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# FORENSIC ANALYSIS OF VIDEO FILE CONTAINERS

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*To myself.*

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# Abstract

# Introduction

In an increasingly digital world, there are more and more applications where digital contents play a significant role.

Thanks to the spread of smartphones and digital cameras, the use of social networks that allow the sharing of digital images and videos is becoming more widespread. These resources, in general, contain information of personal nature; however, since these images and videos are more and more permeating our lives, their content may include information about an event that has occurred and therefore represents a significant source of evidence about a crime that can be used during an investigation.

In this context, many techniques for the analysis of multimedia content have been developed; these methods pose the goal of providing aid in making decisions about a crime so that a digital resource can be legitimately used as evidence in a courtroom.

Such is the task of the Forensic Analysis and in particular of Multimedia Forensics, i.e. to develop and apply techniques that allow, with a certain degree of accuracy, to determine whether the content of a digital resource is authentic or if it has been manipulated.

The questions that the Forensic Analyst must answer about these digital contents are:

- authenticity assessment, or whether what they represent is true and correspond to reality.
- integrity verification, or if they have been altered in such a way that does not compromise their authenticity.

- the determination of the acquisition device, a problem that in Forensic Analysis takes the name of Source Classification or Source Identification.

To give a better understanding of these problems, we provide some application scenarios.

Regarding the Source Identification, imagine a situation in which the very act of creation of an image or video constitutes a crime, due to the content of the digital resource. In this scenario, it is crucial to establish the source device that generated the offending resource, so that this resource can be used as evidence. Depending on the context, determine the origin of a digital content could mean to find the particular acquisition device or the typology of the acquisition device or establish the last processing stage, such as a compression algorithm or an editing step.

In this context, it is also important the integrity check of a digital resource. In fact, the owner of the device that created the offending digital content could change the resource in such a way that it's not possible to trace back its source.

A more particular scenario, regarding the authenticity of a multimedia resource, is when the digital content is changed so as to deceive those who are watching it. The reasons for this manipulation can be different, such as the exaggeration or limitation of the severity of an accident or disaster, as well to change the context of the situation represented.

The tools available to the Multimedia Forensics are only those that can be extracted from the digital content itself. In fact, the fundamental idea of forensic analysis of digital content is based on the observation that both the acquisition process and the post-processing step leave traces, called digital fingerprints. It is the task of the Forensic Analyst to analyze these fingerprints to determine the history and the authenticity of a digital content so that it can be used as evidence in a digital investigation.

In this regard, the analysis techniques of digital content mainly focused on two approaches. The first is the analysis of the data stream, i.e. the audio-visual

signal, which is based on the research of artifacts and inconsistency in the digital content. The second is the analysis of the metadata, i.e. the determination of their compatibility, completeness, and consistency [9] with regards to the context in which it is assumed the resource has been created.

Digital Image Forensics has extensively treated the presented issues; instead, regarding the Digital Video Forensics, the research for these problems is still under study and improvement. The motivation for this discrepancy lies in the much easier way that an image can be falsified than a digital video and the several video formats (MPEG, MPEG2, H26x, VP8, etc.) in contrast to the few main formats for digital images (mostly JPEG, PNG, TIFF).

This thesis proposes a technique for forensic analysis of digital video based on *Gloe et al.* [6], whose work focuses on the study of some video formats standard and the use of the internal structure of the video file container as a tool for the forensic analysis. This choice is justified by the fact that the video file container is very fragile so that it can contain a lot of information about the history of a digital video. Both the acquisition phase and the subsequent post-processing steps or the editing of the file using various tools, modify the content and the structure of the container. This fact can be exploited both regarding Source Identification and Integrity Verification.

The thesis is divided into chapters as follows. Chapter 1 provides an introduction to Multimedia Forensics, discussing both the state of the art techniques and the standards to be followed in all aspects of a digital investigation; it also explained in greater detail the work done by *Gloe et al.* [6], giving more information on video file containers. Chapter 2 will describe in detail the structure of the video file containers for MP4-like formats. In Chapter 3, it is presented the proposed approach along with all the choices made and the details of the implemented tool. Finally, Chapter 4 will show the dataset used and explain the motivation and the organization of the experiments along with a discussion of the results obtained.



# Chapter 1

## State of the Art

### 1.1 Introduction to Multimedia Forensics

With the increasing spread of digital audio and video content, the analysis of these multimedia objects is rapidly assuming importance in the context of digital investigations, which consider both digital data and digital devices.

In digital investigations, multimedia content such as images, audio, and video are more and more being used as forensic evidence. It is, therefore, crucial to be able to extract information from such content in a reliable manner.

Multimedia Forensics has the aim to gain knowledge on a multimedia content life cycle exploiting the traces that the various processing steps leave on the data. In fact, the idea behind Multimedia Forensics is that each acquisition device and each processing operation on a digital resource leave on the media content data some traces, often called fingerprints, which characterize its history.

Many algorithms and techniques have been developed by the scientific community based on the extraction of features from the stream of audio-visual data of the multimedia content. By taking advantage of these features, such techniques try to infer information about the source/acquisition device and about which encoding and editing processes the digital resource was subject to during its life cycle. Specifically for multimedia content such as images and videos, the main approaches set themselves the goal to identify the source of digital resource and to determine if the content is authentic or has been modified from its orig-

inal without any a priori information about the content under analysis. This examination is possible using just these features and tools that allow checking for the presence or absence of such features or fingerprints that are intrinsically linked to the multimedia data by the acquisition device, the encoding step, and any post-processing or editing software tools. In fact, we can distinguish three types of traces left on a multimedia content: acquisition traces, encoding traces, and editing traces.

As explained, from a scientific point of view, research has produced a large number of techniques for the analysis of multimedia content. From the point of view of the application of such methods in the courtroom, however, there is still a significant gap. This gap is probably due to a lack of communication between the legal side and the scientific side, as well as a not full maturity of the techniques that are often based on results obtained in laboratory contexts a not in real-world scenarios.

Also, there is the need for greater sharing of standard in the field of digital multimedia forensics investigations that aid Multimedia Forensics to grow and reach maturity.

Several communities and groups have worked to put together guidelines and standard on important aspects of digital investigations, such as the chain of custody, data authentication, application of the scientific method, documentation, and reporting. The ISO/IEC JTC1 Working Group 4 is one of those groups that seek to give international standards whose primary purpose is to promote the best procedures and methods for the investigation of digital evidence. It also encourages the adoption of approaches for the forensic analysis of multimedia content that are shared at an international level, in order to ease the comparison and the combination of results from different entities and organizations and also through various jurisdictions, so as to increase the reliability of such methods and the results.

Another group that aims at giving standards and guidelines for the digital

investigations is the Scientific Working Group on Digital Evidence (SWGE) that deals with getting in contact different organizations that work in the field of Multimedia Forensics to promote communication and cooperation and to ensure higher quality and consistency within the forensic community.

The Scientific Working Group on Imaging Technologies (SWGIT), instead, focuses his work on image analysis technology and has the aim to facilitate the integration of such methods of analysis of images in the context of the judicial system. In fact, it provides best practices and guidelines for the acquisition, storage, processing, analysis, transmission, output image and archive of digital evidence.

Regarding the forensic analysis of images and videos, the process is defined to be composed of three main tasks: technical preparation, examination, interpretation. The technical preparation is concerned with all those operations necessary to prepare videos and images to the other tasks. The examination is the main part of the forensic analysis and deals with the application of techniques that aim to extract information from images/videos. The interpretation concerns the analysis of digital content from experts in order to provide conclusions on the features extracted from the images/videos under examination.

In this context, it becomes essential the figure of the Forensic Analyst, i.e. one who can develop and apply these methods for the analysis of digital content, interpret the results and make a summary of the results from different techniques to increase the reliability of the conclusions. It is also able to perform all of the analysis tasks following the standards shared by the forensic community. The Forensic Analyst can find the traces left on the multimedia data and acquire information on the object under examination such as who is the source/acquisition device, whether the content is authentic and if the resource is intact, and so on.

### **1.1.1 Applications**

The major applications for forensic analysis are source identification, authentication assessment, and integrity verification of multimedia resources.

The source identification process has as objective the retrieval of information about the device of origin that generated the multimedia content under examination. It is possible to identify the source at various levels of detail. For example, sometimes it is possible to distinguish between types of sources or to make a distinction between different models of the same kind of source or between the various devices that belongs to the same type and model.

The authentication problem has to do with the task of determining whether the multimedia content is an accurate representation of an original event. The analysis process is typically base on finding inconsistency in the features extracted from the audio-visual signal.

The integrity problem concerns the task of determining whether a multimedia content has been changed or not from the moment that the acquisition device has created it. The analysis is based on the search for traces left by the editing tool or post-processing step during the life cycle that are not compatible with the source device that, for this application, is known.

### **1.1.2 Tools**

Multimedia files can be viewed as a package composed of two main parts: the header, which contains the metadata, i.e. the information about the contents of the file; the content itself, i.e. the data stream which forms the audio-visual signal. In general, the feature extraction is based on the analysis of traces left on both the actual data and the metadata of the multimedia file.

As for the inspection of the data stream, specifically for images and videos, the examination consists of two most important aspects:

- interpretation of the content, which is the analysis of the context to un-

derstand what the data represents, who are the subjects and the objects involved, what is the environment. In general, the goal is to retrieve all the information that can be extrapolated from human observation.

- identification of sensitive details from the scene represented, such as audio-visual anomalies, the direction of the light, shadows, perspective inconsistencies, smudge marks, and so on.

Also in the context of the inspection of the audio-visual signal, a useful technique is to enhance the content, such as the improvement of the signal to detect relevant details or objects, the extraction of dimensional relationships between subjects and objects, the visual comparison between known objects and objects represented in the scene.

The other tool regards the extraction and analysis of the metadata. Metadata can be easily extracted and can contain a lot of information regarding the data stream such as source device, color space, resolution, compression parameters, date, GPS coordinates, frame rate, format tags, bitrate, sample rate, the number of channels. Obviously, the type and the number of metadata depends on the type of the file under examination and which processes have undergone during its life cycle. Once the metadata is obtained, it is the Forensic Analyst work to verify the compatibility, the completeness, and the consistency [9] of this information with regards to the context in which it is known or assumed the resource come from. In fact, metadata might be different if a digital resource originates from a social network rather than directly from the acquisition device.

## 1.2 Forensic Analysis of Video File Container

### 1.2.1 *Video File Containers*

The forensic analysis has focused mainly its attention on the analysis of images developing techniques that used either the data stream, the metadata, or both.

Regarding the latter, JPEG [1] and EXIF [4] metadata have become very used. Since each acquisition device and processing software use their customized quantization tables, given an image, it is possible to exploit the difference to limit the search of the origin [5]. Also, by considering the number of EXIF entries and the compression parameters, *Kee et al.* [7] associates images whose origin is not known to a certain class of source device. The forensic analysis of digital videos is currently more and more relevant. Early work has followed procedures similar to the ones used for the images, exploiting artifact and inconsistency in the data stream and examining the information extrapolated from the metadata. However, regarding the use of metadata especially for the identification of digital sources, there are concerns over falsifiability. In fact, it is just a matter of finding the right software tools, often publicly available, to easily edit high-level information such as Exif metadata. However, the known processing software and metadata editors, both for images and videos, do not have a functionality to modify low-level information, such as the internal order of the core file structures. These characteristics are thus extremely valuable and offer a higher reliability than standard metadata information.

The work of *Gloe et al.* [6] expands this idea to the video forensics by exploiting this low-level characteristic using metadata and file format information such as video file container. By identifying specific manufacturer and model characteristics, as well as traces left by processing or editing software, it is possible to assess the authenticity or the integrity of a video and to identify its origin, in terms of a particular device or a type of devices.

*Gloe et al.* [6] noticed that the video format standards for the data container formats prescribe only a limited number of features, thus leaving a lot of freedom to the manufacturer. The Forensic Analyst can exploit this fact as a resource, given a video, to identify the source and to assess its authenticity or its integrity.

As well as for the JPEG and EXIF low-level characteristic, the known tools do not allow you to change the video file containers since they are a core file

structure. For this reason, these low-level features reduce the concerns about the falsifiability of such information as only for a subject in possess of advanced programming skills will be able to modify the internal structure and content of video file containers. Even in this scenario, it would still be very complex to preserve consistency amongst all of the metadata information, thus making the operation of falsifiability not trivial even for a highly technical figure.

*Gloe et al.* [6] explores in details both the AVI [8] and the MP4-like file formats. Digital cameras mainly use the AVI video stream. This thesis focused its work on the analysis of video generated by mobile phones; thus, we will give a brief overview of only the MP4-like file containers structure and the ways its characteristics can be exploited for digital forensics purposes. An explanation in great details about the structure and content of file containers of MP4-like formats will be given in Chapter 2.

Apple introduced the MOV [3] container format in 1991. Using this format as a basis, the MP4 [2] and 3GP formats have also been created. This group of file formats will be referred to as MP4-like file formats.

The video file containers of this formats are composed of atoms (sometimes called boxes) that are identified by a unique 4 bytes characters, preceded by the size of the atom. These atoms can have fields and can be nested, i.e. an atom may contain another atom. Thus, four types of atoms can be encounter:

- atoms without fields and that do not contain other atoms.
- atoms without fields but that contain other atoms.
- atoms with fields that do not contain other atoms.
- atoms with fields that also contain other atoms.

The most typical structure of the MP4-like containers is as follows:

- *ftyp* atom: it is semi-mandatory, i.e. the latest ISO standards expect it to be present and to be explicit as soon as possible in the file container.

It refers to the specific file types with which the video file, to which the container belongs, is compatible.

- *mdat* atom: it contains the data stream and specifies its size.
- *moov* atom: it is the atom with the most complex structure of the container. It is a nested atom which contains many other atoms. In this atom, and in its sub-structure, is included the metadata needed for the decoding of the data stream contained in the *mdat* atom.

This structure is not always respected. The file container of the MP4-like formats are very complex and have many elements and differences that depend on the source and the manufacturing company; thus it can constitute a valuable tool for the Forensic Analysis. The differences of containers across multiple types of video files can be found in many ways, as explained as follows:

- the relative position of the atoms: although the standard gives specifications about the location of specific atoms (especially the main ones described above), these indications are not always respected. Above all, there is a change in position for those atoms whose position is not specified but the standard. This fact is true both at the first level of the container, which contains atoms such as *ftyp*, *mdata*, *moov*, and both concerning the atoms of the sub-structure contained in the *moov* atom.
- the presence of additional non-standard atoms at all level of the container.
- the differences in the fields values of the atoms.

All these possible differences and types of differences give rise to a large set of combinations that the Forensic Analyst can use to analyze a digital video resource.



### ***1.2.2 Applications for Video File Container***

The problem of the authentication is based on the analysis of the audio-visual signal to determine if the data is an actual represents of an original event. Thus, it is not in our domain because video file containers are treated as metadata. With metadata, you can not assess anything about the events represented in a video.

The integrity problem, instead, can be dealt with. As described above, the container of a video file is the container created by the last tool during the file lifecycle. If a video is also slightly modified by software, it will have its own container. This container may contain additional atoms or change the positions and the fields values of the other atoms compared to the file container of the video before it was processed. Therefore, if the file container content and structure of an acquisition device is known, it is possible to compare the container of the query video file with the container of a reference video file (i.e. a video generated by the known or assumed acquisition device). This way it is possible to verify the integrity of the query video file, i.e. whether the file, during the time between its generation from the source device and the present, has been modified or not.

The problem of the source classification makes sense because, since the standards define only a few mandatory features for the file container, the manufacturing companies are left with a lot of freedom. This space for interpretation means that every class of device will have its own different container structure and values. This fact can be used to construct a set of features to distinguish between devices. For examples, in the case of video created by smartphones, it can be used to determine the belonging of a video to a brand, or to a specific brand and model, or to a specific brand, model, and operating system. It becomes necessary to find a way to represent the various classes in a training set properly. Besides, a compatibility measure must be defined to compute the likelihood of a query container to belong to a particular class of devices.

The proposed approach in this thesis will do just that, giving all the theory and the necessary information of how to implement a pipeline to solve the integrity and the source identification problem of a video file using its file container.

## Chapter 2

# Video File Containers

# Chapter 3

## Proposed Approach

### 3.1 Overview

The application is the source identification, i.e. given a video we want to determine its origin. From which devices, services, platform program the video come from? Since the file container structure has a degree of arbitrariness, it has characteristics that can be used to identify the source.

For each of the origins, or classes, of interest, we ask a binary question, namely: does that video come from the source X? The answer must be a likelihood, measured in same way, that will express the degree to which the video belongs to that class; then, thresholding appropriately the likelihood, it will be possible to respond to the binary question. For each question, two queries in the training dataset are made: we take a set of videos that we know belong to the class object of the question, i.e. for which the answer to the binary question will be true, and a complementary set of videos that we know do not belong to the class under examination, i.e. for which the answer is false.

Ground truth is then divided into these two sets. Then, we merge all the file containers in a single XML file so that it contains all atoms and all possible values of the attributes of two sets. During the merge, the weight vector is initialized in the attribute string; each time a value is found, it set to zero its weight in the weights vector. When we find the same weight several times its weight increases, modulated by the total number of videos of the set. This

computation serves to calculate the discriminative power of each attribute for the two classes.

At this point, given a video query as input, we want to determine its class, i.e. its source device. By looking at the values of its attributes for both classes, for each of these attributes we compute the ratio of the weights associated with that value in the two sets. The numerator represents the set that responds to true and the denominator the set that returns false. This ratio has a maximum of 1 and a minimum of zero excluded (see details). The ratios of all the attributes are then multiplied (which is why it cannot be zero). The more this product is greater than 1, the more the video is sure to belong to the set that responds true; the more it is less than 1, the more the video is sure to belong to the set that answers false.

## 3.2 Video Format Tool

### 3.2.1 *Functional Requirements*

In order to use the file containers as video analysis tools, we have implemented a program that allows extracting the file containers from an input video. This program also presents various other features implemented both as low-level functions, to use a simple Java library, and as high-level functions, used as interfaces for the command-line program.

The implemented features are:

- Parse: given input MP4-like format video file (MP4 and MOV), it extracts the file container using the library Mp4Parser and it saves it in an XML file.
- Batch parse: given as input a folder of video files, it parses all the videos in the folder and sub-folder, saving them by recreating the same folder structure.

- Draw: it is used to draw in a window a tree, given an XML file as input that represents a video file container.
- Merge: given two XML input files, it combines them into a single XML file. By taking one as the base for the merge, it adds to it the atoms that only the other XML file has; also, for atoms that are in common, it considers the attributes and, by looking at their values, it adds them to the base XML files, so that for each attributes we will have a vector of values.
- Update: it is an advanced method to use the merge. Instead of giving two XML files as input, it takes a folder that contains XML files and merges them into a single XML as explained above. It also considers sub-folders.
- Compare: given two XML files, it compares them and it returns a measure of how similar they are.

### 3.2.2 *Implementation*

During the development of the application, we have made several implementation choices. In the following, it will be described the reason behind them, in addition to further details. The features that will be explained are only the main ones: parse, merge and appear:

- Parse: the parse feature uses the *Mp4Parser* library (cita), Java API to read, write and create MP4 files-like. The high-level function is *parse()*, which is used as an interface function for the command-line tool. It takes two input strings, the URL of the video file to parse and the path of the output directory where to save the created XML file. It works to make the setup for the operation, it calls the low-level *parser()* function and it saves the extracted container in an XML file.

The *parser()* function is what create the file container. It takes as input the ISO file of the video that we want to parse, extracted using the *Mp4Parser* library. This function creates the root of the XML file (org.dom) and instantiates an object of class *BoxParser*. This class is responsible for reading the ISO file recursively to extract all the atoms and their attributes. In fact, as explained above, the atoms have a nested structure. *BoxParser* implements a recursive function called *getBoxes()*. This work takes as input an *AbstractContainerBox* and an *Element* (jdom). The first parameter is passed as null in the first *parser()* call and the second is the root element created in the *parser()*.

The *getBoxes()* function reads the ISO file (passed in the constructor of *BoxParser*) and extracts atoms recursively. Initially, the *AbstractContainerBox* is initialized to null, so the first time the atoms are obtained directly from the ISO files; these are the top-level atoms (ftyp, moov, mdat, etc.). In general, for each atom the children are extracted. It cycles on the children and, according to their 4-byte code represented by a 4-character string, it calls the right parser for that atom which can extract its attributes. Such "parser" is implemented as a *Wrapper* interface that requires only a *toString()* method. The wrappers implemented, in fact, call the get functions of the particular atom classes and build a string that forms the list of attributes and their value for a given atom. An attribute that has been artificially inserted in the implementation in all the atoms is the *count* attribute with a fixed value to 0, which will subsequently be used only to verify if an atom is present or not.

For unrecognized atoms, or for atoms for which it is not recognized the name of 4 characters, it is handled by a default wrapper; the task of such wrappers is limited only to insert the attribute count. You can always extend the number of supported atoms, merely implementing a new dedicated wrapper.

Once the atoms and the attributes are extracted, it is created XML element with the name equal to the 4-byte code and the attributes of the atom are set as a correspondent XML element attributes. At this point, if the atom has children, it is passed to the *parser()* function, continuing the recursion. When the recursion reaches the end for a certain atom, the XML element is added to the root, which each time will be the XML element that had been passed in the recursion, up to the actual root. At this point, the ISO file parsing the video file is complete and the *parser()* function has a root *Element* that contains the file container represented as XML files. The *parse()* function will save it to disk.

Some implementation details: - To consider the position of the atoms in the container, a variable that assigns a number to each atom child is used, so as to assign an ordering to these children. This numbering is done so that it can be recognized the difference in position between atoms of two videos. The moov atom XML will no longer match the tag XML *moov* but for example *moov-2*. Two atoms *moov* in a different position in the container are considered completely different and help significantly in the discrimination of video files using the file containers. - The position of the attributes of atoms is not considered. Whether it exploited the *toString()* function of *Mp4Parser* library or the one implemented in the *Wrappers*, the order of attributes is still arbitrarily decided by either one of these two proxies and has nothing to do with the choice of the manufacturer as is the case for the order of the atoms.

- Merge: this feature combines two XML files which represent the file containers. It will be used later during the training phase.

Given two XML file as inputs, the first is taken as the basis. The second is explored recursively and each atom is checked whether it is present or not in the base file. If it is present in both, it proceeds to compare the



values of the attributes. If in the second file, it is found a different value for an attribute, it is added to the base file, and then creating a vector of values for that attribute. Along with a vector of values for each attribute, it is create a vector of weights, initialized to zero, the size same as the first vector. If it is not present, the atom of the second file is added to the base file along with its attributes.

The procedure then proceeds recursively, like in the parse feature. Since the merge produces an XML file as output, the merge can be done using an XML file of a video and the XML file produce as output by a previous merge. The only differences is that when will compare the values of the attributes, it will not have to check if the value is different, but rather if the value of the attribute for the second XML file is present in the vector of values for that attribute in the base file.

- Compare: this feature serves to compare two XML files and give a measure of the difference of file containers they represent. The practical application is the Integrity Verification, i.e. determine whether the video is intact, in particular if its file container has not been altered after the acquisition device created it.

To compare two XML files, one is chosen as a reference and the other as a query. In theory, for the reference it is constructed a vector of size equal to the number of elements that can be different, namely all the attributes of all the atoms (for the atoms without attributes it will be considered only the count attribute). The elements of this vector are ideally initialized to 1. For the query is initialized a vector of the same size. Proceeding as before, the reference is explored recursively searching for difference with the query. If the atom is present, the attributes are compared, each different attribute corresponds to a zero in the query vector indicating a difference. If the atom is not present, then it will put as many zeros as the number of

attributes for that particular atom of the reference.

In the end, we obtain two vectors of the same size, one of ones and the other of ones and zeros with a zero indicating a difference. Since doing the Euclidean distance between two vectors of binary values, in which one is all initialized to one, equals to simply count the number of zeros that are present in the second vector and then computing the square root, instead of creating these vectors, we only incremented a variable for each difference found. Besides the number of differences, it is also calculated the total number of attributes of the XML file reference. The final results will be a percentage of difference, compute by dividend the number of differences found with the total number of attributes.

The feature compare finally returns a JSON file with the following fields: reference, query, tot, diff, attributes.

In order to represent the XML files as objects, each XML file (DOM object) will be cast to a custom class called *Tree*, so that they can be manipulated more easily accordingly to our needs. Each XML files tag is a *Node* or a *Leaf*, both classes that implements the *Tree* interface. Each *Tree* has variables for identification (the 4-byte code, converted as *String*), a father (the root that is *Null* object), a list of children trees and a list of fields, that correspond to the attributes of the atom.

### 3.2.3 *Command Line Tool*

‘usage: vft [-b | -c | -d | -h | -m | -p | -u] [-i <file|folder>] [-i2 <file>] [-o <folder>] [-wa] -b,-batch batch parse a directory of video files; it recreates the same folder structure -c,-compare compare two xml files -d,-draw draw a tree from an xml file -h,-help print help message -i,-input <file|folder> video file for -parse, xml file for -draw and -compare, a folder for -batch and -update-config -i2,-input2 <file> second xml file for -merge and -compare -m,-merge merge

two xml file into one -o,-output <folder> output folder for the xml file,for -parse, -merge and -update-config -p,-parse parse a video file container into a xml file -u,-update-config merge all files in the dataset folder into a config.xml file -wa,-with-attributes whether to consider attributes in -merge and -update-config or not. Default is false ‘

## 3.3 File Origin Analysis Tool

### 3.3.1 *Functional Requirements*

L’implementazione della teoria è stata realizzata con un’applicazione java da utilizzare da terminale. Le funzionalità principale sono: - Training: si occupa prendere i due set considerati e di fare il merge di tutti i file xml. Inoltre calcola il potere discriminante di ciascun attributo relativamente ad entrambi i set. - Testing: è la fase che si occupa di rispondere alla domanda. Dato un video in ingresso, calcola la likelihood usando i config file costruiti dalla fase di training. La likelihood viene modulata usando il logaritmo in base 10 e tale score viene sogliaato sullo zero.  $>0$  true,  $<0$  false.

In foa sono state poi implementate una serie di operazione su database sqlite che serviranno successivamente per la web application che serve da interfaccia di foa e verranno quindi descritte in seguito.

### 3.3.2 *Implementation*

Sono state fatte alcune scelte implementative per migliorare la capacità del programma di identificare correttamente la classe: - quando cerco un atomo per calcolare i rapporti, prendo l’atomo corrispondente nel config di training cercando il nome intero es. `*<moov-2>*`. Questo vale per tutti gli atomi tranne per `*<trak>*`. Il codice trak è usato sia per l’atomo delle traccia audio che quello della traccia video. Cercare `*<trak-2>*` potrebbe restituire sia l’atomo

con lo stesso nome ma che invece riguarda l'audio e non il video, dovuto al diverso posizionamento nel file container. - alcuni attributi che sono noti essere unici per il video e non per la classe a cui appartiene non vengono considerati nella fase di testing. Tali attributi sono ad esempio la dimensione del file video, o la data di creazione e modifica. Potremmo considerarli e poi sogliare la likelihood in accordo dopo aver fatto una statistica di quanto sposta tale modifica per tutte le classi. (come in compare). - alcuni atomi non vengono considerati, in particolare xyz e udta. L'atomo xyz è dove sono salvate le informazioni relative alla posizione del dispositivo nel momento dell'acquisizione. Sebbene molto utile per certi scopi, non è utile come discriminante per l'appartenza ad una classe di dispositivi. Infatti basta filmare due video dallo stesso dispositivo una volta col gps acceso e l'altra spento per ottenere due container diversi. Tale diversità è accentuata dal fatto che considerando la posizione degli atomi (numerazione dei figli), l'aggiunta di un tag fa incrementare il valore del numero a tutti gli atomi figli che vengono dopo. Questo significa che i container verrà visto come completamente diverso. Per porsi rimedia basta attivare una flag quando ho trovato ad un certo livello dell'albero creato dal file xml. Quando la flag è attiva, per quel livello del file xml, cerco i tag in base al codice vero senza considerare il numero della posizione. (da rivedere). - dato un atomo ho tanti attributi; nella fase di testing per ogni attributo di un atomo calcolo il rapporto e poi ne faccio il prodotto. Ciò rappresenta la likelihood di quell'atomo. Se però i rapporti degli attributi di un atomo sono tutti esattamente uguali, praticamente sto moltiplicando più volte la stessa cosa; è come se stessi contanto più volte la stessa uguaglianza. Per ovviare è ciò la likelihood di ciascuno atomo è modulata in base ad un'entropia data da una formula (da mettere). Quando l'entropia è massima, ovvero tutti i rapporti diversi fa il prodotto normale; quando è minima ovvero zero praticamente considera solo un rapporto; nei casi medi fa una specie di media per quei gruppetti che hanno i rapporti uguali. Altrimenti alcuni atomi poco discriminanti ma con tanti attributi pesano tantissimo. - rapporto:

quando vado a calcolare il rapporto fra i pesi di un attributo di un atomo, vado a prendere i pesi nel set A e i pesi nel set B. Si possono verificare fra casi diversi:

- numeratore e denominatore = 0: faccio rapporto normale.
- numeratore = 0 e denominatore != 0: siccome non posso avere un rapporto pari a zero altrimenti col prodotto mi manda a zero tutta la likelihood, devo modificare il numeratore. Siccome tale caso in teoria è favorevole alla classe del denominatore (B), mi basta scegliere come numeratore un valore per il quale il rapporto è sempre minore di 1. Quindi scelgo  $1 / \text{il numero di video presenti nella classe B} + 1$ . In tal modo è sempre minore di 1, con il rapporto che però varia in base al valore del denominatore.
- numeratore != 0 e denominatore = 0: il denominatore non può essere zero. Come prima: mi basta che il rapporto sia sempre in favore di numeratore, quindi che sia sempre maggiore di 1. Sceglio il denominatore pari a  $1 / \text{il numero di video della classe A} + 1$ . Anche in questo caso l'intensità di tale rapporto varia in base al valore del numeratore.
- numeratore e denominatore != 0: questo caso si verifica quando il video di query presenta atomi o valori di attributi che non sono presenti nel config di training. Tale caso viene considerato a favore della classe B. Infatti tale problema, seppure binario, non è simmetrico: nel dubbio dico che non è della classe A (meglio lasciare libero un colpevole che mettere condannare un innocente). Questo caso viene considerato come un 0/1, in cui il peso per la classe A è zero e quello per la classe B è pari a 1 massimo. Modifichiamo il numeratore con i principi del secondo caso, ma invece di considerare il numero di video della classe del denominatore, lo scegliamo di quello del denominatore. Infatti, seppure deciso in favore di B, tale caso è comunque dubbio quindi moduliamo il rapporto in base al numero di video di A. (Spiegare meglio discorso dei rapporti e dei numA ecc)

### 3.3.3 *Command Line Tool*

'usage: foa [-cA <xml file>] [-cB <xml file>] [-h | -init | -trn | -tst | -ute | -utr] [-i <xml/txt file or folder>] [-lA <txt/json file>] [-lB <txt/json file>] [-o

<folder>| [-v] -cA,-configA <xml file> xml config file for class A, only for -test -cB,-configB <xml file> xml config file for class B, only for -test -h,-help print help message -i,-input <xml/txt file or folder> xml file or txt file with list of xml paths for which compute the likelihood for class A and B, only for -test, dataset folder path for -update -init,-initialize initialize database -lA,-listA <txt/json file> text/json file containing a list of xml file for class A, only for -train -lB,-listB <txt/json file> text/json file containing a list of xml file for class B, only for -train -o,-output <folder> output folder for the training config files, only for -train -trn,-train train a binary classification problem -tst,-test predict the class of a xml file -ute,-update-testing update testing database -utr,-update-training update trainingdatabase -v,-verbose whether or not display information, only for -test ‘

### 3.4 Web Application

Per utilizzare più semplicemente gli strumenti di analisi forense implementati e spiegati precedentemente, è stato deciso di implementare una web application che funga da interfaccia e permettere ad un utente di customizzare le query e ottenere un output dei risultati. La web app è sviluppata come node.js app ed utilizza un server express. Segue quindi la struttura: html + css per aspetto, js client-side per interattività e ajax call, js server-side per rispondere alle chiamate ajax e eseguire le features e poi rispondere al client (node+express).

Le features principali sono classify, per identificare la classe del dispositivo sorgente dato un video, compare, per integrity analysis, infine test per rendere più veloci i test con query.

Il dataset utilizzato è diviso in training e testing. Ciascun video possiede un file xml di informazioni utilizzato per costruire il groundtruth. Tali informazioni, insieme ai path del video, dell'info.xml e del file xml del container, sono salvati in un database. Tale database viene interrogato per ottenere i video per il training

e per ottenere i video da testare.

### **3.4.1 Features**

È possibile selezionare le features dal nav in cima alla pagina, con in aggiunta una pagina dove spiega come usare tali features.

- Classify: questa feature funziona in due modalità per il training, ovvero manuale e automatica. La modalità manuale si ha quando l'utente è a conoscenza del dispositivo sorgente del video query ma non ha il dispositivo ed intende verificare tale classe. La modalità automatica invece viene utilizzata quando l'utente è totalmente all'oscuro del dispositivo sorgente del video query. Le due modalità funzionano così:

- manual: nel box class l'utente seleziona il brand, il model, e il sistema operativo. Questi elementi sono in sequenza; l'utente può scegliere solo il brand oppure il brand e il model oppure tutti e tre. In base a tale scelta cambierà come la classe avversaria (B) verrà selezionata, ed anche quella scelta (A). Per scegliere la classe A viene fatta un query al database sulla tabella dei video di training in base alla scelta della classe. Se scelgo solo il brand prendo tutti i video di quel brand; se scelgo brand e model prendo tutti i video di quel brand e specifico modello; infine se scelgo brand model e os prendo tutti i video di quel brand e modello con quel sistema operativo specificato. La classe B viene presa sulla base della scelta per la classe A. Se è stato scelto solo il brand prendo tutti i video i cui dispositivi non appartengono a quel brand; se è stato scelto solo brand e model, prendo tutti i video provenienti dai dispositivi di quel brand ma degli altri modelli disponibili per quel brand; infine se è stato scelto brand model e os, prendo tutti i video provenienti dai dispositivi di quel brand e modello ma degli altri sistemi operativi disponibili. Nel caso di brand model e os, se non sono disponibili altri sistemi operativi mi riporto al caso 2, ovvero brand e model. Nel caso di brand model, se non sono disponibili altri modelli per quel brand, mi riporto al caso 1, ovvero brand.

- automatic: nel box class l'utente non seleziona nulla, lascia tutto any. A questo punto verranno testate tutte le classi disponibili nel database. Verrà viene selezionata ogni possibile classe A e di conseguenza ogni possibile classe B.

Nel box upload, viene selezionata il video query che di cui si vuole predire la sorgente. È possibile caricare un video (mp4 o mov) o più video (max 5?), oppure direttamente i file xml dei rispettivi container. Nel caso in cui si caricano i file video, verrà fatto il parse del video prima di procedere.

I file di training sono creati ed aggiornati periodicamente indipendentemente dalla query. Infatti tali file dipendono dai video presenti nel dataset; la scelta della classe da parte dell'utente serve solo a decidere quali file di training utilizzare. Quindi è possibile ottimizzare creandoli prima e andando a selezionare quelli che mi servono di caso in caso.

Una volta che ho caricato il video, scelto la classe A e B, il server utilizza i corretti file di training. Dopo c'è la fase di testing (utilizza foa), che, dati i video caricati, calcola la likelihood rispetto alla classe selezionata. Per il caso automatic verrà calcolata la likelihood per tutte le classi; tali likelihood vengono ordinate dal migliore al peggiore.

Infine, finito tutto, nel box output viene mostrato il nome del video query e la classe testata insieme alla likelihood associata; per il caso automatic vengono mostrati, per ciascun video caricato, i migliori 5 risultati (classe + likelihood).

- Test: serve per fare il classify più velocemente, senza dover caricare ogni volta i video. C'è solo il box class dove selezionare la classe da testare (manual o auto) e il box output. I video da testare vengono presi dal database dalla tabella dei video di testing, dove sono già parsati in file xml. Oltre all'output come prima, viene mostrata una statistica sui risultati della classificazione per tutti i video considerati (true positivi ecc, correct classification rate); infatti in questo caso è nota la classe vera dei video testati, classe (label) che viene mostrata accanto al nome del file video testato.

- Compare: il compare sfrutta la feature compare di vft. È possibile caricare



due video, uno reference l'altro query dal box upload. Una volta finito, nel box output verranno mostrati i risultati, ovvero il numero totale di attributi di reference e le differenze rispetto a query; inoltre lo stesso calcolo è fatto invertendo ref e query, per dare una visione migliore delle differenze ed eventuali somiglianze/uguaglianze.

- vft-parse: se l'utente non è in possesso dei file container, può caricare un video; se però il file video è grande e non si può/vuole aspettare il caricamento sul server, dal box upload può essere scaricato un programmino jar chiamato vft-parse. Tale programma, con una semplice interfaccia in java swing, è una costola di vft completo e permetto di fare il parsing di un video selezionato o di un intera directory. In questo modo è possibile poi caricare i file xml invece dei file video, velocizzando notevolmente il processo per tutte le features.

- problema del parlante: il motivo per cui vengono scelte le classi avversarie nel modo spiegato precedentemente è che si va incontro al problema del parlante. Il problema del parlante consiste nel fatto che ad esempio nel riconoscimento del parlato, se uso un dataset molto vario in cui includo tutte le lingue e dialetti del mondo per fare il training, poi non sono in grado di classificare accuratamente un parlato query; mentre se invece per fare il training seleziono dialetti simili allora sono in grado di classificare correttamente. Ciò sembra contro-intuitivo per la realtà, dove accade il contrario, ma in questi contesti usare cose simili significa dare molto più peso a piccole differenze che nel caso globale andrebbero perse. Questa è l'idea usata alla base della scelta delle classi avversarie, che cercano di essere diverse ma simili alla classe selezionata dall'utente.

# Chapter 4

## Experiments and results

### 4.1 Integrity Analysis based on File Container

### 4.2 Model Identification based on File Container

### 4.3 Application on Social Network

# Conclusions

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