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Ontology-based Privacy Preserving Digital Forensics Framework

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Abstract

Along with the rapid growth of the number of intelligent mobile devices as well as applications in recent years owing to the development of network information and telecommunication technologies, personal privacy faces a unprecedented level of risk. This seems to be especially inevitable in digital forensic investigations. Consequently, there is an urgent need to balance the desire for privacy preservation and information extraction in the process of digital forensic investigations. This paper focuses on the issues related to personal privacy protection by proposing a digital forensics framework based on the theory of ontology. In addition to introducing the basic concepts that will lead to the establishment of the framework, we will also present some experiments that can be viewed as the demonstration of the effectiveness of the framework in privacy protection in the process of digital forensic investigations. The framework can thus serve as the foundation in the design of digital forensic tools and systems that can respect the privacy of individuals.

Keywords: *Forensics; Ontology; Privacy; Android*

1. Introduction

As intelligent mobile devices grow in complexity and maturity in recent years, smart phones and other intelligent mobile devices have experienced a wide-spread use and thus quickly become an important part of the sources for getting digital evidence and hence the main focus of digital forensics research. California has extended privacy protection to the contents of cell phones, settling a judicial split by prohibiting police from searching cell phones in the incident leading to arrest [1]. A growing number of courts believe that a warrant is necessary because of the ubiquity of mobile devices so that the majority of such devices are Internet connected smartphones that contain text messages, pictures, videos, emails and other sensitive and personal information. In Hawaii, New York, Oregon and Washington, just to name a few, it is now the requirement that police use a search warrant to track a person’s movement with a GPS or other electronic tracking devices. The office of the privacy commissioner for personal data in Hong Kong has suggested a number of privacy practices to highlight the importance of privacy protection of personal data [2]. However, the above practices are mainly non-technical means in defining and enforcing privacy requirements during the process of digital forensics.

To respond to privacy requirements as technologies change our society, some attentions have started to be placed on developing technical means to balance the relationship between convenience and privacy. However, privacy protection has not received insufficient attention in current research on digital forensics. In this paper, we propose a novel privacy preserving digital forensics framework aiming to bridge the gap between the

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existing digital forensic disciplines and privacy policies. It worth mentioning that ontology provides a strong foundation for the development of privacy preserving methodologies in the area of digital forensics. In this paper, we propose ontology description model and a privacy preserving digital forensics framework as an effective solution to the significant challenge digital forensics investigators faces.

The remainder of this paper is organized as follows. Section 2 discusses some prior work on the issues of privacy preservation in digital forensics. Section 3 presents the proposed ontology-based privacy preserving digital forensics framework in which we will investigate how ontology can be designed to represent the particular forensics scenarios and then propose the privacy preserving digital forensics framework to meet the demands of specific scenarios. Section 4 serves to demonstrate the effectiveness of the proposed ontology through conducting some experiments using some real data. Finally, Section 5 concludes this paper with an analysis of different types of digital forensics scenarios and some discussions on future development prospect.

2. Related Work

The combination of smartphones and the Internet has become very indispensable to the users. However, such dependency also makes it easy to leak personal private information. Phone calls, emails, text messages and other forms of communication would provide to observers with so many pieces of the puzzle that they could be used as the clues for deducing personal identities and other critical information that can used to break into the devices to get more information about the users. Android has been perceived as a relatively insecure mobile operating system due to its open source nature, but a company named Silent Circle has relabeled it "PrivatOS" through making some significant changes into it that are both visible and behind the scenes [3]. An Android phone known as Blackphone is claimed to be the first smartphone to place "privacy and control directly in the hands of its users" while being used a serious digital device that could carry a wide variety of user personal information [4].

In order to semantically interpret the input data and perform data transformations aiming to minimize the loss of semantic content for unbounded categorical attributes, Martínez et al. [5] proposed a new masking method relying on the knowledge in ontologies. Ntantogian et al. [6] revealed a set of critical observations regarding the privacy of Android mobile applications and devices. In [7], the authors analyzed and retrieved files from several storage media devices by using software called DriveSpy while working in the DOS command mode focusing on floppy drives, which the authors could show to be able to grasp the detailed structure of an entire file system by manually examining a floppy disc sector by sector within a few hours.

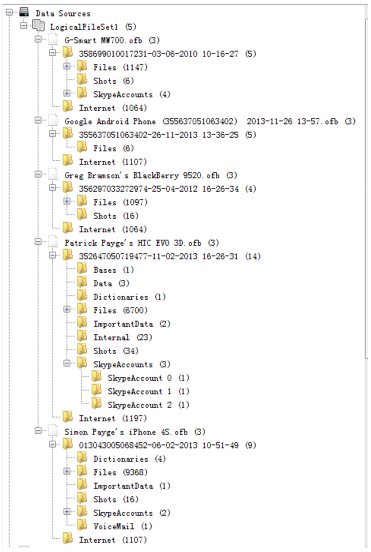
Privacy requirements may define constraints on data types, forensic scenarios and forensic scopes. Kost and Freytag [8] described a formal approach to technically evaluate an information system with respect to privacy protection in the design and implementation. Gupta [9] proposed the Privacy Preserving Efficient Digital Forensic Investigation (PPEDFI) framework to extract the evidence files and rank them based on their relevance of being used as the evidence. In [10], the authors suggested that policies for privacy protection be abstracted as trust attributes in a semantic way. Kanbe et al. [11] proposed RFID privacy protection ontology that consists of goal ontology, function ontology and technology ontology. However, although there are currently a lot of discussions on privacy preservation in the context of digital forensics, there are hardly any general methods that have been developed to be able to deal with the privacy issues in digital forensics. Therefore, the purpose of this paper is to introduce ontology into the privacy issue and customize it to assess the feasibility and the impact on the protection of personal privacy in several real digital forensics scenarios. Then, an ontology-based privacy preserving digital forensics framework is proposed with an analysis on its feasibility as well as its effectiveness in providing the necessary protection on private information in digital forensics.

3. The Ontology-based Framework

As digital mobile devices are used extensively to exchange information between users, privacy concerns has arisen due to potential leakage of personal and private information. Digital devices are usually used to store information with common applications that may touch sensitive data about users, such as photographs taken, electronic accounts established, chat records sent and received, clocks and calendars scheduled, contacts entered into the address book, and social network usernames and passwords. Furthermore, mobile devices are often considered to be very personal and private from the viewpoint of performing the role of personal organizers and being carried around and used by individuals. Stirparo et al. [12] analyzed how mobile applications are used to manage user data after it is loaded into the volatile memory of the devices to raise the awareness of the research and development communities on the poor attention that is generally paid in the secure development of mobile applications. Nevertheless, a technical approach for privacy analysis is largely missing in which a framework will certainly help to fill the gap.

3.1. Disclosure of Privacy Information in Digital Forensics

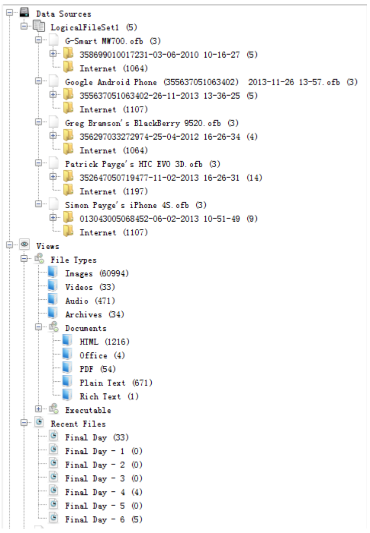
For the purpose of showing what could be revealed when browsing through the data in a captured device just like what an forensic investigator would do, in this part, we test 5 archives download from the Oxygen Forensic Website to emulate real connected devices. The data are analyzed using Autopsy, a digital forensics platform and graphical interface to the open-source tool The Sleuth Kit (TSK). Figure 1 illustrates a view of the tree structure of the files stored in the five devices discovered by Autopsy, where we can see clearly that personal data such as SkypeAccounts, ImportantData and InternetHistory are readily available to the investigator.



```
Data Sources
  LogicalFileSet1 (5)
    G-Smart MW700.ofb (3)
      358699010017231-03-06-2010 10-16-27 (5)
        Files (1147)
        Shots (6)
        SkypeAccounts (4)
      Internet (1064)
    Google Android Phone (355637051063402) 2013-11-26 13-57.ofb (3)
      355637051063402-26-11-2013 13-36-25 (5)
        Files (6)
      Internet (1107)
    Greg Bramson's BlackBerry 9520.ofb (3)
      356297033272974-25-04-2012 16-26-34 (4)
        Files (1097)
        Shots (16)
      Internet (1064)
    Patrick Payge's HTC EVO 3D.ofb (3)
      352647050719477-11-02-2013 16-26-31 (14)
        Bases (1)
        Data (3)
        Dictionaries (1)
        Files (6700)
        ImportantData (2)
        Internal (23)
        Shots (34)
        SkypeAccounts (3)
          SkypeAccount 0 (1)
          SkypeAccount 1 (1)
          SkypeAccount 2 (1)
      Internet (1197)
    Simon Payge's iPhone 4S.ofb (3)
      013043005068452-06-02-2013 10-51-49 (9)
        Dictionaries (4)
        Files (9368)
        ImportantData (1)
        Shots (16)
        SkypeAccounts (2)
        VoiceMail (1)
      Internet (1107)
```

Figure 1. Forensic Data of the 5 Devices using Autopsy

Figure 2 shows that a large amount of forensic data including images, videos, audios and documents exist in the digital devices. Apparently, sensitive data related to personal privacy is revealed. Figure 3 shows the images stored in the forensics digital devices at hand. Figure 4 shows the Skype chat records and user account information. Similarly, we can see from Figures 5 and 6 that important private data becomes available in the forensics views window.



```
Data Sources
  LogicalFileSet1 (5)
    G-Smart MW700.ofb (3)
      358699010017231-03-06-2010 10-16-27 (5)
      Internet (1064)
    Google Android Phone (355637051063402) 2013-11-26 13-57.ofb (3)
      355637051063402-26-11-2013 13-36-25 (5)
      Internet (1107)
    Greg Bramson's BlackBerry 9520.ofb (3)
      356297033272974-25-04-2012 16-26-34 (4)
      Internet (1064)
    Patrick Payge's HTC EVO 3D.ofb (3)
      352647050719477-11-02-2013 16-26-31 (14)
      Internet (1197)
    Simon Payge's iPhone 4S.ofb (3)
      013043005068452-06-02-2013 10-51-49 (9)
      Internet (1107)
Views
  File Types
    Images (60994)
    Videos (33)
    Audio (471)
    Archives (34)
    Documents
      HTML (1216)
      Office (4)
      PDF (54)
      Plain Text (671)
      Rich Text (1)
    Executable
  Recent Files
    Final Day (33)
    Final Day - 1 (0)
    Final Day - 2 (0)
    Final Day - 3 (0)
    Final Day - 4 (4)
    Final Day - 5 (0)
    Final Day - 6 (5)
```

Figure 2. Types of the Extracted Files

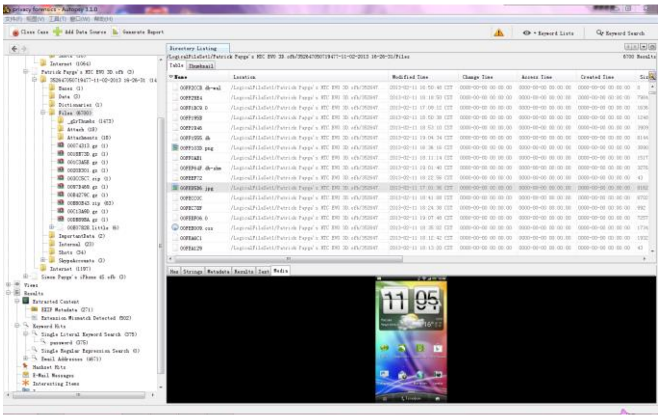
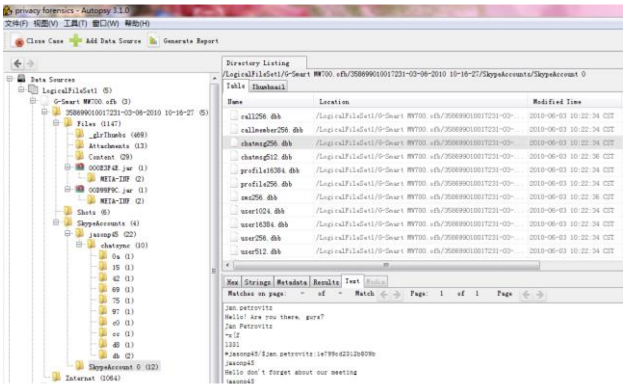


Figure 3. Images Stored in the Mobile Devices



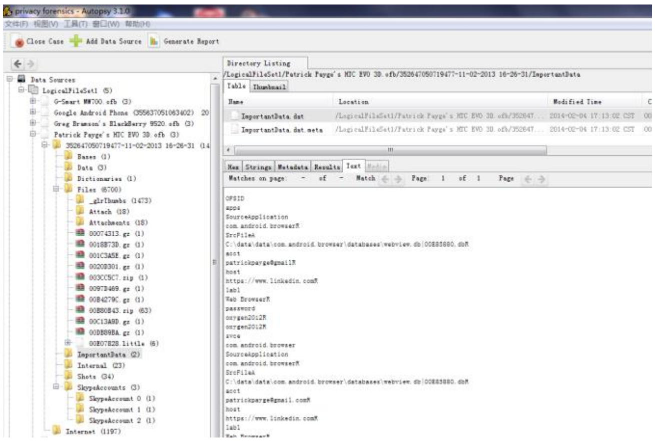
```
Data Sources
  LogicalFileSet1 (5)
    G-Smart MW700.ofb (3)
      358699010017231-03-06-2010 10-16-27 (5)
        Files (1147)
          _glrThumbs (469)
          Attachments (13)
          Content (29)
          000E3F4E.jar (1)
            META-INF (2)
          00D99F9C.jar (1)
            META-INF (2)
        Shots (6)
        SkypeAccounts (4)
          jasonp45 (22)
            chatsync (10)
              0a (1)
              15 (1)
              42 (1)
              69 (1)
              75 (1)
              97 (1)
              c0 (1)
              cc (1)
              d8 (1)
              db (2)
          SkypeAccount 0 (12)
      Internet (1064)
```

/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-06-2010 10-16-27/SkypeAccounts/SkypeAccount 0

Name	Location	Modified Time
call256.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST
callmember256.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST
chatmsg256.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST
chatmsg512.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:36 CST
profile16384.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST
profile256.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST
sms256.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:36 CST
user1024.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST
user16384.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST
user256.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST
user512.dbb	/LogicalFileSet1/G-Smart MW700.ofb/358699010017231-03-...	2010-06-03 10:22:34 CST

```
jan.petrovitz
Hello! Are you there, guys?
Jan Petrovitz
+z[Z
1331
*jasonp45/$jan.petrovitz:1e799cd2312b609b
jasonp45
Hello don't forget about our meeting
jasonp45
```

Figure 4. G-Smart Phone SkypeAccount Context

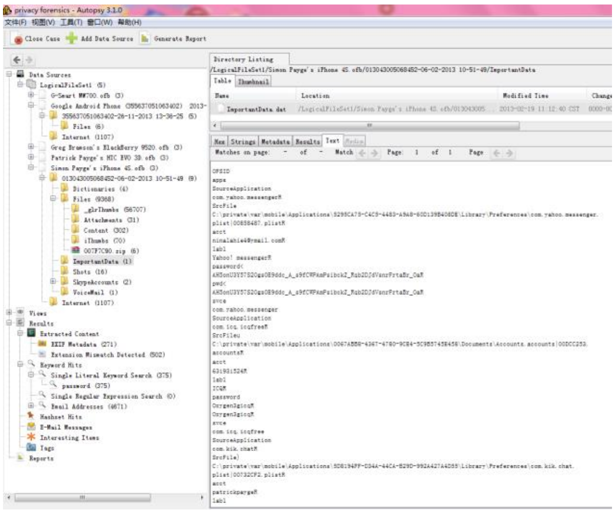


/LogicalFileSet1/Patrick Payge's HTC EVO 3D.ofb/352647050719477-11-02-2013 16-26-31/ImportantData

Name	Location	Modified Time	C
ImportantData.dat	/LogicalFileSet1/Patrick Payge's HTC EVO 3D.ofb/352647...	2014-02-04 17:13:02 CST	00
ImportantData.dat.meta	/LogicalFileSet1/Patrick Payge's HTC EVO 3D.ofb/352647...	2014-02-04 17:13:02 CST	00

```
OPSID
apps
SourceApplication
com.android.browserR
SrcFileA
C:\data\data\com.android.browser\databases\webview.db|00E83880.dbR
acct
patrickpayge@gmailR
host
https://www.linkedin.comR
labl
Web BrowserR
password
oxygen2012R
oxygen2012R
svce
com.android.browser
SourceApplication
com.android.browserR
SrcFileA
C:\data\data\com.android.browser\databases\webview.db|00E83880.dbR
acct
patrickpayge@gmail.comR
host
https://www.linkedin.comR
labl
Web BrowserR
```

Figure 5. Important Data in the HTC Mobile Phone Used in the Experiment



/LogicalFileSet1/Simon Payge's iPhone 4S.ofb/013043005068452-06-02-2013 10-51-49/ImportantData

Name	Location	Modified Time	Change
ImportantData.dat	/LogicalFileSet1/Simon Payge's iPhone 4S.ofb/013043005...	2013-02-19 11:12:40 CST	0000-00

```
OPSID
apps
SourceApplication
com.yahoo.messengerR
SrcFile
C:\private\var\mobile\Applications\5295CA75-C4C5-4483-A9A8-60D139B408DE\Library\Preferences\com.yahoo.messenger.
plist|00858487.plistR
acct
ninalahie4@ymail.comR
labl
Yahoo! messengerR
password<
AH5onU3Y57S20gs0E9ddc_A_s9fCWFAmPsibckZ_Rab2DJdVsnrFrtaBr_OaR
pwd<
AH5onU3Y57S20gs0E9ddc_A_s9fCWFAmPsibckZ_Rab2DJdVsnrFrtaBr_OaR
svce
com.yahoo.messenger
SourceApplication
com.icq.icqfreeR
SrcFileu
C:\private\var\mobile\Applications\0067ABB8-4367-4780-9CB4-5C9B5745E456\Documents\Accounts.accounts|00DCC253.
accountsR
acct
631931524R
labl
ICQR
password
Oxygen3gicqR
Oxygen3gicqR
svce
com.icq.icqfree
SourceApplication
com.kik.chatR
SrcFile)
C:\private\var\mobile\Applications\5D8194FF-D34A-44CA-B29D-992A427A4D55\Library\Preferences\com.kik.chat.
plist|00732CF2.plistR
acct
patrickpaygeR
labl
```

Figure 6. Iphone 4s Important Data

3.2. The Ontology for Digital Forensics Involving Privacy

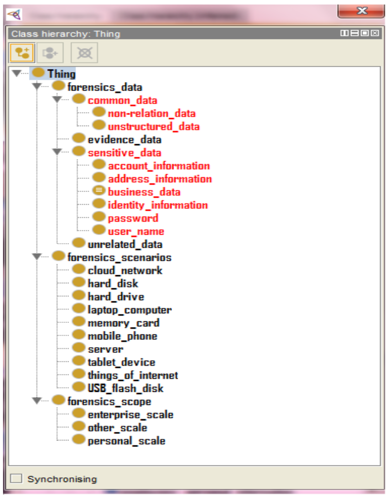
Protégé is an open-source ontology design tool for building intelligent systems with a highly configurable user interface that includes RDF/XML, Turtle, OWL/XML, OBO and other formats available for ontology uploads and downloads. Therefore, in our study, we use Protégé as the tool to design the ontology for the privacy preserving digital forensics framework. In addition, there are three ontology definitions customized below to assist the design to illustrate the ontology.

Definition1: The attributes of the ontology for privacy in digital forensics are defined by the triplet (C, RC, HC): (1) C: the concepts involved in the digital forensics process. (2) RC: the morphisms between concepts. (3) HC: classification levels of the concepts.

Definition2: Cato= (C', RC') is a category of ontology for digital forensics. (1) Cato: ontology category. (2) C': the object of a category including classes defined in the ontology and the relationships between them. (3) RC': the morphisms between objects including classes and hierarchical relationships between objects.

Definition 3: The path of concepts in the ontology is supposed to be a path through the hierarchy that starts from a specified concept node and ends at the root node.

According to the above notions of ontology, we can form a set of ontologies. Figure 7 illustrates how we can classify forensics processes through applying Protégé as the ontology design tool. The figure also depicts the hierarchy of the mentioned ontology in detail.



Class hierarchy: Thing

- Thing
  - forensics_data
    - common_data
      - non-relation_data
      - unstructured_data
    - evidence_data
    - sensitive_data
      - account_information
      - address_information
      - business_data
      - identity_information
      - password
      - user_name
    - unrelated_data
  - forensics_scenarios
    - cloud_network
    - hard_disk
    - hard_drive
    - laptop_computer
    - memory_card
    - mobile_phone
    - server
    - tablet_device
    - things_of_internet
    - USB_flash_disk
  - forensics_scope
    - enterprise_scale
    - other_scale
    - personal_scale

□ Synchronising

Figure 7. Digital Forensics Privacy Ontology

Finally, Figure 8 shows the ontology that is composed of 4 levels in horizontal direction. Moreover, digital forensics is divided into three branches as we can see in the figure. In general, the digital forensics regarded as an object is divided into three categories including forensics scope, forensics data and forensics scenarios.

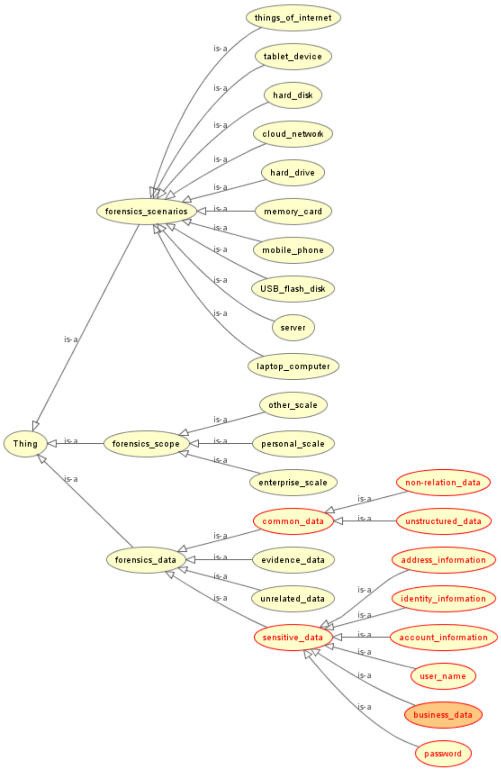


Figure 8. Privacy Ontology of Digital Forensics

3.3. The Ontology-based framework for privacy preservation in digital forensics

Based on the ontology presented above, Figure 9 is our proposed framework for digital forensics for privacy protection. The ontology-based privacy usually consists of sensitive information such as username, password, personal account photograph, etc. The suggested framework can achieve the goal of protecting privacy through means of identifying authentication and the scenario as well as protecting sensitive information and images.

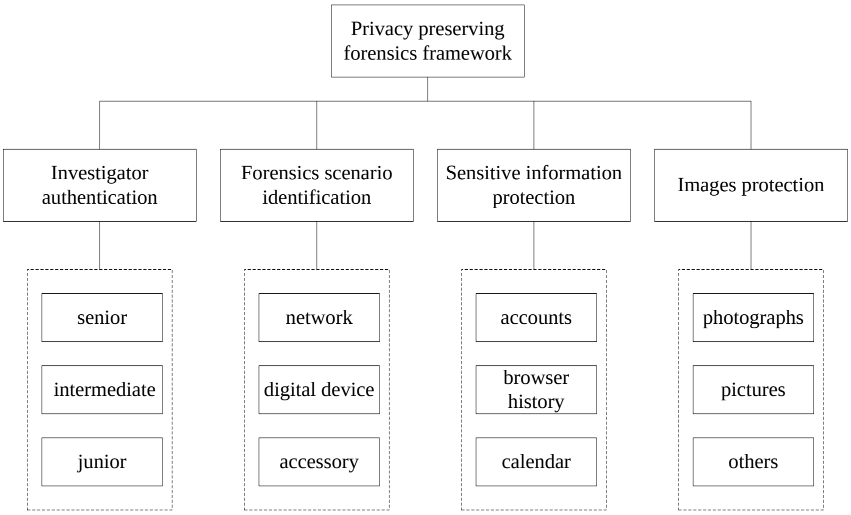

Privacy preserving forensics framework
Investigator authentication
Forensics scenario identification
Sensitive information protection
Images protection
senior
intermediate
junior
network
digital device
accessory
accounts
browser history
calendar
photographs
pictures
others

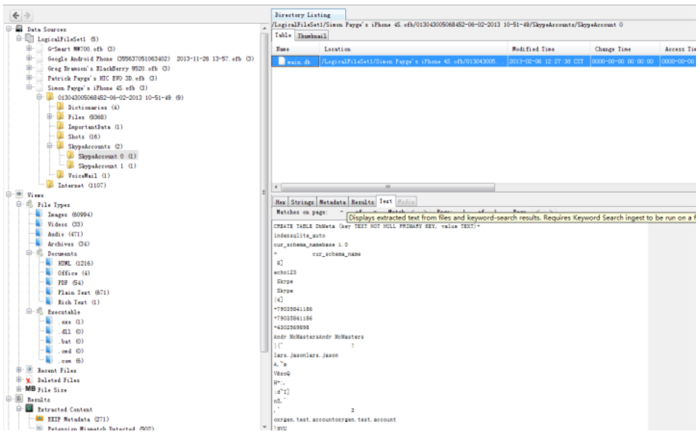
Figure 9. Ontology-based Privacy Preserving Digital Forensics Framework

With such protection, senior level investigators could be assigned permissions to view protected information and images without too much limitation, middle are able to visit permitted information through limiting the forensics scenario, and junior level investigators could be prohibited from viewing protected data for privacy protection in the process digital forensics.

4. Analysis of Effectiveness

Wynand van Staden [13] presented framework for enhancing privacy to prevent – or at least to minimize the risk of – third party from privacy breaches, which includes an analyzing component to profile a search and a filtering component to calculate the diversity in the search results. Nevertheless, Wynand overlooked the variety of forensics scenarios that are supposed to impact the result of forensics significantly. Figures 13-18 show how using our proposed framework, sensitive information can be properly protected when digital forensics is performed by investigators at different levels.

Figures 10 and 11 show how protecting Skype accounts can be realized through implementing the proposed ontology-based framework. Sensitive information is protected by considering the authentication of different investigators together with the identification of forensics scenarios.



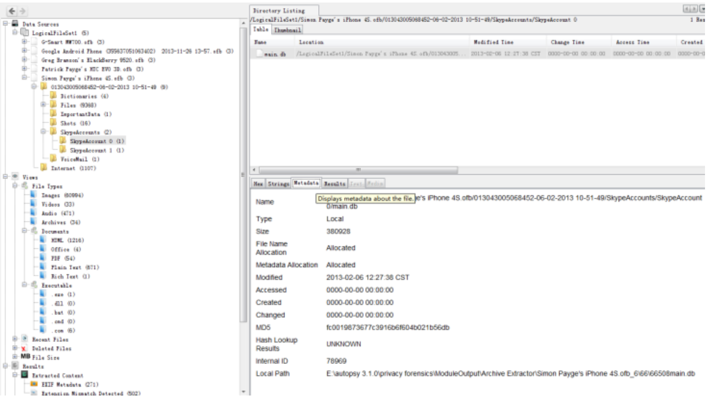
/LogicalFileSet1/Simon Payge's iPhone 4S.ofb/013043005068452-06-02-2013 10-51-49/SkypeAccounts/SkypeAccount 0

Name	Location	Modified Time	Change Time	Access Ti
main.db	/LogicalFileSet1/Simon Payge's iPhone 4S.ofb/013043005...	2013-02-06 12:27:38 CST	0000-00-00 00:00:00	0000-00-00

Displays extracted text from files and keyword-search results. Requires Keyword Search ingest to be run on a f

```
CREATE TABLE DbMeta (key TEXT NOT NULL PRIMARY KEY, value TEXT)+
indexsqlite_auto
cur_schema_namebase 1.0
+           cur_schema_name
 8]
echo123
 Skype
 Skype
|4]
+79035841186
+79035841186
+4302569898
Andy McMastersAndy McMasters
|(`                      !
lars.jasonlars.jason
A.`a
VkzoQ
H+:.
:d`I]
n5.`
,`                       3
oxrgen.test.accountoxrgen.test.account
]9VU
```

Figure 10. Senior View of SkypeAccounts



/LogicalFileSet1/Simon Payge's iPhone 4S.ofb/013043005068452-06-02-2013 10-51-49/SkypeAccounts/SkypeAccount 0 1 Res

Name	Location	Modified Time	Change Time	Access Time	Created
main.db	/LogicalFileSet1/Simon Payge's iPhone 4S.ofb/013043005...	2013-02-06 12:27:38 CST	0000-00-00 00:00:00	0000-00-00 00:00:00	0000-00-0

Displays metadata about the file.

Name	e's iPhone 4S.ofb/013043005068452-06-02-2013 10-51-49/SkypeAccounts/SkypeAccount 0/main.db
Type	Local
Size	380928
File Name Allocation	Allocated
Metadata Allocation	Allocated
Modified	2013-02-06 12:27:38 CST
Accessed	0000-00-00 00:00:00
Created	0000-00-00 00:00:00
Changed	0000-00-00 00:00:00
MD5	fc0019873677c3916b6f604b021b56db
Hash Lookup Results	UNKNOWN
Internal ID	78969
Local Path	E:\autopsy 3.1.0\privacy forensics\ModuleOutput\Archive Extractor\Simon Payge's iPhone 4S.ofb_6\66\66508main.db

Figure 11. Junior or Intermediate View of Skype Accounts

The set of experiments can thus illustrate and verify the effectiveness of the proposed ontology-based framework for privacy preservation in digital forensics. We can see that the lack of proper policies of protecting privacy in digital forensics process will lead to serious privacy issues. On the contrary, the proposed privacy preserving digital forensics framework can serve to balance the privacy requirements and the needs of digital forensics investigations.

5. Conclusion

In this paper, we presented a privacy preserving forensics framework based on ontology by abstracting the privacy attributes in digital forensics scenarios. Privacy protection in the proposed ontology-based digital forensics framework is then realized through allocating rights at different levels of the hierarchy. We discussed the necessity of preserving sensitive information in the process of investigating digital devices and applied the proposed ontology to classify information involving privacy in three aspects: data types, forensics scenarios and forensics scopes. We also analyzed the effectiveness of the framework using real data. Such a privacy enhancing digital forensics framework would enable better categorization of digital forensic disciplines and assist in the development of methodologies and specifications that can offer direction in preserving privacy in digital forensics. Finally, forensic specialists, judicial surveyors and researchers with an interest in the areas of digital forensic tools, privacy discipline and development of forensics methodologies should find the framework in this paper very constructive.

Acknowledgements

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