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Software Validation and Daubert Standard Compliance of an Open Digital Forensics Model

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Abstract - With the widespread increase in Cybersecurity incidents, there has been increased attention on the development of digital forensics tools and methodologies. We investigate a suite of Cyber-Forensic tools in the Open Source CAINE Linux Distribution, and conduct experimental software validation testing in support of open source code compliance with the well-established Daubert Standard for forensic evidence collection. We propose how tools such as Guymager, Autopsy, Fred, and PhotoRec can can be applied as part of a four tier forensic architecture, including experimental results which demonstrate the application of these tools.

Keywords: CAINE, cybersecurity, Forensics, Daubert.

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1. Introduction and Background

In recent years, both the number and severity of cybersecurity attacks have increased significantly; by some estimates, losses from such attacks are expected to exceed \$2 trillion annually by 2019 [1]. The widespread increase in cybercrime has led to a corresponding interest in digital forensics investigation tools and methodologies. Several frameworks have been proposed for structured forensic analysis, but there has been comparatively little discussion around practical implementations of these frameworks. The potential use of open source forensic tools is a particularly attractive approach to this problem, since open source enables rapid development of security forensics tools and places these tools at the disposal of the security community for little or no cost. However, in order for digital evidence to be admissible in a court of law, it must comply with legal precedents such as the Daubert Standard [2]. There has been ongoing technical debate over the compliance of open source tools, and there is a need for additional documented testing in support of typical use cases. Specifically, a new suite of open source forensics tools has recently become available as part of the Computer Aided Investigative Environment (CAINE) distribution of Linux [3]. In this paper, we investigate how these forensics tools may be applied to a structured cybersecurity evidence gathering procedure, and we perform testing which may be used to assess compliance with relevant legal precedents.

While a cybersecurity incident may generate a great deal of interesting data, not all of this data qualified as forensic evidence that is admissible in a court of law. There are a number of professional organizations which have attempted to insure quality and consistency of evidence gathering within the forensic community and provide technical recommendations including how to preserve chain of custody (insuring that evidence possession is always tracked and auditable, compliance with rules of evidence, collection of volatile information first, searching disk slack space, etc.) [4]- [7]. For purposes of this paper, we will concern ourselves primarily with U.S. forensics legal precedents; these may differ from international standards, and may evolve in the future to include new techniques not available at this time. Generally speaking, most forms of digital forensic

Date Received: 2020-05-11 Date Accepted: 2021-08-11 Date Published: 2021-09-02 evidence fall outside the common knowledge of a jury, which must therefore rely on testimony provided by technical subject matter experts. Historically, expert testimony has been required to meet the so-called "general acceptance test" established by the Frye standard [8], which holds that scientific or technical evidence is only admissible in court if it was collected using a framework deemed generally accepted by the scientific community. Under this approach, the scientific community serves as the gatekeeper in determining whether digital forensic evidence is admissible in court.

This approach was modified in the early 1990s to a standard under which the judge, not the scientific community, determines whether forensic evidence is admissible on a case-by-case basis. The standards regarding admissibility of digital evidence and the use of expert witness testimony from computer forensics specialists were derived from the precedent setting U.S. Supreme Court case Daubert vs. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579 [2]. The court found that evidence or expert opinion derived from scientific or technical activities must come from methods that are proven to be "scientifically valid" and which meet five basic criteria [2]. In the context of digital forensics, the Daubert Standard means that tools and techniques used to collect and analyze digital evidence must be validated and proven to meet scientific standards. More specifically, digital evidence presented in a trial must have come from tools that can be proven to yield correct results through empirical testing. The tools and methodology used must pass peer review, use generally accepted theory and technique, and demonstrably meet acceptable error rates and standards. A trial judge may use the Daubert Standard to assess whether digital evidence can be properly applied to the facts at issue in a given case. Under Federal Rule of Evidence 702, digital forensic evidence in U.S. federal courts is governed by the Daubert Standard. Individual states are allowed to establish their own Rules of Evidence, which may follow the Daubert Standard or other criteria under different circumstances [9].

Establishing whether open source digital forensic tools can meet the Daubert Standard requires ongoing, periodic software validation testing. As defined by government organizations such as the U.S. FDA and CDRH [10], software validation is performed on a finished tool or piece of code, and is defined as 'confirmation by examination and provision of objective evidence that software specifications conform to user

needs and intended uses, and that the particular requirements implemented through software can be consistently fulfilled.' In practice, software validation activities may occur both during as well as at the end of the software development life cycle. Such validation depends on testing, inspection, and analysis of tasks performed by the software, along with empirical evidence that software requirements have been correctly and completely implemented, and are traceable to system requirements or so-called "user stories" employed in the software design life cycle. This is not to be confused with software verification, which provides objective proof that design outputs of a given phase in the software development life cycle meet the specified requirements of that phase. Verification may include inspection of source code, documentation reviews, static and dynamic analysis, design walkthroughs, and other techniques. Software verification determines correctness, completeness, and consistency of code (often during the development process), often involving a line-by-line code review. We do not perform this level of analysis, since it has been established reproducible testing at regular intervals, with an acceptable level of granularity, is sufficient to demonstrate Daubert compliance [11], [12]. Conventional approaches to Daubert Standard compliance have favored closed-source code and tools, arguing that such code cannot be easily manipulated and citing widespread adoption and commercial product testing as proof of software validation. However, it may actually be easier to meet the Daubert Standard using open source forensic tools. This argument was originally put forth by Brian Carrier (author of the Autopsy tool discussed later in this paper) [13]. Open source forensic tools are implicitly granted community acceptance by virtue of their continued development and use, whereas closed source tools may rely on the advocacy of a single vendor. Open source tools also comply with aspects of the Daubert Standard related to publication, peer review, and periodic testing. In fact, the natural fit between open source community development efforts and software validation has led to open source forensics being called "the digital Daubert standard" [14]. In other words, open source forensic tools can easily and inherently prove that they are peer reviewed, published, falsifiable, generally accepted, and have a well established error rate.

By contrast, the Daubert Standard's stipulation are more challenging for closed source forensic tools. As

noted previously, such tools often cite their large user base to prove community acceptance. However, the user base for a given closed source tool typically chooses the tool for qualities such as ease of use, intuitive interface design, and service/support/ maintenance/upgrade features [13], which are not related to procedural code development factors. If market share isn't a valid metric, then proving closed source tools to produce reliable output may be impractical. Closed source tools may be presumed reliable for incomplete reasons, such as the assumption that such tools will perform as advertised at all times [14]. Indeed, any such perceived advantages of closed source is analogous to the idea that we might achieve security through obscurity, which can lead to the Daubert Standard being entirely circumvented [14]. If it is more desirable to publish and openly evaluate forensic tools, then a framework of best practices has been recommended to insure that such tools are accepted in a legal setting.

The following steps should be taken to insure long-term acceptance of open source forensic tools [13]:

- 1) Development of comprehensive tests for forensic tools
- 2) Publication of tool designs to help create more effective tests
- 3) Creation of a standard for calculating error rates for both tools and specific procedures
- 4) Publication of specific procedures that a tool uses. While open source tools already publish their source code, they should also clearly document the procedures used by their code
- 5) Public debate on the published procedural details to ensure that they are agreed upon.

In this paper, we will apply this framework to CAINE tools in order to determine if they meet the longterm acceptance criteria listed above. Novel features of this work include empirically testing these open source tools against common use cases to validate that they produce correct and desired output within acceptable error rates. This paper will disseminate these results to the peer community, which will both add to the body of knowledge used by the digital forensics community and encourage the development of additional use cases. We document the features of the CAINE toolkit in this context, and map them against typical user requirements. Our use cases include disk imaging, file recovery, and hive management using CAINE tools including Autopsy, Guymager, Fred, and PhotoRec. We also review how these tools may be applied to a cyberforensics architecture, and discuss relative strengths and weaknesses of this approach based on our experimental testing.

The remainder of this paper is organized as follows. After an introduction and brief review of prior art, Section 2 presents a four tier reference architecture for the various forensic tools available in the CAINE distro. Section 3 provides experimental results from using these tools, compared with other alternatives to help establish their prevailing error rates. A step-bystep description of this validation testing is provided to facilitate reproducibility of our results. Section 4 summarizes our results and conclusions of this work.

2. Forensic Architecture Development

The acceptability of digital evidence in a court of law is based on principles originally developed for more conventional forensic investigations. Both approaches require a chain of custody to insure that original evidence is immune to tampering. Digital evidence is more fragile than other types of physical evidence [15], thus investigative reports must be created to explain the digital evidence examination process and its limitations. There have been many efforts to develop consistent guidelines for digital forensic investigation [16], [17], including the first responders crime scene investigation model published by the U.S. Department of Justice [18]. This approach forms the basis for many different proposed data handling frameworks; while these models differ in the number and details of their process steps, they can conceptually be reduced to a basic four tier approach [19]. We have previously published an approach based on this methodology [20], so we will only provide an overview here. The first tier (the preparation or collection phase) involves the search, recognition, collection, and documentation of electronic evidence. The second tier is the examination phase, which helps to make digital evidence visible, explains its origins and significance, and reveals obscured information. The third tier is the analysis phase, which involves studying the product of the examination tier for its relative importance to the case under investigation. The fourth or reporting tier includes documenting the results of the examination process and limitations of the investigation. In the following sections, we describe a set of tools available in CAINE which address this four tier approach. We then demonstrate experimentally how the tools may be

applied in a practical use case, and use this data as the basis for establishing compliance with the Daubert Standard.

The benefits associated with using open source tools in this framework include rapid innovation driven by a global development community and free or inexpensive access to a broad cross-section of security professionals. Such tools would also facilitate training and education efforts to address the lack of security practitioners and service industry professionals [20]. In October 2014, the forensic Linux distribution known as CAINE (short for Computer Aided Investigative *Environment, but also named after the popular character* Horatio Caine on the television series CSI Miami) first became available from project manager Nanni Bassetti. More recent editions of CAINE are based on Ubuntu 12.04 and Linux kernel 3.2, but with the GNONE 2 fork known as MATE providing the desktop environment. CAINE differs from many other specialized distros because it also provides a suite of general purpose desktop tools which allow it to be used as a classic Ubuntu system, eliminating the need to switch back and forth between a general purpose environment and the advanced forensic tool features. Normally, a general purpose distribution would not be suitable for forensic purposes, because it automatically mounts all available drives as read/write. This poses several problems, including changing the "last mounted" times and potentially erasing data (including hidden data) when writing to the drive. To avoid these issues, CAINE never automatically mounts any device. Mounting is only possible through an applet called Mounter, accessible to the user through the system tray or command line (via the "mount" command). This applet also allows users to toggle the system policy for all future mounts from read/write to read-only and back again. In this paper, we focus on four CAINE tools which can be mapped to four forensics architecture discussed the tier previously. First, *Guymager* is an open source forensic disk imaging tool included with CAINE. It is a QT-based forensic imager [14]. Guymager also includes a compression engine, that can compact a disk image into one file for subsequent forensic analysis without harming the original image. This supports the principle of preserving evidence that will be admissible in a court of law, and provides the first step in our forensic framework. Second, *Autopsy* provides a library of tools that are designed to investigate and analyze disk images, including recovery of lost, deleted, or hidden (steganographic) data. Previously available as the GUI

interface of The Sleuth Kit (TSK) project, Autopsy performs time line analysis, hash filtering, keyword search, extract web artifacts and much more. These functions are useful in the second and third tiers of our framework. Third, the *Forensic Registry Editor* (*FRED*) is a cross-platform registry hive editor including a hex viewer and data interpreter. FRED uses four different hive files: NTUSER.dat, SAM, SOFTWARE, and SYSTEM to generate a report of the interpreted data. These reports are used for the second and third tiers of the forensic analysis framework, because they show the last actions performed on the system. FRED also supports the basic forensics principle of not leaving any trace on the system being analyzed which could cause results to be altered. Normal forensic procedure would require imaging these files to avoid altering them - however hive files running on a system cannot be copied. Running FRED as a stand-alone tool on the operating system would also run the risk of affecting data and damaging files. Both of these concerns are alleviated by running FRED under the CAINE operating system. Fourth, *PhotoRec* is an open source data carver, used to recover deleted, lost, or damaged files or compare file checksums. PhotoRec is useful in the second through fourth tiers of our forensic architecture.

3. Experimental Results

We experimentally validated the use of these four tools in forensic analysis of a suspect disk drive. Tier 1 data recovery was done using Guymager to image the disk, and Tier 2-3 analysis was performed using Autopsy, Fred, and PhotoRec. Built-in features for all these tools (particularly PhotoRec) facilitate Tier 4 documentation throughout the forensic process. We performed disk imaging using Guymager, which provides a list of available mounted disks and details such as the disk size and serial number as shown in Figure 1. From this list, it is possible to right click on any image and select "Acquire Image". The proper image directory location has to be chosen, and information such as case number, examiner, description, and image filename may be entered in the "Acquired Image" window. Clicking Start will begin the process of creating the disk image within the specific directory that was assigned. Our testing for 25 different disk images was completely consistent with other accepted methods for creating forensically sound disk images, with no observed errors. For comparison, we used the bit-by-bit copying techniques available in practically every Linux/UNIX distribution; in particular, Kali Linux uses a version developed by the Department of Defense Digital Computer Forensics Laboratory (DCFLDD). The syntax is:

dd if=<source> of=<destination> bs=<byte size>

The resulting disk image is then imported to Autopsy for analysis. Autopsy was originally created by Brian Carrier [13, 15] as a graphical interface for The Sleuth Kit (TSK) and other digital forensic tools. The architecture is based on modular plug-ins, which allows the selective incorporation of file analysis routines created by third parties. It is recommended to disable JavaScript for these experiments, as it is not required to run Autopsy and may inadvertently modify files, corrupting the chain of custody. Some key features of Autopsy used in forensic analysis are summarized in Table 1.

Table 1 – Key Forensic features available in	Autopsv
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Multi-User	Enables collaboration with teams of
Cases	forensic examiners on larger cases
Timeline	Graphical interface displays system
Analysis	events to help identify causal
	relationships
Web Artifacts	Extracts user activity from common
	web browsers
Registry	Uses RegRipper tool to analyze
Analysis	hives, including recently accessed
	documents
LNK File	Identifies shortcuts and recently
Analysis	accessed documents
Email Analysis	Parses MBOX format messages
EXIF Analysis	Extracts geolocation and camera
	information from JPEG files

Autopsy can be accessed through CAINE in the same way as Guymager. Selecting Autopsy from the menu options automatically opens a terminal shell illustrated in Figure 1, with root authority. Users are prompted to open the GUI in a web browser; by default Autopsy installs to a local web server (localhost) accessible via port 9999.

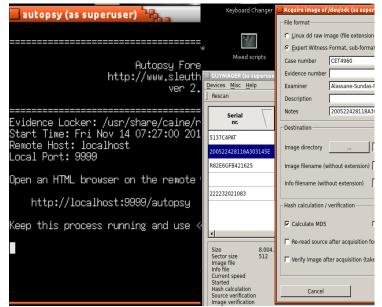


Figure 1 – (L) Autopsy terminal emulator shell (R) screen shot of Guymager disk imaging

The terminal shell will prompt the user to enter the URL provided into a browser to open up the Autopsy GUI, shown in Figure 2. From here the user can select an existing case, creates a new case, or ask for help. When the user creates a new case, they have to provide a name for the case along with up to six names of the investigators (most practical forensic analysis is *conducted by a team of experts*). There is also an option to describe the case. This prompt automatically creates a report as the investigation proceeds. As with all legal cases, it is critical to insure that the disk image has not been tampered with from the time it was captured until the time of the trial. Guymager follows the best practice of generating a hash for the captured disk image. Autopsy provides the option of importing this hash (recommended), or calculating a new hash before the start of image analysis if the hash does not already exist. This illustrates how Tier 4 requirements are enabled throughout the investigative process. In order to analyze an image, the user needs to create a new case for each image as shown in Figure 2.

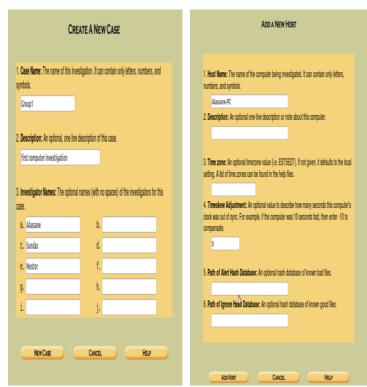


Figure 2 - (L) Creating a New Case (R) Creating a New Host

After creating the case, the user is required to specify a host. Other information are optional, however we found it helpful to include the paths for the Alert and Ignore data bases. These paths can help filter the results, and files that have been tampered with can be identified in this manner. The main part of the analysis occurs after adding the host, when the user is prompted to add an image file. The proper file type and format must be selected in order for Autopsy to analyze the image. The Hash databases option provides additional information, including options for the file activity time line, notes, and event sequencer. This allows the user to create time lines and notes for the investigation. Once the host and case are created, the user will be prompted to add the host to the case. Then an image can be selected for analysis, typically from the same location used when the file was created using Guymager. For our testing, we selected the type of image file as disk and the import method as Symlink. When the image is added, a file summary is displayed including the mount point and type of file system recognized on the image. Examples of mounted images are shown in Figure 3.

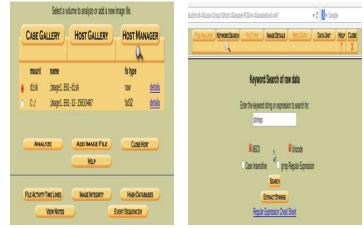


Figure 3 – (L) Mounted images within Autopsy (R) keyword search of raw data

The user can enter a keyword, string or expression that can be searched within the image. The type of data can also be selected, such as ASCII or Unicode. In this case "strings" was entered as the keyword to search. A set of predefined search options are also available. After clicking "Search", a new window shows that in our case, 92 occurrences of "strings" were found with the selected settings (see Figure 4). Subsequent views expand on this screen showing all of the occurrences within that unit. These can be viewed in both HEX and ASCII.

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Unit 26301 (Hax - Asci) 8 7701405 7433940 666619 60011-9 r,le 1CPI rish. his 1:212 6 6 7701405 7403940 666619 60011-9 r,le 1CPI rish. his 2:238 9 7601405 7403974 754453 940395 r,le 1CPI rish. his 2:238 12 8606040 4913561 669440 51445549 r,le 1CPI rish. his Unit 65611 (Hax - Asci) 3 28 6167509 698456; 731462 651605 rish. risk like circle 3: 329 12 6666175 6901844 5745561 675586 66443 risk like circle risk like circle risk like circle Unit 67213 (Hax - Asci) 36 646475 646475 risk like circle risk like circle risk like circle 1016 17219 (Hax - Asci) 226 6667135 601844 5745614 5713746 risk like circle risk like			00 64024765 74537464	69746546 696c650	4		
Contraction Contraction <thcontraction< th=""> <thcontraction< th=""></thcontraction<></thcontraction<>							
1: 212 9 74/14/530 000782 rfts/4/1 554/245 74/27. 5 reft 0 ff/2 2: 238 12 66/57506 c584/34 514/3550 11/27. 1/2 reft 0 ff/2 2: 238 12 66/57506 c584/34 514/3550 11/27. 1/2 reft 0 ff/2 126 66/57506 c584/34 754/3575 66/575 566/34 11/3 reft 1 filter 11/2 reft 1 filter 126 66/57506 c584/36 7 56576 66/345 (r45557 565696 c68/5457 56576 66/3456 (r457569 c68/5457 56576 c68/3457 r475757 66/441 r557172 5776 reft 1 filter 11/2 reft 1 filter 3: 329 12 66/6475 0001348 574/641 r557172 5776 reft 1 filter 11/2 reft 1 filter reft 1 filter reft 1 filter 128 66/6475 0001348 574/641 r557172 5776 reft 1 filter reft 1 filter <t< th=""><th></th><th></th><th></th><th></th><th></th><th>it 26301 (Hex - Ascii)</th><th>Unit 26301 (Hex - Ascii)</th></t<>						it 26301 (Hex - Ascii)	Unit 26301 (Hex - Ascii)
2:238 128 61575696 61575696 61575696 61575696 61575 6667614 1.8 1.0 1.8 1.0 1.0 1.0 5675596 615575 6667614 1.1 1.0 5675596 615575 6667614 1.1 61575596 615575 61575596 615575 61575596 615575 61575596 615575 61575596 615575 61575596 615575596 615575 61575596 615575596 615575 61575596 615575 61575596 615575 61575596 615575 61575596 615575596 615575596 61575596 6157575 6157559							
13 0010500 (SetVald, Faitok, 011000) age: :::11 skrt(0kr. 14 c10456(7 356076 d641675 5606084) .:15 setValue, ::10						238	2-238
Unit 65611 (Hex - Asci) 16 546/735 657546 (657546) Tils etta lue Tils etta lue 3: 329 10 566/435 (557546) C15546 (618542) Tils etta lue							2.200
176 7347355 5500048 423461 1951724 sfree						it CEC11 (Hox Accii)	Unit 65611 (Hox Acoii)
3.02000 122 6666575 0001394 5274655 6770664 r.m. NULL NULL <th></th> <th></th> <th></th> <th></th> <th></th> <th></th> <th></th>							
Unit 67213 (Hax - Asoi) 224 656-14337266 6773766 46173767 461176 764 4:64 208 7245676 6773766 46173767 461176 et al. 10 7245676 4537276 961676 526 565674 531729 456 10 10 mart 517 5:103 256 6667737 6606164 5265748 516646c ngsl 54th and						329	3: 329
4: 64 240 74456e76 6972616e 66656e74 53747269 tEnv iron ment Stri 5: 133 256 6e677357 0006764 3567480 156456c ngsio. Setti and	i ronm	d.a. Free Envi r					11 11 07040 01 1
5: 133 256 6e677357 00006f04 53657448 616e646c ngsilo. SetH and							
3. 100 STATE COMPANY CONTRACT CONTRACT TANKING CONTRACT							
2/2 b543bT/5 be/40000 T3014765 7446696c eCountGe tFil							
0: 357 288 65547970 6500a703 51756572 79506572 eTyp e Quer yPer						357	6: 357
7:434 288 0554/9/0 05068/85 51/505/2 /95065/2 eryp e quer yeer 304 666f726d 616e6365 436f756e 74657280 form ance Counter.						434	7: 434
304 001/200 0126							
Unit 67301 (Hex - Ascii) 336 65737349 64067902 47657453 79737465 essī d.y. GetS yste						it 67301 (Hey - Ascii)	Unit 67301 (Hex - Ascii)
8:117 352 6d54696d 65417346 696c6554 696d6500 mTin eAsF ileT ine.							

Figure 4 – (L) search data results (R) Autopsy Hex report

By selecting the "File Analysis" option, the analyzer generates a list of files within the disk image

(file browsing mode). This allows the access of files and directory content including the date the files were created, last date accessed, size of the files, and other meta-data (Figure 5 shows the files within the C:/ directory). It is also possible to select a view of "Deleted Files" in the image, along with information on when they were created or last used (as seen in Figure 6). Figure 7 shows that files that in red are in data recovery mode. These files can be opened to view their contents (also seen in Figure 7). Although the file contents are typically encoded, Autopsy can scan and analyze the The forensic analyst can explore the image files. contents of the files using File Analysis. They can even search for files that have specific keywords or names that have been deleted. This action cannot be performed on a typical general purpose operating system. As seen in Figure 4, reports of the data can also be generated in ASCII or HEX formats. Forensic analysts can use these reports to determine if there are any dangerous/ suspicious files/directories within the disk whether they are currently on the system or have been deleted. Our testing of 25 different files revealed no detectable errors when using this approach.

		U.			? X					
Directory Seek Enter the name of a directory that you want	Current Direc	lory: <u>C:/</u> Generate MD5 List of Fil	8							
to view. C:/	DEL Type dir/in	Nume	WRITTEN	ACCESSED	CREATED	SIZE	UID	GID	Meta	
	v/v	<u>SFAT1</u>	0000-00-00 00:00:00 (UTC)	0000-00-00 00:00:00 (UTC)	0000-00-00 00:00:00 (UTC)	1953280	0	0	<u>250011</u>	65
View	v/v	<u>\$FAT2</u>	0000-00-00 00:00:00 (UTC)	0000-00-00 00:00:00 (UTC)	0000-00-00 00:00:00 (UTC)	1953280	0	0	<u>250011</u>	65
File Name Search	v/v	<u>SMBR</u>	0000-00-00 00:00:00 (UTC)	0000-00-00 00:00:00 (UTC)	0000-00-00 00:00:00 (UTC)	512	0	0	<u>250011</u>	65
Enter a Perl regular expression for the file names you want to find.	d/d	<u>\$OrphanFiles/</u>	0000-00-00 00:00:00 (UTC)	0000-00-00 00:00:00 (UTC)	0000-00-00 00:00:00 (UTC)	0	0	0	<u>250011</u>	65
SEARCH			File Brows	sing Mode						
ALL DELETED FILES			In this mode, you can view	file and directory cont	ents.					
EXPAND DIRECTORIES		More fi	File contents will be s le details can be found using the Met You can also sort the files	shown in this window. adata link at the end o	the list (on the right).					

Figure 5 – Experimental scan of C: directory files

		File Analysis Keyword	SEARCH FILE TYPE MAGE DET	ALS META DATA	DATA UNIT HELP CLOS	ε			
Directory Seek	All Delet	ed Files							
Enter the name of a directory that you want	Type dir/in	NAME	WRITTEN	Accessed	CREATED	Size	UID	GID	Мета
to view. C:/	tļt	<u>C:/_WRD0000.tmp</u>	2014-11-10 09:58:18 (CET)	2014-11-10 00:00:00 (CET)	2014-11-10 09:58:16 (CET)	315392	0	0	<u>29</u>
_	t/t	C:/_DWINU+1.DOC	2014-10-29 19:39:56 (CET)	2014-10-29 00:00:00 (CET)	2014-10-29 19:39:54 (CET)	0	0	0	<u>30</u>
Vew	t/t	C:/_ET4773.pdf	2014-03-19 13:37:16 (CET)	2014-05-20 00:00:00 (CEST)	2014-03-19 13:36:46 (CET)	42789228	0	0	<u>73</u>
File Name Search	ılı.	<u>C:/ANgaide Midte</u>	2013-12-06 17:50:26 (CET)	2014-01-12 00:00:00 (CET)	2013-12-05 17:34:02 (CET)	1836702	0	0	<u>88</u>
Enter a Perl regular expression for the file names you want to find.	d/d	C:/_RASHE~1.SUU	2013-12-17 21:13:12 (CET)	2013-12-17 00:00:00 (CET)	2013-12-17 21:13:13 (CET)	0	0	0	<u>91</u>
Search			Fi	e Browsing Mode					
ALL DELETED FILES			In this mode, yo	u can view file and directory	contents.				
EXPAND DIRECTORIES			More file details can be found using	nts will be shown in this wind ng the Metadata link at the e nt the files using the column	nd of the list (on the right).				

Figure 6 - View of deleted files

Directory Seek		<u> </u>										
Directory Seek								? X				
Directory Seek					01:23:34 (CEST)	00:00:00 (C	EST) 01:2	3:33 (CEST)				
	t/t	<u>4773.zip</u>			2014-05-20 19:12:52 (CEST)	2014-11-14 00:00:00 (C		I-05-20 2:20 (CEST)	35953677	0	0	<u>67</u>
Enter the name of a firectory that you want o view.	d/d	<u>4773/</u>			2014-05-20 19:11:54 (CEST)	2014-05-20 00:00:00 (C		I-05-20 1:53 (CEST)	16384	0	0	<u>69</u>
::/	d/d	<u>4811/</u>			2014-05-20 19:33:10 (CEST)	2014-05-20 00:00:00 (C		I-05-20 3:08 (CEST)	16384	0	0	<u>68</u>
View	r/r	8784634077-	260849233-regist	ration.pdf	2014-03-04 00:30:22 (CET)	2014-11-10 00:00:00 (C		I-03-04 0:21 (CET)	113709	0	0	<u>57</u>
	✓ th	<u>131.pdf</u>			2013-09-11 01:45:04 (CEST)	2014-01-12 00:00:00 (C		I-09-11 5:02 (CEST)	538923	0	0	<u>497</u>
File Name Search	🗶 th	_0137693.tm	2		2013-05-21 13:19:32 (CEST)	2013-05-21 00:00:00 (C		I-05-21 7:26 (CEST)	231102	0	0	<u>373</u>
inter a Perl regular expression for the file names you want to find.	🗸 tit	_062F65F.tm	2		2013-05-15 19:09:52 (CEST)	2013-05-19 00:00:00 (C	2013	I-05-15 9:49 (CEST)	143110	0	0	<u>257</u>
			ASCII (<u>dis</u>	<u>play</u> - <u>report</u>) * H	lex (<u>display</u> - <u>report)</u> * <i>I</i> File Type: PDF do Deleted File F			<u>export</u> * <u>Add Not</u>	Ē			
Search	Contents Of F	ile: C:/131.pc	If									
ALL DELETED FILES	\PDF-1.7											
EXPAND DIRECTORIES	766*6365666164 G66365\056*66	XXX020H0.0/S60,H	00020>0=0kcl0000< ij00201k/03T000564	00000000;p0vtP0	#888=88828+8888-87884 8884:8881:8841884184	88688/p4>8888<88	Drāvējiete kale ta	1628\6\6q#66F66	NCRNN#rF_}}%	6"6,66]	[666[x0	866° Gill of 66
	gy/ 16j1676b36666	666666 F560 6 #630:	[66)sh6666666yc66	1666]666zYv6	; 66xrHuG 65V64\63; 366666;66vP8.676,c666				6(66 LU662N6p 6/4666::V\6%6bi			+L&o- 66 kL&

Figure 7 - View of files in recovery mode

To successfully analyze the hive files on this system without harming them, the user has to boot the CAINE operating system from a CD. The hard disk and any other USB storage connected to the host computer will be mounted. From there the user can double-click the mounted hard disk and explore the files of the system without any restrictions. It is not possible to tamper with the hard disk since it is read only. The first registry of hive files we scanned was NTUSER.dat. This file was found by going to the mounted hard disk and then USERS \Sundas (or hostname). After copying the file onto the desktop as an additional precaution against tampering, the CAINE GUI was used to select Menu > Forensic Tools > Fred. This enables registry and hive files to be opened, such as the NTUSER.dat file including file keys and hex views illustrated in Figure 8.

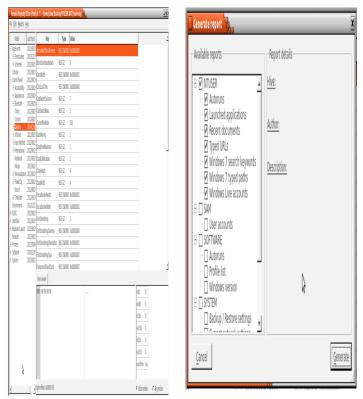


Figure 8 – (L) registry file view (R) available reports and translated data

Figure 8 shows the available reports and translated data that can be generated. For example, the NTUSER gives information on auto runs, launched applications, recent documents, typed URLS, Windows 7 searched keywords, Windows 7 typed paths and Windows live accounts. The resulting report file examples are shown in Figure 9 including the last run dates of those applications on the right. If a user even deletes their history, by running this scan, analyzers can determine which applications are being used within the system and when they were being used last. We confirmed correct operation of these functions with no errors after 25 independent trials.

Launched applications

Application	Run coun	t Last run
UEINE_CTLSESSION	164	2018/10/25
UEME_CTLCUACountidor	0	n/a
AM	0	n/a
Apple.iTunes	0	n/a
C/PROGRA-2/MCROS-1/Diffee12/DIS.EXE	0	2012/12/10
C:Users'Sundas'AppData/Pictures'Applications'NLLab/VEW 2010.v10.0 setup.exe	1	2013/04/10
C:Users/Sundas/AppData/Pictures/Applications/NLLab/VEW/2010.v10.0/keygen/NLLV10_CTG.exe	1	2013/04/10
C:Users/Sundas/AppData/Roaming/Owiklinx/ProcessDetector.exe	0	n/a
C:Users/Sundas/AppData/Roaming/Owiklin/UninstaliPlugin.exe	0	n/a
C:Users/Sundas/AppData/Roaming/Condut/Uninstaller/CT3277370/CT3277370.frefox.uninstall.exe	0	n/a
C:Users/Sundas/AppData/Local/Temp/7zSE455.tmp/Uninst.exe	0	n/a
C:IUsers/Sundas/AppData/Local/Temp/Rar\$EX60.056/httzing.2012.10.09.pc/Fittzing.exe	0	n/a
C:Users/Sundas/AppData/Local/Temp RarSFXI/Photoshop.exe	0	n/a
C:Users/Sundas/AppData1Local/Temp/TeamViewer/Version7/TeamViewer.exe	0	n/a
C:Users/Sundas/AppData/Local/Temp/TeamViewer/Version/TiteamViewerexe	0	n/a
C:Users/Sundas/AppData/Local/Temp/TeamViewer/Version8/TeamViewer.exe	0	n/a
C:Users'Sundas'AppData!Local TempiTeamViewer/Version8 Team Viewer_exe	0	n/a
C:Users Sundas AppData Local Tempi GUM8084.tmpi Google Update.exe	0	n/a
C:Users/Sundas/AppData1Local/Tempinsu5589.tmp17zG.exe	0	n/a

Figure 9 – file report example

Figure 10 shows all of the recent documents that have been opened along with typed URLs and typed keywords. In 25 trials, our system was able to correctly identify the complete hive history with no observable errors when compared with alternative tools such as RegEdit

Report Viewer	Report Viewer
File	Eile
Recent documents	one dc molor.fzz one dc molor.f2(1).fzz EMT2461 Books.rar
PSYCH 3 PSYZ301-Preschool Handout.docx The Genius in all of Us.epub	Typed urls
Ch Ti ppt dn 68 x(1)(ppth PSNDRVE (E) PSY2001- Research Methods Assignment 2 docx PSY2001- In The World Assignment 3 docx	Last added URL Unknown http://go.orgie.com/ Unknown http://go.microsoft.com/twlink/?Linkid=69157
PS1 230 - In the Womb Assignment 3.00cx The Genius Downloads	Document and folder search keywords
ch03.ppt ch02.ppt ch01.ppt DSC_0305.JPG	tab 3 pi trizing pho
Signal 3.docx TestingSignal3.m Zatar FourierSeries.m Zatar Fourier.m	MidtermSundasZafar motorcontholler photoshop 2
Untified m Zafar m Work	z lab fsundaszafar zafarabudulab 13 ardulno
Zalar_origan CET 3615 Lab 6 docx E: CET 3615 Lab 6 Schematics.docx	arduinouno.inf xforce Jso
Cell 9 to Late 9 Schemalics.dock Documents 10503 MG_0185.JPG	.so links craok
NILLabVIEW 2010.v10.0 solupini Lab 3.docx	Typed paths
CET 3615 Lab 3	F:Applications/Autocad 2012 X64/autocad2012 x64

Figure 10 – recently opened documents, URLs, and keywords

We can also analyze a SAM file, as shown in Figure 11, which provides information related to user accounts on the system. Figure 12 shows which users are on the system including their name, the last time the user has been logged in, account expiry, failed logins, the last time a password was changed, and even password hints.

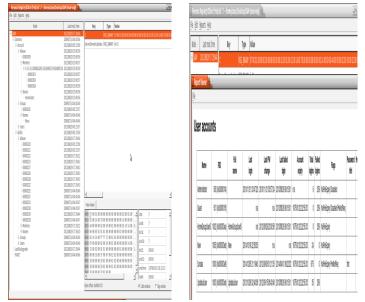


Figure 11 - (L) SAM file analysis (R) user account history

The information given by SAM can help computer forensic analyzers to determine whether someone else is trying to physically log into user accounts. If an individual does not use their computer during a certain time, they can determine from using Fred that someone is logging onto their username at odd hours. From there, further research can be done to determine which files have been accessed. A similar process can be used for the Software hive and other system archives.

SAM 2012/08/2 Report Viewer		REG	BINAR	r 07 00	01 00 00 00 00 00 00 00 00 00					
	<u>,</u>					02 00 01 0				
	h					_	_	_	_	
file			-	-		_	_	_	-	
Last PW	Last failed	Account	Total	Failed		Password	Home drive	Logon	Profile	
change	login	expiry		logins	Flags	hint	and dir	script path		Comment
citatige	Ngill	expiry	ivyilla	indina						
				-				script path	path	
2010/11/21 03:57:24	2013/08/29 06:15:01	nia	6	259	NoPwExpiry Disabled			script path	path	Built-in account for administering the computer/domain
			6					scripi pain	path	
	2013/08/29 06:15:01 2013/08/29 06:15:01	nia 1975/01/22 22:55:33	6	259 259	NoPwExpiry Disabled NoPwExpiry Disabled PwNotReq			scripi pain	path	
nia			6 0 0		NoPwExpiry Disabled PwNotReq			scripi pain	path	Built-in account for guest access to the computeridoma
nia 2012/08/29 23:00:58	2013/08/29 06:15:01 2013/08/29 06:15:01	1975/01/22 22:55:33 1975/01/22 22:55:33	0	259 259	NoPwExpiry Disabled PwNotReq NoPwExpiry			scripi pain	path	Built-in account for guest access to the computeridoma
nia	2013/08/29 06:15:01	1975/01/22 22:55:33	-	259 259	NoPwExpiry Disabled PwNotReq NoPwExpiry			scripi pain	path	Built-in account for guest access to the computeridoma
nia 2012/08/29 23:00:58 nia	2013.08/29 06:15:01 2013.08/29 06:15:01 nia	197501/22 22:55:33 197501/22 22:55:33 197501/22 22:55:33	0	259 259 0	NoPwExpiry Disabled PwNotReq NoPwExpiry NoPwExpiry	first		scripi pain	path	Bull-In account for administering the computer idonain Bull-In account for guest access to the computer idona Bull-In account for homegroup access to the computer
nia 2012/08/29 23:00:58 nia	2013/08/29 06:15:01 2013/08/29 06:15:01	197501/22 22:55:33 197501/22 22:55:33 197501/22 22:55:33	0	259 259 0	NoPwExpiry Disabled PwNotReq NoPwExpiry	first		scripi pain	path	Built-in account for guest access to the computer idoma

Figure 12 - example report generation screen shot

While our approach to the NTUSER file is consistent with our Tier 3 analysis objectives, we also

want to get translated data by generating a report. Figure 12 shows the available reports that can be generated and the information each file provides. The NTUSER gives information on auto runs, launched applications, recent documents, typed URLS, Windows 7 searched keywords, Windows 7 typed paths and Windows live accounts. The generate button will create reports from the NTUSER hive file. If a user even deletes their history, analyzers can use this scan to determine which applications were used and when they were last used. The NTUSER report shows all of the recent documents that have been opened along with typed URLs and typed keywords. If there are unknown URLs or files that are being accessed on the system unknowingly, then the NTUSER file will provide pertinent information. Autopsy will display the current network settings, showing information on each of the five adapters connected to the device, including IP address and subnet mask. The SYSTEM file shows every USB drive ever connected to the computer. The name of the storage device, vendor name, unique ID, class and mount point are given. This type of information is important because some users may be secretly trying to steal information by connecting a USB and copying files.

To further address Tier 4 requirements, the PhotoRec application was enabled to run behind the scenes to scan and document properties of a Windows host. First the CAINE ISO must be downloaded from its open source site (caine.org) and burned into a DVD or USB media (*USB media must be made bootable*). Since CAINE is being run live from a DVD, data cannot be written to it. Therefore, an external hard drive must be connected which is where the recovered files are stored. Guymager can be used to create an image which can be read and analyzed by PhotoRec. Selection of the recovered drive is shown in Figure 13.

"Mou	inte	r" (as supe	ruser)				×
E.				and their current and mount/unmo		itus.	
	Se	lected d	levices	will be mou	nted <mark>WR</mark>	TEABLE	
	Mal	ce a selectio	n:				
		Device	FS Type	Label	Size (MB)	Mount Point	Status
		/dev/sr0	iso9660	sblive	2.752	/cdrom	READ-ONLY
	~	/dev/sdb1	ntfs	New_Volume	3.834	(none)	(none)
					C Refre	sh 🛛 😵 Cancel	√ок

Figure 13 - selection of a recovered drive

Figure 14 shows the selection of the drive that will be scanned by PhotoRec, then the program is

asking the user to define the space or format of the system to be scanned in order to specify its scan to the particular file system, then illustrating scan results.

Jama 🖏	.ex
ile Edit View Search Terminal Help	File Edit View Search Terminal Help
hotoRec 7 0-KLP, Data Recovery Utility, August 2014 Dristophe CRENIER «grenier@cgaecurity org» http://www.cgaecurity.org	PhotoRec 7 0-KIP, Data Recovery Utility, August 2014 Dhristophe GRDNER ogramien(specurity orgp http://www.copecurity.org
1 P HS Data 0 2 5 1021 43 46 78520 tuon] To recover lost files, PhotoRec need to know the filesystem file were stored <u>Steat2[ent3]</u> ext2[ent3]/ext4 filesystem [Other] FAT/NUTS/HES-FRESEFS]	32 [Basic data parti Partition Start End Size in sectors type where the Pass 1 - Reading sector 318484/7856127, 64 files found Elapsed time (b00ml 4s - Estimated time to completion (h05h0) trf 32 recovered exe 22 recovered tr0 7 recovered pp 1 recovered gif 1 recovered gif 1 recovered size

Figure 14 – (L) drive selection (R) space definition and scan results

PhotoRec works by searching data clusters, so the time required for analysis depends on the size of the drive. The screen shot of Figure 14 shows ProtoRec in the process of detecting files which had previously been deleted by the FAT file system. Once this process is completed, the recovered files are moved to a destination specified by the user. We validated that this process generated consistent and correct results for at least 50 scan attempts on various Windows systems.

4. Conclusions

By experimenting with tools from the open source CAINE Linux distribution, a documented process was developed which maps to the proposed theoretical four tier model of Forensic Analysis. We conducted between 25-50 independent trials using typical forensic techniques, and confirmed that these tools had an error rate equivalent to previously establish tools (i.e. no errors were observed during the course of these tests). The results of this software validation testing supports our goal of establishing that CAINE complies with the Daubert Standard of forensic evidence reporting. Another of our goals was to recommend a preferred order for applying the Guymager, Autopsy, Fred and PhotoRec tools. As a Tier 1 tool, Guymager creates images of disks for Forensic Analysis, at Tier 2, Autopsy analyzes the images and allows data recovery, at Tier 3, FRED focuses on scanning and editing registry hives, while at Tier 4 PhotoRec recovers lost or missing data. This combination affords some advantages in the forensic investigation process. For example, unless the user already has an imaged disk, Autopsy as a standalone tool requires the extra step of creating an image before scanning for results. Guymager performs this function as an integral part of CAINE. While Autopsy provides useful results, it requires the overhead of creating a case and adding a host before attempting to recover the contents of a disk. By contrast, PhotoRec directly scans the disk for file recovery and may detect some files missed by Autopsy. In conducting forensics research with the CAINE integrated toolkit, our main obstacle was gaining access to the right type of file for each tool to analyze, since all four tools are very particular about their input file type. Although the CAINE operating system runs within a VMware workstation, an error would occur when the image/file to scan was chosen, even if the file format was correct. Care must be taken in following the mounting directions. It is not recommended to use CAINE on the host operating system, which can result in the actual data being corrupted. Further, there were some issues with creating bootable media by writing the ISO to a USB stick. These issues did not impact our testing against the five long-term factors related to the compliance of open source forensic tools.

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