ECE/CS 572

Final-Report

Ogg Video Coding

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1. Introduction

The follow report will cover the open-source video codec known as Ogg Theora. Ogg Theora, like most video codecs is lossy. It is based on the VP3.1 source code donated by On2 Technologies. The key difference between the two codecs is that VP3 can actually be losslessly transcoded if desirable, whereas Ogg Theora cannot. The report will go on to describe the Ogg Theora codec and its practical implementation, political ramifications of the open-source versus commercial video coding, and simulation/implementation results therein.

1.1 Format Specifications

Generally speaking, Theora currently supports progressive video data of arbitrary dimensions (up to 1048560 x 1048560) at a constant frame rate in one of several Y-Cb-Cr color spaces. Three different chroma sub-sampling formats are supported: 4:2:0, 4:2:2, and 4:4:4. The Theora format does not support interlaced material, variable frame rates, bit-depths larger than 8 bits per component, nor alternate color spaces such as RGB or arbitrary multi-channel spaces [1].

Theora is a block-based lossy transform codec that utilizes an 8 x 8 Type-II Discrete Cosine Transform and block-based motion compensation. This places it in the same class of codecs as MPEG-1, -2, -4, and H.263. However, Theora only supports I-frames and P-frames. B-frames, such as those found din MPEG codecs cannot be used. Theora is a free-form variable bit rate (VBR) codec, this also implies that the decoder is entirely in change of error detection/correction in the bit-stream.

2. The Ogg Thera Codec and Encoding/Decoding Methods

As mentioned above, the Theora codec uses 8 x 8 blocks per frame. 4 x 4 sets of blocks are organized in groups called super-blocks, and 2x2 sets of blocks are interpreted as macro-blocks. Frames have a width and height that are subsequently multiples of 16. However, inside frames there can be regions called picture regions that can be any size that contain the actual video data. Picture regions can be a maximum of 255 pixels from any frame border. One interesting aspect of Theora is that it uses a right-handed coordinate system. In other words, the origin of the frame is in bottom-left corner instead of the top-left that most codecs use. For each 8 x 8 block, the luma and chroma components are sampled. The chroma portions can be sub-sampled however, the luma portions can never be sub-sampled.

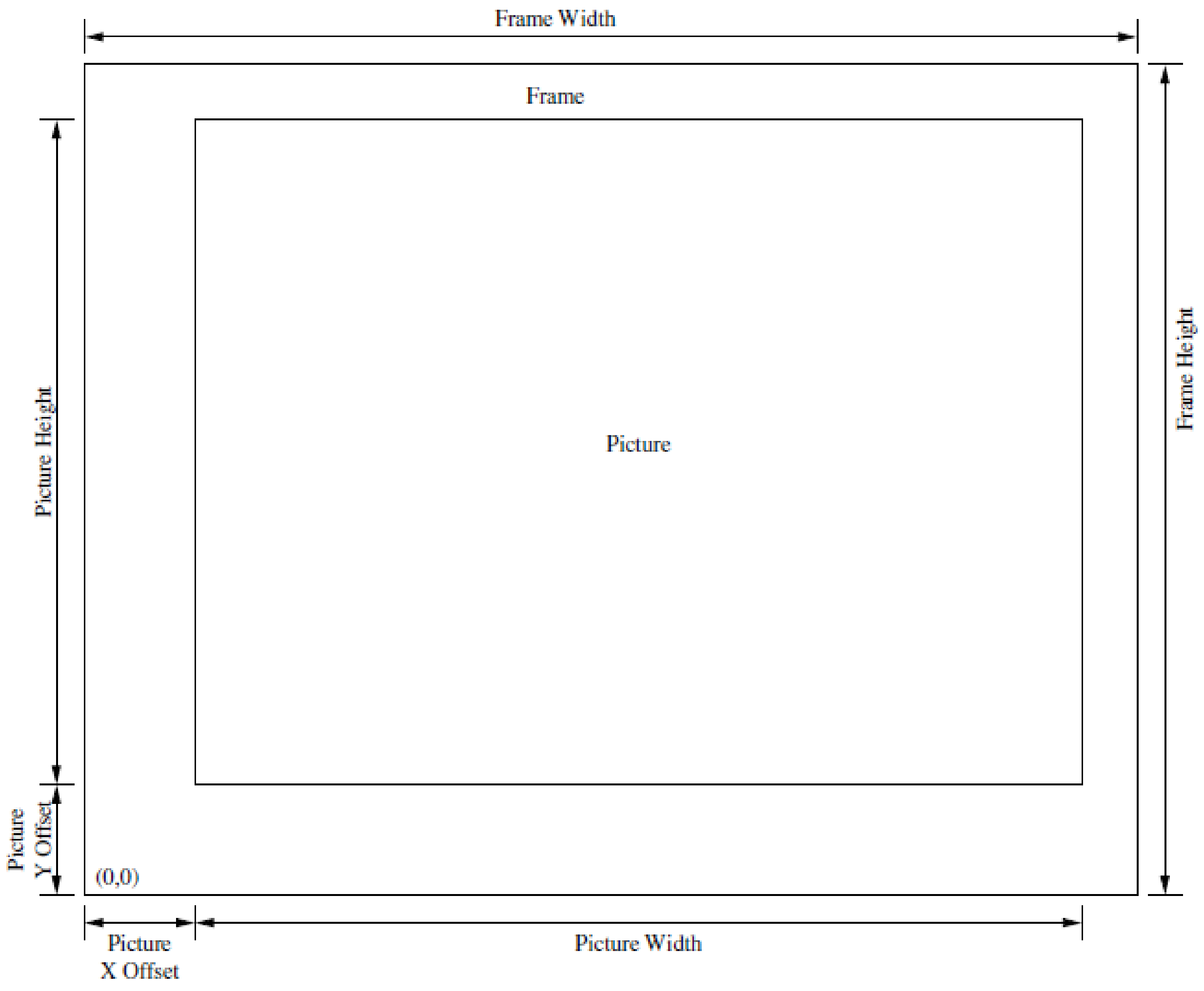


Figure 1: Theora frame and picture regions [1]

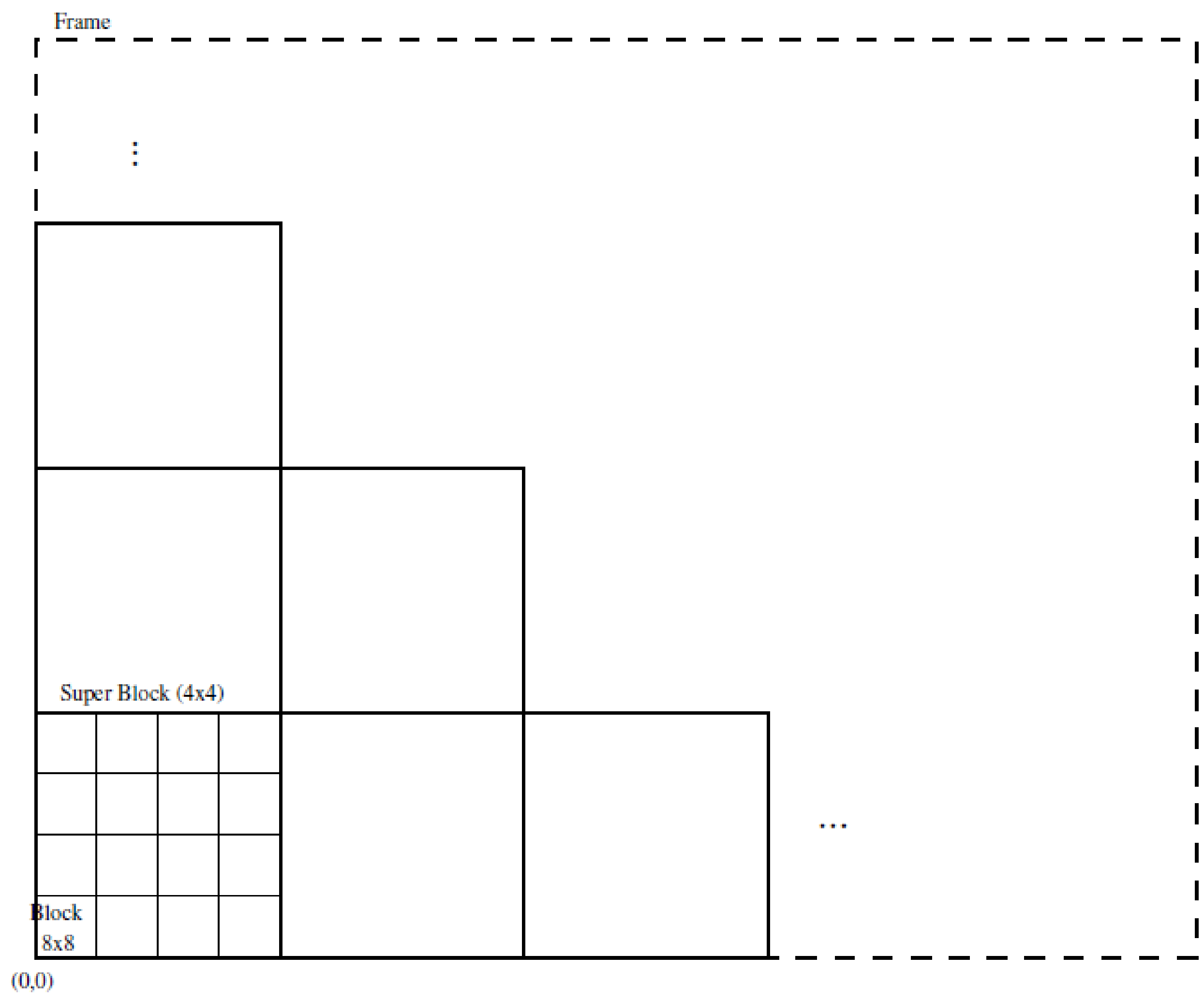


Figure 2: Theora blocks and super-blocks diagram [1]

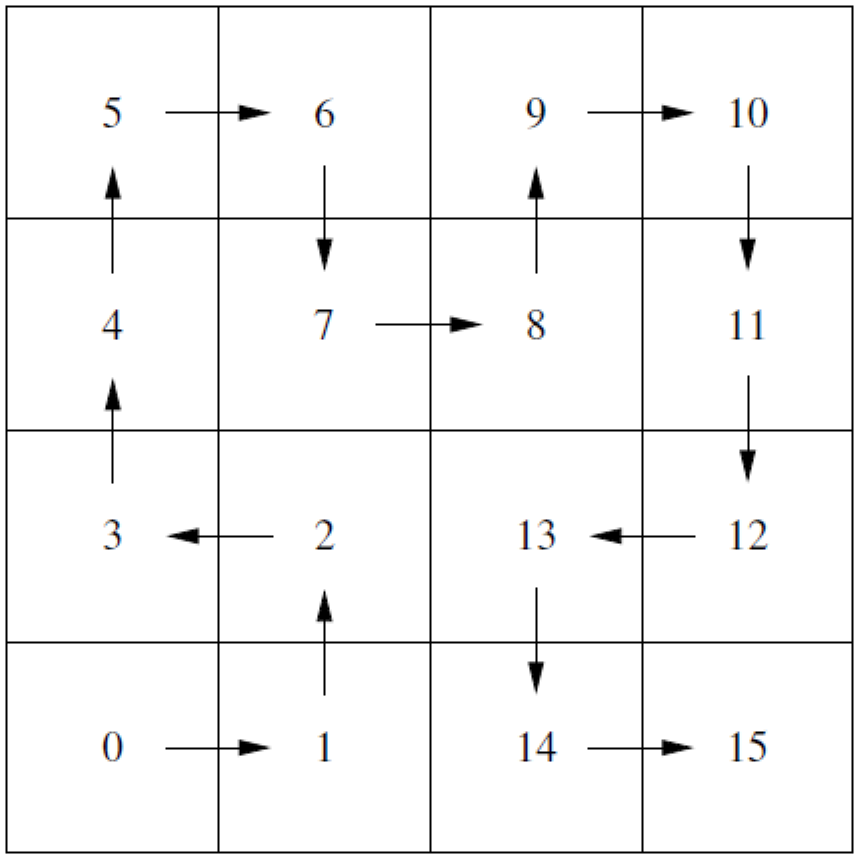


Figure 3: block ordering within super-block (Hilbert curve) [1]

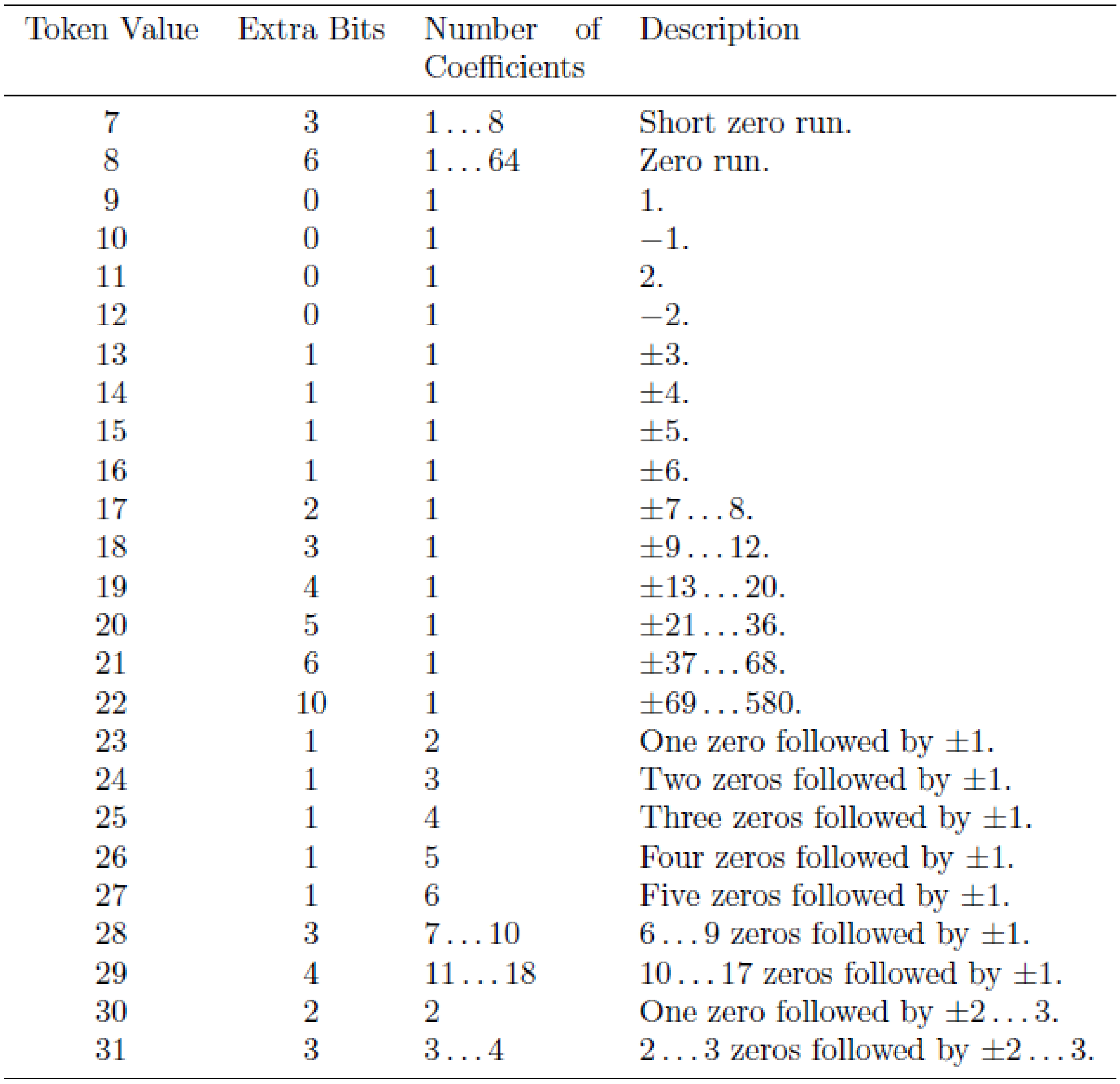
The block ordering in the above figure is an excellent example of the progress of the Ogg Theora video codec. A Hilbert curve was used for the simple reason of it being "cool" form an algorithms perspective. Because of poor cache coherency issues, the Hilbert curve was removed from the next upcoming version of Theora. There are several modifications included in the newest version of Theora. New block ordering, improved motion estimation, lossless encoding and many others. These improvements are sure to help Theora's stand among the video codec field in the future.

2.1 Motion Prediction and Coding Modes

A block is predicted using one of two reference frames, selected according to the coding mode. A reference frame is the fully decoded version of a previous frame in the stream. The first available reference frame is the previous intra frame, called the golden frame. The second available reference frame is the previous frame, whether it was an intra frame or an inter frame. If the previous frame was an intra frame, then both reference frames are the same [1].

2.2 DCT Coefficient Encoding

There have been many improvements that Ogg Theora has made over the conventional MPEG coding scheme. The most notable improvement has been on Discrete Cosine Transform coefficient encoding. When coding DCT coefficients, a more advanced token set is used over MPEG. The primary change is the inclusion of tokens that represent runs of multiple zeros and ones as they are of frequent occurrence. The table below shows the standard DCT coefficient table for Ogg Theora.



Token Value	Extra Bits	Number of Coefficients	Description
7	3	$1 \ldots 8$	Short zero run.
8	6	$1 \ldots 64$	Zero run.
9	0	1	1.
10	0	1	-1.
11	0	1	2.
12	0	1	-2.
13	1	1	± 3.
14	1	1	± 4.
15	1	1	± 5.
16	1	1	± 6.
17	2	1	$\pm 7 \ldots 8$.
18	3	1	$\pm 9 \ldots 12$.
19	4	1	$\pm 13 \ldots 20$.
20	5	1	$\pm 21 \ldots 36$.
21	6	1	$\pm 37 \ldots 68$.
22	10	1	$\pm 69 \ldots 580$.
23	1	2	One zero followed by ± 1.
24	1	3	Two zeros followed by ± 1.
25	1	4	Three zeros followed by ± 1.
26	1	5	Four zeros followed by ± 1.
27	1	6	Five zeros followed by ± 1.
28	3	$7 \ldots 10$	$6 \ldots 9$ zeros followed by ± 1.
29	4	$11 \ldots 18$	$10 \ldots 17$ zeros followed by ± 1.
30	2	2	One zero followed by $\pm 2 \ldots 3$.
31	3	$3 \ldots 4$	$2 \ldots 3$ zeros followed by $\pm 2 \ldots 3$.

Figure 4: DCT Coefficient Table [1]

2.3 Theora Headers

Before decoding can begin, a decoder MUST be initialized using the bit-stream headers corresponding to the stream to be decoded. Theora uses three header packets; all are required, in order, by this specification. This leads to a a minor disadvantage over other, more popular codecs because the header size is often much larger.

The three headers are the: identification header, comment header, and setup header. The identification header identifies the stream as Theora, provides a version number, and defines the characteristics of the video stream such as frame size. The comment header includes user text comments and a vendor string for the application/library that produced the stream. Finally, The setup header includes extensive codec setup information, including the complete set of quantization matrices and Huffman decode tables needed to decode the DCT coefficients [1]. Headers are described in more detail in chapter 6.

2.3.1 Theora Header Formats

There are four types of packets/headers in the Theora specification [1]. All Theora bit-streams begin with three header packets –

- the identification header (HEADERTYPE = 0x80)
- the comment header (HEADERTYPE = 0x81)
- the setup header (HEADERTYPE = 0x82)
- Then there would be any number of Frame headers (video data packets) depending on the length of the video. Here, the MSB of HEADERTYPE is unset.

2.3.2 Identification Header

The Identification header is 42 bytes in length. The following information can be extracted from the Identification header –

- The major version number.
- The minor version number.
- The version revision number.
- The width of the frame in macro blocks.
- The height of the frame in macro blocks.
- The total number of super blocks in a frame.
- The total number of blocks in a frame.
- The total number of macro blocks in a frame.
- The width of the picture region in pixels.
- The height of the picture region in pixels.
- The frame-rate numerator.
- The frame-rate denominator.
- The pixel aspect-ratio numerator.
- The pixel aspect-ratio denominator.
- The color space.
- The pixel format.

- The nominal bitrate of the stream, in bits per second.
- The quality hint.
- The amount to shift the key frame number by in the granule position

2.3.3 Comment Header

The comment header is a variable length UTF-8 encoded string that gives information about the video file like title, artist, version, date, location, copyright, license, organization, director, producer, composer, actor, tag and description.

2.3.4 Setup Header

The Setup header has information like base matrices, scale values used to build the de-quantization tables and the Huffman tables used to unpack the DCT tokens.

2.3.5 Frame Header

The following information can be gathered from the frame header –

- Frame type (FTYPE): INTRA/INTER
- The number of qi values (NQIS):
- QIS array. The qi values will be used for all DC coefficients in all blocks. The AC coefficients can be de-quantized using any qi value on the list, selected on a block-by-block basis.
- Run-length encoded sequence for the block coded flags and the block-level qi values.
- an array indicating the coded macro blocks
- motion vectors for inter-frames

2.4 The Decoding Process

After decoding the headers of the video stream, the video-data decoding process begins. Theora decoding is very similar to the MPEG standard. It is done in the following process:

Decode coded block information (inter frames only).
Decode macro block mode information (inter frames only).
Decode motion vectors (inter frames only).
Decode block-level q information.
Decode DC coefficient for each coded block.
Decode 1st AC coefficient for each coded block.
Decode 2nd AC coefficient for each coded block.
:
Decode 63rd AC coefficient for each coded block.
Perform DC coefficient prediction.
Reconstruct coded blocks.

Copy uncoded blocks.
Perform loop filtering.

These steps don't necessarily have to be in the prescribed order. however, the order is obviously dependent upon order of the data that has streamed.

3. The Politics of Ogg

The current state of web video standards is something of a battleground. The major players in this battle are Apple, Microsoft, Google, Mozilla, and Opera. Apple has long supported h.264 as the future standard, and is a major force in championing it as the video standard for HTML5, the world wide web standard. This is significant, as every browser compliant with HTML5 will have native support for h.264. Apple's support is unsurprising since Apple is a member of the MPEG-LA, the patent holders of h.264. Microsoft has joined forces with Apple in this regard has recently announced its support for h.264 by announcing exclusive native support for it in IE9. [2]

Opposed to these major tech titans are a number of smaller companies, including browser creators Mozilla and Opera Software, and some content providers like Wikimedia. This group is fighting to have HTML5 include a free, open source codec for video. Mozilla has made their intentions very clear. They will never have native support for h.264 in their Firefox because the software laws in many countries would require them to have an h.264 license, and not only is the cost for this license high, it would not transfer to other firefox users such as the numerous Linux distributors.[3] Apple and Microsoft, being licensors of the h.264 rather than licensees, have much different terms. Firefox and Opera both have native support for Theora and together account for 27% of the market.

The tech giant Google represents yet another major factor. Google's browser Chrome currently supports both h.264 and Theora natively. As the largest source of digital video on the web (Youtube), they are in a strong position. They have also been long supporters of open source code and open standards. However, they also have a potential dark horse in the race with their recent acquisition On2 technologies. On2 was the creator of the VP3 codec on which Theora is based. They have continually evolved their own technology with their latest iteration, VP8, which may also be better than h.264. There is a strong possibility that Google will open source this codec, creating a potential 3-way battle.[4]

4. Open Source Tools - Firefogg

One of the excellent examples of the power of the open source community is the project know as "Firefogg." Firefogg is a Firefox plugin that will convert any video format to the Ogg Theora format with the click of a button. This project allows for users that don't have a device capable of video decoding of unpopular codecs to view any video they want. Technology like this is perfect when paired with lower-power smart phones and netbooks. To see Firefogg in action simply point your Firefox browser at http://firefogg.org, install the light-weight plugin, and start coding your videos into the Ogg format.

5. The Ogg Container Format

The Ogg Container format is an open media container format for multimedia codecs. It is perfect for interleaving audio, video, subtitle, and any other media data. The format specification itself provides packet framing as well as error detection. It works by coding periodic time-stamps into the streaming data which works well for efficient seeking as well as software/hardware processing pipelines. Ogg is a stream oriented container, meaning it can be written and read in one pass, making it a natural fit for internet streaming and use in processing pipelines.

Elementary and multiplexed streams are both constructed entirely from a single building block (an Ogg page) comprised of eight fields totalling twenty-eight bytes (the page header) a list of packet lengths (up to 255 bytes) and payload data (up to 65025 bytes). The structure of every page is the same. There are no optional fields or alternate encodings. There is no restriction on size changes from packet to packet. The page structure is written out in-line as packet data is submitted to the streaming abstraction.

In the Ogg container, pages do not necessarily contain integer numbers of packets. Packets may span across page boundaries or even multiple pages. This is necessary as pages have a maximum possible size in order to provide capture guarantees, but packet size is unbounded. In the figure below the timestamped packets that correspond to a certain chronological sequence are represented by the gray boxes (23, 24, 25).

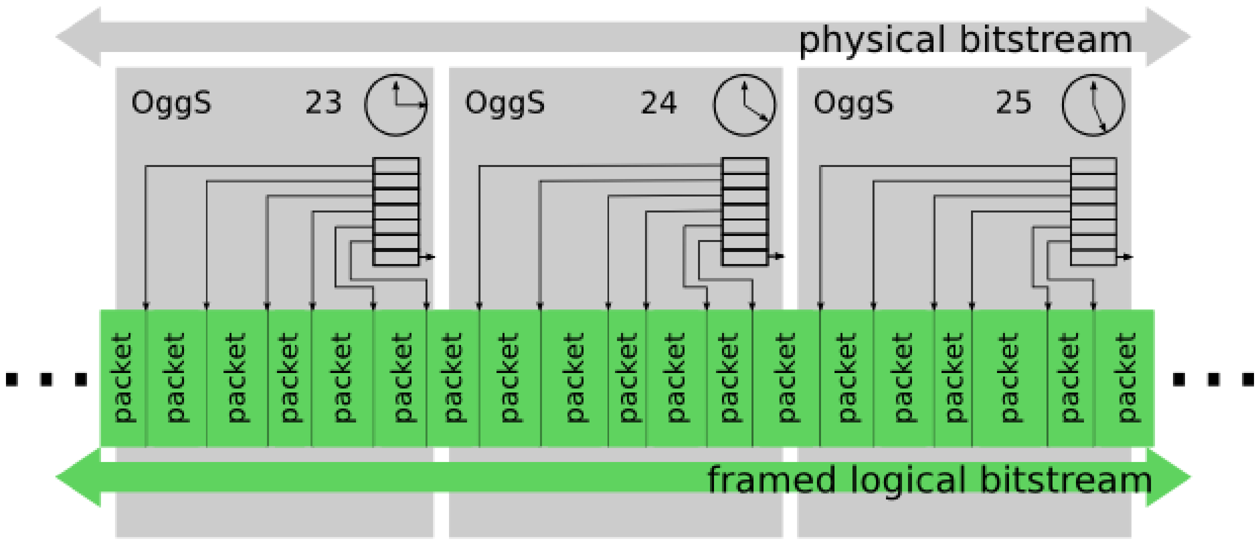


Figure 5: Packet time-stamping

Each logical stream is identified by the unique stream serial number stamped in its pages. A decoder recovers the original logical/elementary bitstreams out of the physical bitstream by taking the pages in order from the physical bitstream and redirecting them into the appropriate logical decoding entity.

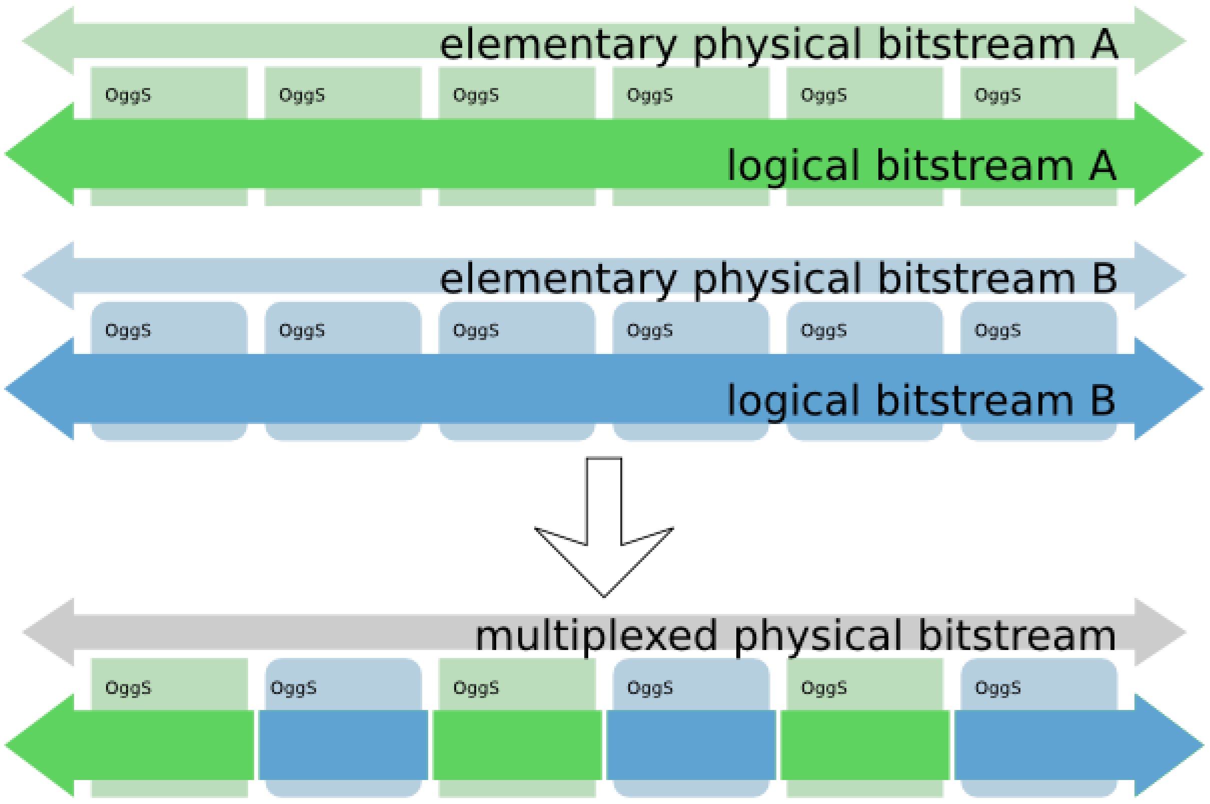


Figure 6: Multiplexing of two logical bit-streams into one combined Ogg bit-stream

6. Simulation Objectives

Given that h.264 is an established codec with a large body of code and optimizations, it is expected to be generally superior to Ogg Theora. The fundamental question is whether it is 'good enough' for web video. Even the just the availability of a competing standard could be enough to ensure the MPEG-LA consortium will not attempt to charge license fees for web-delivered non-commercial content. This is the question we intend to answer.

There are numerous comparisons between h.264 and Theora available on the internet already, many are old and no longer reflect the current state between the codecs, or are flawed in some way. The goal is to compare the standards in as fair and objective manner as possible using the latest encoders.

To accomplish this, we will encode uncompressed video with both codecs at different quality settings. Quality settings will be used rather than bitrate settings in order to isolate either codec's ability to maintain a given bitrate. Since we give the primary consideration to web video which can be buffered, bit rate is not directly relevant. The compressed videos will be objectively compared using the Structural SIMilarity index (SSIM), an image quality comparison method based on psycho-visual error sensitivity.[5]. The compression options will be adjusted until we have an optimally encoded Theora and h.264 video at the same image quality. Then the total file size will be compared. This comparison will also allow us to highlight the types of compression artifacts both codecs tend to produce. At minimum, we will need to encode both a slow moving scene and a fast moving scene. We also need to know the relative compression capabilities at near high quality and low quality.

The SSIM index calculates the overall image quality compared to a reference image based on visual perception factors. Mean squared error is a poor way to gauge image quality as the following picture shows. All of the converted images of the baby have the same error, but they differ substantially in image quality.

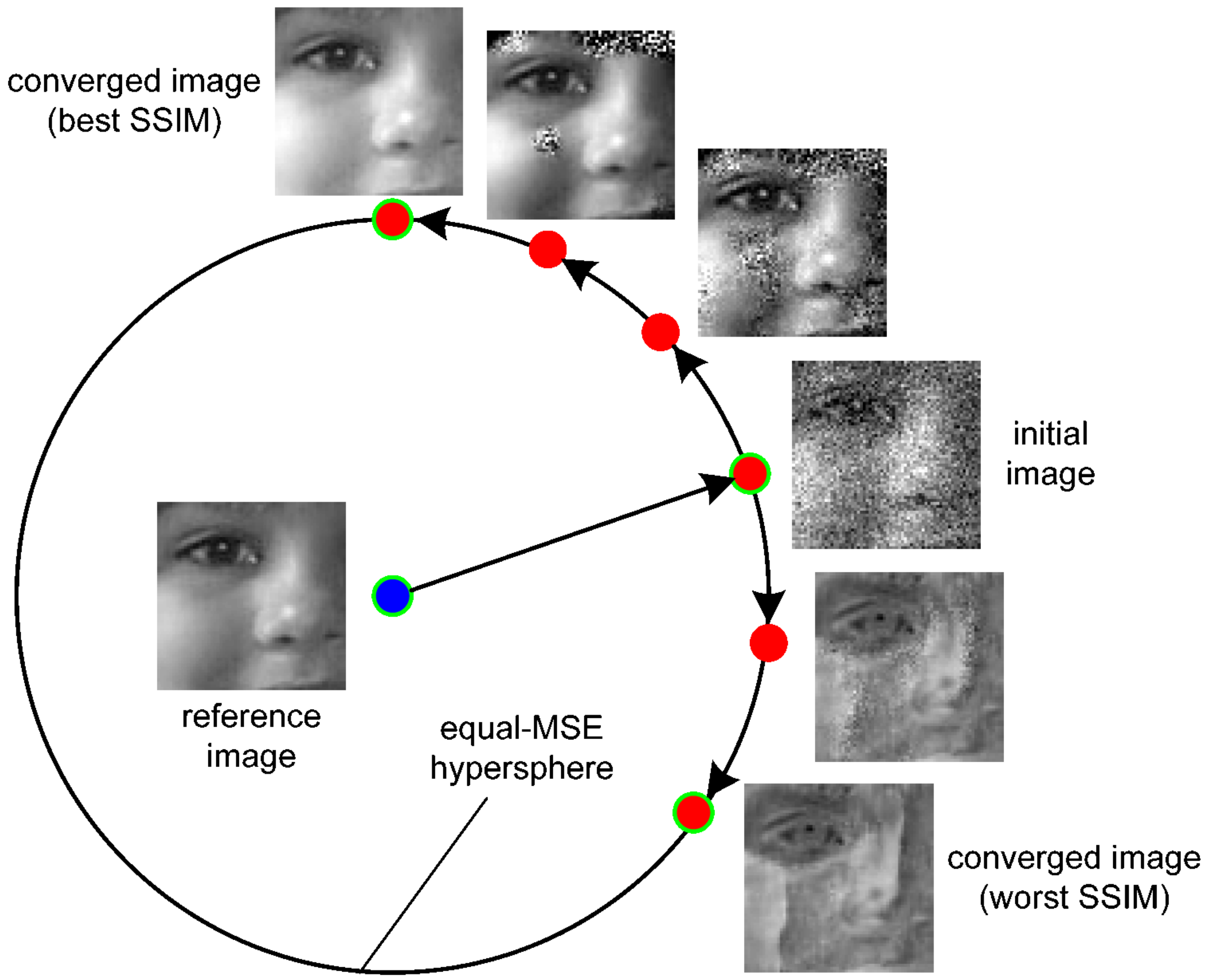


Figure 7: Examples of SSIM image qualities [6]

7. Simulation Results

In order to test the quality of the Ogg codec it was compared against the H.264 commercial codec. An uncompressed video of a man running through a park was used for comparison (parkrun). The parkrun video was encoded with both codecs with an aim of similar file size. An attempt was made to encode the videos with similar quality ratings for comparison but there was limitations on minimum file size that were reached that did not allow for that comparison. Below is a screen-shot of the uncompressed video with theoretical 100% quality.

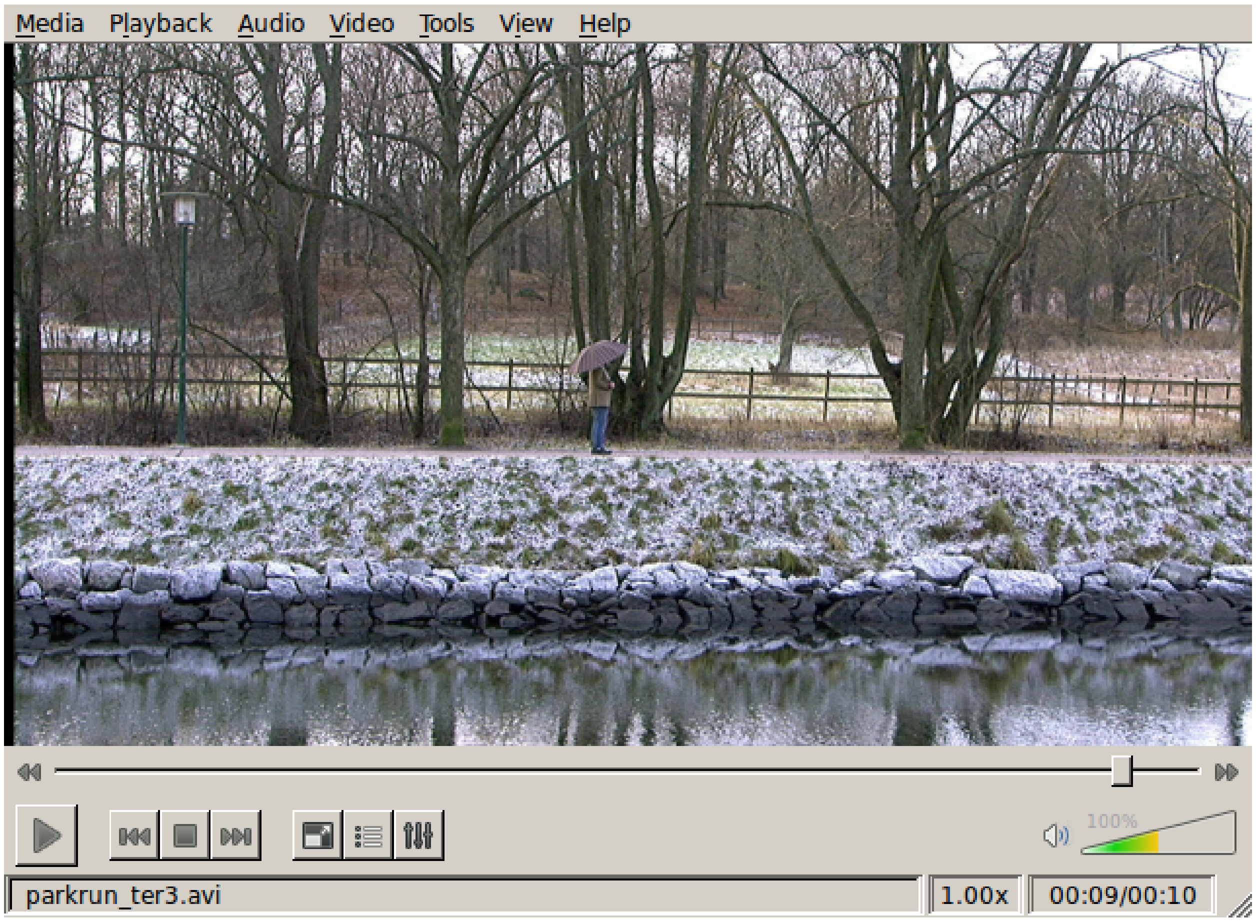


Figure 8: Original Uncompressed Video

The result of coding the video for constant file size is shown in the following two images. It is important to note that although the Ogg video frame may look slightly worse, the frame-to-frame video quality is comprable to H.264.

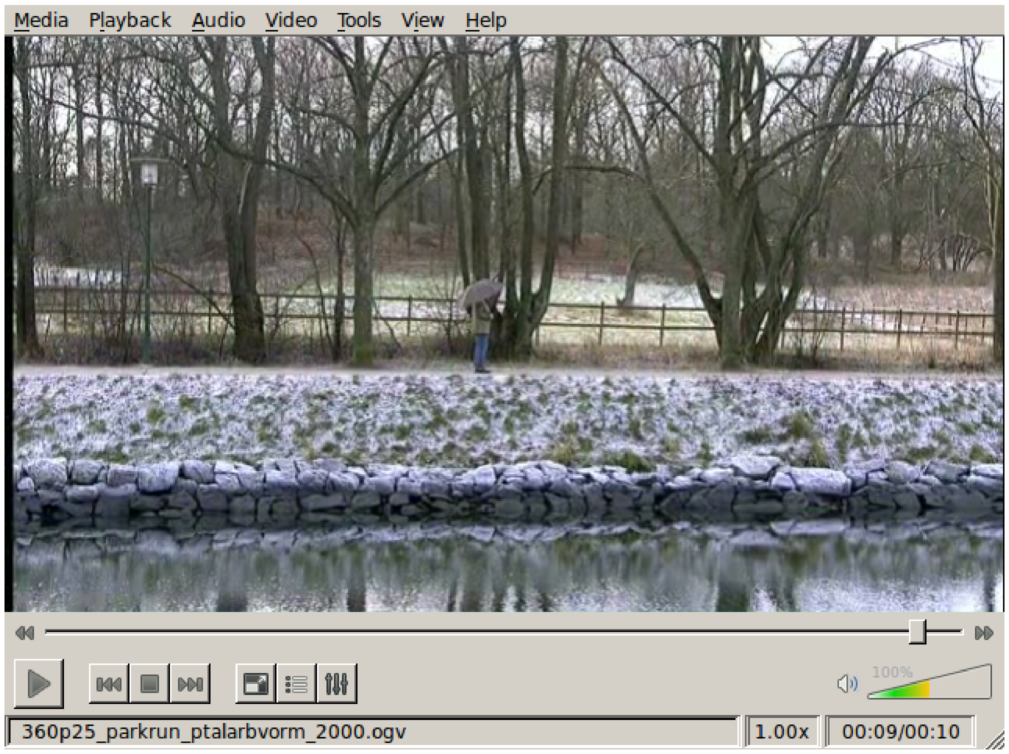


Figure 9: Ogg Encoded Video

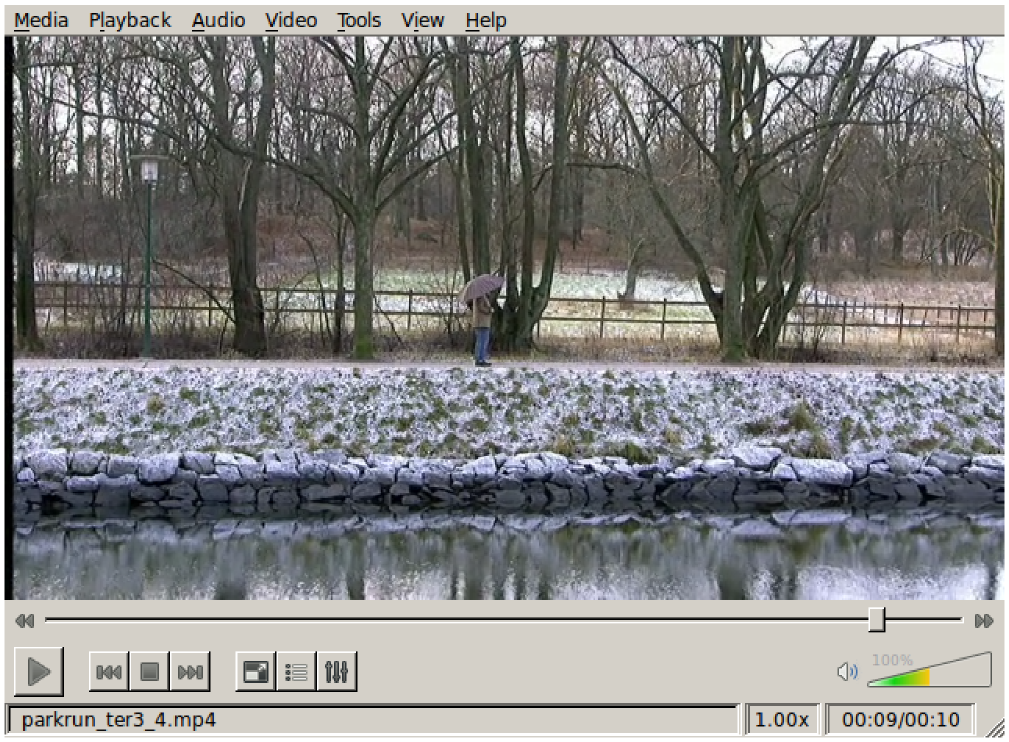
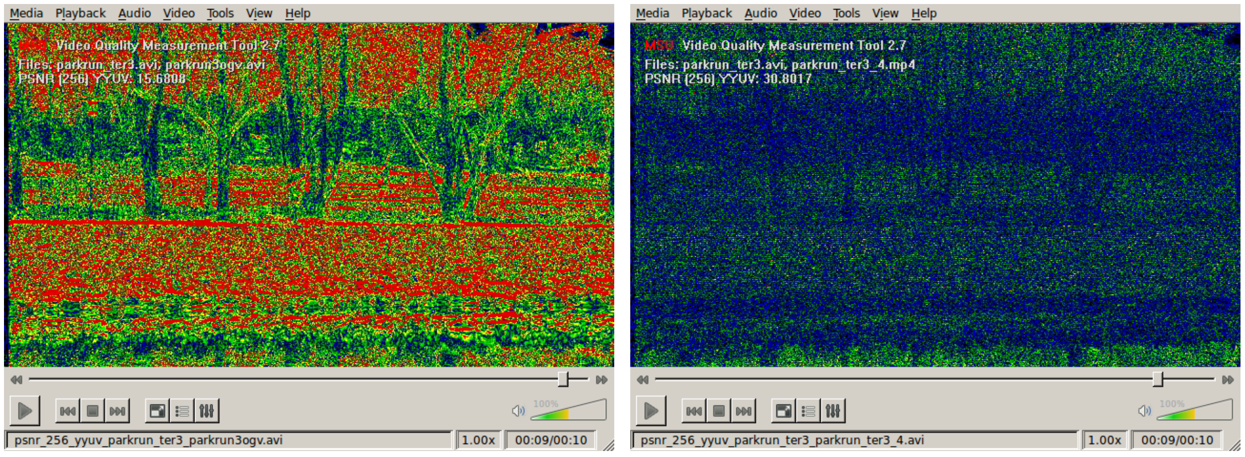


Figure 10: H.264 Encoded Video

In order to qualitatively compare the tow codecs three tests were carried out on each of the videos. Mean Squared Error (MSE), Structural SIMilarity index (SSIM), and Video Quality Measure (VQM). As shown above, MSE isn't the best measure of visual quality. With that in mind there is a large difference between the Ogg and H.264 videos. In the images below the more intense colors (like red) are a sign of poor MSE. This is a surprise to most people because the the human eye makes most people believe that the Ogg video looks best.


Media Playback Audio Video Tools View Help
1.00x
00:09/00:10
Media Playback Audio Video Tools View Help
1.00x
00:09/00:10

MSU Video Quality Measurement Tool 2.7
Files: parkrun_ter3.avi, parkrun3ogv.avi
PSNR [256] YYUV: 15.6808

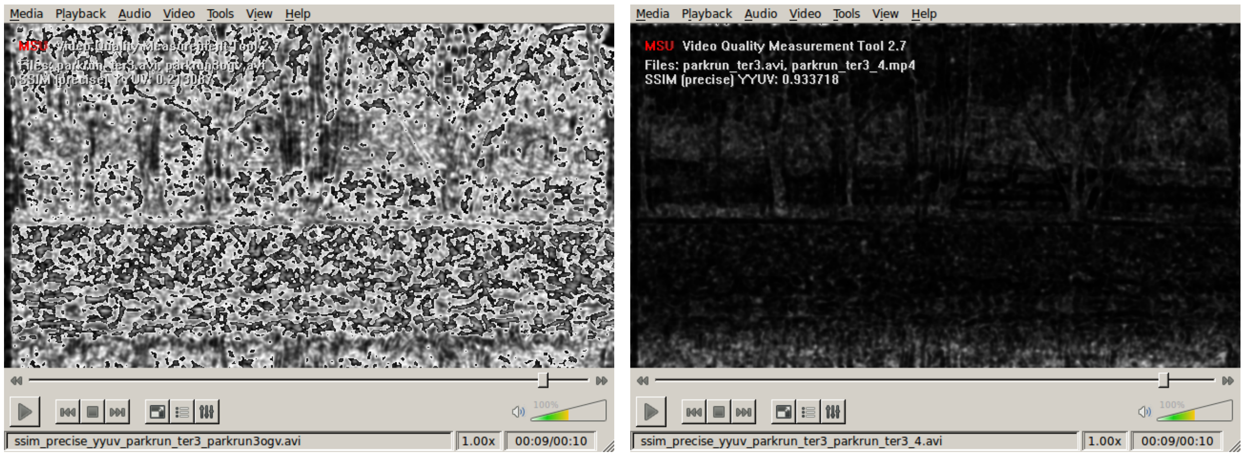
psnr_256_yyuv_parkrun_ter3_parkrun3ogv.avi

MSU Video Quality Measurement Tool 2.7
Files: parkrun_ter3.avi, parkrun_ter3_4.mp4
PSNR [256] YYUV: 30.8017

psnr_256_yyuv_parkrun_ter3_parkrun_ter3_4.avi

Figure 11: MSE comparison on Ogg (left) and H.264 (right)

The second comparison has similar results. Using the SSIM index a similar result was noted as with MSE. One important note is that at second 8 of the video the man stops running and the camera becomes still. At that point the H.264 video starts to decrease in error as the frame-to-frame changes are reduced. However, the Ogg coded video does not have a increase in quality after the camera stops. This phenomena is illustrated in the following two images.


Media Playback Audio Video Tools View Help
1.00x
00:09/00:10
Media Playback Audio Video Tools View Help
1.00x
00:09/00:10

MSU Video Quality Measurement Tool 2.7
Files: parkrun_ter3.avi, parkrun3ogv.avi
SSIM [precise] YYUV: 0.213087

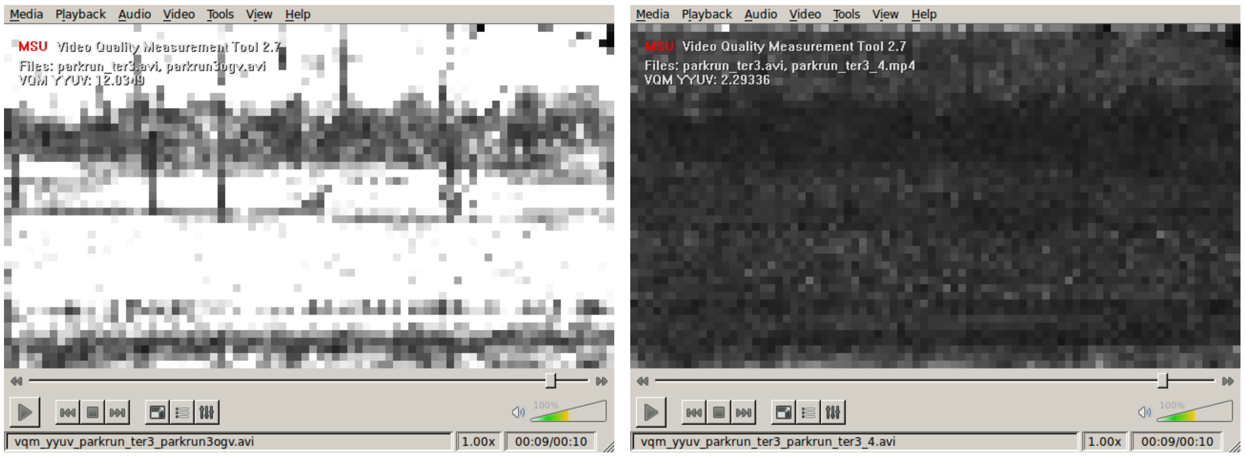
ssim_precise_yyuv_parkrun_ter3_parkrun3ogv.avi

MSU Video Quality Measurement Tool 2.7
Files: parkrun_ter3.avi, parkrun_ter3_4.mp4
SSIM [precise] YYUV: 0.933718

ssim_precise_yyuv_parkrun_ter3_parkrun_ter3_4.avi

Figure 12: SSIM comparison on Ogg (left) and H.264 (right)

Because the benchmark was available, a third test, the VQM test was also run. This test has similar results to the others which supports the conjecture that when videos are encoded for similar file sizes H.264 outperforms Ogg Theora.


Media Playback Audio Video Tools View Help
100%
1.00x
00:09/00:10
Media Playback Audio Video Tools View Help
100%
1.00x
00:09/00:10

MSU Video Quality Measurement Tool 2.7
Files: parkrun_ter3.avi, parkrun3ogv.avi
VQM YYUV: 12.0349
vqm_yyuv_parkrun_ter3_parkrun3ogv.avi

MSU Video Quality Measurement Tool 2.7
Files: parkrun_ter3.avi, parkrun_ter3_4.mp4
VQM YYUV: 2.29336
vqm_yyuv_parkrun_ter3_parkrun_ter3_4.avi

Figure 13: VQM comparison on Ogg (left) and H.264 (right)

Form the tests described above, even though the visual quality may be similar to the human eye, H.264 in a similar-file-size test out performs Ogg Theora.

8. Conclusions

Open source codecs such as the Ogg family are clearly important in todays world of ever-present multimedia systems and communications. Ogg Theora provides a competitive opposition against the expensive, lawsuit-bound commercial codecs currently stealing the limelight such as H.264. This work has shown that Ogg Theora, even though it is technically poorer quality in comparison, can be an excelent alternative to H.264, especially with it's upcoming improvements. Ogg Theora is designed for future scalability with features such as the Ogg container format and integration with other open source projects such as Mozilla Firefox.

9. References

[1] Xiph.org Foundation "Theora Specification" August 5, 2009. [Online]. Available: http://theora.org/doc/Theora.pdf [Accessed: May, 5, 2010]
[2] S. Shankland. "Microsoft takes H.264 stand in Web Video Debate," April 30, 2010. [Online]. Available: http://news.cnet.com/8301-30685_3-20003838-264.html [Accessed: May 6, 2010]
[3] M. Shaver, "HTML5 Video and Codecs," January 23, 2010. [Online]. Available: http://shaver.off.net/diary/2010/01/23/html5-video-and-codecs/ [Accessed: May 6, 2010]
[4] R. Lawler, "Google to Open Source VP8 for HTML5 video," April 10, 2010. [Online]. Available: http://newteevee.com/2010/04/12/google-to-open-source-vp8-for-html5-video/ [Accessed: May 6, 2010]
[5] Z. Wang et al, "Image Quality Assessment: From Error Visibility to Structural Similarity" IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 13, NO. 4, APRIL 2004. [Online] Available: http://www.cns.nyu.edu/pub/eero/wang03-reprint.pdf.
[6] Z. Wang et al, "Maximum SSIM" [Online]. Available: http://www.ece.uwaterloo.ca/~z70wang/research/ssim/maxmin_SSIM.gif [Accessed: 6 May, 2010]