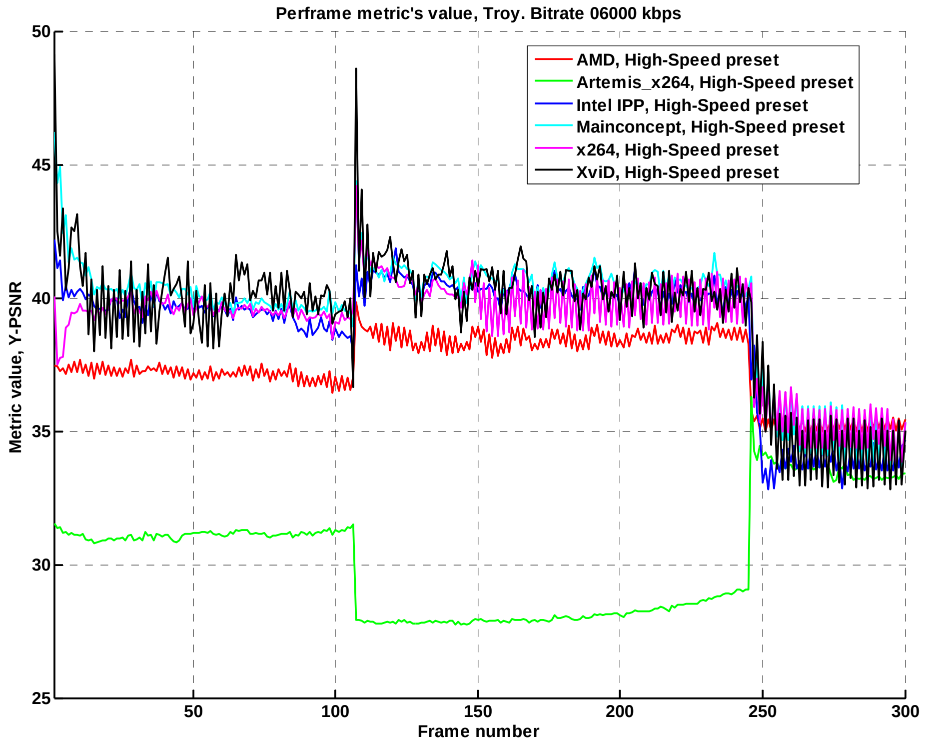


Figure 165. Per-frame quality. Usage area “HDTV”, “Troy” sequence, “High Speed” preset, 6000 kbps

This graph shows that Artemis x264 yields low quality over the entire sequence and that all codecs have significant quality deviation at the 107th frame (I-frame, scene change) and at the 246th and 247th frames (I-frame, scene change). Some points of interest are summarized as follows:

- All codecs demonstrate a quality increase at the 107th frame, with the exception of Artemis x264, which demonstrates a quality decrease
- All codecs demonstrate a quality decrease between frames 246 and 247, except for Artemix x264, which demonstrates a quality increase

6 Appendix 1. Multi-core Encoding Speed

Nowadays multi-core processors have become available to most users. Parallelization of the encoding process is a challenge for modern video codec development, however. Additional tests were performed using multi-core processors to assess codec effectiveness in this context.

As a rule, quality degradation is imperceptible when using multi-thread encoding. This fact allows independent measurement of encoding speed instead of just speed/quality trade-off.

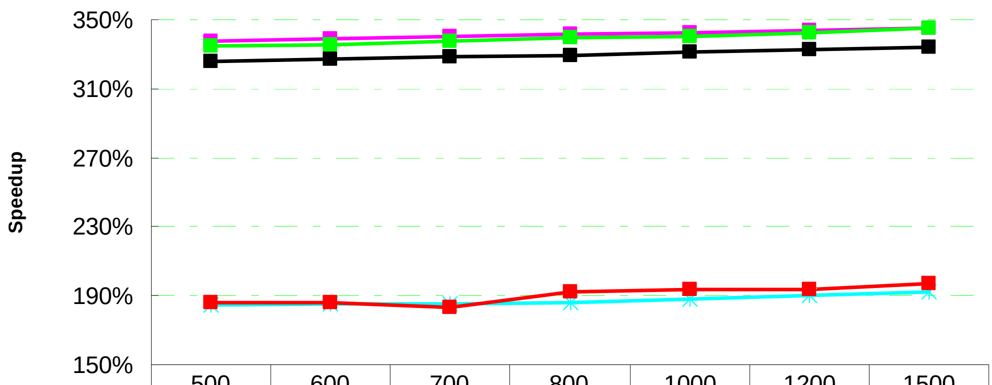
Table 15 lists the computer configuration used to perform these tests.

Table 15. Configuration of computer for multi-core tests

Operating System	Microsoft(R) Windows(R) XP Professional x64 Edition
Version	5.2.3790 Service Pack 1 Build 3790
Processor	4xEM64T Family 6 Model 15 Stepping 11 GenuineIntel ~2400 MHz
BIOS Version/Date	Intel Corporation. BX97520J.86A.2802.2007.1024.1947
Total Physical Memory	4,093.42 MB
Video Adapter Type	NVIDIA GeForce 8500 GT

The High Quality preset was used for all of the codecs for movie sequences. For the test sequence "Battle," two trials each with one thread and four threads were performed (the number of threads was set using the codec parameters). Here, codec speed-up is defined as the ratio of encoding times for one thread and four threads.

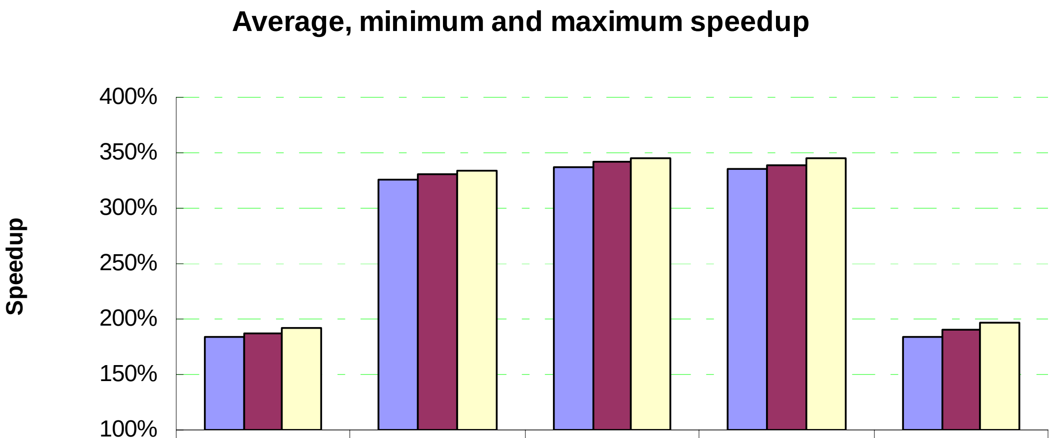
Multi-core Speedup Encoding



	500	600	700	800	1000	1200	1500
AMD	184%	185%	186%	186%	188%	190%	192%
IPP	326%	327%	328%	329%	331%	333%	334%
MainConcept	338%	339%	340%	342%	342%	343%	345%
x264	335%	335%	337%	340%	340%	342%	345%
XviD	186%	186%	183%	192%	193%	194%	197%

Bitrate , kbps

Figure 166. Average Encoders Speedup with 4 Processors



	AMD	IPP	MainConcept	x264	XviD
Minimum	184%	326%	338%	335%	183%
Average	187%	330%	341%	339%	190%
Maximum	192%	334%	345%	345%	197%

Codec

Figure 167. Average Encoders Speedup with 4 Processors

Figure 166 depicts the codec speed-up as a function of the target bitrate. As can be seen, there are two groups of codecs: one with a speed-up range of 150% to 200% and one with a speed-up range of 250% to 300%. Note that there is no difficulty with automatic detection of processors: the number of threads was set explicitly both for the AMD and XviD encoders. The codec speed-up increases slightly with increasing bitrate.

Figure 167 demonstrates average speed-up. Results for the x264 and MainConcept codecs turn out to be the same when measurement errors are taken into account. The Intel IPP encoder lags slightly behind the two leaders. Results for AMD and XviD are very similar.

7 Appendix 2. Codecs Analysis using Synthetic Sequences

This appendix contains some examples of codec analysis using synthetic sequences. The main purpose of this method is to track some important codec properties using specially created synthetic video sequences. Two types of analysis have been performed:

- Sequences for motion compensation quality estimation
- Sequences for moving object tail area distortion estimation

7.1 Estimation of Motion Compensation Quality

Synthetic sequences are used for detailed analysis of the motion compensation algorithm. The sequence consists of squares that move from frame to frame. Each object can be described with the following parameters:

- Texture
- Size
- Position (X, Y)
- Speed (V_x, V_y)

Textures for moving objects and for backgrounds are created using superposition of sinusoids.

The size of each object is selected randomly using a normal distribution with parameters that depend on the frame resolution.

The initial position of each square is random. Later, for each frame *i+1*, the position is calculated using the following formulas:

$$X_{i+1} = X_i + V_x^i$$
$$Y_{i+1} = Y_i + V_y^i$$

Calculation of the speed of the square has two stages:

1. Addition of a random component to the speed: a uniform random variable in the range [0, *MAX_SPEED*]. The *MAX_SPEED* constant is used to control sequence complexity.
2. Calculation of the correlation component for the speeds of different objects. The correlation component is used for emulating the correlation between the motion of different objects in the scene.

Figure 168 depicts an example frame from a synthetic sequence.

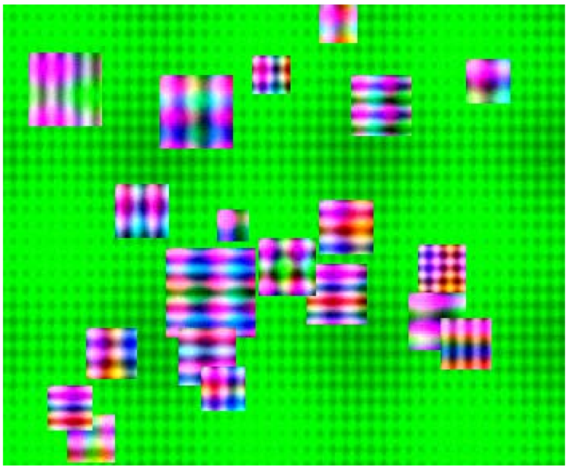


Figure 168. Example frame from a synthetic sequence used for motion analysis.

Two synthetic sequences with different complexities are used in this test. The first step is relative values calculation. The codec under test is launched for each synthetic sequence, and the resulting output quality is compared to that of the reference codec. Therefore, for each sequence and codec, there is one descriptive number (the average bitrate ratio, relative to the reference codec, for a fixed quality).

The final score consist of two parts:

- Encoding quality for the first version of the motion sequence (with simple motion)
- Quality variation for the second version of the motion sequence (with complex motion)

Figure 169 presents the final results for this method of codec analysis. The range of possible scores is [0, 100], with the best codec having a score of 100 and the worst codec having a score of 0. The leaders in this test are the AMD, x264 and MainConcept encoders. Note, however, that the quality of the AMD encoder is rather low, but the encoder demonstrates significant quality improvement when motion complexity increases. The poorest result is demonstrated by the Artemis modification of the x264 codec.

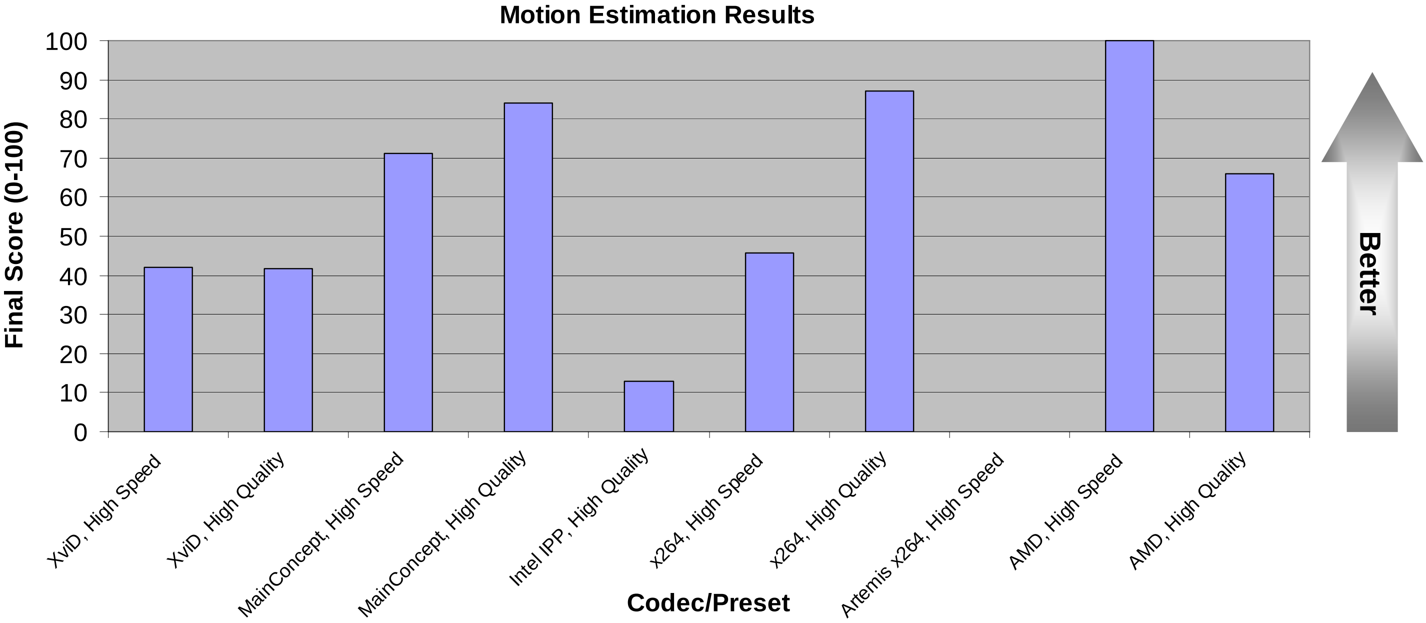


Figure 169. Final results of motion compensation analysis.

7.2 Analysis of Distortion in Tail Area

The main purpose of tail area analysis is to test the ability of a codec to properly deal with newly appeared objects and areas.

The synthetic sequence for this analysis consists of a static background and a single moving square. The square moves from right to left with a slight random variation in speed. When the object reaches the left border of the frame, it appears again at the right border with a new Y coordinate.

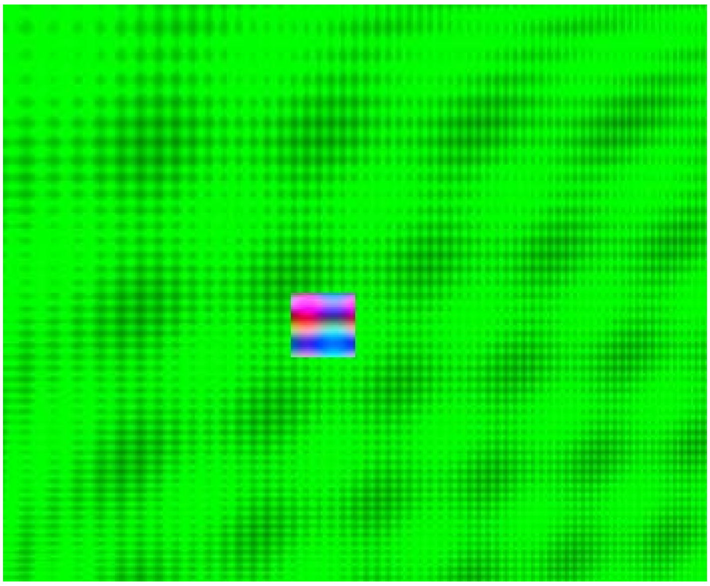


Figure 170. Synthetic sequence for tail area analysis.

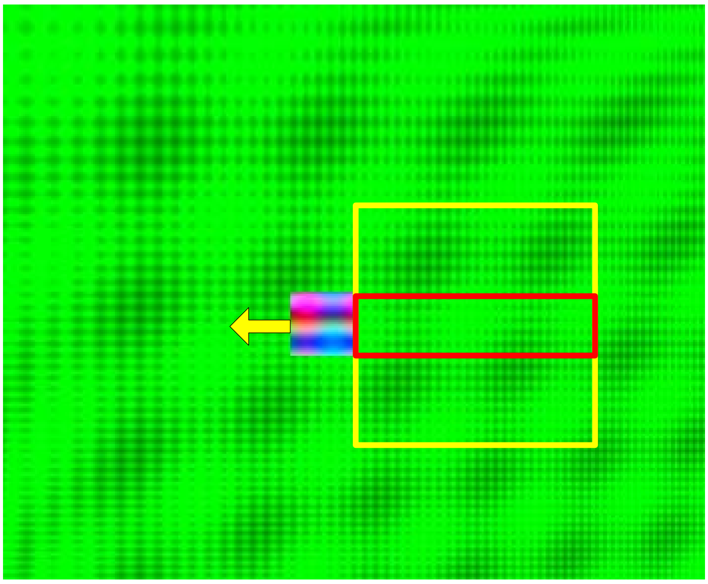


Figure 171. Areas for calculating the quality metric for tail area analysis.

The first step of the final score calculation involves computing the tail area metric for one frame. A rectangle of a specific size, located directly to the right of the moving objects, is considered. This rectangle is divided into two areas: a center area, traversed by the moving object (the red rectangle in figure above) and the remaining area (the yellow rectangle). The ratio of per-frame distortions in those areas is the tail area metric for this frame. The metric for the sequence is the average of the per-frame ratios.

Figure 170 and Figure 171 show an example of a frame from a synthetic sequence as well as the areas used for the calculation of the metrics. Figure 173 is an example of tail area metric measurements for various codecs. Note that the Intel IPP encoder has a rather large value. This means that the IPP encoder demonstrates extensive distortion in the tail area as compared to other regions of the frame.

Figure 172 depicts the final results for this type of analysis. The range of scores is [0, 100]. The leaders are the x264 (for both presets) and MainConcept (for the High Quality preset) encoders. It is interesting to note the large difference between the results for the MainConcept encoder in the two different presets. The worst result among all the codecs is the Intel IPP encoder.

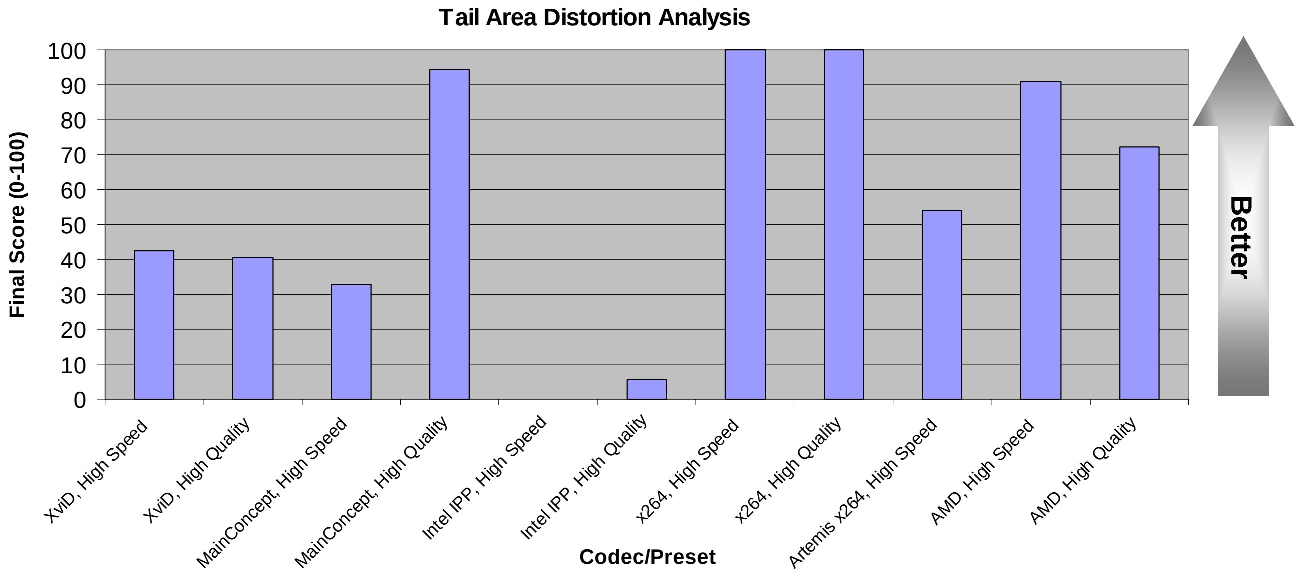


Figure 172. Final results of tail area analysis

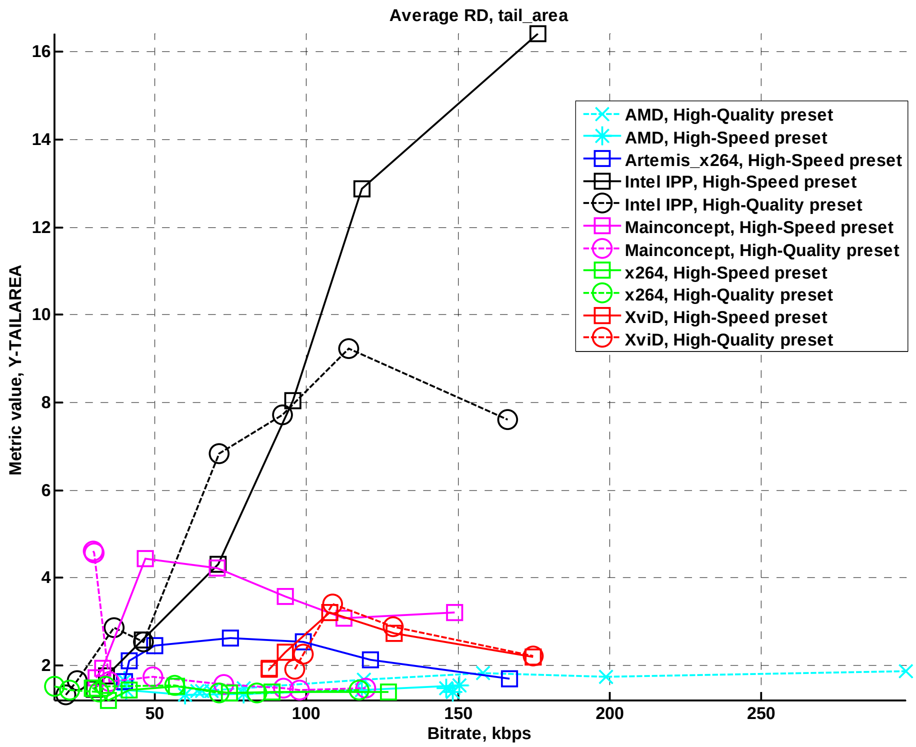


Figure 173. Example of metric for tail area distortion calculation

7.3 Other Types of Analysis

The Graphics & Media Lab Video Group performs extensive research in the field of automatic codec analysis. The results of this section are just examples of codec analysis methods developed by the Video Group. Some analyzers currently being developed at the laboratory include the following:

- Blurring analyzer – test codec performance for high-texture sources
- Decimation analyzer – test the quality of the codec's motion estimation (ME) algorithm
- Frames with noise analyzer – test the stability of the codec's frame-level rate control
- Frames with variable noise and noise macro-blocks analyzers – test the quality of the codec's MB-level rate control
- Frame rotation analyzer – test for errors in the codec's ME
- Synthetic motion analyzer – test the quality of the codec's ME
- Tail area analyzer – analysis of codec mode selection
- Edge capture analyzer – analysis of codec MB subdivision selection
- Border quality analyzer – analysis of codec performance for sequences with sharp edges

8 Appendix 3. Artemis x264 and x264 PNSR and SSIM Comparative Analysis

Artemis x264 is a modification of a previous version of the x264 encoder, so it is interesting to compare branched modified x264 and current x264.

Consider the RD curve for the "Salesman" sequence using the High Speed preset.

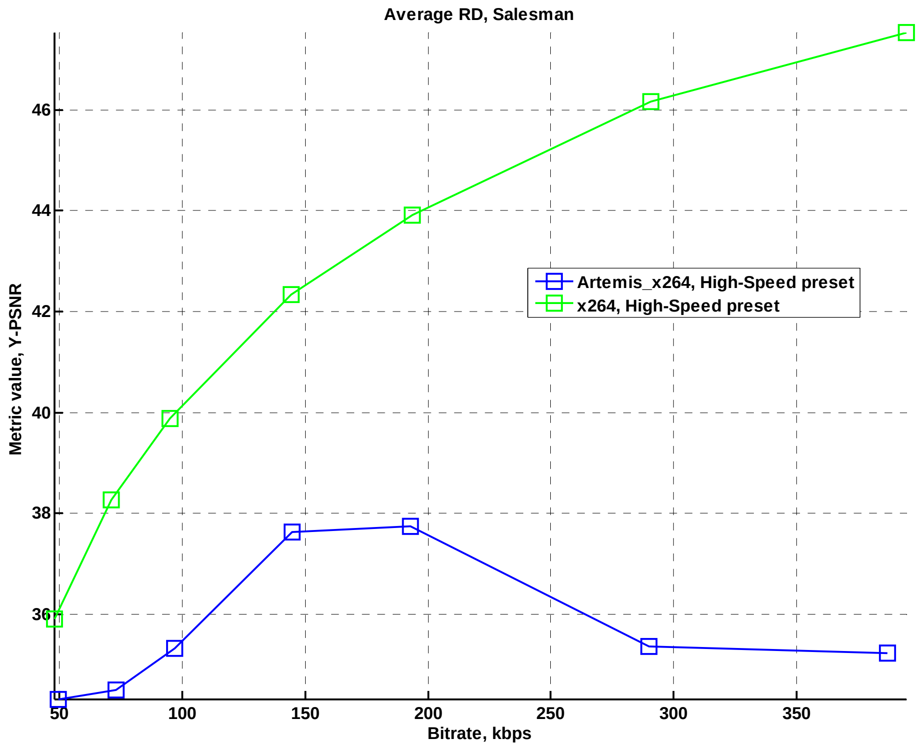


Figure 174. RD curve for "Salesman" sequence, High-Speed preset, Artemis_x264 and x264, Y-PSNR

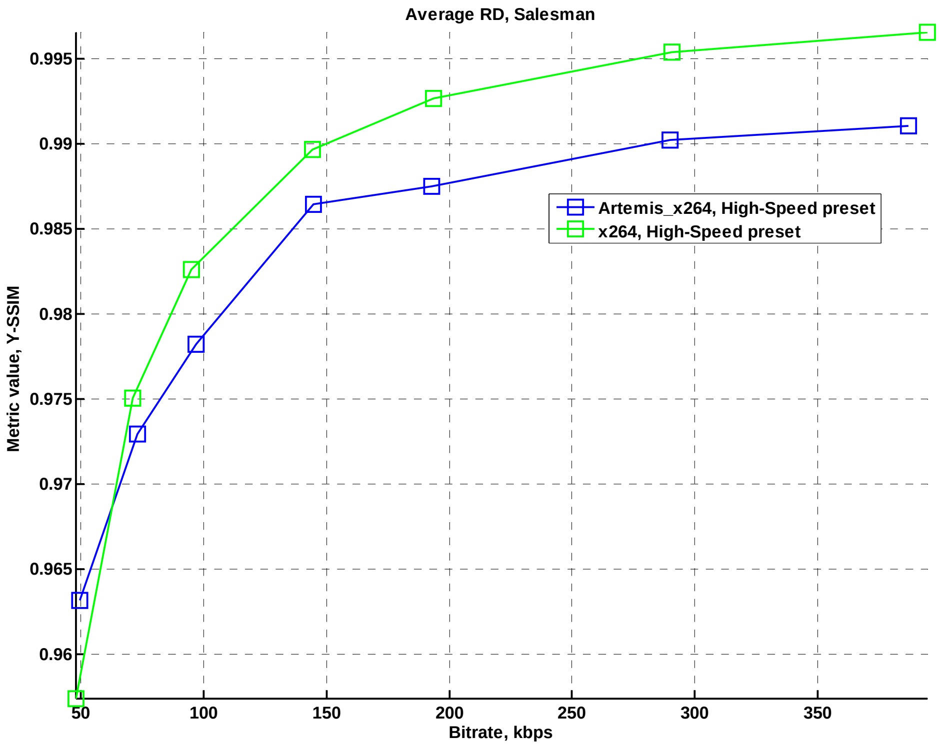


Figure 175. RD curve for "Salesman" sequence, High-Speed preset, Artemis_x264 and x264, Y-PSNR

It is noticeable that the RD curve for the Artemis x264 has different slope characteristics for different objective quality metrics:

- Y-PSNR RD curve is not monotonic
- Y-SSIM RD curve is monotonic with a small decrease at 200 kbps

Next consider per-frame graphs of objective quality for the Artemis x264 encoder.

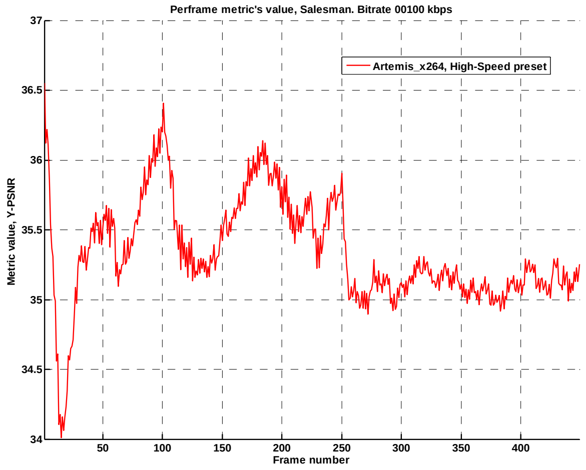


Figure 176. Per-frame Y-PSNR, sequence "Salesman", Artemis_x264, 100 kbps

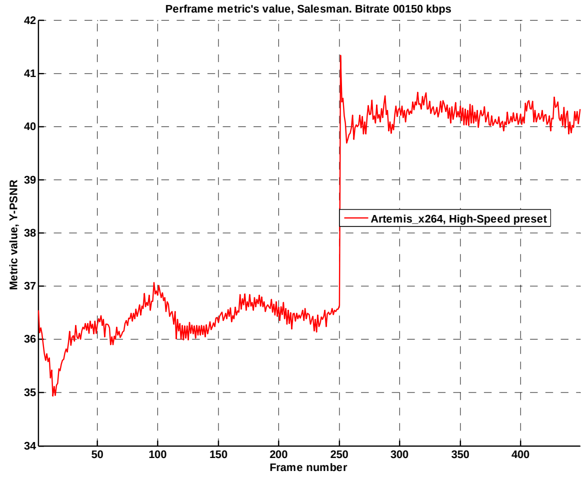


Figure 177. Per-frame Y-PSNR, sequence "Salesman", Artemis_x264, 150 kbps

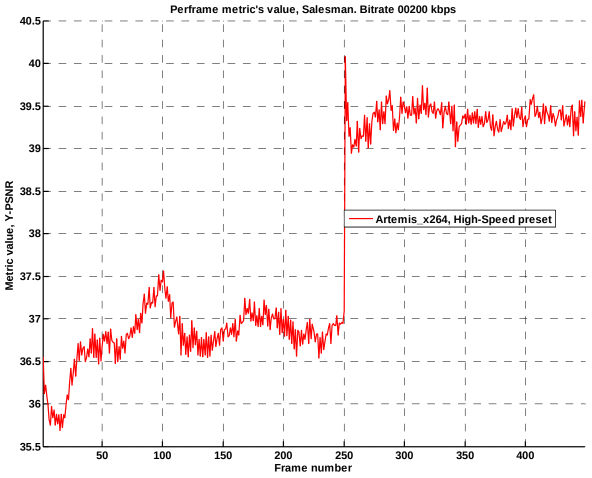


Figure 178. Per-frame Y-PSNR, sequence "Salesman", Artemis_x264, 200 kbps

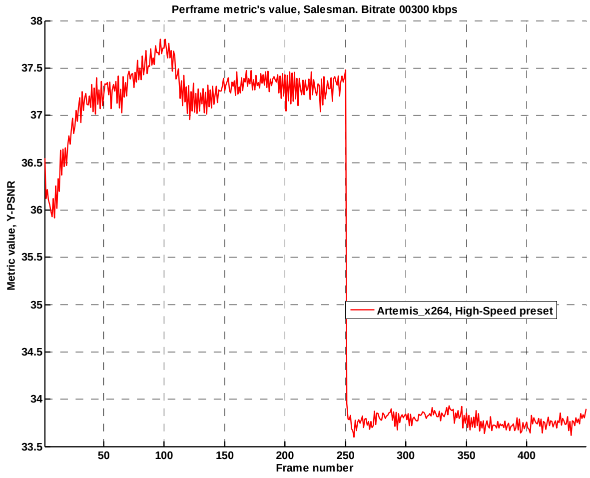


Figure 179. Per-frame Y-PSNR, sequence "Salesman", Artemis_x264, 300 kbps

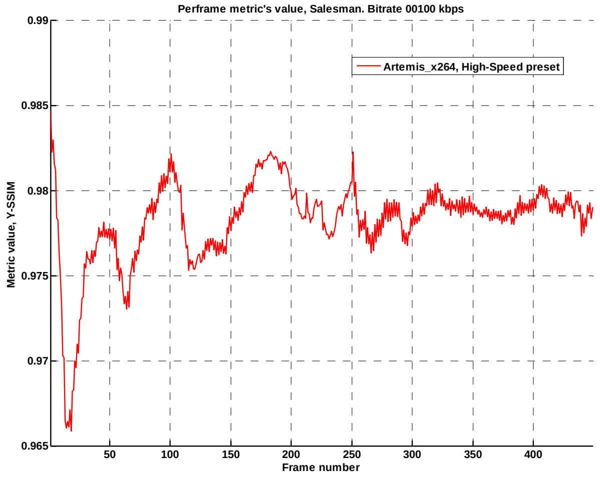


Figure 180. Per-frame Y-SSIM, sequence "Salesman", Artemis_x264, 100 kbps

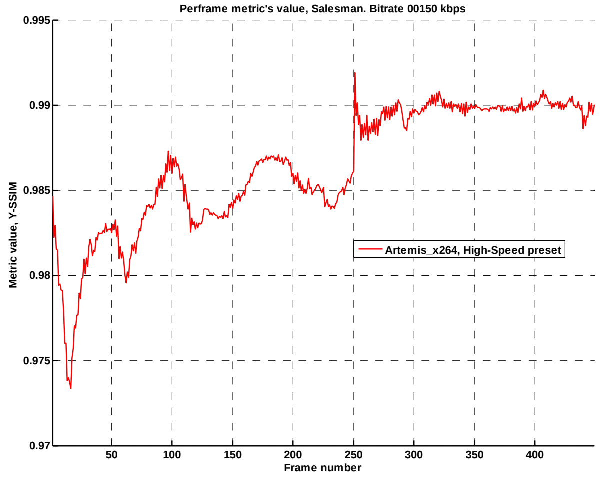


Figure 181. Per-frame Y-SSIM, sequence "Salesman", Artemis_x264, 150 kbps

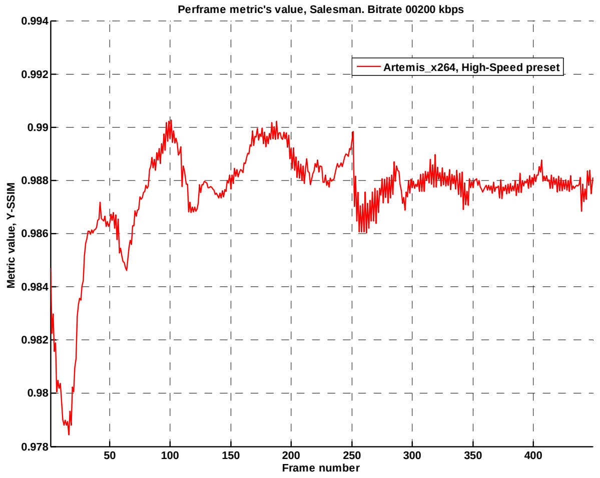


Figure 182. Per-frame Y-SSIM, sequence "Salesman", Artemis_x264, 200 kbps

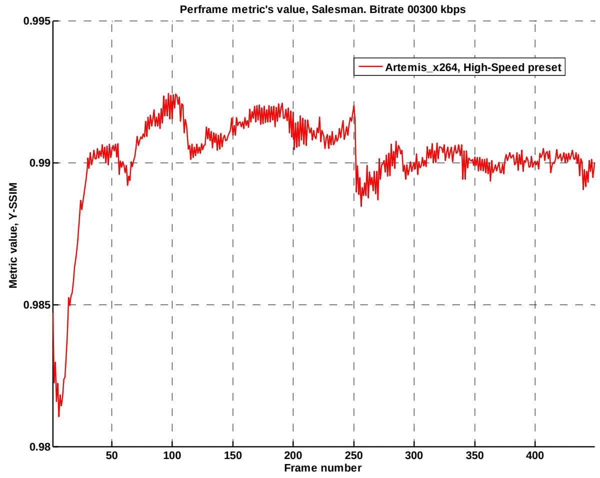


Figure 183. Per-frame Y-SSIM, sequence "Salesman", Artemis_x264, 300 kbps

The main difference between the per-frame graphs is at 250th frame in the case of the Y-PSNR graphs. For the Y-SSIM graphs this difference is not as obvious.

The explanation of this difference is that the Artemis x264 encoder placed the I-frame at the 250th frame, and this I-frame has an average brightness that is different than the average brightness of the previous frame. Also, Y-PSNR is very sensitive to variation in average brightness, but Y-SSIM takes into account more than just the average brightness.

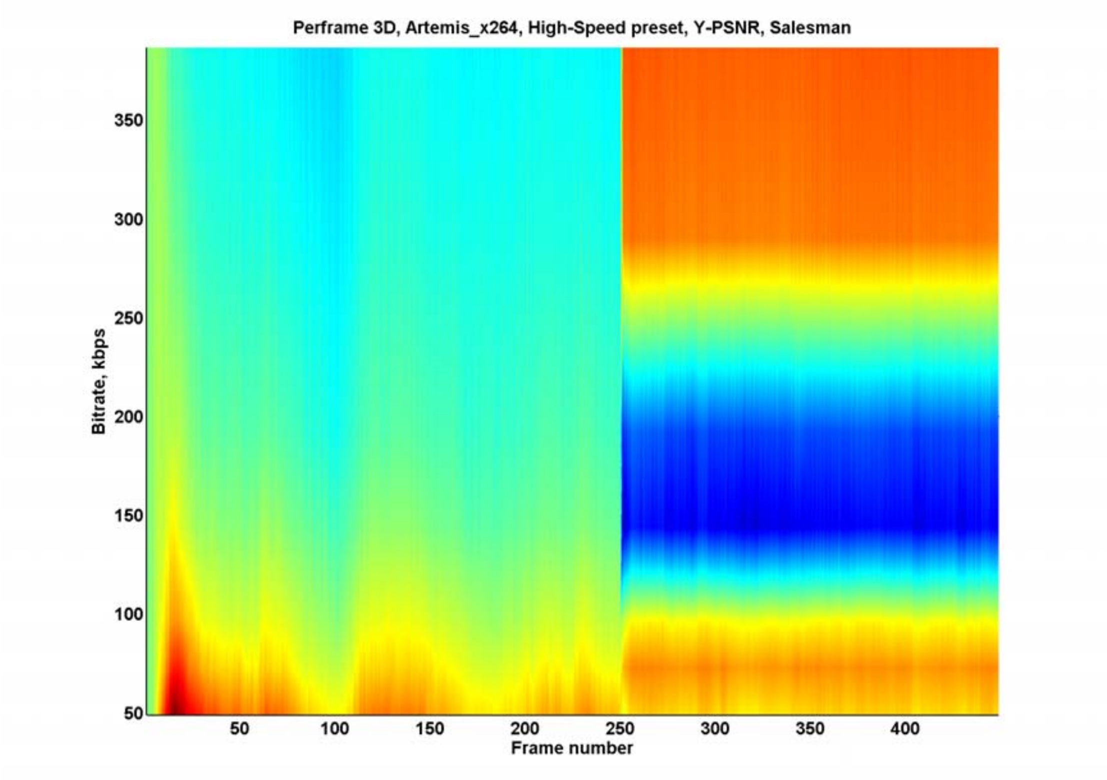


Figure 184. 3D per-frame quality for "Salesman" sequence, High-Speed preset, Artemis x264, Y-PSNR

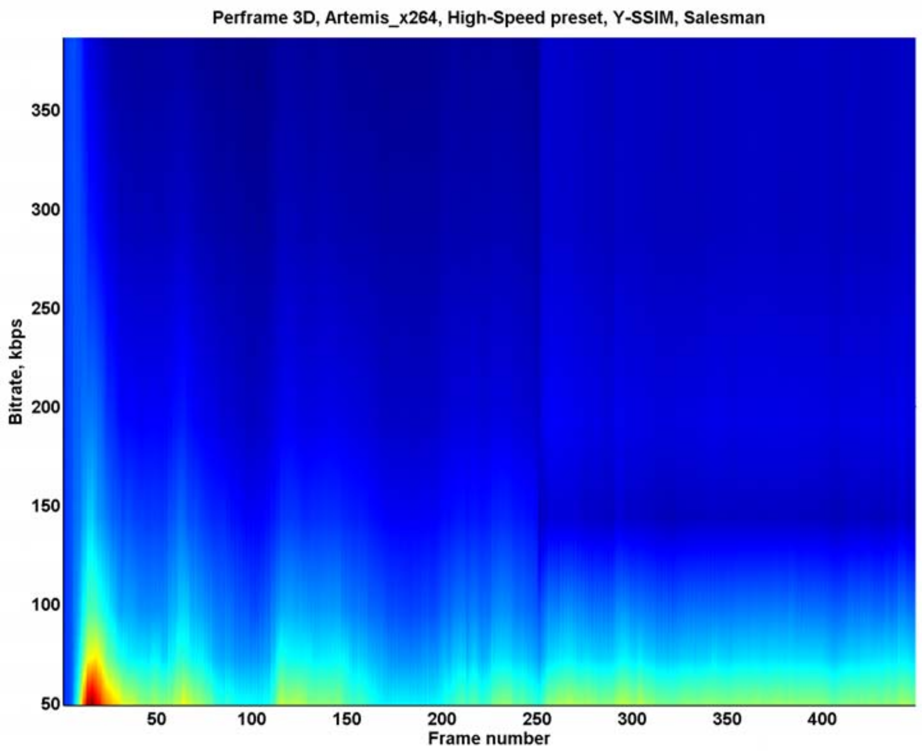


Figure 185. 3D per-frame quality for "Salesman" sequence, High-Speed preset, Artemis x264, Y-SSIM

Figure 184 is the 3D visualization of per-frame quality using the Y-PSNR metric; Figure 185 is the same visualization for the Y-SSIM case. Red colors correspond to low quality and blue colors correspond to high quality. The colors inside each chart are relative, so two charts cannot be compared by way of color. It is obvious from the visualizations that the quality of the Artemis x264 encoder shows significant variation with encoding bitrate after the 250th frame.

8.1.1.1 Conclusion

The Artemis modification of x264 has extensive difficulties with I-frame compression, especially with the Y-plane of the YUV color space.

9 Appendix 4. Test Set of Video Sequences

9.1 Videoconference Sequences

9.1.1 "Salesman"

Sequence title	Salesman
Resolution	176x144
Number of frames	449
Color space	YV12
Frames per second	30
Source	Uncompressed (standard sequence), progressive

Figure 186. Salesman sequence, fame 1

Figure 187. Salesman sequence, fame 100

The following is a well-known sequence that shows a man sitting at a table and engaging in moderate gestures and mimic. The camera is static, and there is not a tremendous amount of motion. Due to these characteristics, this sequence can be used to test the behavior of a codec for static scenes with very low spatial resolution, such as might be used in videoconferences.

9.1.2 "Foreman"

Sequence title	Foreman
Resolution	352x288
Number of frames	300
Color space	YV12
Frames per second	30
Source	Uncompressed (standard sequence), progressive

Figure 188. Foreman sequence, frame 77

Figure 189. Foreman sequence, frame 258

This is one of the most well-known sequences. The sequence includes a face with very rich mimic. There is not a high level of motion, but the motion that is present is disordered and does not have any forward characteristics. The intricate character of the motion creates problems for the motion compensation process. In addition, the camera is shaking, thus making the image unsteady. At the end of the sequence, the camera suddenly turns to the building site, and another scene with almost no motion follows. As a result, this sequence can also be used to test the behavior of the codec for a static scene that follows one with abundant motion.

9.1.3 “News”

Sequence title	News
Resolution	352x288
Number of frames	300
Color space	YV12
Frames per second	30
Source	Uncompressed (standard sequence), progressive

Figure 190. News sequence, frame 1

Figure 191. News sequence, frame 100

This well-known sequence presents two television announcers in front of a static background. This background does include, however, a television display with moving pictures. The camera is static. The motion of announcers is not extensive here, but the motion on the background display is intensive. Therefore, this sequence can be used to test the behavior of a codec for a mostly static scene with an area of intensive motion.

9.2 Movie Sequences

9.2.1 "Battle"

Sequence title	Battle
Resolution	704x288
Number of frames	1599
Color space	YV12
Frames per second	24
Source	MPEG-2 (DVD), FlaskMPEG deinterlace

Figure 192. Battle sequence, frame 839

This sequence is a fragment from the beginning of the "Terminator 2" movie. In terms of compression, this sequence is the most difficult among all of the sequences that were used in the analysis. This difficulty is due to three main reasons: continual brightness variation (resulting from explosions and laser flashes as seen in the picture above), very fast motion and frequent scene changes. These characteristics often cause codecs to compress frames as I-frames.

9.2.2 "Smith"

Sequence title	Smith
Resolution	720x432
Number of frames	772
Color space	YV12
Frames per second	24
Source	MPEG-2 (DVD)

Figure 193. Smith sequence, frame 650

This sequence is a fragment from the beginning of the "Mr. and Mrs. Smith" movie. In terms of compression, this sequence is difficult because of fast panoramic camera movements; there are almost no static scenes.

9.2.3 "Iceage"

Sequence title	Iceage
Resolution	720x576
Number of frames	491
Color space	YV12
Frames per second	24
Source	MPEG-2 (DVD)

Figure 194. Iceage sequence, frame 160

This sequence is a fragment of the "Ice Age" cartoon that contains two parts: the first part includes chaotic, intense motion and the second part contains a static background with chaotic motion in the foreground. In terms of compression, this sequence is difficult because its motion characteristics can be difficult to estimate and compensate.

9.2.4 “Lord of the Rings”

Sequence title	Lord of the Rings
Resolution	720x416
Number of frames	292
Color space	YV12
Frames per second	24
Source	MPEG-2 (DVD)

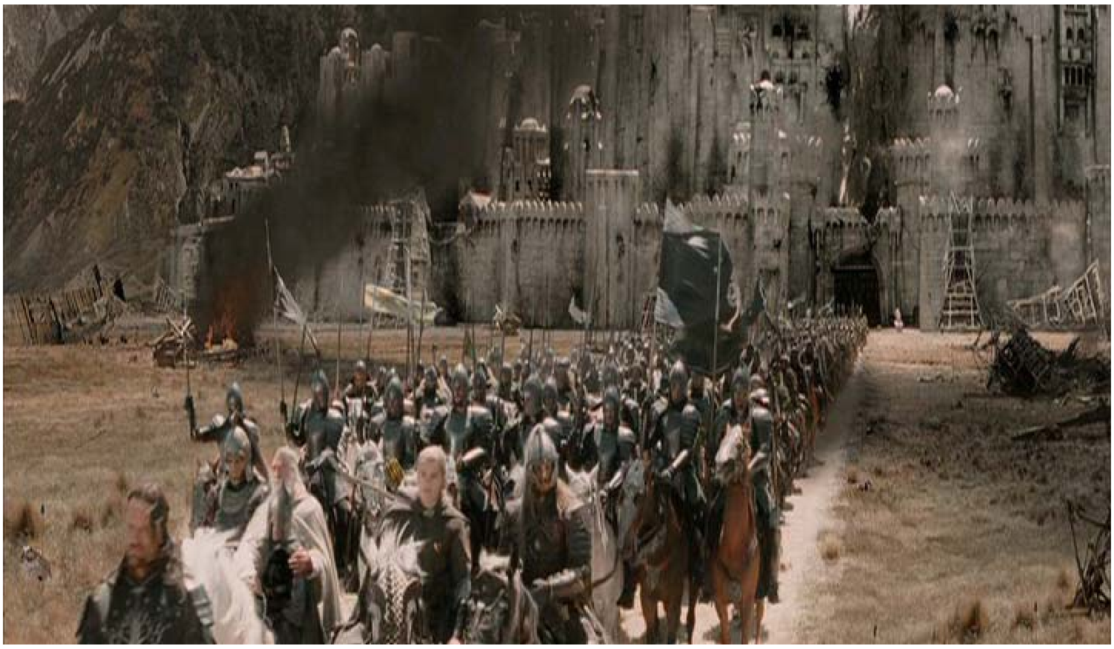


Figure 195. Lord of the Rings sequence, frame 100

This sequence is a fragment of the “Lord of the Rings” movie. The sequence contains two parts: the first part includes a static background with slow-moving foreground containing many small details, and the second part shows up-close faces that are constantly moving. In terms of compression, this sequence is not very difficult, but, because of the two different parts, some codecs might have difficulties in compression when not using correct internal encoding parameters.

9.3 HDTV Sequences

9.3.1 "Troy"

Sequence title	Troy
Resolution	1920x1072
Number of frames	300
Color space	YV12
Frames per second	24
Source	MPEG-2 (DVD)

Figure 196. Troy sequence, frame 1

This sequence is a fragment of the "Troy" movie and contains three parts with sharp scene changes. The video includes medium scene motion and slow camera motion. In terms of compression, this sequence is difficult to compress because of the many small details.

9.3.2 "Matrix"

Sequence title	Matrix
Resolution	1920x1072
Number of frames	250
Color space	YV12
Frames per second	30
Source	MPEG-2 (DVD)

Figure 197. Matrix sequence, frame 1

This sequence is a fragment of the "Matrix" movie. The video is a portion of the fight between Neo and Morpheus, and it contains fast scene motion and moderate camera motion. The video is difficult to compress because of strong chaotic motion and many small details.

10 Appendix 5. Tested Codecs and Presets

10.1 Codecs

10.1.1 MainConcept H.264/AVC encoder

- Console encoding program
- Reference decoder JM 9.8 was used for decoding
- Codec and presets were provided by MainConcept AG Company specifically for this test

Remarks:

No remarks.

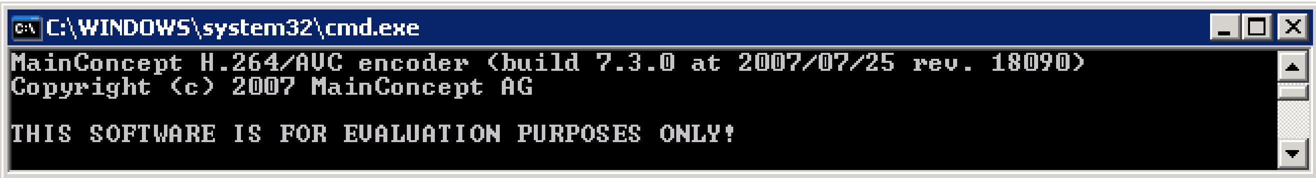


Figure 198. MainConcept H.264/AVC encoder

10.1.2 AMD H.264/AVC encoder

- Console encoding program
- Reference decoder JM 9.8 was used for decoding
- Codec and presets were provided by Advanced Micro Devices, Inc. specifically for this test

Remarks:

No remarks.

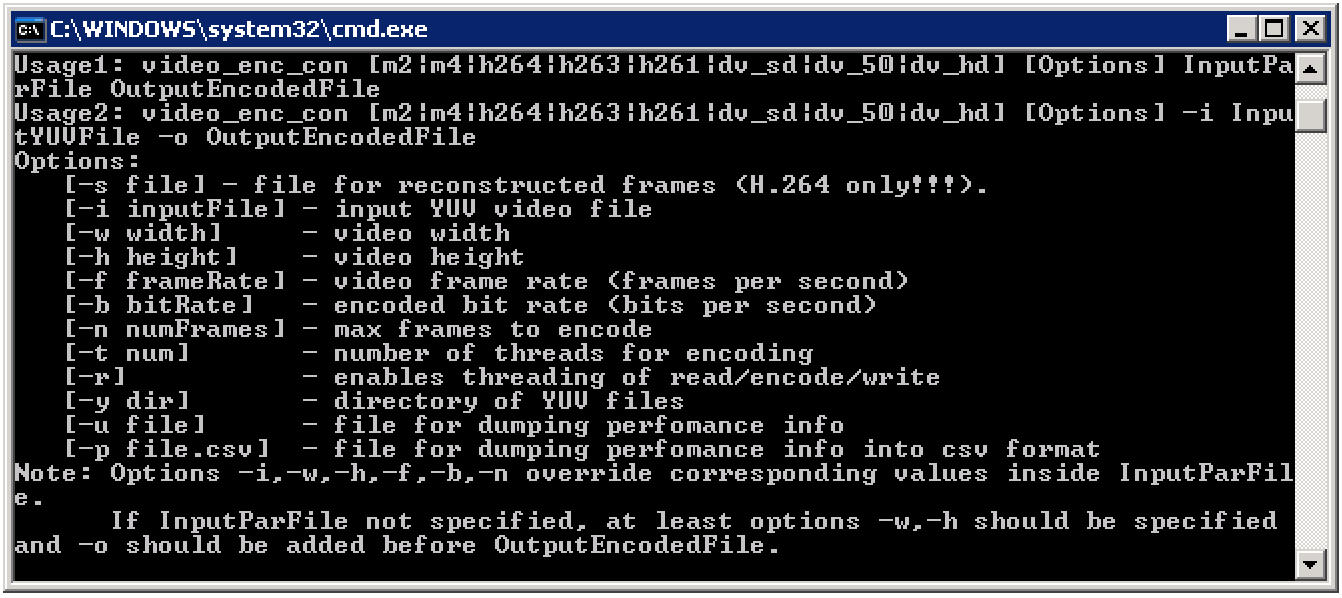
Figure 199. AMD H.264/AVC encoder

10.1.3 Intel H.264 enc

- Console encoding program based on Intel(r) IPP v. 5.1
- Reference decoder JM 9.8 was used for decoding
- Codec and presets were provided by Intel Corp specifically for this test

Remarks:

No remarks.



```
C:\WINDOWS\system32\cmd.exe
Usage1: video_enc_con [m2|m4|h264|h263|h261|dv_sd|dv_50|dv_hd] [Options] InputPa
rFile OutputEncodedFile
Usage2: video_enc_con [m2|m4|h264|h263|h261|dv_sd|dv_50|dv_hd] [Options] -i Inpu
tYUVFile -o OutputEncodedFile
Options:
   [-s file] - file for reconstructed frames (H.264 only!!!).
   [-i inputFile] - input YUV video file
   [-w width]     - video width
   [-h height]    - video height
   [-f frameRate] - video frame rate (frames per second)
   [-b bitRate]   - encoded bit rate (bits per second)
   [-n numFrames] - max frames to encode
   [-t num]       - number of threads for encoding
   [-r]           - enables threading of read/encode/write
   [-y dir]       - directory of YUV files
   [-u file]      - file for dumping perfomance info
   [-p file.csv]  - file for dumping perfomance info into csv format
Note: Options -i,-w,-h,-f,-b,-n override corresponding values inside InputParFil
e.
      If InputParFile not specified, at least options -w,-h should be specified
and -o should be added before OutputEncodedFile.
```

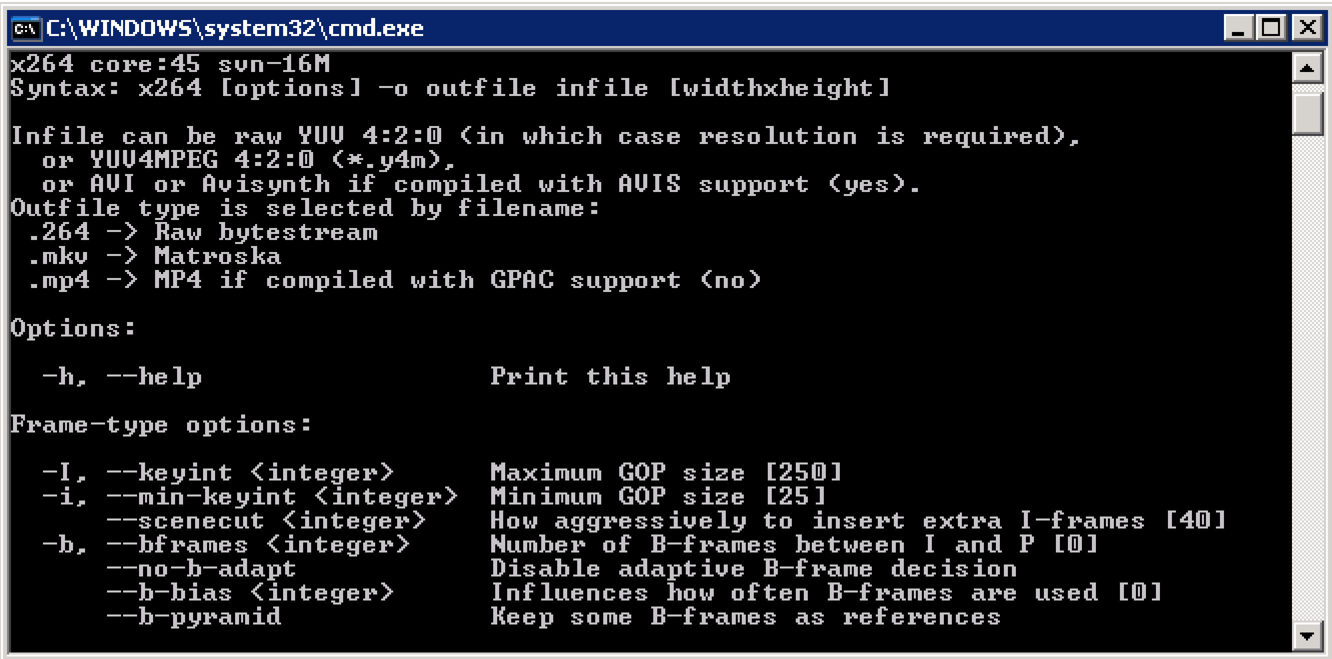
Figure 200. Intel H.264 encoder

10.1.4 Artemis x264 encoder

- Console encoding program
- Reference decoder JM 9.8 was used for decoding
- Codec and presets were provided by developers specifically for this test

Remarks:

No remarks.



```
C:\WINDOWS\system32\cmd.exe
x264 core:45 svn-16M
Syntax: x264 [options] -o outfile infile [widthxheight]

Infile can be raw YUV 4:2:0 (in which case resolution is required),
  or YUV4MPEG 4:2:0 (*.y4m),
  or AVI or Avisynth if compiled with AVIS support (yes).
Outfile type is selected by filename:
 .264 -> Raw bytestream
 .mkv -> Matroska
 .mp4 -> MP4 if compiled with GPAC support (no)

Options:

  -h, --help                  Print this help

Frame-type options:

  -I, --keyint <integer>      Maximum GOP size [250]
  -i, --min-keyint <integer>  Minimum GOP size [25]
      --scenecut <integer>    How aggressively to insert extra I-frames [40]
  -b, --bframes <integer>     Number of B-frames between I and P [0]
      --no-b-adapt            Disable adaptive B-frame decision
      --b-bias <integer>      Influences how often B-frames are used [0]
      --b-pyramid             Keep some B-frames as references
```

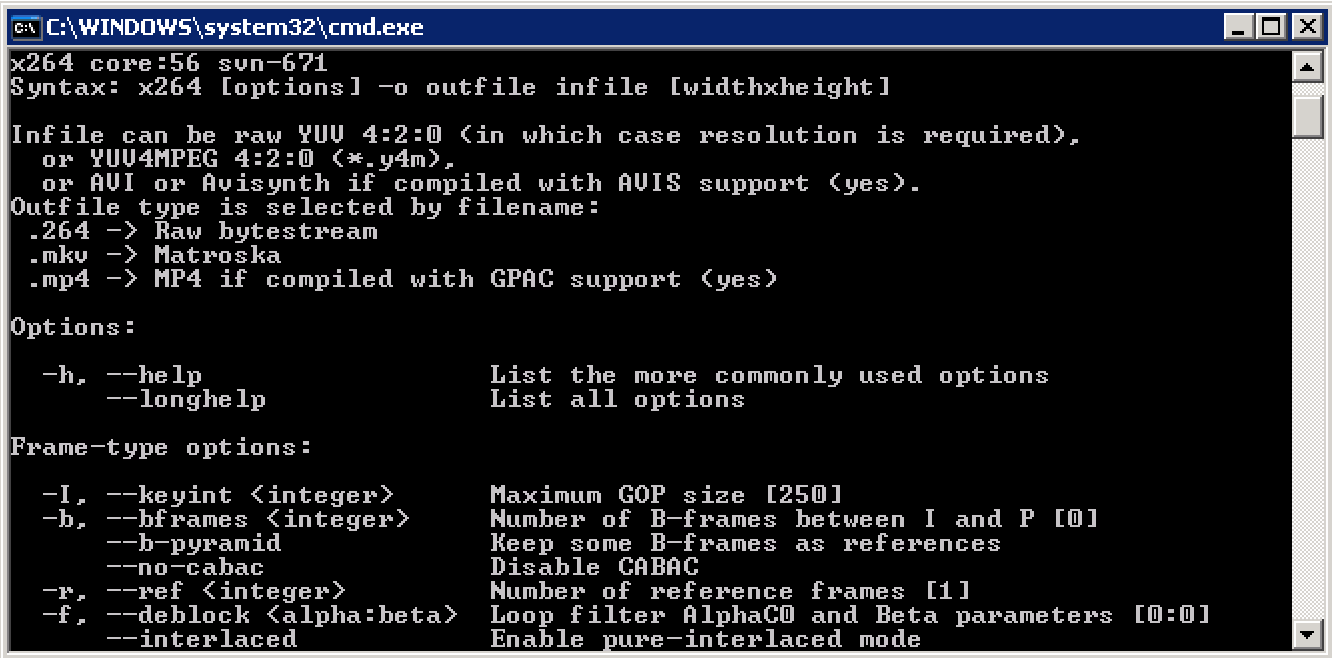
Figure 201. Artemis x264 encoder

10.1.5 x264 encoder

- Console encoding program
- Reference decoder JM 9.8 was used for decoding
- Codec and presets were provided by developers specifically for this test

Remarks:

No remarks.



```
C:\WINDOWS\system32\cmd.exe
x264 core:56 svn-671
Syntax: x264 [options] -o outfile infile [widthxheight]

Infile can be raw YUV 4:2:0 (in which case resolution is required),
  or YUV4MPEG 4:2:0 (*.y4m),
  or AVI or Avisynth if compiled with AVIS support (yes).
Outfile type is selected by filename:
 .264 -> Raw bytestream
 .mkv -> Matroska
 .mp4 -> MP4 if compiled with GPAC support (yes)

Options:

  -h, --help                  List the more commonly used options
      --longhelp              List all options

Frame-type options:

  -I, --keyint <integer>      Maximum GOP size [250]
  -b, --bframes <integer>     Number of B-frames between I and P [0]
      --b-pyramid             Keep some B-frames as references
      --no-cabac              Disable CABAC
  -r, --ref <integer>         Number of reference frames [1]
  -f, --deblock <alpha:beta>  Loop filter AlphaC0 and Beta parameters [0:0]
      --interlaced            Enable pure-interlaced mode
```

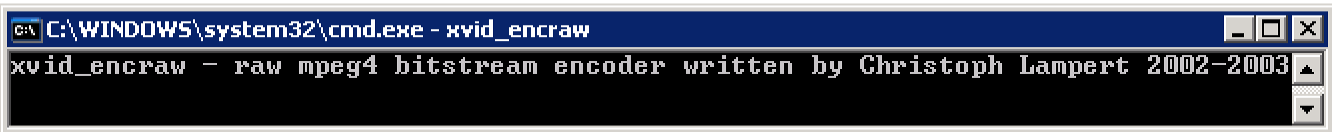
Figure 202. x264 encoder

10.1.6 Xvid encoder

- Console encoding program
- Codec and presets were provided by developers especially for this test

Remarks:

No remarks.



```
C:\WINDOWS\system32\cmd.exe - xvid_encraw
xvid_encraw - raw mpeg4 bitstream encoder written by Christoph Lampert 2002-2003
```

Figure 203. Xvid encoder

10.2 Presets

The table below lists the settings used in this comparison for all of the codecs.

Codec	Preset Name	Preset
Xvid	VideoConference "High Speed"	-max_bframes 2 -quality 6 -vhqmode 1 -bvhq -qpel -turbo -single
	VideoConference "High Quality"	-max_bframes 2 -quality 6 -vhqmode 4 -bvhq -qpel -turbo -single
	Movie "High Speed"	-max_bframes 2 -quality 6 -vhqmode 1 -bvhq -single
	Movie "High Quality"	-max_bframes 2 -quality 6 -vhqmode 4 -bvhq -gmc -single
	HDTV "High Speed"	-max_bframes 2 -quality 6 -vhqmode 1 -bvhq -turbo -single
	HDTV "High Quality"	-max_bframes 2 -quality 6 -vhqmode 4 -bvhq -gmc -single
MainConcept	VideoConference "High Speed"	BFramesCount = 1 BFramesReference = 0 PyramidCoding = 0 NumRefFrames = 2 FastIntraDecision = 1 FastInterDecision = 1 FastMRME = 1 FastSBME = 0
	VideoConference "High Quality"	BFramesCount = 3 BFramesReference = 1 PyramidCoding = 1 NumRefFrames = 4 FastIntraDecision = 0 FastInterDecision = 0 FastMRME = 0 FastSBME = 1
	Movie "High Speed"	BFramesCount = 1 BFramesReference = 0 PyramidCoding = 0
	Movie "High Quality"	BFramesCount = 3 BFramesReference = 1 PyramidCoding = 1
	HDTV "High Speed"	BFramesCount = 1 BFramesReference = 0 PyramidCoding = 0 NumRefFrames = 2 InsaneRDO = 0 FastIntraDecision = 1 FastInterDecision = 1 FastSBME = 1
	HDTV "High Quality"	BFramesCount = 3 BFramesReference = 1 PyramidCoding = 1

		NumRefFrames = 4 InsaneRDO = 1 FastIntraDecision = 0 FastInterDecision = 0 FastSBME = 0
AMD	“High Speed”	FramesInGOP = 60 IPFrameDistance = 1
	“High Quality”	FramesInGOP = 15 IPFrameDistance = 3
Intel	VideoConference “High Speed”	1 //subblock split 4 // search_x, 4 // search_y 0
	VideoConference “High Quality”	2 //subblock split 8 // search_x, 8 // search_y 1
	Movie “High Speed”	1 //num_ref_frames (2-16) 1 //subblock split 16 // search_x, 16 // search_y 0
	Movie “High Quality”	3 //num_ref_frames (2-16) 2 //subblock split 12 // search_x, 12 // search_y 1
	HDTV “High Speed”	1 //number of B frames between I (or P) and the next P 2 //num_ref_frames (2-16) 0 //subblock split 8 // search_x, 8 // search_y 1
	HDTV “High Quality”	2 //number of B frames between I (or P) and the next P 6 //num_ref_frames (2-16) 1 //subblock split 12 // search_x, 12 // search_y 3
Artemis x264	VideoConference “High Speed”	--bframes=4 --b-pyramid -8 -A --mixed-refs --i-predmax 352 --p-predmax 384 -r 2
	Movie “High Speed”	--bframes=4 --b-pyramid -8 -A --mixed-refs --i-predmax 352 --p-predmax 384 -r 2
	HDTV “High Speed”	--bframes=4 --b-pyramid -8 -A --mixed-refs --i-predmax 352 --p-predmax 384 -r 2 --me umh --merange=18
x264	VideoConference “High Speed”	--bframes=3 --b-pyramid --8x8dct --mixed-refs --keyint=500 --no-b-adapt

		--scenecut=10 --subme=4 --ref=3
	VideoConference “High Quality”	--bframes=3 --b-pyramid --8x8dct --mixed-refs --keyint=500 --no-b-adapt --scenecut=10 --subme=6 --ref=3 --b-rdo --me umh --merange=8
	Movie “High Speed”	--bframes=3 --b-pyramid --8x8dct --mixed-refs --keyint=500 --subme=4 --ref=3 --trellis=1
	Movie “High Quality”	First pass: --bframes=3 --b-pyramid --8x8dct --mixed-refs --keyint=500 --pass=1 --direct=auto --subme=1 Second pass: --bframes=3 --b-pyramid --8x8dct --mixed-refs --keyint=500 --pass=2 --direct=auto --subme=7 --ref=5 --trellis=1 --b-rdo --me=umh --merange=16 --bime --no-fast-pskip
	HDTV “High Speed”	--bframes=3 --b-pyramid --8x8dct --mixed-refs --keyint=500 --subme=4 --ref=2 --trellis=1 --me=umh --merange=12
	HDTV “High Quality”	First pass: --bframes=3 --b-pyramid --8x8dct --mixed-refs --keyint=500 --pass=1 --direct=auto --subme=1 Second pass: --bframes=3 --b-pyramid --8x8dct --mixed-refs --keyint=500 --pass=2 --direct=auto --subme=7 --ref=6 --trellis=2 --b-rdo --me=umh --merange=24 --bime --no-fast-pskip

11 Appendix 6. Figures Explanation

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

11.1.1.1 RD curves

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

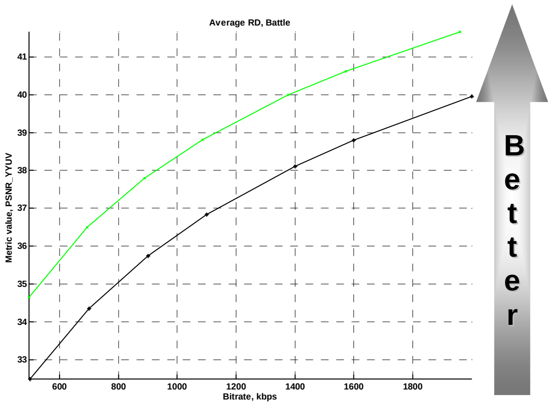
11.1.1.2 Relative Bitrate/Relative Time Charts

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

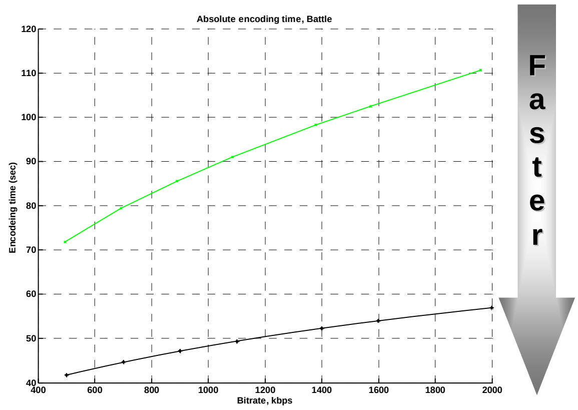
The X-axis shows the relative encoding time for the codec under test. Larger values indicate a slower codec. For example, a value of 2.5 means that the codec under test works 2.5 times slower, on average, than the reference codec.

11.1.1.3 Graph Example

Figure 204 shows a case where these graphs can be useful. In the top left graph, it is apparent that the “Green” codec encodes with significantly 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: it is clearly visible in the bottom graph that one of the codecs is slower, but yields higher visual quality, and that the other codec is faster, but yields lower visual quality.



RD curve. "Green" codec is better!



Encoding time (seconds). "Green codec is slower!

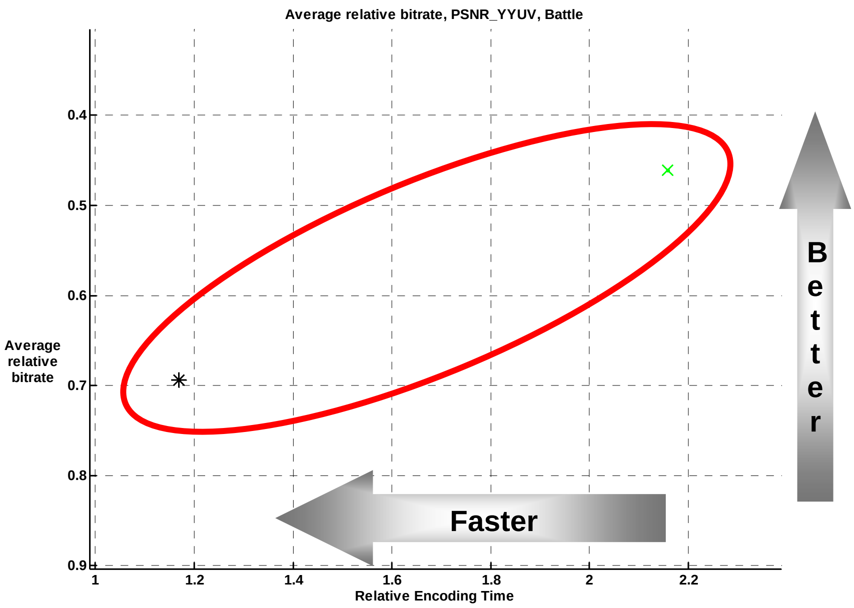


Figure 204. Integral situation with codecs. This plot shows the situation more clearly.

As a result of these advantages, relative bitrate/relative time graphs are used frequently in this report since they assist in the evaluation of the codecs in the test set, especially when number of codecs is large.

A more detailed description of the preparation of these graphs is given below.

11.2 Bitrates Ratio with the Same Quality

The first step in computing the average bitrate ratio for a fixed quality is inversion of the axes of the bitrate/quality graph (see Figure 206). All further computations are performed using the inverted graph.

The second step involves averaging the interval over which the quality axis is chosen. Averaging is performed only over those segments for which there are results for both codecs. This limitation is due to the difficulty of developing extrapolation methods for classic RD curves; nevertheless, for interpolation of RD curves, even linear methods are acceptable.

The final step is calculation of the area under the curves in the chosen interpolation segment and determination of their ratio (see Figure 207). This result is an average bitrate ratio for a fixed quality for the two codecs. If more than two codecs are considered, then one of them is defined as a reference codec and the quality of others is compared to that of the reference.

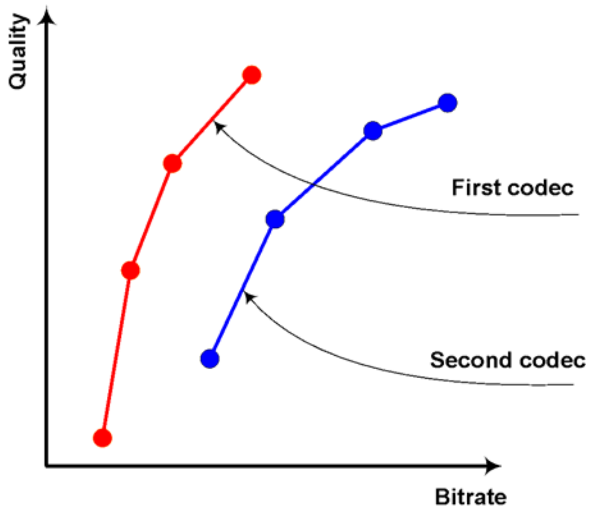


Figure 205. Source Data

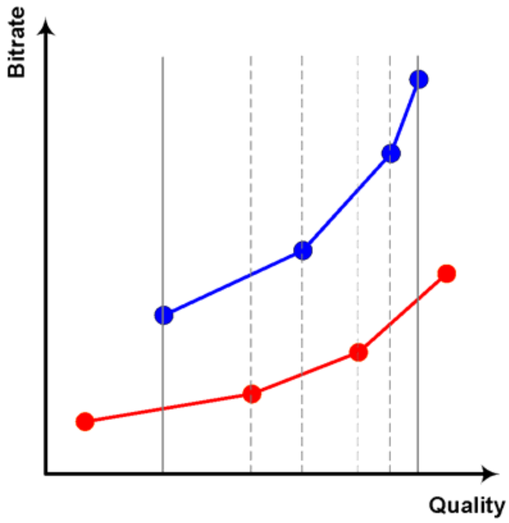


Figure 206. Axes' Inversion and Averaging Interval Choosing

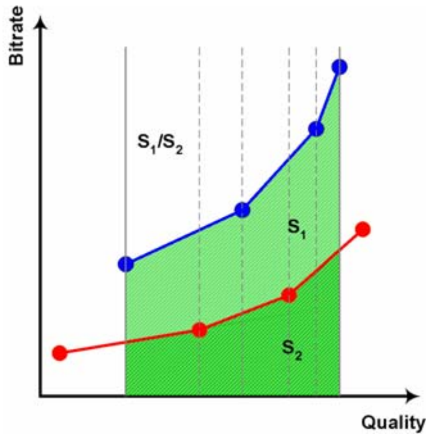


Figure 207. Areas' under Curves Ratio

11.3 Relative Codec Encoding Time Computation

To compute the relative processing time of two codecs for a particular video sequence, the encoding time is calculated for both codecs (the encoding times are summed for all bitrates) and the ratio is taken. For three or more codecs, one codec is chosen as a reference and the ratio of its encoding time to that of the others is calculated.

For multiple sequences, each codec is assigned an arithmetic mean of average relative encoding times for each sequence.

12 Appendix 7. Objective Quality Metrics Description

12.1 PSNR (Peak Signal-to-Noise Ratio)

12.1.1 Brief Description

This metric, which is often used in actual practice, is called the peak signal-to-noise ratio, or PSNR.

$$d(X,Y) = 10 \cdot \log_{10} \frac{255^2 \cdot m \cdot n}{\sum_{i=1, j=1}^{m,n} (x_{ij} - y_{ij})^2},$$

Where *d(X,Y)* – PSNR value between *X* and *Y* frames

x_{ij} – the pixel value for *(i,j)* position for the *X* frame

y_{ij} – the pixel value for *(i,j)* position for the *Y* frame

m,n – frame size *mxn*

Generally, this metric has the same form as the mean square error (MSE), but it is more convenient to use because of the logarithmic scale. It still has the same disadvantages as the MSE metric, however.

In MSU Video Quality Measurement Tool the PSNR can be calculated for all YUV and RGB components and for the L component of LUV color space. The PSNR value is quick and easy to calculate, but it is sometimes inappropriate as relates to human visual perception.

A maximum deviation of 255 is used for the PSNR for the RGB and YUV color components because, in YUV files, there is 1 byte for each color component. The maximum possible difference, therefore, is 255. For the LUV color space, the maximum deviation is 100.

The values of the PSNR in the LUV color space are in the range [0, 100]; the value 100 means that the frames are identical.

12.1.2 Examples

PSNR visualization uses different colors for better visual representation:

- Black – value is very small (99 – 100)
- Blue – value is small (35 – 99)
- Green – value is moderate (20 – 35)
- Yellow –value is high (17 – 20)
- Red –value is very high (0 – 17)

The following is an example of the PSNR metric:

Original Processed PSNR

Figure 208. PSNR example for two frames

The following are further examples demonstrating how various distortions can influence the PSNR value.

Original image

Image with added noise

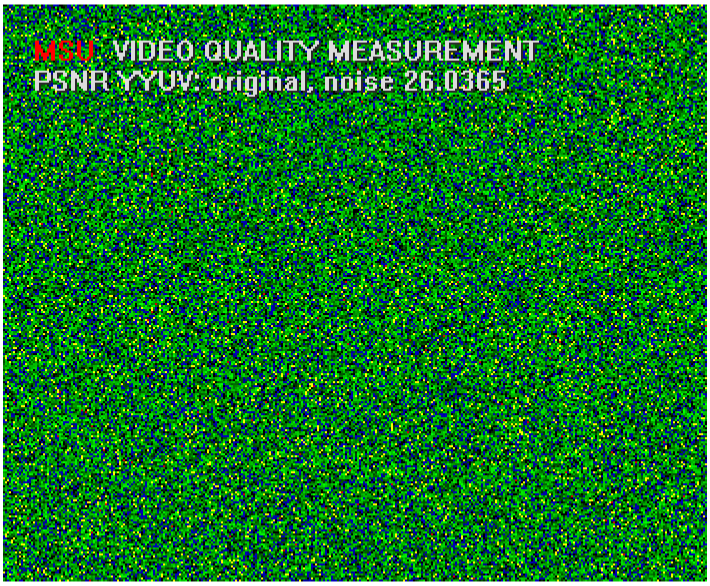
Blurred image

Sharpen image

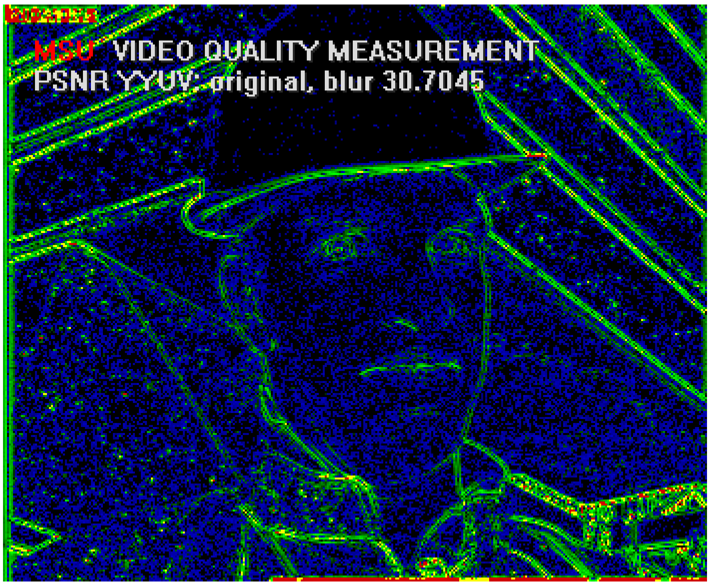
Figure 209. Original and processed images (for PSNR example)

Next are the PSNR values for the Y–plane for these images

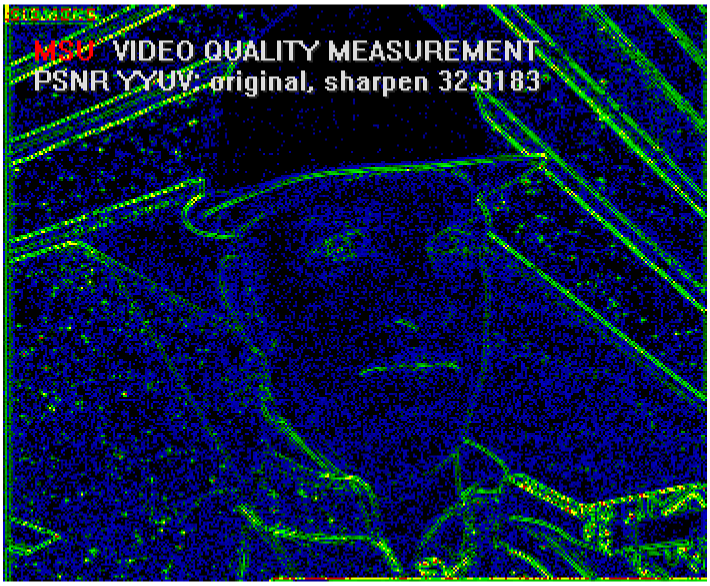
PSNR for image with itself, value = 0



PSNR for image with noisy image, value = 26.0365



PSNR for image with blurred image, value = 30.7045



PSNR for image with sharpen image, value = 32.9183

Figure 210. PSNR values for original and processed images

12.2 SSIM (Structural SIMilarity)

12.2.1 Brief Description

The original paper on the SSIM metric was published by Wang, et al.[1] The paper can be found at the following URL: http://ieeexplore.ieee.org/iel5/83/28667/01284395.pdf

The SSIM author homepage is found at the following URL: http://www.cns.nyu.edu/~lcv/ssim/

The scheme of SSIM calculation can be presented as follows. 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 the following:

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

where

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

$$\sigma_x=\left(\sum_{i=1}^{N}\omega_i(x_i-\mu_x)\right)^{\frac{1}{2}}$$

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

The constants C_1 and C_2 are defined according to the following expressions:

$$C_1=(K_1L)^2$$
$$C_2=(K_2L)^2$$

where L is the dynamic range of the pixel values (255 for 8-bit grayscale images), and $K_1, K_2 << 1$.

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

For the implementation used in this comparison, 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 of the advantages of the SSIM metric is that it better represents human visual perception than does PSNR. SSIM is more complex, however, and takes more time to calculate.

[1] 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.

12.2.2 Examples

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

Original Processed SSIM

Figure 211. SSIM example for compressed image

The following are more examples how various types of distortion influence the SSIM value.

Original image

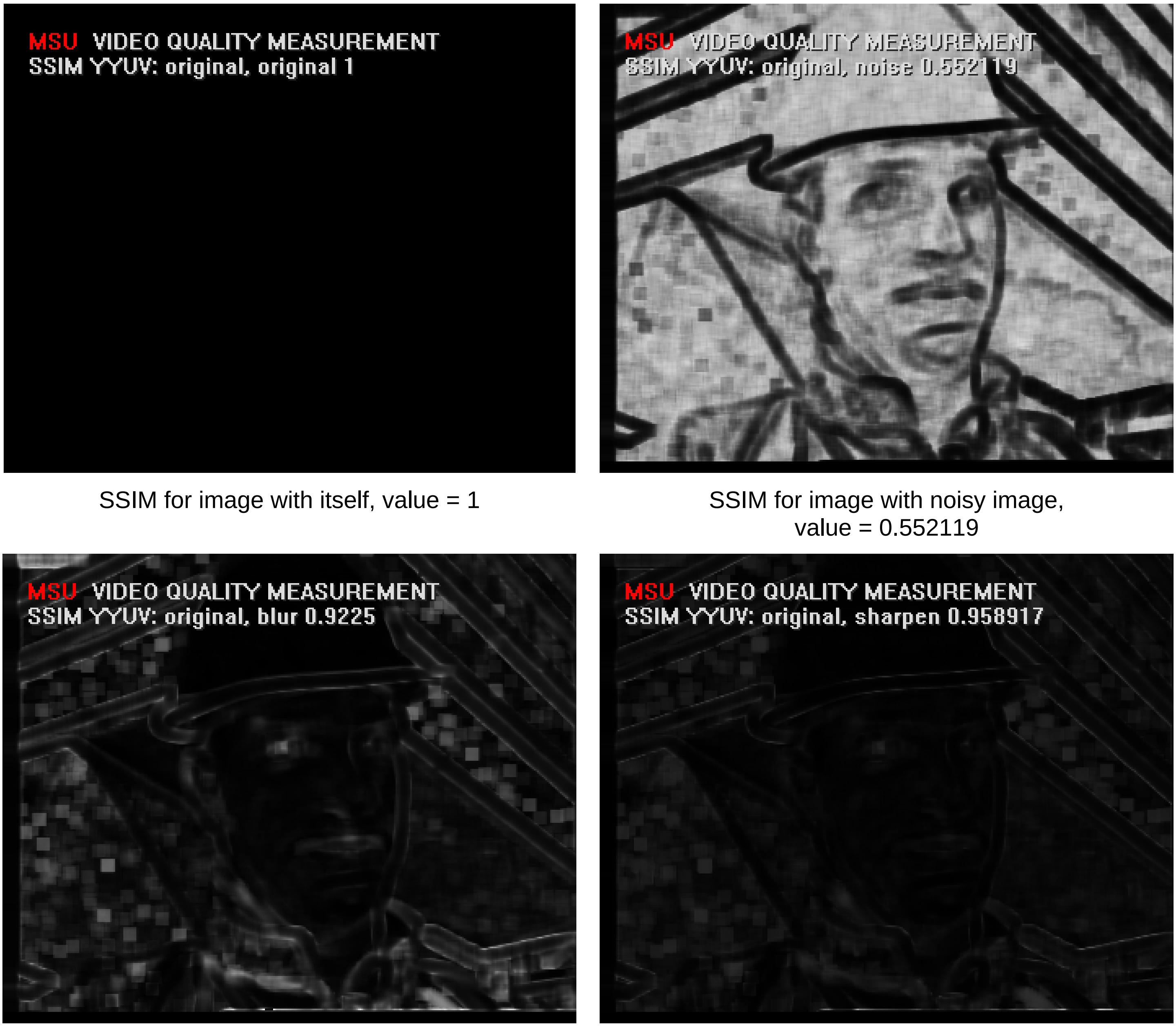
Image with added noise

Blurred image

Sharpen image

Figure 212. Original and processed images (for SSIM example)

The SSIM values for the Y-plane for these images are given below.



SSIM for image with itself, value = 1

SSIM for image with noisy image, value = 0.552119

SSIM for image with blurred image, value = 0.9225

SSIM for image with sharpen image, value = 0.958917

Figure 213. SSIM values for original and processed images

13 List of Figures

14 About the Graphics & Media Lab Video Group

GRAPHICS & MEDIA LAB
VIDEO GROUP

The Graphics & Media Lab Video Group is part of the Computer Science Department of 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