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# Implementing a video framework based on IIIF: a customized approach from long-term preservation video formats to conversion on demand

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## Abstract

*This paper addresses the issue of elaborating a structure for digital video assets based on the International Image Interoperability Framework (IIIF) concepts for the use in archival environments. With a view to tailoring a solution to fit the end user's needs, the dissemination copies of video material could be automatically converted on demand from their master files. Such a reduced data structure simplifies access to digital video sources but leads as well to simplified preservation due to reduced data volume and data complexity. Dissemination copies do not require specific dispositions for digital archiving anymore.*

*Memory institutions would greatly benefit from a technology that can be integrated into a Web-based infrastructure. In such a way video content can for example be embedded into flexible Virtual Research Environments which allow scholars to work and cite more accurately video resources using IIIF.*

## Motivation

A general tendency is that scholars want to access and work with digital objects aided by virtual research infrastructures. This enables normalization as data and metadata are gathered in the same technological environment. Such an approach simplifies maintenance and contributes to cost efficiency, and both are important aspects for data permanence. From the end user's point of view, this means a growing number of tools to work with content as well as the possibility to interlink data from different sources.

Digital asset management for video material can greatly differ from one institution to another from which format (encoding and container) they may choose from to how they want to display the content to their users. Reformatting, storing, converting, transcoding and sharing digital video assets can be daunting tasks. In order to address these issues, this paper will give an insight into the following facets: a web-based framework to manage video assets, suitable video destination formats for long-term preservation purposes, and a transcoding tool able to easily convert video on demand into web supported video formats.

## Problem

### A simpler framework for video assets

The long-term digital information preservation and access strategy is generally based on the OAIS reference model which depicts a framework where digital assets (data, metadata, and descriptive information) are contained in three different types of packages according to their life cycle: Submission Information Package (SIP), Archival Information Package (AIP), and Dissemination Information Package (DIP). This conceptual model is widely adopted. It has been an ISO Standard since 2003 and was revised in 2013[1] [1]. Nonetheless, GLAM (Galleries, Libraries, Archives, Museums) institutions don't necessarily have enough resources in the IT domain and often lack the needed expertise to implement OAIS properly, and the application of the reference model varies from institution to institution [2]. As for digital video assets, it is even more an intricate process for memory institutions who have to handle different aspects that are quite time-consuming and expensive. Therefore, a simpler framework, more convenient to all institutions but especially to smaller ones, has to be developed. This framework could run alongside the OAIS reference model (as engine to create DIPs on-the-fly) or on its own. The International Image Interoperability Framework (IIIF[2]) [3] may well be the best solution for disseminating digital assets, even more so when it will be extended to all forms of audiovisual material.

### Long-term preservation purposes

If the consensus for preserving digital audio files seems to a certain extent straightforward (e.g. the target format recommended by IASA is BWF 96kHz 24-bit [4]), for video files this is not the case. For instance, the Library of Congress updates annually their recommended formats statements on which there is a dedicated section for moving image works [5]. Moreover, the Federal Agencies Digitization Guidelines Initiative (FADGI) compared in 2014 different video formats for reformatting [6]. FADGI narrowed down to five file wrappers (AVI, MOV, MKV, MXF, and MPEG-2 as ad-hoc format) and five encodings (two uncompressed: 4:2:2 8-bit UYVY/YUY2 and 4:2:2 10-bit v210, two lossless: JPEG2000 and FFV1, and one lossy: MPEG-2 4:2:2 Main Level). Finally, the International Association of Sound and Audiovisual Archives (IASA) is currently working on a technical guideline (IASA-TC 06), due in 2017, concerning video preservation [7] which has retained the recommendations elaborated by FADGI less the uncompressed 8-bit encodings and MPEG-2. However, instead of separating wrappers and encodings, they will highlight and compare four format families composed of eight different combinations or subtypes based on well-documented profiles and/or ongoing standardization efforts. For instance, the Advanced Media Workflow Association (AMWA) in their AS-07 specification has been working on defining how the MXF wrapper should carry either lossless JPEG2000 or uncompressed v210 [8]. Besides, the Internet Engineering Task Force (IETF) has set up a working group called CELLAR (Codec Encoding for LossLess Archiving and Realtime transmission) who

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[1] An upcoming review of the OAIS standard is taking place in 2017. http://wiki.dpconline.org/index.php?title=OAIS_Community
[2] IIIF is pronounced "Triple-Eye-Eff"

‘will seek consensus and refinements for specifications for both FFV1 and Matroska in order to provide authoritative, standardized specifications for users and developers’ [9]. The four families mentioned in the upcoming IASA-TC 06 will be the long-term preservation target formats for this paper.

### Video dissemination on the Web

As for handling multimedia data, FFmpeg, a free software that produces libraries and programs since 2000, is probably one of the most powerful tools available [10]. A very interesting feature would be to convert popular Web supported video formats (e.g. VP9/WebM, H.264/MP4) on-the-fly with FFmpeg with a view to tailoring the end user’s needs. Different aspects and features could be integrated into our framework.

Finally, if the transcoding could be fast enough, perhaps the DIP would not necessarily need to be stored by memory institutions. They might not gain substantial amounts of storage but this will indeed simplify their dissemination process and it will reduce responsibility as they will no longer have to handle unnecessary digital assets in terms of long-term archiving criteria. Amongst speed encoding, other technical challenges like bandwidth or cost emerge. However, memory institutions would greatly benefit from having a framework based on the IIIF concepts owing to the fact that they will be part of a community and that their end users will use, annotate, and cite their video sources in a standardized and flexible manner.

## Background

This section will look deeper into the three aforementioned facets as well as displaying an existing infrastructure integrating our IIIF-like conceptual ideas around Web-accessible videos on demand.

### IIIF and IIIF A/V

The IIIF initiative began in a Cuban restaurant in California where technologists from Stanford University, the British Library and Oxford had a dinner. The concepts were scribed on the back of a napkin and since then, memory institutions and diverse organizations '[…] have worked together to agree on common APIs for image delivery and developed an ecosystem of compliant systems' [11].

The four defined application programming interfaces (APIs) by IIIF are Image API [12], a web service that returns an image in response to a HTTP or HTTPS request, Presentation API [13], a web service that returns JSON-LD structured documents, Content Search API [14] which returns annotated content, and Authentication API [15] which grants access to protected content.

To comply with IIIF concepts, memory institutions need first to have an image server that supports the Image API, then publish the metadata accordingly to the Presentation API, and finally deploy and integrate software that can cope with the IIIF technology stack [16].

In July 2015, Tom Crane, Technical Director at Digirati, coined the 'IxIF' acronym in its wish to extend IIIF to non-image-sequence resources [17]. For him, ‘IxIF [fell] into two parts’: the extension of the Presentation API to cover audiovisual assets and the assessment of creating an equivalent of the Image API if required. For the latter, Crane points out that needs could greatly differ from institutions who would want their video resources to be rendered at a “discovery level” and others who would like a more versatile experience for their end users such as being able to start a video at a certain frame.

In April 2016, a IIIF A/V workshop took place in London. Demos, use cases, and the steps needed to build or extend the APIs were discussed. An A/V Technical Specification Group has since been created to oversee these matters and for future developments [18].

A more versatile experience is what the University of Basel’s Digital Humanities Lab (DHLab) wants to achieve by promoting and enhancing IIIF-compliant servers for archival purposes with on-the-fly transcoding.

However, a fully defined Audio and Video Content API from the IIIF community is expected to be done by 2018. The Presentation API will be revised as well to comply both with the Image API and the future A/V API.

Finally, Tom Crane did some new musings about the relationship between the A/V API and the Presentation API, pointing interesting challenges and questions such as what kind of video formats the A/V API should support and what is the minimum scenario for interoperability [19]. In addition, Jason Ronallo, Interim Head of the Digital Library Initiatives at North Carolina State University Libraries, gave an example of what a JSON response containing a video resource both in WebM and MP4 might look like [20] and some proposed fixtures came out after a recent meeting at the British Library in February 2017 [21].

### Video target formats for long-term preservation

A unique and de facto long-term preservation target format for video resources is hardly something that will occur in the near future. Preferred formats for the long-term vary as ‘video preservation practices are not yet mature’ [7]. Formats, for us digital files, either digital-born or reformatted from analogue material, comprise of an encoding (v210, H.264, VP9, FFV1, etc.), that is how the bit stream is encoded, wrapped in a container (MXF, MP4, MKV, etc.); because of its extension it is more easily recognizable and understood by the general public. Other technical aspects not covered by this article, such as colour space, bit-depth, frame rate, aspect ratio, or scanning methods, must be handled in order to have the necessary knowledge of what a video format consists (FADGI proposes a thorough glossary [22] and excellent summaries of formats assessments are being done by the Digital Preservation Coalition and the Library of Congress [23, 24]).

The widely accepted digital process by memory institutions is to have multiple copies of their master files (equivalent to the AIP in OAIS) stored for example in hard disks and magnetic tapes and one or several access files (DIP). AIPs are normally uncompressed or lossless formats, which should fulfil criteria like the sustainability factors exposed later in this paper, and DIPs are often lossy formats.

Video target formats for the long-term recommended by the IASA in their TC-06 are the four following families [7]:

- **Marketplace wrappers** (OpenDML AVI or QuickTime MOV) with **FFV1 or uncompressed v210**
- **Uncompressed v210 in MXF** (AS-07 Baseband Shim or BBC Archive Format)
- **Lossless JPEG2000 in MXF** (AS-07 Baseband Shim or SAMMA profile)
- **FFV1 in Matroska** (CELLAR)

The comparison of these four families are based on the Library of Congress sustainability factors: disclosure, adoption, transparency, self-documentation, external dependencies, impact of patents, and technical protection mechanisms[3] The TC-06 should give the incentive for memory institutions to choose one or several of these family formats as they are all well-documented and some of them are not expensive in terms of infrastructure. As an example, FFV1 in Matroska has a strong and helpful community, and all the tools are free.

If still unsure of which to pick from, it is worth noting that a report by George Blood Audio and Video has been written for institutions that can't afford to migrate and transcode for the time being their video files into JPEG2000/MXF [25]. This report dates from 2011 and was specifically aimed for institutions who wish to have an interim approach before opting for the Library of Congress' preferred video format. Yet, this method could still be done before choosing FFV1/MKV as the long-term preservation target format.

### Dissemination and conversion on demand

We have seen which video formats a memory institution could choose from for long-term preservation schemes. If there is no general consensus for preservation, there isn't one for dissemination either, but the constraints are quite different. Digital assets have to be Web-accessible to gain visibility and are therefore tied to technical parameters such as what kind of formats Web browsers support or what is the bandwidth available to the end user. HTML5 has though become the de-facto standard on the Web and a large number of different video formats have now disappeared, or are about to be obsolete, as a consequence.

Well-spread video formats on the Web are the following: VP9/WebM and H.264/MP4 (also known as MPEG-4 AVC). Besides, a new codec called High Efficiency Video Coding (HEVC) or H.265 is a video compression standard developed by the ITU-T Video Coding Experts Group (VCEG), inclined to succeed H.264 in the near future, supposedly when the royalty-free alternative codec will be deployed [26]. H.265 offers better data compression than H.264 for the same level of quality or better quality at the same bit rate. This is why it is worth counting on this encoding which can more conveniently carries high-definition images like 4K. VP9/WebM, H.264/MP4, and H.265/MP4 are then the three video formats to consider for video dissemination.

On figure 1, there is a simple flowchart that shows the different layers that could have a IIIF A/V-compliant structure. It will be an interesting challenge and feature if the input (long-term preservation target formats) could be converted on-the-fly for the end-user's needs and constraints.

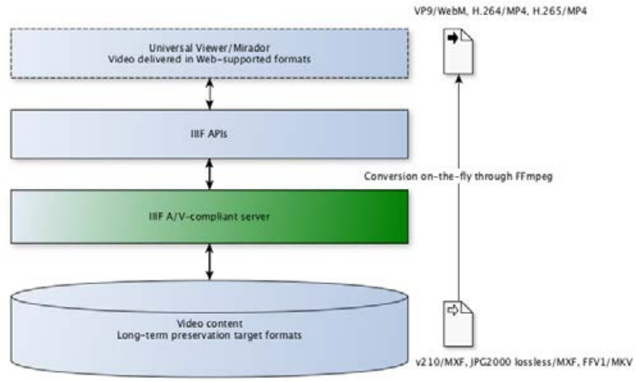


*Figure 1. IIIF and conversion on-the-fly with preferred destination formats for long-term preservation and for dissemination purposes*

On-the-fly transcoding is a technical challenge as real-time conversion is not necessarily something straightforward to achieve in terms of computing power. This issue should be addressed though as there are direct benefits: end users would be able to request what they need and not necessarily what is available. In addition, memory institutions wouldn't have to look after these derivative formats and would focus on sustaining their master files.

### The Knora RDF-based data model

The DHLab has developed an RDF-based software framework called Knora (Knowledge Organization, Representation, and Annotation)[4]. It is used by multiple institutions for storing, sharing, and working with primary sources and data in the humanities. Knora consists of the following components, which can be used together or separately:

- **The Knora Ontologies** is a set of OWL ontologies describing a common structure for describing humanities data in RDF.
- **SALSAH** is a server program written in Scala that implements a HTTP-based API for accessing and working with data stored in an RDF triplestore according to the structures defined in the Knora ontologies.
- Simple Image Presentation Interface (**Sipi**) is a high-performance media server written in C++ and is IIIF-compliant[5]
- **SALSAH GUI** is a web-based virtual research environment for working with data managed by the Knora API server[6]

### One step further into our IIIF A/V structure

The figure 2 takes into account the IIIF concepts and the Knora RDF-based data model as a structure which could be displayed through the SALSAH GUI or any kind of front-end applications such as IIIF-compliant viewers like Mirador and the Universal Viewer.

[3] Besides the Library of Congress, various national organizations have made recommendations and selections of criteria for preserving audiovisual content. In Switzerland, those are KOST-CECO and Memoriav.

[4] http://www.knora.org

[5] https://github.com/dhlab-basel/Sipi

[6] SALSAH GUI is still at a beta level of development at the time of writing and should be released in the near future.

 

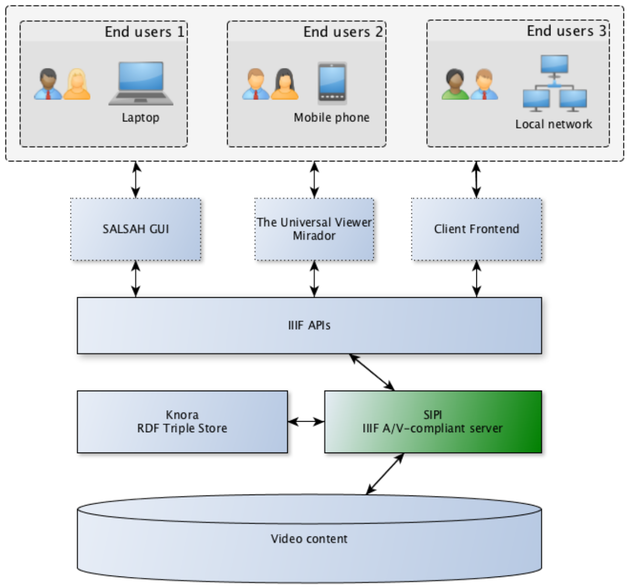


*Figure 2. Architecture of Knora integrating SIPI as a IIIF- compliant media server capable of retrieving video content.*

## Approach

We wanted to explore how fast video encoding and decoding take on an off-the-shelf computer from long-term target formats to Web-supported formats using FFmpeg. Most of the command lines and the steps used for this experiment are based on the comparison on video codecs and containers conducted by the Austrian Mediathek [27] and Ashley Blewer's ffmprovisr [28]. The setup used for transcoding is as follows:

**Test setup**

| | |
|---|---|
| Processor | Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz x 8 |
| Memory | 15.6 GiB |
| Disks | KINGSTON SHFS37A240G – 240 GB (SSD)<br>WDC WD20EZRZ-00Z5HB0 – 2 TB |
| OS | Ubuntu 16.04.2 LTS, 64-bit |
| FFmpeg | ffmpeg version N-81572-g207d781 Copyright (c) 2000-2016 the FFmpeg developer built with gcc 5.4.0 (Ubuntu 5.4.0-6ubuntu1~16.04.2) 20160609 |

The video samples were given from the EPFL's MetaMedia Center who has been overseeing the Montreux Jazz Digital Project since 2010[7]. Their long-term preservation target format is v210/MOV which referred to the first video family format recommended by IASA. The video, an extract of Carlos Santana's 1970 concert in the Montreux Jazz Festival, was transcoded into two other recommended target formats: lossless JPEG2000/MXF and FFV1/MKV. During this first step, each frame was assigned a MD5 checksum. Quality metrics tests by means of the peak-to-signal noise ratio (PSNR) and the structural similarity index (SSIM) were also run against the original sample video.

**Transcoding command lines and PSNR/SSIM command line**

| | |
|---|---|
| JPEG2000/MXF | ffmpeg -i [input] -y -threads 8 -g 1 -c:v libopenjpeg -c:a copy [output.mxf] 2>[log.txt] -f framemd5 -an [logMD5.txt] |
| FFV1/MKV | ffmpeg -i [input] -y -map 0 -dn -c:v ffv1 -level 3 -g 1 -slicecrc 1 -slices 16 -c:a copy [output.mkv] 2>[log.txt] -f framemd5 -an [logMD5.txt] |
| PSNR/SSIM | ffmpeg -i [main input] -i [reference input] -lavfi "ssim;[0:v][1:v]psnr" -f null - |

After controlling that our three video samples/inputs were identical in terms of quality, the conversion to Web-supported formats could begin. As stated before, the three selected Web-supported formats are VP9/WebM, H.264/MP4, and H.265/MP4. Each of our inputs were transcoded into these aforementioned formats, resulting in nine Web-supported outputs. Except the use of 8 threads, most of the default settings were kept. Average encoding and decoding speeds are summarized in the next section.

**Transcoding command lines to Web-supported formats**

| | |
|---|---|
| VP9/WebM | ffmpeg -i [input] -y -threads 8 -c:v libvpx-vp9 -c:a libvorbis [output.webm][8] |
| H.264/MP4 | ffmpeg -i [input] -y -threads 8 -c:v libx264 -pix_fmt yuv422p10le -c:a aac [output.mp4] |
| H.265/MP4 | ffmpeg -i [input] -y -threads 8 -c:v libx265 -pix_fmt yuv422p10le -c:a aac [output.mp4] |
| Decoding | ffmpeg -i [input] -y -threads 8 -f null /dev/null |

[7] http://metamedia.epfl.ch/
[8] VP9 Profile 3, which supports 10 and 12-bit depth, couldn't be tried on FFmpeg as documentation is very scarce on this matter. Hence, the outputs generated with this codec and the WebM wrapper were only 8-bit depth.

## Results

### *Encoding speed*

On average, the libx264 library is the fastest to encode with 61.67 frames per second (fps), libx265 encodes at 39.33 fps, and libvpx-vp9 arrives last at 7.77 fps. The fastest combination is to transcode from v210 to H.264. The latter is the only suitable option which could handle videos up to 60fps for live streaming.

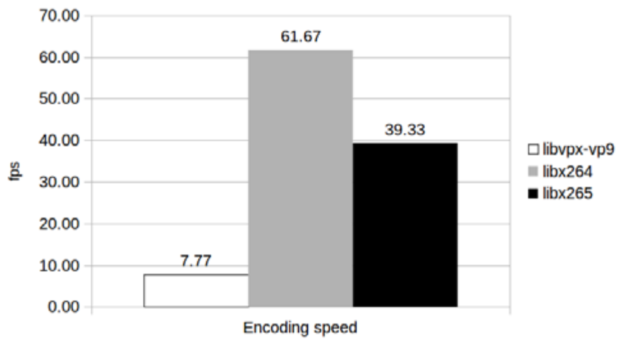


*Figure 3. Average encoding speed (frames per second) between three libraries (libvpx-vp9, libx264, libx265) using FFmpeg on an off-the-shelf computer.*

### *Decoding speed*

Libvpx-vp9 might be slow to encode, but it is twice as fast as libx264 to decode (2,731.67 fps to 1,141.33 fps). libx265 comes last at 634.67 fps.

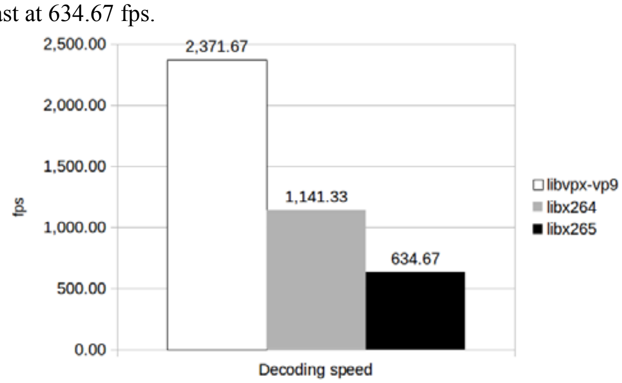


*Figure 4. Average decoding speed (frames per second) between three libraries (libvpx-vp9, libx264, libx265) using FFmpeg on an off-the-shelf computer.*

### *Scope and limitations*

The first purpose of this approach was to demonstrate how fast three libraries on FFmpeg can encode and decode our chosen Web-supported formats and if real-time conversion seemed achievable on a consumer grade computer. For the latter, other technique as HTTP streaming is surely more suitable. It must be noted though that it was also done to give examples to smaller memory institutions of how video transcoding can be done with an open-source infrastructure.

In addition, only a handful of FFmpeg libraries were installed and enabled during the compilation and different results on how fast FFmpeg can encode and decode greatly depend on the command line presets, as well as the library's and codec's properties.

## Future Work

Below are a couple of transcoding aspects that can and should still be done for further investigations:

- Tests could be done with a dedicated server
- Trying different libraries and presets to convert the bit stream to our chosen Web-supported formats and compare the speed results with this former test
- Enquiring how to perform live streaming through FFmpeg with MPEG-DASH and Apple's HLS and the CPUs required to do so
- Looking into scalable video coding (SVC)

Software performance is very important if we speak about on-the-fly image transcoding and it gets crucial if in the case of video and motion picture (1 hour of video is equal to a medium sized photo collection with 90'000 single images). In the DHLab we addressed this issue by developing Sipi a fully self-developed IIIF-compliant, high performance server, that is "reduced to the max".

In addition, the DHLab has joined the IIIF Consortium (IIIF-C) in January 2017 in order to collaborate '[...] on the development of simplified, standardized data structures to facilitate interoperability and digital preservation' [29].

## Conclusion

Standardized and well-documented formats are needed for long-term preservation in the digital video field. However, simplicity and reduction of data volume are also two important aspects of digital preservation. Therefore, IIIF is a very promising approach, not only for standardized dissemination but also as a principal concept how digital assets can be preserved and rendered in one go.

The expansion of IIIF to A/V assets is a matter of work and time. It will be really appreciated by memory institutions, employees and end users alike, to get a clear framework for rendering and accessing video resources. Even if video transcoding on-the-fly is not yet a priority for the IIIF community as they are now in the process of gathering use cases, mockups, and prototypes in a charter, which is currently under review by the IIIF Coordinating Committee [30]. The probable outcome is an A/V Content API that mirrors the existing Image API, but first IIIF will extend the Presentation API to include a time dimension, then the A/V Technical Specification Group will look at the potential for an A/V bitstream API.

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## Author Biographies

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