Exploratory Multimodal Data Analysis with Standard Multimedia Player

Multimedia Containers: A Feasible Solution to Make Multimodal Research Data Accessible to the Broad Audience

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Abstract: The analysis of multimodal data comprised of images, videos and additional recordings, such as gaze trajectories, EEG, emotional states, and heart rate is presently only feasible with custom applications. Even exploring such data requires compilation of specific applications that suit a specific dataset only. This need for specific applications arises since all corresponding data are stored in separate files in custom-made distinct data formats. Thus accessing such datasets is cumbersome and time-consuming for experts and virtually impossible for non-experts. To make multimodal research data easily shareable and accessible to a broad audience, like researchers from diverse disciplines and all other interested people, we show how multimedia containers can support the visualization and sonification of scientific data. The use of a container format allows explorative multimodal data analyses with any multimedia player as well as streaming the data via the Internet. We prototyped this approach on two datasets, both with visualization of gaze data and one with additional sonification of EEG data. In a user study, we asked expert and non-expert users about their experience during an explorative investigation of the data. Based on their statements, our prototype implementation, and the datasets, we discuss the benefit of storing multimodal data, including the corresponding videos or images, in a single multimedia container. In conclusion, we summarize what is necessary for having multimedia containers as a standard for storing multimodal data and give an outlook on how artificial networks can be trained on such standardized containers.

1 INTRODUCTION

Multimodal data analysis applications and software are usually tailored to a single analysis task based on a specific dataset. This is because stimulus material (e.g. images and videos), metadata (e.g. object annotations and tags), along with their associated multimodal sensor data (e.g. gaze and EEG) are stored in separate files. Making things even worse, all additional data—gaze trajectories, EEG curves, emotional state descriptors, heart and respiration rates, object annotations etc.—are stored in a diversity of formats, e.g. *plain text*, XML, *MATLAB* format, or *binary*. For the purpose of making these multimodal datasets public, all files are usually compressed into a data archive. The data structures of these archives are also customized and can even be unique. For experts, the use of these data is quite cumbersome and time-consuming, as accessing, visualizing and sonifying them requires special tools. Accordingly, these datasets are very difficult or even impossible to access for the general audience.

Multimedia players can visualize and sonify data. Therefore, it is feasible to encapsulate stimulus material, with multimodal data in a standard multimedia container format, which can be then played back. A similar approach has become common practice for storing text and data, e.g., in the PDF container. State of the art video containers like the open container formats (OGG) (Xiph.org, 2016), MPEG-4 (ISO/IEC, 2003), or MKV (Matroska, 2016) can encapsulate a diversity of data formats, such that they can be interpreted as a single file by standard multimedia players and can be streamed via the Internet. In doing so, exploratory multimodal data analysis with a standard multimedia player is possible. Consequently, multi-

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modal research data become accessible to the broad audience[1].

Therefore we argue to store the complete spectrum of data:

- *stimuli* like video, images and audio,
- *metadata of the stimuli* like capturing details, object tags, subtitles, and labels,
- *additional object or scene data* like 3D descriptions, online links, scene maps, and object-object or object-scene relations, and
- *sensor data of one or several subjects* like gaze trajectories, heart rate, and EEG curves

in a single multimedia container. Establishing multimedia containers as a standard format for multimodal data will facilitate software applications in various fields, ranging from exploratory analysis tasks, to developing deep neural networks trained on both sensor and annotation data for e.g. bio-empowered face detection or multimedia communication aids for disabled people, like automatic audio scene descriptions based on a virtual viewpoints for blind persons. Furthermore, a standard format will significantly boost accessibility and shareability of these data.

Focusing on the exploratory multimodal data analysis on video and image stimuli with a standard multimedia player, this paper starts with a general section on multimedia data, followed by our proposed methods for storing multimodal data in multimedia container to provide instantaneous visualizations and sonifications in Section 3. Two datasets are introduced in Section 4. The first dataset contains short movies and single frames taken from each movie, together with the corresponding gaze trajectories of multiple observers who viewed those movies and frames in the absence of a specific task. The second data set focuses neurophysiological recordings in a real world environment. It consists of a video along with gaze trajectories and EEG data from one subject. Both datasets were converted to our proposed format. The conversion process, which leads to visualization and sonification, is described in general in Section 5. The statements and the impression from expert and non-expert users, performing explorative multimodal analysis with a multimedia player, are summarized in Section 6. Based on their statements, the converted datasets, and the conversion process, we discuss the benefits of storing multimodal data including the corresponding stimuli in a single multimedia container in Section 7. In the last section, we summarize what is necessary for having multimedia containers as a standard for storing multimodal data.

[1]cf. video demonstration https://ikw.uos.de/%7Ecv/publications/VISAPP17

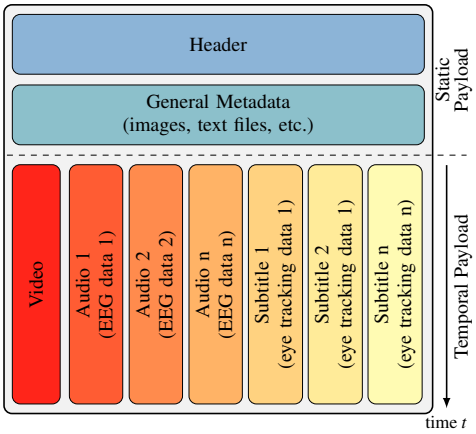


Figure 1: General data structure of a multimedia container. The header and the general metadata, which have no temporal dependencies, are stored before the data with temporal dependencies, like video, audio, subtitle, and metadata. For streaming this video, only the non-temporal data have to be transmitted before playing, while the temporal data are transmitted during playing. To encapsulate multimodal data the audio and subtitle tracks were reused to carry sensor data—marked with brackets.

2 STATE OF THE ART

Multimedia content used in the domain of entertainment (ISO/IEC, 2003; Bertellini and Reich, 2010), research (Açık et al., 2014; Vernier et al., 2016; Petrovic et al., 2005), or education (Martin et al., 2015; Rackaway, 2010) usually consists of multiple parallel tracks like video tracks, audio tracks, images, subtitle tracks, and metadata related to its content. For storage, distribution, or broadcasting of these multimedia content in the domain of entertainment, these tracks are combined into a single container. To support seeking and synchronized playback of the relevant tracks, multimedia containers have to account for the temporal nature of their payload (cf. Figure 1). In comparison to classical archival file format ZIP (PKWARE Inc., 2016) or TAR (GNU, 2016), the temporal payload handling is a major difference. For converting and packing multimodal data into a single multimedia container which is playable with any standard player, at least the temporal structure, as well as the supported data formats of the container format, must be considered. In brief: Not every payload is suited for every container. Further, various multimedia containers with their encapsulated formats are mentioned.

For *DVD*s, common multimedia containers, like the formats *VOB* and *EVO*, are based on the MPEG-PS (ISO/IEC, 1993, 2015) standard. In MPEG-4 (ISO/IEC 14496, Part 14) (ISO/IEC, 2003), the more modern MP4 format to hold video, audio and timed

text data, is specified. Though MP4 is carefully specified, it handles only the formats introduced in the other parts of this standard, like MPEG-7 (ISO/IEC, 2001), but does not conform to arbitrary video, audio and timed text formats.

The non-profit Xiph.Org (Xiph.org, 2016) foundation initiated the free OGG container format for streaming VORBIS encoded audio files. This container becomes a popular format for streaming multimedia content on the web with the ability to encapsulate *Theora* and *Dirac* video formats. Thus OGG is nowadays supported by many portable devices. The open the *Matroška* container format (MKV) (Matroska, 2016) aims at flexibility to allow for an easy inclusion of different types of payload. To establish a standard for multimedia content on the web, a reduced and more restricted version, of MKV serves as a basis for the WEBM (WebM, 2016) format.

3 MULTIMODAL DATA IN MULTIMEDIA CONTAINER

For encapsulating multimodal data which multimedia container format is best? Focusing on the specification only, the best solution is to encode all meta, object, and sensor data in accordance with the elaborate vocabulary of the MPEG-7 standard and encapsulate these encoded data as *MP4* containers. Because—unfortunately—no standard media player (like VLC, MediaPlayer, and Windows Media Player) seems to support MPEG-7, an explorative analysis of multimodal data stored in MP4 containers is not possible. To our knowledge, the MPEG-7 support in standard multimedia players is not available—this might be caused by the elaborate specification that requires considerable implementation effort.

However, to provide a solution that makes exploratory multimodal data analysis possible with standard multimedia players, and to highlight the advantages of a single multimedia container file—carrying all multimodal data—a MKV container based approached is proposed here. One advantage is that popular video players, like VLC, support this format well. The flexibility of this multimedia container format allows utilizing a wide selection of data formats, which can be used for the sonification, visualization, and storing of multimodal data. Providing sonifications, one can use common audio formats supported by MKV as WAV or MP3 and encapsulate them as an audio track. By rededicating the subtitle tracks, meaningful visualization of different data streams can be created on top the of video content. Other scientific data can be encapsulated into the MKV format, too. Thus our solution (cf. Figure 1) provides instantaneous visualization and sonification on the one hand, and all data combined in single files on the other hand. Note that all multimodal data combined in a single file can also be stored by packing them into a data archive, but that such an archive does not provide visualizations, sonifications, and is not streamable via the Internet.

Following the previous discussion (Schöning et al., 2016b, 2017) to reuse, or more precisely, on modifying an existing subtitle format for incorporating visualization of sensor data like gaze trajectories, two kinds of multimedia container prototypes were implemented. The first is based on the *Universal Subtitle Format* (USF) (Paris et al., 2016) and losslessly encapsulates the complete sensor data for visualization. However, for using this approach a slightly modified version of the VLC media player is needed[2]. The second is based on the *Advanced Sub Station Alpha* (ASS) (SSA v4.00+, 2016) format and is only able to carry selected sensor data like viewpoints, which can be visualized by most current media players.

3.1 Sensory Data as *USF*

To use USF for encapsulating sensor data, we analyzed which features of USF are made available in the latest releases of common multimedia players. The current version 3.0.0 of VLC already supports a several of USF attributes (cf. Listing 1), which are *text*, *image*, *karaoke* and *comment*. The latest USF specification introduces an additional attribute *shape*. Note, the specification is still marked as under development, although the last modifications happened seven years ago. Since almost every visualization can be created out of simple geometric shapes, like ellipses and polygons, the use of the *shape* attributes for instantaneous visualization is appropriate.

Since the exact specification of the *shape* attribute is, as mentioned, not complete, we extended it with respect to rectangles, polygons, and points, as marked in Listing 1. These simple geometric shapes were taken as first components to visualize a multitude of different types of elements. Point-like visualizations are useful to describe locations without area information, e.g., for gaze position analysis in eye tracking studies. Rectangles are most commonly used for bounding box object of interest annotations. In contrast, polygons provide a more accurate, but complex way of describing the contour of an object.

The visualization of USF data is handled by VLC in a codec module. This codec module receives

[2]source code, software tools and datasets can be downloaded from the project homepage cf. [1]

streams of the subtitle data for the current frame from the demuxer of VLC. We extended this module with additional parsing capabilities for our specified shape data[2], which is then drawn into the so-called *subpictures* and passed on to the actual renderer of VLC. Since the thread will be called for every frame, the implementation is time-critical, and we decided to use the fast rasterization algorithms of Bresenham (1965). Additionally, we added an option to fill the shapes, which is implemented with the scan line algorithm (Wylie et al., 1967). In the course of this project, an open source software[2] is developed which converts time-depended sensor data files of several subjects to USF files and encapsulate them together with the original video in a single MKV file.

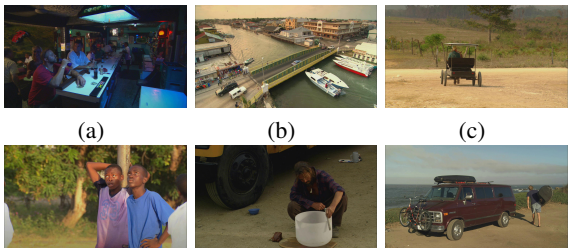
Listing 1: Section of the USF specification (Paris et al., 2016), * marked attributes are added to the specification and implemented in our altered VLC player.

```
...
<subtitle                    +-subtitle     (1..N)
 start="hh:mm:ss.mmm"          @-start      (1)
 stop="hh:mm:ss.mmm"           @-stop       (0..1)
 duration="hh:mm:ss.mmm"       @-duration   (0..1)
 type="SubtitleType">          @-Type       (0..1)
 <text></text>                +-text        (0..N)
 <image></image>              +-image       (0..N)
 <karaoke></karaoke>          +-karaoke     (0..N)
 <shape>                      +-shape       (0..N)*
   <polygon>                   +-polygon    (0..N)*
     <points                    +-points    (2..N)*
       posx="x"                   @-pos x   (1)*
       posy="y" />                @-pos y   (1)*
   </polygon>
   <rectangle                  +-rectangle  (0..N)*
    posx="x"                     @-pos x    (1)*
    posy="y"                     @-pos y    (1)*
    width="width"                @-width    (1)*
    height="height" />           @-height   (1)*
   <point                      +-point      (0..N)*
    posx="x"                     @-pos. x   (1)*
    posy="y"                     @-pos. y   (1)*
    diameter="diameter" />       @-diameter (1)*
 </shape>
 <comment></comment>          +-comment     (0..N)
</subtitle>
...
```

3.2 Sensory Data as *ASS*

Since our extensions in USF require a modified version of the VLC media player, the broad audience is still excluded from watching the visualizations. Therefore, we provide a prototype multimedia container based on ASS subtitles as it already supports geometric drawing commands. In contrast to USF, the ASS subtitle format cannot carry all desired data as it is, is not capable of representing complex data structures, and does not account for non-visualizable content like non-frame based elements.

From our USF files of the data, one can generate ASS files using extensible stylesheet language transformations with a simple translation stylesheet[2]. After the conversion, a MKV container can be packed in the same manner as with USF. The resulting container with ASS visualizations makes the multimodal data accessible for a broad audience, as many unmodified players can display these visualizations.



(a) (b) (c) (d) (e) (f)

Figure 2: Example frames from the movie and frame dataset— (a) bar scene, multiple persons moving, some egomotion; (b) bridge, several objects with linear motion; (c) cart ride, slow continuous movement; (d) street basketball, moving and still persons; (e) musician, slow circular motion; (f) demounting surfboard, object interaction.

4 DATASETS

For demonstrating that multimodal analysis can be done with a standard multimedia player, we used one existing dataset and introduced a new, unpublished dataset preview along with this work. All scientific data—here eye tracking raw data, EEG data, stills, video stimuli, etc.—are encoded in our proposed MKV based container format.

4.1 Movie and Frame Dataset

This dataset, presented in Açık et al. (2014), consists of 216 movie clips featuring a single continuous shot. The clips were taken from two commercial *DVD*s, Highway One and Belize both from the Colourful Planet collection (Telepool Media GmbH, 2014). The clips had a duration range of 0.8*s* to 15.4*s*. Moreover, from each movie clip the median frame was taken to serve as a still image to be presented with a duration equaling the length of the corresponding clip. Some of the frames are displayed in Figure 2. These 532 stimuli (216 movies and 216 frames) were shown in random order to human observers (median age 25) while their eye position was recorded with an Eyelink II eye tracker at a sampling rate of 500Hz. There was

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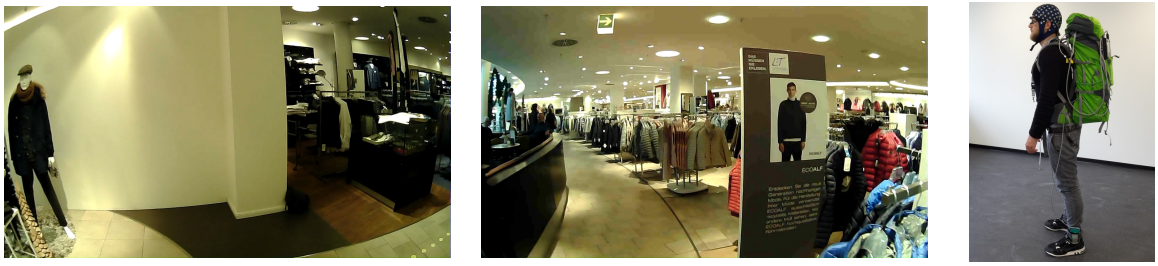


(a) (b) (c)

Figure 3: Real World Visual Processing example of one subject. (a) first frame, starting point of the subject; (b) last frame, end point reached; (c) Picture showing the working recording setup using EEG, eyetracking, worldcam and step-sensor.

no explicit task, and the sole instruction given was to observers was to "study the images and videos carefully". Here we use representative examples of the movies and frames together with the eye data taken from single observers.

4.2 Real World Visual Processing Dataset

These data are part of a larger data set, investigating electrophysiological markers during free navigation in a complex, real-world environment. Participants freely moved and inspected objects in the environment. No other task was given to the subject. Together with 128 channel EEG, the recording includes two custom-made, pressure-sensitive foot sensors, eye tracking data and a scene camera capturing the visual input (cf. Figure 3). EEG data was recorded at 1024Hz, eye tracking data was recorded at around 100Hz, and the world camera recorded at 60Hz. Frames taken from the world camera showing the environment and the complete experimental setup are presented in Figure 3.

5 PROTOTYPES

The datasets, mentioned above, are used for prototyping. For providing instantaneous meaningful visualizations and sonification, one has to define which attribute of the scientific payload should be used. After that, one can build the multimedia with these data. In the following, we describe an example of how one could create visualizations as well as sonifications, how these are mixed into the MKV and finally how non-experts and experts can use these multimedia containers.

5.1 Visualization of Data

No matter which subtitle format—ASS or USF—one uses for encoding the visualization of sensor data, one has to select which data attributes are to be visualized and in what way. All datasets introduced in Section 4 provide gaze data, which need to be visualized for prototyping. As data attributes to be visualized, we select the subjects gaze position as viewpoint on the video, their pupil size, and fixations.

Using our open source dataset to USF converter introduced above, we encode the gaze position as *point*, where the viewpoints on the video correspond to *x* and *y* attribute of *point*. Using the *diameter* attribute, we visualize the pupil size relative to the average pupil size of the subject. A visualization of the absolute pupil size will, due to individual size variations between subject, not be meaningful in our opinion. Fixations are visualized as squares using the *rectangle* shape. The square's center corresponds to the point of fixation on the video and width corresponds to the pupil size. Due to the usually higher sampling rates of the eye trackers compared to the frames per second of videos, more than one viewpoint is visualized per frame, as shown in Figure 4.

The original data content is stored as *comment* within the USF file. Note, as described in Section 3, once the visualization is done in the USF, it can be easily converted to ASS.

5.2 Sonification of Data

To extract the alpha rhythm from the raw EEG data, we chose a parietal-occipital electrode (PO3) and those samples that corresponded to the corresponding frames of the video (61440 samples). Afterward, the raw signal was band-pass filtered to incorporate the respective frequency band ($8-13$Hz). We used a FIR filter with a Hamming window of 1690 samples. To calculate the power of the resulting filtered signal, the absolute of the Hilbert transformed data was



(a) (b)

Figure 4: Visualized gaze data by a reused subtitle track on a video by a standard multimedia player. The gaze position on the frames is visualized by a red circle with its diameter depending on the relative pupil size. Squares visualize fixations. In this example, the sampling rate of the eye tracker is higher than the frame rate of the video. Thus multiple points and squares are shown.

squared (Cohen, 2014). The resulting signal represents the alpha power with respect to the onset of the video. All preprocessing of the EEG data was done in EEGlab (Delorme and Makeig, 2004).

We generated the audio signal using *MATLAB* (The MathWorks Inc., 2014). To sonify the resulting alpha power, two different approaches were taken. For the frequency modulation, a carrier frequency of 220Hz—corresponding to note a—was modulated in its frequency by the power of the alpha signal. For the volume modulation, the same carrier frequency was modulated in its power with respect to the alpha power, with a louder tone meaning a stronger power. The resulting audio streams were exported as WAV files.

5.3 Creating the *MKV* Container

Creating, or more precisely muxing, a MKV container is quite easy and can be done with the command line or with the graphical user interface version of *mkvmerge* (MKVToolNix, 2016). Due to the rededicated subtitle formats for the visualizations, all visualizations are muxed as subtitle tracks, the sonifications are muxed as audio tracks, and the video or image stimuli are muxed as video track. As seen in the track selection of Figure 5, any other data corresponding to the multimodal data, like the raw data, for detailed scientific analysis are muxed as an attachment to the MKV file. In consequence, the whole data set is archived in one single file, but in contrast to a data archive, it can be inspected without compiling or writing any tool.

5.4 Using the *MKV* Container

The usage of multimodal data presented in a multimedia container is quite intuitive, as it uses the same user interface metaphors known from entertainment content. Hence, the user can change the visualizations like subtitles as well as the sonifications like audio languages, shown in Figure 6(a) and (b). Besides this, the user can use built-in visualizations tools of the media player to enhance the representation of sonified content (cf. Figure 6(c)). For the expert use, one can extract all data using *mkvextract* (MKVToolNix, 2016) as illustrated in Figure 5.

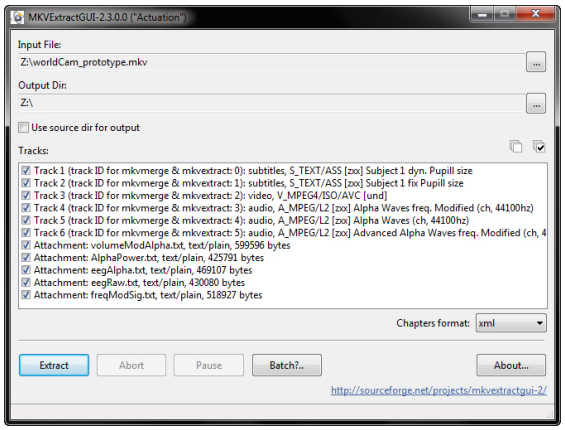


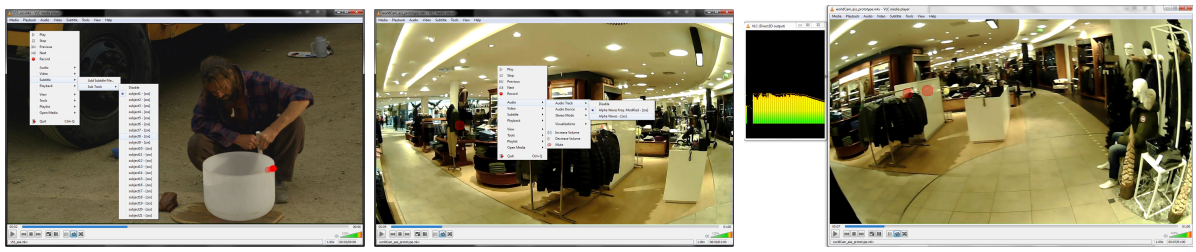
Figure 5: Demuxing a MKV file, an option for an expert to extract the raw data for intensive research. In the track select, one can see the tracks for instantaneous visualization (video and subtitle tracks), sonification (audio tracks) and the attachment (general metadata) carrying the raw data.

6 USER STUDY

Is multimodal analysis possible with a standard multimedia player by the use of our multimedia containers? To answer this, we asked one expert and two non-experts in the field of multimodal analysis to exploratively investigate these datasets. The major points of their feedback are mentioned below and discussed in the next section.

6.1 Professionals

The first response of the expert to this multimodal data in a multimedia container was “It’s a beautiful approach because one gets a first expression of the data without the need to run any scripts or install a special player”. The expert considers the exploration of unprocessed data highly useful for several reasons. First, it allows a plausibility check of the data. Experimental setups are highly complex and mistakes, for example in alignment of reference frames or synchronization, might otherwise go undetected. Second, standard statistical testing often concentrates on low dimensional subspaces with strong assumptions regarding the underlying statistical properties of com-



(a) (b) (c)

Figure 6: Exploratory analysis with VLC. (a) one can change the visualizations, here the eye tracking, like subtitles; (b) one can change the sonification like audio languages; (c) example of sonification. The operator can hear the alpha wave, here visualized by VLC's spectrometer.

plex data. Here the visualization and sonification of high-dimensional data sets is an important tool. Third, presently the investigation of human sensorimotor interaction under realistic conditions in natural environments is largely exploratory (Einhäuser and König, 2010; Einhäuser et al., 2007). For these circumstances, the multimodal analysis for the complex experimental settings is an invaluable tool and guides the development of explicit hypotheses.

6.2 General Audience

The non-expert users highly appreciated the easy and interactive demonstration of multimodal data. They were less interested in complex statistical evaluation of the data set, but in the generation of a qualitative look and feel for the data. Furthermore, it "brought to live" the data and improved understanding of a quantitative evaluation. Finally, it served as a helpful backdrop and means of communication for discussion and the exchange of ideas. Here, the interactive nature of data exploration was instrumental. In summary, the ease of use lowered thresholds to get in close contact with the data and fostered fruitful discussions.

7 DISCUSSION

Multimodal data, in general, is hard to analyze but an instantaneous visualization makes selected data comprehensible to the broad audience, which is in our opinion, the main advantage of our proposed approach of storing them in multimedia containers. Experts might argue that the broad audience is not capable of formulating the correct assumption from the data. We, in contrast, think that the broad audience will understand and agree on assumptions easily if they can explore the data by themselves. Further, only selected data and attributes can be visualized or sonified. Thus, a careful selection by experts must be made to ensure an objective representation of the multimodal dataset.

8 CONCLUSIONS

The importance of multimodal datasets in combination with video and image stimuli as well as their fields of applications will significantly increase if they are distributed in multimedia containers, as suggested. Thereby exploratory analysis with common multimedia players with their well-known user metaphors is realized and can be performed by both experts and non-experts. As a result, the datasets become accessible to the broad audience. The conversion of multimedia data into the proposed MKV multimedia container is quite simple as shown in this work. The converted dataset is a single, streamable file which still contains all necessary raw data for a detailed analysis by experts. In a user study, datasets in the proposed format received almost only positive feedback. For promoting multimedia containers as a standard for storing, sharing, representing and using multimodal data, we published the datasets in our format and all conversion tools developed in this project[2].

In case a significant amount of multimodal dataset are stored in such standardized format, new fields of applications can be covered. One of these areas is cognitive learning using artificial neuronal networks (ANN). Therefore different kinds of ANNs could be trained on a specific task like visual search or face recognition with both kind of data: the stimuli and the human response. Such training data will lead to bio-inspired ANNs which help improve current applications or explain patterns in humans brain by mimic human-like sensory input. In further work, we are planning to extend the collection of available multimodal datasets for realizing semantic segmentation by ANNs.

In conclusion, we believe that the datasets pro-

vided, shared, visualized and sonified in such a way will facilitate, besides analysis tasks, applications in various fields, ranging from sensor improved computer vision (Schöning et al., 2016a), over communication aids in movies for disabled people, to neural networks with human-like multimodal sensor input.

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