



Lossless Audio Codec Comparison
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Introduction

While testing the efficiency of lossy codecs can be quite cumbersome (as results differ for each person), comparing lossless codecs is much easier. As the last well documented and comprehensive test available on the internet has been a few years ago, I thought it would be a good idea to update.

Beside comparing with CD-audio (which is often done to assess codec performance) and spitting out a grand total, this comparison also looks at extremes that occurred during the test and takes a look at 'high-resolution audio' and multichannel/surround audio.

While the comparison was made to update the comparison-page on the FLAC website, it aims to be fair and unbiased. Because of this, you'll probably won't find anything that looks like conclusions: test results are displayed and analysed, but there is no judgement or choice made. As different people have different demands, there is probably not a single codec that can is 'the best' at all really.

It is important to understand that nothing in this document is set in stone, codecs are still being tweaked and big surprises are still very well possible, see for example the still recent move of Apple to make ALAC open-source. Besides that, the test material is, while being quite diverse, currently limited to 29 CDs for the CD-audio test, 2 sources for the high-resolution audio test and 1 source for the multichannel test. Because of this, the results should be used with care. Furthermore, this comparison is "only about numbers", comparing speed to compression. Other important stuff, like software/hardware support and development activity are not mentioned at all. For more information on these features, I would like to recommend the HydrogenAudio comparison of lossless codecs [5] and the codec comparison on FLAC's homepage [4].

Chapter 1

Test setup

Because of time and labour constraints, not all available codecs are checked for all material. The most notable exception are WMA Lossless and Real Audio Lossless, as command line encoders for these formats seem to be only available for Windows and these did not work over wine. WMA Lossless is included in the first overall CD-test, but these values were added manually. The in-depth comparisons don't feature WMA Lossless.

All codecs were tested either directly or via wine on a linux machine. The choice for linux (kubuntu 12.10 in this case) was mainly because it offers comprehensive timing tools, which make it easy to check how much CPU time a process has used. In this way, tests could be run fully automatic which makes it possible to test a wide range of codecs, settings and music.

The machine used is a HP Elitebook 8530w, equipped with an Intel Core2Duo T9600 and 4GB of RAM. The CPU frequency for both cores is fixed with `cpufreq` at 2.13GHz to be sure thermal management won't throttle the machine and thrash the results. Timing was done with 'time', both real time and cpu time where measured but only cpu time has been used in the following analyses. Before the test starts, the WAVE files are copied to a ramdisk (`ramfs`) to bypass the hard drive entirely.

1.1 Scripting and graphing

The scripting was done in PHP (because I'm familiar with it, not because it's a good choice for this use) and was basically executing encoding and decoding commands within the `time`-command and sanitizing this data before it went into the `cvs`-file. It made sure every encoder would have a fresh copy of the files (in

case one encoder would mangle them) in the ramdisk and measured the size of the WAV-files and compressed files to extract a compression ratio.

These cvs-data was ordered by hand and fed into a graph generator, also written in PHP. This resulted in four graphs: two with the familiar 'encoding or decoding speed' versus compression and two which displayed more or less the inverse of the speed versus the compression. The latter two graphs were added because the linear scale used doesn't display the really slow codecs well. Using logarithmic scales was possible as well, but considering those are hard to read for most people this wasn't done. Furthermore, the inverse of encoding speed happens to be CPU-usage, which is a value that is probably easy to relate for most readers.

1.2 Codecs and parameters used

Every known lossless codec that could be easily used on Wine or Linux has been tested. Considering the parameters, the ones recommended by the developer (or the command-line help of the encoders) were used, with some exceptions. For example, not all available compression modes of OptimFROG were used, because there are a lot and the codec is pretty slow. Also, after some preliminary tests, it was chosen to drop ALS's -7 mode and OptimFROG's maximumcompression. ALS -7 was simply too slow with little or even negative gain (see figure 1.1) and OptimFROG's -maximumcompression is not advised for daily use, only for benchmark purposes. While this is a benchmark, daily use is the focus of this report.

As you can see in figure 1.1, the encoding of ALS -7 and OptimFROG maximum-compression both took 2.5 times the playing length of the files, which for such a comprehensive test is far to long: together they used half of the running time of the test, while they offer no real benefit. On this CD, ALS -7 is actually even worse than ALS without parameters, but this usually wasn't the case. This is strange, as the comparison I did in may 2009 (with an earlier version of ALS) did show fairly large gains, but with this version it seems those gains were lost.

1.3 WMA, RealAudio and ALAC

For WMA Lossless, Realaudio Lossless and ALAC there was no command line encoder (or at least, not one that would run on Linux or Wine), so for these some measurements on a Windows computer where made. Because this was all done by hand, only the first 4 CDs of the list have been tested, otherwise the amount of work added would have been disproportionate. After testing, the

Encoding CPU-usage vs compression (Fanfare Ciocarlia - Baro Biao: World Wide Wedding)

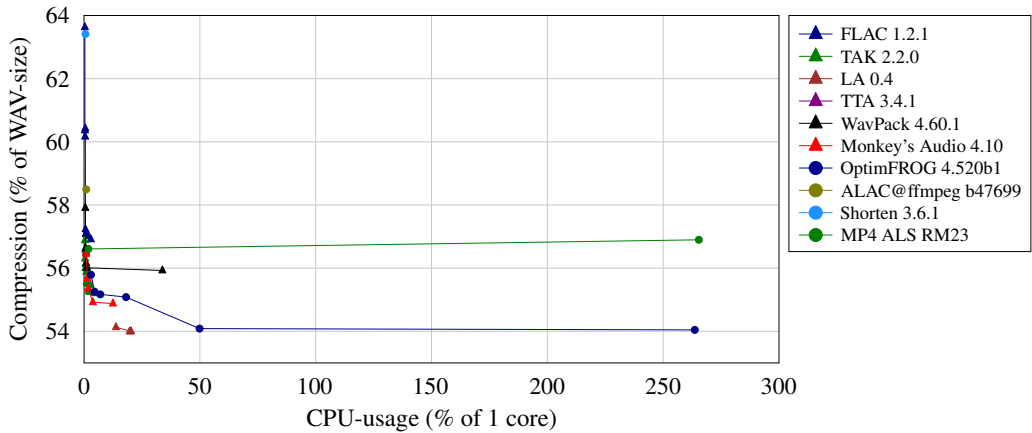


Figure 1.1: Encoding speed as 'calculated CPU-usage' versus compression for 'Fanfare Ciocarlia - Baro Biao: World Wide Wedding'

4th CD (the audiobook of Dan Brown) was rejected because RealAudio's low-complexity setting struggled with the mono content, and it would not have been representative to show this.

P.S.: It seems there is a command line encoder for ALAC called refalac nowadays, but I didn't know of it when I did the comparison. I'll use that one for the next revision of this document.

WMA Lossless has encoding and decoding support through DirectShow, so these were encoded and decoded with dBpoweramp. RealAudio only has encoding tools available and iTunes has only encoding support. The decoding of RealAudio and ALAC via iTunes was tested using ffmpeg on the Linux computer. The results of the Windows machine were 'scaled' to the level of the Linux-box by running FLAC -6 on the same files and retrieving an 'speed factor' from that. The uncompensated outcome for encoding at the Windows-machine is shown in figure 1.2a, the decoding performance of FLAC and WMA Lossless plus the compensated RealAudio Lossless and ALAC, which were both decoded with FFmpeg.

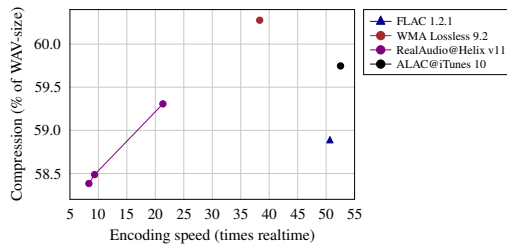
As the results of the Windows-computer are unreliable (real time was measured, not CPU time) and because only 3 CD were used to calculate this 'scaling factor', these results should be used with care: **they are not as reliable and precise as the other results.** However, they do provide insight in the global performance of these codecs. In particular, it can be seen that both WMA Lossless and ALAC do not perform very well, as FLAC -6 is not considered strong compression nor fast encoding but still outperforms them.

For RealAudio it should be noted that decoding them is nearly impossible: Real

Codec	Parameters used
FLAC	-0, -1, -2, -3, -4, -5, -6, -7, -8
TAK	-p0, -p0e, -p0m, -p1, -p1e, -p1m, -p2, -p2e, -p2m, -p3, -p3e, -p3m, -p4, -p4e, -p4m
LA	[-], -high, -high -noseek
TTA	[-]
WavPack	-f, [-], -h -x, -hh -x
Monkeys Audio	-c1000, -c2000, -c3000, -c4000, -c5000
OptimFROG	-mode fast, -mode normal, -mode high, -mode best, -mode bestnew
ALAC	[-]
Shorten	[-]
MP4ALS	[-]

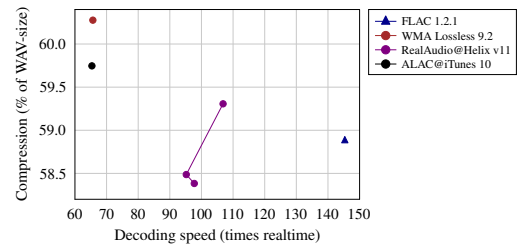
Table 1.1: Parameters used for each codec

Encoding speed vs compression (First 3 CDs for W-only codecs)



(a) Encoding performance

Decoding speed vs compression (First 3 CDs for W-only codecs)



(b) Decoding performance

Figure 1.2: Codec performance for the three CDs tested on Windows

has tried to ban any 3th party decoder, and the ffmpeg decoder can't decode them without errors. Several decoded files had (small) missing parts or hiccups. Therefore, the decoding speed measurement is probably not really reliable.

The scaling factor retrieved from the tests and used to extrapolate the results to the overall test graph are shown in table 1.2.

Codec	Compression	Encoding speed	Decoding speed
WMA Lossless	1.024	0.755	0.452
RA Lossless - low	1.008	0.420	0.735
RA Lossless - medium	0.993	0.181	0.654
RA Lossless - high	0.991	0.160	0.670
ALAC @ iTunes 10	1.015	1.036	0.450

Table 1.2: Scaling values with respect to FLAC -6

Chapter 2

CD-audio test

The most important use of lossless codecs nowadays is containing CD-audio. Because of this, most of this report focusses on CD-audio. First, the performance of all codecs on the whole corpus will be examined. Next, some CDs will be examined separately to comment on particular quirks and weak points of certain codecs.

2.1 CD's used

The CD's used in this test are listed below, with a very general indication of the kind of music it is, should represent or what special significance it has, in case the performer is unfamiliar to you. These CD's should encompass a wide range of music and therefore give balanced results, with the weak spots of each codec exposed equally.

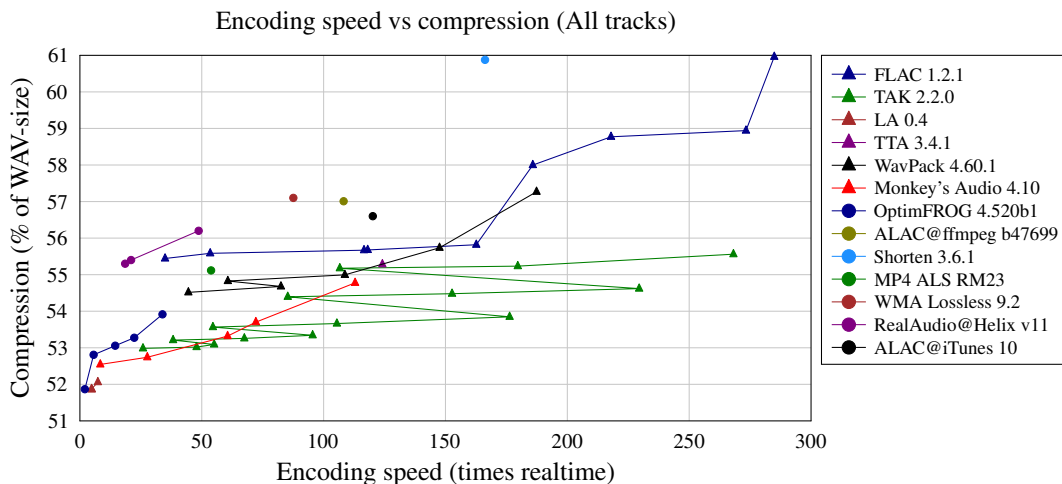
- 30 Seconds to Mars - This Is War (rock)
- Confido Domino Minsk - Sacred choral music from White Russia (choral, religious)
- Daft Punk - Alive 2007 (electronic, live)
- Dan Brown - Angels and Demons (audiobook)
- Enya - Amarantine (new age)
- Fanfare Ciocarlia - Baro Biao: World Wide Wedding (world music, brass)
- Gilberto Santa Rosa - Esencia (salsa)
- Giuseppe Verdi - Messa da Requiem (Berliner Philharmoniker feat. conductor Claudio Abbado) (classical, romantic)

- Howard Shore - The Hobbit: An Unexpected Journey (soundtrack, orchestral)
- Iron Maiden - Brave New World (metal)
- John Coltrane - Live at the half note, vol. 1 (jazz)
- Joss Stone - Mind, Body & Soul (soul)
- J.S. Bach - Magnificat (orchestral, baroque)
- Koninklijke Militaire Kapel - [no name] (military brass, vinyl rip)
- Kraftwerk - Autobahn (electronic)
- Lana del Rey - Born to Die (pop)
- Lil Wayne - Tha Carter III (hip hop)
- Martin O'Donnell & Michael Salvatori - Halo: Reach O.S.T. (ambient-ish, soundtrack)
- Michael Bublé - meets madison square garden (pop, live)
- Mike Oldfield - Tubular Bells (not classifiable)
- Rosenberg Trio - Djangologists (jazz)
- Rush - Grace under Pressure (1997 remaster) (rock)
- System of a Down - Mezmerize (metal)
- Szakcsi - Virágom, virágom (world music)
- Tiësto - In Search of Sunrise 7: Asia (dance)
- Various - Jeff Waynes Musical Version of The War of the Worlds (radio drama-ish, rock, orchestral)
- Various - Latin Village, CD 1: Salsa (compilation of salsa)
- Xzibit - At the Speed of Life (hip hop)
- Yann Tiersen - Le Fabuleux Destin d'Amélie Poulain (minimalism, soundtrack)

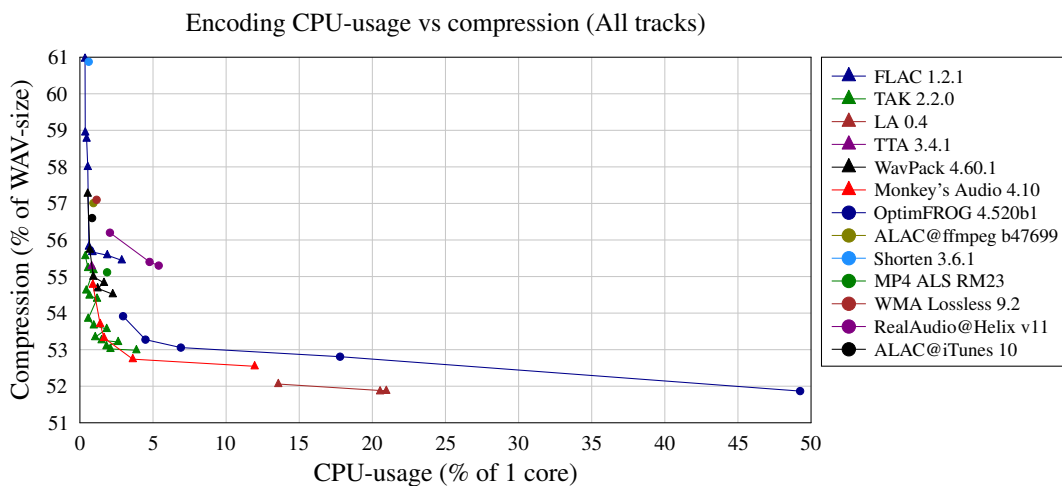
Quite some effort was put into choosing and balancing this list, with a lot of help from [3]. In particular, Tom Beck, developer of the TAK codec, pointed out that mastering can make a real difference in codec performance, and therefore the test should encompass as much different 'mastering techniques as possible'. For more information on the CDs and why they were used for this test, see Appendix A.

2.2 Results all CD's together

The results following are from all the CDs mentioned above averaged. This was done by averaging the CD-results, not those of the individual tracks. The WMA Lossless, Real Audio Alternative and iTunes ALAC results were added later, with the method explained in section 1.3 and therefore are not as precise as the others.

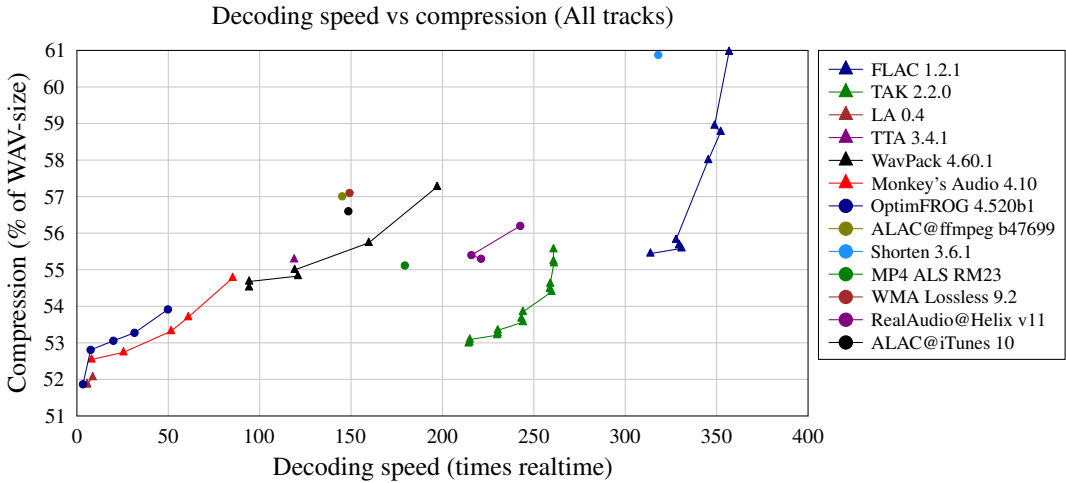


(a) Displayed the usual way

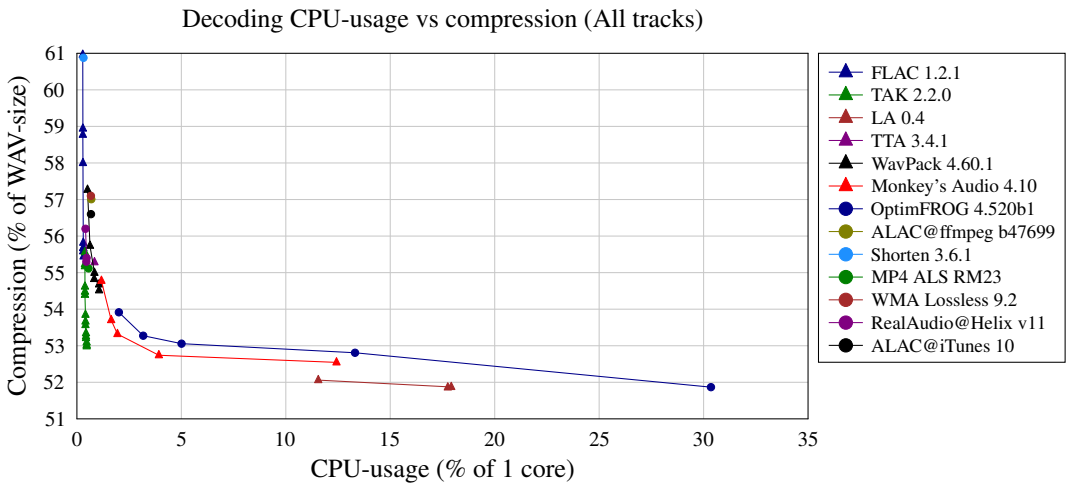


(b) Displayed as realtime CPU-usage

Figure 2.1: Encoding codec performance of all CD's averaged



(a) Displayed the usual way



(b) Displayed as realtime CPU-usage

Figure 2.2: Decoding codec performance of all CD's averaged

2.3 Interesting quirks

While testing different CD's to obtain a balanced total, the results of the individual CD's were plotted as well to look for certain peculiarities, both to report and to assess the validity of the test. If the results of most CD's look similar and any strange behaviour is explainable, one could say the test is more or less valid because it converges. Apart from ALAC, FLAC setting -0 and -3 and Shorten fluctuating a lot (the latter two because of lacking stereo decorrelation), there was only one case in which non-standard behaviour was observed, which will be discussed next.

2.3.1 Mono encoded as stereo (Dan Browns Angels and Demons)

The biggest difference with the all-round test is the audio book. The tested material contains a lot of silence, is pure mono (encoded as stereo of course) and features only one voice. The encoding and decoding performance is displayed in figure 2.3 on page 15.

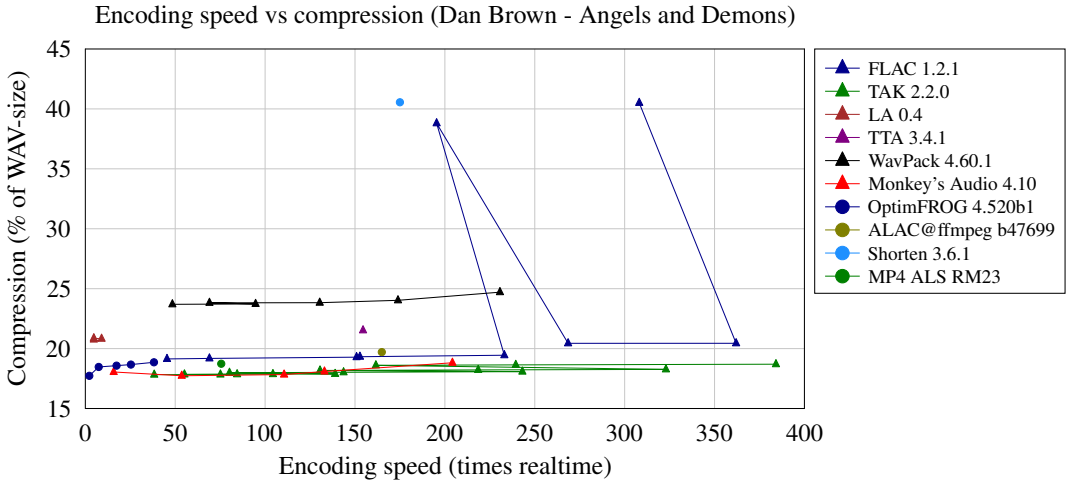
The most obvious features are the behaviour of FLAC and the bad performance of WavPack and LA. FLAC's behaviour is because at modes -0 and -3 (which are the two peaks visible) there is no stereo decorrelation tried. All other modes have some form of stereo decorrelation, which obviously helps as this is pure mono: it halves the size of the files here. WavPacks bad performance is a known 'bug'. Newer encoders have an option `-optimize-mono`, but it has to be set manually as it might break compatibility with older decoders.

When looking for best compression, OptimFROG lead here with a very small lead. Its `-bestnew` mode has the lowest compression (17.727%) while Monkey's Audio -c4000 (extra high) compresses only little less (17.733%). It is strange, but Monkey's Audio insane mode (which is slower than the extra high mode) gets only 18.0%. TAK and FLAC both perform very well considering their speed. A last remark is that LZMA2 (7-zip's compression mode) does very well considering it is not an audio codec, it scores 30% compression and outperforms both FLAC -0, -3 and Shorten here.

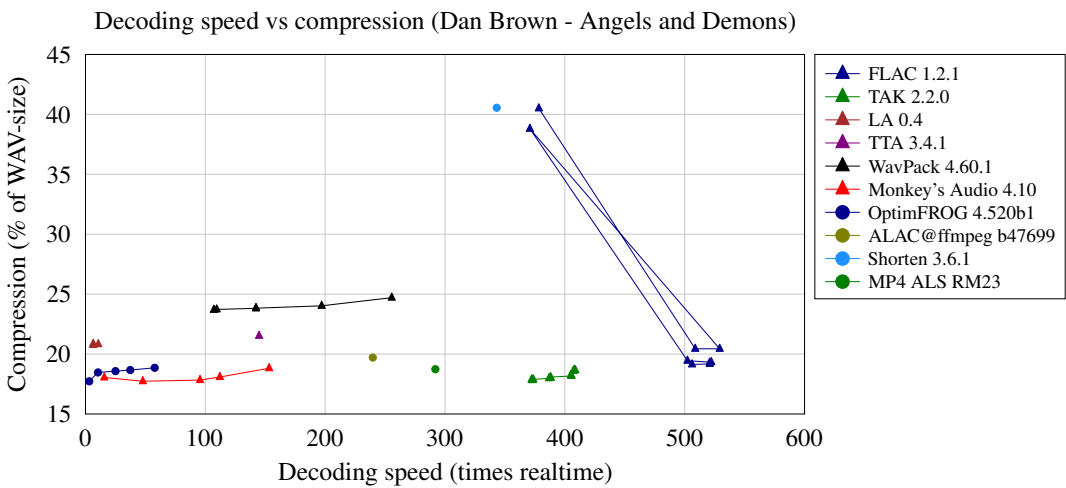
To find out which part of the performance of the codecs was due to the file being mono and which was due to the file containing lots of silence and only one voice, I decided to rerun the test with the files mixed to mono. This mono mixing was done with SoX using "remix 1" as a filter. So no mixing, I just took the first (left) channel to form the mono-channel.

The results are displayed in figure 2.4 on page 16. The results for this test are

more like the overall result, with the performance of LA and WavPack back on par and shorten (which seems to have no stereo decorrelation at all) benefits the most. The strange behaviour of Monkey's Audio stays, however. The most striking difference between the stereo original and the mono mix is that FLAC and the lower TAK and WavPack levels have halved their encoding time: apparently, stereo decorrelation takes a lot of time. In FLAC, stereo correlation is more or less 'brute-force', so that fits the picture very well.

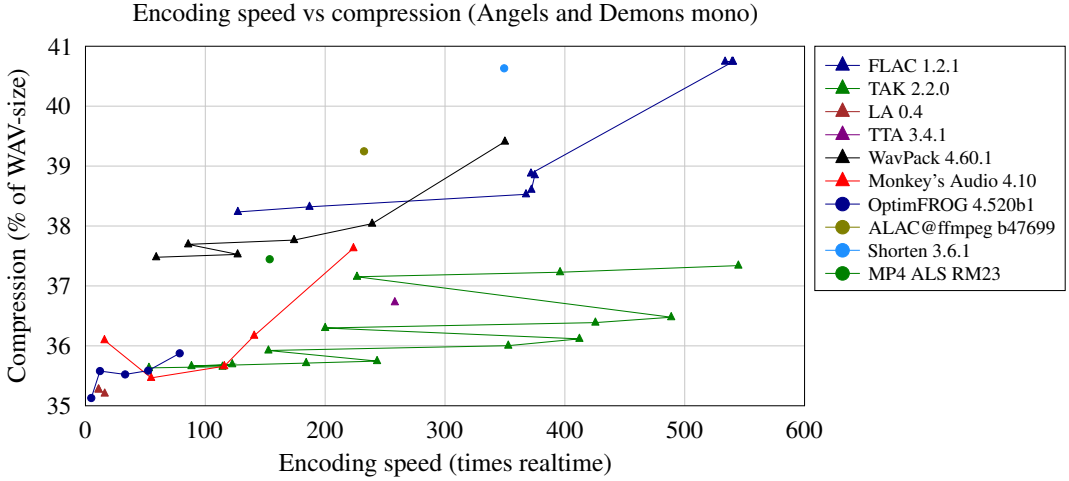


(a) Encoding performance

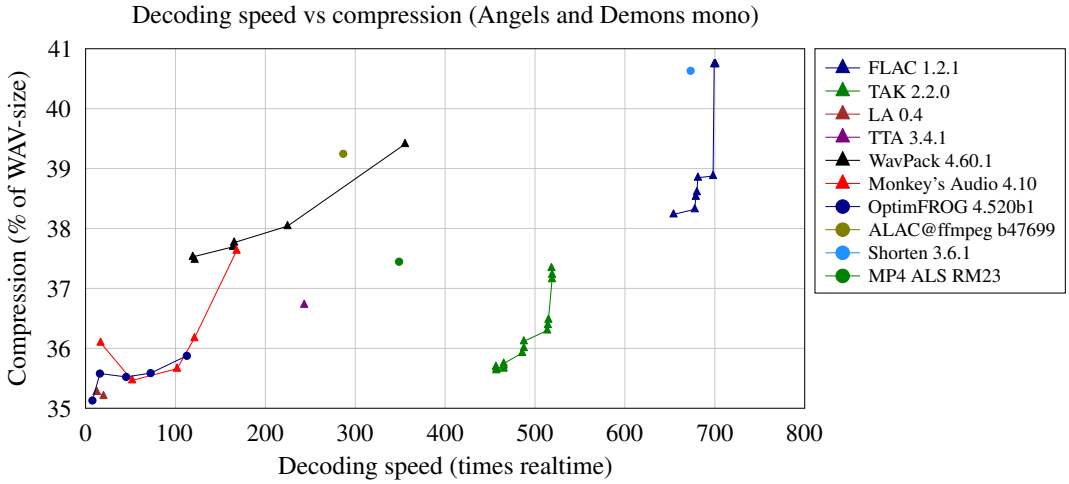


(b) Decoding performance

Figure 2.3: Codec performance for the audiobook Angels & Demons as written by Dan Brown and read by Richard Poe



(a) Encoding performance



(b) Decoding performance

Figure 2.4: Codec performance for the audiobook mixed to mono

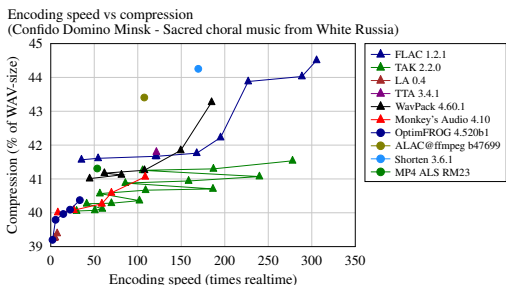
2.4 Convergence of the results

One of the most important questions regarding any results of this test would be whether the results are truly 'average' and whether they represent all different kinds of CD-audio out there. As pointed out in section 2.3, this is not the case: some codecs perform better than usual at certain CD's. However, most results seem fairly similar while being obtained from very different material.

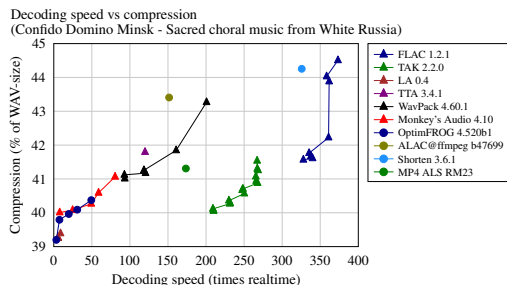
From comparing results and trying to draw conclusions on the convergence of the results, one can observe differences regarding the reliability of certain codecs. For example, when one takes a look at figure 2.3 on page 15, certain codecs (FLAC -3 and Monkey's Audio -insane) generate larger files while being slower: choosing a higher 'mode' will not always result in better results.

In figure 2.5 on the next page the encoding and decoding performance of all codecs are graphed for five very different kinds of music: a capella choral, metal, soul and jazz. While the average compression achieved and speed differs, codecs all perform similar for different kinds of music: LA and OptimFROG take turns in achieving the best compression while both being pretty slow, FLAC is always the fastest decoding, Shorten performs at FLAC -0 but slower, Monkey's Audio ranges from OptimFROG's -best to WavPacks default setting (but being slower than the latter), TAK is almost always the best performer when trading off compression to encoding speed etc.

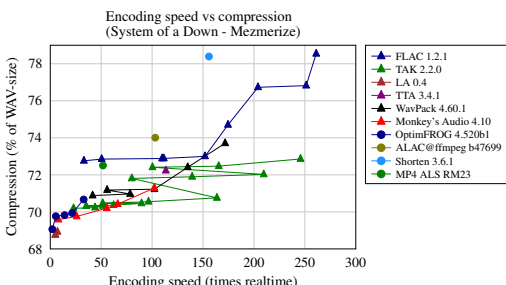
The 'typical' position of each codec works for very different kinds of music and is never much better or worse when compared to the average of all CD's, except perhaps FLAC -0 through FLAC -3 and Shorten.



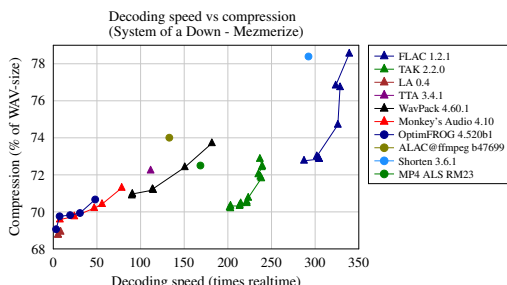
(a) Encoding choral music



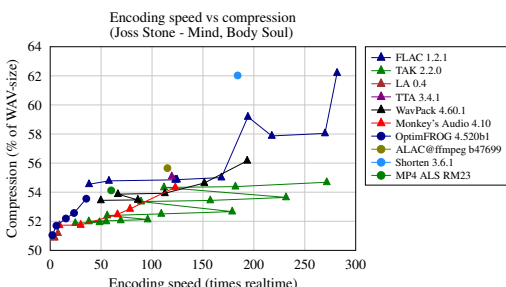
(b) Decoding choral music



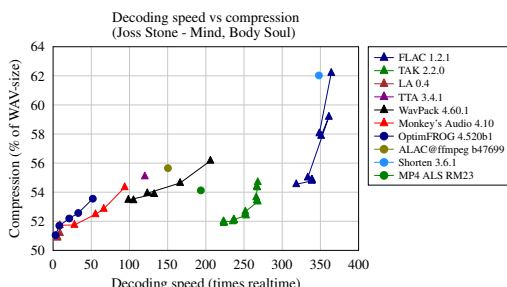
(c) Encoding metal



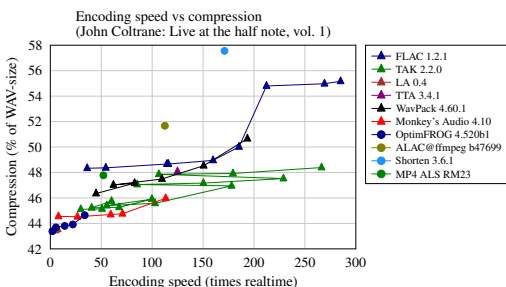
(d) Decoding metal



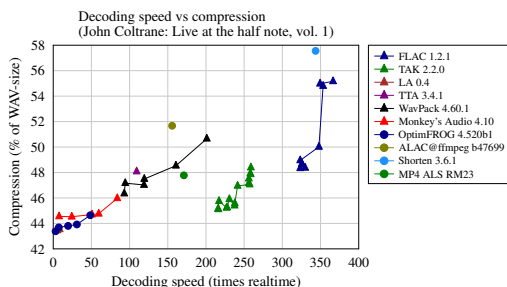
(e) Encoding soul



(f) Decoding soul



(g) Encoding jazz



(h) Decoding jazz

Figure 2.5: Codec performance for various music genres

Chapter 3

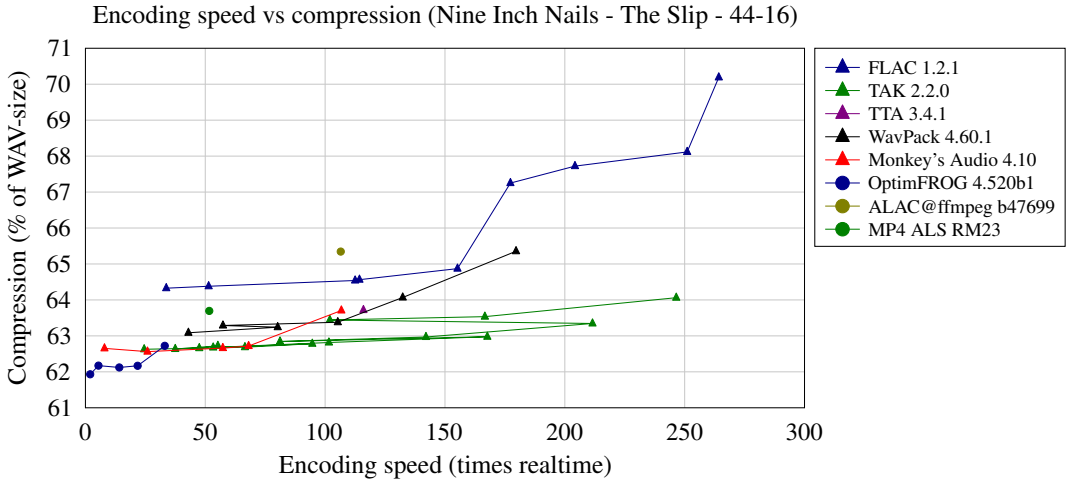
High-resolution audio

While the use for 'high resolution' (i.e. a high sample rate or high bit depth) is open to discussion, lossless codecs are used to pack this kind of material, so it should be tested as well. Two codecs do not participate in this test: both LA and Shorten do not handle these sample rates/bit depths at all.

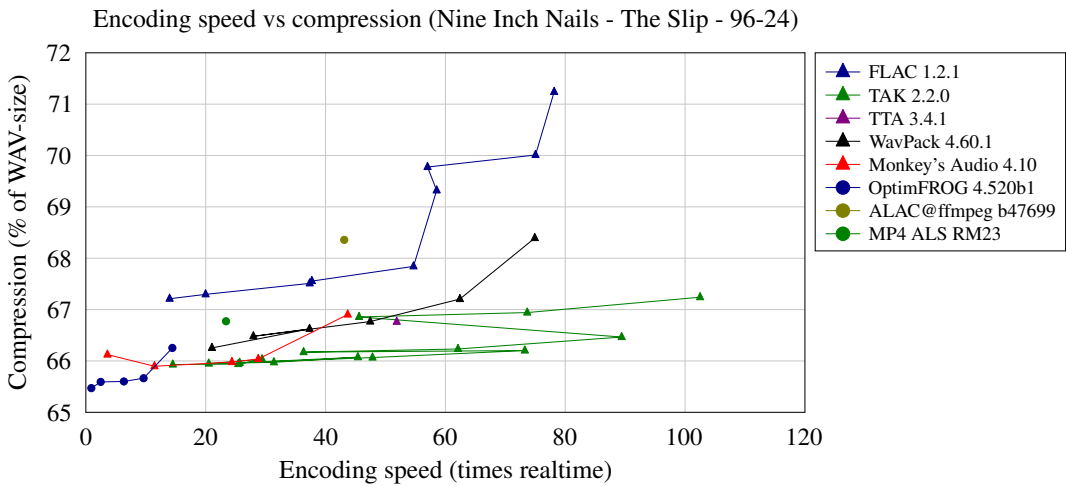
3.1 Nine Inch Nails' The Slip

The Slip was made available free of charge from the website of NIN, releasing both 44kHz/16-bit FLAC-files as well as 96kHz/24-bit files.

The results are shown in figure 3.1 and 3.2. Nothing spectacular: all codecs perform similar when compared to the CD-audio, only FLAC seems to perform worse, being much slower than usual in both encoding and decoding and compressing a little less. Monkey's Audio -insane (or -c5000) preset misbehaves here, just like with the Dan Brown audiobook test and the next test in this chapter, it is slower and compresses less than -c4000.

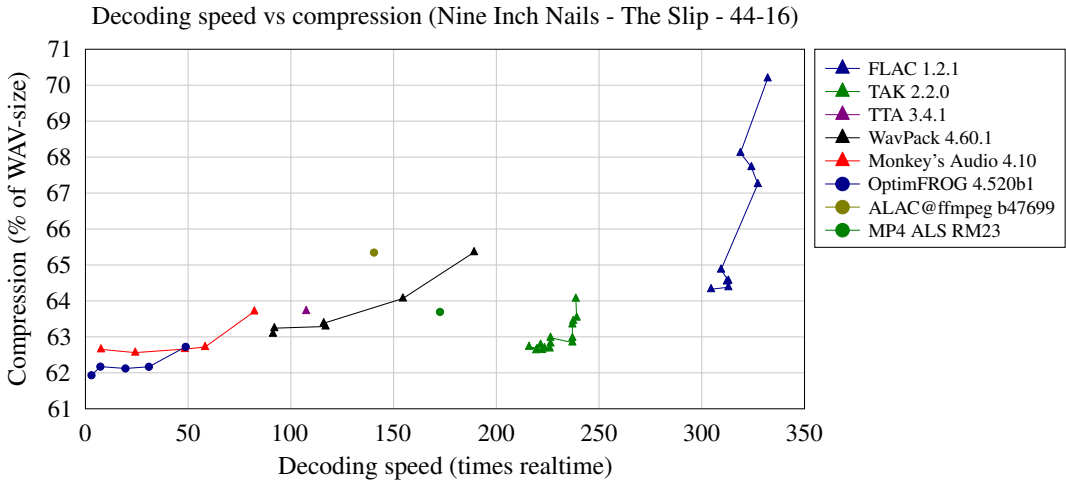


(a) Sample with 44/16

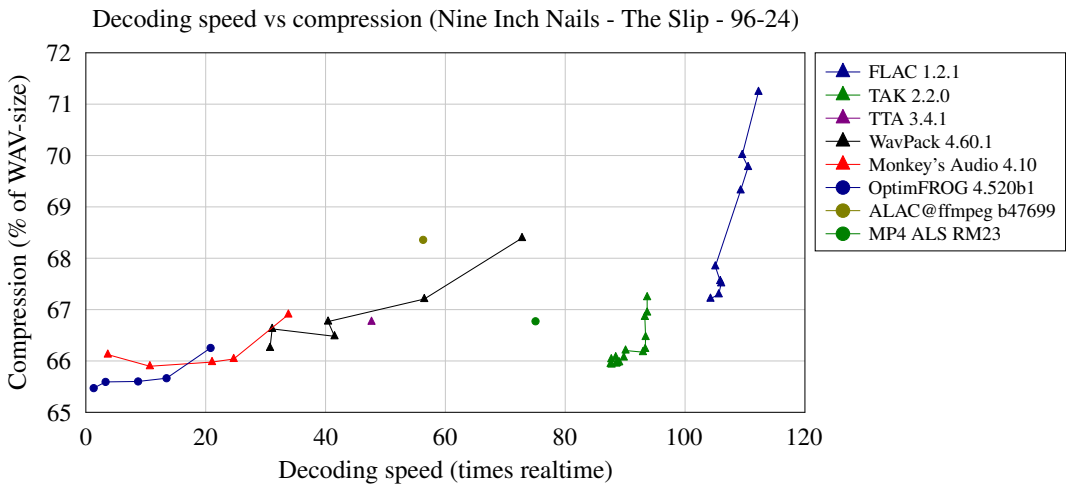


(b) Sample with 96/24

Figure 3.1: Encoding performance



(a) Sample with 44/16



(b) Sample with 96/24

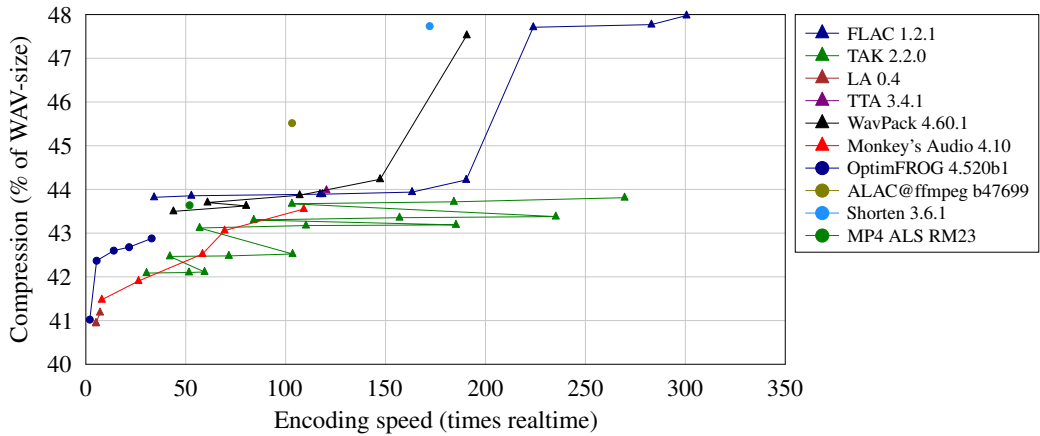
Figure 3.2: Decoding performance

3.2 Howard Shore's soundtrack for The Lord of the Rings: The Return of the King

The complete recordings of the soundtrack for The Return of the King features an DVD-A along with the 4 audio CDs. This disc was used in the following test. While I first tried another DVD-A from the same trilogy, this disc had some features that made it unsuitable for this comparison, see section 3.3 on the matter. The results are shown in figure 3.3 and 3.4.

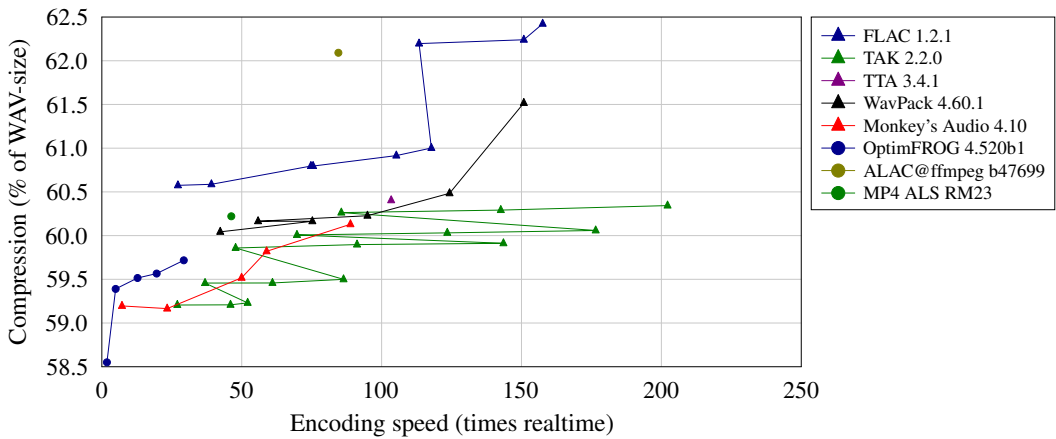
The results are very similar to those obtained with NIN's The Slip in section 3.1, but FLAC performs a little better. Interesting to note it that the differences between different codecs and compression modes are even smaller.

Encoding speed vs compression (Lord of the Rings: The Return of the King - stereo 44-16)



(a) Sample with 44/16

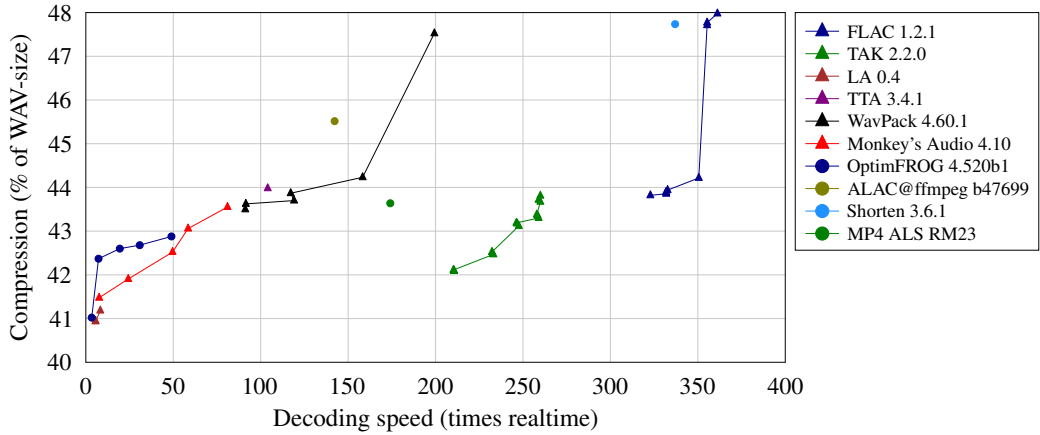
Encoding speed vs compression (Lord of the Rings: The Return of the King - stereo 48-24)



(b) Sample with 48/24

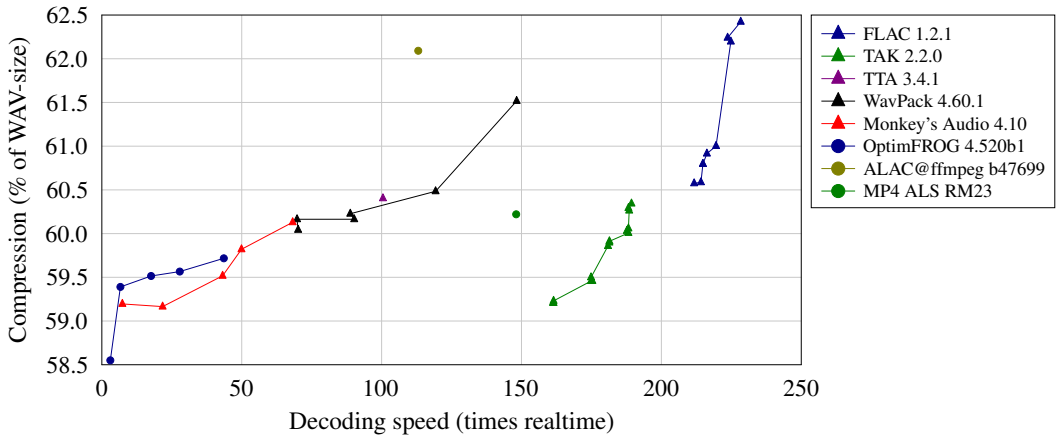
Figure 3.3: Encoding performance

Decoding speed vs compression (Lord of the Rings: The Return of the King - stereo 44-16)



(a) Sample with 44/16

Decoding speed vs compression (Lord of the Rings: The Return of the King - stereo 48-24)



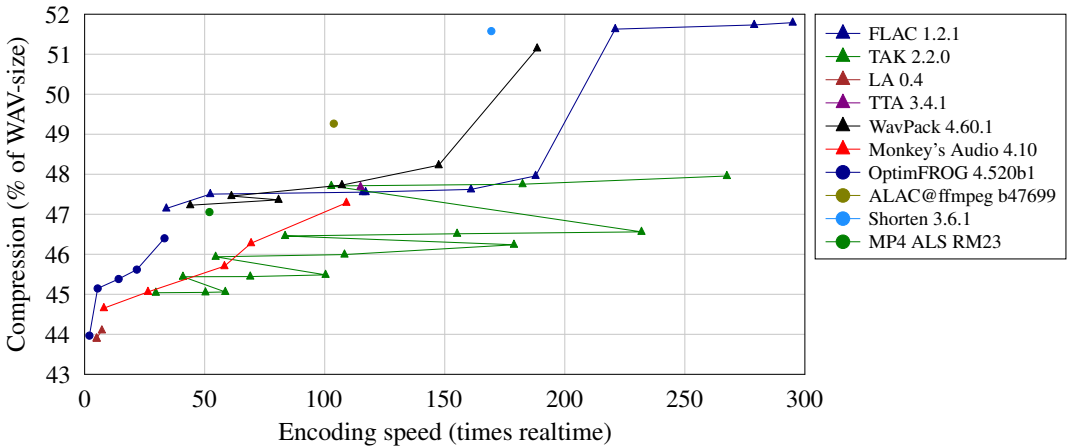
(b) Sample with 48/24

Figure 3.4: Decoding performance

3.3 Wasted bits

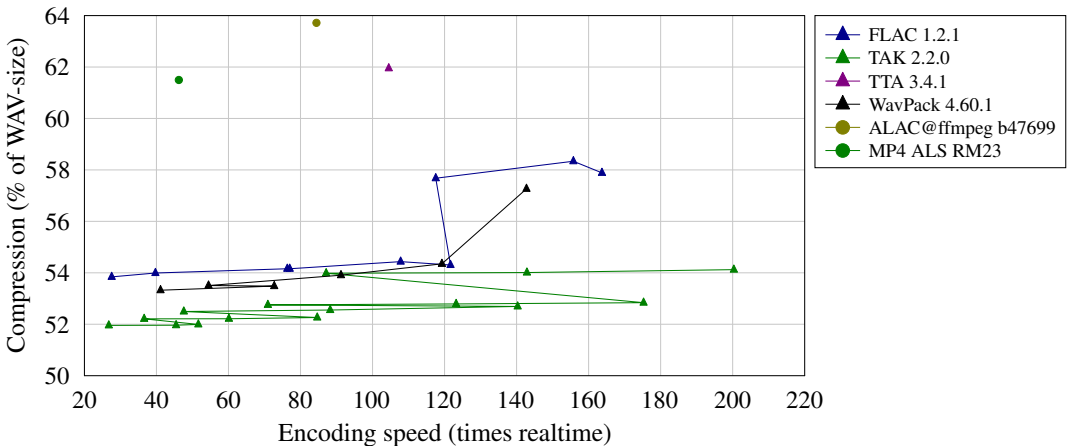
When testing the complete recordings of The Lord of the Rings (The Two Towers) soundtrack, some rather strange results were obtained, shown in figure 3.5 and 3.6. After looking at the analyse-files generated by the official FLAC decoder, it became clear that something called 'wasted bits' was responsible for this behaviour.

Encoding speed vs compression (Lord of the Rings: The Two Towers - stereo 44-16)



(a) Sample with 44/16

Encoding speed vs compression (Lord of the Rings: The Two Towers - stereo 48-24)



(b) Sample with 48/24 (2 wasted bits)

Figure 3.5: Encoding performance

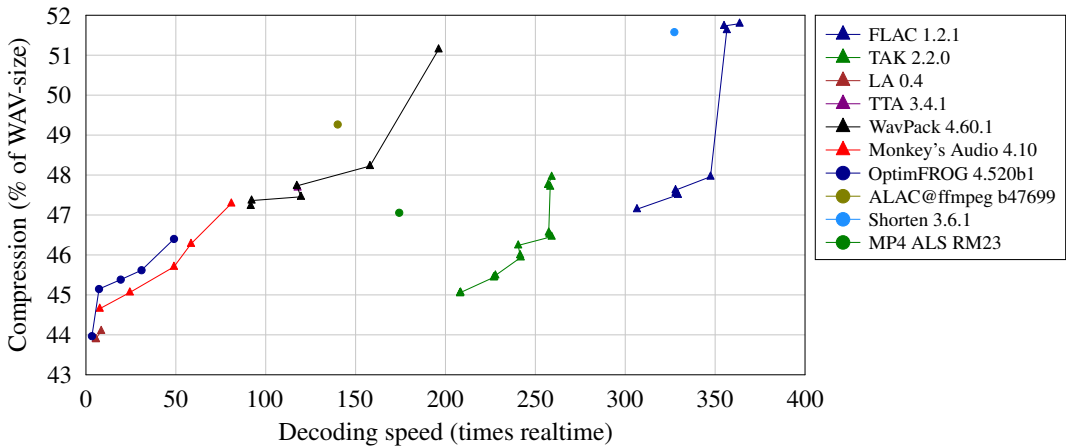
The first thing that stands out when looking at these results is that the results seem to form two groups: one group (consisting of FLAC, WavPack, TAK and

OptimFROG) that does pretty well on these samples and one group (Monkeys Audio, ALAC, TTA and MP4ALS) that fall short. This is because the latter group of codecs do not search for so called wasted bits. This 2 wasted bits mean that, while the files are packed in a 24-bit file, the data actually is 22-bit only and the two least significant bits are always zero. ALS can perform better, but a switch (-l) has to be used on encoding.

Of course one could wonder why this exists, material which is 'only' 22-bit while it is advertised as being 24-bit. In this case, the material was packed on the DVD-A with a lossless codec which is called MLP (Meridian Lossless Packaging) which is a proprietary format. (Just as a side note: It's compression was 59.3%) MLP is among the codecs that benefits from wasted bits as well, so this way it was possible to fit the audio on one disc, with 8GB of 8.5GB filled, without these wasted bits the disc would have been too small. It actually is listed as an 'feature' by its creators, but is not often seen on commercial discs apparently.

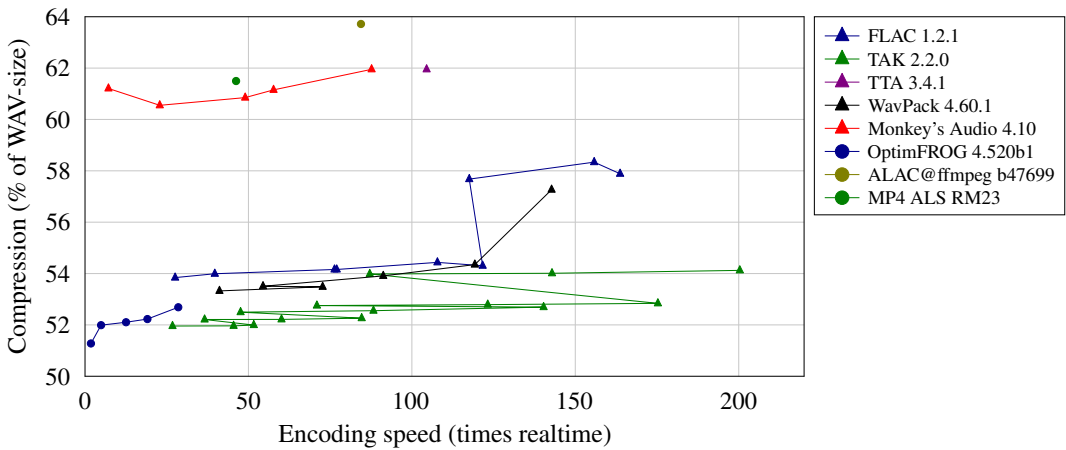
So, in the rare case you come across a disc which is compressed with MLP and is packed-as-24bit-but-actually-isnt-24bit, half of the tested codecs might not be able to handle this very well.

Decoding speed vs compression (Lord of the Rings: The Two Towers - stereo 44-16)



(a) Sample with 44/16

Encoding speed vs compression (Lord of the Rings: The Two Towers 48-24)



(b) Sample with 48/24 (2 wasted bits)

Figure 3.6: Decoding performance

Chapter 4

Multichannel audio

While surround sound is usually paired with a movie and not often sold 'just audio', it might become an interesting topic in the future. Since the introduction of stereo sound, people have been talking about 'more than 2 channels', and while sales of surround-sound music never really took off it has some really interesting advantages over stereo.

Because it never really took off, codecs usually focus on mono and stereo sound. For example, FLAC has a few tricks to use the similarity of stereo channels to get some more compression, but there is no such decorrelation for multichannel audio. Other codecs, like Monkey's Audio, OptimFROG and shorten have no support for multichannel audio at all.

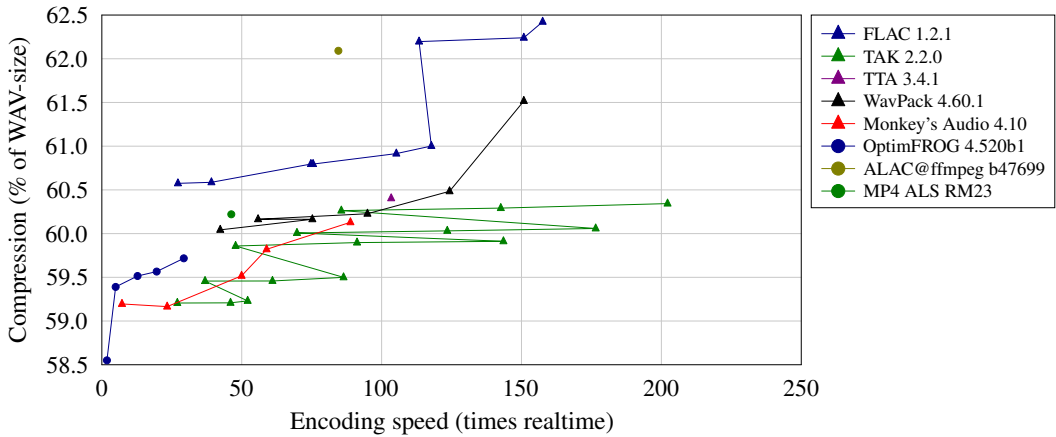
4.1 Howard Shore's soundtrack for *The Lord of the Rings: The Return of the King*

The complete recordings of *The Lord of the Rings* (*The Two Towers*) soundtrack feature the usual 44.1kHz/16-bit stereo sound on CD, but also pack an Audio-DVD with the same music in 48kHz/24-bit stereo sound and 48kHz/24-bit surround sound. As this and the same package for the *Two Towers* discussed in section 3.3 are the only 2 sources of lossless multichannel audio I have, this is the only material used for comparison. Only the first 8 tracks are tested because of size constraints on the ramdisk.

The results for these tests are depicted in 4.1 and 4.2. It seems that, like the comparison between 16-bit and 24-bit audio, the number of channels does not seem to matter much. The only strange thing is that TTA performs pretty bad compared to its usual performance. This is strange because being able to encode

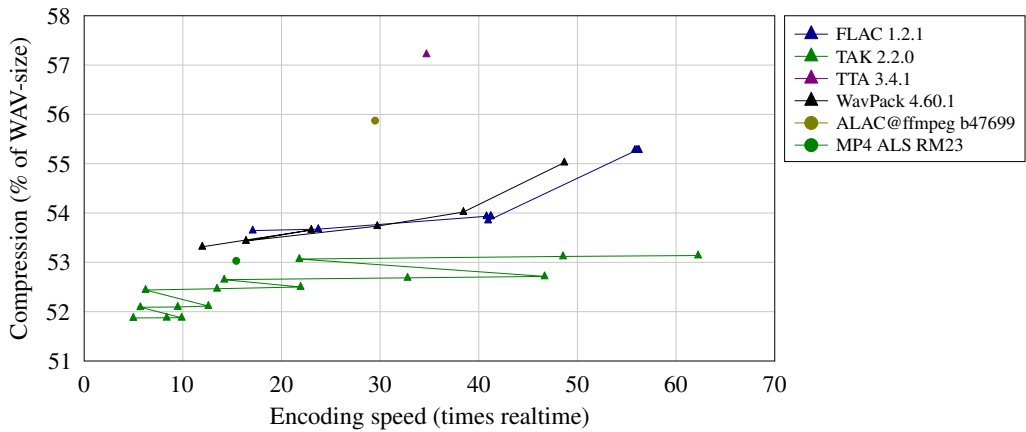
multichannel-audio (up to 65536 channels) is one of its selling points on the TTA-website. FLAC is performing better than usual, but the difference is only small so mastering (or the way of down-mixing to stereo) could be a reason for this, this is no reason to believe that FLAC performs better than usual on all multichannel material.

Encoding speed vs compression (Lord of the Rings: The Return of the King - stereo 48-24)



(a) Sample with 48/24 stereo

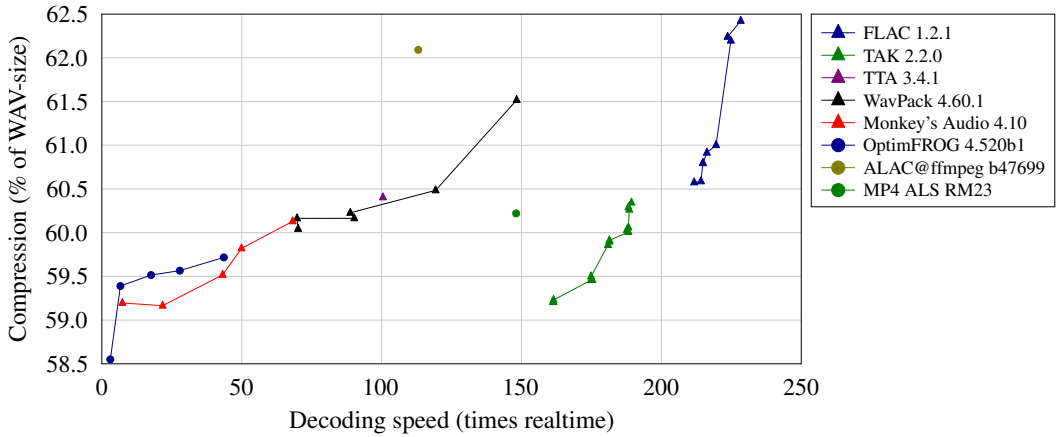
Encoding speed vs compression (Lord of the Rings: The Return of the King - surround 48-24)



(b) Sample with 48/24 surround

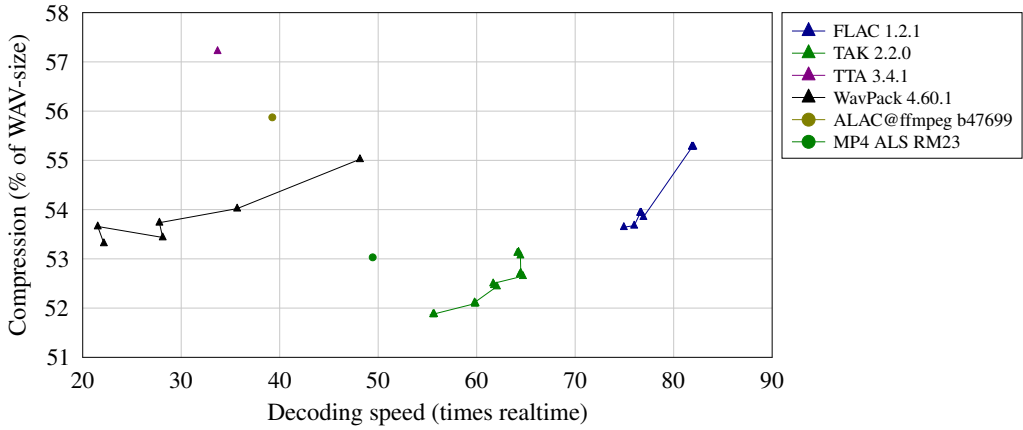
Figure 4.1: Encoding performance

Decoding speed vs compression (Lord of the Rings: The Return of the King - stereo 48-24)



(a) Sample with 48/24 stereo

Decoding speed vs compression (Lord of the Rings: The Return of the King - surround 48-24)



(b) Sample with 48/24 surround

Figure 4.2: Decoding performance

Appendix A

Motivation for choosing these CDs

The validity of this test is for a large part dependent on the audio material used. It was chosen to pick full CDs instead of single tracks because single tracks might exhibit a single strong 'characteristic' which could influence the test. We want to capture the influence of a certain genre, not that of a peculiarity of a track. However, we might still capture the 'sound' of a certain album (for example the way it was mixed or mastered), but this is not reasonably avoidable, as one would have to test an awful lot of CDs.

See table A.1 for the CDs and some data describing their contents

Each CD in this list is there for a reason. First of all, for every main genre I could find (with some help of wikipedia [2] and the list of genres for which Grammy-awards are awarded [1]) I tried to add 2 CDs. The genres that are probably missing are country, blues and reggae and gospel, but these might be added in the future. However, R&B (Rhythm and Blues) can be seen as a form of blues and gospel while country can be viewed as world-music from the southern part of the USA. At least one can conclude that drawing a line and getting the list right is not easy.

The reason for trying to add about 2 CDs for every genre is not easily explained: one could argue that certain music genres feature much more diverse kinds of subgenres or that certain (distinct) genres sound much alike technically, and the division is mainly on lyrics. While this all holds true, I would say there is no inherently better way to 'balance' a test.

For rock, "**30 Seconds to Mars - This is War**" and "**Rush - Grace under Pressure**" were added. The first is more recent and is quite heavily compressed, while the second is (despite it being a later remaster) from the '80s and has a

Album	Genre	Peculiarities	DR
30 Seconds to Mars - This Is War	rock	-	6
Confido Domino Minsk - Sacred choral music from White Russia	choral, religious	-	12
Daft Punk - Alive 2007	electronic	live	5
Dan Brown - Angels and Demons	audiobook	-	16
Enya - Amarantine	new age	-	8
Fanfare Ciocarlia - Baro Biao: World Wide Wedding	world music, brass	-	12
Gilberto Santa Rosa - Esencia	salsa	-	9
Giuseppe Verdi - Messa da Requiem (Berliner Philharmoniker feat. conductor Claudio Abbado)	classical, romantic	-	12
Howard Shore - The Hobbit: An Unexpected Journey	soundtrack, orchestral	-	10
Iron Maiden - Brave New World	metal	-	7
John Coltrane - Live at the half note, vol. 1	jazz	-	11
Joss Stone - Mind, Body & Soul	soul	-	7
J.S. Bach - Magnificat	orchestral, baroque	-	13
Koninklijke Militaire Kapel - [no name]	military brass	vinyl rip	11
Kraftwerk - Autobahn	electronic	-	13
Lana del Rey - Born to Die	pop	-	5
Lil Wayne - Tha Carter III	hip hop	-	7
Martin O'Donnell & Michael Salvatori - Halo: Reach O.S.T.	ambient-ish, soundtrack	-	11
Michael Bublé - meets madison square garden	pop, live	-	8
Mike Oldfield - Tubular Bells (2000 remaster)	not classifiable	-	11
Rosenberg Trio - Djangologists	jazz	-	7
Rush - Grace under Pressure (1997 remaster)	rock	-	10
System of a Down - Mezmerize	metal	-	5
Szakcsi - Virágom, virágom	world music	-	10
Tiësto - In Search of Sunrise 7: Asia	dance	-	8
Various - Jeff Waynes Musical Version of The War of the Worlds	radio drama-ish, rock, orchestral	-	11
Various - Latin Village, CD 1: Salsa	salsa	compilation	8
Xzibit - At the Speed of Life	hip hop	-	10
Yann Tiersen - Le Fabuleux Destin d'Amélie Poulain	minimalism, soundtrack	-	11

Table A.1: CD data

lot more dynamic range. They are musically quite different 'spots' of the rock-genre as well. Considering rock, "Jeff Waynes Musical Version of the War of The Worlds" might be regarded as rock as well, but this features far more electronic influences and is half audiobook, half music, so it fits no general category at all.

Confido Domino Minsk's Sacred choral music from White Russia is half orchestral plus choir and half a capella choir. It features, as it's name would suggest, mainly religious music and tests the various codecs on their handling of only voice content.

For electronic music, 3 CDs were used: "**Daft Punk - Alive 2007**", "**Kraftwerk - Autobahn**" and "**Tiësto - In Search of Sunrise 7: Asia**". The first is because Daft Punk has been an popular electronic artist for quite some time and this album is quite recent. Kraftwerk's Autobahn was added to counter any recent mastering issues and is as well well known. Tiësto was added because it was the only dance music I have in my collection and seems to fit in this test well: it is quite different from the other two CDs in this category. Daft Punk's CD is a live album.

Dan Browns book Angels and Demons as read by Richard Poe was added to add pure speech to the test as well.

Enya - Amarantine represents New Age music in this test.

Considering world music **Fanfare Ciocarlia - Baro Biao: World Wide Wedding** and **Szakcsi - Virágom, virágom** were added. They are both European (Romanian and Hungarian to be precise), they are very different and seem to feature two extremes of what one would call world music. Fanfare Ciocarlia can be typed as gypsy music as well and is mainly brass. Szakcsi is very different and features both very serene and wild folk music, it consists of variations on children's songs and features no brass instruments at all.

To add some latin (which one could call 'world music' as well of course), two CDs featuring salsa music were added: **Gilberto Santa Rosa - Escencia** and a compilation-CD. The first sounds more like traditional salsa, while the second features more elements of current popular music.

Classical music is represented by **Guissepe Verdi's Requiem** and **Bach's Magnificat**. The first is from the romantic movement and, as is typical Verdi, sound more like and opera than a requiem. Bach was an baroque composer. Both cultural movements are more or less opposing considering size: baroque features a small orchestra and a small choir, while romantic music features large orchestra's and very large choirs. In this respect, these two recordings span different kinds of orchestral music. **Howard Shore's soundtrack for The Hobbit: An Unexpected Journey** is orchestral as well, but only features choir in a few tracks and is less brass-heavy than the other two. Furthermore, this was composed in

2011-2012, so it is still relatively fresh.

To add metal to the test **Iron Maiden - Brave New World** and **System of a Down - Mezmerize** were added. System of a Down is quite chaotic and fast, while Iron Maiden is more steady and brutal.

John Coltrane - Live at the half note vol.1 and **The Rosenberg Trio - Djangologists** were added to represent jazz. Coltrane's CD represents live recorded music as well.

Joss Stone - Mind, Body & Soul adds soul to the test.

The vinyl rip of the Koninklijke Militaire Kapel adds some military wind music to the test.

Lana del Rey's Born to Die and **Michael Bublé's live album** both add some pop music to the test. Picking pop music was hard, as quite a lot of pop music can be classified as rock as well (that's why there is a lot of poprock out there) so I took these two, while not strictly being traditional pop music.

Lil Wayne - Tha Carter III and **Xzibit - At the speed of life** were added to represent hip hop. There is no particular reason to choose these, they were the only two I had in my collection.

Martin O' Donnell & Michael Salvatori's soundtrack for Halo: Reach is mainly ambient music, and was added to represent it

Mike Oldfield - Tubular Bells was added to add some older popular music as well, while it is not really possible to name a genre this would fit to.

Finally, **Yann Tiersen's soundtrack for Amélie** features music with different (but always a few) instruments, and is usually regarded minimalism music. It was added to check performance on the 'less popular' instruments featured.

Revision history

- Revision 1 - January 7, 2013 - Initial version
- Revision 2 - March 19, 2013 - Improved graph readability and optimized for screenreading

Bibliography

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- [4] FLAC - comparison, <http://xiph.org/flac/comparison.html>
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