MPEG-4 AVC/H.264 Video Codecs Comparison

Advanced User 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**
- **Artemis x264 Development Team**

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

2 Overview

2.1 Difference between Short and Full Versions

This document is short freely distributed version of the comparison report. This version contains only few examples of figures and main comparison conclusions.

The following additional information is present in the full report version:

- Figures for all the tested sequences in every usage area;
- SSIM metric results;
- Video Conferences usage area detailed analysis (RD curves, bitrate handling, encoding speed, etc.)l
- HDTV usage area detailed analysis (RD curves, bitrate handling, encoding speed, etc.);
- Additional codecs analysis using synthetic sequences;
- List of codecs' settings for each preset;
- Codecs per-frame comparison.

Full version is available for download at the following web-page:

http://compression.ru/video/codec_comparison/mpeg-4_avc_h264_2007_en.html

2.2 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. Ice Age	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 2. Test Set of Video Sequences.

2.3 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 3. Tested Codecs.

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

An example of High Quality preset results is presented in Figure 1. 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. 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.

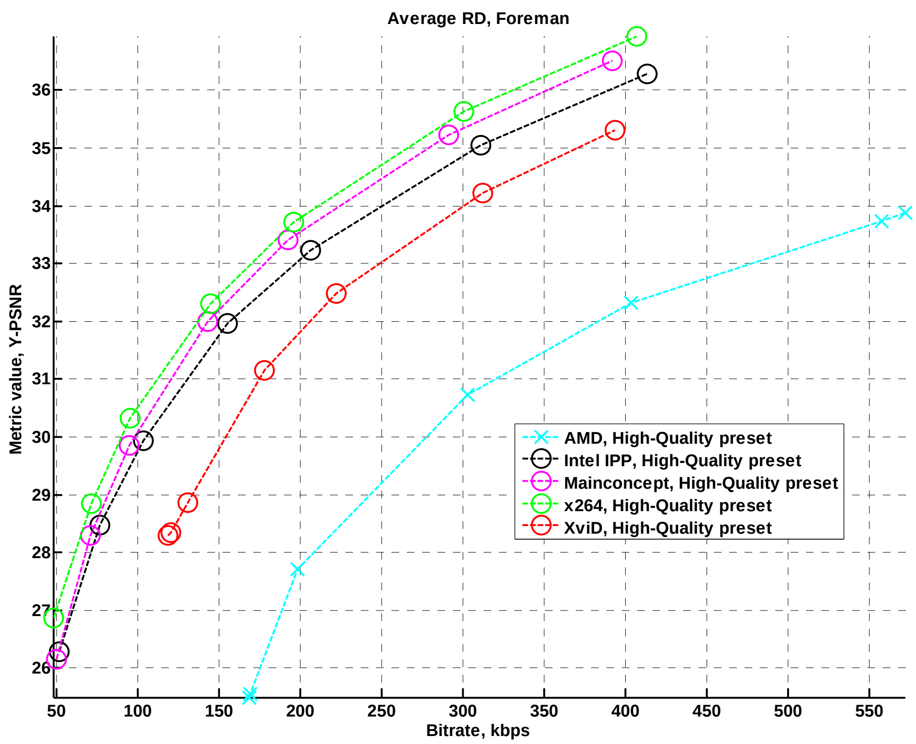


Figure 1. Bitrate/Quality. Usage area “Video Conferences”, “Foreman” sequence, “High Quality” preset, Y-PSNR

4.1.1.2 High Speed Preset

An example of RD curve for the High Speed preset is shown in Figure 2. 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.

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.

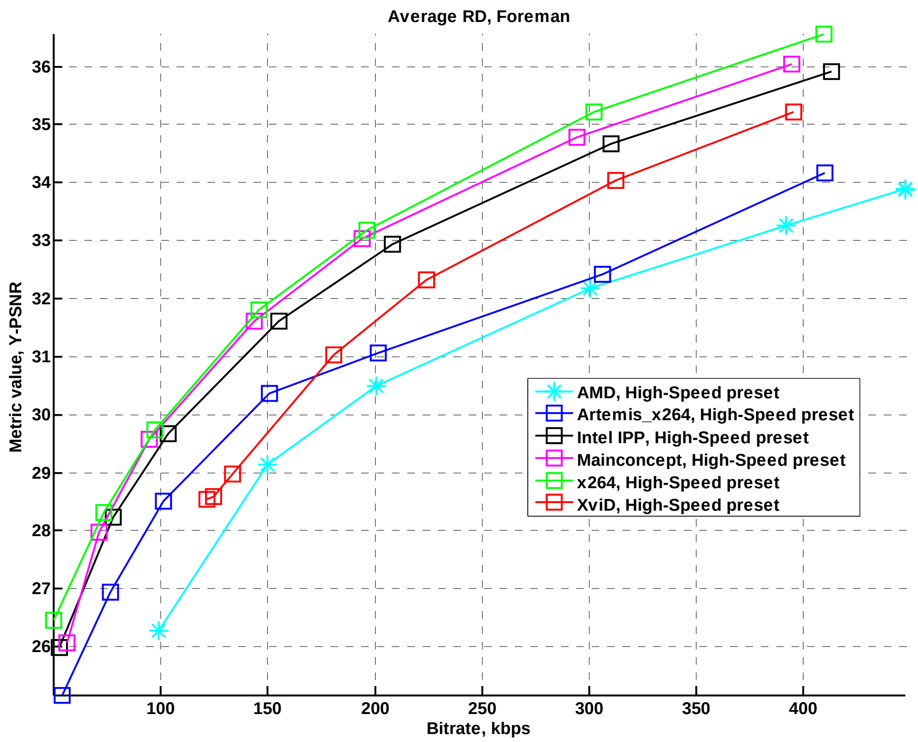


Figure 2. Bitrate/Quality. Usage area “Video Conferences”, “Foreman” sequence, “High Speed” preset, Y-PSNR

4.1.2 Encoding Speed

Examples of absolute speed results are presented in Figure 3 through Figure 6. 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.

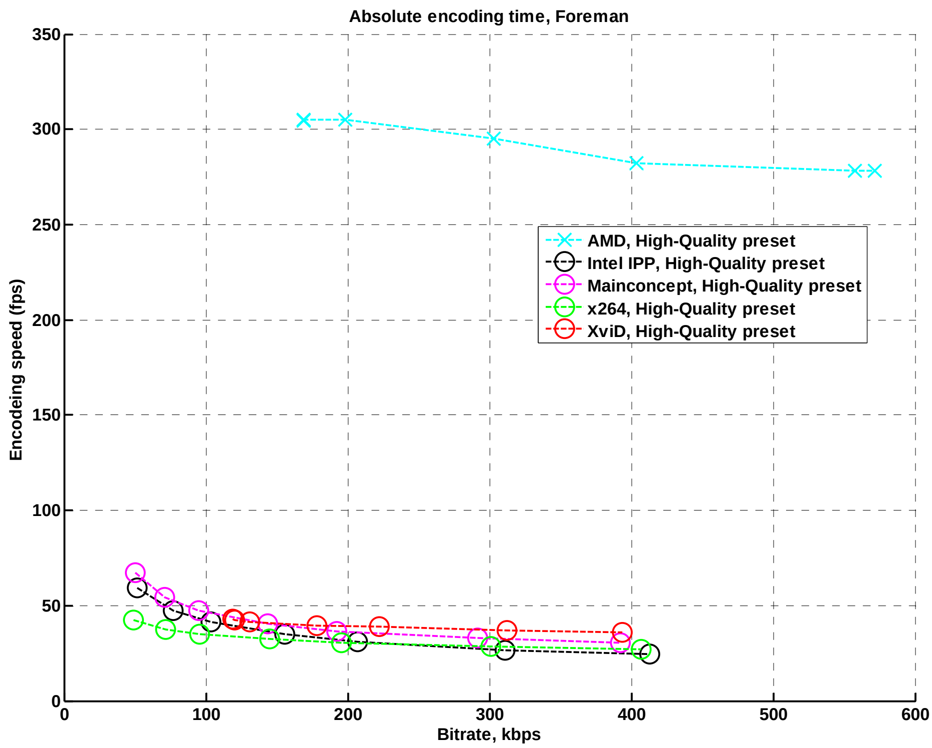


Figure 3. Encoding speed. Usage area “Video Conferences”, “Foreman” sequence, “High Quality” preset

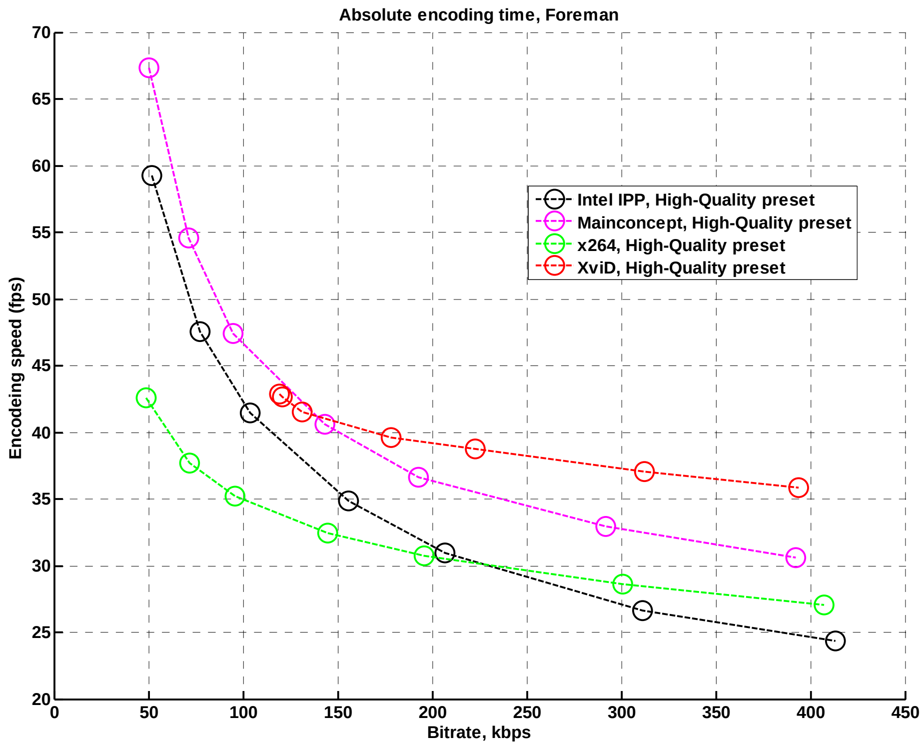


Figure 4. Encoding speed. Usage area “Video Conferences”, “Foreman” sequence, “High Quality” preset. All encoders except AMD

4.1.2.1 High Speed Preset

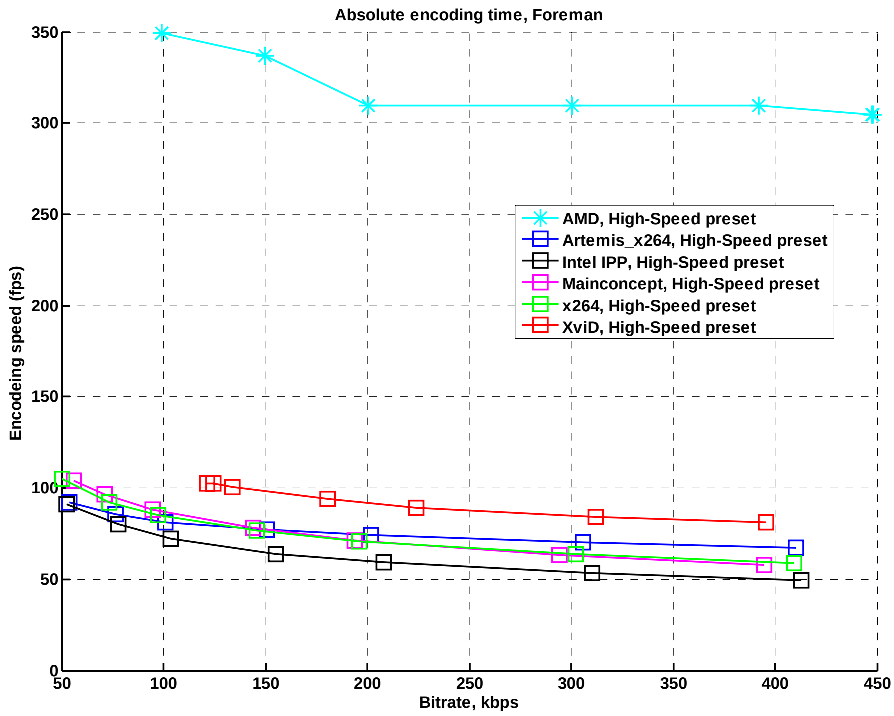


Figure 5. Encoding speed. Usage area “Video Conferences”, “Foreman” sequence, “High Speed” preset

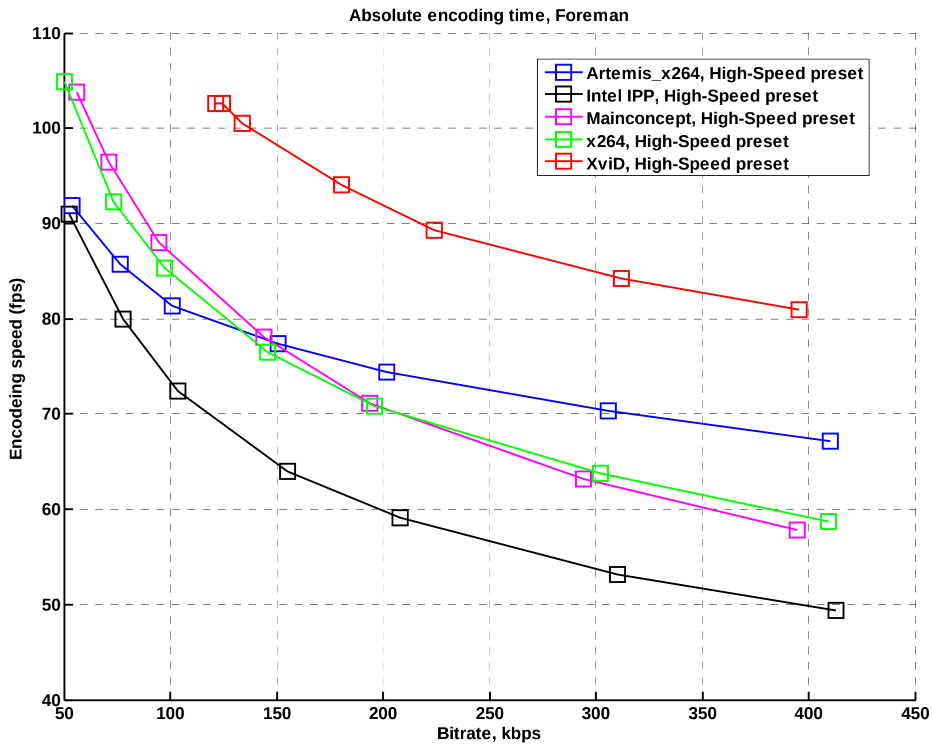


Figure 6. Encoding speed. Usage area "Video Conferences", "Foreman" sequence, "High Speed" preset. All encoders except AMD

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 4. 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 7 and Figure 8 are examples of the results 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.

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.

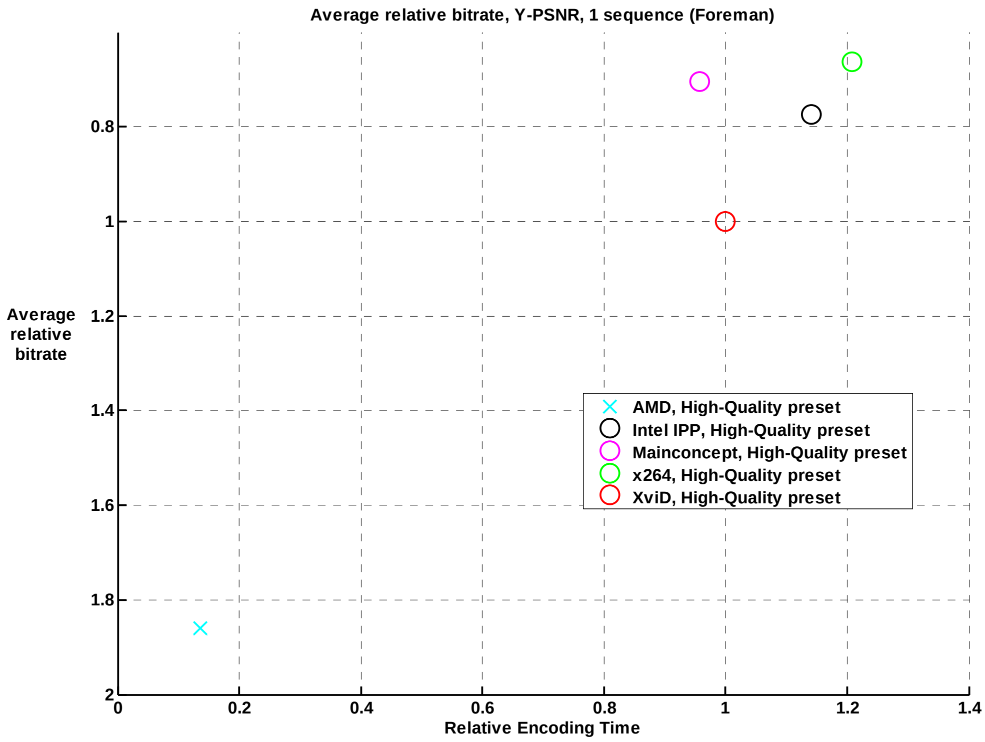


Figure 7. Speed/Quality tradeoff. Usage area "Video Conferences", "Foreman" sequence, "High Quality" preset, Y-PSNR

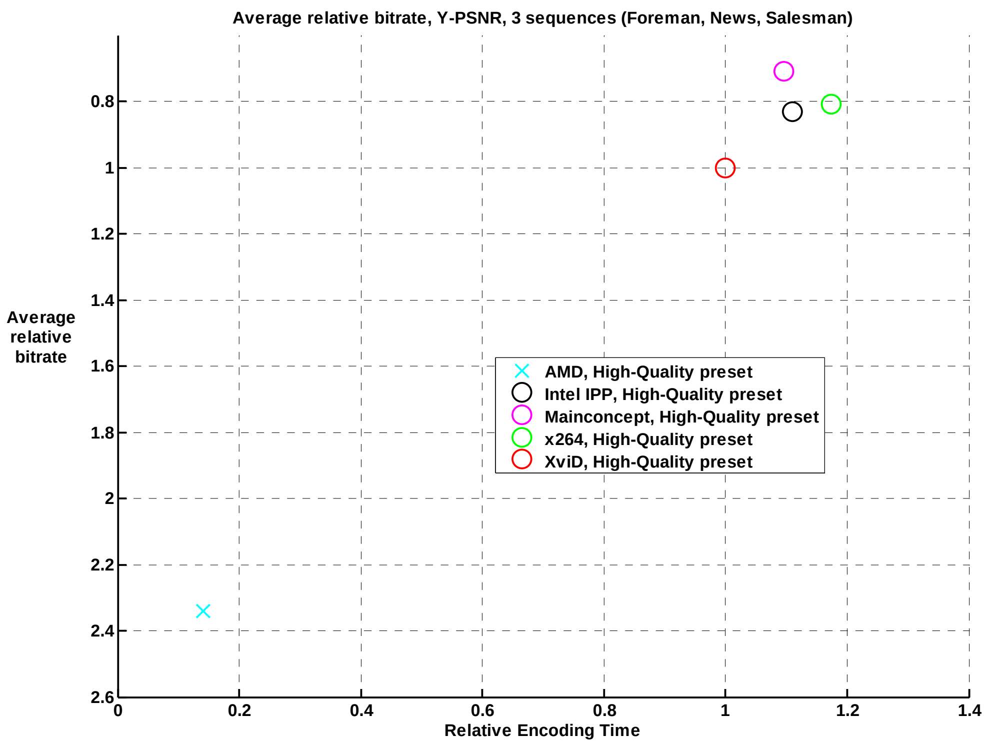


Figure 8. Speed/Quality tradeoff. Usage area "Video Conferences", all sequences, "High Quality" preset, Y-PSNR

4.1.3.1 High Speed Preset

Figure 9 and Figure 10 show examples the results 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.

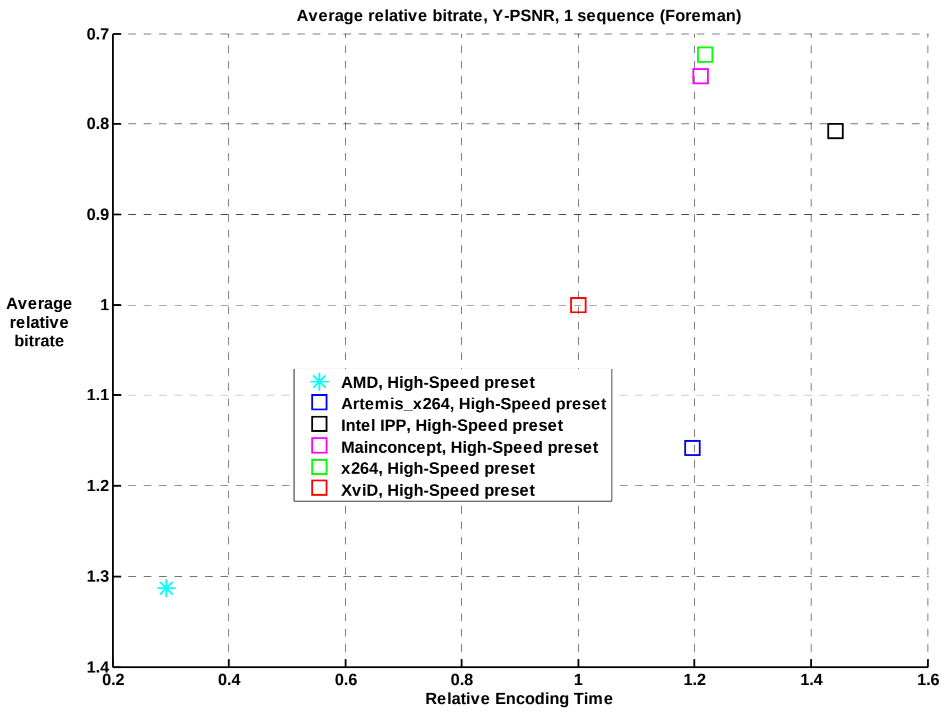


Figure 9. Speed/Quality tradeoff. Usage area "Video Conferences", "Foreman" sequence, "High Speed" preset, Y-PSNR

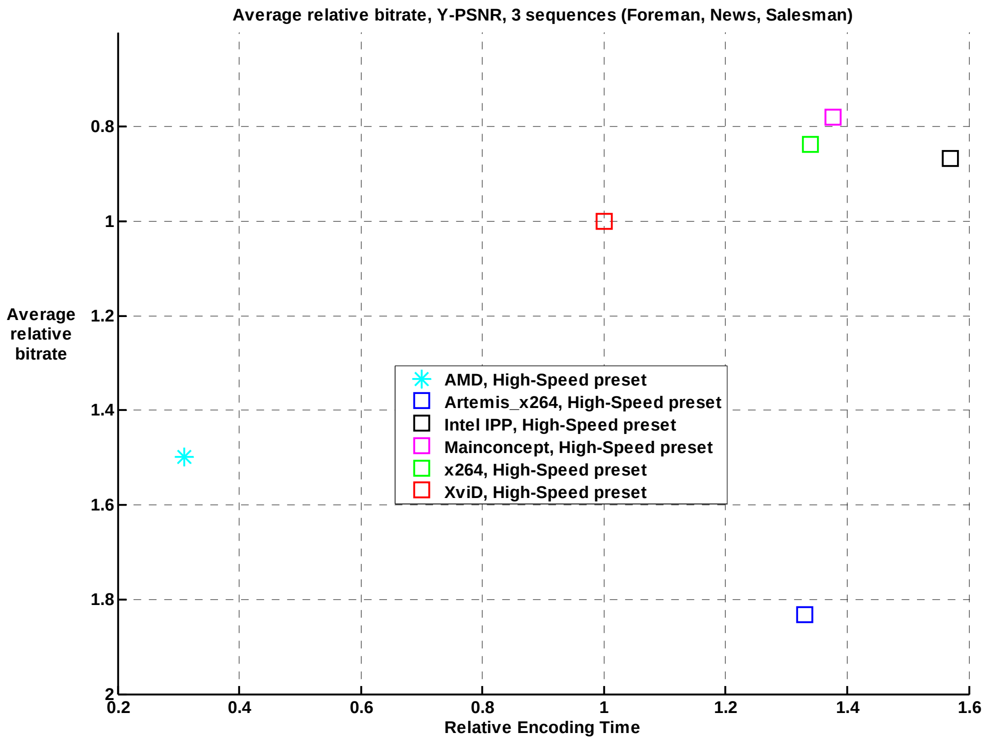


Figure 10. Speed/Quality tradeoff. Usage area "Video Conferences", all sequences, "High Speed" preset, Y-PSNR

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.

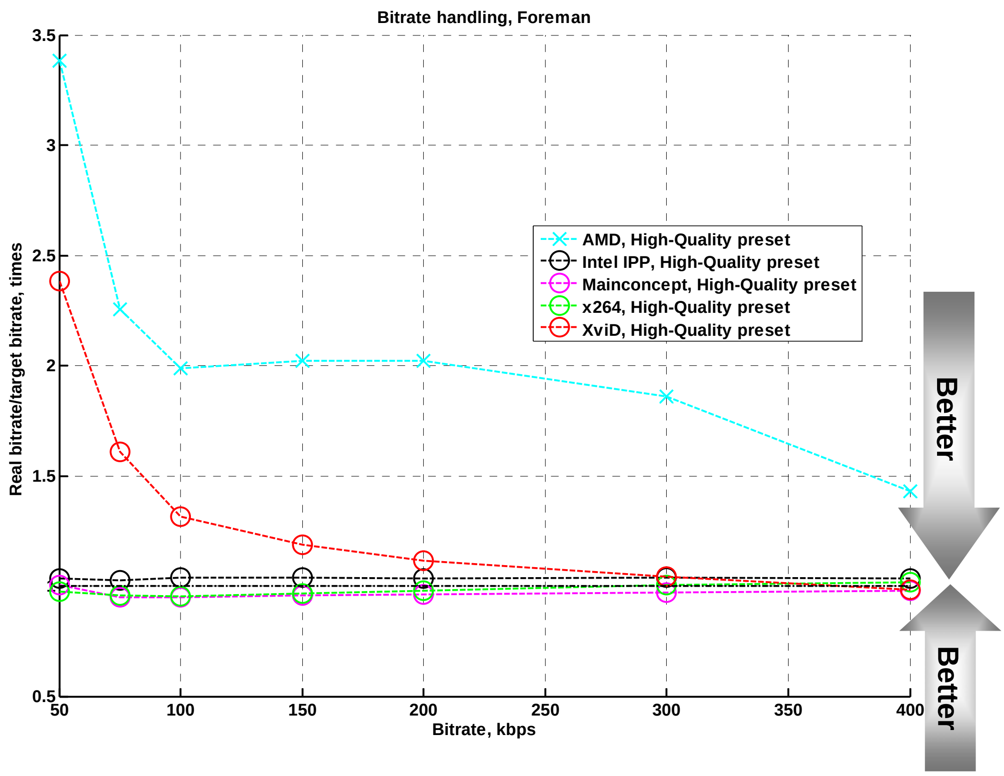


Figure 11. Bitrate Handling. Usage area “Video Conferences”, “Foreman” sequence, “High Quality” preset

4.1.4.1 High Speed Preset

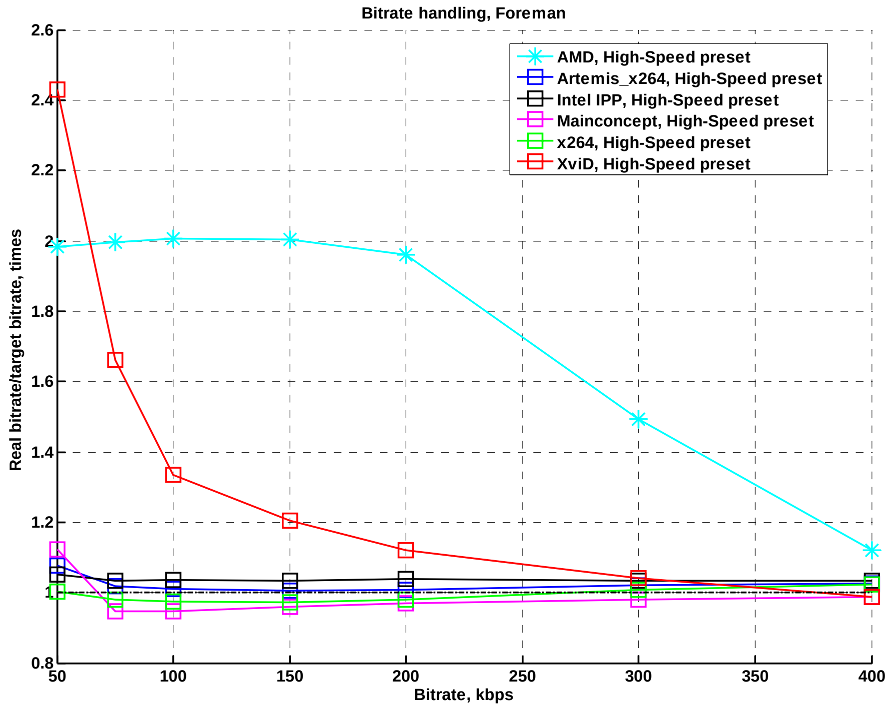


Figure 12. Bitrate Handling. Usage area "Video Conferences", "Foreman" sequence, "High Speed" preset

4.1.5 Relative Quality Analysis

Table 3 and Table 4 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 4. 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 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%

Figure 13 and Figure 14 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.

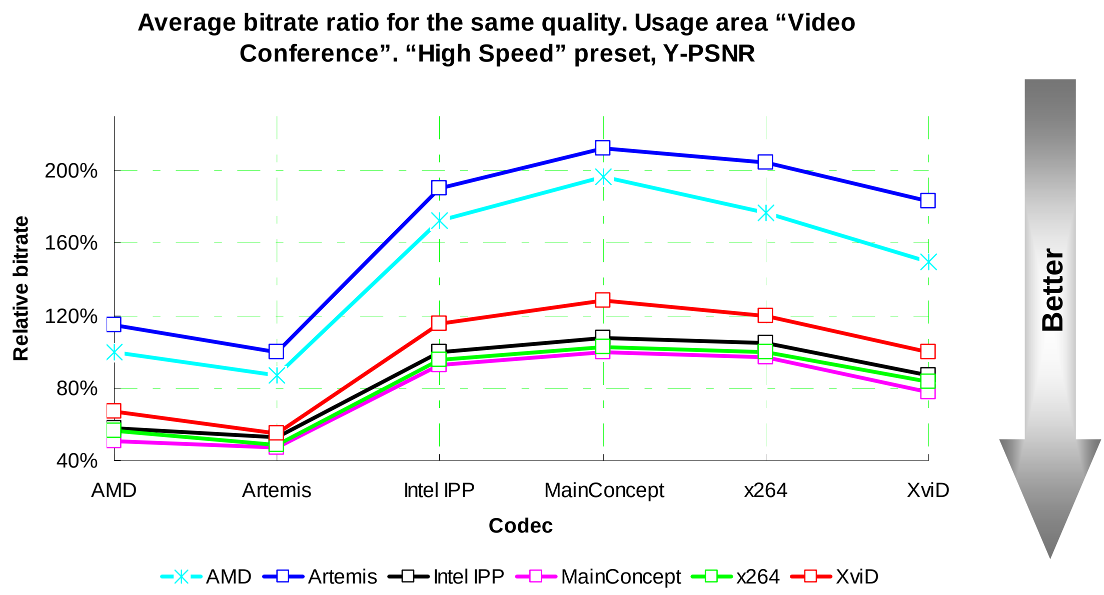


Figure 13. Average bitrate ratio for a fixed output quality using videoconference sequences and the High Speed preset (Y-PSNR metric).

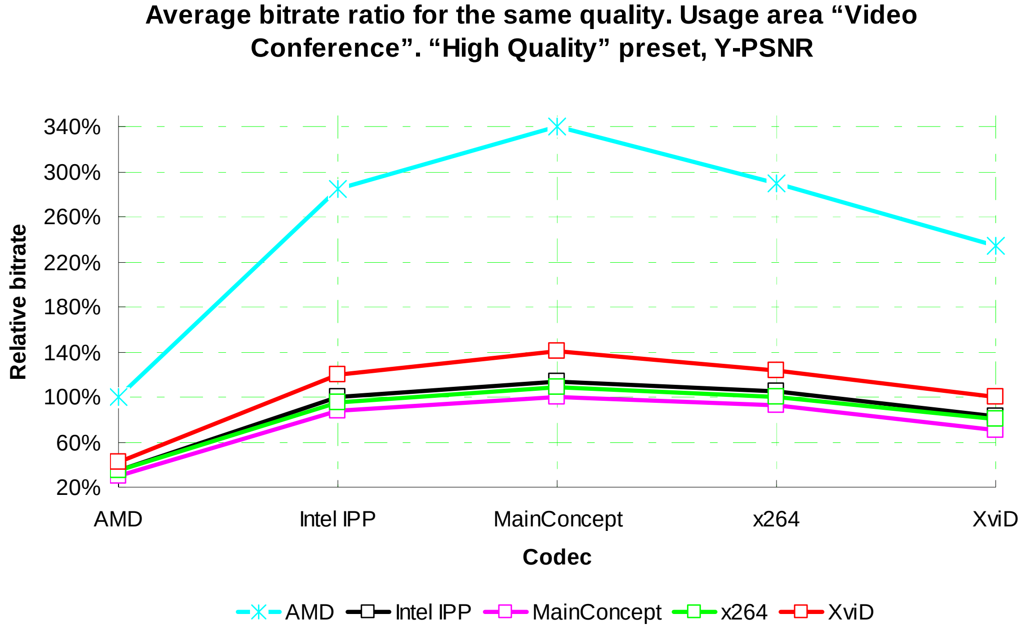


Figure 14. Average bitrate ratio for the same quality. Usage area “Video Conferences”. “High Quality” preset, Y-PSNR.

4.2 Movies

This is the short version of the report. Only few examples of figures and part of conclusions are present below. You can purchase the full version of the report at the comparison web-page.

4.2.1 RD Curves

Examples of the High Quality preset results are presented in Figure 15 and Figure 16. 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.

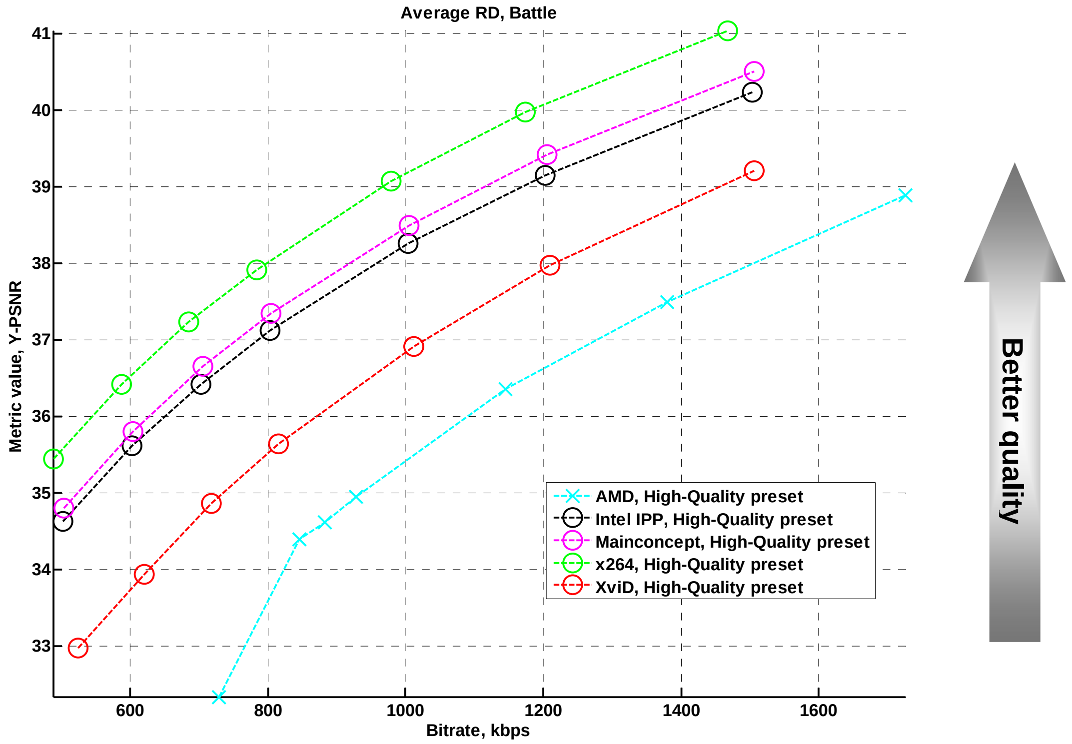


Figure 15. Bitrate/Quality. Usage area "Movies", "Battle" sequence, "High Quality" preset, Y-PSNR

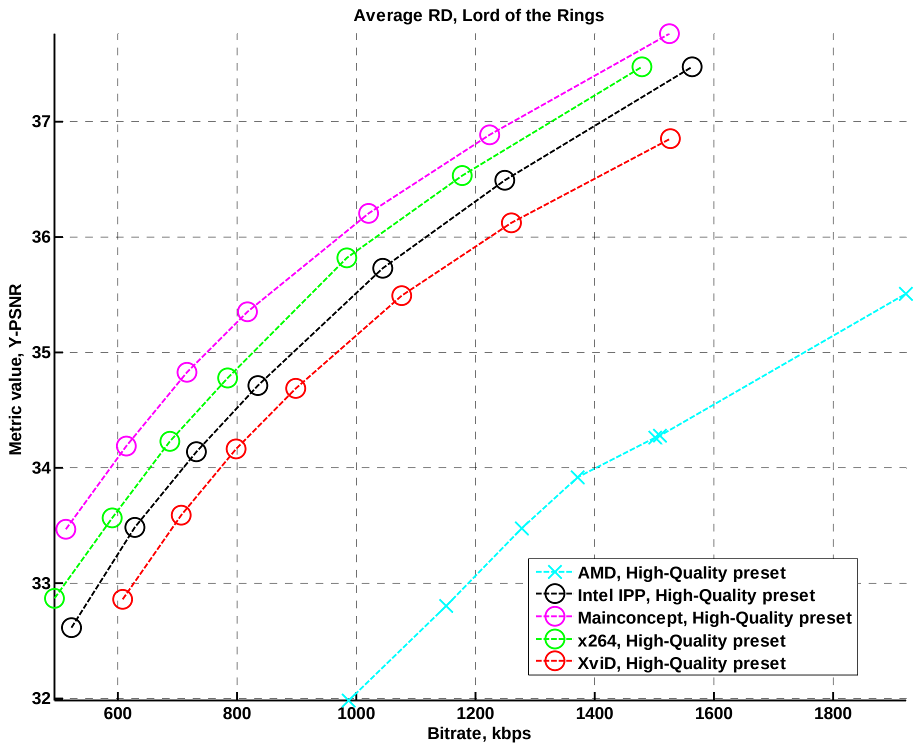


Figure 16. Bitrate/Quality. Usage area "Movies", "Lord of the Rings" sequence, "High Quality" preset, Y-PSNR

4.2.1.1 High Speed Preset

Examples of the RD curves for the High Speed preset are shown in Figure 17 and Figure 18. 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.

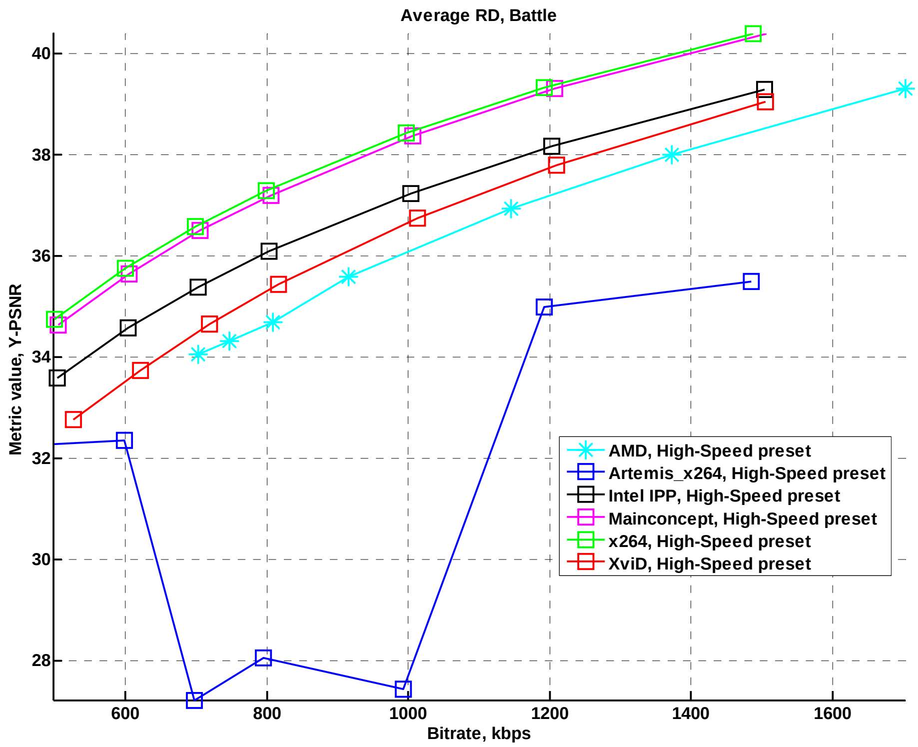


Figure 17. Bitrate/Quality. Usage area “Movies”, “Battle” sequence, “High Speed” preset, Y-PSNR

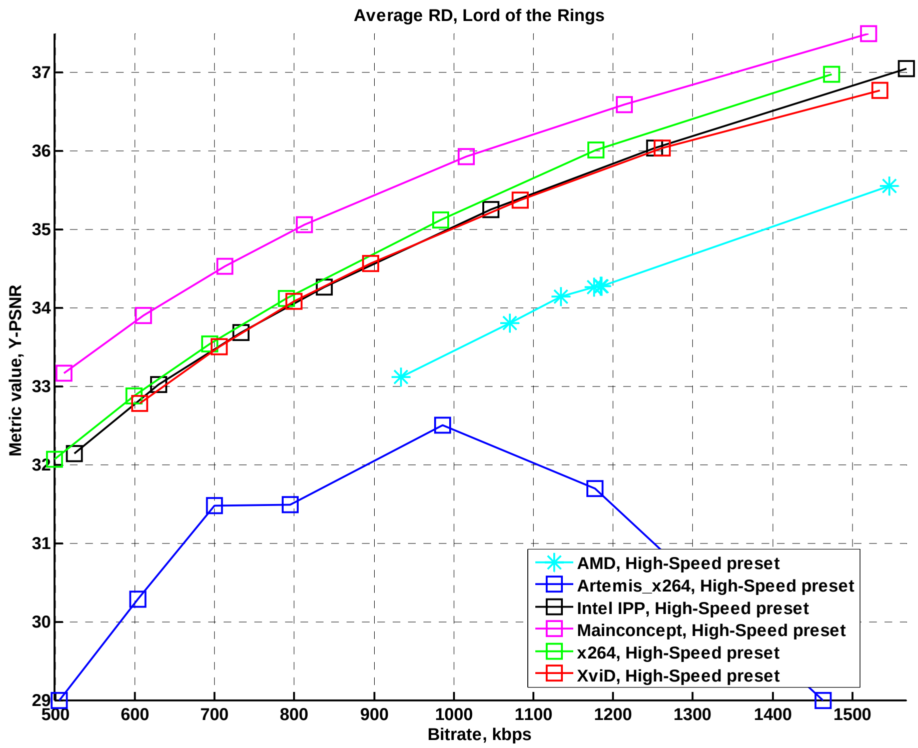


Figure 18. Bitrate/Quality. Usage area “Movies”, “Lord of the Rings” sequence, “High Speed” preset, Y-PSNR

4.2.2 Encoding Speed

Absolute speed results examples are presented in Figure 19 through Figure 22. 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.

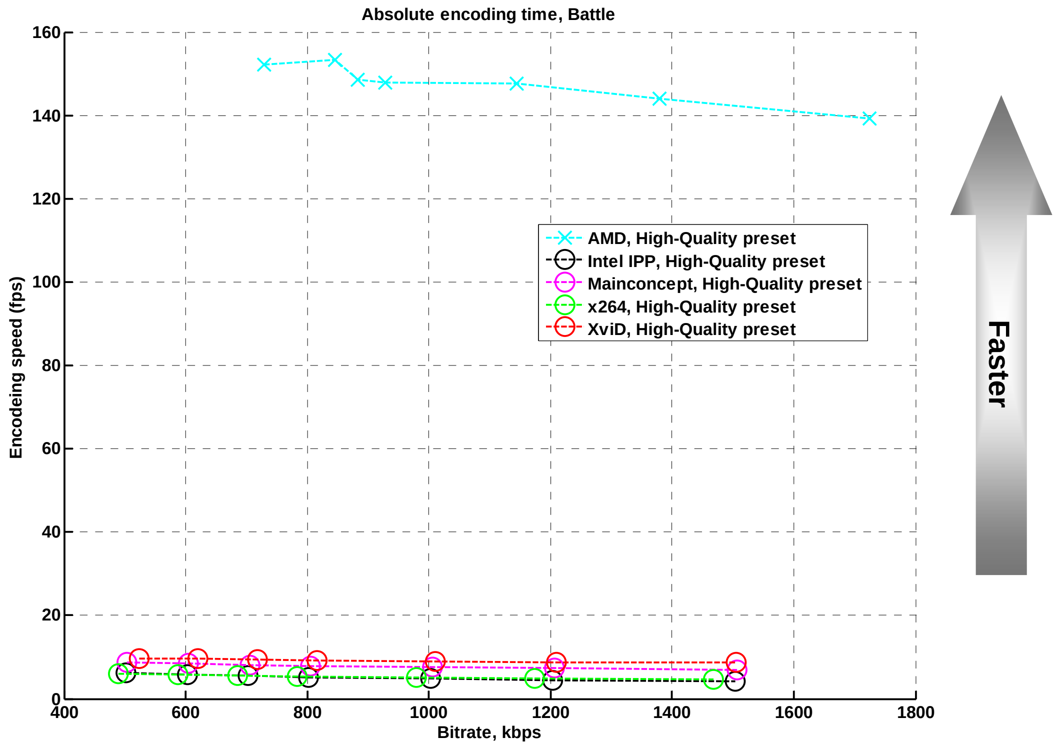


Figure 19. Encoding speed. Usage area “Movies”, “Battle” sequence, “High Quality” preset

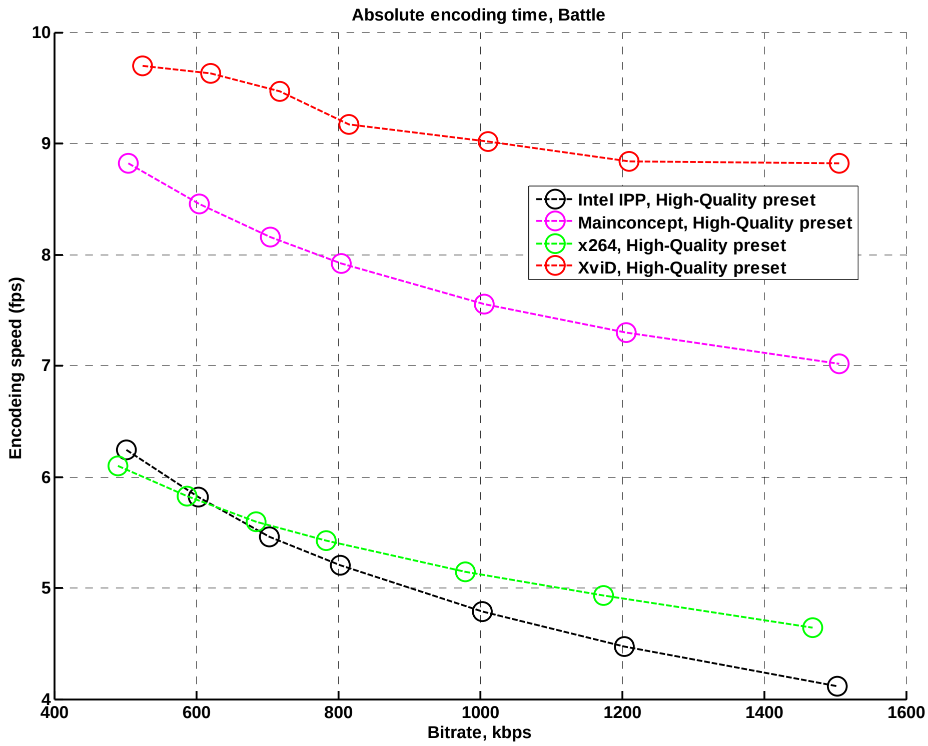


Figure 20. Encoding speed. Usage area “Movies”, “Battle” sequence, “High Quality” preset. All encoders except AMD

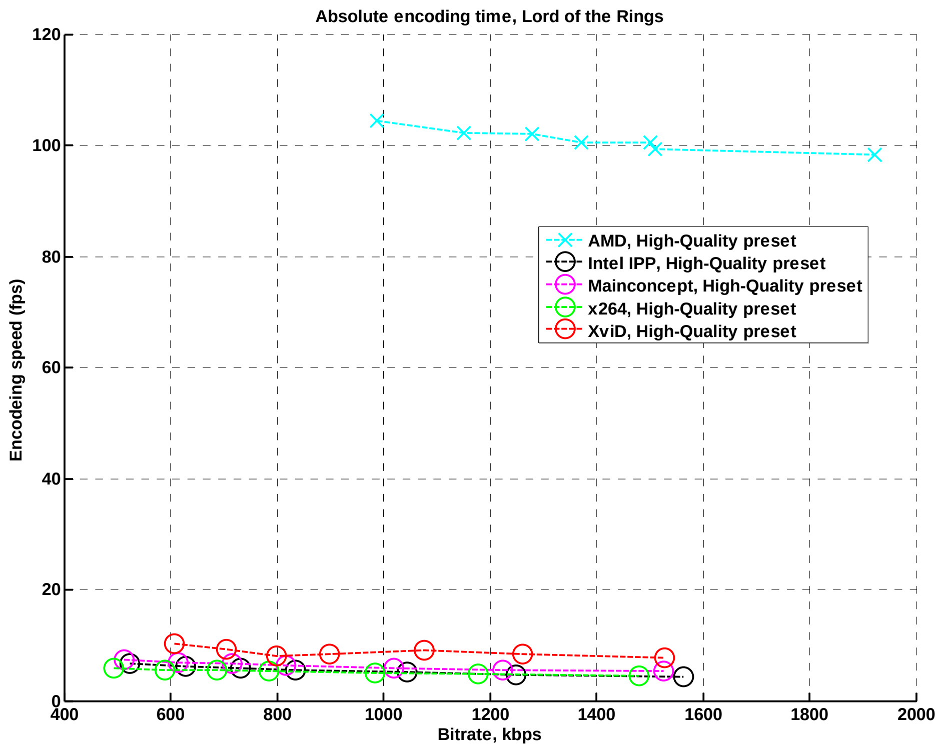


Figure 21. Encoding speed. Usage area “Movies”, “Lord of the Rings” sequence, “High Quality” preset

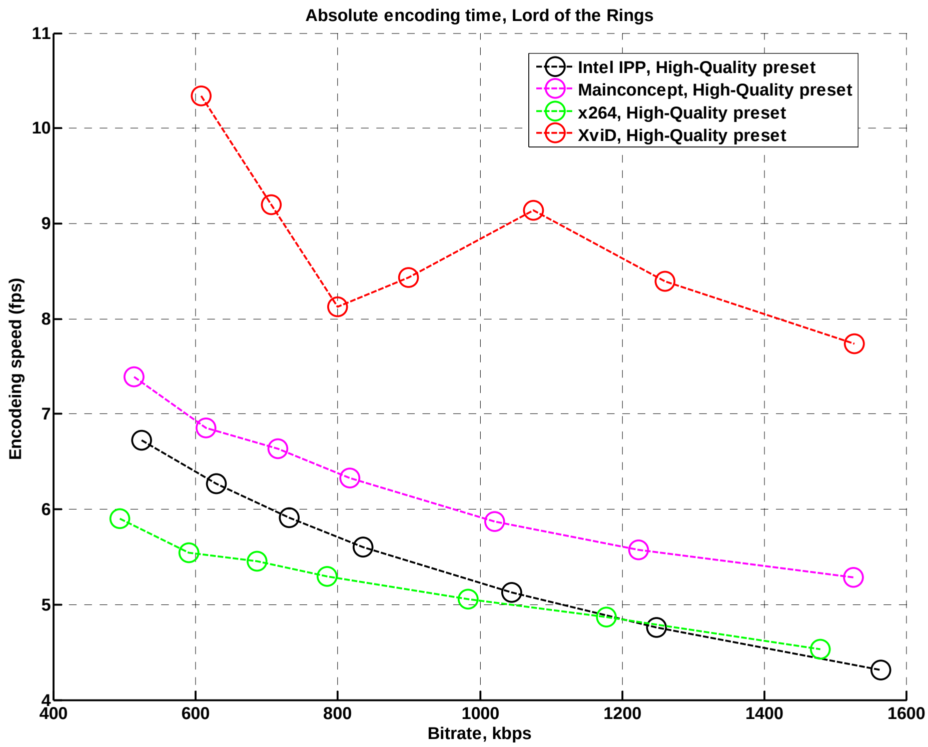


Figure 22. Encoding speed. Usage area “Movies”, “Lord of the Rings” sequence, “High Quality” preset. All encoders except AMD

4.2.2.1 High Speed Preset

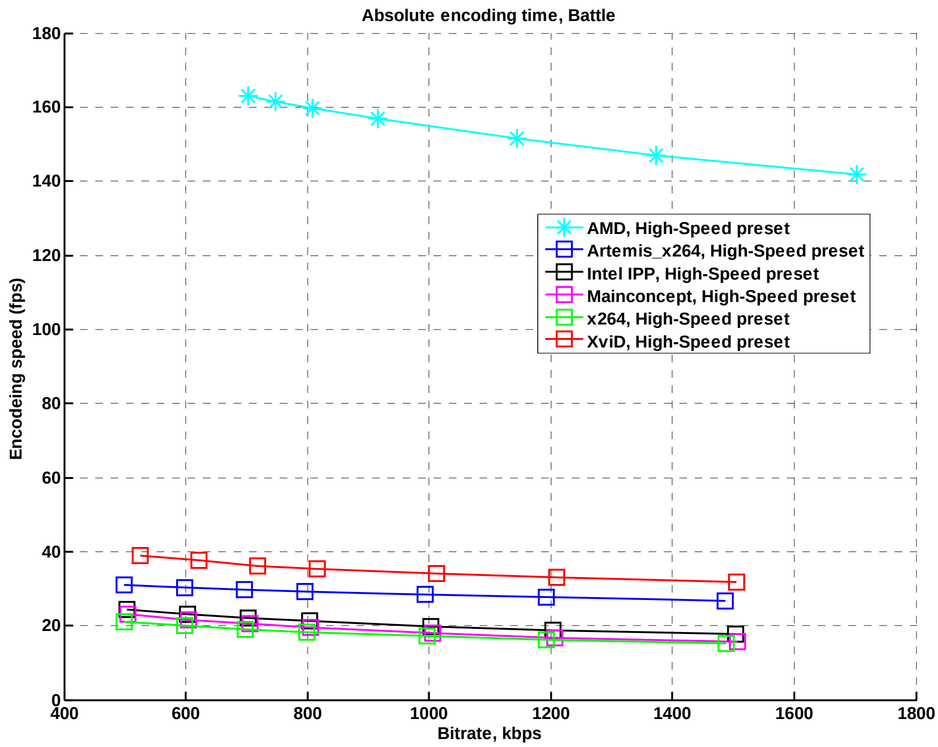


Figure 23. Encoding speed. Usage area "Movies", "Battle" sequence, "High Speed" preset

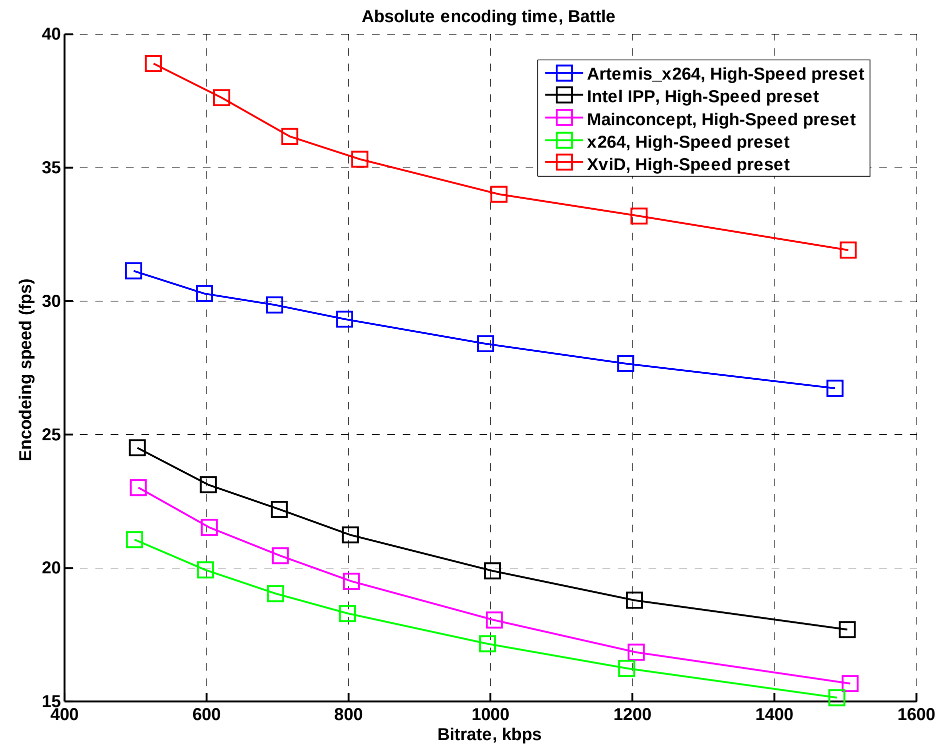


Figure 24. Encoding speed. Usage area "Movies", "Battle" sequence, "High Speed" preset. All encoders except AMD

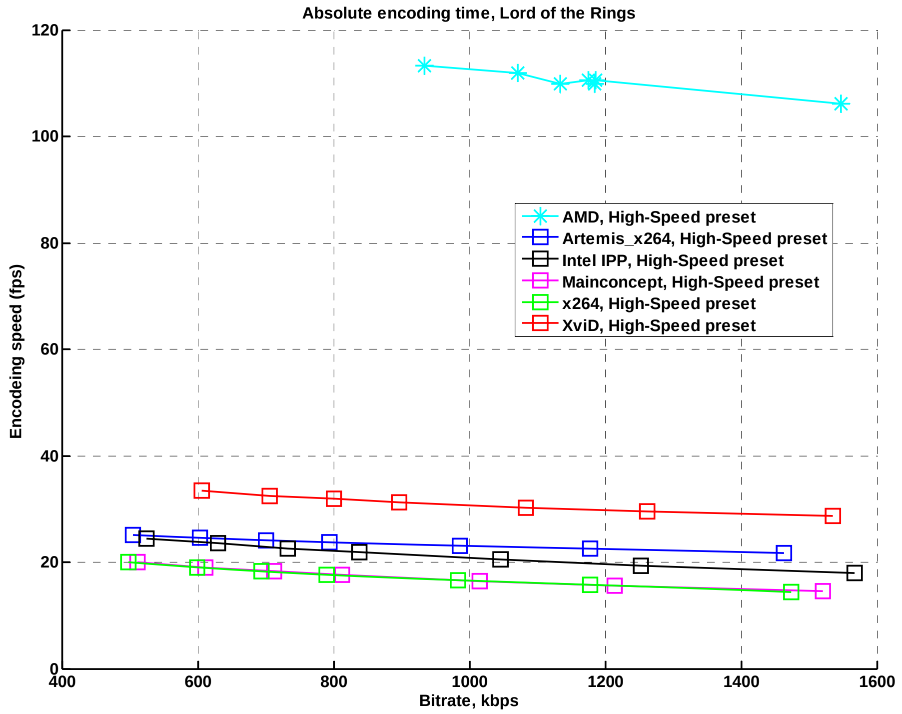


Figure 25. Encoding speed. Usage area "Movies", "Lord of the Rings" sequence, "High Speed" preset

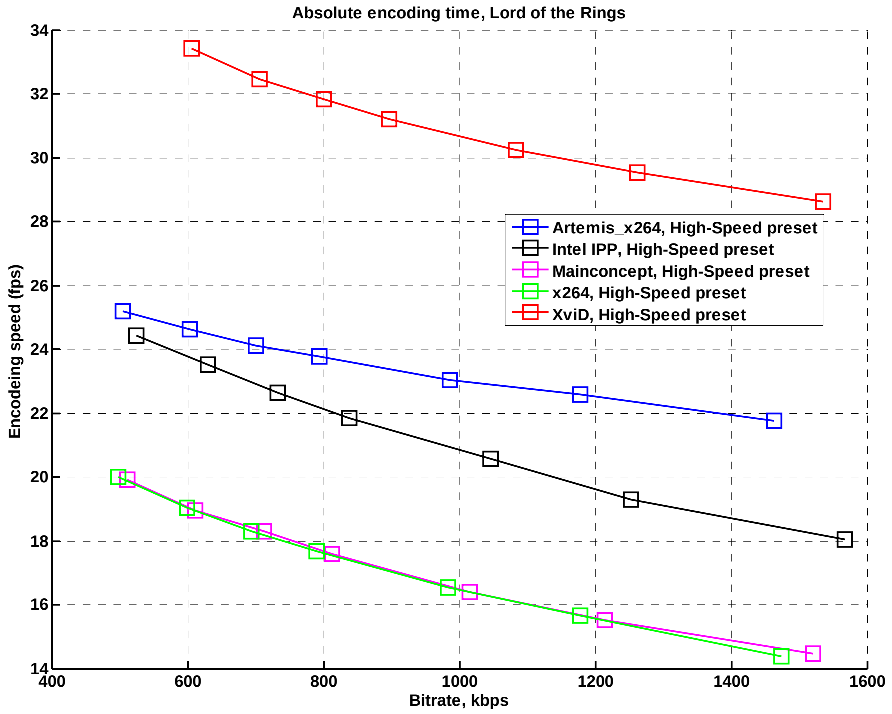


Figure 26. Encoding speed. Usage area "Movies", "Lord of the Rings" sequence, "High Speed" preset. All encoders except AMD

4.2.3 Speed/Quality Tradeoff

Detailed descriptions of the speed/quality trade-off graphs can be found in Appendix 4. 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 27 through Figure 29 show examples of the 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.

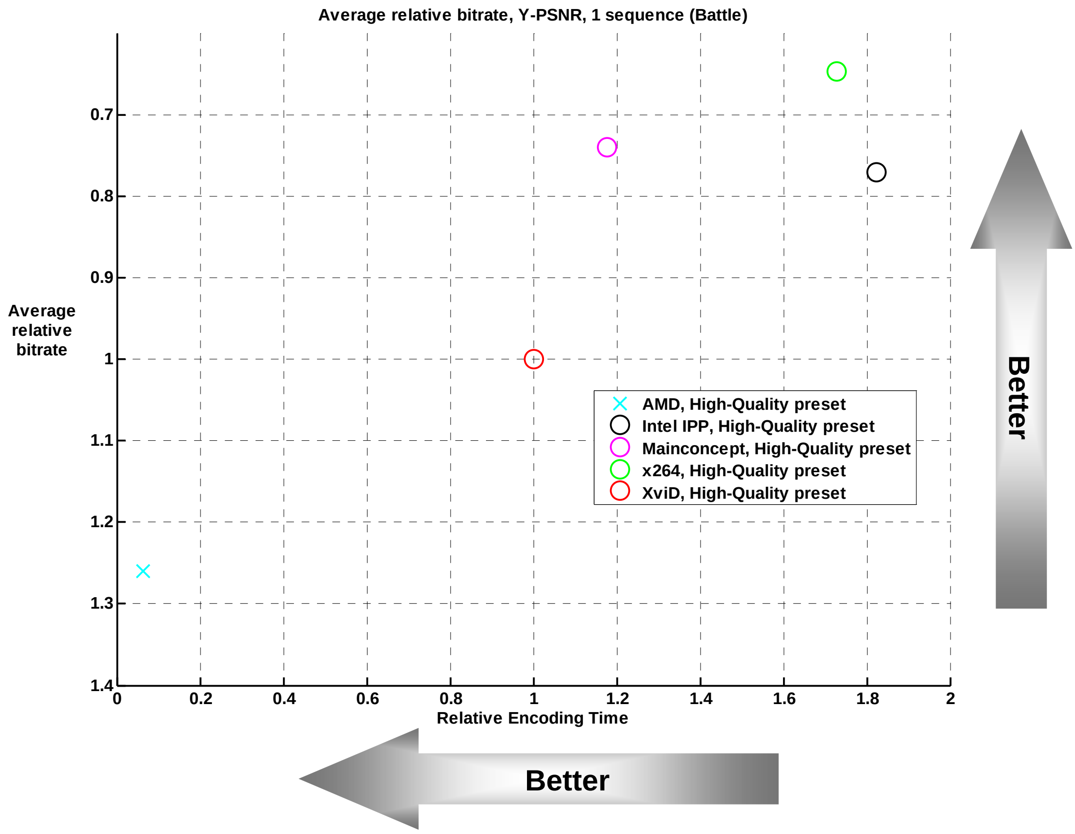


Figure 27. Speed/Quality tradeoff. Usage area "Movies", "Battle" sequence, "High Quality" preset, Y-PSNR

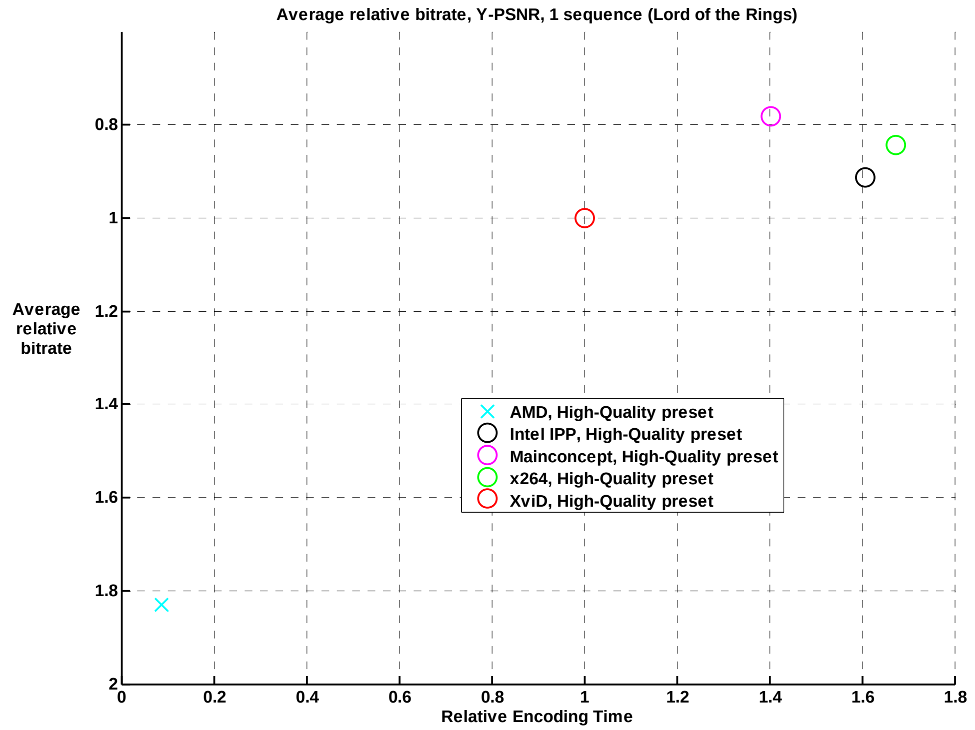


Figure 28. Speed/Quality tradeoff. Usage area “Movies”, “Lord of the Rings” sequence, “High Quality” preset, Y-PSNR

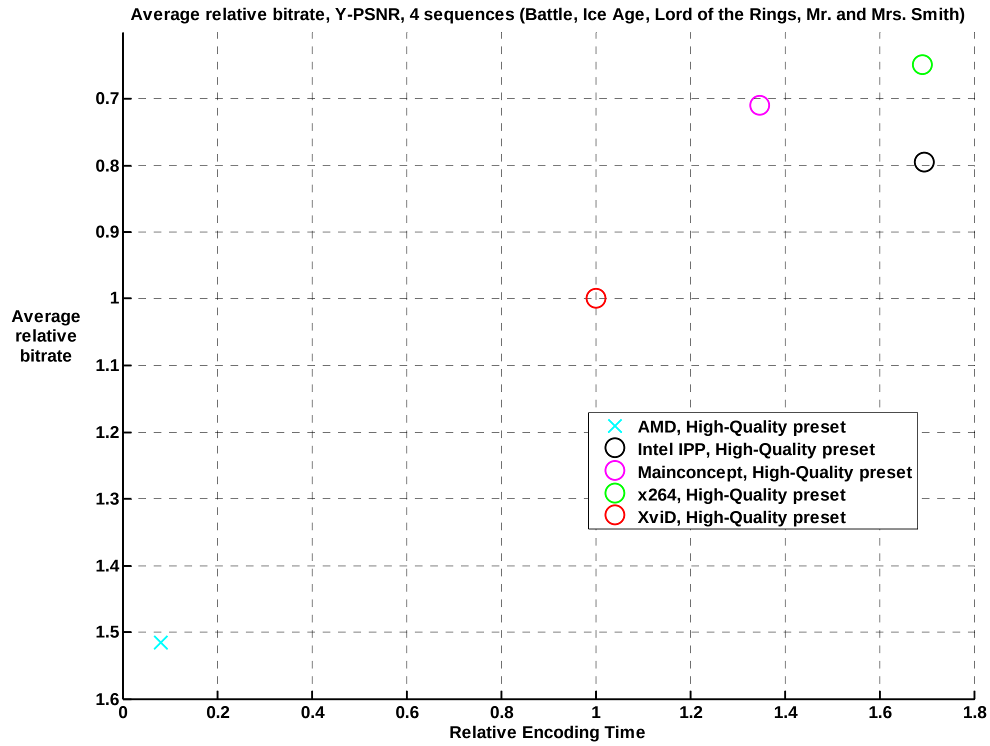


Figure 29. Speed/Quality tradeoff. Usage area “Movies”, all sequences, “High Quality” preset, Y-PSNR

4.2.3.1 High Speed Preset

Figure 30 through Figure 32 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.

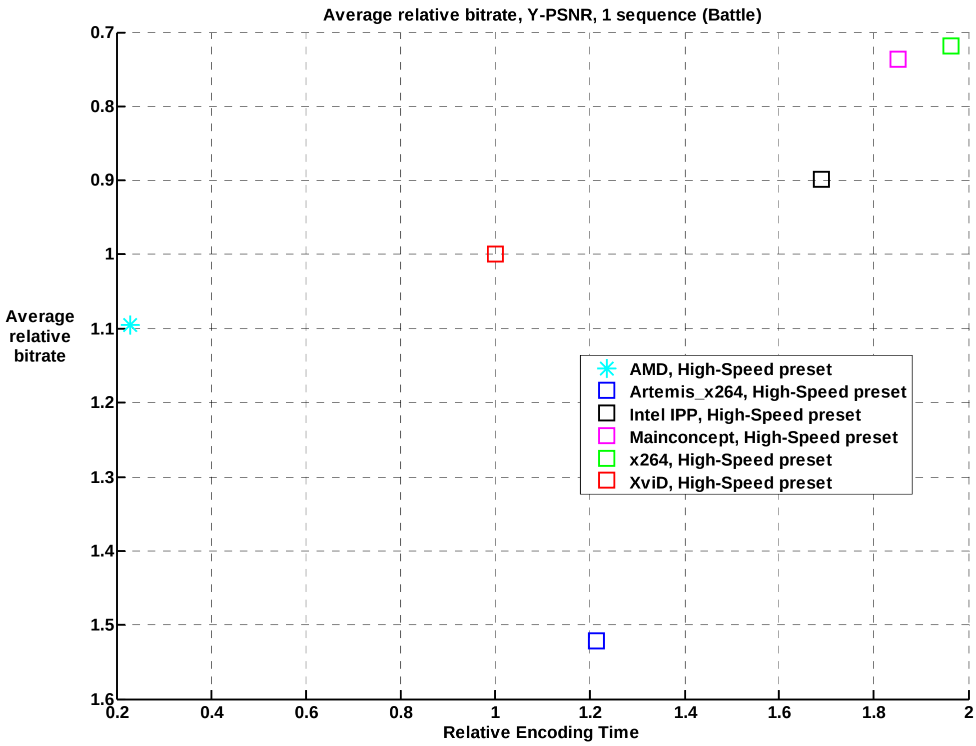


Figure 30. Speed/Quality tradeoff. Usage area “Movies”, “Battle” sequence, “High Speed” preset, Y-PSNR

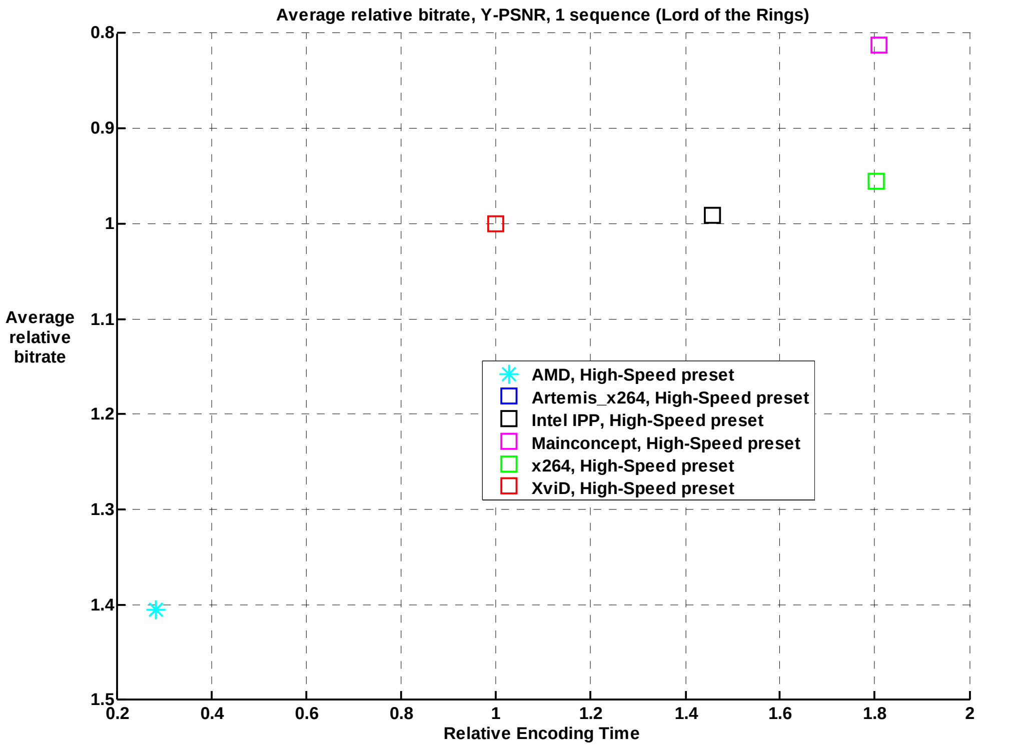


Figure 31. Speed/Quality tradeoff. Usage area “Movies”, “Lord of the Rings” sequence, “High Speed” preset, Y-PSNR

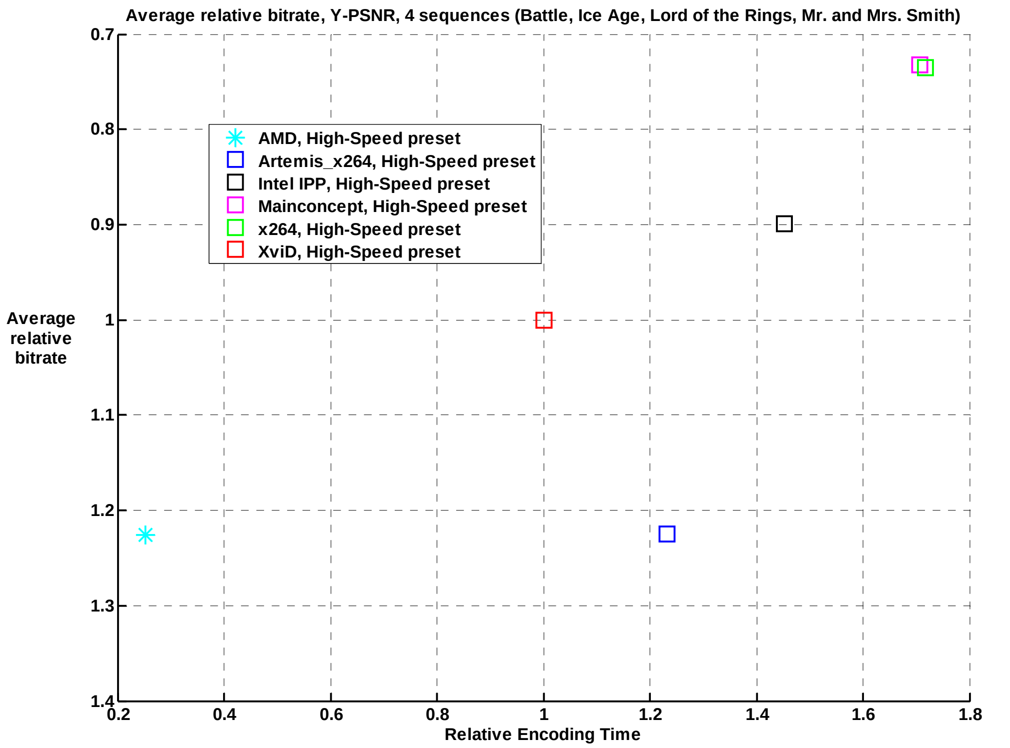


Figure 32. Speed/Quality tradeoff. Usage area “Movies”, all the sequences, “High Speed” preset, Y-PSNR

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 as perfect as for MainConcept, x264 and Intel IPP.

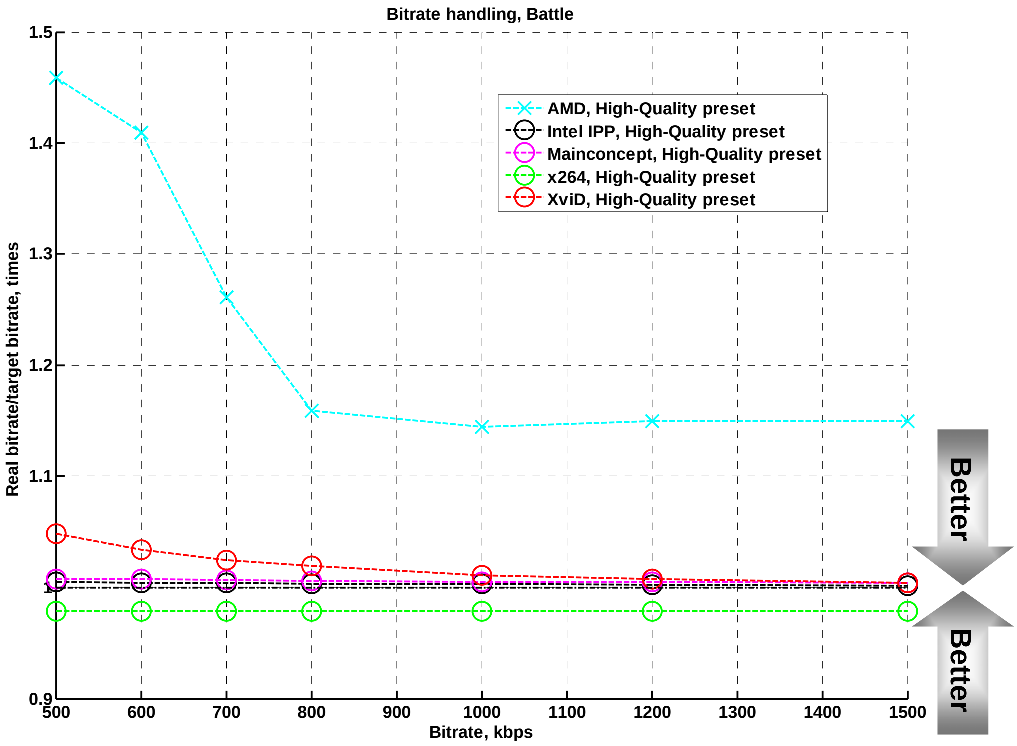


Figure 33. Bitrate Handling. Usage area “Movies”, “Battle” sequence, “High Quality” preset

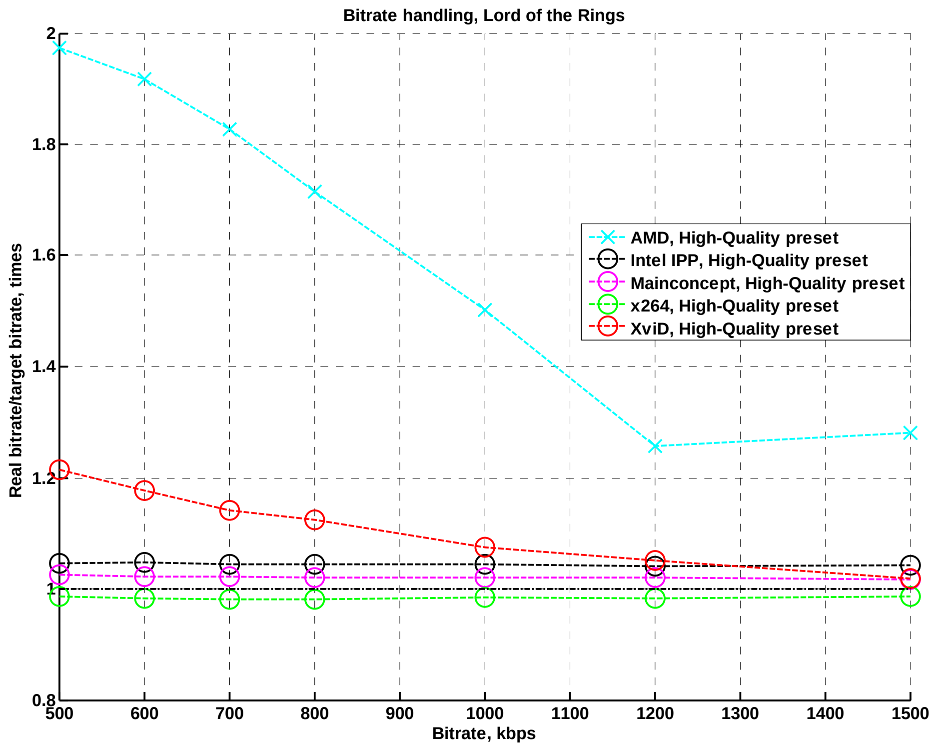


Figure 34. Bitrate Handling. Usage area "Movies", "Lord of the Rings" sequence, "High Quality" preset

4.2.4.1 High Speed Preset

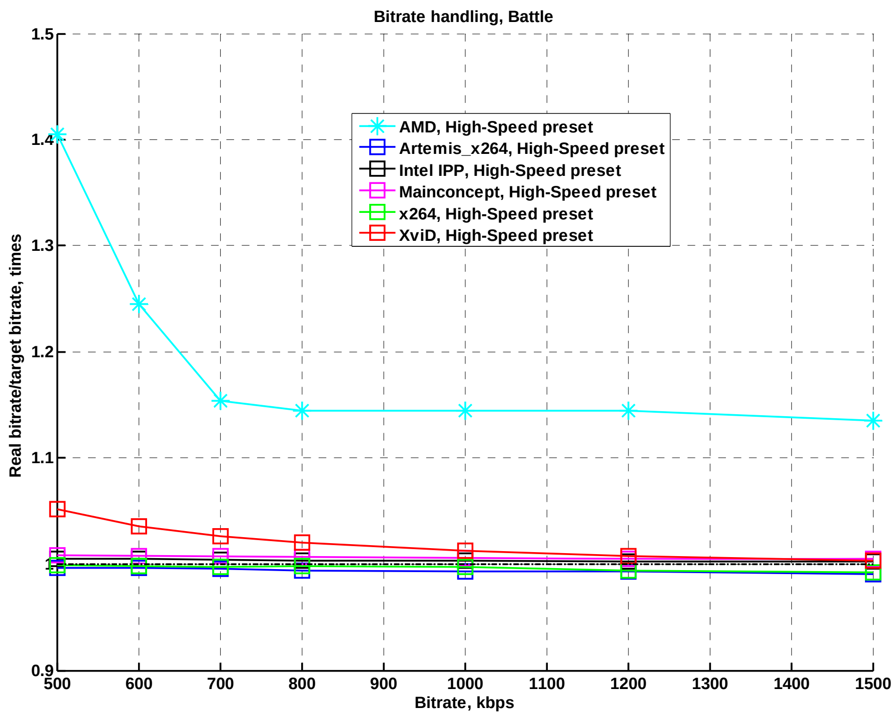


Figure 35. Bitrate Handling. Usage area "Movies", "Battle" sequence, "High Speed" preset

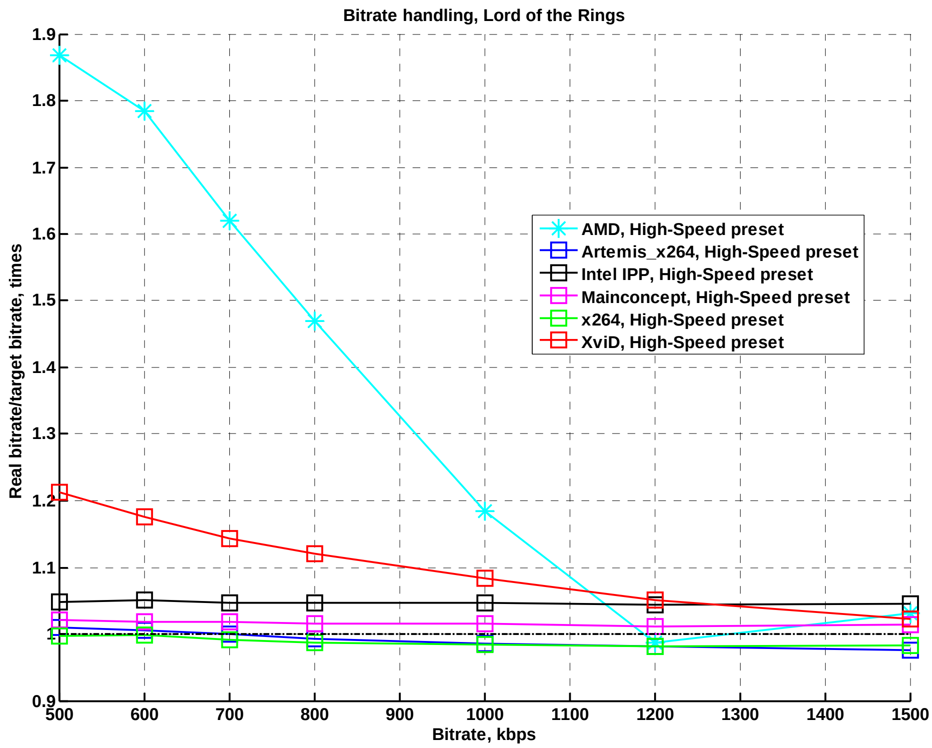


Figure 36. Bitrate Handling. Usage area "Movies", "Lord of the Rings" sequence, "High Speed" preset

4.2.5 Relative Quality Analysis

Table 5 and Table 6 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 4. 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 are present in Table 5). 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 6 present the High Quality preset results for the Y-PSNR quality metrics. 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 5. 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 6. 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%

Figure 37 and Figure 38 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.

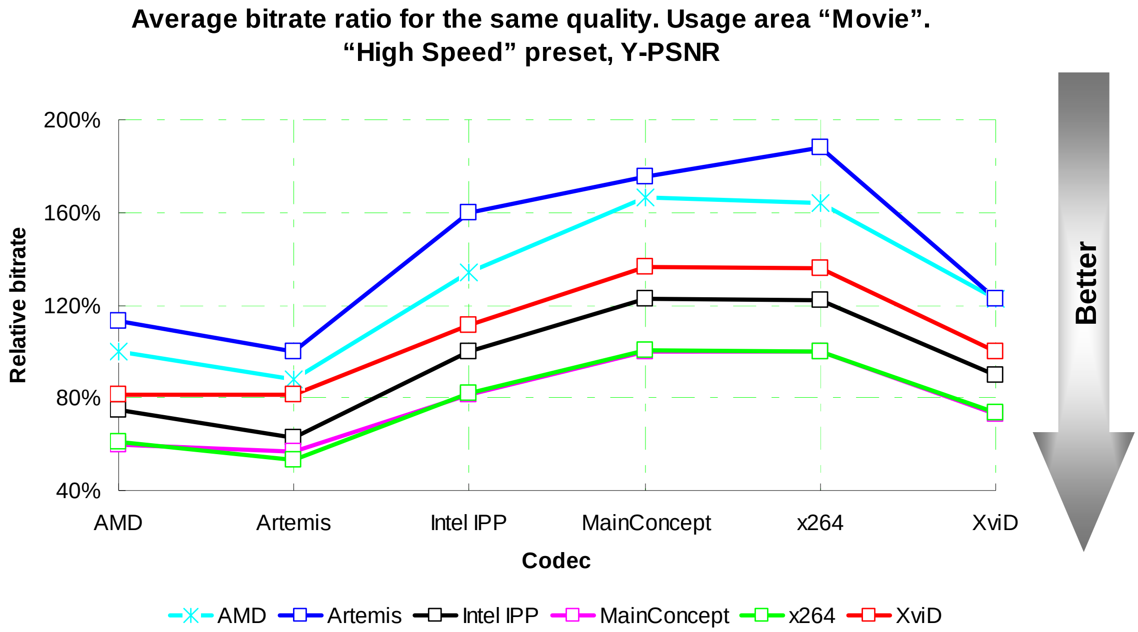


Figure 37. Average bitrate ratio for the same quality. Usage area "Movie". "High Speed" preset, Y-PSNR.

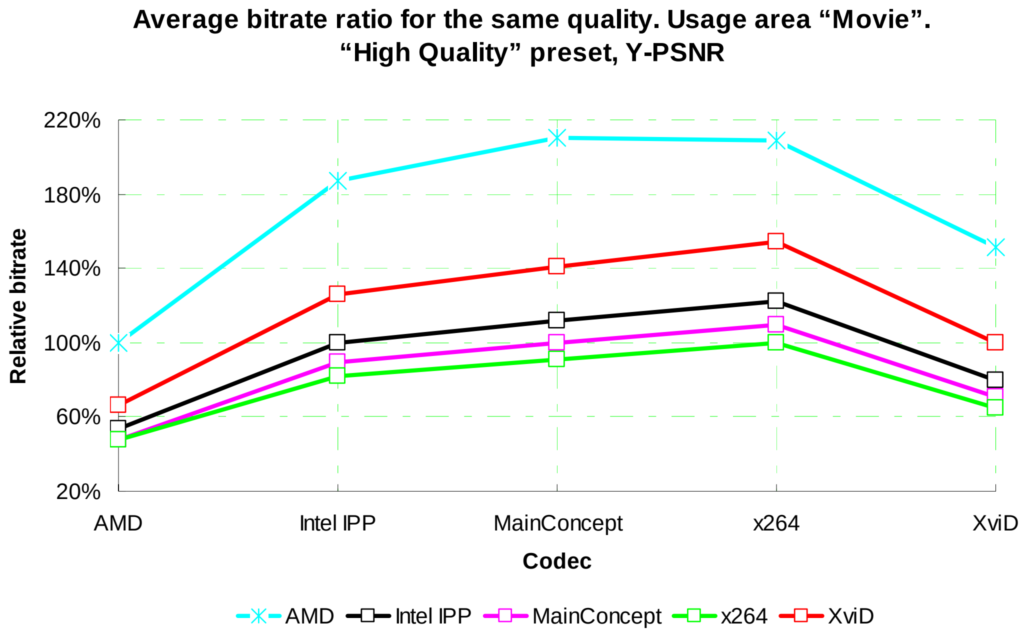


Figure 38. Average bitrate ratio for the same quality. Usage area "Movie". "High Quality" preset, Y-PSNR.

4.3 HDTV

4.3.1 RD Curves

Figure 39 is an example of 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.

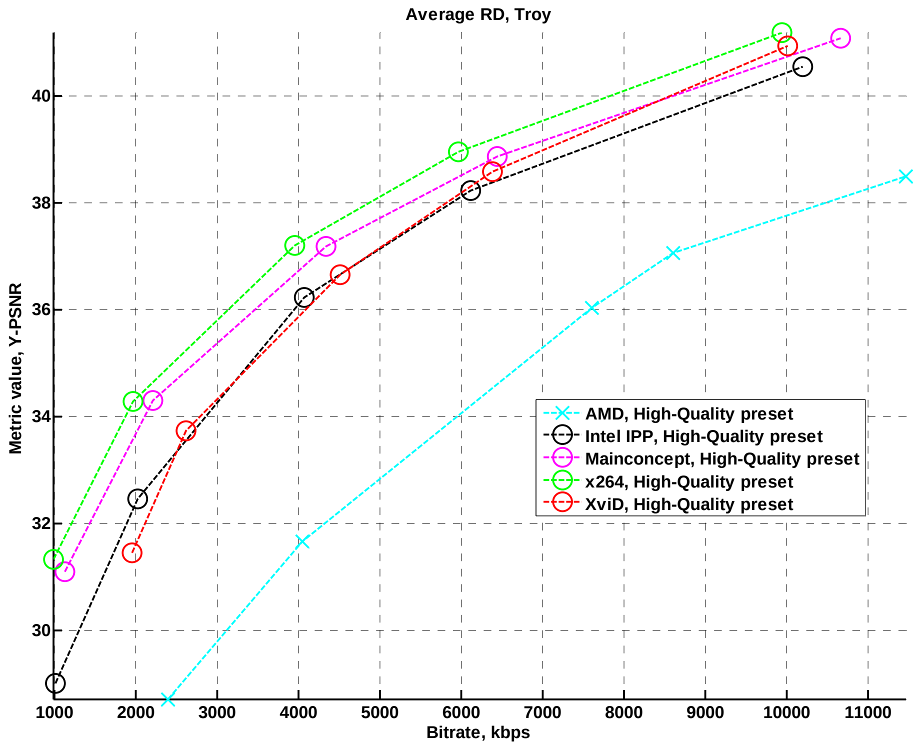


Figure 39. Bitrate/Quality. Usage area "HDTV", "Troy" sequence, "High Quality" preset, Y-PSNR

4.3.1.1 High Speed Preset

Figure 40 is an example of 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 1. 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.

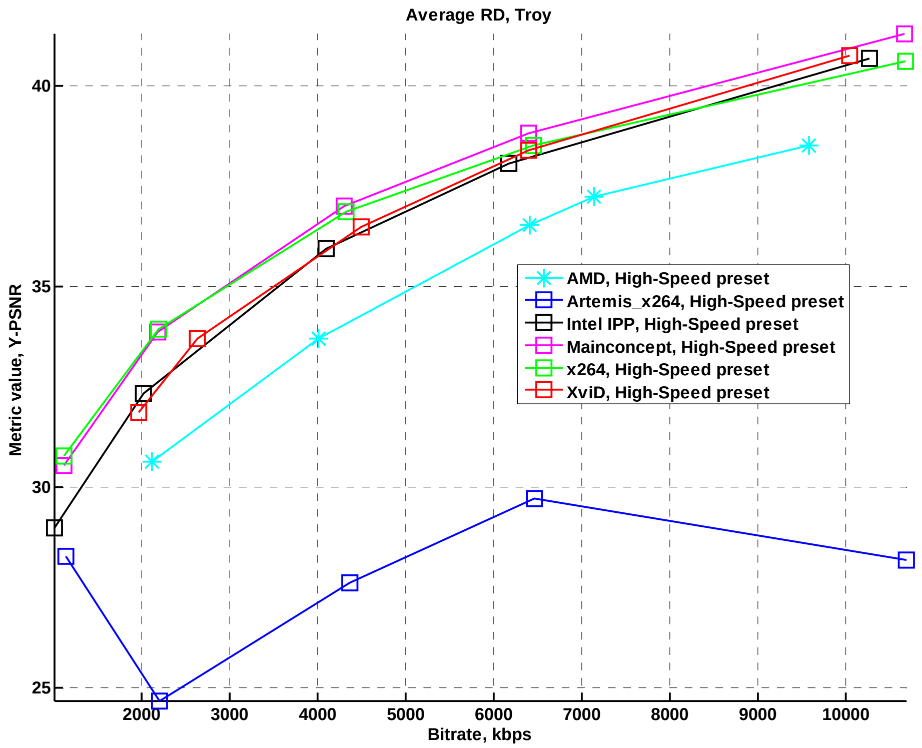


Figure 40. Bitrate/Quality. Usage area “HDTV”, “Troy” sequence, “High Speed” preset, Y-PSNR

4.3.2 Encoding Speed

Figure 41 through Figure 44 are examples of codec encoding speed visualizations. 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.

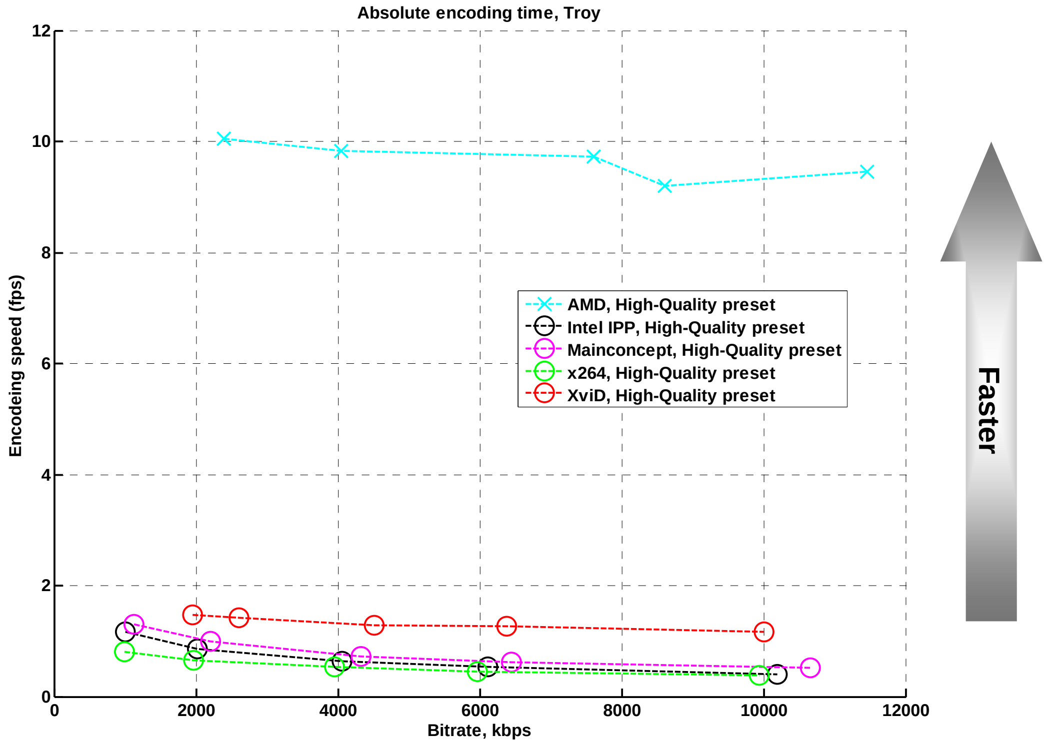


Figure 41. Encoding speed. Usage area “HDTV”, “Troy” sequence, “High Quality” preset

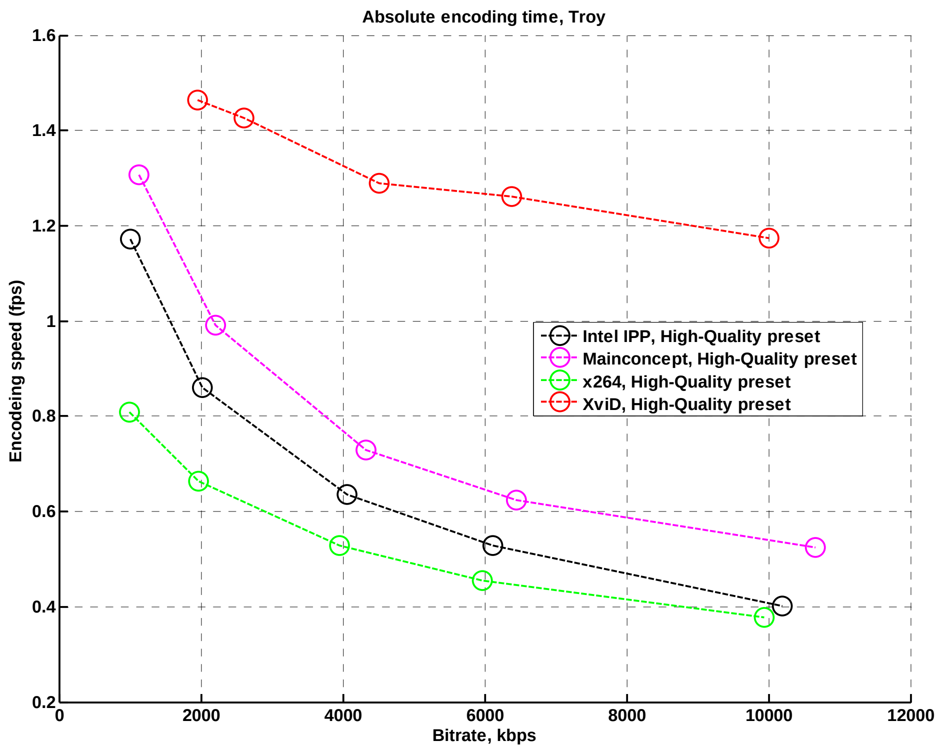


Figure 42. Encoding speed. Usage area "HDTV", "Troy" sequence, "High Quality" preset. All encoders except AMD

4.3.2.1 High Speed Preset

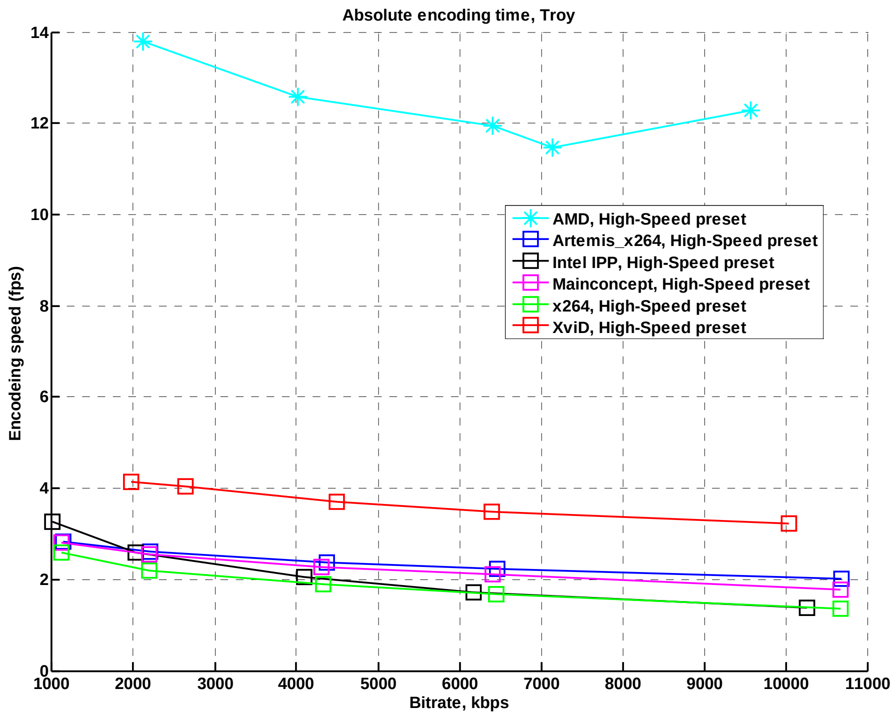


Figure 43. Encoding speed. Usage area "HDTV", "Troy" sequence, "High Speed" preset

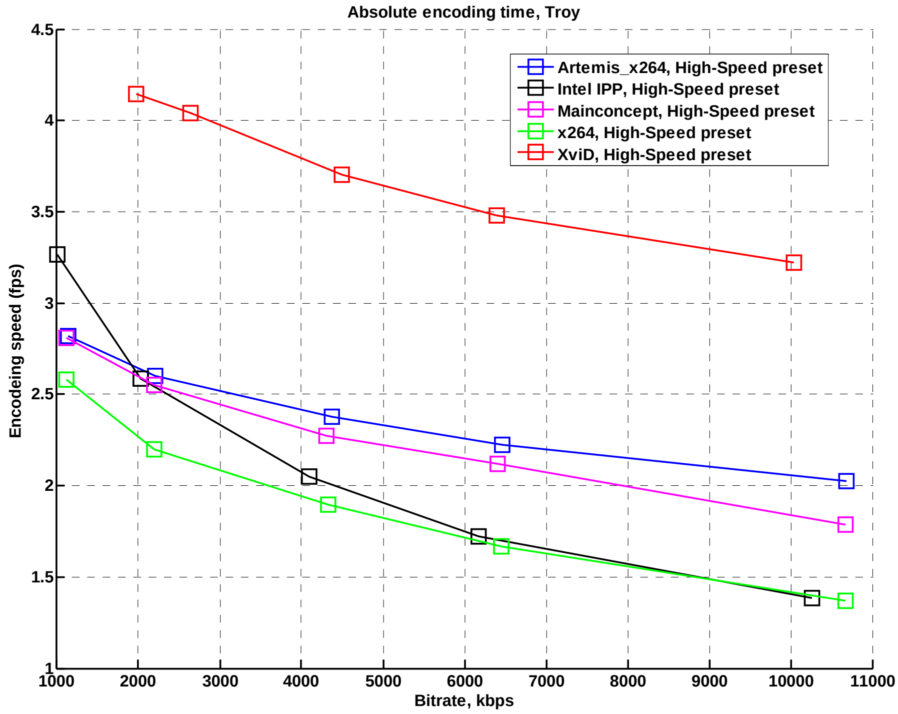


Figure 44. Encoding speed. Usage area "HDTV", "Troy" sequence, "High Speed" preset. All encoders except AMD

4.3.3 Speed\Quality Tradeoff

Detailed descriptions of speed/quality trade-off graphs can be found in Appendix 4. 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.

Examples of the High Quality preset results are presented in Figure 45 and Figure 46. 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.

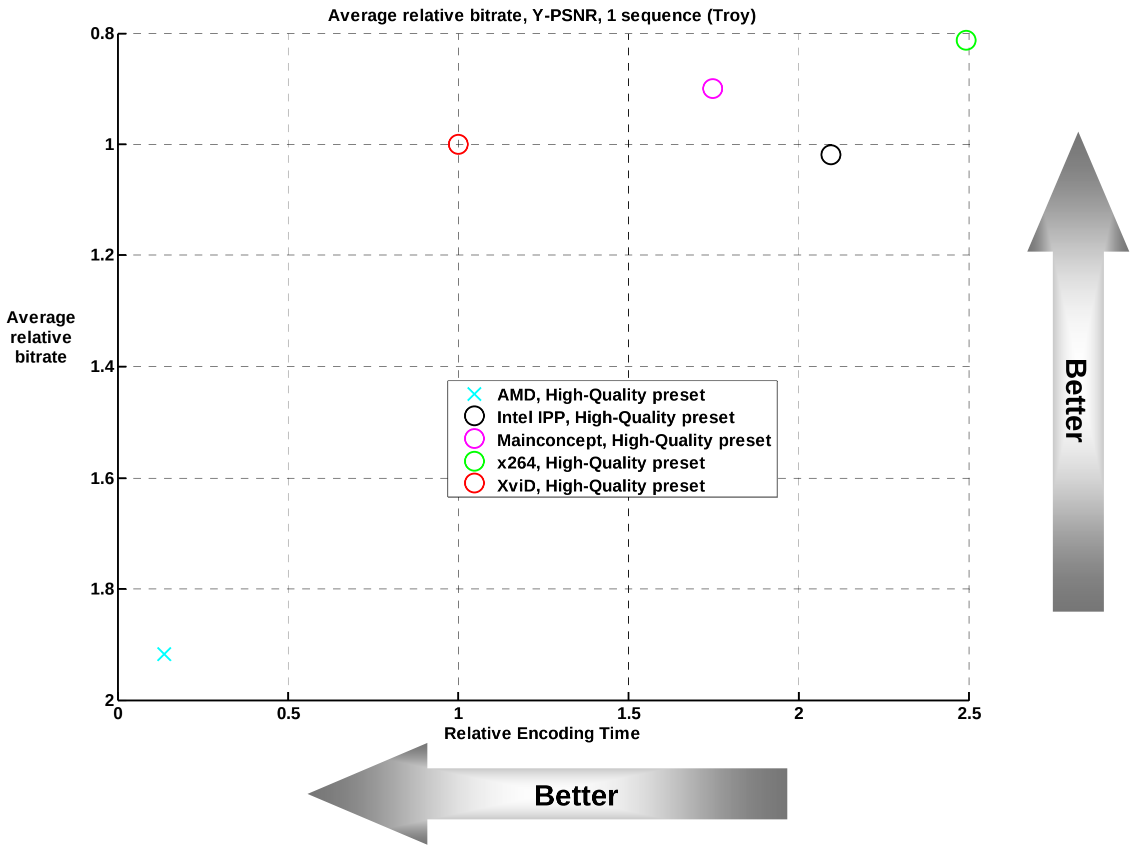


Figure 45. Speed/Quality tradeoff. Usage area "HDTV", "Troy" sequence, "High Quality" preset, Y-PSNR

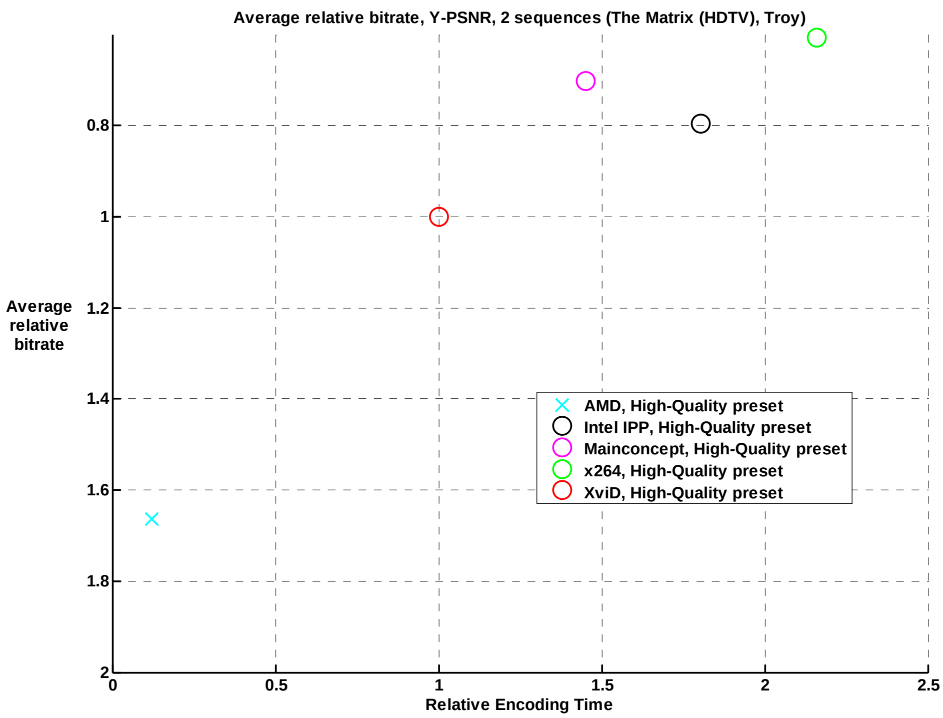


Figure 46. Speed/Quality tradeoff. Usage area "HDTV", all sequences, "High Quality" preset, Y-PSNR

4.3.3.1 High Speed Preset

Figure 47 and Figure 48 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.

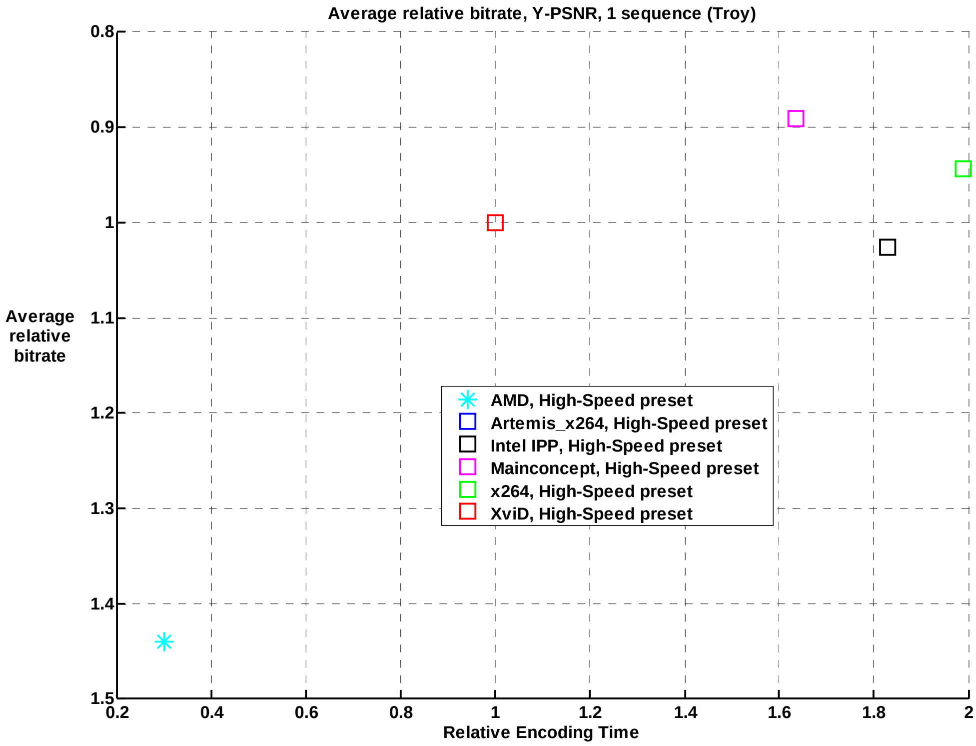


Figure 47. Speed/Quality tradeoff. Usage area “HDTV”, “Troy” sequence, “High Speed” preset, Y-PSNR

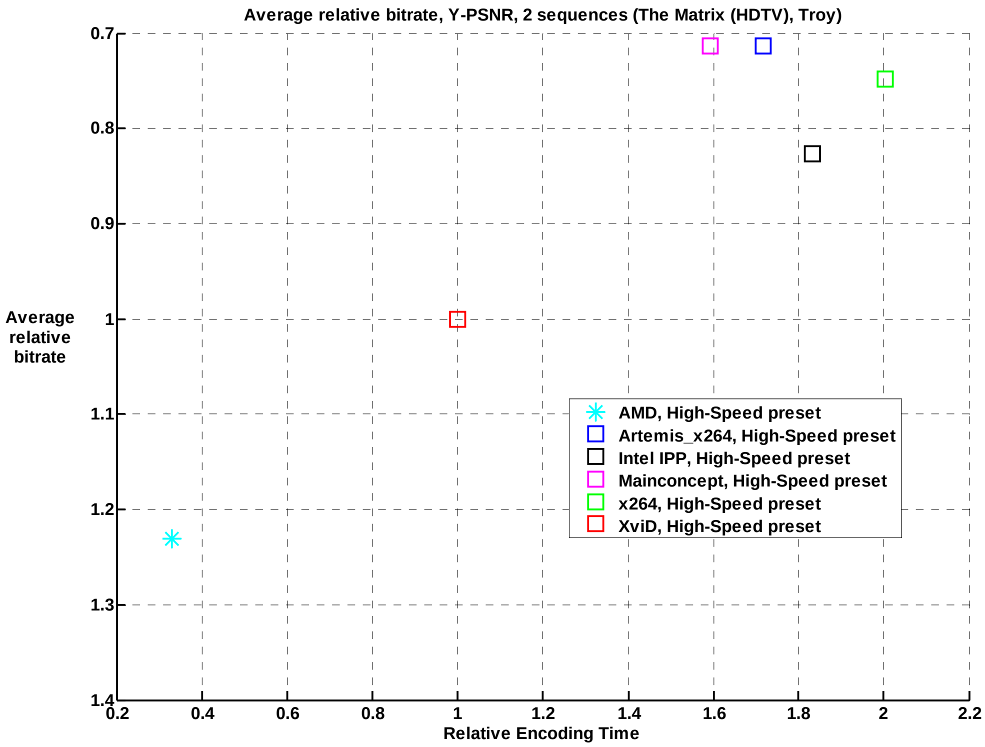


Figure 48. Speed/Quality tradeoff. Usage area "HDTV", all sequences, "High Speed" preset, Y-PSNR

4.3.4 Bitrate Handling

Bitrate handling results are presented in Figure 49 through Figure 50. 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.

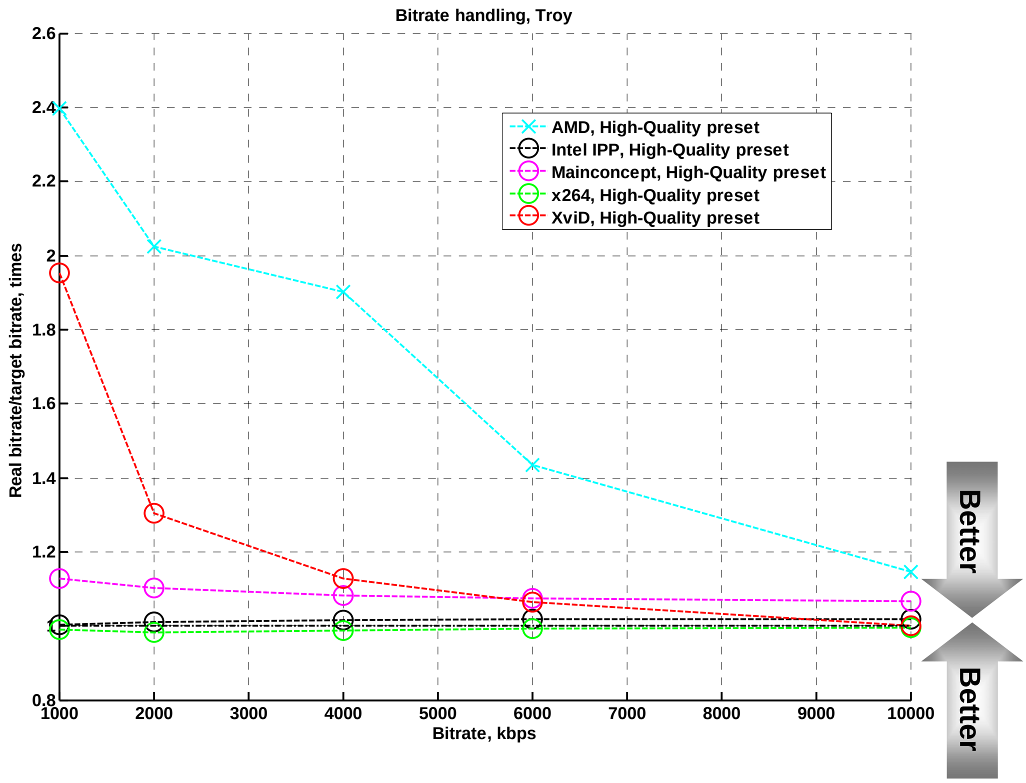


Figure 49. Bitrate Handling. Usage area "HDTV", "Troy" sequence, "High Quality" preset

4.3.4.1 High Speed Preset

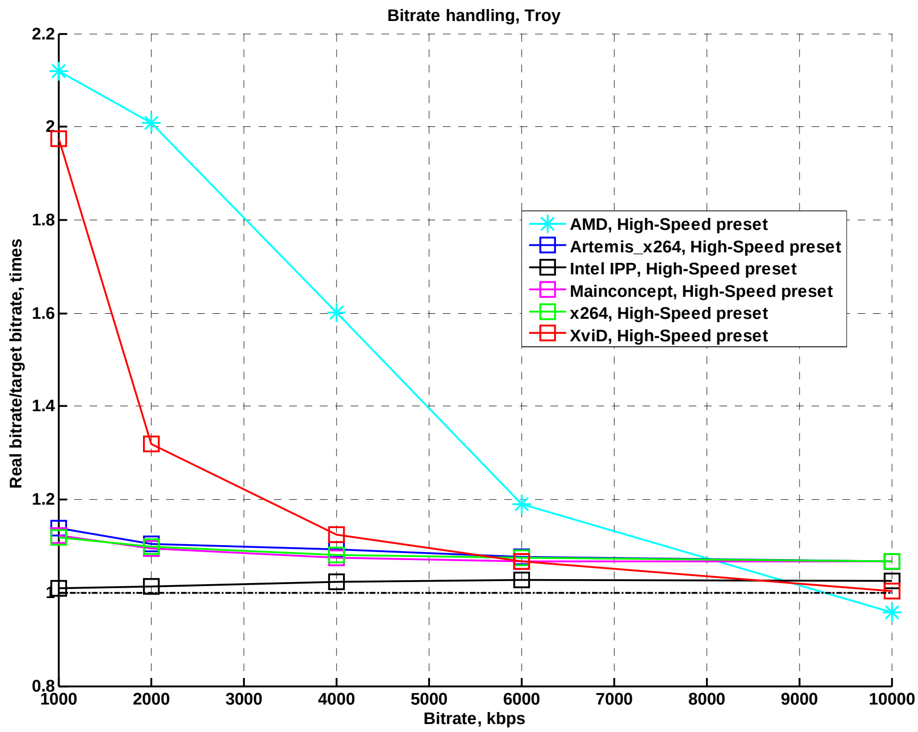


Figure 50. Bitrate Handling. Usage area "HDTV", "Troy" sequence, "High Speed" preset

4.3.5 Relative Quality Analysis

Table 7 and Table 8 contain relative bitrate data for a fixed quality output (only Y-PSNR metric) for all the encoders.

Note that each number in tables below corresponds to some segment of bitrates (see Appendix 4. 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 7. 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 8. 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%

Figure 51 and Figure 52 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.

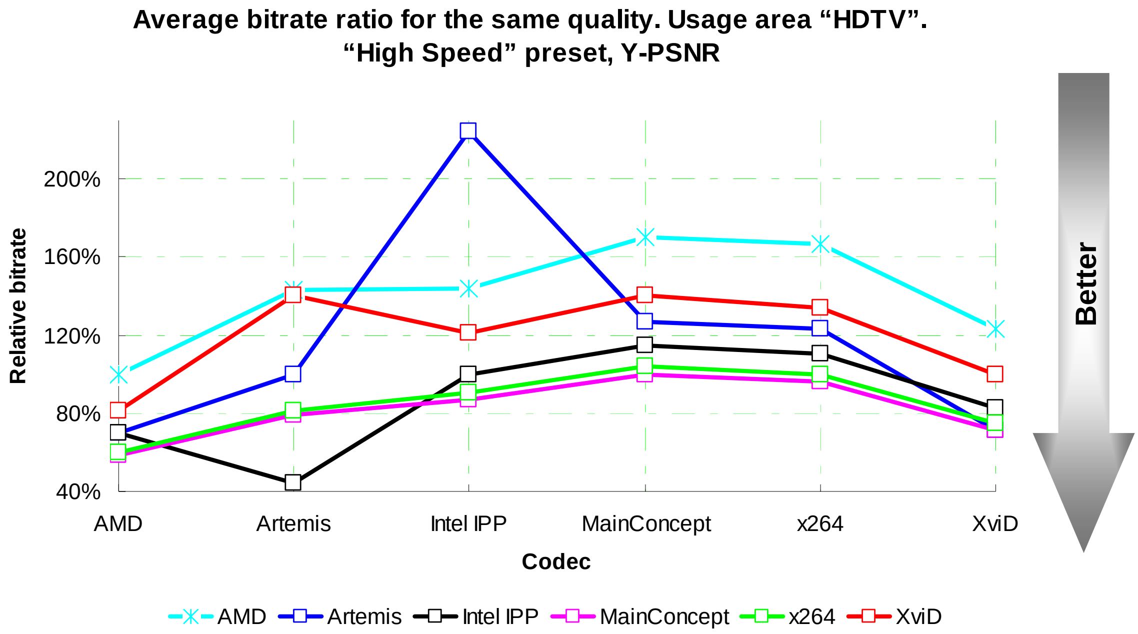


Figure 51. Average bitrate ratio for the same quality. Usage area "HDTV". "High Speed" preset, Y-PSNR.

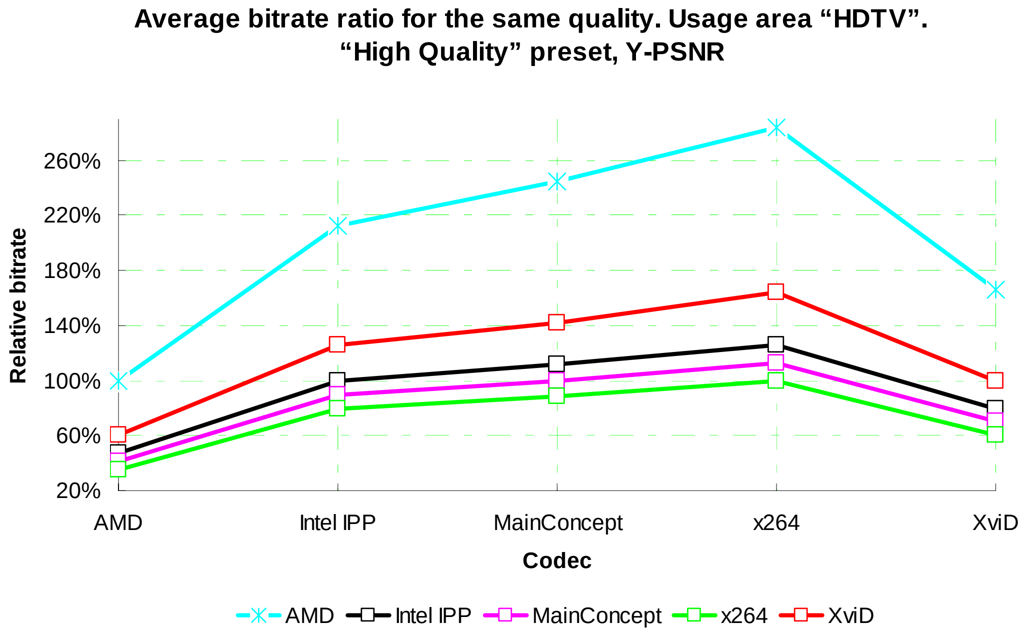


Figure 52. Average bitrate ratio for the same quality. Usage area "HDTV". "High Quality" preset, Y-PSNR.

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.

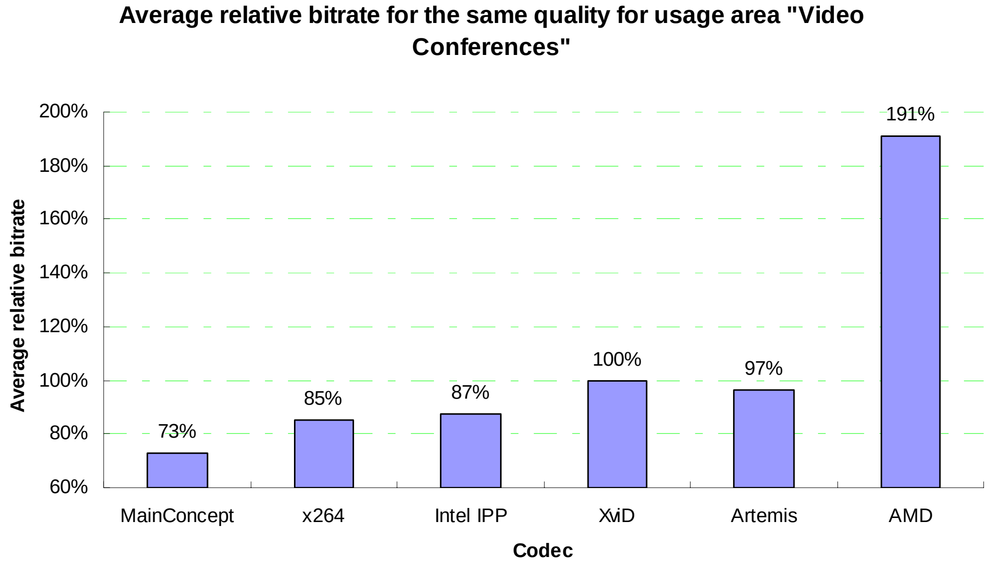


Figure 53. Average bitrate ratio for the same quality. Usage area "Video Conferences". All presets, Y-SSIM.

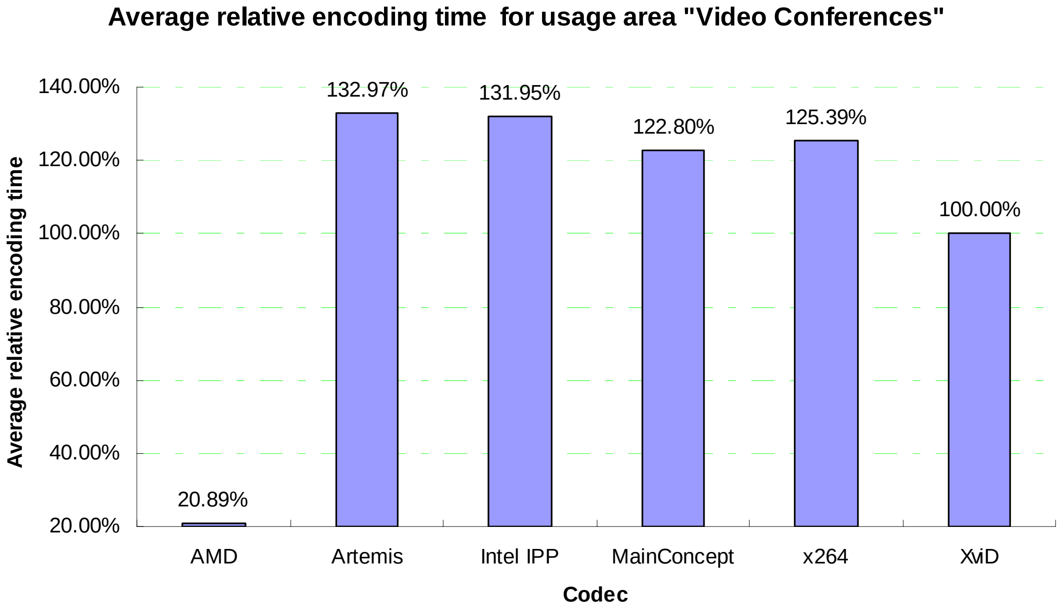


Figure 54. Average relative encoding time. Usage area “Video Conferences”. All presets.

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.

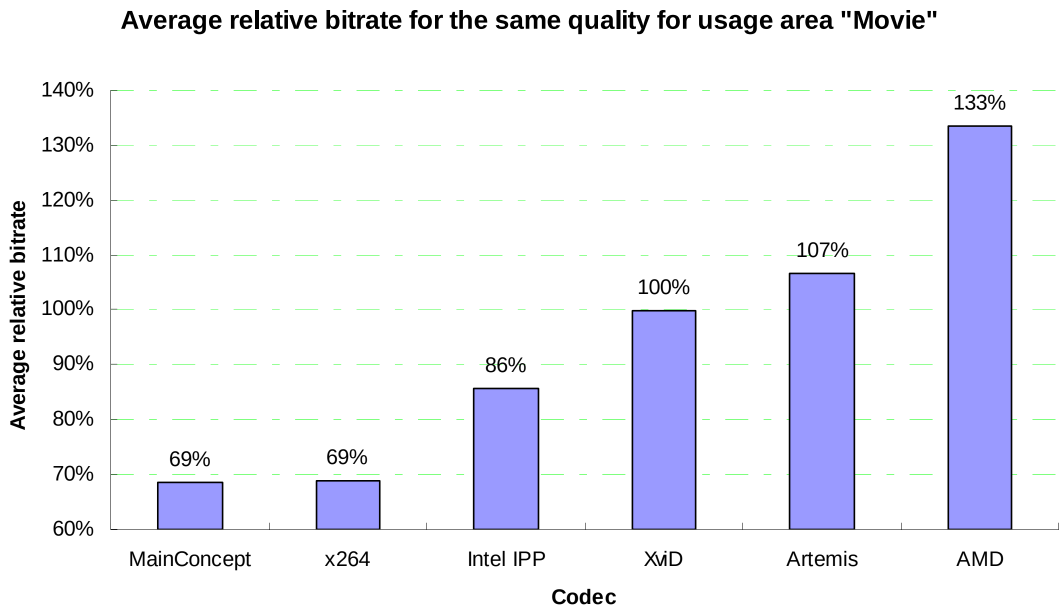


Figure 55. Average bitrate ratio for the same quality. Usage area "Movie". All presets, Y-SSIM.

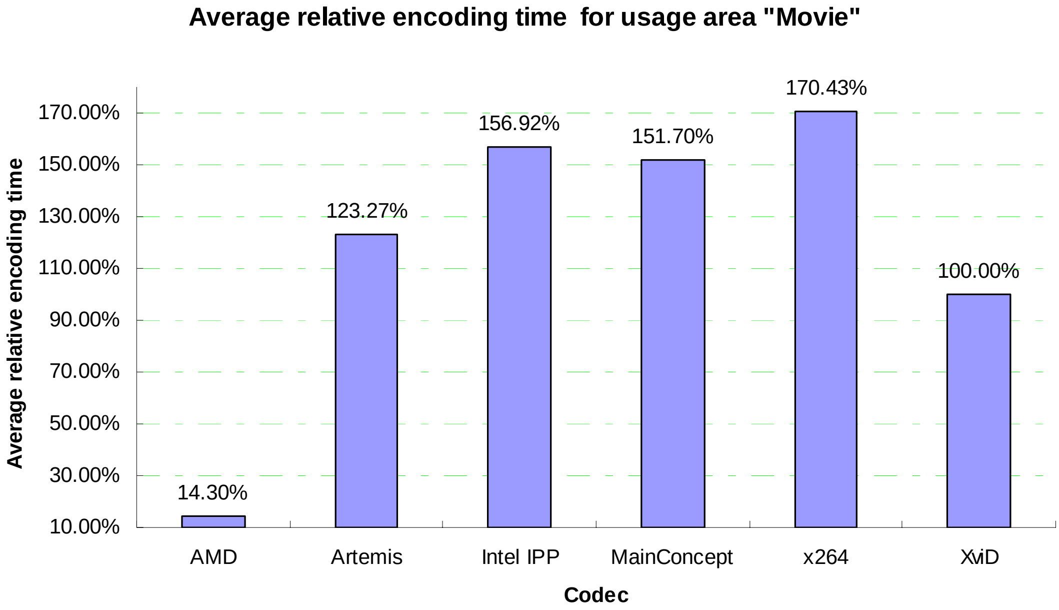


Figure 56. Average relative encoding time. Usage area “Movie”. All presets.

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.

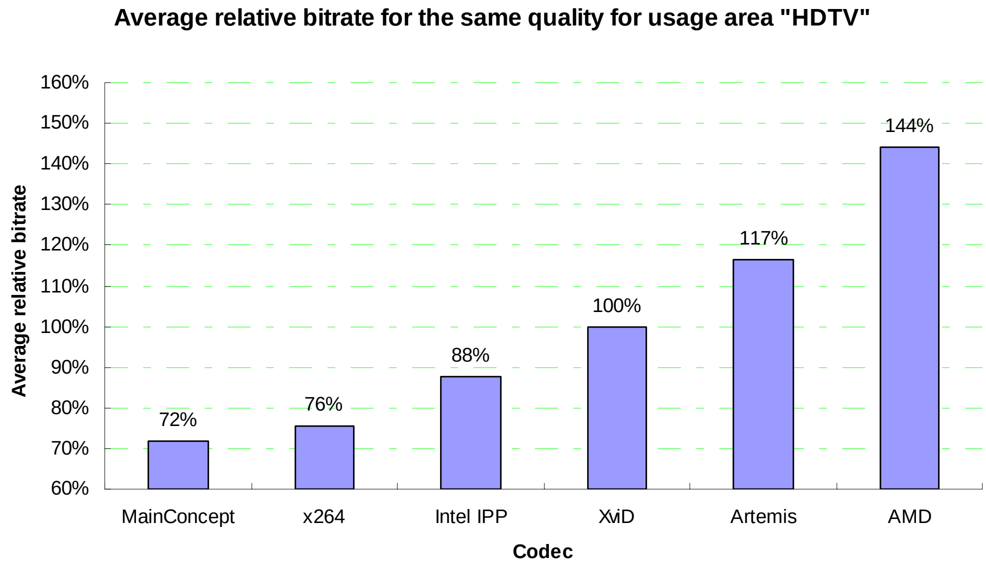


Figure 57. Average bitrate ratio for the same quality. Usage area “HDTV”. All presets, Y-SSIM.

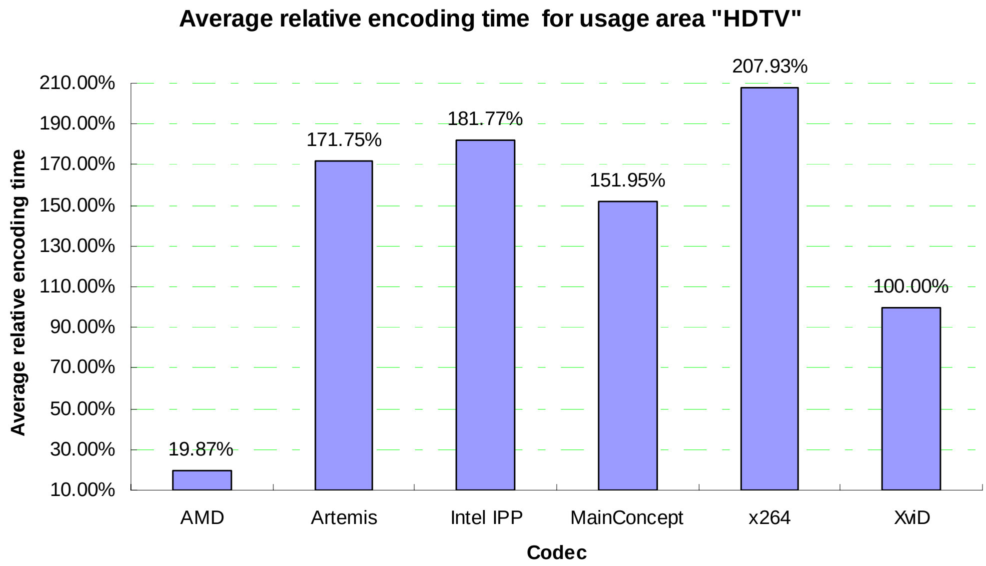


Figure 58. Average relative encoding time. Usage area "HDTV". All presets.

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.

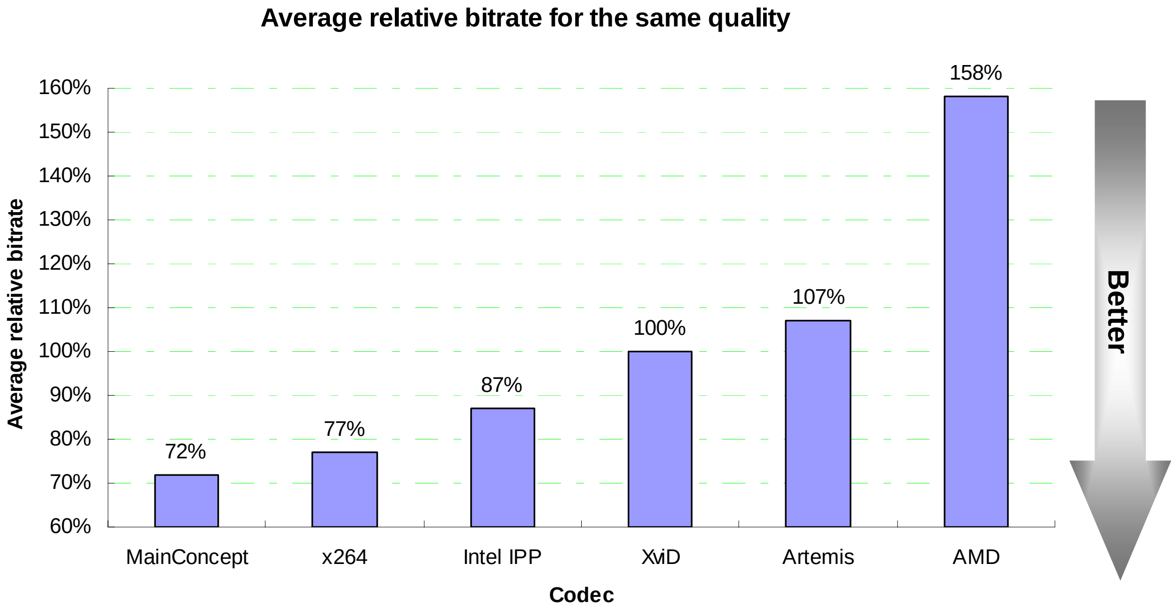


Figure 59. Average bitrate ratio for a fixed quality for all categories and all presets (Y-SSIM).

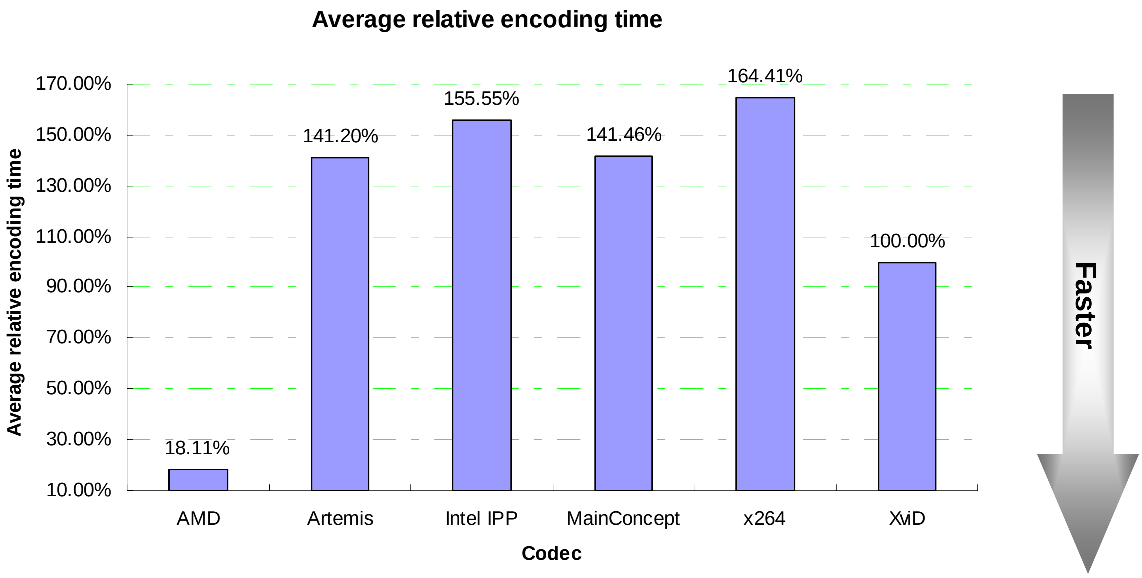


Figure 60. Average relative encoding time for all categories and all presets.

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 59). 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).

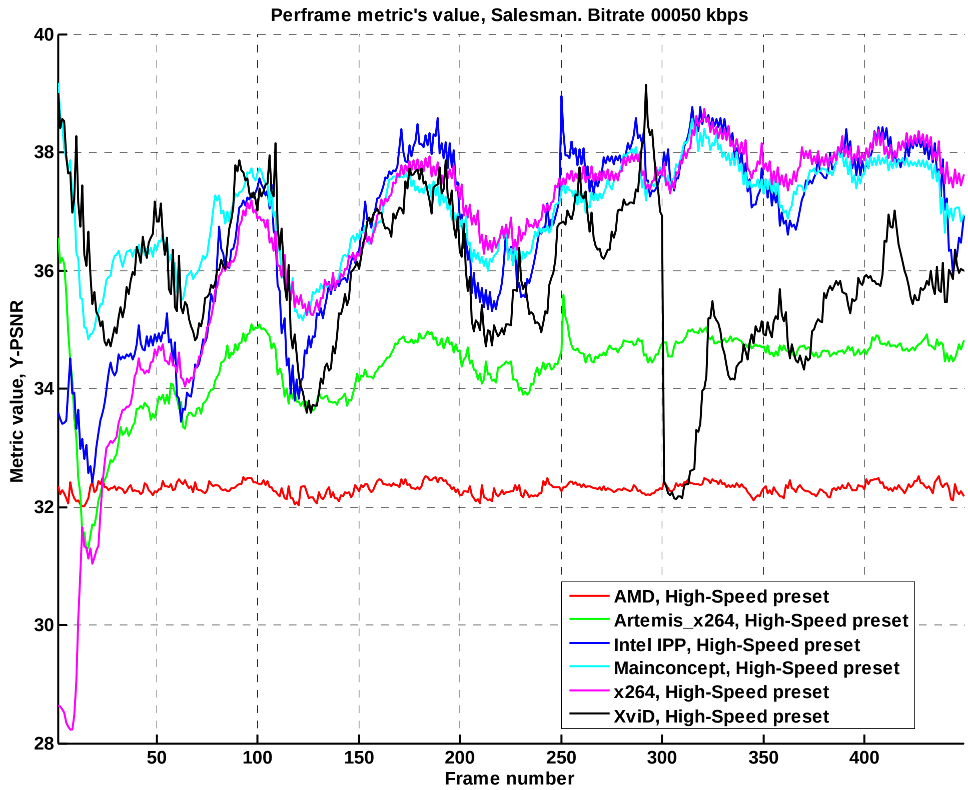


Figure 61. Per-frame quality. Usage area “Video Conferences”, “Salesman” sequence, “High Speed” preset, 50 kbps

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).

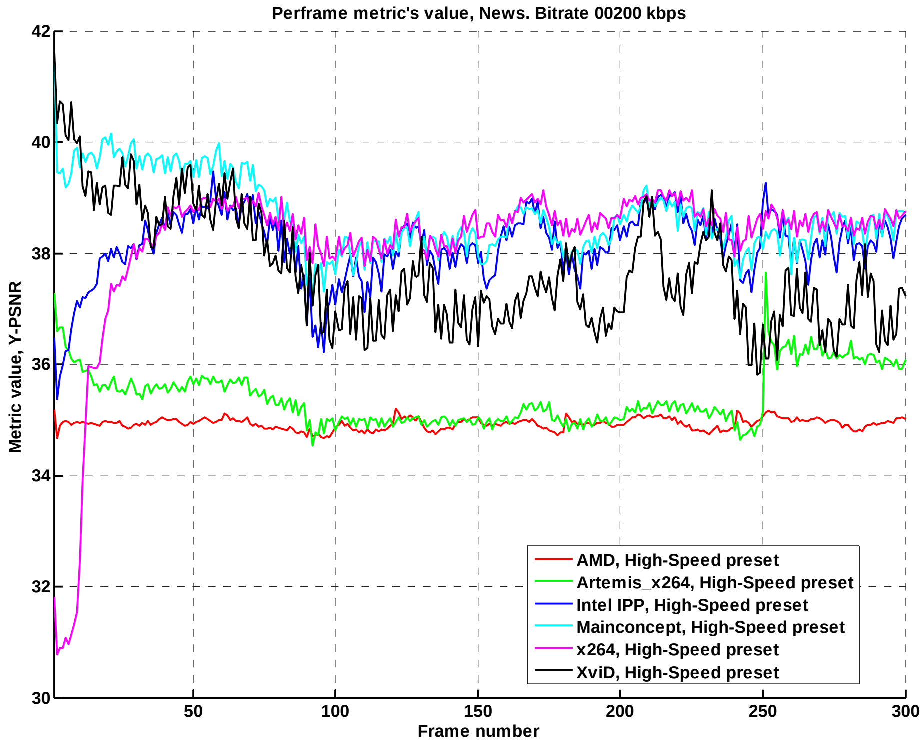


Figure 62. Per-frame quality. Usage area “Video Conferences”, “News” sequence, “High Speed” preset, 200 kbps

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).

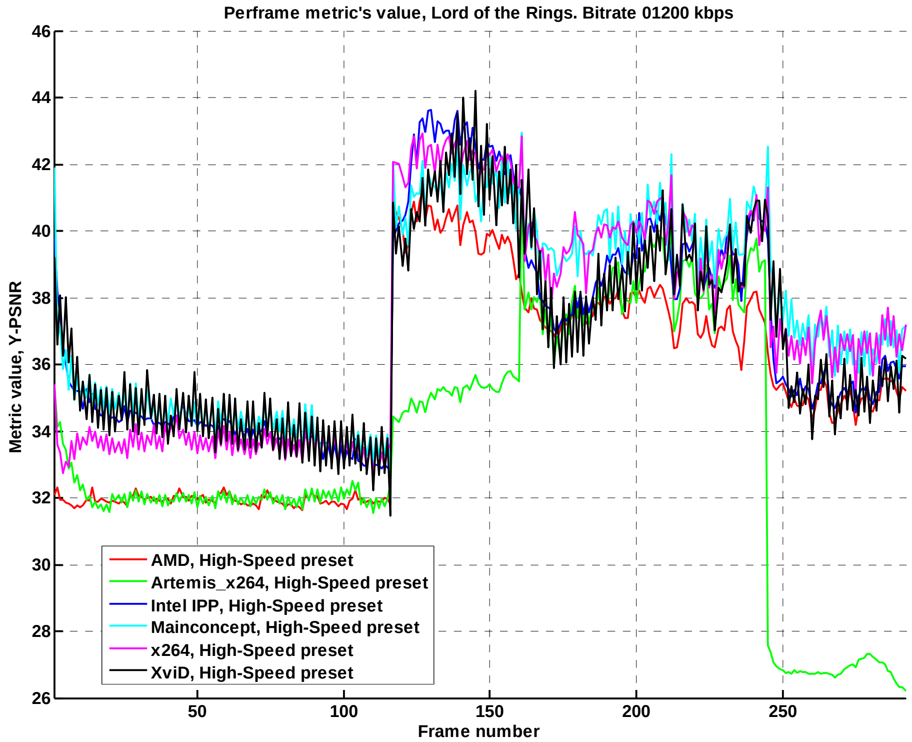


Figure 63. Per-frame quality. Usage area "Movies", "Lord of the Rings" sequence, "High Speed" preset, 1200 kbps

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).

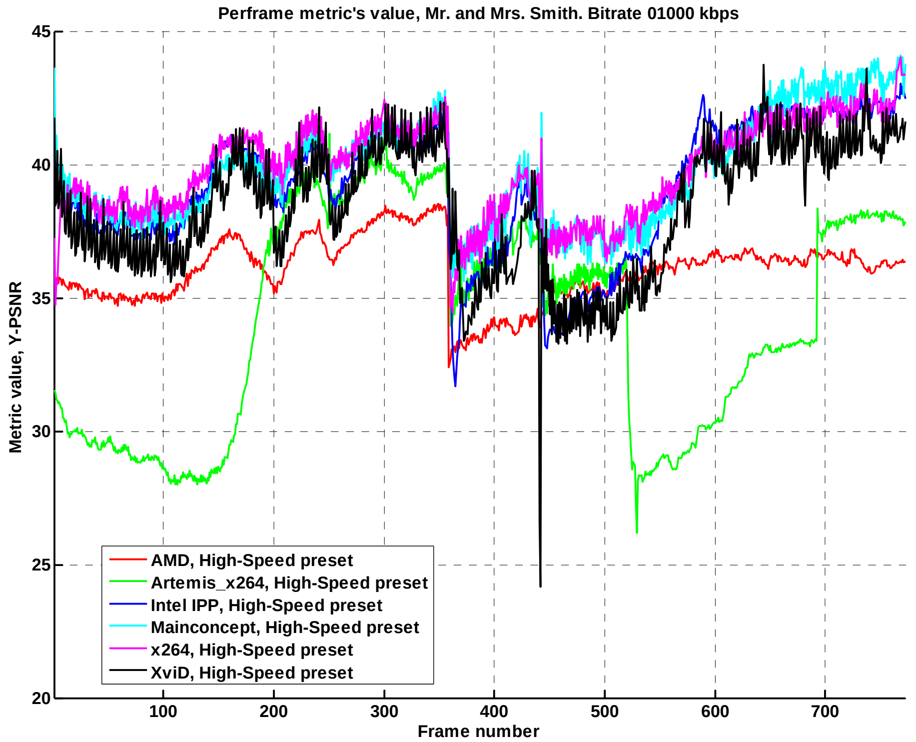


Figure 64. Per-frame quality. Usage area "Movies", "Mr. and Mrs. Smith" sequence, "High Speed" preset, 1000 kbps

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).

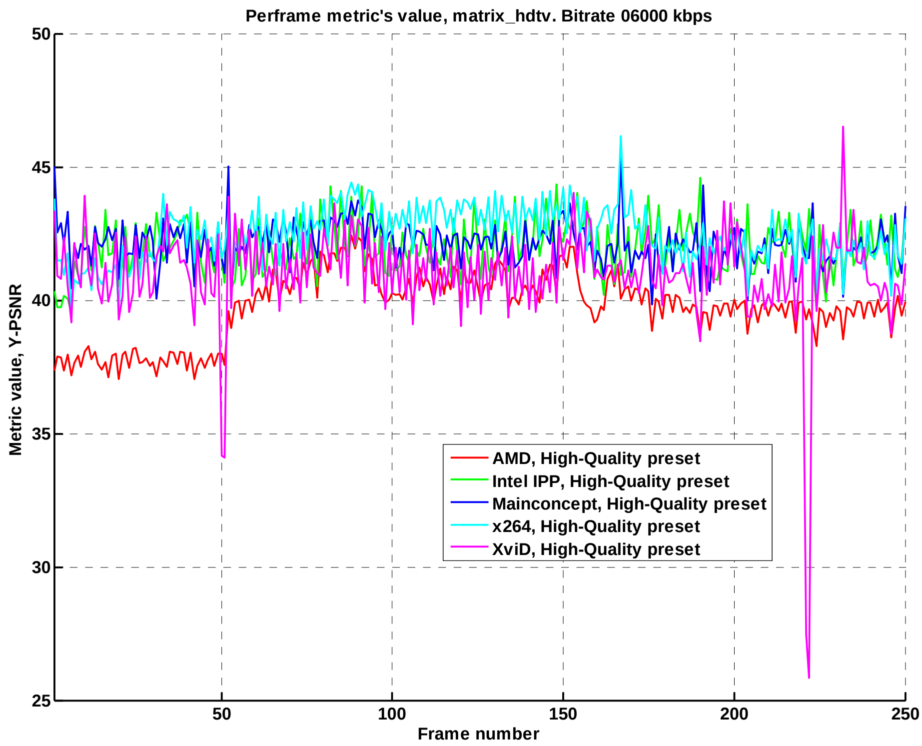


Figure 65. Per-frame quality. Usage area “HDTV”, “Matrix (HDTV)” sequence, “High Speed” preset, 6000 kbps

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).

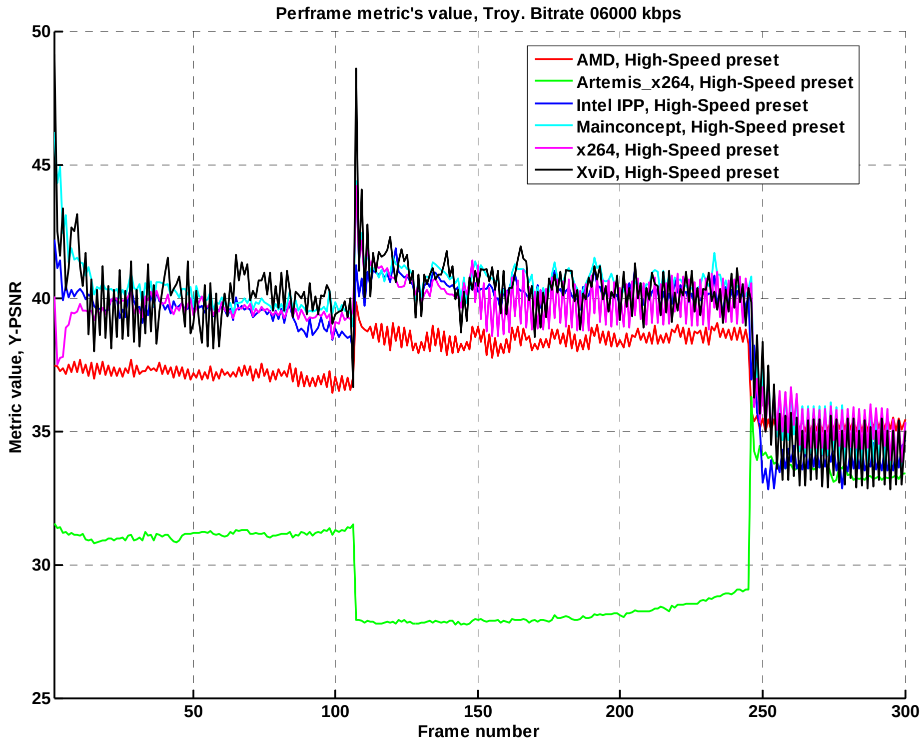


Figure 66. Per-frame quality. Usage area “HDTV”, “Troy” sequence, “High Speed” preset, 6000 kbps

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 Artemis x264, which demonstrates a quality increase

6 Appendix 1. 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.

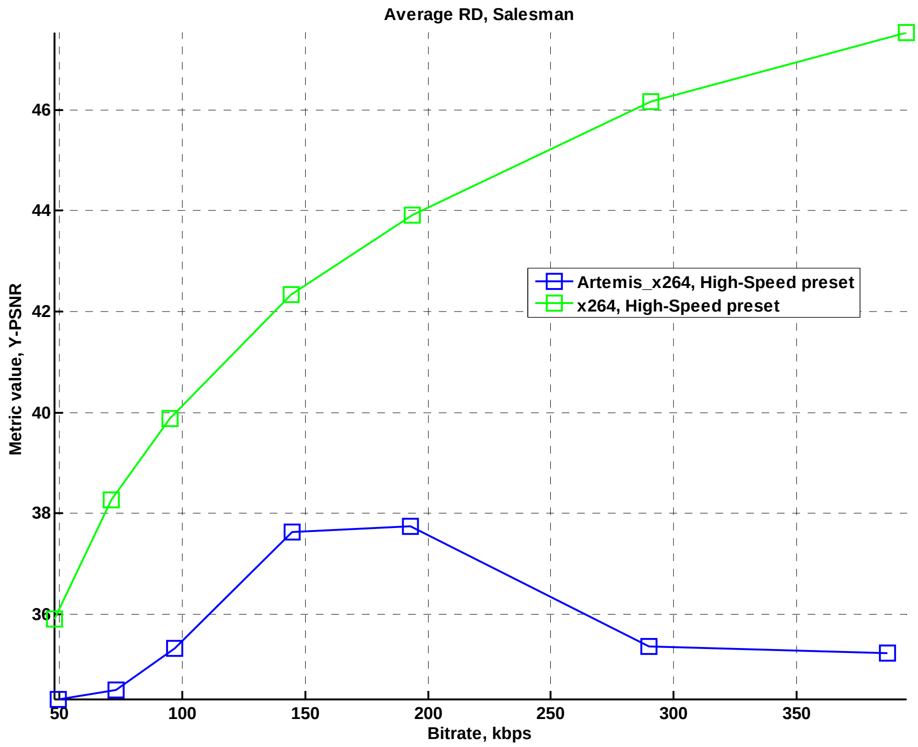


Figure 67. RD curve for "Salesman" sequence, High-Speed preset, Artemis_x264 and x264, Y-PSNR

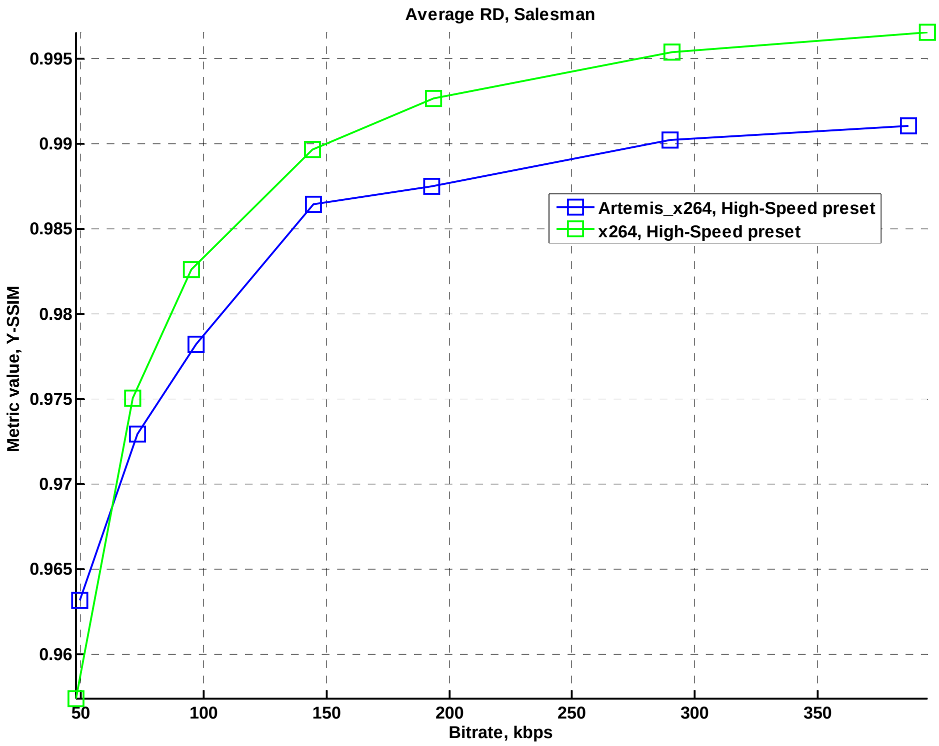


Figure 68. RD curve for "Salesman" sequence, High-Speed preset, Artemis_x264 and x264, Y-PSNR

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.

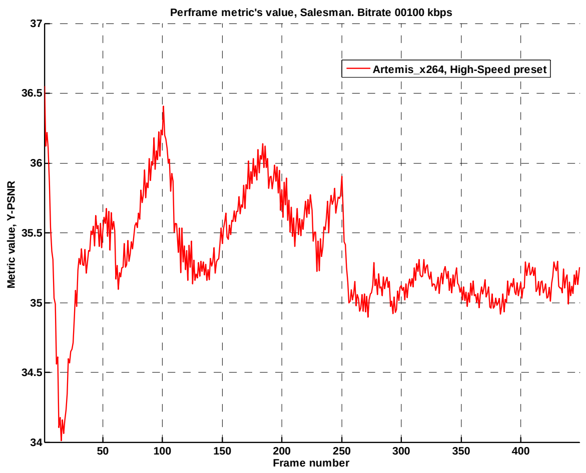


Figure 69. Per-frame Y-PSNR, sequence "Salesman", Artemis_x264, 100 kbps

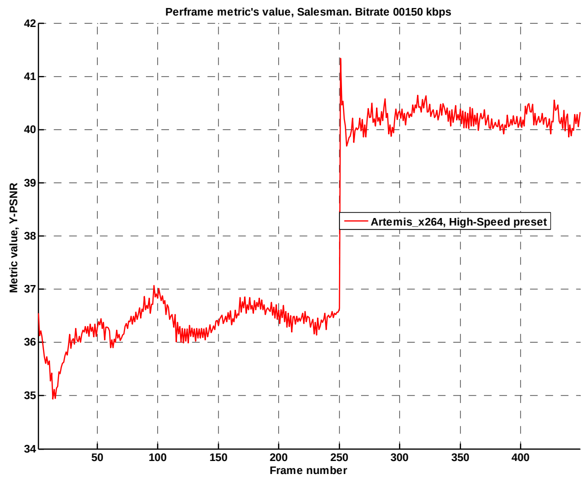


Figure 70. Per-frame Y-PSNR, sequence "Salesman", Artemis_x264, 150 kbps

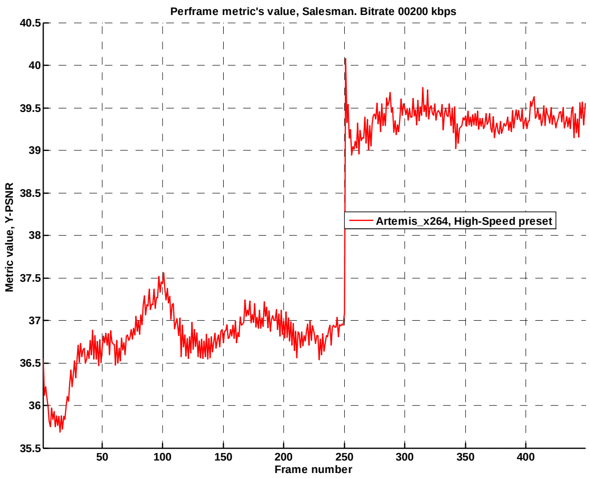


Figure 71. Per-frame Y-PSNR, sequence "Salesman", Artemis_x264, 200 kbps

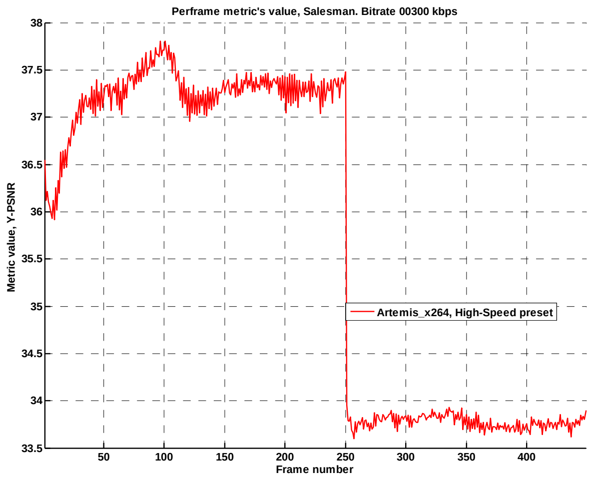


Figure 72. Per-frame Y-PSNR, sequence "Salesman", Artemis_x264, 300 kbps

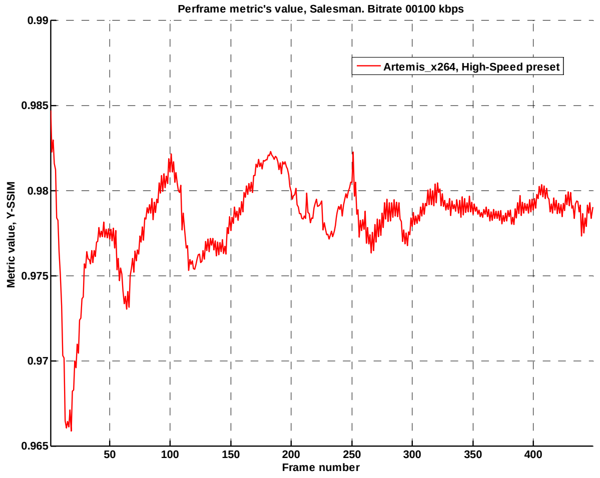


Figure 73. Per-frame Y-SSIM, sequence "Salesman", Artemis_x264, 100 kbps

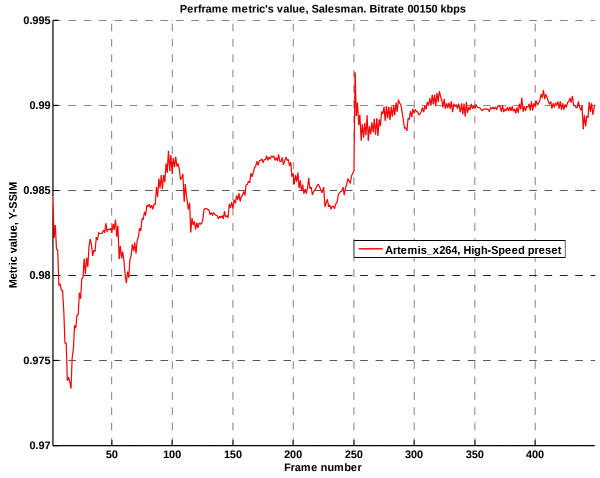


Figure 74. Per-frame Y-SSIM, sequence "Salesman", Artemis_x264, 150 kbps

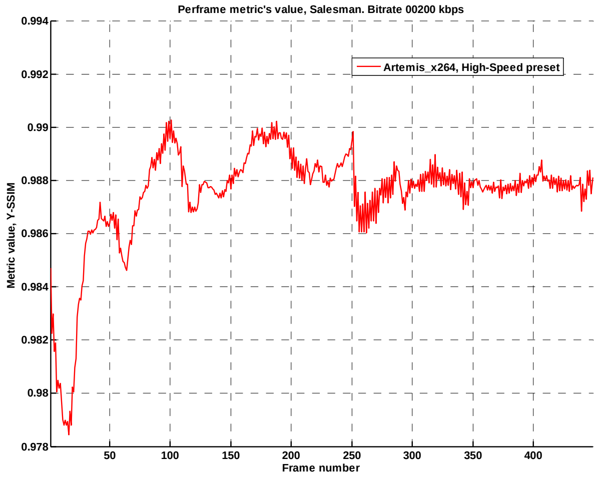


Figure 75. Per-frame Y-SSIM, sequence "Salesman", Artemis_x264, 200 kbps

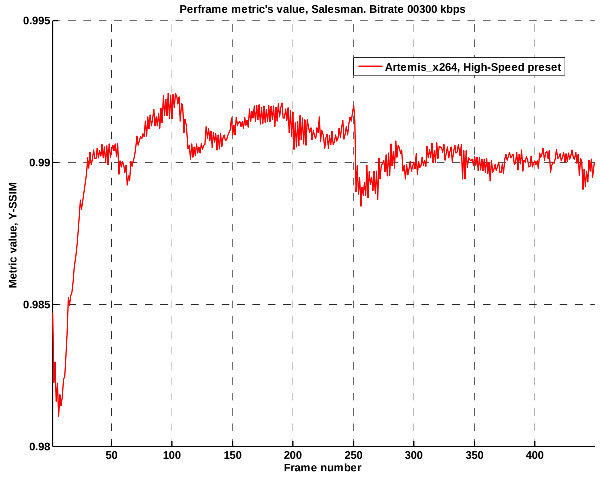


Figure 76. Per-frame Y-SSIM, sequence "Salesman", Artemis_x264, 300 kbps

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.

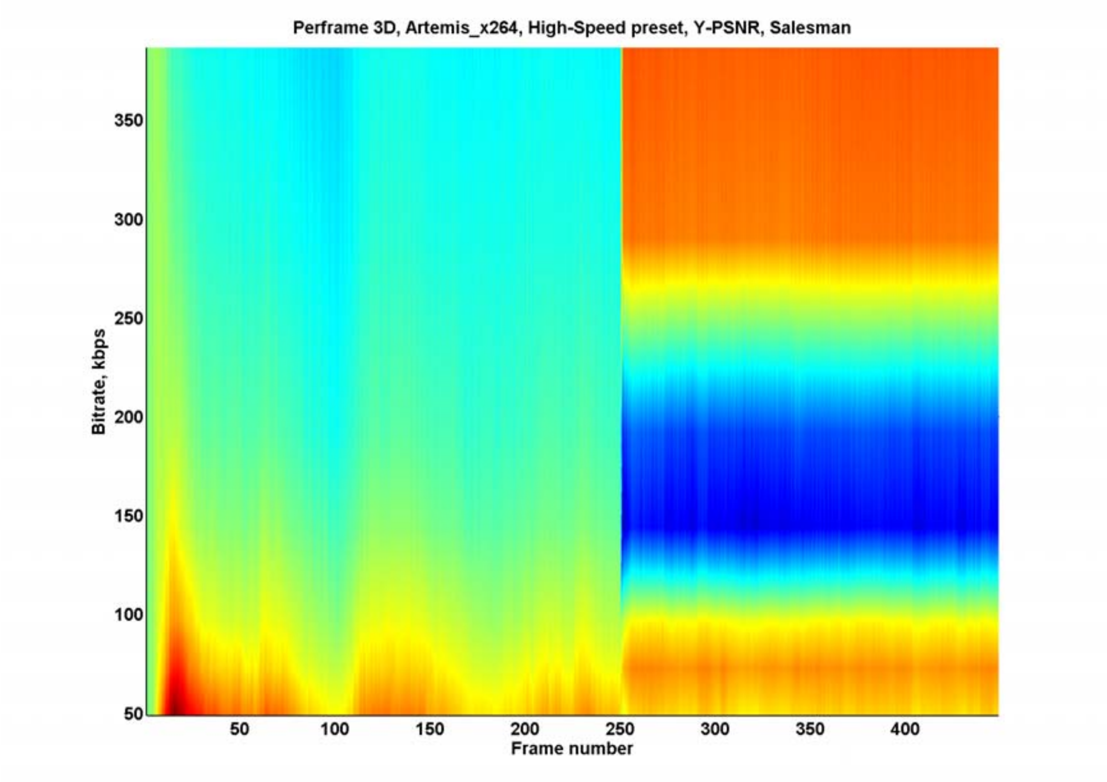


Figure 77. 3D per-frame quality for "Salesman" sequence, High-Speed preset, Artemis x264, Y-PSNR

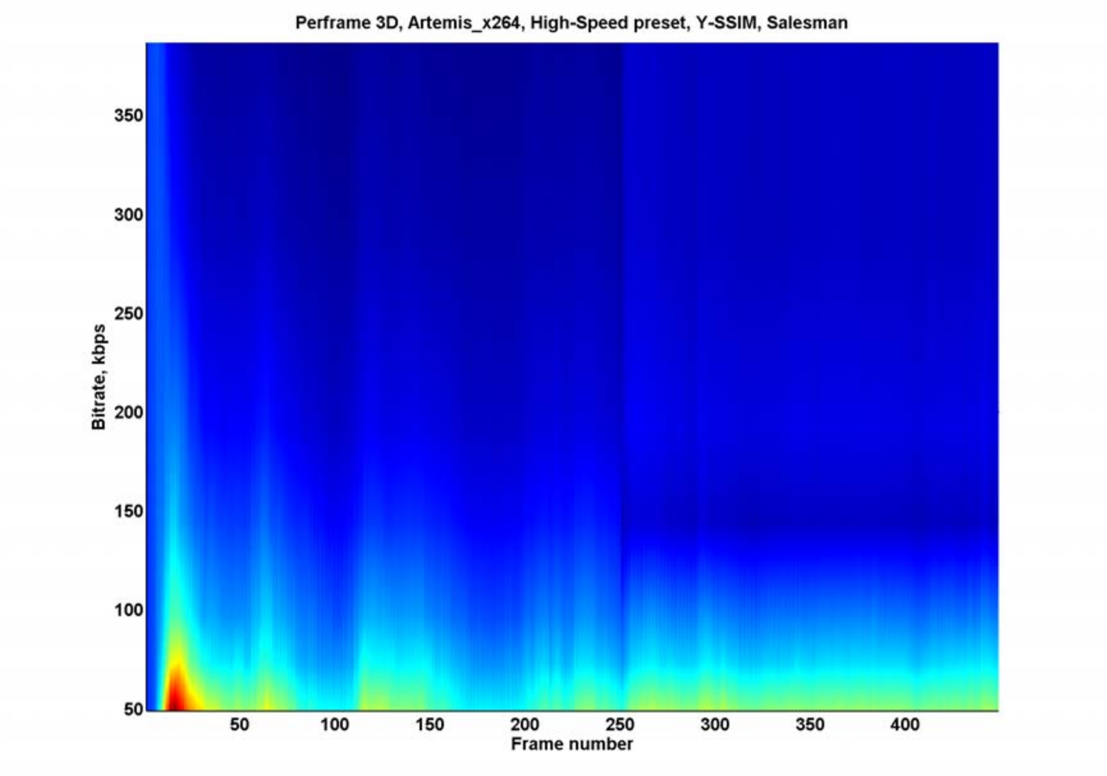


Figure 78. 3D per-frame quality for “Salesman” sequence, High-Speed preset, Artemis x264, Y-PSNR

Figure 77 is the 3D visualization of per-frame quality using the Y-PSNR metric; Figure 78 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.

6.1.1.1 Conclusion

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

7 Appendix 2. Test Set of Video Sequences

7.1 Videoconference Sequences

7.1.1 "Salesman"

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

Figure 79. Salesman sequence, fame 1

Figure 80. 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.

7.1.2 "Foreman"

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

Figure 81. Foreman sequence, frame 77

Figure 82. 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.

7.1.3 "News"

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

Figure 83. News sequence, frame 1

Figure 84. 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.

7.2 Movie Sequences

7.2.1 "Battle"

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

Figure 85. 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.

7.2.2 "Smith"

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

Figure 86. 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.

7.2.3 “Iceage”

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

Figure 87. 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.

7.2.4 "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)

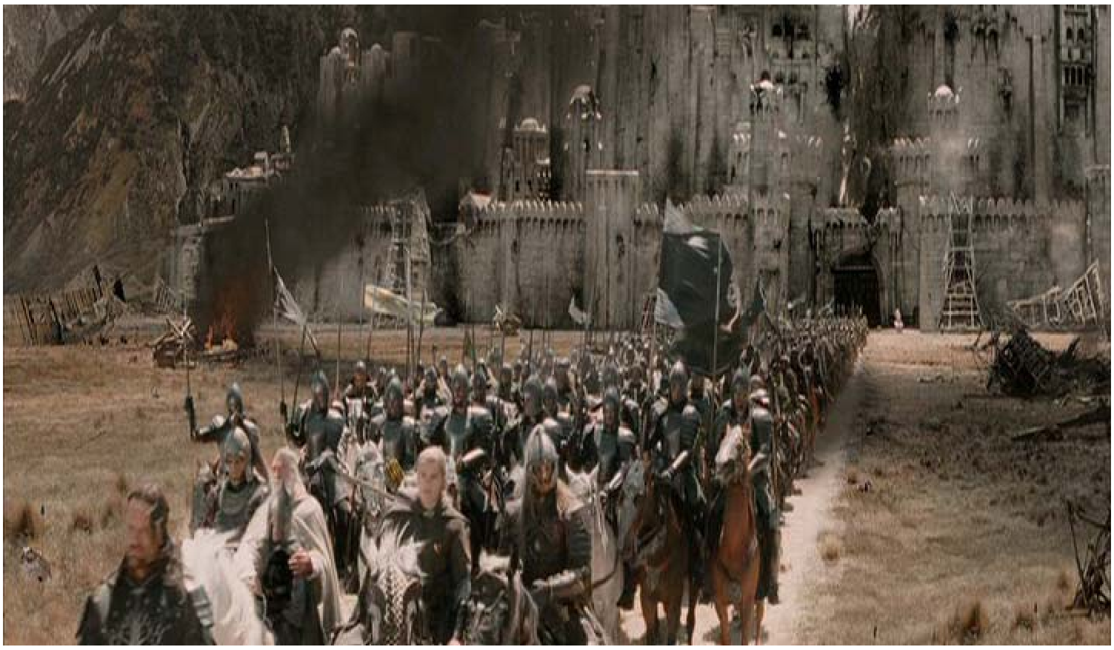


Figure 88. Lord of the Rings sequence, frame 100

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.

7.3 HDTV Sequences

7.3.1 "Troy"

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

Figure 89. 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.

7.3.2 “Matrix”

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

Figure 90. 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.

8 Appendix 3. Tested Codecs and Presets

8.1 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.

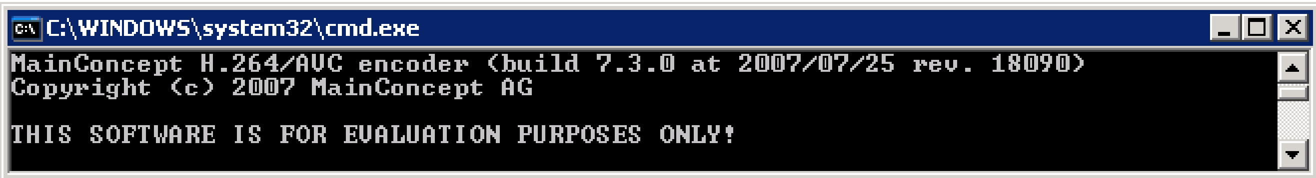


Figure 91. MainConcept H.264/AVC encoder

8.2 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.

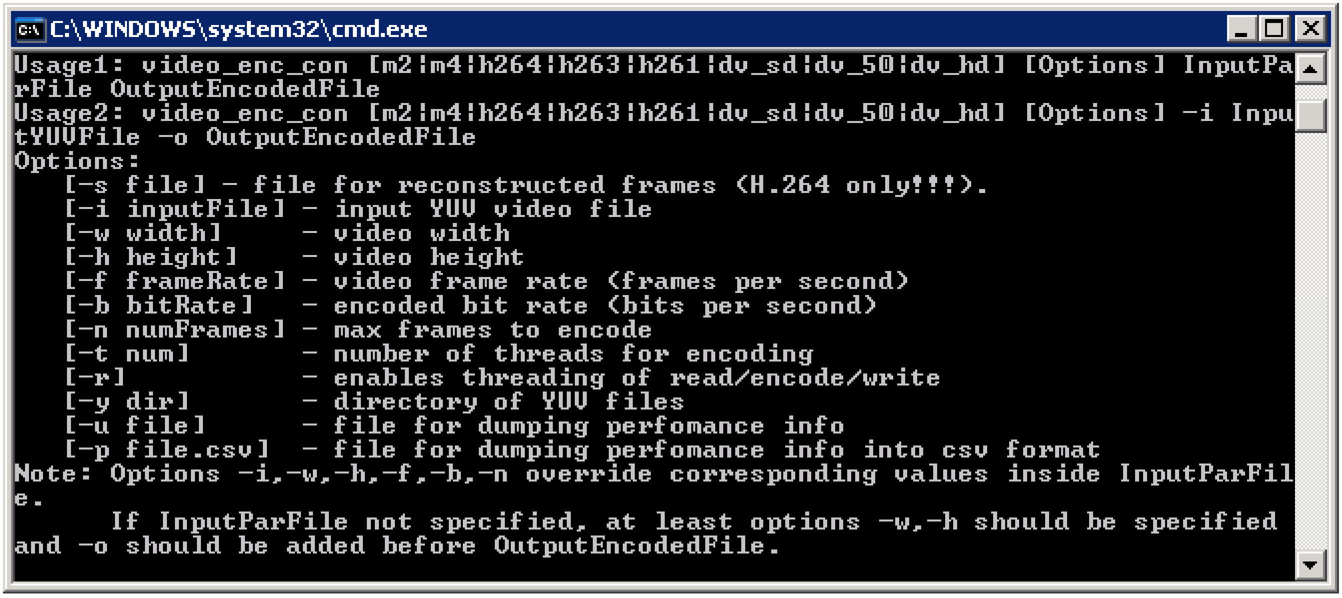
Figure 92. AMD H.264/AVC encoder

8.3 Intel H.264 encoder

- 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.
```

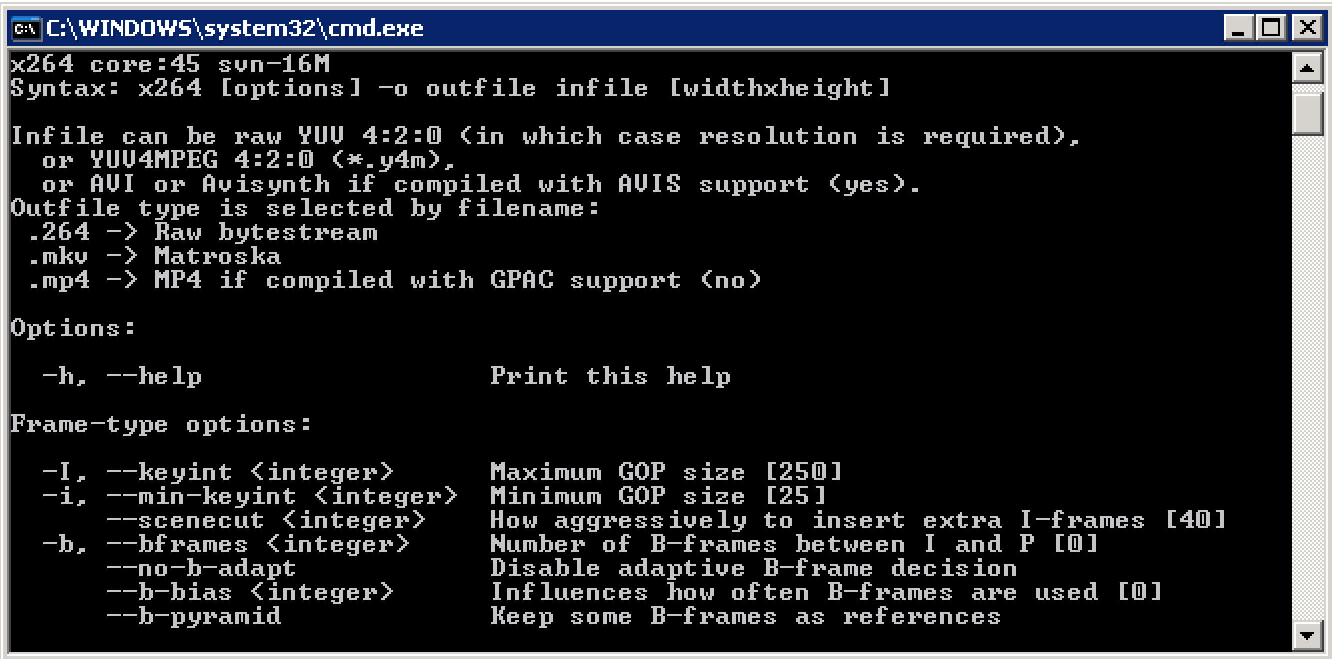
Figure 93. Intel H.264 encoder

8.4 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 94. Artemis x264 encoder

8.5 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.

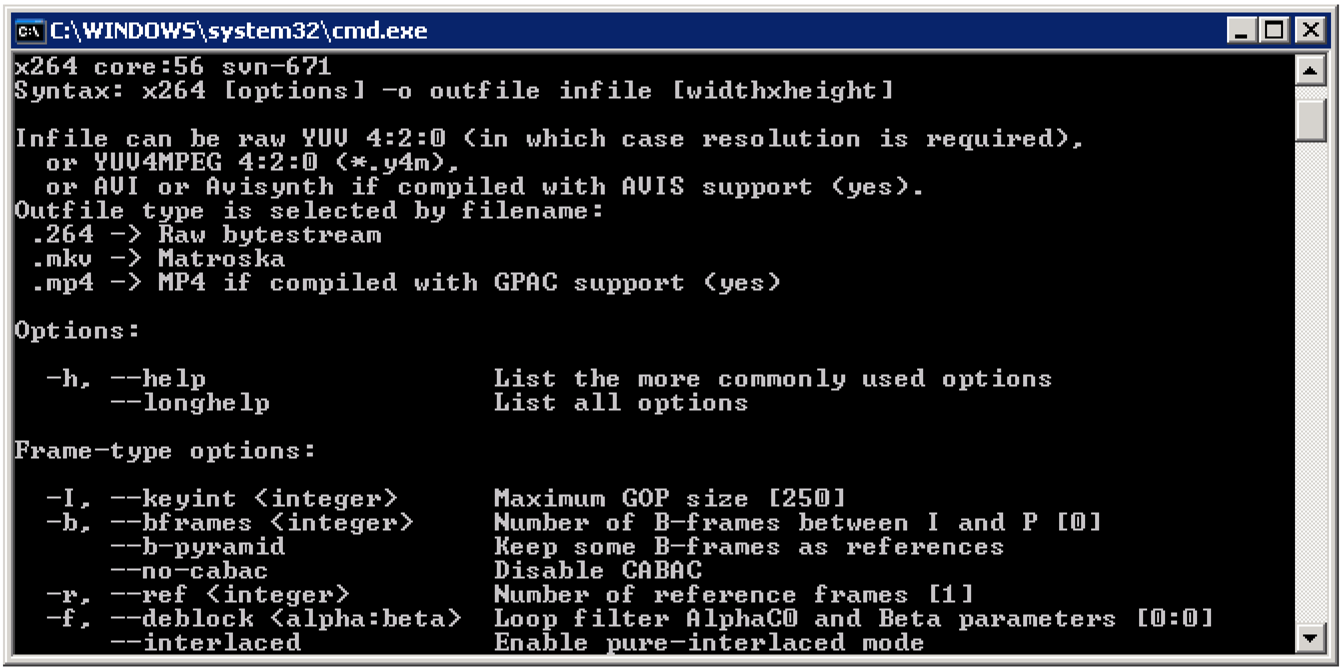


Figure 95. x264 encoder

8.6 XviD encoder

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

Remarks:

No remarks.

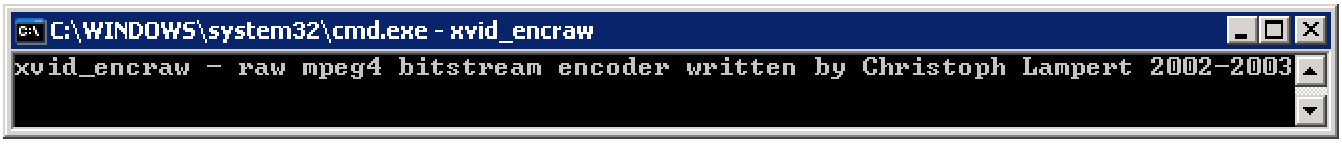


Figure 96. XviD encoder

9 Appendix 4. 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.

9.1.1.1 RD curves

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

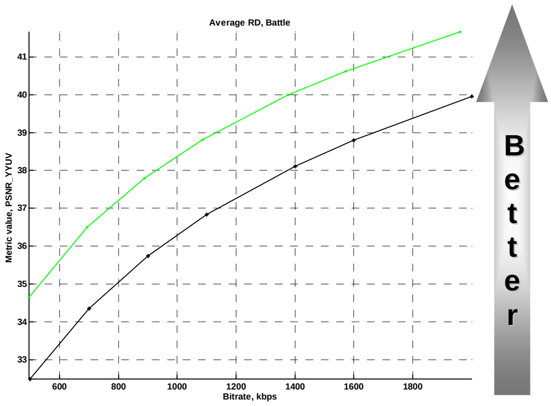
9.1.1.2 Relative Bitrate/Relative Time Charts

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.

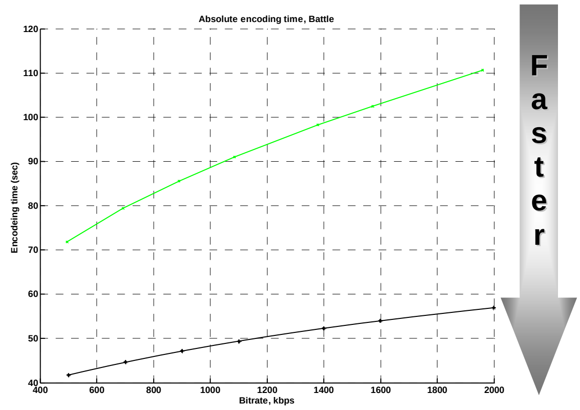
The X-axis shows the relative encoding time for the codec under test. Larger values indicate a slower codec. For example, a value of 2.5 means that the codec under test works 2.5 times slower, on average, than the reference codec.

9.1.1.3 Graph Example

Figure 97 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!

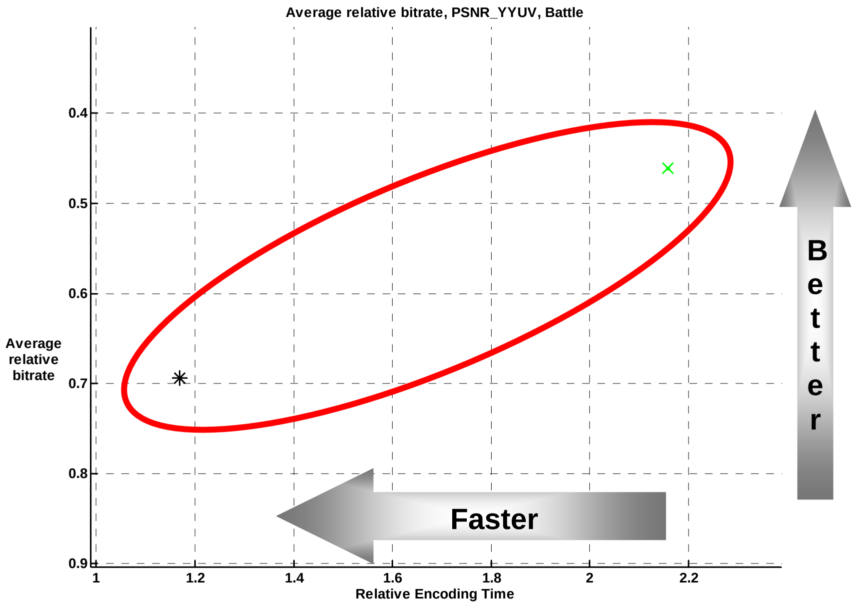


Figure 97. Integral situation with codecs. This plot shows the situation more clearly.

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.

9.2 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 99). 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 100). 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.

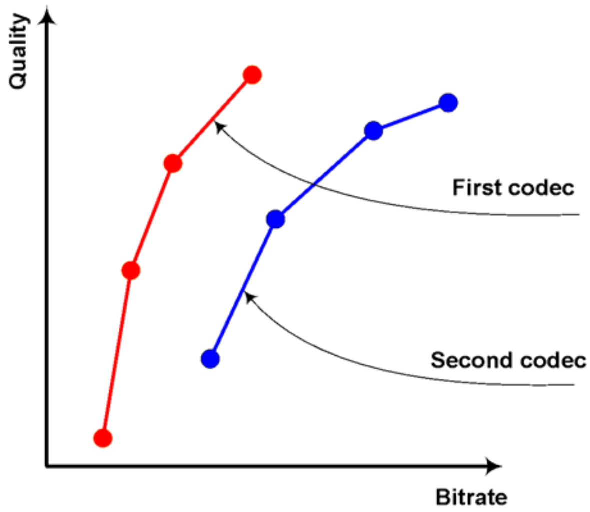


Figure 98. Source Data

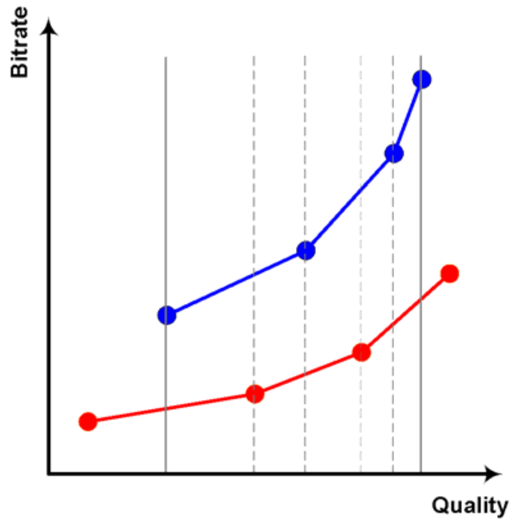


Figure 99. Axes' Inversion and Averaging Interval Choosing

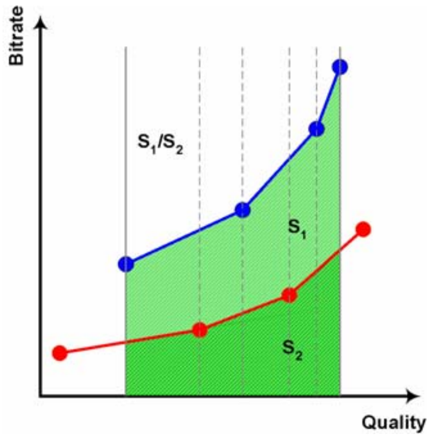


Figure 100. Areas' under Curves Ratio

9.3 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.

10 Appendix 7. Objective Quality Metrics Description

10.1 PSNR (Peak Signal-to-Noise Ratio)

10.1.1 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.

10.1.2 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 101. 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

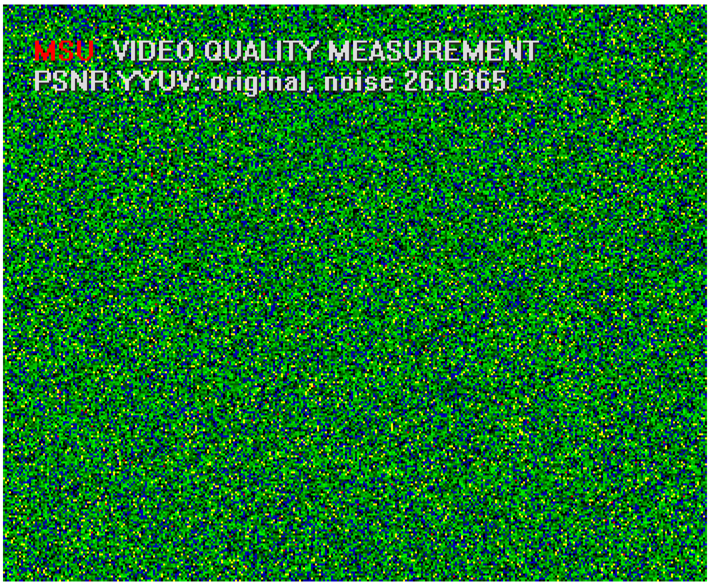
Blurred image

Sharpen image

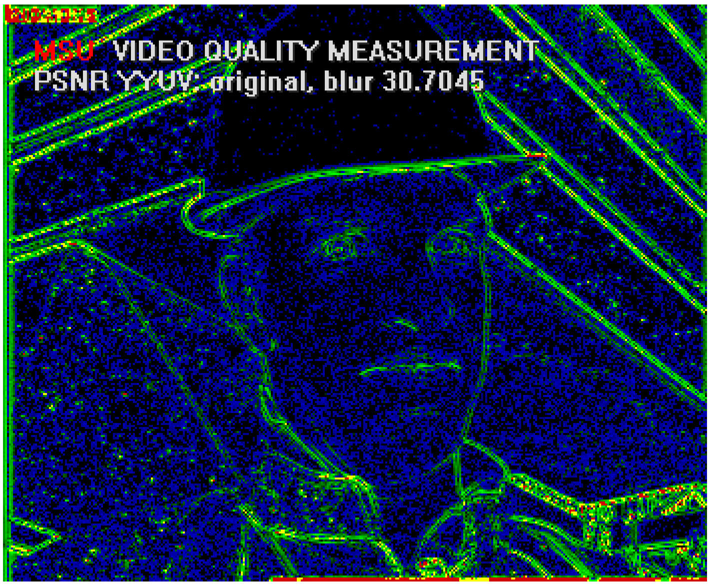
Figure 102. Original and processed images (for PSNR example)

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

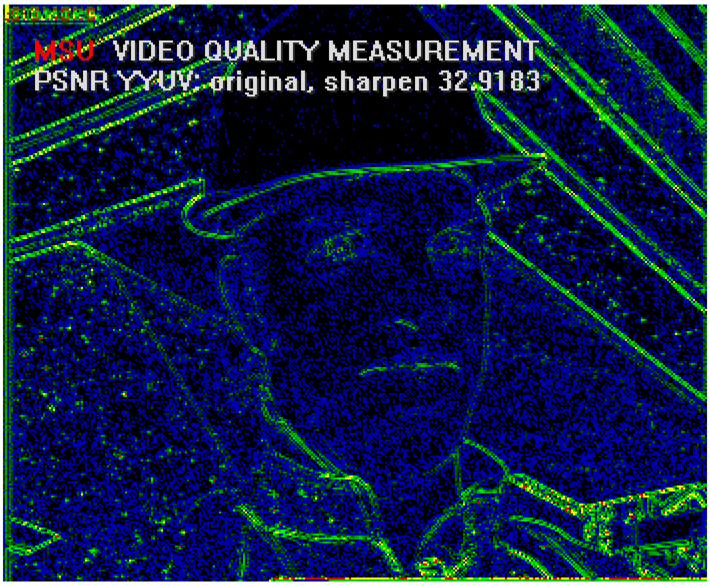
PSNR for image with itself, value = 0



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 103. PSNR values for original and processed images

10.2 SSIM (Structural SIMilarity)

10.2.1 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.

10.2.2 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 104. 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

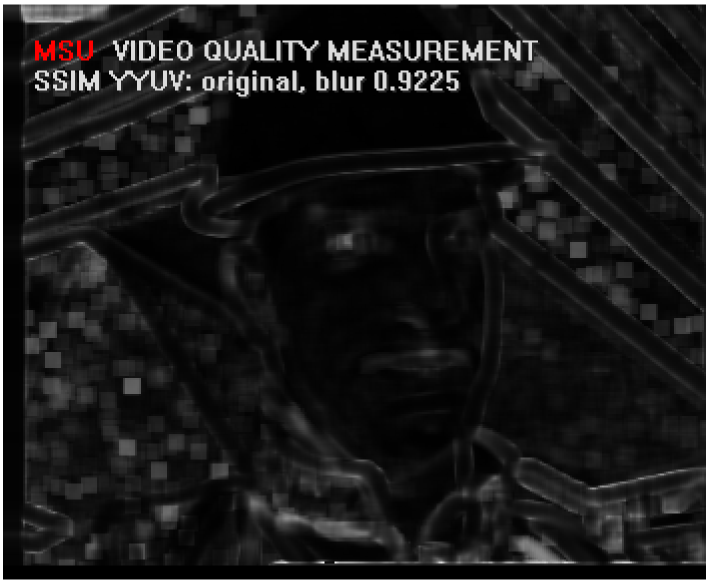
Sharpen image

Figure 105. 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 106. SSIM values for original and processed images

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12 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.

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