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Web Browser Private Mode Forensics Analysis

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Abstract

To maintain privacy of the end consumers the browser vendors provide a very good feature on the browser called the “Private Mode”. As per the browser vendors, the Private Mode ensures Cookies, Temporary Internet Files, Webpage history, Form data and passwords, Anti-phishing cache, Address bar and search AutoComplete, Automatic Crash Restore (ACR) and Document Object Model (DOM) storage information is not stored on the system [45].

To put to test the browser vendors claim, I had setup a test to confirm the claims. During the first test the file system was monitored for all reads and writes. On the second test the image of the RAM was taken after the browser was used in private mode. The image was analyzed to check if the RAM contained any data related to the user browsing. The browsers chosen to perform this test were: Internet Explorer, Firefox, Google Chrome and Safari.

During the file system monitoring analysis for the browsers in private mode it was found that Google Chrome and Firefox didn’t write any data on the file system. Safari wrote data on just a single file called “WebpageIcons.db”. Internet Explorer wrote browsing data on the file system and then deleted it. This data can be recovered using any recovery tool such as Recuva.

During the memory dump based analysis for the browsers in private mode, it was found that browser data was recoverable for all the browsers.

Therefore from data privacy perspective Google Chrome and Firefox are safer to use than Safari and Internet Explorer.

1 Introduction

1.1 Introduction

Malicious users over the internet are constantly trying to steal as much data as they can for personal benefit from other users. The kind of information that can be valuable to the malicious user include but not limited to Social Security numbers, credit card numbers, online banking passwords, user email addresses, user address book, user browsing history, user download history, user search history, autocomplete information stored in browsers, user temporary internet files and user browser cookies, etc. Therefore, it is very important to ensure privacy over the internet. The server side privacy is generally enforced by regulations like Health Insurance Portability and Accountability Act (HIPAA) [39], Sarbanes-Oxley (SOX) [40] [41] [42], Privacy Act of 1974 [43], Payment Card Industry (PCI) [44], etc. However, the client side information which is also important is something that can be controlled by the end user. To handle information stored at end users' systems, the different browser vendors have introduced a new feature in their browser called InPrivate Browsing (Internet Explorer), Private Browsing (Firefox), Incognito Window (Chrome) and Private Browsing (Safari). These vendors claim that when the feature is used, following data is usually discarded after the browser is closed: Cookies, Temporary Internet Files, Webpage history, Form data and passwords, Anti-phishing cache, Address bar and search AutoComplete, Automatic Crash Restore (ACR) and Document Object Model (DOM) storage [45].

1.2 Problem Statement

Privacy has always been an issue with browsers, therefore the goal of this thesis would be to investigate and determine how well the new “Private” mode of browsers protect and ensure user privacy.

1.3 History of Browsers

Current day browsers are based on the idea proposed by Tim Berners-Lee and Robert Cailliau back in 1990 mainly to create a medium to distribute research papers to other interested people [1][2]. This led them to create the first browser known as the WWW short for WorldWideWeb [3]. The browser was used to interpret HTML to normal text and graphics better known as web page. Servers usually store these web pages and users use client systems to view the page. A user would type in the name of the web page they would like to access in the web browser and the server would grant the user access to the web page [4].

After the first browser WWW, lots of other browsers were shortly developed but one of the most widely used browser back then was NCSA Mosaic. The same team later created the first commercial browser called the Netscape Navigator [3]. Later the team created an open source version the browser known as Mozilla [3]. Microsoft quickly jumped into the market and launched their version of browser known as Internet Explorer in 1995 [8]. This quickly turned into a war between the two companies to increase their market presence. The two companies kept releasing on a monthly basis a new beta version of the browser without thinking about fixing bugs from earlier releases. This also made them only think about thrilling the clients with rich features and not follow standard coding practices released by W3C. This made the companies only think about adding new features and not worry about security. Therefore, the browsers released during that period were poorly designed in terms of code [5]. Due to this each release handled the tags and display layout differently and also had compatibility issues on different platforms (Microsoft and Macintosh)[6].

Initially Macintosh was shipped with Netscape Navigator, later they signed a five year deal with Microsoft to have Internet Explorer as the default browser. After the five year deal, Apple released their browser called Safari in 2003. It was first release only for the Mac OS and in 2007 released a Windows version of Safari too. They were third most widely used browser until 2008.

In 2008, Google released Google Chrome web browser which came as a surprise by a company whose main business is internet search engine. It mainly happened after they hired a group of developers from Firefox and demonstrated a working model of Chrome. The code for the browser was kept as open source. This helped other developers, learn the code and help in porting into other operating systems such as Mac OS and Linux based systems. As of today Google Chrome is the third most widely used browser followed by Safari [10][9][28].

1.4 Browser Security History

Browsers have become the most important part of the computer as they had become an interface between the user and the internet. Therefore it was really important to concentrate on the security of the browsers and not let any personal information of the end users leak due to vulnerabilities present in the browser. To handle all security related issues with browsers, Microsoft started the Trustworthy Computing initiative in 2002. This fully concentrated on finding and fixing all flaws related to the Internet Explorer Browser. Mozilla too fully focused on security aspect from the release of their first version of Firefox Browser in 2004 [7].

With the increase in market share of Macs, they are also being targeted in terms of finding vulnerabilities and exploiting them [18]. Also lately there are instance where more vulnerabilities have been found on Macs compared to Microsoft products [19]. Also since browsers form the big interface between the user and the internet, Safari has been a big target too for a lot of attackers [20]. But Safari also has been trying to concentrate on protecting their users as they were one of the first browsers to come out with the "Private Browsing" feature [21].

Google Chrome browser has been built with two separate modules called protection domains: the browser kernel which exchanges messages with the operating system and a rendering engine which runs with limited privileges in a sandbox. The main aim of Chrome is to prevent a malware from being run through the browser and file theft. The way the sandboxing works is that the browser runs on a restricted token instead of running with the users token and also every tab opened by a user is a new process by itself running with limited privileges. This would ensure that any malicious code would be running with limited privileges and can access data accessible only by the security token given to the limited privilege process [22][23][26]. Also due to this reason at a browser security competition Chrome survived the hit and was considered the most secure browser [25]. But it is not like Chrome didn't get hit with a series of vulnerability discoveries [24]. To improve the security on the browser Google started the bug-bounty program which would pay all the researchers who would submit vulnerabilities they find on the browser code and submit it to Google to release a fix for the same [27].

Finally, the ultimate goal of every vendor is to have a flaw free browser without any vulnerability and boast about it, which will always remain a dream [7].

2

Background Information

2.1 Forensics Definition

The usage of science and technology to gather, investigate and review evidence discovered at a crime scene and submit facts drawn from the evidence for a case in the court of law is the definition of Forensics. Facts from evidence can be drawn from different areas of science such as biology, chemistry, physics, geology and more recent being computers [11].

2.2 Digital forensics

Digital forensics is a branch of forensics that deals with the recovery, investigation and analysis of evidences found in digital devices suitable enough to be presented in a court of law. The different branches of digital forensics but not limited to include Computer forensics, Mobile device forensics, Network forensics and Database forensics [12][13][14]. These different branches help in gathering evidences from computer based crime, recovering destroyed files, discovering altered photographs, retrieving traces of hacking using logs from different sources and also recovering data stored on cell phones [13].

While performing this kind of investigation, it is really important to follow proper procedures and protocols and also maintaining well documented chain of custody for the movement of the evidence while digging out evidence in a computer and finding out would was responsible for it [16].

2.3 Chain of Custody

It is really important to maintain a chain of custody for the digital evidences too. Following proper forensic process is an important aspect of all forensic investigations. If proper processes and procedures are not following this could result in losing the integrity of the evidence. Therefore it is important to maintain a chain of custody and have a digital hash taken at every movement of the evidence and ensure that it matches all the time and there is no deviation for the original evidence [17].

3

Forensics Process

3.1 Introduction

Every forensic investigation should follow proper set of process and procedures for the evidence to be admissible in the court of law. The process used to retrieve the evidence till getting the final results should be repeatable using the process and procedure. If not the end result after the analysis would be considered void [12][15][16].

3.2 Forensic Process

A forensic process can be of two kinds, based on how you collect the data. The two kinds are: Live Acquisition and Dead Acquisition.

From a forensic investigation firm point of view, every case would have the following phases:

I. Pre-Investigation Phase

II. Investigation Phase

III. Post Investigation Phase

I. Pre-Investigation Phase:

a. Request from Clients:

The clients would send an information request for services by email or phone. A formal meeting would be arranged with the client to discuss different services that the company has to offer. Also if it is an urgent matter and requires live acquisition, all documents will be processed fast and would directly jump to the acquisition part of the investigation phase. For the dead acquisition, the below process would be continued to be followed.

b. Signing Service Level Agreement (SLA) and Legal Agreement:

The client would sign up for one or more services and would also clearly explain the case in detail. The SLA would also include the preferred delivery medium for the final report and the evidence gathered. A hash of the media would be taken immediately as a measure of integrity as well as a detailed description of the drive would be entered into the Chain of Custody report.

c. Chain of Custody:

Original media will be used to create a minimum of 2 copies of which hashes will be taken and compared to the original. At no time will any of the analyst would have direct access to the original media. The original media would be stored in a fire safe. Access to the copies will be restricted and would require multiple authorizations and additional documentation.

d. Hashing Mismatch:

If at any given point of time a hash mismatch would happen to occur, a high priority analysis would have to be executed to account for the mismatch. Documentation needs to be provided explaining the reason for the mismatch and eliminate any possibility of evidence contamination.

II. Investigation Phase:

a. Planning:

The examiner will begin by identifying the sources and types of evidence. Based on the case description the Examiner will ensure that the necessary equipment to carry out the investigation is present. As soon as the examiner receives the digital evidence, he would compare the hash of the drive to the hash of the original to ensure the integrity of the evidence and this will be documented. The examiner will also verify the presence of Chain of Custody documents, logs, fire safe for reports and evidence storage and a labeller to label all the physical evidence with the case number.

b. Acquisition:

If it is a live acquisition, the examiner would connect his flash drive and run a volatile memory imaging tool and copy the image to another storage device. Dead acquisition involves disk imaging, gathering information from different sources such as servers, client machines, network devices and flash drives etc. using best practices and following the chain of custody for admissibility. During the imaging process, the examiner would place the disk in the imaging bay drive and make an image of the drive while employing a write blocker hardware device to prevent any change to the original drive. The examiner would need to note the hash of the original drive before the imaging process and after the imaging process to ensure nothing has been modified on the original drive. The copy also will be hashed and checked against the original drives hash to ensure that the two devices have got identical data on them. During the imaging process only one examiner would have access to the imaging bay and no other examiner should have access to the imaging bay until the imaging task is completed. All actions taken by the examiner will be recorded in the logbook which would include date and time of the task performed and the duration.

c. Examination:

The examination process involves systematic search of evidence related to the suspected crime or service requested as explained by the client in the initial pre investigation phase. Initial examination would be to search for evidences in the most common places based on the description provided by the client. During the examination the examiner will search for evidence and information in the deleted files, formatted drives, hidden files and slack space to look for evidences. A hash of the drive copy will occur prior to this phase and one at the end of the phase to ensure admissibility.

d. Analyze:

This phase requires putting together all the findings and the data collected from the previous phases, determining the importance of the data found and coming to a conclusion based on the collected data. After the investigation is complete, the examiner would again compute two different hash values of the disk image to endure that the image was not tampered and has been intact throughout the investigation. During this phase there will be an emphasis on the timeline development, detection of malware and verification of results using alternative utilities.

III. Post Investigation Phase:

a. Reporting:

A collection of all the findings and final outcome from the investigation phase would form the report.

b. Report Delivery:

The report would be delivered as agreed while signing the SLA. The final package would include the final report (Executive Summary report and Technical details), copy of the log book, cop of the chain of custody, copy of the disk drive used by the team and other documents agreed during the SLA.

4
Web Browser Forensics

4.1 Introduction

Every forensic investigation should follow proper set of process and procedures for the evidence to be admissible in the court of law. The process used to retrieve the evidence till getting the final results should be repeatable using the process and procedure. If not the end result after the analysis would be considered void [12][15][16].

4.2 Types of Evidence

During an investigation the below are the different kinds of evidences that an investigator would be looking for [29]:

a. Surfing history:

   Surfing history of a user would mainly contain typed URLs, redirects and also the number of visits to a particular site.

b. Bookmarks:

   This would mainly contain shortcuts or bookmarks created to specific websites by the user.

c. Downloads:

An investigator would mainly need to check for downloaded file in the default locations, also in the user defined locations or sometimes files are downloaded to default locations and then are moved or copied to user defined locations.

d. Cookies:

   These are files that contain a wealth of information about the user. It would contain information like usernames, passwords and web session information.

e. Cache:

   It is a temporary area on the disk which is used to store most recently visited web sites.

4.3 Related Work

As referenced earlier, forensics is mainly performed to collect evidence based on the subject of the case. The evidence can be collected from different parts of a communication channel. Those different parts can be: Server side which stores access logs, error logs, application logs, system logs etc; Intermediate site logs which can be from firewall logs, router logs, anti-virus logs, web filter logs, switch logs, network access control logs etc; Client side which stores temporary internet files, index.dat files, history.dat, cookies, favorites, html stored in unallocated space, registry etc. Our main topic of discussion is with regards to client side logs and mainly pertaining to web browser. To help an investigator, researchers have written papers clearly explaining where to look for evidence for different browsers installed on different operating systems. Below is a list of browsers and different techniques of extracting evidence from them [29].

I. Internet Explorer:

Windows XP: On Windows XP systems, IE stores data in the “drive:\Documents and Settings\<username>\ profile folder. Folders that you would find there would be Favorites, Cookies, History and Temporary Internet Files. Also Registry stored information like Typed URLs, Passwords and Protected Storage Information [29].

IE Temporary Internet Files are stored in drive:\Documents and Settings\<username>\Local Settings. This folder contains an index.dat file that stores URL, Filename, Username and Content Info. This also provides us information even if the user deletes their Temporary Internet files [29].

The Registry saves the Typed URL at NTUSER.DAT\Microsoft\Internet Explorer\Typed URLs. The Protected Storage System Provider stores user IDs and passwords for websites at NTUSER.DAT\Software\Microsoft\Protected Storage System Provider. This is usually stored in encrypted form which can be viewed in clear text using Registry Viewer, tool by Access Data [30].

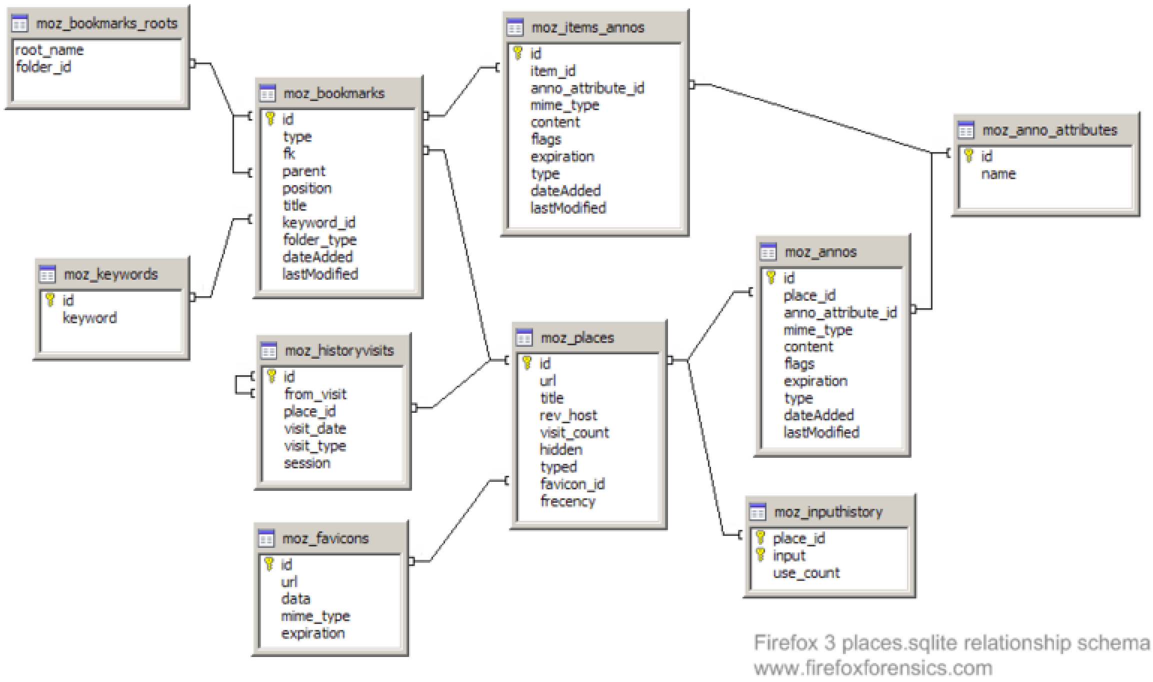
Windows Vista/7/8: On Windows Vista and Windows 7 systems, the cache and history information is stored in drive:\Users\<user name>\AppData\Local\Microsoft\Windows\. The cache here would contain files stored from different webpages browsed by the user. The history would tell you what sites someone has visited, when and how many times [31].

The cookies, that can contain a password or a session ID to a website they had authenticated to, are stored in drive:\ Users\<user name>\AppData\Roaming\Microsoft\Windows\Cookies [31].

The Registry stores the Typed URL at HKEY_CURRENT_USER\Software\Microsoft\Internet Explorer\TypedUrls, while the AutoComplete data like forms data and passwords at HKEY_CURRENT_USER\Software\Microsoft\Internet Explorer\IntelliForms. The form data and passwords are in obfuscated form and would need tools like Registry viewer or PassView [32] to view the data in clear text.

II. Firefox:

From version 3 onwards, Firefox stores all browsing information in a SQLite database instead of a flat file (mork file format). Below image shows the database structure used to store Firefox browsing information.



Firefox 3 places.sqlite relationship schema
www.firefoxforensics.com

Figure 1: Database structure for Firefox history [33]

The database files that are required are places.sqlite, formhistory.sqlite, downloads.sqlite, cookies.sqlite, search.sqlite and signons.sqlite.

a) places.sqlite

The places.sqlite database mainly consists of accessed URLs and bookmarks. Lot of tables stores this information, but the most important ones are:

Moz_places table is the central table where all the URLs are stored. The following fields are part of the moz_places table:

- *id:* This is the table's primary key
- *url:* This stores URLs accessed
- *title:* this stores the title of the page
- *visit_count:* this stores the number visits count
- *hidden:* this is mainly used for URL queries and RSS feeds. This tells us if the URL would be displayed by the autocomplete functions. If the value is set to 1 would mean that it is hidden.
- *typed:* this would tell you if the URL was typed or not. A value of 1 would mean that the URL was typed and 0 would mean it was not typed.
- *frecency:* this is a score given to URLs, bookmarks, history and tags. The scoring is done based on the number of times the site was visited, the type of visit, last visit and if the URL was bookmarked or tagged.

The other important table within the places.sqlite database is the **moz_bookmarks** table. This stores the bookmarks and the following are the important fields:

- *id:* this is the tables primary key
- *type:* if the value is 1, it means that the entry is a URL. If the value is 2, it means it is a folder and 3 means a separator

- *fk:* a foreign key used to link the moz_places with the moz_bookmarks table.
- *parent:* this indicates parent folder id of this record, usually used in conjunction with *position.*
- *position:* this indicates the position of the record within the folder.
- *title:* the title of the page is stored here.
- *folder_type:* this identifier tells us if the record is a folder.
- *dateAdded:* this stores the time and date when the record was added.
- *lastModified:* this stores the date and time when the record was last modified.

The **moz_historyvisits** is also another important table in the places.sqlite database. Below are the important fields:

- *id:* this is the table's primary key
- *place_id:* this is a reference to the moz_places table
- *from_visit:* this stores the referrer information for the current page.
- *visit_date:* this stores the date and time the URL was accessed.

b) formhistory.sqlite

formhistory.sqlite database has just one table called moz_formhistory and this stores the id, fieldname and the value.

c) downloads.sqlite

downloads.sqlite again like formhistory.sqlite has only one table called the moz_downloads table and the important fields are as below:

- *id:* contains the tables primary key
- *name:* this stores the filename of the file being downloaded.
- *source:* source URL of the download
- *target:* directory where it was downloaded
- *startTime and endTime:* download start and end time.
- *state:* shows if the download is paused, completed or cancelled.
- *referrer:* stores URL information of the previous page.
- *curnBytes:* stores information about the current downloaded bytes
- *maxBytes:* stores information about the total bytes to be downloaded

d) cookies.sqlite

This file has one table called the moz_cookies and stores all of the cookie data like id, name, value, host, path, expiry, lastAccessed, isSecure and isHttpOnly.

Different operating systems store this information in different locations.

The different locations are:

Windows XP

C:\Documents and Settings\<username>\Application Data\Mozilla\Firefox\Profiles\<profilefolder>\

Windows Vista/Windows 7/8

C:\Users\<user>\AppData\Roaming\Mozilla\Firefox\Profiles\<profile folder>\

Linux based systems

/home/<user>/.mozilla/firefox/<profile folder>/places.sqlite

Mac OS X

/Users/<user>/Library/Application Support/Firefox/Profiles/default.lov/

/Users/<user>/Library/Caches/Firefox/Profiles/*.default/

/Users/<user>/Library/Caches/Firefox/Profiles/*.default/Cache/

There different tools developed by different people from the forensics community. The most popular tools are mainly Firefox 3 Extractor (also known as f3e) and FoxAnalysis [47][48].

III. Google Chrome:

Chrome also stores its history in SQLite database but the structure is different from Firefox. The History folder stores the database file that contains the browsing history and can be viewed using any SQLite browser. The important tables are downloads, presentation, urls, keyword_search_terms, segment_usage, visits, meta and segments. The most significant ones are downloads, urls and visits. The list of all downloaded files is stored in downloads table. The urls contains all accessed or visited URLs. And visits table contains the type of visit and the time the site was visited [46].

We can view the *urls* table by running the below query

```
sqlite> .schema urls
```

```
CREATE TABLE urls(id INTEGER PRIMARY KEY,url LONGVARCHAR,title LONGVARCHAR,visit_count INTEGER
DEFAULT 0 NOT NULL, typed_count INTEGER DEFAULT 0 NOT NULL,last_visit_time INTEGER NOT NULL,hidden
INTEGER DEFAULT 0 NOT NULL, favicon_id INTEGER DEFAULT 0 NOT NULL);

CREATE INDEX urls_favicon_id_INDEX ON urls (favicon_id);

CREATE INDEX urls_url_index ON urls (url);
```

The same can be done for *visits* table

```
sqlite> .schema visits

CREATE TABLE visits(id INTEGER PRIMARY KEY,url INTEGER NOT NULL,visit_time INTEGER NOT NULL,from_visit
INTEGER,transition INTEGER DEFAULT 0 NOT NULL,segment_id INTEGER,is_indexed BOOLEAN);

CREATE INDEX visits_from_index ON visits (from_visit);

CREATE INDEX visits_time_index ON visits (visit_time);

CREATE INDEX visits_url_index ON visits (url);
```

Therefore user browsing information can be retrieved by running the query

```
SELECT urls.url, urls.title, urls.visit_count, urls.typed_count, urls.last_visit_time, urls.hidden, visits.visit_time,
visits.from_visit, visits.transition FROM urls, visits WHERE  urls.id = visits.url
```

The history files are stored in the following locations:

Windows (Vista and 7/8): C:\Users\<username>\AppData\Local\Google\Chrome\

Windows XP: C:\Documents and Settings\<username>\Local Settings\Application Data\Google\Chrome\

Linux: /home/$USER/.config/google-chrome/ or sometimes

/home/$USER/.config/chromium/

Mac OSX: /Users/<user>/Library/Caches/Google/Chrome/Default/Cache

/Users/<user>/Library/Application Support/Google/Chrome/Default/

Since the database tables are quite similar the f3e tool has an option of retrieving the user internet browsing information. The other tool that can be used for retrieving browsing information is ChromeAnalysis [49].

IV. Safari:

Safari too uses SQLite database to store its browsing related data. The files of interest in Safari are Bookmarks.plist, TopSites.plist, History.plist, LastSession.plist, Cookies.plist and Cache.db[55][56].

Bookmarks.plist: This file is mainly used to store bookmarks used by end on Safari [56].

TopSites.plist: This file stores all the most frequently visit website of the user [56].

LastSession.plist: This is used to track sites that are currently open by the end user and has active connections to the site. This would also include multiple tabs or multiple windows open to different sites. In cases where the browser would crash unexpectedly, this file is used to restore the previous browsing session.

History.plist: This list contains the date and time when a site was visited and number of times the site was visited.

Cookies.plist: This is similar to History.plist contains the date and time when a site was visited, but additionally also contains account names that were used on the website.

Cookies.db: This too is similar to History.plist contains the date and time when the site was visited but also pictures and other temporary browsing data. This can be extracted using any carving tool to extract the required information.

Typical locations for the browsing data are as per listed below:

Windows (Vista and 7/8):

C:\Users\<username>\AppData\Roaming\Apple Computer\Safari

C:\Users\<username>\AppData\Local\Apple Computer\Safari

Windows XP:

C:\Documents and Settings\<username>\Local Settings\Application Data\Apple Computer\Safari\

C:\Documents and Settings\<username>\Application Data\Apple Computer\Safari\

Mac OSX:

/Users/<username>/Library/Safari/

/Users/<username>/Library/Caches/com.apple.Safari/

4.4 Related work on Private mode Analysis

Researchers earlier have performed similar analysis of private mode and have released papers related to the findings. The research performed by Donny and Narasimha in [66] have used a tool called DaemonFS and was restricted to just Windows 7 operating system. They found that the Internet Explorer stored data on the file system as well as in the memory and the browsing data were recoverable using file recovery tools. Google Chrome and Firefox did not store any data on the file system but the data was recoverable from the memory. Safari stored data only on a single file called the WebpageIcons.db and browsing data was again recoverable from the memory.

The research performed by Huwida, Noora, Ibtesam and Mario in [67] covered private mode analysis of Internet Explorer, Firefox and Chrome only on Windows XP setup. Their approach was to run the browsers in private mode, then look for evidences in typical browsing history locations. Then also take live memory and hard drive image capture to look for evidences. They had similar findings as Donny and Narasimha in [66]. They were able to find that no data was written to the file system by Chrome and Firefox, but were able to find data in the live memory captures. But for Internet Explorer they were able to recover data that written to the file system during the InPrivate session. They were also able to recover the contents from the memory for Internet Explorer.

5

Browser Private Mode Analysis

5.1 Private Browsing

The private mode in all vendor browsers claim that all browsing history, temporary internet files, form data, cookies, usernames and passwords leaves no traces or evidence of the browsing or search history behind [35][36][37][38]. Chrome, Firefox and Safari also claim that they don't store download list entries [36][37][38].

5.2 Approach

Previous research performed by Donny and Narasimha in [66] covered only Windows 7 operating system and research performed by Huwida, Noora, Ibtesam and Mario in [67] had covered only Windows XP. My work would verify findings from [66] and [67] on Windows XP, Windows 7 and Windows 8 using different tool (Processmon) and extend the same tests to Ubuntu and Mac OS. As both the research groups have not identified the operating system operation that writes the data to the file system during the file system analysis. My work would show which process would write or delete the data from the file system.

To achieve the thesis goals the following two approaches will be used:

File system monitoring tools will be used to trace different reads and writes on the file system. On Windows based system Regmon, Processmon and Filemon will be used. For Linux and MAC OSX based systems DaemonFS will be used.

Live memory would be captured and imaged to recover and carve out browsing related information to see if data can be recovered from the physical memory itself.

5.3 Data Carving

Data carving is the process of extracting specific type of data from unstructured data. Usually when files are written to File System they are indexed based on type of file system ie FAT, FAT32, NTFS, ext4 etc and written on to disk. Recovery of such files are easy as when a file is deleted from the Operating system, usually the OS puts a marker in front of the entry of the file in the index to show that the file is deleted and the space is available to be reused.

The same is not the case when we deal with physical memory. All the core Operating system files and all the applications are loaded on the physical memory. This is done so that the CPU can access and process operating system related data requests faster. Operating system usually allocates a block of memory for each application and process running on the system. Once the process is terminated, the operating system reallocates the memory to be used by other processes. Now by running data carving tools it is possible to retrieve data that was written to these memory blocks. The tool scans for data block by block to look for specific type of header and footer information.

5.4 Tools Used

RegMon: RegMon is a registry monitoring tool developed by Sysinternals to monitor modifications made to the registry by different processes running on the operating system. It does not need any installation and is a portable executable [51].

FileMon: FileMon is a filesystem activity monitoring tool developed by Sysinternals to monitor and watch different reads and writes to the file system by different processes running on the operating system [52]. FileMon for Mac OS was also used. The FileMon for Mac OS is developed by DeepIT. It has similar functionality as the FileMon for Windows [60].

DaemonFS: This is a FileMon like tool used to monitor specific files and folders for reads and writes to the specific monitored files and folder. This was specifically used for Ubuntu and Mac OS [59].

Recuva: Recuva is a recovery tool used to recover deleted files in the operating system. It can perform deep scan to recover files from different parts of the operating system [53].

Belkasoft Ram Capturer: This tool is mainly used to capture Ram image to be analyzed by other tool to recover browser related evidence [58].

Rekall: dd on Linux with kernel later than version 2.6 has locked down direct access to the memory for tools like dd [64]. Therefore to perform memory acquisition of Linux based system it is required to install an external tool like Rekall which can perform memory acquisition that can help for further analysis [63].

Magnet Forensics Internet Evidence Finder: This tool carves out data from the disk/ram image that is loaded for analysis [57].

OSXPmem: This is an open source tool used to acquire physical memory contents from an Intel based Mac. To run the tool you need to have root access to the system as the tool runs under root privilege [65].

5.5 Private Mode Analysis

5.5.1 File System

The first approach was to just monitor the file system reads and writes to check what is written to the disk by the browser process. The following were the finding related to the different browsers:

I. Internet Explorer 8/9:

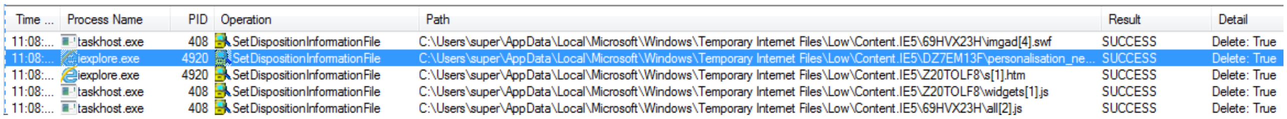
Internet Explorer is main browser built-in with all Windows systems. To monitor all the reads and writes by the browser, FileMon and RegMon were used.

While using the browser in the InPrivate mode in Internet Explorer, it was notice that Internet Explorer write all the data to the disk as mentioned below for the different operating systems:

For Windows XP: drive:\Documents and Settings\<username>\ profile folder.

For Windows 7/8:
drive:\Users\<username>\AppData\Local\Microsoft\Windows\

For Internet Explorer in all Windows Operating System, the browser writes the data to the disk and then deletes the data by a file system operation called "SetDispositionInformationFile". This operation deletes the file when the file is closed [54]. This deleted data can be easily recovered using recovery tools like Recuva.



Time ...	Process Name	PID	Operation	Path	Result	Detail
11:08:...	taskhost.exe	408	SetDispositionInformationFile	C:\Users\super\AppData\Local\Microsoft\Windows\Temporary Internet Files\Low\Content.IE5\69HVX23H\imgad[4].swf	SUCCESS	Delete: True
11:08:...	iexplore.exe	4920	SetDispositionInformationFile	C:\Users\super\AppData\Local\Microsoft\Windows\Temporary Internet Files\Low\Content.IE5\DZ7EM13F\personalisation_ne...	SUCCESS	Delete: True
11:08:...	iexplore.exe	4920	SetDispositionInformationFile	C:\Users\super\AppData\Local\Microsoft\Windows\Temporary Internet Files\Low\Content.IE5\Z20TOLF8\s[1].htm	SUCCESS	Delete: True
11:08:...	taskhost.exe	408	SetDispositionInformationFile	C:\Users\super\AppData\Local\Microsoft\Windows\Temporary Internet Files\Low\Content.IE5\Z20TOLF8\widgets[1].js	SUCCESS	Delete: True
11:08:...	taskhost.exe	408	SetDispositionInformationFile	C:\Users\super\AppData\Local\Microsoft\Windows\Temporary Internet Files\Low\Content.IE5\69HVX23H\all[2].js	SUCCESS	Delete: True

Figure 2: SetDispositionInformationFile screenshot

II. Firefox:

Firefox was downloaded and installed on the scoped operating systems ie, Windows XP, Windows 7, Windows 8, Ubuntu, and Mac OS. The following were the findings related to the browser:

Windows XP: The browser did not write any browsing related information on the file system.

Windows 7/8: The browser had similar behavior in this operating system too. It did not write any browsing history related information in the file system.

Ubuntu: The browser did not write any browsing related information to the file system.

Mac OS: The browser did not write any browsing related information to the file system.

III. Google Chrome:

Google Chrome was downloaded and installed on the scoped operating systems ie Windows XP, Windows 7, Windows 8, Ubuntu, and Mac OS. All the process reads and writes were monitoring using file monitor tools.

Windows XP: The browser did not write any browsing related information on the file system.

Windows 7/8: The browser had similar behavior in this operating system too. It did not write any browsing history related information in the file system.

Ubuntu: The browser did not write any browsing related information to the file system.

Mac OS: The browser did not write any browsing related information to the file system.

IV. Safari:

Safari comes pre-installed on all MAC OS systems. It had to be downloaded and installed on the scoped Windows operation systems ie Windows XP, Windows 7 and Windows 8. Monitoring tools were used to monitor all the reads and writes to the file system.

Windows XP:

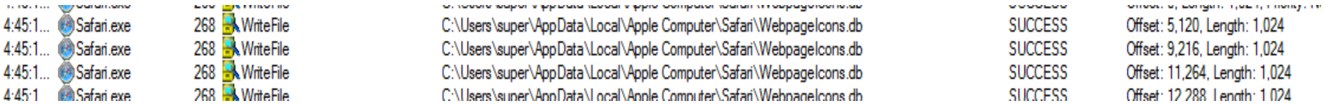
It was noted that during the private mode no information was written to file system except for one write to a file called “WebpageIcons.db” located in the below directory:

C:\Documents and Settings\<username>\Local Settings\Application Data\Apple Computer\Safari\

Windows 7/8:

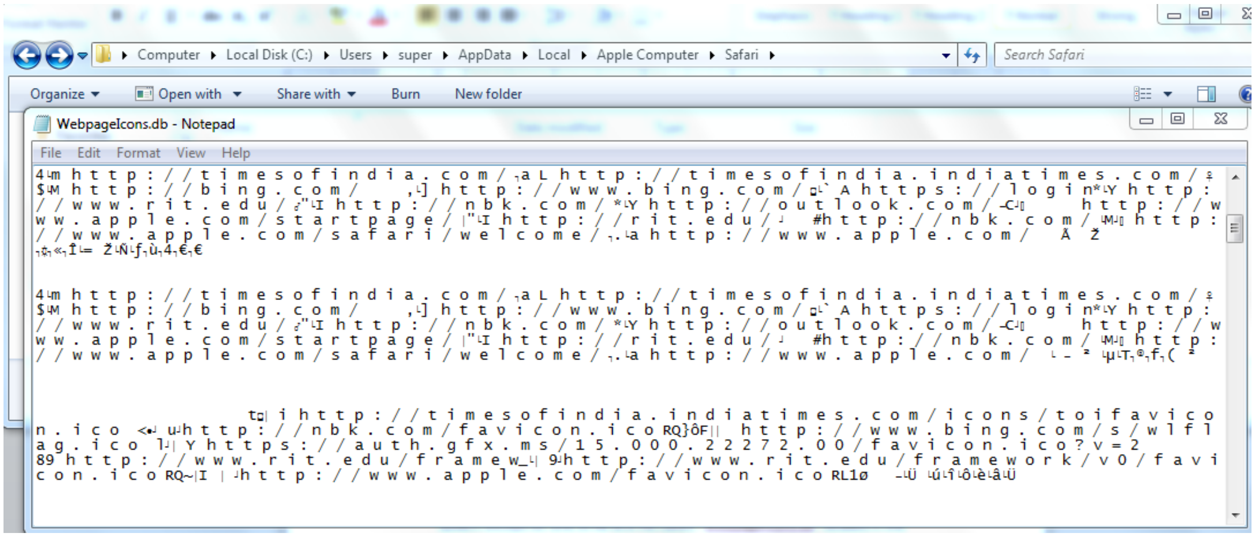
It was noted that during the private mode no information was written to file system except for one write to a file called “WebpageIcons.db” located in the below directory:

C:\Users\<user>\AppData\Local\Apple Computer\Safari



```
4:45:1...  Safari.exe  268  WriteFile  C:\Users\super\AppData\Local\Apple Computer\Safari\WebpageIcons.db  SUCCESS  Offset: 5,120, Length: 1,024
4:45:1...  Safari.exe  268  WriteFile  C:\Users\super\AppData\Local\Apple Computer\Safari\WebpageIcons.db  SUCCESS  Offset: 9,216, Length: 1,024
4:45:1...  Safari.exe  268  WriteFile  C:\Users\super\AppData\Local\Apple Computer\Safari\WebpageIcons.db  SUCCESS  Offset: 11,264, Length: 1,024
4:45:1     Safari.exe  268  WriteFile  C:\Users\super\AppData\Local\Apple Computer\Safari\WebpageIcons.db  SUCCESS  Offset: 12,288, Length: 1,024
```

Figure 3: Safari writing data on WebpageIcons.db Windows Screenshot



Computer ▸ Local Disk (C:) ▸ Users ▸ super ▸ AppData ▸ Local ▸ Apple Computer ▸ Safari ▸
Search Safari
Organize
Open with
Share with
Burn
New folder
WebpageIcons.db - Notepad
File
Edit
Format
View
Help

```
4└m http://timesofindia.com/┐aL http://timesofindia.indiatimes.com/♀
$└M http://bing.com/   ,└] http://www.bing.com/▫└` A https://login*└Y http:
//www.rit.edu/♪"└I http://nbk.com/*└Y http://outlook.com/‐C┘▯    http://w
ww.apple.com/startpage/|"└I http://rit.edu/┘  #http://nbk.com/└M┘▯ http:
//www.apple.com/safari/welcome/┐.└a http://www.apple.com/  Å Ž
┐₫┐«┐Î└= Ž└Ñ└ƒ┐ù┐4┐€┐€


4└m http://timesofindia.com/┐aL http://timesofindia.indiatimes.com/♀
$└M http://bing.com/   ,└] http://www.bing.com/▫└` A https://login*└Y http:
//www.rit.edu/♪"└I http://nbk.com/*└Y http://outlook.com/‐C┘▯    http://w
ww.apple.com/startpage/|"└I http://rit.edu/┘  #http://nbk.com/└M┘▯ http:
//www.apple.com/safari/welcome/┐.└a http://www.apple.com/ └ - ² └µ└T┐®┐ƒ┐( ²


              t▫| i http://timesofindia.indiatimes.com/icons/toifavico
n.ico <•┘ u┘http://nbk.com/favicon.ico RQ}ôF||  http://www.bing.com/s/wlfl
ag.ico 1┘| Y https://auth.gfx.ms/15.000.22272.00/favicon.ico?v=2
89 http://www.rit.edu/framew_└| 9┘http://www.rit.edu/framework/v0/favi
con.ico RQ~|I | ┘http://www.apple.com/favicon.ico RL1ø  ‐└Ü └ú└î└ô└è└â└Ü
```

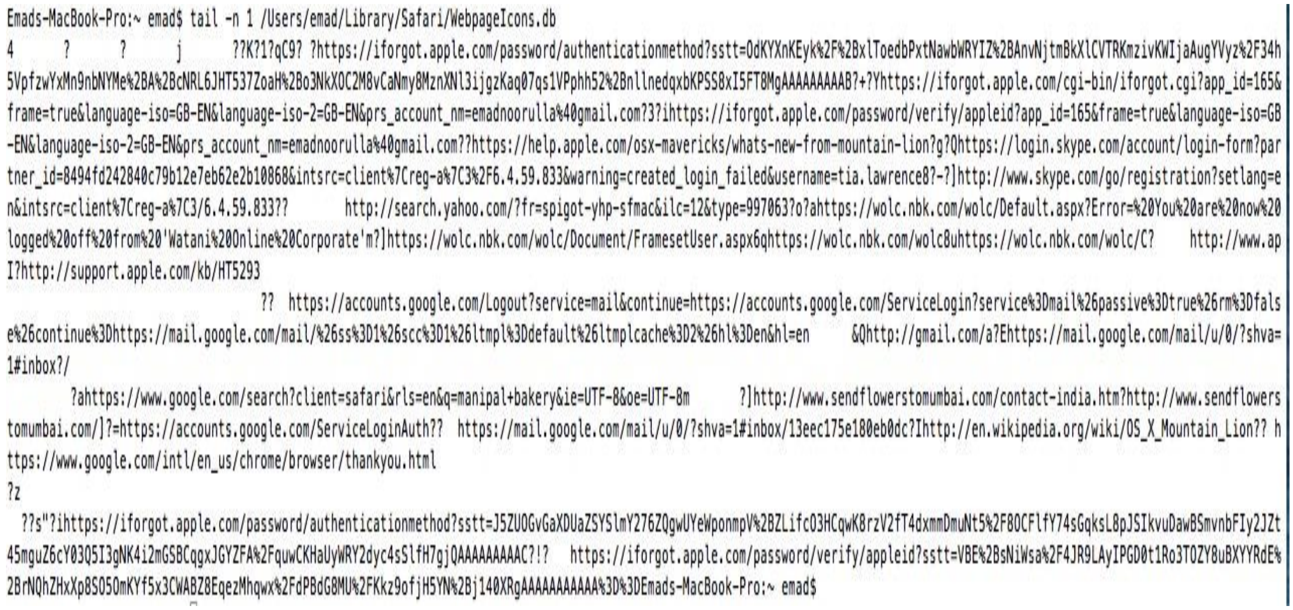
Figure 4: Safari WebpageIcons.db on Windows Screenshot

Mac OSX:

It was noted that during the private mode no information was written to file system except for one write to a file called “WebpageIcons.db” located in the below directory:

/Users/<username>/Library/Safari/

Note: This was only applicable to the old versions of Safari ie 6.1.5. The newer version 7.0.5 has fixed this issue and it was not possible to retrieve any browsing data.



```
Emads-MacBook-Pro:~ emad$ tail -n 1 /Users/emad/Library/Safari/WebpageIcons.db
4       ?       ?       j       ??K?1?qC9? ?https://iforgot.apple.com/password/authenticationmethod?sstt=OdKYXnKEyk%2F%2BxlToedbPxtNawbWRYIZ%2BAnvNjtmBkXlCVTRKmzivKWIjaAugYVyz%2F34h
5VpfzwYxMn9nbNYMe%2BA%2BcNRL6JHT537ZoaH%2Bo3NkXOC2M8vCaNmy8MznXNl3ijgzKaq07qs1VPphh52%2BnllnedqxbKPSS8xI5FT8MgAAAAAAAAB?+?Yhttps://iforgot.apple.com/cgi-bin/iforgot.cgi?app_id=165&
frame=true&language-iso=GB-EN&language-iso-2=GB-EN&prs_account_nm=emadnoorulla%40gmail.com?3?ihttps://iforgot.apple.com/password/verify/appleid?app_id=165&frame=true&language-iso=GB
-EN&language-iso-2=GB-EN&prs_account_nm=emadnoorulla%40gmail.com??https://help.apple.com/osx-mavericks/whats-new-from-mountain-lion?g?Qhttps://login.skype.com/account/login-form?par
tner_id=8494fd242840c79b12e7eb62e2b10868&intsrc=client%7Creg-a%7C3%2F6.4.59.833&warning=created_login_failed&username=tia.lawrence8?-?]http://www.skype.com/go/registration?setlang=e
n&intsrc=client%7Creg-a%7C3/6.4.59.833??        http://search.yahoo.com/?fr=spigot-yhp-sfmac&ilc=12&type=997063?o?ahttps://wolc.nbk.com/wolc/Default.aspx?Error=%20You%20are%20now%20
logged%20off%20from%20'Watani%20Online%20Corporate'm?]https://wolc.nbk.com/wolc/Document/FramesetUser.aspx6qhttps://wolc.nbk.com/wolc8uhttps://wolc.nbk.com/wolc/C?     http://www.ap
I?http://support.apple.com/kb/HT5293
                                    ??  https://accounts.google.com/Logout?service=mail&continue=https://accounts.google.com/ServiceLogin?service%3Dmail%26passive%3Dtrue%26rm%3Dfals
e%26continue%3Dhttps://mail.google.com/mail/%26ss%3D1%26scc%3D1%26ltmpl%3Ddefault%26ltmplcache%3D2%26hl%3Den&hl=en      &Qhttp://gmail.com/a?Ehttps://mail.google.com/mail/u/0/?shva=
1#inbox?/
        ?ahttps://www.google.com/search?client=safari&rls=en&q=manipal+bakery&ie=UTF-8&oe=UTF-8m       ?]http://www.sendflowerstomumbai.com/contact-india.htm?http://www.sendflowers
tomumbai.com/]?=https://accounts.google.com/ServiceLoginAuth??  https://mail.google.com/mail/u/0/?shva=1#inbox/13eec175e180eb0dc?Ihttp://en.wikipedia.org/wiki/OS_X_Mountain_Lion?? h
ttps://www.google.com/intl/en_us/chrome/browser/thankyou.html
?z
  ??s"?ihttps://iforgot.apple.com/password/authenticationmethod?sstt=J5ZUOGvGaXDUaZSYSlmY276ZQgwUYeWponmpV%2BZLifcO3HCqwK8rzV2fT4dxmmDmuNt5%2F8OCFlfY74sGqksL8pJSIkvuDawBSmvnbFIy2JZt
45mguZ6cY03Q5I3gNK4i2mGSBCqgxJGYZFA%2FquwCKHaUyWRY2dyc4sSlfH7gjQAAAAAAAAC?!?   https://iforgot.apple.com/password/verify/appleid?sstt=VBE%2BsNiWsa%2F4JR9LAyIPGD0t1Ro3TOZY8uBXYYRdE%
2BrNQhZHxXp8SO5OmKYf5x3CWABZ8EqezMhqwx%2FdPBdG8MU%2FKkz9ofjH5YN%2Bj140XRgAAAAAAAAAAA%3D%3DEmads-MacBook-Pro:~ emad$
```

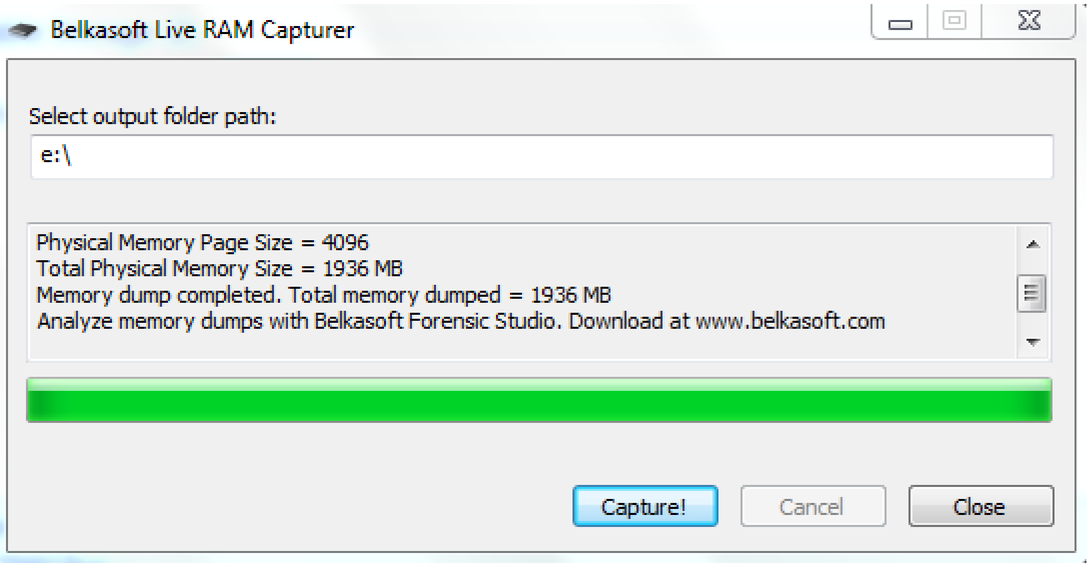
Figure 5: Safari WebpageIcons.db on MAC Screenshot

5.5.2 Live Memory Capture

The second approach was to launch the browser in Private mode and browse any website and then close the browser. Then take a live memory capture using any memory capture tool and save it on an external drive. After copying to external drive we would run data carving tool against the image to extract the required evidence [61] [62].

Windows Analysis:

For all Windows system, Belkasoft RAM capturer was used to capture the physical memory contents. It is a simple portable executable that can be run without any installation on the file system and you can define the output location. I chose the output to be dumped to an external drive as part of best practice in forensics. This was done as shown below:



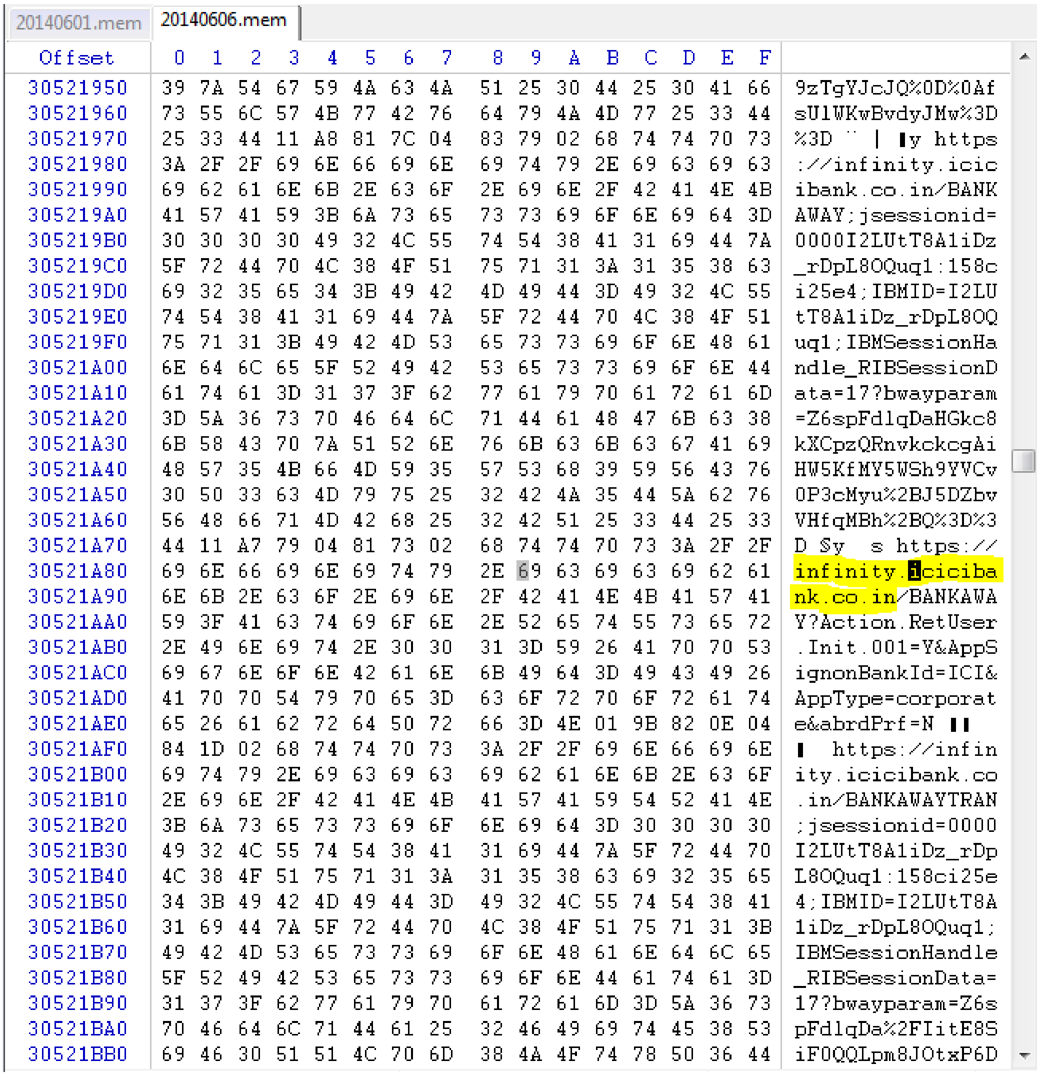
e:\

```
Physical Memory Page Size = 4096
Total Physical Memory Size = 1936 MB
Memory dump completed. Total memory dumped = 1936 MB
Analyze memory dumps with Belkasoft Forensic Studio. Download at www.belkasoft.com
```

Figure 6: RAM Capture on Windows Screenshot

Internet Explorer:

The browser was launched in InPrivate mode and websites were accessed. The browser was closed after accessing websites. The physical memory contents were captured using Belkasoft Live memory Capturer as shown earlier. Analysis was performed by opening the image file in Winhex. It was found that the browsing information existed in the captured image.

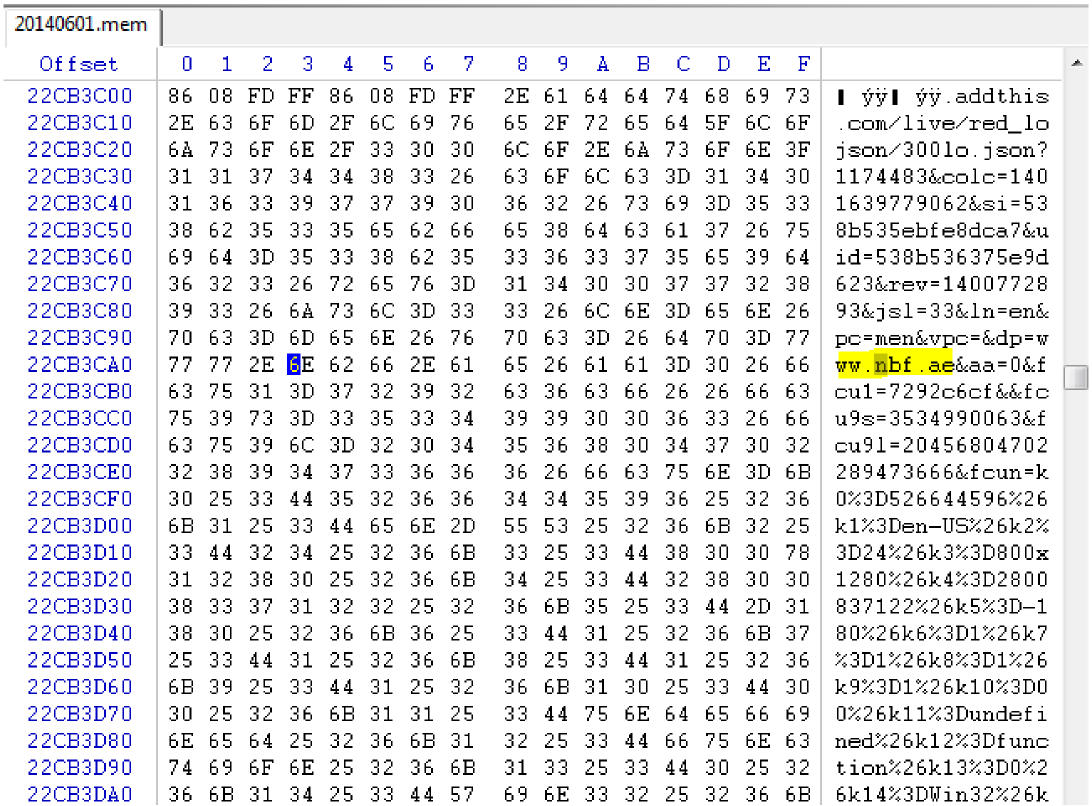


```
  Offset    0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
30521950   39 7A 54 67 59 4A 63 4A  51 25 30 44 25 30 41 66   9zTgYJcJQ%0D%0Af
30521960   73 55 6C 57 4B 77 42 76  64 79 4A 4D 77 25 33 44   sUlWKwBvdyJMw%3D
30521970   25 33 44 11 A8 81 7C 04  83 79 02 68 74 74 70 73   %3D ¨  |  ▌y https
30521980   3A 2F 2F 69 6E 66 69 6E  69 74 79 2E 69 63 69 63   ://infinity.icic
30521990   69 62 61 6E 6B 2E 63 6F  2E 69 6E 2F 42 41 4E 4B   ibank.co.in/BANK
305219A0   41 57 41 59 3B 6A 73 65  73 73 69 6F 6E 69 64 3D   AWAY;jsessionid=
305219B0   30 30 30 30 49 32 4C 55  74 54 38 41 31 69 44 7A   0000I2LUtT8A1iDz
305219C0   5F 72 44 70 4C 38 4F 51  75 71 31 3A 31 35 38 63   _rDpL8OQuq1:158c
305219D0   69 32 35 65 34 3B 49 42  4D 49 44 3D 49 32 4C 55   i25e4;IBMID=I2LU
305219E0   74 54 38 41 31 69 44 7A  5F 72 44 70 4C 38 4F 51   tT8A1iDz_rDpL8OQ
305219F0   75 71 31 3B 49 42 4D 53  65 73 73 69 6F 6E 48 61   uq1;IBMSessionHa
30521A00   6E 64 6C 65 5F 52 49 42  53 65 73 73 69 6F 6E 44   ndle_RIBSessionD
30521A10   61 74 61 3D 31 37 3F 62  77 61 79 70 61 72 61 6D   ata=17?bwayparam
30521A20   3D 5A 36 73 70 46 64 6C  71 44 61 48 47 6B 63 38   =Z6spFdlqDaHGkc8
30521A30   6B 58 43 70 7A 51 52 6E  76 6B 63 6B 63 67 41 69   kXCpzQRnvkckcgAi
30521A40   48 57 35 4B 66 4D 59 35  57 53 68 39 59 56 43 76   HW5KfMY5WSh9YVCv
30521A50   30 50 33 63 4D 79 75 25  32 42 4A 35 44 5A 62 76   0P3cMyu%2BJ5DZbv
30521A60   56 48 66 71 4D 42 68 25  32 42 51 25 33 44 25 33   VHfqMBh%2BQ%3D%3
30521A70   44 11 A7 79 04 81 73 02  68 74 74 70 73 3A 2F 2F   D §y  s https://
30521A80   69 6E 66 69 6E 69 74 79  2E 69 63 69 63 69 62 61   infinity.iciciba
30521A90   6E 6B 2E 63 6F 2E 69 6E  2F 42 41 4E 4B 41 57 41   nk.co.in/BANKAWA
30521AA0   59 3F 41 63 74 69 6F 6E  2E 52 65 74 55 73 65 72   Y?Action.RetUser
30521AB0   2E 49 6E 69 74 2E 30 30  31 3D 59 26 41 70 70 53   .Init.001=Y&AppS
30521AC0   69 67 6E 6F 6E 42 61 6E  6B 49 64 3D 49 43 49 26   ignonBankId=ICI&
30521AD0   41 70 70 54 79 70 65 3D  63 6F 72 70 6F 72 61 74   AppType=corporat
30521AE0   65 26 61 62 72 64 50 72  66 3D 4E 01 9B 82 0E 04   e&abrdPrf=N ▌▌
30521AF0   84 1D 02 68 74 74 70 73  3A 2F 2F 69 6E 66 69 6E   ▌  https://infin
30521B00   69 74 79 2E 69 63 69 63  69 62 61 6E 6B 2E 63 6F   ity.icicibank.co
30521B10   2E 69 6E 2F 42 41 4E 4B  41 57 41 59 54 52 41 4E   .in/BANKAWAYTRAN
30521B20   3B 6A 73 65 73 73 69 6F  6E 69 64 3D 30 30 30 30   ;jsessionid=0000
30521B30   49 32 4C 55 74 54 38 41  31 69 44 7A 5F 72 44 70   I2LUtT8A1iDz_rDp
30521B40   4C 38 4F 51 75 71 31 3A  31 35 38 63 69 32 35 65   L8OQuq1:158ci25e
30521B50   34 3B 49 42 4D 49 44 3D  49 32 4C 55 74 54 38 41   4;IBMID=I2LUtT8A
30521B60   31 69 44 7A 5F 72 44 70  4C 38 4F 51 75 71 31 3B   1iDz_rDpL8OQuq1;
30521B70   49 42 4D 53 65 73 73 69  6F 6E 48 61 6E 64 6C 65   IBMSessionHandle
30521B80   5F 52 49 42 53 65 73 73  69 6F 6E 44 61 74 61 3D   _RIBSessionData=
30521B90   31 37 3F 62 77 61 79 70  61 72 61 6D 3D 5A 36 73   17?bwayparam=Z6s
30521BA0   70 46 64 6C 71 44 61 25  32 46 49 69 74 45 38 53   pFdlqDa%2FIitE8S
30521BB0   69 46 30 51 51 4C 70 6D  38 4A 4F 74 78 50 36 44   iF0QQLpm8JOtxP6D
```

Figure 7: IE Winhex analysis Screenshot

Google Chrome:

The browser was launched in incognito mode and websites were accessed. After accessing the site, the browser was closed and the RAM contents were captured using Belkasoft Live RAM Capturer as shown earlier. The captured file was opened using Winhex to perform analysis. During the analysis it was found that the browsed websites were stored in the RAM.



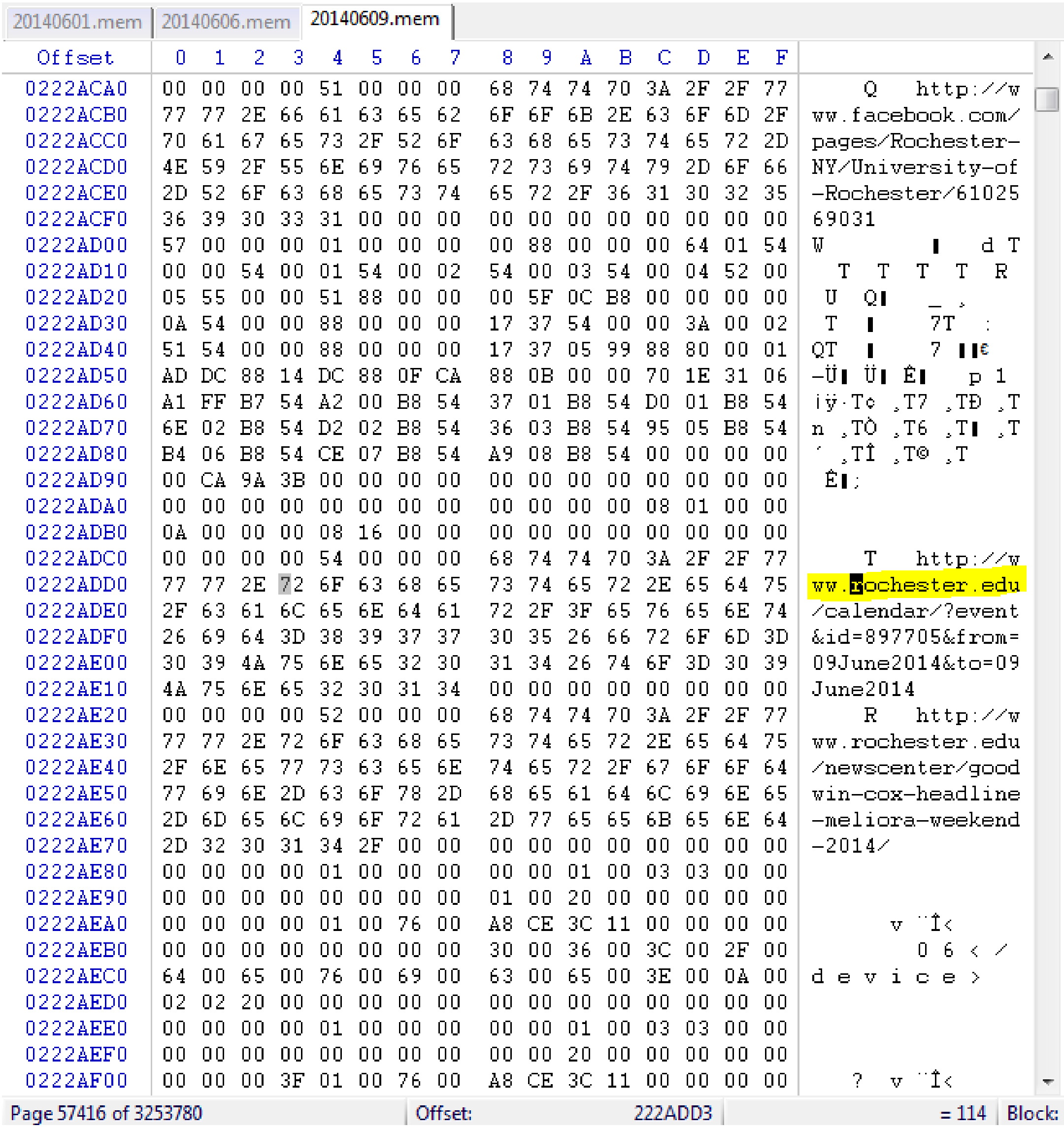
```
20140601.mem

 Offset     0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
22CB3C00   86 08 FD FF 86 08 FD FF  2E 61 64 64 74 68 69 73   ▌ ýÿ▌ ýÿ.addthis
22CB3C10   2E 63 6F 6D 2F 6C 69 76  65 2F 72 65 64 5F 6C 6F   .com/live/red_lo
22CB3C20   6A 73 6F 6E 2F 33 30 30  6C 6F 2E 6A 73 6F 6E 3F   json/300lo.json?
22CB3C30   31 31 37 34 34 38 33 26  63 6F 6C 63 3D 31 34 30   1174483&colc=140
22CB3C40   31 36 33 39 37 37 39 30  36 32 26 73 69 3D 35 33   1639779062&si=53
22CB3C50   38 62 35 33 35 65 62 66  65 38 64 63 61 37 26 75   8b535ebfe8dca7&u
22CB3C60   69 64 3D 35 33 38 62 35  33 36 33 37 35 65 39 64   id=538b536375e9d
22CB3C70   36 32 33 26 72 65 76 3D  31 34 30 30 37 37 32 38   623&rev=14007728
22CB3C80   39 33 26 6A 73 6C 3D 33  33 26 6C 6E 3D 65 6E 26   93&jsl=33&ln=en&
22CB3C90   70 63 3D 6D 65 6E 26 76  70 63 3D 26 64 70 3D 77   pc=men&vpc=&dp=w
22CB3CA0   77 77 2E 6E 62 66 2E 61  65 26 61 61 3D 30 26 66   ww.nbf.ae&aa=0&f
22CB3CB0   63 75 31 3D 37 32 39 32  63 36 63 66 26 26 66 63   cu1=7292c6cf&&fc
22CB3CC0   75 39 73 3D 33 35 33 34  39 39 30 30 36 33 26 66   u9s=3534990063&f
22CB3CD0   63 75 39 6C 3D 32 30 34  35 36 38 30 34 37 30 32   cu9l=20456804702
22CB3CE0   32 38 39 34 37 33 36 36  36 26 66 63 75 6E 3D 6B   289473666&fcun=k
22CB3CF0   30 25 33 44 35 32 36 36  34 34 35 39 36 25 32 36   0%3D52664596%26
22CB3D00   6B 31 25 33 44 65 6E 2D  55 53 25 32 36 6B 32 25   k1%3Den-US%26k2%
22CB3D10   33 44 32 34 25 32 36 6B  33 25 33 44 38 30 30 78   3D24%26k3%3D800x
22CB3D20   31 32 38 30 25 32 36 6B  34 25 33 44 32 38 30 30   1280%26k4%3D2800
22CB3D30   38 33 37 31 32 32 25 32  36 6B 35 25 33 44 2D 31   837122%26k5%3D-1
22CB3D40   38 30 25 32 36 6B 36 25  33 44 31 25 32 36 6B 37   80%26k6%3D1%26k7
22CB3D50   25 33 44 31 25 32 36 6B  38 25 33 44 31 25 32 36   %3D1%26k8%3D1%26
22CB3D60   6B 39 25 33 44 31 25 32  36 6B 31 30 25 33 44 30   k9%3D1%26k10%3D0
22CB3D70   30 25 32 36 6B 31 31 25  33 44 75 6E 64 65 66 69   0%26k11%3Dundefi
22CB3D80   6E 65 64 25 32 36 6B 31  32 25 33 44 66 75 6E 63   ned%26k12%3Dfunc
22CB3D90   74 69 6F 6E 25 32 36 6B  31 33 25 33 44 30 25 32   tion%26k13%3D0%2
22CB3DA0   36 6B 31 34 25 33 44 57  69 6E 33 32 25 32 36 6B   6k14%3DWin32%26k
```

Figure 8: Chrome on Windows Winhex analysis Screenshot

FireFox:

The browser was launched in Private mode and websites were accessed. After that the browser was closed and the physical memory was captured using Belkasoft Live RAM Capturer as shown previously. Then the image file was opened using Winhex to perform analysis. During the analysis it was found that the browsing data existed in the captured memory file.

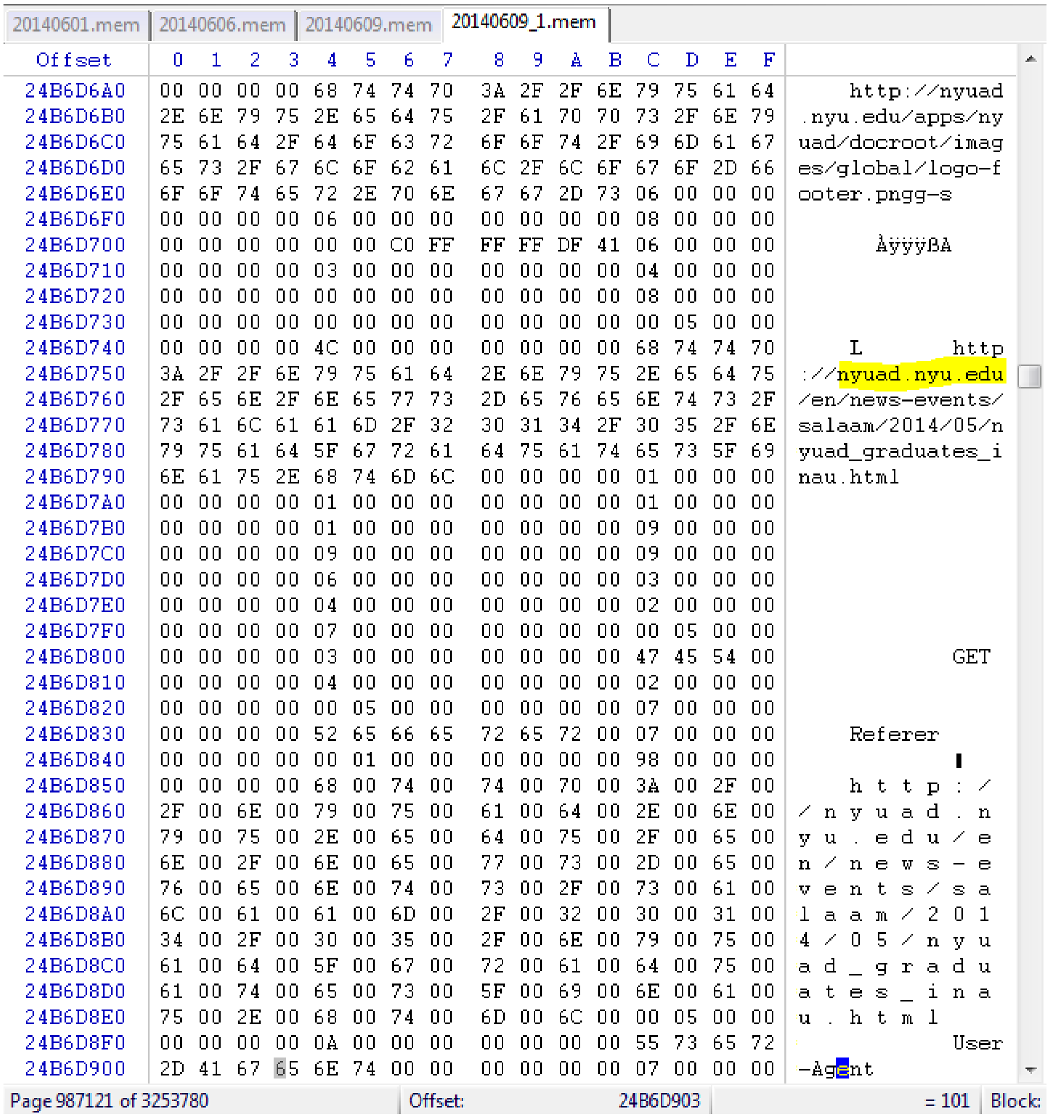


```
  Offset    0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
0222ACA0   00 00 00 00 51 00 00 00  68 74 74 70 3A 2F 2F 77      Q    http://w
0222ACB0   77 77 2E 66 61 63 65 62  6F 6F 6B 2E 63 6F 6D 2F  ww.facebook.com/
0222ACC0   70 61 67 65 73 2F 52 6F  63 68 65 73 74 65 72 2D  pages/Rochester-
0222ACD0   4E 59 2F 55 6E 69 76 65  72 73 69 74 79 2D 6F 66  NY/University-of
0222ACE0   2D 52 6F 63 68 65 73 74  65 72 2F 36 31 30 32 35  -Rochester/61025
0222ACF0   36 39 30 33 31 00 00 00  00 00 00 00 00 00 00 00  69031
0222AD00   57 00 00 00 01 00 00 00  00 88 00 00 00 64 01 54  W         ▌   d T
0222AD10   00 00 54 00 01 54 00 02  54 00 03 54 00 04 52 00    T  T  T  T  R
0222AD20   05 55 00 00 51 88 00 00  00 5F 0C B8 00 00 00 00   U  Q▌     _ ¸
0222AD30   0A 54 00 00 88 00 00 00  17 37 54 00 00 3A 00 02   T   ▌    7T   :
0222AD40   51 54 00 00 88 00 00 00  17 37 05 99 88 80 00 01  QT  ▌     7 ▌▌€
0222AD50   AD DC 88 14 DC 88 0F CA  88 0B 00 00 70 1E 31 06  -Ü▌ Ü▌ Ê▌   p 1
0222AD60   A1 FF B7 54 A2 00 B8 54  37 01 B8 54 D0 01 B8 54  ¡ÿ·T¢ ¸T7 ¸TÐ ¸T
0222AD70   6E 02 B8 54 D2 02 B8 54  36 03 B8 54 95 05 B8 54  n ¸TÒ ¸T6 ¸T▌ ¸T
0222AD80   B4 06 B8 54 CE 07 B8 54  A9 08 B8 54 00 00 00 00  ´ ¸TÎ ¸T© ¸T
0222AD90   00 CA 9A 3B 00 00 00 00  00 00 00 00 00 00 00 00   Ê▌;
0222ADA0   00 00 00 00 00 00 00 00  00 00 00 00 08 01 00 00
0222ADB0   0A 00 00 00 08 16 00 00  00 00 00 00 00 00 00 00
0222ADC0   00 00 00 00 54 00 00 00  68 74 74 70 3A 2F 2F 77      T    http://w
0222ADD0   77 77 2E 72 6F 63 68 65  73 74 65 72 2E 65 64 75  ww.rochester.edu
0222ADE0   2F 63 61 6C 65 6E 64 61  72 2F 3F 65 76 65 6E 74  /calendar/?event
0222ADF0   26 69 64 3D 38 39 37 37  30 35 26 66 72 6F 6D 3D  &id=897705&from=
0222AE00   30 39 4A 75 6E 65 32 30  31 34 26 74 6F 3D 30 39  09June2014&to=09
0222AE10   4A 75 6E 65 32 30 31 34  00 00 00 00 00 00 00 00  June2014
0222AE20   00 00 00 00 52 00 00 00  68 74 74 70 3A 2F 2F 77      R    http://w
0222AE30   77 77 2E 72 6F 63 68 65  73 74 65 72 2E 65 64 75  ww.rochester.edu
0222AE40   2F 6E 65 77 73 63 65 6E  74 65 72 2F 67 6F 6F 64  /newscenter/good
0222AE50   77 69 6E 2D 63 6F 78 2D  68 65 61 64 6C 69 6E 65  win-cox-headline
0222AE60   2D 6D 65 6C 69 6F 72 61  2D 77 65 65 6B 65 6E 64  -meliora-weekend
0222AE70   2D 32 30 31 34 2F 00 00  00 00 00 00 00 00 00 00  -2014/
0222AE80   00 00 00 00 01 00 00 00  00 00 01 00 03 03 00 00
0222AE90   00 00 00 00 00 00 00 00  01 00 20 00 00 00 00 00
0222AEA0   00 00 00 00 01 00 76 00  A8 CE 3C 11 00 00 00 00        v ¨Î<
0222AEB0   00 00 00 00 00 00 00 00  30 00 36 00 3C 00 2F 00          0 6 < /
0222AEC0   64 00 65 00 76 00 69 00  63 00 65 00 3E 00 0A 00  d e v i c e >
0222AED0   02 02 20 00 00 00 00 00  00 00 00 00 00 00 00 00
0222AEE0   00 00 00 00 01 00 00 00  00 00 01 00 03 03 00 00
0222AEF0   00 00 00 00 00 00 00 00  00 00 20 00 00 00 00 00
0222AF00   00 00 00 3F 01 00 76 00  A8 CE 3C 11 00 00 00 00     ?  v ¨Î<
Page 57416 of 3253780        Offset:        222ADD3                = 114   Block:
```

Figure 9: Firefox on Windows Winhex analysis Screenshot

Safari:

The browser was launched in Private mode and websites were accessed. After accessing websites the browser was closed. The RAM image was capturer using Belkasoft Live Ram Capturer as shown earlier. The captured image was opened using Winhex for analysis. During analysis it was noted that the browsing information remained on the RAM.



```
 Offset    0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
24B6D6A0  00 00 00 00 68 74 74 70  3A 2F 2F 6E 79 75 61 64      http://nyuad
24B6D6B0  2E 6E 79 75 2E 65 64 75  2F 61 70 70 73 2F 6E 79  .nyu.edu/apps/ny
24B6D6C0  75 61 64 2F 64 6F 63 72  6F 6F 74 2F 69 6D 61 67  uad/docroot/imag
24B6D6D0  65 73 2F 67 6C 6F 62 61  6C 2F 6C 6F 67 6F 2D 66  es/global/logo-f
24B6D6E0  6F 6F 74 65 72 2E 70 6E  67 67 2D 73 06 00 00 00  ooter.pngg-s
24B6D6F0  00 00 00 00 06 00 00 00  00 00 00 00 08 00 00 00
24B6D700  00 00 00 00 00 00 C0 FF  FF FF DF 41 06 00 00 00        ÀÿÿßA
24B6D710  00 00 00 00 03 00 00 00  00 00 00 00 04 00 00 00
24B6D720  00 00 00 00 00 00 00 00  00 00 00 00 08 00 00 00
24B6D730  00 00 00 00 00 00 00 00  00 00 00 00 00 05 00 00
24B6D740  00 00 00 00 4C 00 00 00  00 00 00 00 68 74 74 70      L       http
24B6D750  3A 2F 2F 6E 79 75 61 64  2E 6E 79 75 2E 65 64 75  ://nyuad.nyu.edu
24B6D760  2F 65 6E 2F 6E 65 77 73  2D 65 76 65 6E 74 73 2F  /en/news-events/
24B6D770  73 61 6C 61 61 6D 2F 32  30 31 34 2F 30 35 2F 6E  salaam/2014/05/n
24B6D780  79 75 61 64 5F 67 72 61  64 75 61 74 65 73 5F 69  yuad_graduates_i
24B6D790  6E 61 75 2E 68 74 6D 6C  00 00 00 00 01 00 00 00  nau.html
24B6D7A0  00 00 00 00 01 00 00 00  00 00 00 00 01 00 00 00
24B6D7B0  00 00 00 00 01 00 00 00  00 00 00 00 09 00 00 00
24B6D7C0  00 00 00 00 09 00 00 00  00 00 00 00 09 00 00 00
24B6D7D0  00 00 00 00 06 00 00 00  00 00 00 00 03 00 00 00
24B6D7E0  00 00 00 00 04 00 00 00  00 00 00 00 02 00 00 00
24B6D7F0  00 00 00 00 07 00 00 00  00 00 00 00 00 05 00 00
24B6D800  00 00 00 00 03 00 00 00  00 00 00 00 47 45 54 00              GET
24B6D810  00 00 00 00 04 00 00 00  00 00 00 00 02 00 00 00
24B6D820  00 00 00 00 00 05 00 00  00 00 00 00 07 00 00 00
24B6D830  00 00 00 00 52 65 66 65  72 65 72 00 07 00 00 00      Referer
24B6D840  00 00 00 00 00 01 00 00  00 00 00 00 98 00 00 00              ▌
24B6D850  00 00 00 00 68 00 74 00  74 00 70 00 3A 00 2F 00      h t t p : /
24B6D860  2F 00 6E 00 79 00 75 00  61 00 64 00 2E 00 6E 00  / n y u a d . n
24B6D870  79 00 75 00 2E 00 65 00  64 00 75 00 2F 00 65 00  y u . e d u / e
24B6D880  6E 00 2F 00 6E 00 65 00  77 00 73 00 2D 00 65 00  n / n e w s - e
24B6D890  76 00 65 00 6E 00 74 00  73 00 2F 00 73 00 61 00  v e n t s / s a
24B6D8A0  6C 00 61 00 61 00 6D 00  2F 00 32 00 30 00 31 00  l a a m / 2 0 1
24B6D8B0  34 00 2F 00 30 00 35 00  2F 00 6E 00 79 00 75 00  4 / 0 5 / n y u
24B6D8C0  61 00 64 00 5F 00 67 00  72 00 61 00 64 00 75 00  a d _ g r a d u
24B6D8D0  61 00 74 00 65 00 73 00  5F 00 69 00 6E 00 61 00  a t e s _ i n a
24B6D8E0  75 00 2E 00 68 00 74 00  6D 00 6C 00 00 05 00 00  u . h t m l
24B6D8F0  00 00 00 00 0A 00 00 00  00 00 00 00 55 73 65 72              User
24B6D900  2D 41 67 65 6E 74 00 00  00 00 00 00 07 00 00 00  -Agent
```

Figure 10: Safari on Windows Winhex analysis Screenshot

Linux Analysis:

For Linux based on Ubuntu distribution, I had to use Rekall for capturing the physical memory contents. It was not possible to use dd as the new kernel 2.6 and later have additional security control to protect the memory [63][64]. Therefore in order to get Rekall workin we need to install a package called “linux-headers-server” for Ubuntu based Linux and “gcc” and “kernel-headers” for CentOs based Linux. After that the memory contents were captured and transfer to an external drive using the dcfldd command as shown below:

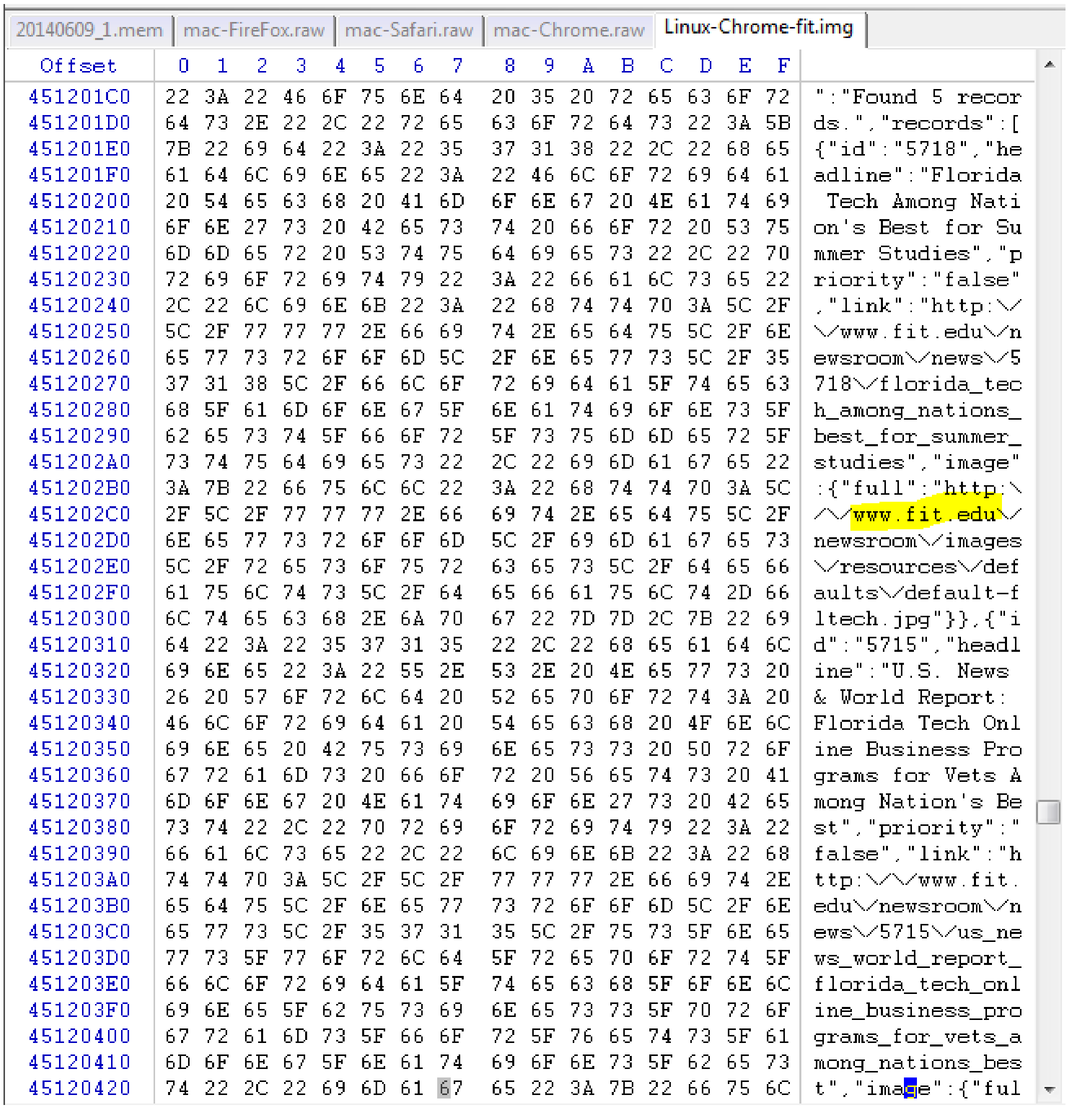
------------------------------Output---

```
emad@emad-VirtualBox:~/linux$ sudo dcfldd if=/dev/pmem
of=/media/8437-F391/test.img bs=1024
[sudo] password for emad:
1524480 blocks (1488Mb) written.
1524671+1 records in
1524671+1 records out
emad@emad-VirtualBox:~/linux$
```

--------------------------------End of Output--

Chrome:

The browser was launched in Incognito mode and website “fit.edu” was accessed. After the site was access the browser was closed. The RAM contents were captured on an external drive. The captured image was opened using Winhex for analysis. During analysis it was found that URL existed in the memory.

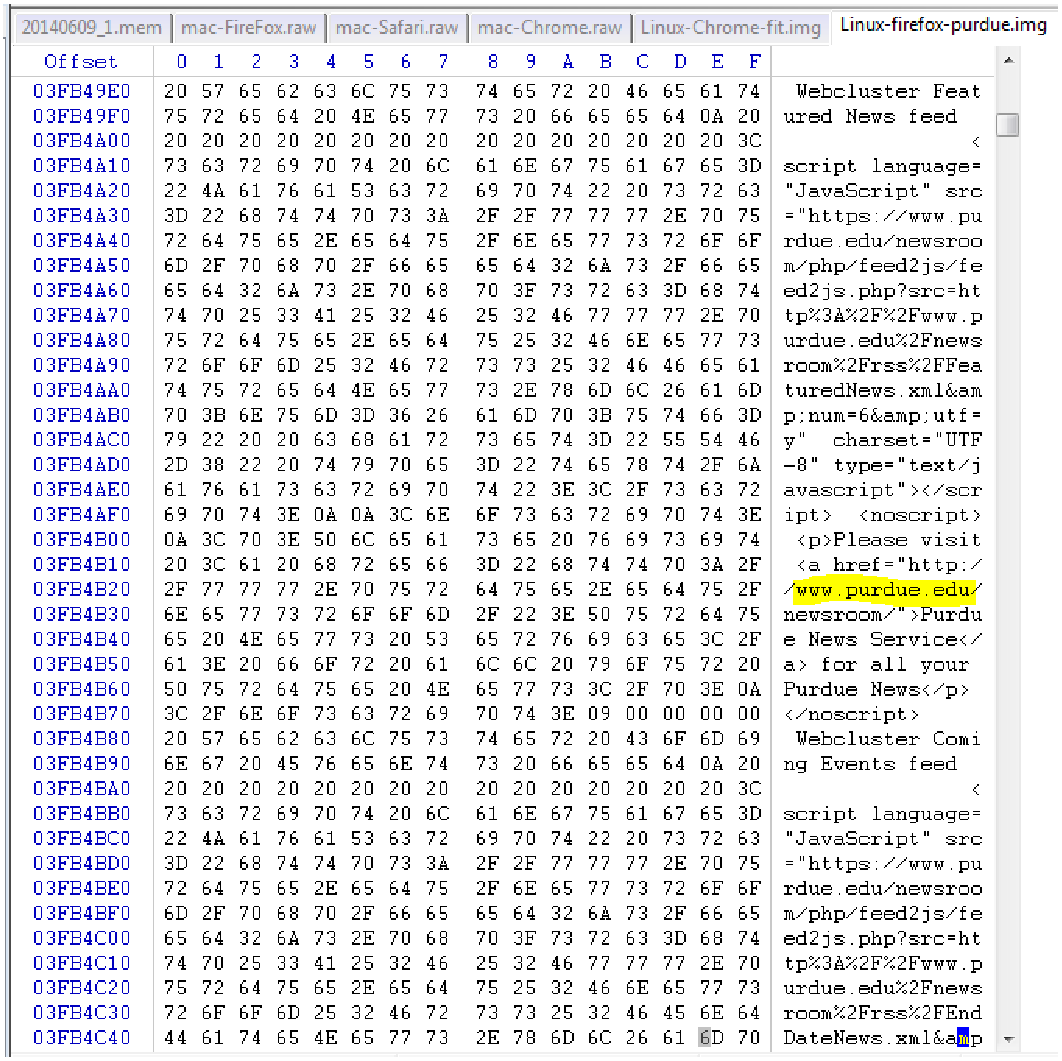


```
Offset     0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
451201C0  22 3A 22 46 6F 75 6E 64  20 35 20 72 65 63 6F 72   ":"Found 5 recor
451201D0  64 73 2E 22 2C 22 72 65  63 6F 72 64 73 22 3A 5B   ds.","records":[
451201E0  7B 22 69 64 22 3A 22 35  37 31 38 22 2C 22 68 65   {"id":"5718","he
451201F0  61 64 6C 69 6E 65 22 3A  22 46 6C 6F 72 69 64 61   adline":"Florida
45120200  20 54 65 63 68 20 41 6D  6F 6E 67 20 4E 61 74 69    Tech Among Nati
45120210  6F 6E 27 73 20 42 65 73  74 20 66 6F 72 20 53 75   on's Best for Su
45120220  6D 6D 65 72 20 53 74 75  64 69 65 73 22 2C 22 70   mmer Studies","p
45120230  72 69 6F 72 69 74 79 22  3A 22 66 61 6C 73 65 22   riority":"false"
45120240  2C 22 6C 69 6E 6B 22 3A  22 68 74 74 70 3A 5C 2F   ,"link":"http:\/
45120250  5C 2F 77 77 77 2E 66 69  74 2E 65 64 75 5C 2F 6E   \/www.fit.edu\/n
45120260  65 77 73 72 6F 6F 6D 5C  2F 6E 65 77 73 5C 2F 35   ewsroom\/news\/5
45120270  37 31 38 5C 2F 66 6C 6F  72 69 64 61 5F 74 65 63   718\/florida_tec
45120280  68 5F 61 6D 6F 6E 67 5F  6E 61 74 69 6F 6E 73 5F   h_among_nations_
45120290  62 65 73 74 5F 66 6F 72  5F 73 75 6D 6D 65 72 5F   best_for_summer_
451202A0  73 74 75 64 69 65 73 22  2C 22 69 6D 61 67 65 22   studies","image"
451202B0  3A 7B 22 66 75 6C 6C 22  3A 22 68 74 74 70 3A 5C   :{"full":"http:\
451202C0  2F 5C 2F 77 77 77 2E 66  69 74 2E 65 64 75 5C 2F   /\/www.fit.edu\/
451202D0  6E 65 77 73 72 6F 6F 6D  5C 2F 69 6D 61 67 65 73   newsroom\/images
451202E0  5C 2F 72 65 73 6F 75 72  63 65 73 5C 2F 64 65 66   \/resources\/def
451202F0  61 75 6C 74 73 5C 2F 64  65 66 61 75 6C 74 2D 66   aults\/default-f
45120300  6C 74 65 63 68 2E 6A 70  67 22 7D 7D 2C 7B 22 69   ltech.jpg"}},{"i
45120310  64 22 3A 22 35 37 31 35  22 2C 22 68 65 61 64 6C   d":"5715","headl
45120320  69 6E 65 22 3A 22 55 2E  53 2E 20 4E 65 77 73 20   ine":"U.S. News 
45120330  26 20 57 6F 72 6C 64 20  52 65 70 6F 72 74 3A 20   & World Report: 
45120340  46 6C 6F 72 69 64 61 20  54 65 63 68 20 4F 6E 6C   Florida Tech Onl
45120350  69 6E 65 20 42 75 73 69  6E 65 73 73 20 50 72 6F   ine Business Pro
45120360  67 72 61 6D 73 20 66 6F  72 20 56 65 74 73 20 41   grams for Vets A
45120370  6D 6F 6E 67 20 4E 61 74  69 6F 6E 27 73 20 42 65   mong Nation's Be
45120380  73 74 22 2C 22 70 72 69  6F 72 69 74 79 22 3A 22   st","priority":"
45120390  66 61 6C 73 65 22 2C 22  6C 69 6E 6B 22 3A 22 68   false","link":"h
451203A0  74 74 70 3A 5C 2F 5C 2F  77 77 77 2E 66 69 74 2E   ttp:\/\/www.fit.
451203B0  65 64 75 5C 2F 6E 65 77  73 72 6F 6F 6D 5C 2F 6E   edu\/newsroom\/n
451203C0  65 77 73 5C 2F 35 37 31  35 5C 2F 75 73 5F 6E 65   ews\/5715\/us_ne
451203D0  77 73 5F 77 6F 72 6C 64  5F 72 65 70 6F 72 74 5F   ws_world_report_
451203E0  66 6C 6F 72 69 64 61 5F  74 65 63 68 5F 6F 6E 6C   florida_tech_onl
451203F0  69 6E 65 5F 62 75 73 69  6E 65 73 73 5F 70 72 6F   ine_business_pro
45120400  67 72 61 6D 73 5F 66 6F  72 5F 76 65 74 73 5F 61   grams_for_vets_a
45120410  6D 6F 6E 67 5F 6E 61 74  69 6F 6E 73 5F 62 65 73   mong_nations_bes
45120420  74 22 2C 22 69 6D 61 67  65 22 3A 7B 22 66 75 6C   t","image":{"ful
```

Figure 11: Chrome on Linux Winhex analysis Screenshot

Firefox:

The browser was launched in Private and the website “purdue.edu” was accessed. After accessing the site, the RAM image was captured on an external drive. The captured image was opened using Winhex for further analysis. During analysis it was found that the URL was stored in the memory.



```
 Offset    0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
03FB49E0  20 57 65 62 63 6C 75 73  74 65 72 20 46 65 61 74   Webcluster Feat
03FB49F0  75 72 65 64 20 4E 65 77  73 20 66 65 65 64 0A 20  ured News feed  
03FB4A00  20 20 20 20 20 20 20 20  20 20 20 20 20 20 20 3C                 <
03FB4A10  73 63 72 69 70 74 20 6C  61 6E 67 75 61 67 65 3D  script language=
03FB4A20  22 4A 61 76 61 53 63 72  69 70 74 22 20 73 72 63  "JavaScript" src
03FB4A30  3D 22 68 74 74 70 73 3A  2F 2F 77 77 77 2E 70 75  ="https://www.pu
03FB4A40  72 64 75 65 2E 65 64 75  2F 6E 65 77 73 72 6F 6F  rdue.edu/newsroo
03FB4A50  6D 2F 70 68 70 2F 66 65  65 64 32 6A 73 2F 66 65  m/php/feed2js/fe
03FB4A60  65 64 32 6A 73 2E 70 68  70 3F 73 72 63 3D 68 74  ed2js.php?src=ht
03FB4A70  74 70 25 33 41 25 32 46  25 32 46 77 77 77 2E 70  tp%3A%2F%2Fwww.p
03FB4A80  75 72 64 75 65 2E 65 64  75 25 32 46 6E 65 77 73  urdue.edu%2Fnews
03FB4A90  72 6F 6F 6D 25 32 46 72  73 73 25 32 46 46 65 61  room%2Frss%2FFea
03FB4AA0  74 75 72 65 64 4E 65 77  73 2E 78 6D 6C 26 61 6D  turedNews.xml&am
03FB4AB0  70 3B 6E 75 6D 3D 36 26  61 6D 70 3B 75 74 66 3D  p;num=6&amp;utf=
03FB4AC0  79 22 20 20 63 68 61 72  73 65 74 3D 22 55 54 46  y"  charset="UTF
03FB4AD0  2D 38 22 20 74 79 70 65  3D 22 74 65 78 74 2F 6A  -8" type="text/j
03FB4AE0  61 76 61 73 63 72 69 70  74 22 3E 3C 2F 73 63 72  avascript"></scr
03FB4AF0  69 70 74 3E 0A 0A 3C 6E  6F 73 63 72 69 70 74 3E  ipt>  <noscript>
03FB4B00  0A 3C 70 3E 50 6C 65 61  73 65 20 76 69 73 69 74   <p>Please visit
03FB4B10  20 3C 61 20 68 72 65 66  3D 22 68 74 74 70 3A 2F   <a href="http:/
03FB4B20  2F 77 77 77 2E 70 75 72  64 75 65 2E 65 64 75 2F  /www.purdue.edu/
03FB4B30  6E 65 77 73 72 6F 6F 6D  2F 22 3E 50 75 72 64 75  newsroom/">Purdu
03FB4B40  65 20 4E 65 77 73 20 53  65 72 76 69 63 65 3C 2F  e News Service</
03FB4B50  61 3E 20 66 6F 72 20 61  6C 6C 20 79 6F 75 72 20  a> for all your 
03FB4B60  50 75 72 64 75 65 20 4E  65 77 73 3C 2F 70 3E 0A  Purdue News</p> 
03FB4B70  3C 2F 6E 6F 73 63 72 69  70 74 3E 09 00 00 00 00  </noscript>     
03FB4B80  20 57 65 62 63 6C 75 73  74 65 72 20 43 6F 6D 69   Webcluster Comi
03FB4B90  6E 67 20 45 76 65 6E 74  73 20 66 65 65 64 0A 20  ng Events feed  
03FB4BA0  20 20 20 20 20 20 20 20  20 20 20 20 20 20 20 3C                 <
03FB4BB0  73 63 72 69 70 74 20 6C  61 6E 67 75 61 67 65 3D  script language=
03FB4BC0  22 4A 61 76 61 53 63 72  69 70 74 22 20 73 72 63  "JavaScript" src
03FB4BD0  3D 22 68 74 74 70 73 3A  2F 2F 77 77 77 2E 70 75  ="https://www.pu
03FB4BE0  72 64 75 65 2E 65 64 75  2F 6E 65 77 73 72 6F 6F  rdue.edu/newsroo
03FB4BF0  6D 2F 70 68 70 2F 66 65  65 64 32 6A 73 2F 66 65  m/php/feed2js/fe
03FB4C00  65 64 32 6A 73 2E 70 68  70 3F 73 72 63 3D 68 74  ed2js.php?src=ht
03FB4C10  74 70 25 33 41 25 32 46  25 32 46 77 77 77 2E 70  tp%3A%2F%2Fwww.p
03FB4C20  75 72 64 75 65 2E 65 64  75 25 32 46 6E 65 77 73  urdue.edu%2Fnews
03FB4C30  72 6F 6F 6D 25 32 46 72  73 73 25 32 46 45 6E 64  room%2Frss%2FEnd
03FB4C40  44 61 74 65 4E 65 77 73  2E 78 6D 6C 26 61 6D 70  DateNews.xml&amp
```

Figure 12: Firefox on Linux Winhex analysis Screenshot

Mac OSX Analysis:

For Mac OSX, I used OSXPmem for capturing the physical memory contents. The memory contents were captured and copied directly to an external drive as shown below:

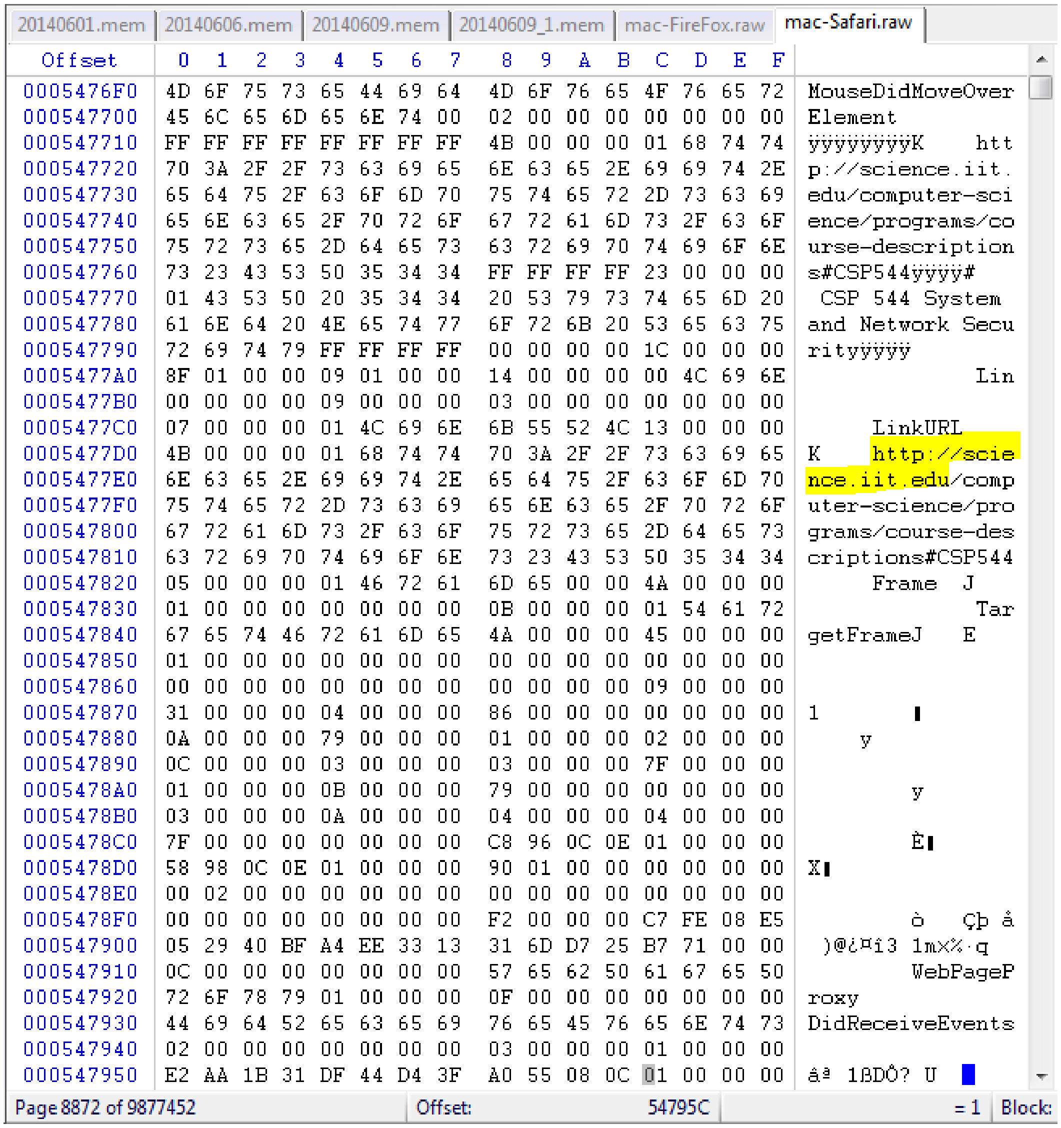
---Output---

```
 Emads-MacBook-Pro:OSXPMem emad$ sudo ./osxpmem -v -f raw
/Volumes/Untitled/macosdump.raw
Password:
Loading kext from ./pmem.kext
Recieved memory map, size:12528 bytes (descriptors: 48)
[0000000000000000 - 000000000008e000] Conventional    [WRITTEN]
[000000000008e000 - 0000000000090000] Reserved        [PADDED]
[0000000000090000 - 00000000000a0000] Conventional    [WRITTEN]
……………………………………………………………………………………………………………
……………………………………………………………………………………………………………
                                    Part of Output Omitted
……………………………………………………………………………………………………………
……………………………………………………………………………………………………………
[00000000e00f8000 - 00000000e00f9000] MMIO            [PADDED]
[00000000fed1c000 - 00000000fed20000] MMIO            [PADDED]
[00000000ffe70000 - 00000000ffea0000] MMIO            [PADDED]
[0000000100000000 - 000000016f600000] Conventional    [WRITTEN]
Acquired 1024816 pages (4197646336 bytes)
Size of physical address space: 6163529728 bytes (261 segments)
Successfully wrote raw image of memory to /Volumes/Untitled/macosdump.raw
Kernel directory table base: 0x0000000750e000
Unloading kext volatility.driver.pmem
Emads-MacBook-Pro:OSXPMem emad$
```

--End of Output--

Safari:

The browser was launched in Private mode and website “iit.edu” was accessed. After accessing the site, the browser was closed and the RAM image was captured on an external drive using OSXPmem as shown earlier. The RAM image was opened in Winhex for analysis. During analysis it was found that the browsed URL existed in the memory.

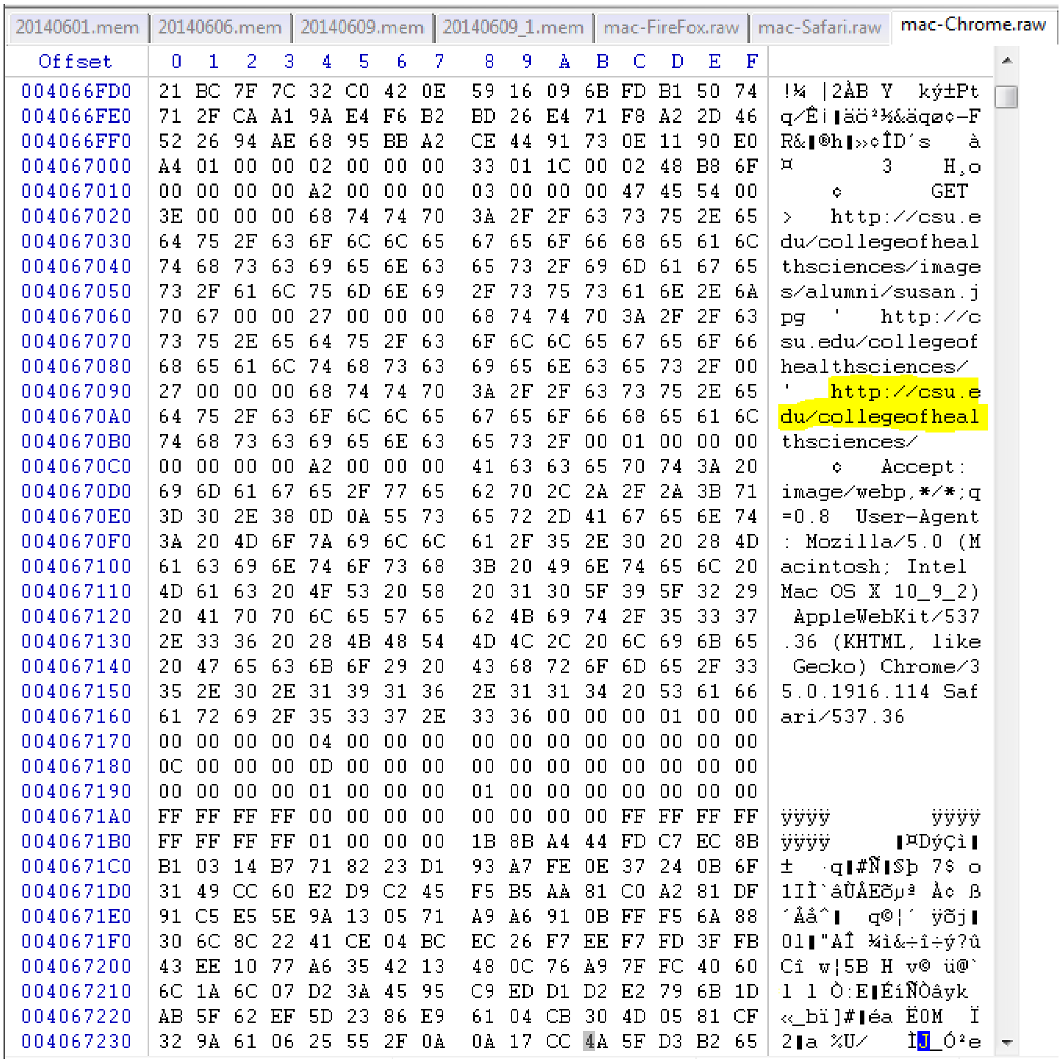


```
  Offset    0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
0005476F0  4D 6F 75 73 65 44 69 64  4D 6F 76 65 4F 76 65 72  MouseDidMoveOver
000547700  45 6C 65 6D 65 6E 74 00  02 00 00 00 00 00 00 00  Element
000547710  FF FF FF FF FF FF FF FF  4B 00 00 00 01 68 74 74  ÿÿÿÿÿÿÿÿK    htt
000547720  70 3A 2F 2F 73 63 69 65  6E 63 65 2E 69 69 74 2E  p://science.iit.
000547730  65 64 75 2F 63 6F 6D 70  75 74 65 72 2D 73 63 69  edu/computer-sci
000547740  65 6E 63 65 2F 70 72 6F  67 72 61 6D 73 2F 63 6F  ence/programs/co
000547750  75 72 73 65 2D 64 65 73  63 72 69 70 74 69 6F 6E  urse-description
000547760  73 23 43 53 50 35 34 34  FF FF FF FF 23 00 00 00  s#CSP544ÿÿÿÿ#
000547770  01 43 53 50 20 35 34 34  20 53 79 73 74 65 6D 20   CSP 544 System
000547780  61 6E 64 20 4E 65 74 77  6F 72 6B 20 53 65 63 75  and Network Secu
000547790  72 69 74 79 FF FF FF FF  00 00 00 00 1C 00 00 00  rityÿÿÿÿ
0005477A0  8F 01 00 00 09 01 00 00  14 00 00 00 00 4C 69 6E               Lin
0005477B0  00 00 00 00 09 00 00 00  03 00 00 00 00 00 00 00
0005477C0  07 00 00 00 01 4C 69 6E  6B 55 52 4C 13 00 00 00       LinkURL
0005477D0  4B 00 00 00 01 68 74 74  70 3A 2F 2F 73 63 69 65  K    http://scie
0005477E0  6E 63 65 2E 69 69 74 2E  65 64 75 2F 63 6F 6D 70  nce.iit.edu/comp
0005477F0  75 74 65 72 2D 73 63 69  65 6E 63 65 2F 70 72 6F  uter-science/pro
000547800  67 72 61 6D 73 2F 63 6F  75 72 73 65 2D 64 65 73  grams/course-des
000547810  63 72 69 70 74 69 6F 6E  73 23 43 53 50 35 34 34  criptions#CSP544
000547820  05 00 00 00 01 46 72 61  6D 65 00 00 4A 00 00 00       Frame  J
000547830  01 00 00 00 00 00 00 00  0B 00 00 00 01 54 61 72               Tar
000547840  67 65 74 46 72 61 6D 65  4A 00 00 00 45 00 00 00  getFrameJ   E
000547850  01 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
000547860  00 00 00 00 00 00 00 00  00 00 00 00 09 00 00 00
000547870  31 00 00 00 04 00 00 00  86 00 00 00 00 00 00 00  1       ▌
000547880  0A 00 00 00 79 00 00 00  01 00 00 00 02 00 00 00      y
000547890  0C 00 00 00 03 00 00 00  03 00 00 00 7F 00 00 00
0005478A0  01 00 00 00 0B 00 00 00  79 00 00 00 00 00 00 00          y
0005478B0  03 00 00 00 0A 00 00 00  04 00 00 00 04 00 00 00
0005478C0  7F 00 00 00 00 00 00 00  C8 96 0C 0E 01 00 00 00          È▌
0005478D0  58 98 0C 0E 01 00 00 00  90 01 00 00 00 00 00 00  X▌
0005478E0  00 02 00 00 00 00 00 00  00 00 00 00 00 00 00 00
0005478F0  00 00 00 00 00 00 00 00  F2 00 00 00 C7 FE 08 E5          ò   Çþ å
000547900  05 29 40 BF A4 EE 33 13  31 6D D7 25 B7 71 00 00   )@¿¤î3 1m×%·q
000547910  0C 00 00 00 00 00 00 00  57 65 62 50 61 67 65 50          WebPageP
000547920  72 6F 78 79 01 00 00 00  0F 00 00 00 00 00 00 00  roxy
000547930  44 69 64 52 65 63 65 69  76 65 45 76 65 6E 74 73  DidReceiveEvents
000547940  02 00 00 00 00 00 00 00  03 00 00 00 01 00 00 00
000547950  E2 AA 1B 31 DF 44 D4 3F  A0 55 08 0C 01 00 00 00  âª 1ßDÔ? U
Page 8872 of 9877452    Offset:    54795C    = 1  Block:
```

Figure 13: Safari on MAC Winhex analysis Screenshot

Chrome:

The browser was launched in Incognito mode and website “csu.edu” was accessed. After the accessing the website, the browser was closed and image of the RAM was captured using OSXPmem as shown earlier. The image was taken directly on an external drive. The captured image was opened using Winhex for further analysis. During analysis it was found that the URL was stored in the memory.

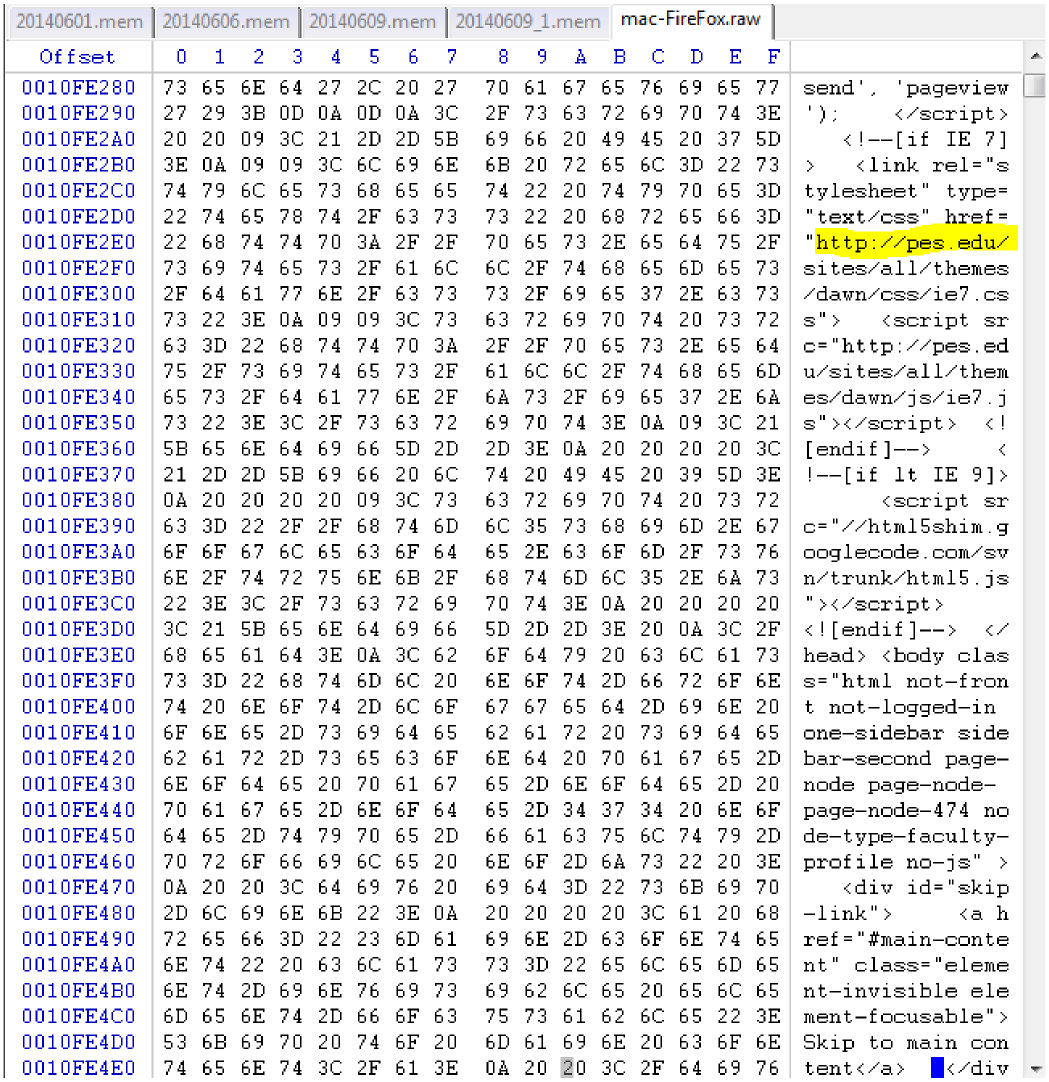


```
  Offset     0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
004066FD0   21 BC 7F 7C 32 C0 42 0E  59 16 09 6B FD B1 50 74   !¼ |2ÀB Y  ký±Pt
004066FE0   71 2F CA A1 9A E4 F6 B2  BD 26 E4 71 F8 A2 2D 46   q/Êi▮äö²½&äqø¢-F
004066FF0   52 26 94 AE 68 95 BB A2  CE 44 91 73 0E 11 90 E0   R&▮®h▮»¢ÎD's   à
004067000   A4 01 00 00 02 00 00 00  33 01 1C 00 02 48 B8 6F   ¤       3    H¸o
004067010   00 00 00 00 A2 00 00 00  03 00 00 00 47 45 54 00       ¢       GET
004067020   3E 00 00 00 68 74 74 70  3A 2F 2F 63 73 75 2E 65   >   http://csu.e
004067030   64 75 2F 63 6F 6C 6C 65  67 65 6F 66 68 65 61 6C   du/collegeofheal
004067040   74 68 73 63 69 65 6E 63  65 73 2F 69 6D 61 67 65   thsciences/image
004067050   73 2F 61 6C 75 6D 6E 69  2F 73 75 73 61 6E 2E 6A   s/alumni/susan.j
004067060   70 67 00 00 27 00 00 00  68 74 74 70 3A 2F 2F 63   pg  '   http://c
004067070   73 75 2E 65 64 75 2F 63  6F 6C 6C 65 67 65 6F 66   su.edu/collegeof
004067080   68 65 61 6C 74 68 73 63  69 65 6E 63 65 73 2F 00   healthsciences/
004067090   27 00 00 00 68 74 74 70  3A 2F 2F 63 73 75 2E 65   '   http://csu.e
0040670A0   64 75 2F 63 6F 6C 6C 65  67 65 6F 66 68 65 61 6C   du/collegeofheal
0040670B0   74 68 73 63 69 65 6E 63  65 73 2F 00 01 00 00 00   thsciences/
0040670C0   00 00 00 00 A2 00 00 00  41 63 63 65 70 74 3A 20       ¢   Accept:
0040670D0   69 6D 61 67 65 2F 77 65  62 70 2C 2A 2F 2A 3B 71   image/webp,*/*;q
0040670E0   3D 30 2E 38 0D 0A 55 73  65 72 2D 41 67 65 6E 74   =0.8  User-Agent
0040670F0   3A 20 4D 6F 7A 69 6C 6C  61 2F 35 2E 30 20 28 4D   : Mozilla/5.0 (M
004067100   61 63 69 6E 74 6F 73 68  3B 20 49 6E 74 65 6C 20   acintosh; Intel
004067110   4D 61 63 20 4F 53 20 58  20 31 30 5F 39 5F 32 29   Mac OS X 10_9_2)
004067120   20 41 70 70 6C 65 57 65  62 4B 69 74 2F 35 33 37    AppleWebKit/537
004067130   2E 33 36 20 28 4B 48 54  4D 4C 2C 20 6C 69 6B 65   .36 (KHTML, like
004067140   20 47 65 63 6B 6F 29 20  43 68 72 6F 6D 65 2F 33    Gecko) Chrome/3
004067150   35 2E 30 2E 31 39 31 36  2E 31 31 34 20 53 61 66   5.0.1916.114 Saf
004067160   61 72 69 2F 35 33 37 2E  33 36 00 00 00 01 00 00   ari/537.36
004067170   00 00 00 00 04 00 00 00  00 00 00 00 00 00 00 00
004067180   0C 00 00 00 0D 00 00 00  00 00 00 00 00 00 00 00
004067190   00 00 00 00 01 00 00 00  01 00 00 00 00 00 00 00
0040671A0   FF FF FF FF 00 00 00 00  00 00 00 00 FF FF FF FF   ÿÿÿÿ        ÿÿÿÿ
0040671B0   FF FF FF FF 01 00 00 00  1B 8B A4 44 FD C7 EC 8B   ÿÿÿÿ      ▮¤DýÇì▮
0040671C0   B1 03 14 B7 71 82 23 D1  93 A7 FE 0E 37 24 0B 6F   ±  ·q▮#Ñ▮§þ 7$ o
0040671D0   31 49 CC 60 E2 D9 C2 45  F5 B5 AA 81 C0 A2 81 DF   1IÌ`âÙÂEõµª À¢ ß
0040671E0   91 C5 E5 5E 9A 13 05 71  A9 A6 91 0B FF F5 6A 88   'Åå^▮  q©¦' ÿõj▮
0040671F0   30 6C 8C 22 41 CE 04 BC  EC 26 F7 EE F7 FD 3F FB   0l▮"AÎ ¼ì&÷î÷ý?û
004067200   43 EE 10 77 A6 35 42 13  48 0C 76 A9 7F FC 40 60   Cî w¦5B H v© ü@`
004067210   6C 1A 6C 07 D2 3A 45 95  C9 ED D1 D2 E2 79 6B 1D   l l Ò:E▮ÉíÑÒâyk
004067220   AB 5F 62 EF 5D 23 86 E9  61 04 CB 30 4D 05 81 CF   «_bï]#▮éa Ë0M  Ï
004067230   32 9A 61 06 25 55 2F 0A  0A 17 CC 4A 5F D3 B2 65   2▮a %U/   ÌJ_Ó²e
```

Figure 14: Chrome on MAC Winhex analysis Screenshot

FireFox:

The browser was launched in Private mode and website "pes.edu was accessed. After accessing the website, the browser was closed and live capture of the RAM was taken on an external drive. The captured image was opened using Winhex for further analysis. During analysis it was found that the URL was stored in the memory.



```
  Offset    0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
0010FE280  73 65 6E 64 27 2C 20 27  70 61 67 65 76 69 65 77  send', 'pageview
0010FE290  27 29 3B 0D 0A 0D 0A 3C  2F 73 63 72 69 70 74 3E  ');    </script>
0010FE2A0  20 20 09 3C 21 2D 2D 5B  69 66 20 49 45 20 37 5D     <!--[if IE 7]
0010FE2B0  3E 0A 09 09 3C 6C 69 6E  6B 20 72 65 6C 3D 22 73  >   <link rel="s
0010FE2C0  74 79 6C 65 73 68 65 65  74 22 20 74 79 70 65 3D  tylesheet" type=
0010FE2D0  22 74 65 78 74 2F 63 73  73 22 20 68 72 65 66 3D  "text/css" href=
0010FE2E0  22 68 74 74 70 3A 2F 2F  70 65 73 2E 65 64 75 2F  "http://pes.edu/
0010FE2F0  73 69 74 65 73 2F 61 6C  6C 2F 74 68 65 6D 65 73  sites/all/themes
0010FE300  2F 64 61 77 6E 2F 63 73  73 2F 69 65 37 2E 63 73  /dawn/css/ie7.cs
0010FE310  73 22 3E 0A 09 09 3C 73  63 72 69 70 74 20 73 72  s">   <script sr
0010FE320  63 3D 22 68 74 74 70 3A  2F 2F 70 65 73 2E 65 64  c="http://pes.ed
0010FE330  75 2F 73 69 74 65 73 2F  61 6C 6C 2F 74 68 65 6D  u/sites/all/them
0010FE340  65 73 2F 64 61 77 6E 2F  6A 73 2F 69 65 37 2E 6A  es/dawn/js/ie7.j
0010FE350  73 22 3E 3C 2F 73 63 72  69 70 74 3E 0A 09 3C 21  s"></script>  <!
0010FE360  5B 65 6E 64 69 66 5D 2D  2D 3E 0A 20 20 20 20 3C  [endif]-->     <
0010FE370  21 2D 2D 5B 69 66 20 6C  74 20 49 45 20 39 5D 3E  !--[if lt IE 9]>
0010FE380  0A 20 20 20 20 09 3C 73  63 72 69 70 74 20 73 72        <script sr
0010FE390  63 3D 22 2F 2F 68 74 6D  6C 35 73 68 69 6D 2E 67  c="//html5shim.g
0010FE3A0  6F 6F 67 6C 65 63 6F 64  65 2E 63 6F 6D 2F 73 76  ooglecode.com/sv
0010FE3B0  6E 2F 74 72 75 6E 6B 2F  68 74 6D 6C 35 2E 6A 73  n/trunk/html5.js
0010FE3C0  22 3E 3C 2F 73 63 72 69  70 74 3E 0A 20 20 20 20  "></script>
0010FE3D0  3C 21 5B 65 6E 64 69 66  5D 2D 2D 3E 20 0A 3C 2F  <![endif]-->  </
0010FE3E0  68 65 61 64 3E 0A 3C 62  6F 64 79 20 63 6C 61 73  head> <body clas
0010FE3F0  73 3D 22 68 74 6D 6C 20  6E 6F 74 2D 66 72 6F 6E  s="html not-fron
0010FE400  74 20 6E 6F 74 2D 6C 6F  67 67 65 64 2D 69 6E 20  t not-logged-in
0010FE410  6F 6E 65 2D 73 69 64 65  62 61 72 20 73 69 64 65  one-sidebar side
0010FE420  62 61 72 2D 73 65 63 6F  6E 64 20 70 61 67 65 2D  bar-second page-
0010FE430  6E 6F 64 65 20 70 61 67  65 2D 6E 6F 64 65 2D 20  node page-node-
0010FE440  70 61 67 65 2D 6E 6F 64  65 2D 34 37 34 20 6E 6F  page-node-474 no
0010FE450  64 65 2D 74 79 70 65 2D  66 61 63 75 6C 74 79 2D  de-type-faculty-
0010FE460  70 72 6F 66 69 6C 65 20  6E 6F 2D 6A 73 22 20 3E  profile no-js" >
0010FE470  0A 20 20 3C 64 69 76 20  69 64 3D 22 73 6B 69 70     <div id="skip
0010FE480  2D 6C 69 6E 6B 22 3E 0A  20 20 20 20 3C 61 20 68  -link">     <a h
0010FE490  72 65 66 3D 22 23 6D 61  69 6E 2D 63 6F 6E 74 65  ref="#main-conte
0010FE4A0  6E 74 22 20 63 6C 61 73  73 3D 22 65 6C 65 6D 65  nt" class="eleme
0010FE4B0  6E 74 2D 69 6E 76 69 73  69 62 6C 65 20 65 6C 65  nt-invisible ele
0010FE4C0  6D 65 6E 74 2D 66 6F 63  75 73 61 62 6C 65 22 3E  ment-focusable">
0010FE4D0  53 6B 69 70 20 74 6F 20  6D 61 69 6E 20 63 6F 6E  Skip to main con
0010FE4E0  74 65 6E 74 3C 2F 61 3E  0A 20 20 3C 2F 64 69 76  tent</a>   </div
```

Figure 15: Firefox on MAC Winhex analysis Screenshot

6

Private Mode Analysis Results

6.1 Conclusion

As mentioned earlier, browser vendors claim to not store any browsing related on the end device. But the results of testing and investigation are as follows:

Recovery from file system method:

Browser Vendor	Comments	Result
Internet Explorer	Browsing related information is recoverable as the browser writes the data on the file system and then deletes it by a file system operation called “SetDispositionInformationFile”.	Fail
Firefox	The browser doesn’t write anything to the filesystem and no data can be recovered.	Pass
Chrome	The browser doesn’t write anything to the filesystem and no data can be recovered.	Pass
Safari	The browser writes browsing data on a file “WebpageIcons.db”.	Fail

Recovery from physical memory (RAM) method:

Browser Vendor	Comments	Result
Internet Explorer	Browsing related information is recoverable as the browser writes data on the RAM.	Fail
Firefox	Browsing related information is recoverable as the browser writes data on the RAM.	Fail
Chrome	Browsing related information is recoverable as the browser writes data on the RAM.	Fail
Safari	Browsing related information is recoverable as the browser writes data on the RAM.	Fail

Therefore from a user privacy perspective it is preferable to use Google Chrome and Firefox than using Safari or Internet Explorer.

6.2 Mitigation

We have discussed two methods on how browsing history of private sessions can be recovered, one was recovery from file system method and the other was using physical memory recovery method.

For the file system method the browser vendor should ensure that the browser in private should not write any data on the file system as writing data on the file system makes it easy for anyone to perform recovery.

For the memory recovery method the browser vendor should ensure that when the process is shut down, the memory allocated or used by the browser is filled with random characters so that data cannot be recovered from the memory.

6.3 Future work

Future work could be to assess the effectiveness of the popular privacy eraser software to check if they would actually get rid of all the browsing history related information.

Additionally further assessment can be performed for the remaining browsers in the market.

With a shift in users heavily adopting mobile devices, there have been browsers developed specifically for mobile devices. Performing analysis of these browsers in normal mode and private mode would be a good area for future analysis.

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