NASA Planetary Data System (PDS): MPEG-4 (H.264 Video and AAC Audio)

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Introduction to PDS4 Video and Audio:

In 2017 PDS approved a restricted set of digital (compressed) video formats as a valid "document" format (in Product_Document). PDS documents assist users in understanding data contained in the PDS archive; documents mainly include textual or text-based information but may also include graphics and/or images. In 2017 and later, videos were not intended to archive scientific data for distribution or analysis but rather to facilitate the understanding of the aforementioned scientific data. For example, an animated video could show 3D rendered scenes of orbital coverage over the time covered by archived data or an animation of data graphed over time. Video documents may not supplant text-based documentation, which must continue to include everything necessary to understand the uncompressed scientific data being archived.

In 2021 PDS then approved digital (compressed) audio for archiving Waveform Audio (WAV) files returned from SuperCam on the Mars 2020 rover; the WAV data were considered 'supplementary' to primary products archived as binary tables of raw and calibrated measurements. WAV was authorized as a valid format in Product_Ancillary and Product_Browse (but not Product_Observational); although not used at the time, MPEG-4 compressed Advanced Audio Coding (AAC) was also authorized.

Since its initial release, PDS4 has restricted data providers' abilities to archive compressed file types for science data. The current method to archive video as Product_Observational includes splitting the original video into individual frames. A one-minute video, at 30 frames/second, results in 1,800 separate image frames. As videos continue to get longer, supporting individual frames becomes less sustainable; more concerning is that the videos will become increasingly unusable by viewers. For audio, PDS4 does support the uncompressed (lossless) format in the Waveform Audio File (WAV), but audio can also benefit from compression. The ability to compress data through time or frames (temporally) is how files are dramatically reduced in size for both video and audio. While lossless video formats do exist, they result in huge files and are essentially unusable even in modern computers.

This document assesses the video/audio landscape and describes how PDS4 can incorporate compressed video and audio. It also reviews currently approved use of MPEG-4 for documents.

Background:

In 2017 PDS chose the 'MP4' video format (MPEG-4 Part 14), encoded with the H.264 (MPEG-4 Part 10) and AAC COmpression/DECompression (codec) algorithms (MPEG-4 Part 3) for documents. MP4 is a standard developed by the Moving Picture Experts Group (MPEG) which is commonly used for sharing video files on the Internet. However, MP4 (generally with a file extension of .mp4), is simply a container format which does not specify the type of video and/or audio codec method used within the format. For MP4 video, the PDS requires, due to its broad support, the video codec H.264. For MP4 audio, when available for the video stream, the PDS requires the Advanced Audio Coding (AAC). In general, both of these codecs (H.264 and AAC) are lossy formats and have not previously been considered suitable for archiving scientific data.

H.264 video codec (MPEG-4 Part 10): While H.264 is patent-encumbered and licensed by MPEG LA, Cisco has released an open source H.264 implementation called OpenH264. This release enables any open source project to incorporate Cisco's H.264 module without paying MPEG LA license fees. OpenH264 is released under the terms of the Simplified BSD License (URL: http://www.openh264.org/). As an alternative to the Cisco implementation, another open source software library and application, called x264, also exists for encoding and decoding video streams into the H.264 compression format. x264 is released under the terms of the GNU GPL (URL: http://www.videolan.org/developers/x264.html). Thanks to Cisco and GNU, PDS (without restriction) may host H.264 encoded video since it is free to distribute for non-commercial use.

Advanced Audio Coding (AAC) audio codec (MPEG-4 Part 3): AAC was developed by several companies including AT&T Bell Laboratories, Fraunhofer IIS, Dolby Laboratories, Sony Corporation and Nokia. It is specified both as Part 7 of the MPEG-2 standard and as Subpart 4 in Part 3 of the MPEG-4 standard. While declared an international standard in 1997, it was made popular in the mid-2000's by Apple's iTunes application (and portable music devices) and has been included in videos on YouTube, now owned by Google. License fees are only due on the sale of encoder and/or decoder applications. No licenses are required for the PDS to stream or distribute content in AAC format. AAC encoders released by the FFmpeg team are LGPL-licensed and open source (URL: https://ffmpeg.org/). When compressed audio accompanies compressed video, AAC is often used. For music- or audio-only files, the .m4a extension is generally used (for examples of audio-only conversions see https://trac.ffmpeg.org/wiki/Encode/AAC).

Restricted Use of Compression with Science (Observational) Data:

To accommodate the rapidly growing use of video in planetary exploration, and recognizing that video files may become very large without compression, PDS now allows restricted use of compressed video and audio for archiving observational data as well as documentation. Note that along with the including video and audio for observational data, these types can also be included in ancillary and browse products. Restrictions are documented in "Policy on Formats for PDS4 Data and Documentation" (see https://pds.nasa.gov/datastandards/documents/policy).

The remainder of this document summarizes recommended use, conversion, and compliance verification.

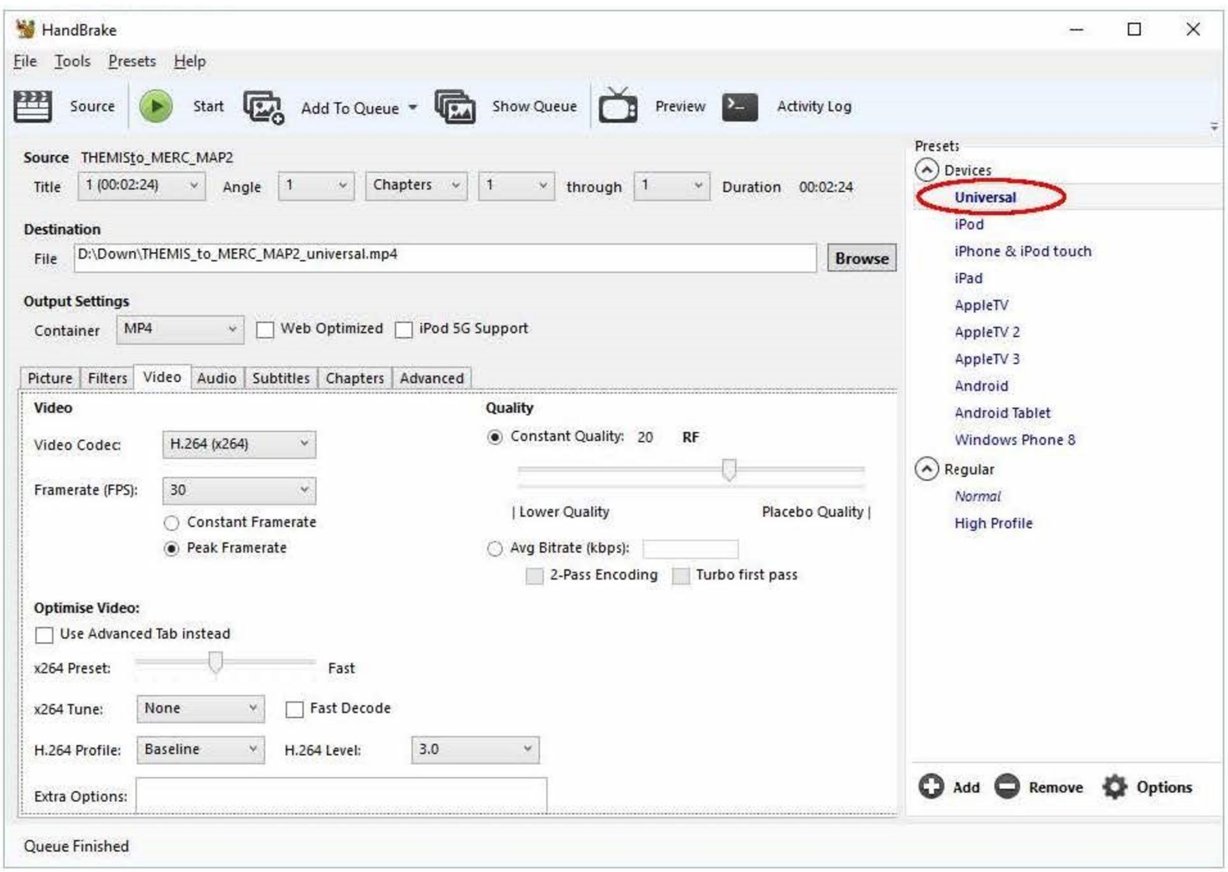
Viewing Applications:

In addition to MP4 support available in most web browsers, there are many different applications to view MP4 videos encoded with the H.264 and AAC codecs. One open source application, with broad support across a variety of operating systems (including portable devices and phones), is the VLC media player by VideoLAN (URL: https://www.videolan.org/vlc/).

Conversion to MP4 (H.264 and AAC):

Nearly all video production software will support H.264 video and AAC audio encoding during the creation of a MP4 formatted file.

1. If your video application does not support H.264 and/or AAC encoding, the open source program *HandBrake* (URL: https://handbrake.fr/) may be used to convert from most video formats to MP4. Below is a screen shot of *Handbrake* with a video loaded for conversion. Simply choosing “Universal” under devices (circled in red) should provide you with recommended settings for a compliant PDS4 video file.



2. Another open source method to convert from a different video type to MP4 (using H.264 and AAC encoders) is *ffmpeg*, freely released by the FFmpeg team (URL: https://ffmpeg.org/). This routine can also convert a series of image frames (*e.g.*, JPEGs or PNGs) to an MP4 video. For command-line options see URL: https://trac.ffmpeg.org/wiki/Encode/H.264.

Testing for PDS MP4 Compliance:

There are several methods to test an MP4 video for compliance with H.264 video and AAC audio encoded streams. Two simple methods are described below.

1. The first method is to use *HandBrake* above. Simply load the video using the "Source" button. Under the activity log (scan tab), *HandBrake* will list the MP4 file metadata for the codecs used.
2. The open source and command-line routine *ffprobe*, freely released by the FFmpeg team and built across several operating systems, can also be used (URL: https://ffmpeg.org/). See below for output from an example run. Note the two lines which are highlighted in bold (some lines have been removed for brevity).

```
$ ffprobe THEMIS_to_MERC_MAP2_universal.mp4
ffprobe version N-86129-g1e8daf3 Copyright (c) 2007-2017 the FFmpeg developers
. . .
Input #0, mov,mp4,m4a,3gp,3g2,mj2,from 'THEMIS_to_MERC_MAP2_universal.mp4':
  Metadata:
    major_brand     : mp42
    compatible_brands: isomiso2avc1mp41
    creation_time   : 2017-05-23T18:47:55.000000Z
    encoder         : HandBrake 0.10.5 2016021100
  Duration: 00:02:24.82, start: 0.000000, bitrate: 429 kb/s
    Stream #0:0(und): Video: h264 (Constrained Baseline) (avc1 /
0x31637661), yuv420p(tv, bt709), 1280x720 [SAR 52243:52200 DAR 587:435],
262 kb/s, SAR 26729:26707 DAR 587:435, 15 fps, 15 tbr, 90k tbn, 180k tbc
    Metadata:
      handler_name    : VideoHandler
    Stream #0:1(eng): Audio: aac (LC) (mp4a / 0x6134706D), 44100 Hz,
stereo, fltp, 162 kb/s (default)
    Metadata:
      handler_name    : Stereo
```

Quality:

The "Universal" preset in *HandBrake* defaults the video quality setting to 20 "Constant Quality" (CRF) and will define a variable frame rate with the allowable peak of 30 frames per second. Using these defaults will result in a quality video conversion suitable for archival documentation. However, for primary science data, set the *HandBrake* CRF quality to 10 or 12 (which will increase the video bit rate) and set the "Optimize Video" x264 Preset to **Slower**.

The default bit rate for the AAC audio encoder will be set to a 160 kilobytes per second, which is more than sufficient for speech and most music. If you are concerned about the audio quality, set the bit rate to 320 kilobytes per second. Note that changing these default settings will result in a larger file size.

For video that already conforms to the H.264 encoding standard — for example, as taken onboard a spacecraft — there would be no need to re-encode using the recommended CRF setting of 10 or 12 as this would just add compression artifacts to the original video.

Testing against an original image, using a recommended CRF of 10 or 12, shows that original data will be affected; but the visual impact is negligible. Comparing a single compressed frame against an original frame resulted in a root-mean-square error of less than 0.01 and a standard deviation of ~1.0.

Recommendations for video size and aspect ratio, which are generally set by the source application or camera, include the following. All are 16:9 ratio, which is common for high definition (HD) television and web services like YouTube. Suffix "p" stands for progressive scan and "width x height" dimensions are in pixels.

- 720p: 1280x720 (HD, High-Definition TV quality), currently recommended for web services
- 1080p: 1920x1080 (Full HD, Blu-ray quality), currently recommended for archive and web services
- 2160p: 3840x2160 (Ultra-HD, 4K quality), beginning to grow in popularity