

Politécnico de Leiria  
Escola Superior de Tecnologia e Gestão  
Departamento de Engenharia Informática  
Mestrado em Cibersegurança e Informática Forense

**AUTOPSY – ENHANCED DISTRIBUTED  
FORENSIC ANALYSIS**

**PEDRO HENRIQUE GASPAR CORDEIRO FERREIRA**

Leiria, 25 de Fevereiro de 2020



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## RESUMO

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TODO.





## ABSTRACT

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## LIST OF ABBREVIATIONS

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**API** Application Programming Interface.  
**ASCII** American Standard Code for Information Interchange.  
**BSD** Berkeley Software Distribution.  
**CSS** Cascading Style Sheets.  
**DOS** Disk Operating System.  
**EXIF** Exchangeable Image File Format.  
**FTK** Forensics Toolkit.  
**FTP** File Transfer Protocol.  
**GPT** GUID Partition Table.  
**HTML** HyperText Markup Language.  
**JSON** JavaScript Object Notation.  
**JWT** JSON Web Token.  
**NFTS** New Technology File System.  
**NIST** National Institute of Standards and Technology.  
**OS** Operating System.  
**OTP** One Time Password.  
**REST** REpresentational State Transfer.  
**RSA** Rivest-Shamir-Adleman.  
**STIX** Structured Threat Information eXpression.  
**TSK** The Sleuth Kit.  
**U2F** Universal Second Factor.  
**UUID** Universally Unique Identifier.  
**XML** Extensible Markup Language.



## INTRODUCTION

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In the scope of the master's degree in Cybersecurity and Digital Forensics, students had the choice between writing a thesis, developing a project or doing an internship. This document is the report for a curricular internship conducted at VOID SOFTWARE, S.A., where the main goal of the internship was to develop a collaborative digital forensics platform, while also learning to develop software in an enterprise environment.

This chapter encompasses the motivation for this internship, a characterization of the host entity, the scope of the proposed project, and a summary of this document's structure.

### 1.1 MOTIVATION

Collaboration is a major feature included in most forensics software, and while Autopsy [1] allows the software to be configured in a manner to allow collaboration it involves a complicated setup and has certain limitations. The setup required for collaborative cases in Autopsy is as follows:

- Shared hard drive accessible to every machine using the same drive letter
- PostgreSQL [2] Database server
- Apache Solr [3] indexing server
- Apache ActiveMQ [4] messaging server

The limitations of Autopsy's multi-user case feature are that it requires every user to be using a Windows [Operating System \(OS\)](#) computer and it also requires specific configuration on each machine involved in the case that is set up.

The goal of this internship is to transform the existing Autopsy platform, into a more complete digital forensics platform, including a client-server model that facilitates collaboration.

As a computer science student, my major interest has always been software engineering, and even after completing the first year of a master's degree in a more

advanced subject, my interests remained unchanged. Based on that interest, the opportunity to work in an enterprise environment was captivating, as I could gain experience in the field while also developing an interesting project to complement my education.

### 1.2 HOST ENTITY

As a first step, an interview was conducted at “VOID SOFTWARE, S.A.”, and a 9 month long curricular internship was planned. The initial project proposals were (1) the development of a client-server model for the existing Autopsy platform, or (2) the adaptation of the existing Autopsy platform for MacOS environments, the chosen proposal was the former.

#### 1.2.1 *Company Characterization*

VOID is a privately held software development company established in Leiria, Portugal, in 2006, focused on building high-end products embodied in web, mobile and desktop applications, supported by creative software engineering tailored to each challenge’s specific needs. It currently employs 30 high-end professionals in several fields of expertise.

VOID prides itself in providing very good conditions to it’s workers, making them feel like they are at home while working, and also to feel motivated to come to work every day. These conditions include the work environment itself, which is an open space where everyone can interact with each other, the “play areas“ where people can relax while playing a game of pool or video games, and the rooftop terrace where workers can relax on sunny days. The company also makes sure nothing is missing to provide the best work environment possible by providing food and drink to all it’s workers at any time.

#### 1.2.2 *Areas of Expertise*

VOID mostly functions as a company that develops software tailored to the specifications provided by the client, although it can also provide services in different areas like cybersecurity and digital forensics.

The company is capable of comfortably providing services in the following areas:

- Blockchain
- Machine learning and data science
- Augmented reality and virtual reality
- Mobile applications
- Web applications
- Desktop applications
- Cybersecurity and digital forensics

Throughout it's 14 years of being active in the software development industry, VOID has conducted some very interesting projects, as can be seen in Table 2.

Name	Description
Yes Account	A suite of applications for automated digitization of accounting documents
Web Portal	A large scale project for the European commission
Digital Archive	A digital preservation application
Dream Football	A social network along with web and mobile applications
Fuel Write	A comprehensive platform for fleet management, data collection and route optimization
Caspers	A mobile augmented reality customer experience and engagement
PBCore Toolkit	A desktop application to support the creation, editing, and export of moving image-related inventory metadata as PBCore <a href="#">XML</a> records
Avenue Securities	A trading platform

Table 2: VOID's Main Projects

### 1.3 PROJECT SCOPE

The proposed solution consists in adapting Autopsy into a client-server model, and such adaptation can be categorized in the field of digital forensics. Even though the main focus is on typical software development, there are plenty of advanced concepts related to forensics science and cybersecurity that must be assimilated for the project to succeed.

The platform aims to cover three main aspects:

1. Accessibility
2. Collaboration
3. Organization

### 1.3.1 *Accessibility*

Given a client-server architecture, any client with access to the network where the server is located can access the contents provided by the server. The aim is to condense the processing heavy features of Autopsy in a single server and provide any number of clients access to this information, requiring less resources from each client, allowing collaboration and removing any type of setup required for each of the client machines, while also providing a more modern and user friendly design.

### 1.3.2 *Collaboration*

In order to provide collaboration, all the information is maintained in a single server, or a collection of servers providing different functions (like exposing endpoints, storing data, and indexing searches), and every client can perform all the allowed actions whether they consist in consulting, generating, or removing information. Collaboration comes naturally with a client-server model, as the same server that provides the endpoints can also communicate with each client using WebSockets, and maintain information in a coordinated state along every connected client.

### 1.3.3 *Organization*

Digital forensics investigations are usually done by specialized organizations, who need to organize their human resources in an efficient and secure manner. Assigning investigators to teams, assigning teams to cases, allowing access to the platform and certain information is a critical part of the activities performed by a company that specializes in digital forensics, so having these functionalities properly integrated into a digital forensics platform should be an important feature.

## 1.4 DOCUMENT STRUCTURE

This document contains five chapters, the first one provides an introduction about the internship that was carried out, the second contains important concepts to help better understand the contents of this document, the third focuses on the main goal of the internship which is the development of the proposed platform, the fourth presents experiences from being involved in different projects inside the company, and finally the conclusion about the performed internship is presented in the fifth chapter.





## BACKGROUND

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The scope of this internship concerns digital forensics, as it focuses on adapting an existing forensics platform into a collaborative client-server model.

In this chapter, a contextualization of digital forensics is given, an analysis of both [The Sleuth Kit \(TSK\)](#) [5] and Autopsy is made, and it's given a brief description and analysis of the existing forensic platform alternatives.

### 2.1 DIGITAL FORENSICS

Forensic science [6] is the use of scientific methods or expertise to investigate crimes or examine evidence that might be presented in a court of law.

The definition of digital forensics is directly related to the definition of computer forensics which is the collection, preservation, analysis, and presentation [7] of evidence stemming from digital sources for use in a legal matter using investigative processes, tools, and practices.

Digital forensics [8] is the application of computer technology to criminal cases where evidence includes items that are created by digital systems.

Digital forensics is the field of forensic science that is concerned with retrieving, storing and analyzing electronic data that can be useful in criminal investigations. This includes information from computers, hard drives, mobile phones and other data storage devices.

Digital forensic investigators face challenges such as extracting data from damaged or destroyed devices, locating individual items of evidence among vast quantities of data, and ensuring that their methods capture data reliably without altering it in any way.

Personal data should ultimately be attributable to an individual; however, making that attribution can be difficult due to the presence or absence of individualized user accounts, security to protect those user accounts, and the actual placement of a person at the same location and time when the data is created.

### 2.1.1 *Digital Evidence*

Digital evidence is any type of digital data with incriminating characteristics, which can result from any type of action preformed by a user, like transactions and recordings.

Nowadays it's virtually impossible not to leave a digital track behind, since most of us carry and use devices capable of connecting to the internet.

The explosion of social media sites has created a whole new area of electronic evidence. Most people today are willing to share all kinds of information through social media platforms.

In order for electronic data to become digital evidence, it must be stored and be recoverable by a forensic examiner. One of the great challenges is not whether digital evidence may exist, but where the evidence is stored, getting access to that storage, and finally, recovering and processing that digital evidence for relevance within a civil or criminal action.

The potential storage options for electronic evidence has shifted from being only contained locally to being either located locally or remotely in what is called "The Cloud" [9].

More and more everyday computing processes are moving to the Internet where companies offer software as a service [10]. Software as a service means that the customer no longer has to install software on their computer, allowing access to the software remotely, and not storing any data locally.

### 2.1.2 *Processes and Procedures*

Digital forensics is the application of forensic science to electronic evidence in a legal matter.

While there are many different subdisciplines and many types of devices, communication, and storage methods available, the basic principles of digital forensics apply to all of them.

These principles encompass four areas:

1. Acquisition
2. Preservation

### 3. Analysis

### 4. Presentation

Each of these areas includes specific forensic processes and procedures.

#### *Acquisition*

Acquisition is the process of collecting electronic data. Seizing a computer at a crime scene or taking custody of a smartphone in a civil suit are examples of device acquisition, but the data must be extracted from these devices using specific procedures that equate to making a copy of the storage devices, while following strict rules to ensure the integrity of all the extracted data.

Since acquisition is the first interaction between the investigators and the evidence, it is the step where it's most likely to occur modifications of the contents of the seized devices, because turning on the device or extracting the data without following the right procedures can alter it's contents irreversibly.

#### *Preservation*

For evidence to be defensible in court it must be preserved properly. Preservation in the forensics context is the process of creating a chain of custody [11] that begins before collecting the evidence and ends when the evidence is released. Any interference in the chain of custody can lead to issues regarding the validity of the evidence. Additionally, preservation includes maintaining the evidence in a safe environment, preventing intentional destruction with malicious purpose or accidental modification by unqualified people.

A chain of custody log allows proving that the integrity of the evidence has been maintained from seizure through presentation in court. It should contain entries for every time that a piece of evidence has been touched, including collection, storage transport, and any time the evidence is checked out for handling by any personnel.

#### *Analysis*

Analysis is the process of locating and categorizing items from evidence that has been collected in a case. Each case is unique as the circumstances surrounding each case can vary immensely, not only in the evidence being analyzed, but also in the approach used to perform the analysis. The analysis is the area where the

individual skills, tools used, and the training of the forensic examiner have the greatest impact on the outcome of the examination. Considering that electronic evidence appears in so many forms and comes from diverse locations and devices, the training and experience of the examiner has a much greater impact on the results of the examination.

Analysis of digital evidence is more than just determining whether a file exists on a hard drive, it involves finding out how that file got on the hard drive, and if possible, who put the file on the hard drive.

### *Presentation*

Presentation of the examiner's findings is the last step in the process of forensic analysis of electronic evidence. This includes not only the written findings or forensic report, but also the creation of sworn statements, depositions of experts, and court testimony. There are no exact rules or standards for reporting the results of an examination. Each entity may have its own particular guidelines for reporting. However, forensic examination reports should be written clearly, concisely, and accurately, explaining what was examined, the tools used for the examination, the procedures used by the examiner, and the results of the examination. The report should also include the collection methods used, including specific steps taken to protect and preserve the original evidence and how the verification of the evidence was performed.

## 2.2 THE SLEUTH KIT

[TSK](#) is a library and collection of command line tools that allow the investigation of disk images. The core functionality of [TSK](#) allows volume and file system data analysis. The plug-in framework allows incorporation of additional modules to analyze file contents and build automated systems. The library can be incorporated into larger digital forensics tools and the command line tools can be directly used to find evidence.

The original part of [TSK](#) is a C library and collection of command line file and volume system forensic analysis tools. The file system tools allow examining file systems of a computer in a non-intrusive fashion. Because the tools do not rely on the operating system to process the file systems, deleted and hidden content can be shown.

The volume system tools allow examination of the layout of disks and other media. [TSK](#) supports [DOS](#) partitions, [BSD](#) partitions, Mac partitions, Sun slices, and GPT disks. With these tools, partition locations can be identified and extracted so that they can be analyzed with file system analysis tools.

When performing a complete analysis of a system, command line tools can become tedious. Autopsy is a graphical interface to the tools in [TSK](#), which allows easier conduction of an investigation. Autopsy provides case management, image integrity, keyword searching, and other automated operations.

A complete analysis also requires more than just file and volume system analysis. However, a single tool can't provide support for all file types and analysis techniques. The [TSK](#) Framework allows tools to easily incorporate file analysis modules that were written by other developers.

[TSK](#) allows listing allocated and deleted [ASCII](#) and Unicode file names, can display the details and contents of all [NFTS](#) attributes, can display file system and meta-data structure details, can create time lines of file activity, which can be imported into a spread sheet to create graphs and reports. [TSK](#) allows the lookup of file hashes in hash databases, it organizes files based on their type, and pages of thumbnails can be made from graphic images to facilitate quick analysis.

## 2.3 AUTOPSY

Autopsy is a digital forensics platform and a graphical interface to [TSK](#) along with other digital forensics tools. It is used by law enforcement, military, and corporate examiners to investigate what happened on a computer. It can even be used by anyone to recover photos from a camera's memory card.

Autopsy was designed to be intuitive out of the box. Installation is easy and wizards guide the user through every step. All results are shown in a single tree, as can be seen in [Figure 1](#).

Autopsy was designed to be an end-to-end platform with modules that come with it out of the box and others that are available from third-parties. An overview of Autopsy's modules can be found in [Table 4](#).

Autopsy runs background tasks in parallel using multiple cores and provides results as soon as they are found.

Autopsy is free and open source, allowing for cost-effective digital forensics analysis and community contributions.

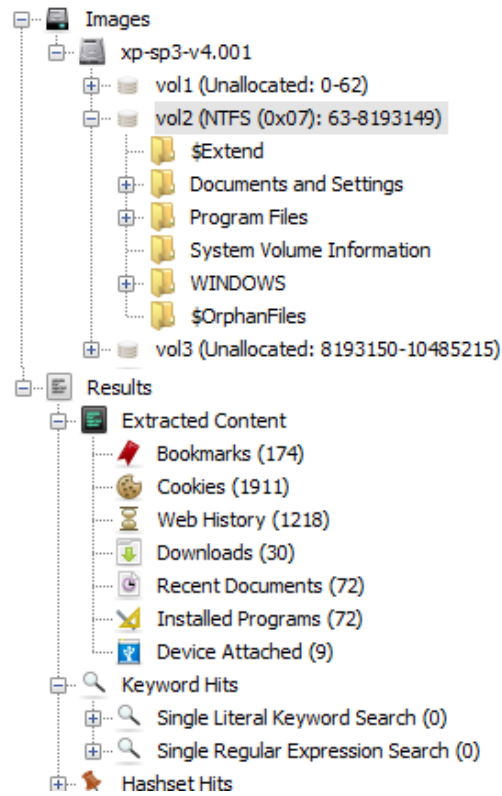


Figure 1: Autopsy's Explorer Tree

Name	Description
Timeline Analysis	Advanced graphical event viewing interface
Hash Filtering	Flag known bad files and ignore known good
Keyword Search	Indexed keyword search to find files that mention relevant terms
Web Artifacts	Extract history, bookmarks, and cookies from Firefox, Chrome, Internet Explorer and Microsoft Edge
Data Carving	Recover deleted files from unallocated space
Multimedia	Extract <a href="#">EXIF</a> metadata from pictures and videos and display these files
Indicators of Compromise	Scan a computer using <a href="#">STIX</a>

Table 4: Autopsy's Modules

## 2.4 RELATED SOFTWARE

There are plenty of alternatives to Autopsy in the form of digital forensic analysis platforms, but the ones with most recognition work on a software as a service model,

without providing a free trial, so even though it wasn't possible to test them, they were analysed based on the available information.

#### 2.4.1 *Nuix Lab*

Nuix Lab [12] allows investigators to work on large investigations. It can be used for local or small regional forensic labs handling high data volume, variety, and complex digital evidence and looking to build or upgrade a dedicated digital forensics facility.

The core technologies of the Nuix Lab, Nuix Workstation and Nuix Investigate, give digital forensic technicians and case investigators different viewpoints into the same case data. Investigators can collaborate on the same data at the same time by using browser based tools.

The Implementation of Elasticsearch [13] as a data store for the Nuix Lab boosts evidence processing, investigation, and intelligence capabilities.

Nuix Lab also claims to contain powerful artificial intelligence, machine learning, and analytics which should make it stand out from the competition.

#### 2.4.2 *EnCase Forensic*

EnCase Forensic [14] enables searching, identifying, and prioritizing potential evidence, in computers and mobile devices, to determine whether further investigation is warranted.

It can collect from a wide variety of operating and file systems, including over 25 types of mobile devices, and parses the most popular mobile apps across iOS, Android, and Blackberry devices. Has strong decryption capabilities, allowing identification and unlocking password-protected files, and contains a custom indexing engine.

EnCase Forensic provides a wide range of capabilities that enable performing deep forensic analysis as well as fast triage analysis from the same solution, and provides a flexible reporting framework that empowers tailoring case reports to meet specific needs.

### 2.4.3 Forensics Toolkit

**Forensics Toolkit (FTK)** [15] is an award-winning, court-cited digital investigations solution.

It locates evidence, collects and analyzes any digital device or system producing, transmitting or storing data by using a single application for multiple devices.

All digital evidence is stored in one case database. It reduces the time, cost and complexity of creating multiple datasets, and there is continuous data transfer between AccessData’s forensic and e-discovery solutions, allowing for collaboration between all parties working on the case.

**FTK** allows users to create images, process a wide range of data types, analyze the registry, crack passwords, and build reports.

**FTK** allows collaboration, contains indexed searches, constructs timelines and other graphical assets, categorizes all the extracted artifacts, and also contains malware identification modules.

## 2.5 COMPARISON

A comparison of the features offered by each software is presented in Table 6.

Feature	Autopsy	Nuix	Encase	FTK
Collaboration	✓	✓	✓	✓
Web Based Interface	✗	✓	✗	✗
Indexed Searches	✓	✓	✓	✓
Decryption	✗	✗	✓	✓
Artificial Intelligence	✗	✓	✓	✗
Malware Analysis	✗	✗	✗	✓
Report Generation	✓	✓	✓	✓
Free and Open Source	✓	✗	✗	✗
Modular Plugins	✓	✗	✗	✗

Table 6: Software Comparison

Every software listed has it’s pros and cons, Autopsy mainly benefits from being free and open source, and allowing the development of modular plugins, while the other options seem to try to offer a very complete package out of the box.



Any of these software options seem viable for any kind of digital forensics investigation, and as a digital forensics firm, the teams should first test all these available options and chose the ones that best suit their needs.



## KENSENTME PLATFORM DEVELOPMENT

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The main goal of the internship is the development of a collaborative platform based on Autopsy, which was soon named “Kensentme” by the company’s designer.

Each step taken towards the development of this platform is documented in this chapter, from project planning to full roll out on a production environment.

### 3.1 DEVELOPMENT FRAMEWORK

The project development followed an agile workflow, using a JIRA [\[16\]](#) board to organize bi-weekly sprints.

The project had four intervening parties involved. The developer was responsible for developing the software. The product owner provided help in decisions surrounding the developed product. The designer came up with ideas for the user interface and user experience of the platform. And the tester made sure everything was working as intended.

For each sprint the process was identical, a sprint review was conducted to assess the progress made in the previous sprint, then a new sprint would be planned by the developer, the features would be implemented during the two week duration of the sprint, and developed features would be tested thoroughly before the sprint ended.

### 3.2 PROJECT AIM AND MILESTONES

Autopsy by itself is capable of providing a distributed solution for multi user collaboration, but it is very resource intensive and requires many complex configuration steps, and is also only fully supported on the Windows [OS](#).

The plan for this project is to achieve the same kind of functionality provided by the original software, but without the dependency on arduous pre-configuration or hardware intensive requirements, resulting in needing only single capable server,

and allowing the program to be used by multiple low capacity client devices using any web capable OS.

To achieve that goal, the project is an adaptation of the original Autopsy source code, into a client-server model, with the server developed in Java using the Quarkus [17] framework, and the client developed in JavaScript using the React [18] framework.

The project is outlined to work in a multi user environment, allowing users to be assigned to teams and teams assigned to cases, and allowing multiple users to interact with a case simultaneously.

Autopsy has a major limitation, which is it only allows one case to be open at a time, ideally in this project a workaround should be created to allow working on multiple cases at once, but dedicating a server instance (which a single machine can have many virtualized within) per case is a good enough approach, though as future work the ability to spawn different containers as requested to work on different cases at once is an interesting challenge.

Given that the core features will be running in a remote server, it was decided that the addition of data sources to cases will be handled by an FTP client, allowing users to transfer files to their respective data source directories, and FTP access will be controlled according to each user's credentials on the platform.

The architecture of the expected result is represented in Figure 2, where it can be seen that multiple clients can connect through a REST API, WebSockets and FTP with the Kensentme server, which requests and provides data to both database and indexation servers.

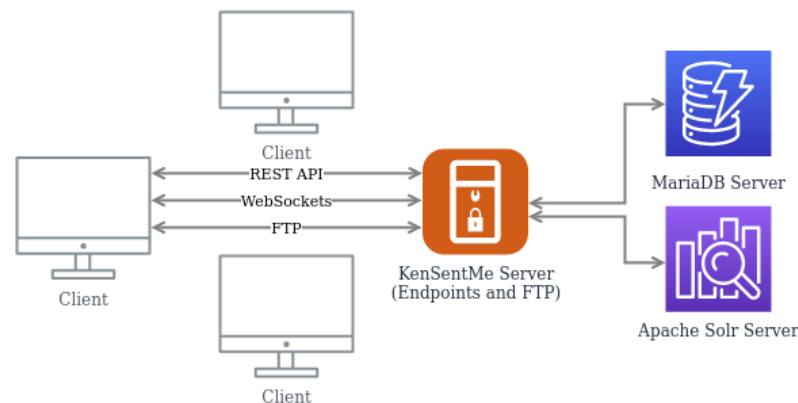


Figure 2: Software Architecture

The KenSentMe server described in the previous figure provides different services, such as authentication, case resources, entity management, and others, as can be seen in Figure 3.

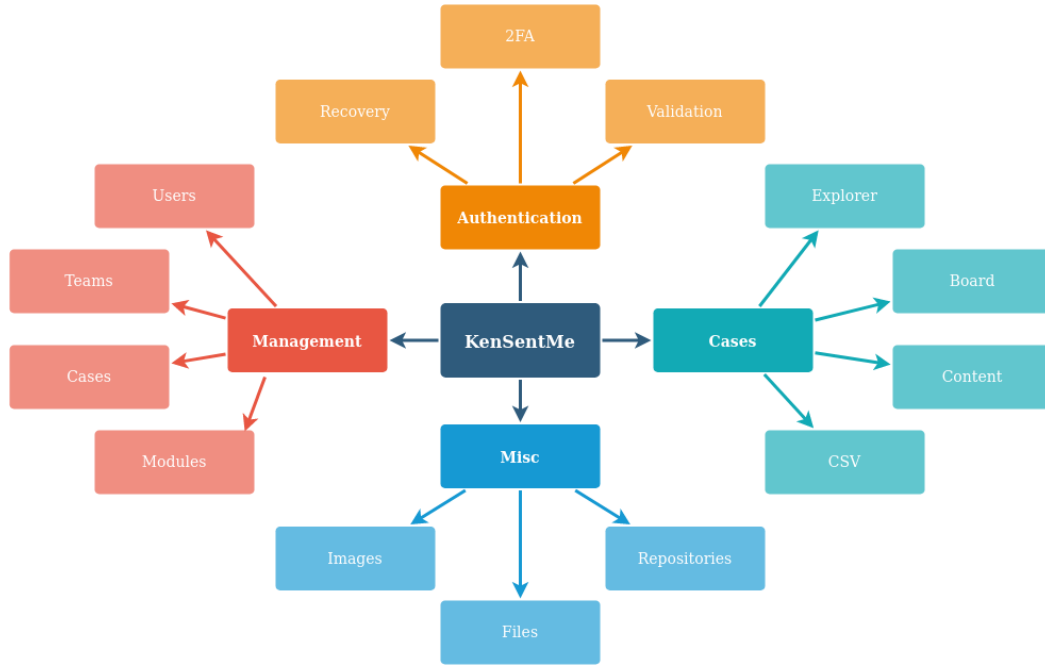


Figure 3: Platform’s Services

### 3.3 AUTOPSY SOURCE CODE ANALYSIS

Autopsy is a digital forensics analysis software that is available as Open Source Software [19] on GitHub [20].

With the goals set for this project, the source code was analyzed to understand which components need to be replicated and adapted in order to obtain the same logic flow.

The “Core“ module is where the most important components are located, and after analysis it was concluded that the following directories present in Table 7 contain relevant information.

Name	Description
Actions	User interactions
Casemodule	Case class and other resources needed for the functioning of an autopsy case like data sources and artifacts
Centralrepository	Data persisted and accessed by multiple cases (Correlation Engine)
Contentviewers	Panels used for data representation
Coordinationsservice	Configuration information distribution system
Core	Addition of command line options, system configurations and collaboration monitor
Corecomponents	Main user interface components
Datamodel	All the entities needed to represent ingested data
Datasourceprocessors	Data processing utilities
Directorytree	File explorer for ingested artifacts
Ingest	Utilities and events for data ingestion
Keywordsearchservice	Utility to search artifacts by keyword
Modules	All the pre-included modules (data ingestion procedures)
Progress	Progress indicators and similar classes
Python	Resources needed for the functioning of the Jython language
Rejview	Resources used to analyse Windows registry
Report	Report generation utilities and modules
Timeline	Recent addition to Autopsy, allows visualization of artifacts in temporal chart, only available for Windows OS

Table 7: Autopsy Modules Overview

The “KeywordSearch“ module is also of critical importance as it provides one of the most meaningful features which is filtering all the artifacts in a case with a keyword search using the Apache Solr search platform, which indexes the text contents of all the artifacts and allows extremely fast searching through a large amount of data.

Another module that needs to be adapted is the “RecentActivity“ module, which contains the tools needed to extract information from browsers, registry and other important resources, providing a great amount of critical evidence from data sources.

Each autopsy case contains it’s own SQLite [21] database, which contains the tables present in Table 8.

tsk_db_info	tsk_db_info_extended	tsk_objects
tsk_image_info	tsk_image_names	tsk_vs_info
tsk_vs_parts	tsk_fs_info	data_source_info
tsk_files	file_encoding_types	tsk_files_path
tsk_files_derived	tsk_files_derived_method	tag_names
review_statuses	blackboard_artifacts	blackboard_attributes
ingest_modules	blackboard_attribute_types	ingest_module_types
reports	blackboard_artifact_types	ingest_jobs
ingest_job_modules	ingest_job_status_types	account_types
accounts	account_relationships	tsk_event_types
tsk_examiners	blackboard_artifact_tags	content_tags
tsk_file_layout	tsk_event_descriptions	tsk_events
tsk_pool_info		

Table 8: Case Database Tables

The tables containing the information accessed most frequently are the ones related to blackboard artifacts, along with tables related to files and tags.

Autopsy’s source code allows access to most of the important entities present in this database, through pre-defined queries which return entities like data sources, abstract files, or artifacts. But in order to add features like pagination and tag deletion, custom queries must be created, so that the queries may return only a specific amount of entity ids, or so that delete commands may be executed.

### 3.4 DEVELOPMENT STAGES

#### 3.4.1 *Basic Autopsy Functionalities*

As a first step into replicating the functionalities of the original program, the most basic functionality from Autopsy was adapted, the ability to open an Autopsy case, as can be seen in Figure 4.

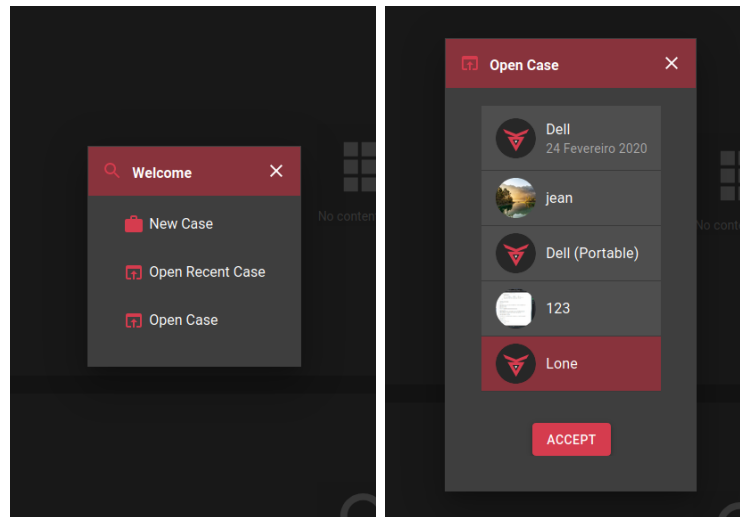


Figure 4: Welcome and Open Case Modals

For this some elements of the original "Casemodule" package were adapted, and after that all the other similar actions like closing, creating and deleting cases were also adapted.

Autopsy cases have a case file containing case metadata, which allows the program to connect to the right database when the case is open, this database is also present in a file inside the file system, which uses the SQLite database engine. So for the cases to be usable in the server these files must also be present in the server, which resulted in the creation of a directory within the server called "repository", containing all the different cases created within the application.

Later in the development there was the need to create an additional directory alongside the "repository" called "central-repository" which contains the database used by the Correlation Engine, which is a feature that finds files present in multiple cases, to ingest data that can be queried by any case.

The development of autopsy features was done with the original software as a reference, so that every new feature implemented into the platform could be compared and verified with the original software, and it was reassuring to see that



cases created through one of the versions of the software were capable of being opened through the other version, meaning that the source code provided by autopsy, with some tinkering, can definitely be used in a client-server model.

### 3.4.2 Authentication Process

The authentication process is handled through a [REST API](#), when the authentication is completed the user receives a [JSON Web Token \(JWT\)](#).

[JWT](#) is an open standard that defines a compact and self-contained way for securely transmitting information between parties. This information can be verified and trusted because it is digitally signed. [JWT](#) contain three parts, as can be seen in Table 10.

Name	Contents
Header	Information about the signing algorithm used
Payload	Information about the user, such as username, e-mail and roles
Signature	A signature used to verify the contents weren't changed

Table 10: [JWT](#) Composition

The authentication can be performed with either username or e-mail and a password, and extra authentication factors can be added such as [One Time Password \(OTP\)](#) and [Universal Second Factor \(U2F\)](#).

If no extra factors were added to an account, the authentication attempt with the user's credentials will return the [JWT](#) when successful and the user can freely access protected content.

When extra factors are present in an account, the response from the same request will contain an array with the extra factors added, and a [UUID](#), which is a pseudo random string, which must be sent in the next request to validate the user's identity.

This [UUID](#) is saved in the database in the form of salted hash using the Blowfish [22] algorithm, and is invalidated after a successful login attempt. The user then has the choice between any of the extra factors and must complete the required steps to validate that factor, as can be seen in Figure 5.

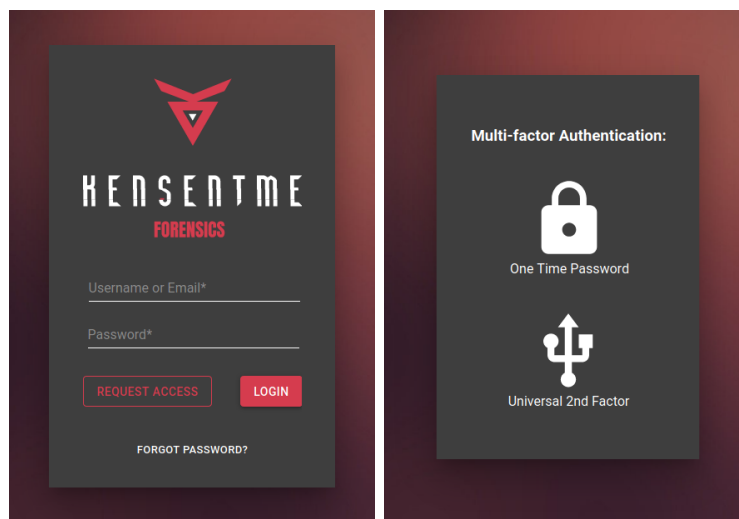


Figure 5: Login Screen and Extra Factors

### *One Time Password*

The process of setting up **OTP** for an account begins with generating a secret string, which is used by both the server and the authenticator app to generate **OTP**, when the secret is generated, it is saved as a temporary secret after being encrypted by the RSA algorithm.

The temporary secret must be added to the user's device, either by inserting the string itself or by scanning a QR code [23], and must be validated by the user by submitting the current **OTP**, after validation the temporary secret is considered permanent.

All OTP validations have a 30 second threshold, which means the current **OTP** is valid for an extra 30 seconds after being replaced by the next **OTP**, allowing the user to have a better experience with these passwords.

The processes of authenticating and removing this authentication factor both depend on validating the current **OTP**, which is provided by the user's app.

In the event of loss of the device that the user uses to generate **OTP**, all the authentication factors can be reset using the "Reset Password" functionality, which relies on e-mail validation to prove the user's identity.

### *Universal Second Factor*

Both the set up and validation of **U2F** are very similar, as these procedures require the server to generate a challenge. This challenge is transmitted to the client, and

then transmitted to the U2F device, which then generates the response which is used to validate the challenge.

In the case of setting up the device, if the response is validated successfully, the information present in Table 12 is stored in the server and the procedure is completed.

Name	Description
Key Handle	Identification of the registration, allows the same key to be used for multiple accounts in the same domain
Public Key	Resulting from the generation of a key pair specific to the domain, used to verify the information provided by the device
Attestation Certificate	A certificate that can be used to verify the authenticity of the device
Counter	The device's authentication counter, used to prevent the use of cloned devices
Compromised	Flag indicating if the credential is considered to be compromised

Table 12: U2F Registration Composition

When authenticating the challenge depends on the public key previously stored, which means only the device used to set up can generate the right response to the challenge.

The U2F procedure is represented in Figure 6.

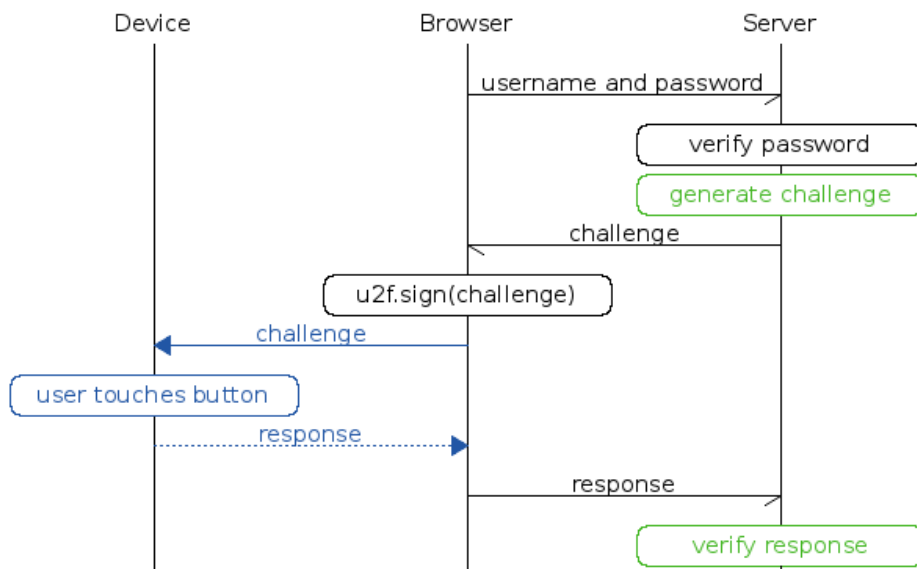


Figure 6: U2F Procedure [24]

### 3.4.3 Management Entities

Further in the development, the different persisted entities were created, which are Users, Teams, and Cases. All the endpoints for actions involving these entities were created, resulting in the ability for the client program to interact with these entities and modify their relationships and other variables.

For these functionalities there are two roles associated, (1) the Manager role allows manipulation of the existing entities while (2) the Investigator role only has access to his own information and the teams and cases he was assigned to. For these interactions, it was decided to create a drag and drop interface, which allows users to be dragged into teams and teams dragged into cases. All these entities are listed side by side and each have their own options and filtering input, as can be observed in Figure 7.

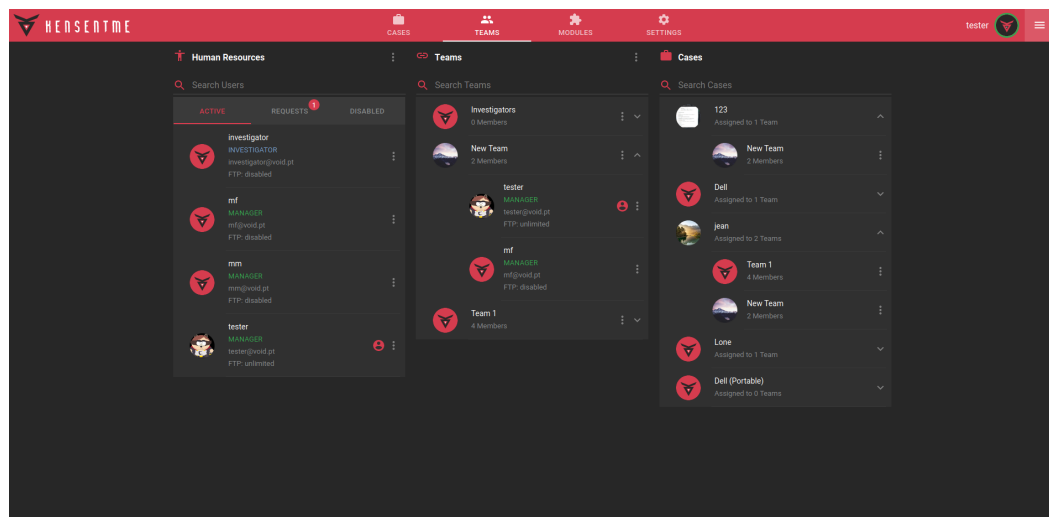


Figure 7: Entity Management Interface

Users can change their own profile picture, while Managers can also change any team or case's display picture.

Managers can add new users to the platform, can approve membership requests, can enable/disable user accounts and can create new teams.

When a user is added by a Manager or his membership request is approved, he must define a password when activating his account through a received e-mail message.

It was at this step in development that was made clear by the testers, that validations must be preformed on both server and client side, and that error handling must be streamlined in order to provide a seamless experience to the user,

while also allowing future additions to the platform to be implemented in a similar way without much tinkering.

Because even though the platform still wasn't fully developed, it already suffered from possible exploits that could break the experience for its users, like the upload of a 5GB file as an image file, which would stop the page from loading, or possible directory traversal attacks, resulting from the creation of case directories.

The lessons learned from the testers on this stage of development carried on through the entire development process and ensured that every new feature added was accounting for possible weaknesses which may result from the new implementations, resulting in a more secure development process.

The platform's resulting data model can be observed in Figure 8.

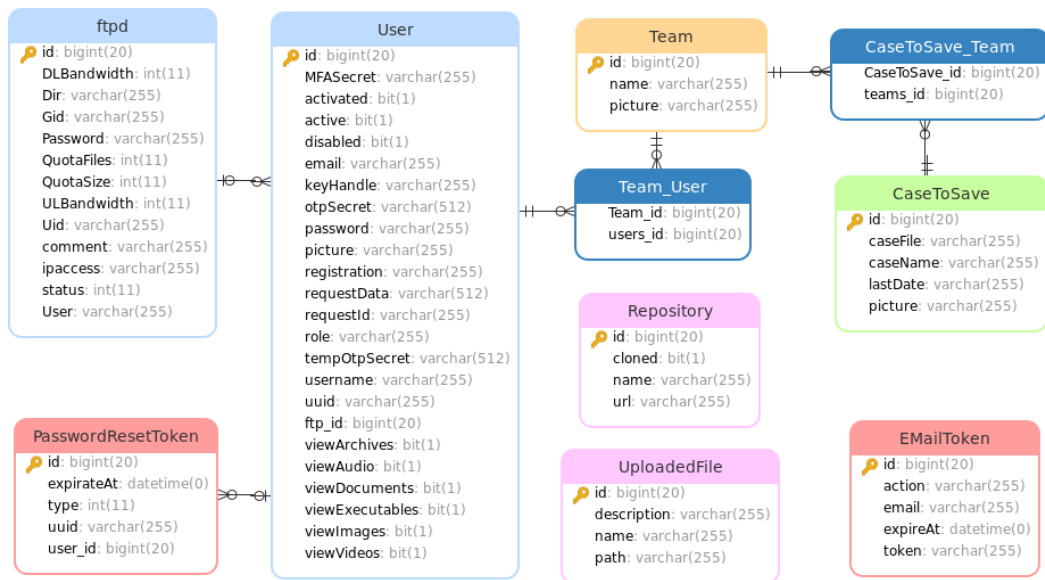


Figure 8: Database Structure

#### 3.4.4 Ingested Results Presentation

Ingested results are the items present inside the provided data sources. Autopsy can run multiple modules on each data source to extract results, and the extracted results can either be a file instance or an artifact instance. The difference between a file and an artifact is that an artifact represents only a smaller piece of a file's information, which means a file can contain multiple artifacts, for example a registry file can contain multiple OS user account artifacts.

Even though the data ingestion features weren't implemented yet on the platform, the data that was ingested into a case using the original program could also be used on this platform, which allowed this feature to be developed earlier.

The ingested results are presented in three different containers, one taking the shape of a file explorer, allowing exploration of the structure of all the results, one taking the shape of a table or thumbnail viewer, that can be referenced as a board, presenting all the contents of the results selected from the explorer, and one taking the shape of a content viewer, allowing visualization of the data contained inside the result selected from the table as can be seen in Figure 9.

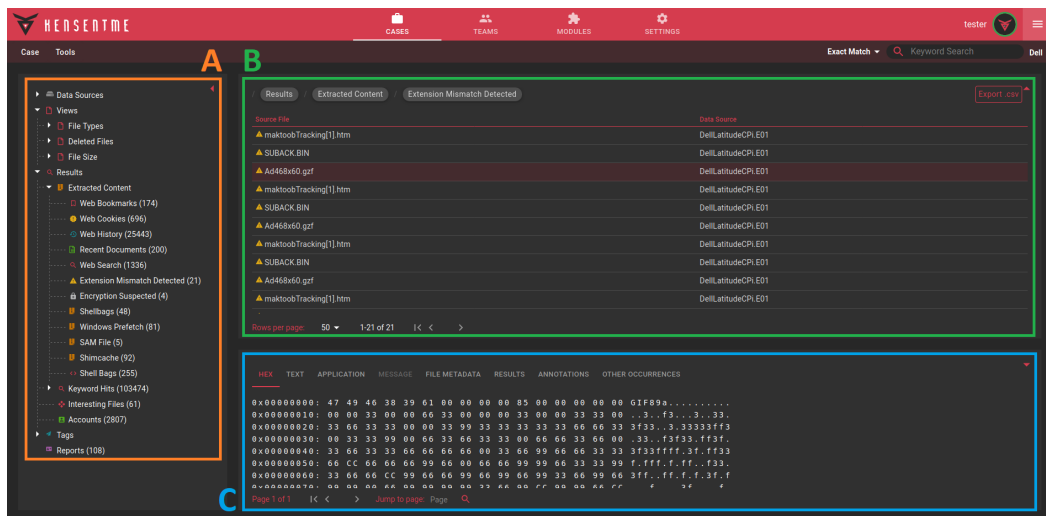


Figure 9: Ingested Results Presentation (A) Explorer; (B) Board; (C) Content Viewer

The content viewer can display different kinds of information depending on the type of item selected, these can be some of the following:

- Text browser
- Media viewer
- Database browser
- Registry browser
- Key-value browser
- Table data viewer

The layout for the ingested results presentation, and for all the case related actions, was based on the original Autopsy layout, so that each container can be re-sized as needed, allowing the user to focus on the information that is most important to him.

This development stage was one of the most intensive, as it required understanding Autopsy's data structure very well. The source code used here was rewritten almost completely, because of the way the user interface and the data structure in the original program are interconnected, resulting in the need to adapt and write custom queries to obtain the desired results (which include pagination), creating 65 endpoints so that all the needed information could be supplied, as well as creating and adjusting all the user interface elements to achieve an user experience similar to what Autopsy's users are used to.

### 3.4.5 Tag Management

Tagging content is a very important step in forensics investigations, as it allows the investigators to keep an organized list of important information.

Tagging was added to the platform in the form of a context menu, that is shown by selecting information from the table/thumbnail viewer, as can be seen in Figure 10.

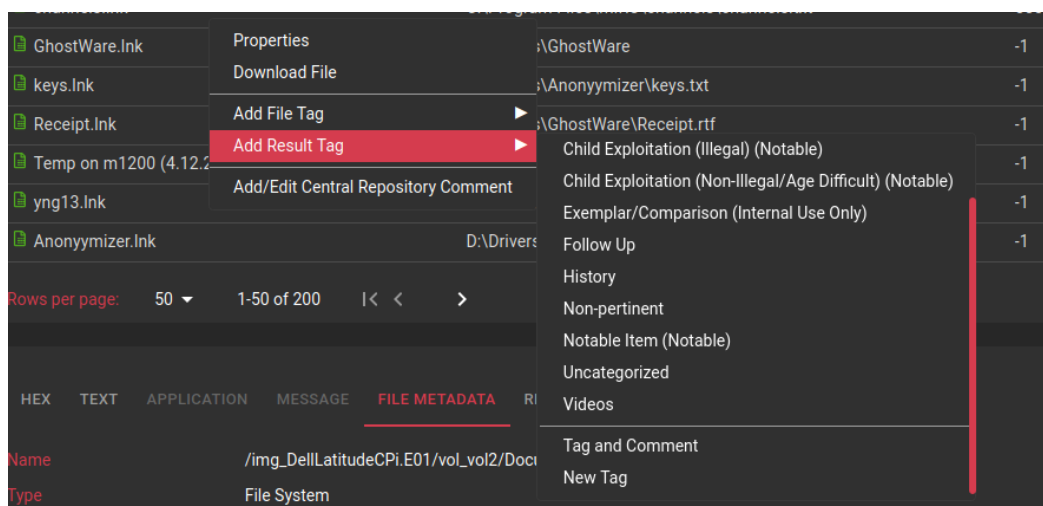


Figure 10: Tags Context Menu

Tags take the form of file or result tags, and the difference is that a result tag is specific to an artifact, while a file tag is related to the file itself.

Autopsy contains 10 different tag types by default, and more can be added, which can result in a high amount of tag types in use, which deteriorates the user experience.

Tag names are also shared between cases, so it seemed important to have more control over the management of these tags, and the ability to delete tag types was added, even though it didn't exist in the original software.

Since each case contains its own database, it's impossible to synchronize every case at once when a tag is deleted, so it was necessary to create a procedure to synchronize case tags when a case is opened.

#### 3.4.6 Data Sources

Using the same credentials used to log-in to the platform, the user can also upload data source files into his folder located inside the server, using an [FTP](#) client like FileZilla [25]. Then the user can browse these directories using the web interface and select a data source to add to the case, as can be seen in Figure 11.

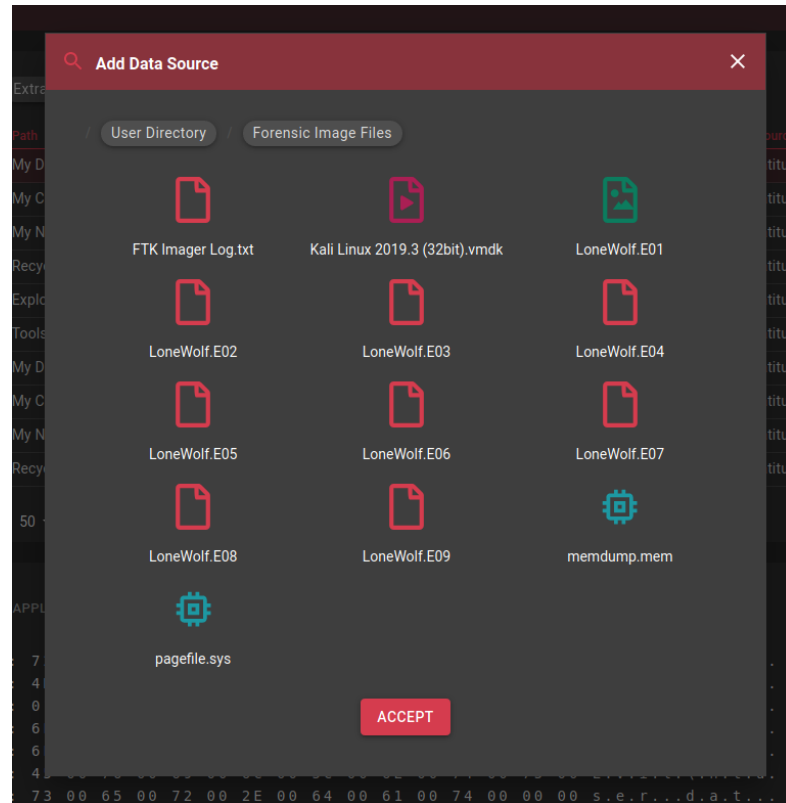


Figure 11: Data Source Selection

The procedure for adding a data source to a case was adapted from Autopsy's source code, and depends on the type of data source added, which can be one of the following:

- Disk image



- Virtual machine
- Logical file collection
- Autopsy Logical Imager [26] results

Local disk data sources were also an option provided by Autopsy but since the local disks the software has access to belong to a server, this feature is undesired.

When a data source is added to a case, it is processed and instances of abstract files and other entities are created, which allow the user to navigate the data source's contents as soon as it is processed.

Just navigating the data source contents isn't very useful, as the contents are in a raw state, showing mostly the file structure of the source, and not even categorizing files by mime types, so running data ingestion modules is a critical step into allowing a deeper analysis of a data source, which is covered in the next section.

#### 3.4.7 *Data Ingestion Modules*

Data ingestion modules can be either file ingest modules, which analyse each file contained in a data source, one by one, or data source ingest modules, which run on specific components of a data source.

To run a collection of modules, the user selects which modules to run, and may also configure some parameters related to the modules, when the request is received by the server, the modules are started in a background thread.

When the modules are running the server communicates to each client through WebSockets, offering feedback on the progress of the modules, as can be seen in Figure 12.

Originally it was intended to have the clients update their explorer as new information is ingested, but it would slow down the ingest progress considerably, so what was decided was that every client would refresh it's explorer every 30 seconds while ingests are running.

There were other measures taken into consideration to improve the performance of the ingest procedure, while also maintaining the user informed of it's progress, the server communicates a maximum of one file name per second, and it also only communicates a module's progress when it advances at least one percentage point.

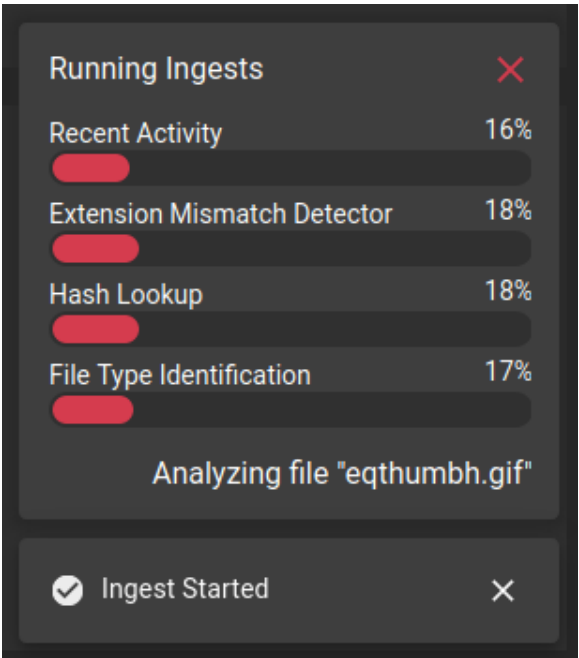


Figure 12: Ingest Modules Communication

3.4.8 Report Modules

Report modules consist in generating a file or collection of files, to further process, filter, or present the results found in a case. They can take many shapes such as a text file, spreadsheets, [HTML](#) pages or even a portable case that can be imported into Autopsy.

Report modules have the ability to process existing data and generate results based on that, such as validating e-mail addresses or credit card numbers, which are found based on regular expressions by the keyword search module and may contain false positives.

The adaptation of the source code for report modules went pretty smoothly, with the exception that some modules require the user to provide a file when running the module, which resulted in the creation of a file repository within the server, for files to be used in this manner.

### 3.4.9 Add-on Modules

Autopsy supports third party modules in the form of NetBeans [27] module files (NBM), and in the form of python scripts, using the Jython language, which allows python code to run alongside classes defined in Java.

Since the developed platform doesn't support a java user interface, the procedure to install Netbeans modules could not be implemented, as this feature is specific to Netbeans applications. But most modules are made in the Jython language, and the addition of this modules was implemented as intended.

A user with a manager role can add new modules to the platform by either selecting from defined repositories or by uploading a zip archive containing the modules, as can be seen in Figure 13.

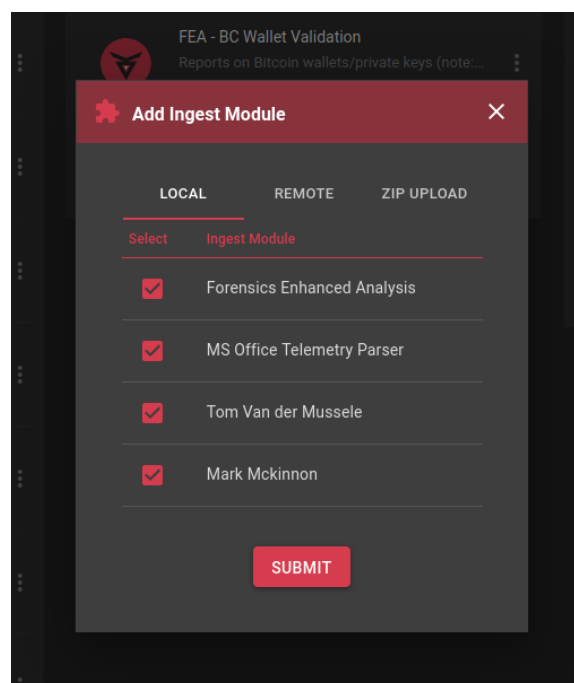


Figure 13: Add-on Modules Addition

These repositories previously mentioned can be defined in the platform itself, or accessed from a remote source, which is a standalone platform developed just for this purpose and could allow the company to provide repository sources to any deployed version of the platform.

The platform also allows management of the added modules, so that managers can enable, disabled and remove certain modules, as can be seen in Figure 14.

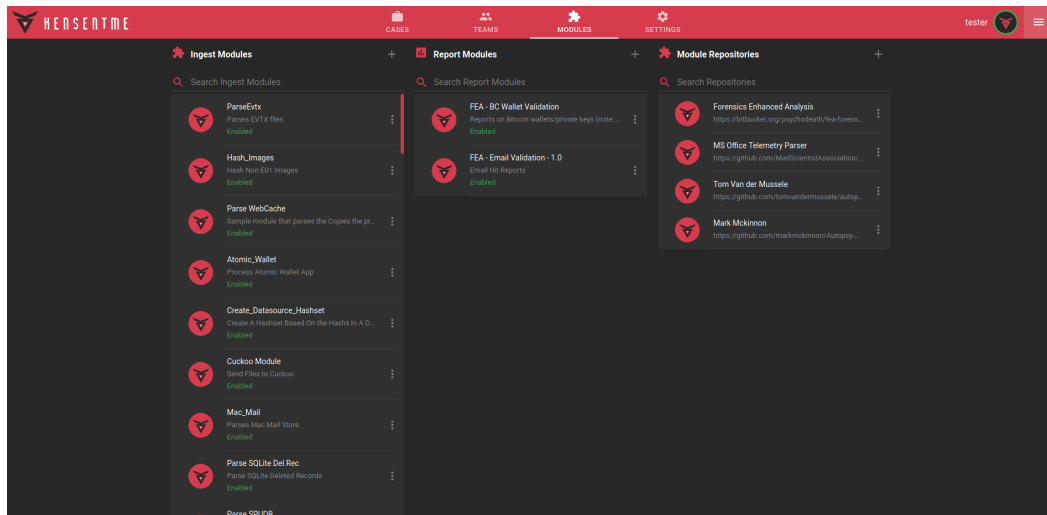


Figure 14: Add-on Modules Management

Third party modules require that a great deal of the original Autopsy source code is accessible in the original namespace, which resulted in the separation of the developed and adapted code into two different namespaces, the original software's namespace which is `org.sleuthkit.autopsy`, and the company's namespace which is `pt.voidsoftware.kensentme`.

This requirement of the original code can also mean that some modules which weren't tested may fail to run due to missing code, but a procedure to handle failure to run modules is implemented, and it informs the user about which modules are failing to run, allowing the user to disable the unsupported modules.

#### 3.4.10 *Project Deployment and Documentation*

A "Read Me" document was created, detailing each step required to setup the platform, which involves installing all the dependencies required, as well as compiling the developed code.

The setup was tested in multiple versions of Linux and with different versions of needed dependencies, resulting in a controlled step-by-step guide that can be followed in about 30 minutes that leads to a successful deployment of the complete platform.

The documentation of every endpoint of the platform can be consulted in [Appendix A](#).

#### 3.5 CRITICAL ANALYSIS AND PROPOSED IMPROVEMENTS

The development of the platform halted due to it being considered in a finished state, which means that all the objectives for the project were completed successfully.

Given that Autopsy is still in active development, it would be very important to keep following it's development, and complementing this platform with new features and bug fixes which might come up in the future.

Besides accompanying Autopsy's improvements, it could also be interesting to further develop the platform to better serve the needs of it's users, which would require installations of the platform, and a feedback channel to better understand the user's needs.



## CONCLUSIONS

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TODO





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## APPENDICES





## APPENDIX A

The endpoints of the KenSentMe platform are presented in the following pages, using the Swagger tool.



/openapi

Explore

### KenSentMe 1.0.0 OAS3

/openapi

Authorize



#### Authentication



**POST** /authentication/activate-account Activate account from e-mail message

**POST** /authentication/finishValidation/{username}/{secret} Validate U2F Response

**POST** /authentication/login Login Procedure

**POST** /authentication/login/otp Validate OTP

















**POST** /authentication/recover-password Request password recovery e-mail

**POST** /authentication/reset-password Reset password and multi factor auth

**GET** /authentication/startValidation/{username}/{secret} Get U2F Challenge

#### Board























GET	/board/directory/children/prev/{id}/{current}/{firstId}/{limit}	Get previous page of a directory's contents	
GET	/board/directory/children/{id}/{current}/{lastId}/{limit}	Get page of a directory's contents	
POST	/board/keyword	Run a keyword search	
POST	/board/keyword/prev	Get the previous keyword search page	
GET	/board/reports/prev/{current}/{firstId}/{limit}	Get previous page of reports	
GET	/board/reports/{current}/{lastId}/{limit}	Get page of reports	
GET	/board/results	Get the listing of artifact categories	
GET	/board/results/artifacts/prev/{id}/{current}/{firstId}/{limit}	Get previous page of artifact of a specific type	
GET	/board/results/artifacts/setname/prev/{setname}/{current}/{firstId}/{limit}	Get previous page of artifacts of a specific set name	
GET	/board/results/artifacts/setname/{setname}/{current}/{lastId}/{limit}	Get page of artifacts of a specific set name	
GET	/board/results/artifacts/{id}/{current}/{lastId}/{limit}	Get page of artifact of a specific type	
GET	/board/results/generic/{result}	Get the listing of an artifact category	
GET	/board/sources	Get the listing of data sources	
GET	/board/sources/{id}	Get contents of the selected data source	
GET	/board/tags	Get the listing of tag types	
GET	/board/tags/files/prev/{id}/{current}/{firstId}/{limit}	Get previous page of file tags for a specific tag	
GET	/board/tags/files/{id}/{current}/{lastId}/{limit}	Get page of file tags for a specific tag	
GET	/board/tags/results/prev/{id}/{current}/{firstId}/{limit}	Get previous page of file tags for a specific tag	
GET	/board/tags/results/{id}/{current}/{lastId}/{limit}	Get page of result tags for a specific tag	

GET	/board/tags/{id}	Get the total usages of result and file tags for a tag type	
GET	/board/views	Get the listing of file views	
GET	/board/views/deleted/prev/{view}/{current}/{firstId}/{limit}	Get previous page of files from a specific deleted files view	
GET	/board/views/deleted/{view}/{current}/{lastId}/{limit}	Get page of files from a specific deleted files view	
GET	/board/views/filter/prev/{filterId}/{current}/{firstId}/{limit}	Get previous page of files filtered by extension	
GET	/board/views/filter/{filterId}/{current}/{lastId}/{limit}	Get page of files filtered by extension	
GET	/board/views/generic/{view}	Get contents of a specific view	
GET	/board/views/mimes/prev/{mime}/{current}/{firstId}/{limit}	Get previous page of files of a specific mime type	
GET	/board/views/mimes/{mime}/{current}/{lastId}/{limit}	Get page of files of a specific mime type	
GET	/board/views/size/prev/{view}/{current}/{firstId}/{limit}	Get previous page of files from a specific size view	
GET	/board/views/size/{view}/{current}/{lastId}/{limit}	Get page of files from a specific size view	
GET	/board/volume/prev/{id}/{current}/{firstId}/{limit}	Get previous page of a volume's contents	
GET	/board/volume/{id}/{current}/{lastId}/{limit}	Get page of a volume's contents	

## CSV



GET	/csv/directory/children/{id}	Get csv of a directory's contents	
POST	/csv/keyword	Get csv of a keyword search	
GET	/csv/reports	Get csv of reports	
GET	/csv/results	Get csv of artifact categories	
GET	/csv/results/artifacts/setname/{setname}	Get csv of artifacts of a specific set name	

















GET	/csv/results/artifacts/{id}	Get csv of artifact of a specific type	
GET	/csv/results/generic/{result}	Get csv of an artifact category	
GET	/csv/sources	Get csv of data sources	
GET	/csv/sources/{id}	Get csv of the selected data source	
GET	/csv/tags	Get csv of tag types	
GET	/csv/tags/files/{id}	Get csv of file tags for a specific tag	
GET	/csv/tags/results/{id}	Get csv of result tags for a specific tag	
GET	/csv/tags/{id}	Get csv of total usages of result and file tags for a tag type	
GET	/csv/views	Get csv of file views	
GET	/csv/views/deleted/{view}	Get csv of files from a specific deleted files view	
GET	/csv/views/filter/{filterId}	Get csv of files filtered by extension	
GET	/csv/views/generic/{view}	Get csv of the contents of a specific view	
GET	/csv/views/mimes/{mime}	Get csv of files of a specific mime type	
GET	/csv/views/size/{view}	Get csv of files from a specific size view	
GET	/csv/volume/{id}	Get csv of a volume's contents	




















## Cases








GET	/case	Get the currently open case	
POST	/case	Create a case	
DELETE	/case	Delete the currently open case	














GET	/case/close	Close the currently open case	
GET	/case/comment/artifact/{id}	Get central repository comment for a file using an artifact id	
POST	/case/comment/artifact/{id}	Submit central repository comment for a file using an artifact id	
GET	/case/comment/content/{id}	Get central repository comment of a file	
POST	/case/comment/content/{id}	Submit central repository comment for a file	
GET	/case/database	Get a list of the existing case entities	
PUT	/case/database	Assign team to case	
DELETE	/case/database	Revoke access to a case for a team	
GET	/case/database/own	Get a list of the cases the authenticated user has access to	
POST	/case/datasource/image	Add a disk image as data source	
POST	/case/datasource/imager	Add autopsy logical imager files as data source	
POST	/case/datasource/logical	Add logical file set as data source	
GET	/case/details	Get the details of the currently open case	
GET	/case/ingest	Stop the currently running ingest jobs	
GET	/case/ingest/running	Get status of whether an ingest job is running	
GET	/case/ingest/{id}	Get a list of enabled ingest modules	
POST	/case/ingest/{id}	Run a set of ingest modules	
GET	/case/metadata	Get the currently open case's metadata	
POST	/case/open	Open a case	

PUT	/case/picture	Set the case's picture	
GET	/case/picture/{id}	Get a case's image file	
POST	/case/portable	Unpack a portable case and open as current case	
GET	/case/projects	Get a list of the existing cases	
GET	/case/recent	Get a list of the recently opened cases	
GET	/case/reports	Get a list of enabled report modules	
POST	/case/reports	Generate a report	
POST	/case/reports/delete	Delete the selected reports	
GET	/case/reports/download/{id}	Download report	
GET	/case/restore	Restore database using a backup	
GET	/case/sources	Get the contents of the user's ftp directory	
GET	/case/summary	Get the current case's data source summary	
GET	/case/tags	Get a list of the existing tag names	
POST	/case/tags/artifact	Add a result tag	
POST	/case/tags/artifact/create	Create a new tag and add a result tag	
POST	/case/tags/artifact/create/replace	Create a new tag and replace a result tag	
POST	/case/tags/artifact/replace	Replace a result tag	
GET	/case/tags/artifact/{id}	Get tags added to an artifact	
DELETE	/case/tags/artifact/{id}	Remove a result tag	

POST	/case/tags/content	Add a file tag	
POST	/case/tags/content/create	Create a new tag and add a file tag	
POST	/case/tags/content/create/replace	Create a new tag and replace a file tag	
POST	/case/tags/content/replace	Replace a file tag	
GET	/case/tags/content/{id}	Get tags added to a file	
DELETE	/case/tags/content/{id}	Remove a file tag	
GET	/case/timezones	Get a list of timezones	

## Content



GET	/content/download/{id}	Download the currently selected file	
GET	/content/file/{id}	Get video or image as file to display in application tab	
GET	/content/hex/{id}/{page}	Get specific page of the hex contents of a file	
GET	/content/html/{id}	Get html as file for application tab	
GET	/content/image/{id}	Get image for thumbnail view	
GET	/content/indexed/{id}/{artifact} /{page}	Get specific page of the indexed text of a file	
GET	/content/registry/{id}	Get registry object for application tab	
GET	/content/results/{id}/{page}	Get specific page of the results tab	
GET	/content/sqlite/{id}/{table}/{rows}/{page}	Get specific table page of sqlite file	
GET	/content/text/{id}/{page}	Get specific page of the file's text contents	
GET	/content/{id}/{artifact}	Get file or artifact details for content viewer	

## Explorer



**GET** **/explorer** Get the case's directory tree



**GET** **/explorer/{id}** Expand contents of a directory in the tree



## Files



**GET** **/file** Get a list stored files



**POST** **/file** Store a file



**GET** **/file/{id}** Get a file by id



**PUT** **/file/{id}** Set a stored file's details



**DELETE** **/file/{id}** Delete a stored file



## Repositories



**GET** **/repository** Get a list of saved repositories

**PUT** **/repository** Edit an existing repository entry

**POST** **/repository** Add a new repository entry

**POST** **/repository/url** Get a specific repository by URL

**DELETE** **/repository/{id}** Remove an existing repository entry

## Settings



**POST** **/settings/clone** Sync repositories based on remote list















**POST** **/settings/clone/local** Sync repositories based on local list









**GET** **/settings/ingest** Get list of added ingest modules






GET	/settings/ingest/delete/{className}	Remove an ingest module	
GET	/settings/ingest/disable/{className}	Disable an ingest module	
GET	/settings/ingest/enable/{className}	Enable an ingest module	
POST	/settings/nbm	Unsupported - Add NBM module	
GET	/settings/repo	Get repository list from remote server	
GET	/settings/report	Get list of added report modules	
GET	/settings/report/delete/{className}	Remove a report module	
GET	/settings/report/disable/{className}	Disable a report module	
GET	/settings/report/enable/{className}	Enable a report module	
GET	/settings/tags	Get list of tag definitions	
DELETE	/settings/tags/{index}	Delete a tag definition	
POST	/settings/zip	Upload module(s) in zip format	

## Teams


























GET	/teams	Get the list of teams	
PUT	/teams	Add user to a team	
POST	/teams	Create a new team	
DELETE	/teams	Delete a team	
PUT	/teams/name	Change a team's name	
GET	/teams/own	Get the list of teams the authenticated user is in	


PUT	/teams/picture	Set a team's picture	
GET	/teams/picture/{id}	Get a team's image file	
DELETE	/teams/remove	Remove a user from a team	

## Users



GET	/users	Get the list of users	
POST	/users	Store a user join request	
DELETE	/users	Deny a user application	
PUT	/users/disable	Disable a user	
PUT	/users/enable	Enable a user	
POST	/users/finishRegistration	Validate U2F challenge for registration	
POST	/users/finishValidation	Validate U2F challenge for factor removal	
PUT	/users/ftp/disable	Disable a user's FTP access	
PUT	/users/ftp/enable	Enable a user's FTP access	
PUT	/users/ftp/quota/{id}	Change a user's FTP quota	
PUT	/users/investigator	Approve a new user with the investigator role	
PUT	/users/manager	Approve a new user with the manager role	
POST	/users/manager	Add a new user to the platform	
GET	/users/otp/secret	Generate a OTP secret to setup OTP authentication	
PUT	/users/otp/secret	Validate OTP secret to make permanent	

POST	/users/otp/secret	Remove the OTP authentication factor	
GET	/users/own	Get the authenticated user	
PUT	/users/permissions/{id}	Change a user's content permissions	
PUT	/users/picture	Change user's own picture	
GET	/users/picture/{id}	Get a user's image file	
PUT	/users/role	Change a user's role	
GET	/users/startRegistration	Generate challenge for U2F registration	
GET	/users/startValidation	Generate U2F challenge for factor removal	

Schemas 
<p><b>ActivateUserRequest</b></p>
<p><b>Credentials</b></p>
<p><b>Permissions</b></p>
<p><b>Role</b></p>
<p><b>UserRequest</b></p>
<p><b>File</b></p>

**Repository**

**ListRepository**

**KeywordRequest**

**ListLong**

**AddTagRequest**

**ImageRequest**

**LogicalRequest**

**CaseAddRequest**

**NewTagRequest**

**CaseDetails**

**ModuleAttributes**

**ListModuleAttributes**

**ReportModuleItem**

**ModuleItem**



**ListModuleItem**

**TeamAddRequest**

**TeamChangeRequest**

**Info**



## DECLARAÇÃO

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Declaro, sob compromisso de honra, que o trabalho apresentado nesta dissertação, com o título “*AUTOPSY – Enhanced distributed forensic analysis*”, é original e foi realizado por Pedro Henrique Gaspar Cordeiro Ferreira (2180078) sob orientação de Professora Doutora Marisa da Silva Maximiano ([marisa.maximiano@ipleiria.pt](mailto:marisa.maximiano@ipleiria.pt)).

*Leiria, 25 de Fevereiro de 2020*

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Pedro Henrique Gaspar Cordeiro Ferreira