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In order to comply with best preservation and curation practices, collecting institutions must ensure that private and sensitive information contained in born-digital materials has been properly redacted before the materials are made available. Institutions receiving donor media in the form of hard disks, USB flash drives, compact disks, floppy disks, and even entire computers, are increasingly creating bit-identical copies called disk images. Redacting data from within a disk image currently is a manual, time-consuming task. In this project, I demonstrate the feasibility of automating disk image redaction using open-source, forensic software. I discuss the problems encountered when redacting disk images using automated methods and ways to improve future disk image redaction tools.

Headings:

Disk image redaction

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Data sanitization

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AUTOMATING DISK IMAGE REDACTION

by
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Introduction

As collecting institutions receive born-digital material from donors, they must mitigate any private or sensitive material from within the material before making it available. The consequences of not properly protecting donor data could ultimately result in the institution appearing to be not trustworthy or incompetent, resulting in fewer donations. To ensure personal or sensitive information is not disseminated in the collection, digital material must be sanitized. When receiving donor media in the form of hard disks, USB flash drives, compact disks, and floppy disks, collecting institutions are increasingly creating bit-identical copies of the media called disk images. Collection professionals are then responsible for ensuring that private or sensitive material, referred to as target data, are not accessible on the disk image. However, redacting target data from within a disk image currently is a manual task that can add a substantial amount to curatorial workflows. Increasing curatorial processing time can delay processing existing backlogs, allowing them to grow larger.

To improve the speed at which disk images can be redacted, I investigate the feasibility of redacting sensitive material from disk images while maintaining the provenance of the disk image using open-source, forensic software. I demonstrate that disk image redaction can be accurately automated and discuss methods of improving future disk image redaction systems. The rest of this paper is divided into the following sections: Background, Related Work, Project Design, Limitations, Results, Discussion, Implications, Future Work, and finally the Conclusion.

Background

To understand how disk image redaction works, a general understanding of digital storage media, computer file systems, and disk images is needed. I will touch on each topic in the following subsections.

Digital Storage Media

Digital storage media are used to store digital information. Common storage media include random access memory, hard disk, USB flash, Solid State Disk (SSD), floppy disk, compact disk, and tape. Each medium type has advantages and disadvantages.

The most common type of storage medium, the hard disk, is used for both short-term and long-term storage of digital information. Hard disks are usually comprised of several stacked, round, magnetic platters spun by a motor.[1] A small read/write head mounted to an arm passes over the top and bottom surface of each platter and detects magnetic variations on the surface of the platter.[2] Each side of each platter is divided into concentric rings called tracks.[3] Tracks are numbered, starting with zero on the outside and increasing toward the center of the platter.[4] Each circular track is divided into sectors.[5] A sector is where data is stored and is the smallest unit of storage on a hard

[1] Brian Carrier, *File System Forensic Analysis*, Vol. 3 (Reading: Addison-Wesley, 2005).
[2] Carrier, *File System Forensic Analysis*, 22.
[3] Ibid.
[4] Ibid.
[5] Ibid, 23.

disk.[6] The typical size of a sector is 4,096 bytes on a modern hard disk and 512 bytes on older hard disks.[7] The hard disk maintains an internal map of which sectors are in each block. If a sector goes bad, the hard disk automatically reassigns an unused sector to the block.[8] Blocks are sequentially numbered and often referred to as offsets.

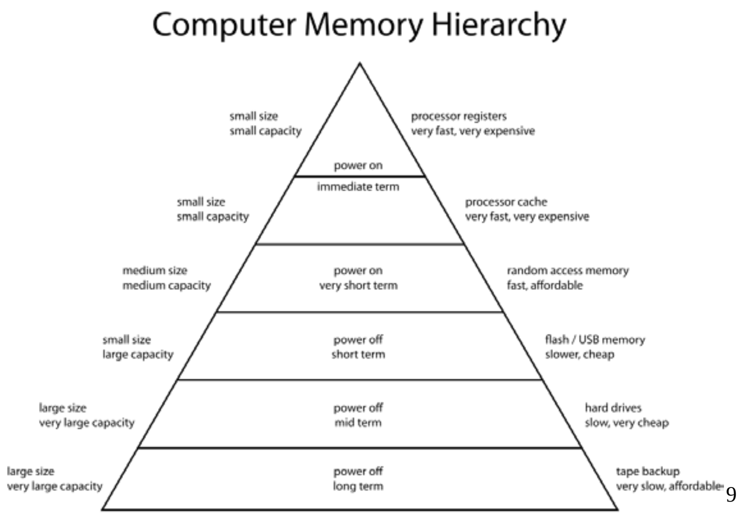

Figure 1. Storage volatility. Source: http://en.wikipedia.org/wiki/File:ComputerMemoryHierarchy.svg

Random access memory (RAM) is typically used as a temporary storage space for data that the central processing unit (CPU) is processing. The most common form of memory is Dynamic Random Access Memory (DRAM) and is comprised of billions of transistor capacitor pairs that each store a single bit of information.[10] The capacitors are either charged or discharged, thus representing the two values of a bit: one (charged) or zero (discharged).[11] The transistor acts as a switch that can either charge or discharge the

[6] Ibid, 22.
[7] Matthew Kirschenbaum et al., “Digital Forensics and Born-Digital Content in Cultural Heritage Collections,” *CLIR Publication* No. 149 (Council on Library and Information Resources, 2010).
[8] Carrier, *File System Forensic Analysis*, 23.
[9] “ComputerMemoryHierarchy,” 2010, Wikipedia, http://en.wikipedia.org/wiki/File:ComputerMemoryHierarchy.svg.
[10] Random-Access Memory, n.d. http://en.wikipedia.org/wiki/Random-access_memory (accessed February 11, 2014).
[11] Ibid.

capacitor.[12] However, because all capacitors leak electricity, the charge stored in each capacitor is periodically refreshed by transferring and amplifying the existing charge into another capacitor transistor pair.[13] As a result of this process, DRAM is considered volatile since all data will be lost shortly after power is removed. The primary advantage of RAM is its fast read/write speed compared to hard disks.

Optical storage disks such as compact disks (CD) or digital video disks (DVD) are also common media for distributing software and user files; however, as new computing devices get smaller, fewer new devices include optical disk drives. This medium is currently being supplanted by other forms of storage like flash memory or network-based cloud storage. The optical disc is a round, thin plastic disc with one or more layers of metallic film sandwiched between two polycarbonate discs.[14] The surface of the metallic film alternates between lands and pits.[15] A narrow laser beam is directed at the disk and the metallic film reflects the beam from the surface of the disk.[16] Pits scatter the light, whereas lands reflect light back to a detector.[17] The detector is a light-sensing diode that produces a small electrical voltage each time light is reflected back from a land.[18] The pits and hills etched into the metallic film on an optical disk are stored in a continuous spiral path starting at the center of the disk, moving outward.[19] Transitions between pits and lands or lands and pits represent an optical 1 bit, whereas

[12] Ibid.
[13] Ibid.
[14] “Compact Disk,” n.d., Wikipedia, accessed February 11, 2014, http://en.wikipedia.org/wiki/Compact_disc.
[15] Ron White and Timothy Downs, *How Computers Work* (Que Corp., 2007), 186.
[16] “Compact Disk.”
[17] White, *How Computers Work*, 186.
[18] Ibid.
[19] “Compact Disk.”

the lack of a transition represents an optical 0 bit.[20] Optical bits are not the same as data bits; the former are demodulated by grouping several optical bits together to form a data bit.[21] The exact number of optical bits that constitute a data bit depends on the type of disc format, e.g., CD, DVD, HD-DVD, Blu-Ray.[22] Optical disks also use error correction to ensure that sectors damaged from dust, scratches, and smudges do not cause irreversible damage.[23]

The now obsolete floppy disk has been superseded by the hard disk, optical disc, the USB flash disk, and network storage systems. Floppy disks were created in three main sizes: 8 inch, 3.5 inch (pronounced three and a half), and 5.25 inch (pronounced five and a quarter). All three types of floppy disk were constructed with a thin circular plastic disc, coated with magnetic oxide, and enclosed in a rectangular plastic case.[24] Similar to hard disks, some floppy disks can store data on both sides of the plastic disk. Each side can be divided into concentric rings called tracks. Tracks are numbered, starting with zero on the outside and increasing toward the center of the disk.[25] Each circular track is divided into sectors. Sectors are where the data is stored and are the smallest unit of storage on a floppy disk. The typical size of a floppy disk sector is 512 bytes; however, different disk manufacturers used different sector sizes.[26] Both 8 inch and 5.25 inch floppy disk drives require special controllers that are not included on

[20] White, *How Computers Work*, 193.
[21] Ibid.
[22] Ibid, 192.
[23] Malcolm Stitch, *Laser handbook* (1972), 1787-l788.
[24] "Floppy Disk," n.d., Wikipedia, accessed February 11, 2014, http://en.wikipedia.org/wiki/Floppy_disk.
[25] Ibid.
[26] Ibid.

modern motherboards.[27] Specialized equipment can be used to connect a floppy controller to a USB floppy controller, which can then be read by a modern computer.

Magnetic tape cassettes are commonly used to back up servers because of their low cost per gigabyte. The cassettes, sometimes referred to as cartridges, consist of a hard plastic enclosure containing two reels with a continuous span of flexible magnetic-coated plastic.[28] Like hard disks and floppy disks, data is written to sectors contained in tracks. However, the tracks are not circular, and instead, are written parallel to the length of tape, perpendicular to the length of tape, or in short diagonal stripes on the tape.[29] Tape drives require special controllers to interface with the host computer.

The Solid State Disk (SSD) is a newer digital storage medium than the others discussed above and is poised to supersede hard disks for many purposes. SSDs operate in a similar fashion to RAM, in that data is stored in integrated circuits. However, the storage is non-volatile and unlike RAM, can hold data long after power has been removed. Data in an SSD is stored in sectors comprised of many logical NOT AND (NAND) transistors, referred to as registers. The typical size of a sector is 4,096 byte, but this varies between manufacturers. The SSD maintains an internal map of which NAND gates are in each sector and which sectors are in each block. If a register fails, the SSD automatically reassigns an unused register to the sector. Unlike electromechanical storage media like hard disks, floppy disks, and tapes, SSDs have no moving parts and therefore are not susceptible to mechanical failure. But data can only be written to each chip within

[27] Ibid.
[28] “Magnetic Tape Data Storage,” n.d., Wikipedia, accessed April 4, 2014, http://en.wikipedia.org/wiki/Data_cartridge_%28tape%29#Cartridges_and_cassettes.
[29] Ibid.

the SSD a limited number of times.[30] The SSD performs a process called wear-leveling where it moves data to different registers throughout the drive based on the number of times data has been written to the register. This movement of data is transparent to the operating system. Blocks in an SSD are sequentially numbered and often referred to as offsets. Due to wear-leveling, block location assignments are dynamic and change without notice; however, the data in the blocks remains the same.

SSDs have a unique quality that directly affects anyone attempting to recover data from the disk. SSDs can irrevocably erase data on the disks with unprecedented speed. 500 gigabyte SSD drives have been shown to erase all of the data on the disk in less than six minutes when performing a disk format.[31] This is important to note because it is very easy to permanently delete data when working with SSDs.[32]

A cloud network storage system is simply storage to which users can connect via a network. Typically, cloud storage refers to a system that can be reached over the commodity Internet, but can also refer to a private enterprise networked storage system. Cloud or network storage systems are comprised of redundant physical storage media like hard disks, SSDs, tapes, etc., arranged in such a way that provides end users with storage space.[33] Cloud storage systems usually co-locate different users' data within storage nodes. They use authentication and file permissions to co-locate user data on a given storage medium. The primary reason to reference cloud network storage in a redaction context is that the data is usually backed up in multiple locations. Redacting information

[30] Matthew Levendoski, "Solid State Drives and the Forensic Process" (Master's thesis, Purdue University, 2013).
[31] Ibid.
[32] Ibid.
[33] Jonathan Strickland, "How Cloud Storage Works," HowStuffWorks, accessed April 2, 2014, http://computer.howstuffworks.com/cloud-computing/cloud-storage.htm.

from cloud storage can be difficult because it involves overwriting the same data in different locations. Complicating the matter further is that most cloud storage systems are owned and operated by third party vendors.

File Systems

File systems organize data on a storage medium in a hierarchy of files and directories. Every file system has a boot sector at the beginning of the disk in sector zero that contains information about the file system and instructions for what the processor should do to boot or start up the computer.[34] The file system also contains metadata describing each file and directory. Since redaction usually involves overwriting data, it is necessary to understand how file systems work and the differences in how each file system refers to data. As shown in Table 1 below, there are many different file systems with different features and attributes.[35]

	Maximum volume size	Maximum file size	Maximum filename length	Stores file owner	Create timestamp	Last access timestamp	Last modification timestamp	Supports encryption	Original operating system	Year introduced
FAT12	32 MB	32 MB	255 UTF-16	no	partial	partial	yes	no	QDOS, 86-DOS	1980
FAT16	4 GB	2 GB	255 UTF-16	no	partial	partial	yes	no	MSDOS	1984
FAT32	2 TB	4 GB	255 UTF-16	no	partial	partial	yes	no	Windows 95	1996
NTFS 3.1	16 EB	16 EB	255 bytes	yes	yes	yes	yes	yes	Windows XP	2001
ReFS	1 YB	16 EB	32,767 UTF	yes	yes	yes	yes	yes	Windows 2012 Server	2012
HFS	2 TB	2 GB	31 bytes	no	yes	no	yes	no	Mac OS	1985
HFS+	8 EB	8 EB	255 UTF-16	yes	yes	yes	yes	yes	Mac OS 8.1	1998
EXT2	32 TB	2 TB	255 bytes	yes	no	yes	yes	no	Linux	1993
EXT3	32 TB	2 TB	255 bytes	yes	no	yes	yes	yes	Linux	1999
EXT4	1 EB	16 TB	255 bytes	yes	yes	yes	yes	yes	Linux	2006

Table 1. File System Comparison Table. Source: http://en.wikipedia.org/wiki/Comparison_of_file_systems

In the context of data redaction, it is important to understand how each file system refers to data and stores metadata. The metadata describing the presence of a file or directory can sometimes be as important as the file itself. Because file systems are designed to save and track the locations of data, many file systems duplicate the file

[34] Carrier, *File System Forensic Analysis*, 155.
[35] A comprehensive table detailing more file systems and can be found: http://en.wikipedia.org/wiki/Comparison_of_file_systems

tables. In the event a table is corrupted or lost, the locations of files and directories can be recovered from the duplicate table. As a result, it is more difficult to sanitize all descriptive metadata from within file systems. Even popular whole-disk sanitization tools struggle with eliminating all metadata.[36]

When redacting data, the original file system will not likely be used to remove the sensitive data. Instead, external programs will likely search the data on the disk and overwrite the data directly, bypassing the file system.

The File Allocation Table (FAT) file system was originally developed in the late 1970s by Microsoft for use on floppy disks; however, it was soon adapted for use on hard disks and became the ubiquitous file system for computers worldwide.[37] FAT stores the cluster addresses of each file and directory in a table.[38] The table and root directories are stored at a fixed location at the beginning of the volume.[39,40] The table is comprised of data structures for each file and directory on the disk. Each data structure contains the file name, the starting cluster location of the file, the file size, and related file attributes. File attributes are additional metadata that describe each file. The FAT file system supports the following four file attributes: read-only, hidden, system, and archive.[41]

FAT stores files starting in the first available cluster. If the file size exceeds the size of a cluster, the remainder of the file is split over remaining clusters until the entire file has been written to the volume. As files are deleted, clusters are marked available and

[36] Simson Garfinkel and David Malan, "One Big File is Not Enough: A Critical Evaluation of the Dominant Free-Space Sanitization Technique," *Privacy Enhancing Technologies* (Springer Berlin Heidelberg, 2006): 135-151.
[37] FAT has since been supplanted by NTFS as the default file system for Windows operating systems.
[38] “Overview of FAT, HPFS, and NTFS File Systems,” 2007, *Microsoft: Support* http://support.microsoft.com/kb/100108/EN-US.
[39] “Overview of FAT, HPFS, and NTFS File Systems.”
[40] FAT32 and FAT64 allow the root directory to be stored anywhere within the volume.
[41] “Overview of FAT, HPFS, and NTFS File Systems.”

new files are written to them. As a result, clusters in the first part of the storage medium are written more often than clusters at the end of the medium. The biggest disadvantage of the file system starting with the first available cluster is that files become fragmented across the disk. Fragmentation decreases disk performance, because the read/write heads have to spend time seeking to several areas of the disk to read the full contents of a file.

There are four FAT versions: FAT12, FAT16, FAT32, and FAT64 (ExFAT). The primary difference between the versions is the maximum file and volume sizes that each can support. FAT12 limits cluster addresses to 12 bits in length and does not support hierarchical directories.[42] It has a maximum file size of 32 megabytes and a maximum volume size of 256 megabytes.[43] FAT12 was primarily used on floppy disks and was compatible with the MS-DOS operating system. FAT16 was an improvement over FAT12, in that it used 16 bits for addressing clusters.[44] As a result the maximum file and volume size for FAT16 is 2 gigabytes.[45] FAT16 increased the number of entries in the root directory to 512 and enabled hierarchal directories.[46] FAT32 improved several shortcomings of the previous FAT versions. First, it increased the cluster addressing size to 32 bits which increased the maximum file size to 4 gigabytes and the maximum volume size to 2 terabytes.[47,48] The second improvement was that the root folder could be located anywhere on the volume and therefore was not constrained to a specific number

[42] "What is FAT File System," HDD Tool, http://www.hdd-tool.com/hdd-basic/what-is-fat-file-system.htm.
[43] "Comparison of File Systems," n.d., Wikipedia, accessed February 18, 2014, http://en.wikipedia.org/wiki/Comparison_of_file_systems.
[44] "What is FAT File System."
[45] "Comparison of File Systems."
[46] "FAT16 vs. FAT32," n.d., Microsoft: TechNet, http://technet.microsoft.com/en-us/library/cc940351.aspx.
[47] "Comparison of File Systems."
[48] "What is FAT File System."

of entries.[49] The third improvement was that the file system stored a copy of the boot sector in sector six that could be used if the primary table became corrupted.[50,51] FAT64 or Extended FAT (ExFAT) is optimized for removable media and uses 64 bits for addressing clusters.[52] As a result, the maximum file size is 127 petabytes and the maximum volume size is 64 zeta bytes.[53] ExFAT is not commonly used in user operating systems but rather in appliances where the simplicity of a FAT structure is needed for file sizes greater than 4 gigabytes.

FAT is supported by Windows, Macintosh, and most flavors of Linux.[54] Because of its simplicity, FAT is commonly used on removable media such as memory cards and portable electronic devices, e.g., cameras and voice recorders.[55]

The New Technology File System (NTFS) was developed by Microsoft as a secure and scalable file system for use on large storage volumes.[56] It has replaced FAT as the standard file system for use in the majority of Microsoft Windows operating systems. Windows NT, Windows 2000, Windows XP, Windows Server, Vista, and Windows 7 all use the NTFS file system.[57] NTFS can also be used on Mac and on many Linux operating systems.[58]

The first sector of an NTFS volume is a boot sector that contains the cluster size for the storage medium, volume information, a pointer to the start of the Master File

[49] "FAT16 vs. FAT32."
[50] Ibid.
[51] Carrier, *File System Forensic Analysis*, 156.
[52] "NTFS vs FAT," 2010, HDD Tool, http://www.hdd-tool.com/pic/FAT-NTFS.png.
[53] "Comparison of File Systems."
[54] Carrier, *File System Forensic Analysis*, 154.
[55] Ibid.
[56] Ibid, 199.
[57] Ibid.
[58] Ibid.

Table (MFT), and the size in bytes of entries in the MFT.[59] NTFS stores file and directory entries in the MFT.[60] Each MFT record contains a header, several standard attributes, and unstructured space for additional attributes.[61] As shown in Figure 2 below, the first 24 entries in the MFT are reserved for standard files that are used by the file system. Unlike the FAT file allocation tables that simply point to the location of the data, the MFT is a file itself and each entry within the MFT contains metadata and file data.[62] Because the boot sector of the NTFS volume contains a pointer to the start of the MFT file and no additional information about the size and layout of the MFT file, the first entry in the MFT describes the size and layout of the rest of the MFT file.[63] The operating system must process the first entry in the MFT file simply to understand how to read the rest of the MFT file. The only information describing the size and layout of the MFT is in this initial entry.[64] The advantage of this design is the NTFS boot sector for the volume doesn't need to change as the MFT increases in size.

[59] "Overview of FAT, HPFS, and NTFS File Systems."
[60] Carrier, *File System Forensic Analysis*, 200.
[61] Ibid, 206.
[62] Ibid.
[63] Ibid, 202.
[64] Ibid, 200.

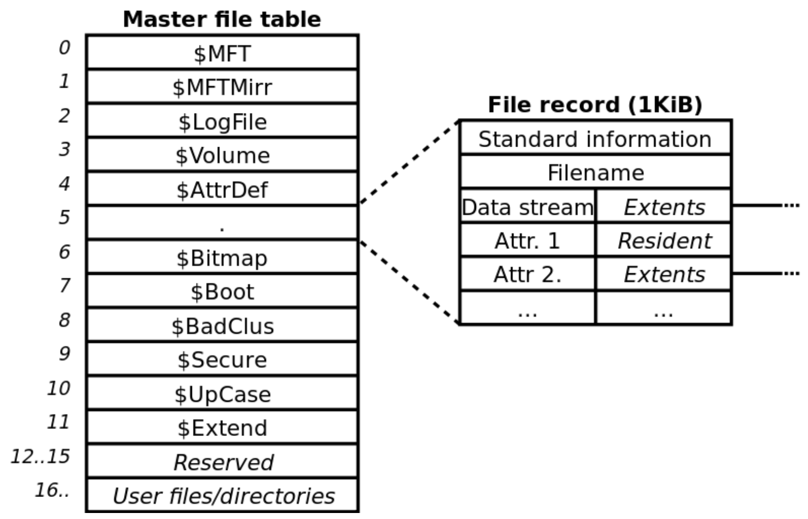

Figure 2. NTFS Master File Table. Source: http://commons.wikimedia.org/wiki/File:Ntfs_mft.svg

The second entry in the MFT is $MFTMirr, which points to a backup copy of the MFT.[65] The third entry in the MFT is $LogFile, which contains a record for all metadata transactions.[66] The seventh entry in the MFT is $BITMAP, which contains an allocation status for every cluster in the file system.[67] In terms of digital redaction and file sanitization, it is important to note that MFT entries are not immediately overwritten when a file is deleted. Instead the entry is marked as unallocated in the $BITMAP attribute and the data may be overwritten if a new file entry is written into that entry address.[68] As a result, deleted files and their file attributes can be recovered after they have been marked as “deleted” and if another file has not been written into the address.

From a redaction perspective, there are several attributes within an MFT entry that are important to understand. The first is the $DATA attribute because it contains raw file content.[69] Information contained within the $DATA attribute is the primary file content data that will be targeted for redaction. Because MFT entries are typically fixed

[65] Ibid, 220.
[66] Ibid, 281.
[67] Ibid, 203.
[68] Ibid, 201.
[69] Ibid, 264.

at 1,024 bytes each, the $DATA attribute can only contain 700 bytes of file contents within a given MFT entry.[70] For files that are larger than 700 bytes, the $DATA attribute points to external clusters on the volume that contain the file contents.[71] Attributes with data stored within the MFT entry are called resident attributes.[72] Attributes with data stored in clusters external to the MFT are called non-resident attributes. Depending on the size of the file, target data will be located either in the MFT in a resident $DATA attribute or elsewhere on the volume in a non-resident $DATA attribute. The second important attribute from a redaction perspective is $FILE_NAME, because it contains the name of the file or directory, its size and its timestamps for when it was created, written, and last accessed.[73] The metadata contained within the $STANDARD_INFORMATION attribute is also important as it contains the security ID and owner of a file or directory.[74] Both the $FILE_NAME and the $STANDARD_INFORMATION attributes could contain additional sensitive information describing data to be redacted from the $DATA attribute. The fourth and fifth important attributes are the $INDEX_ROOT resident attribute and its child attribute, the $INDEX_ALLOCATION non-resident attribute.[75] Both attributes are only assigned to directories and contain information about the files and subdirectories within a given directory, which is useful when redacting entire directory structures.[76] For example, to redact the contents within a Windows My Documents directory, the contents of the My Documents directory can be derived from information stored within these two attributes.

[70] Ibid, 204.
[71] Ibid, 264.
[72] Ibid.
[73] Ibid, 205.
[74] Ibid.
[75] Ibid, 267.
[76] Ibid.

When NTFS is first installed on a volume, the MFT starts out small and grows larger as needed.[77] As a result, the MFT can be fragmented over many different clusters as it grows.[78] In Windows environments, the MFT will never shrink in size, even if all user files are deleted.[79] As previously mentioned, this “deleted” data is not actually overwritten on the storage medium and is recoverable.

One of the security improvements NTFS supports is file encryption, which can present problems for finding and redacting sensitive data. Encrypted attribute content would need to be decrypted before the data could be searched or redacted. NTFS uses a symmetric encryption algorithm called DESX to encrypt attribute content.[80] In Windows operating systems, the encryption keys are generated by combining a random key issued to the MFT entry with the user’s password.[81]

Disk Images

A disk image is a bit-identical copy of a storage medium’s data clusters.[82] A disk image can be stored in one or more files.[83] Creating a disk image is different from simply copying files from one location to another. When copying files from one file system to another, descriptive metadata may be replaced or omitted when the file is copied to the destination file system. Because imaging a disk preserves the data on the entire storage medium, it also saves files marked as deleted and file-fragments located in slack space. Slack space refers to unused sectors within a data cluster. It occurs when a file segment

[77] Ibid, 201.
[78] Ibid.
[79] Ibid.
[80] Ibid, 210.
[81] Ibid.
[82] Kirschenbaum, *Digital Forensics and Born-Digital*, 17.
[83] Kam Woods and Christopher A. Lee and Simson Garfinkel, "Extending digital repository architectures to support disk image preservation and access," *Proceedings of the 11th annual international ACM/IEEE joint conference on Digital libraries* (ACM, 2011), 58.

assigned to a cluster is smaller than the total size of the cluster. [84] Because most file systems do not immediately overwrite file clusters when a file is deleted, fragments from previously deleted files can be found in unassigned sectors within a cluster.[85]

Disk images have many uses, including forensic examination, data rescue, and the preservation of information. In Information Technology (IT) communities, disk images are used to rapidly deploy operating system and software configurations to computers.[86] In a preservation context, a disk image allows the information from a given storage medium to be transferred to a new medium while preserving the original structure of the data.[87] In forensic contexts, imaging a disk can help to establish a trustworthy chain of custody of the data.[88] In a preservation setting, a cardinal rule is to minimize irreversible transformations to the data. By creating a disk image of a medium, it is possible to perform transformations on copies of the disk image without affecting the original data.

Disk Image Formats

Disk images can be created in several formats by a variety of different programs. Common programs for imaging disks are Data Dump (dd) included with Linux, Guymager, FTK Imager, and EnCase. The most common image formats are RAW, EWF, AFF, and ISO.[89,90] Each format is designed for specific use-cases.

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[84] Kirschenbaum, *Digital Forensics and Born-Digital*, 43-44.
[85] Kirschenbaum, *Digital Forensics and Born-Digital*, 43.
[86] Simson Garfinkel, "Digital forensics XML and the DFXML toolset," *Digital Investigation 8*, no. 3 (2012) 162.
[87] Kam Woods and Christopher A. Lee, "Acquisition and Processing of Disk Images to Further Archival Goals," *Archiving Conference*, vol. 2012, no. 1, pp. 147-152. Society for Imaging Science and Technology, (2012): 148.
[88] Woods, *Extending Digital Repository*, 57.
[89] Garfinkel, *Digital Forensics XML*, 162-163.
[90] Simson Garfinkel, "Providing Cryptographic Security and Evidentiary Chain-of-Custody with the Advanced Forensic Format, Library, and Tools," *International Journal of Digital Crime and Forensics (IJDCF) 1* (2009): 3.

The RAW image format produces an uncompressed and unencrypted, bit-for-bit duplicate of data on a disk.[91] The RAW format does not add metadata about the original storage medium or the operating system. Originally used by the Linux Data Dump (dd) program, the RAW format was designed to allow the simple duplication of disk drives.[92] It is important to note that because the RAW format is uncompressed, the disk image will be the same size as the original disk.[93] A 300 gigabyte disk will produce a single 300 gigabyte disk image file. Split-RAW allows large disk images to be divided by size over multiple files. This makes it easier to transfer disk images on smaller storage media like compact disk or flash disk.

As computer forensics began using disk images to gather evidence, additional metadata describing the case and file compression were added to the image formats. As a result, several forensic disk image formats emerged. The Expert Witness Format (EWF) is a proprietary, forensically packaged imaging format created by Guidance Software for use with their commercial forensic examination software, EnCase.[94] The name was later changed to the EnCase Image File format and used the ".E01" file extension.[95] The EWF format is arguably the most popular image format used in forensics and archives.[96] EWF uses file compression to reduce the size of disk images.[97] The EWF format also stores metadata about the original media, as well as information about the case and the person creating the image.[98] The proprietary EWF format was reverse-engineered by Joachim

[91] Carrier, *File System Forensic Analysis*, 43
[92] Kirschenbaum, *Digital Forensics and Born-Digital*, 15.
[93] Carrier, *File System Forensic Analysis*, 43
[94] Carrier, *File System Forensic Analysis*, 43
[95] Garfinkel, *Digital Forensics XML*, 162.
[96] Ibid.
[97] Woods, *Extending Digital Repository Architectures*, 58.
[98] Garfinkel, *Digital Forensics XML*, 162.

Metz, who created libewf, a code library that allows other programs to read and write EWF format files.[99]

Data within the EWF format is organized into a header, followed by disk image data, and then by a one-way hash of the file.[100] The file header contains information about the disk image, including “Case Number, Evidence Number, Unique Description, Examiner Name, and Notes”.[101] The disk image itself is compressed and divided into 32-kilobyte data blocks.[102] At the end of each data block is an Adler32 checksum which is used for error correction.[103] The disk image data is followed by a one-way hash of the disk image data.

Because the EWF disk image format was designed for use in forensics, it was created with safeguards to identify if any part of the file is altered. If any chunk of data within the disk image is changed, the checksum at the end of the data block has to be recomputed, as does the one-way hash at the end of the file. One can test the validity of a EWF disk image by computing the checksum of each data block and the hash for the file. According to Joachim Metz, the open source libewf library cannot edit EWF files.[104] To protect disk images from unauthorized access, EWF includes the ability to encrypt the disk image as well as require passwords to access the file.[105]

The Advanced Forensic Format (AFF), developed by Simson Garfinkel and Basis Technology, is an open format for storing disk images and associated forensic

[99] “Libewf,” Forensics Wiki, last modified February 16, 2014, http://www.forensicswiki.org/wiki/Libewf.
[100] “Encase Image File Format,” Forensics Wiki, last modified July 15, 2013, http://www.forensicswiki.org/wiki/Encase_image_file_format.
[101] “ASR Data's Expert Witness Compression Format,” Forensics Wiki, last modified March 29, 2013, http://www.forensicswiki.org/wiki/ASR_Data%27s_Expert_Witness_Compression_Format.
[102] “Encase Image File Format.”
[103] “Encase Image File Format.”
[104] Joachim Metz, e-mail message to author, January 3, 2014.
[105] “Encase Image File Format.”

metadata.[106] The primary advantage that AFF has over EWF is that it contains a hash of the disk image in the metadata section within the file. This allows edits to be made to the metadata without changing the hash of the imaged data and thus casting doubt on the data within the disk image portion of the file.[107] All transformations performed on the disk image can be detailed in Digital Forensic XML (DFXML) metadata. DFXML is an XML (Extensible Markup Language) implementation designed for the exchange of structured forensic information.[108]

The latest AFF version called AFF4 was developed by Michael Cohen, Simson Garfinkel and Bradley Schatz and added features like multiple data streams within one file and links between archives.[109] There is still no complete, publicly available implementation of AFF4. Many forensics tools support AFF, but its adoption does not appear to be as widespread as the adoption of EWF.

Viewing Disk Images

Disk images can be read and interpreted by several different software packages. Most commercial forensic tools can read and interpret all of the major image formats. But there are also a number of open-source tools that can view the contents of disk images.

The bulk_extractor tool is an open-source forensic triage application that can parse and extract text from storage media and disk images.[110] It extracts forensic features consisting of email addresses, Uniform Resource Locators (URLs), search terms (extracted from URLs), credit card numbers, and phone numbers, EXIF (Exchange Image

[106] "AFF," Forensics Wiki last modified January 29, 2014, http://www.forensicswiki.org/wiki/AFFLIB.
[107] "AFF."
[108] Garfinkel, *Digital Forensics XML*, 161.
[109] "AFF."
[110] Simson Garfinkel, "Digital Media Triage with Bulk Data Analysis and bulk_extractor," *Computers & Security* 32 (2013): 56-72.

File Format) from JPEG images, Global Positioning System (GPS) coordinates, and other types of information.[111] Although it was designed to be used as a command line tool, there is also a graphic user interface (GUI) for bulk_extractor called Bulk Extractor Viewer (BEViewer), which can be used to run the scanners, and view and search extracted features.[112] When bulk_extractor parses a disk image, it splits the image file into 16 megabyte chunks called *pages* and allocates each page to an available computer processing core.[113] By leveraging the multi-threading capabilities of most modern computer processors, bulk_extractor has been shown to process disk images up to 10 times faster than single-threaded forensic tools.[114]

The fiwalk tool is an open source forensics batch analysis application that interrogates the file system(s) on a disk image and outputs the contents in DFXML objects corresponding to allocated, deleted, and orphaned files and directories.[115] In addition to the file system data, fiwalk can also extract forensic metadata (e.g., examiner name, examiner notes) from the EWF and AFF packaged disk image formats.[116] Even if the disk image contains multiple file systems on multiple partitions, fiwalk can analyze and parse the different file systems and produce the contents in DFXML objects.[117]

Digital Redaction

A common definition of the word *redaction* in a digital context is the obscuring or removing of sensitive information. For this paper, I will use the following definition: the

[111] Garfinkel, *Digital Media Triage*, 60.
[112] Garfinkel, *Digital Media Triage*, 67.
[113] Garfinkel, *Digital Media Triage*, 59.
[114] Garfinkel, *Digital Media Triage*, 66.
[115] Garfinkel, *Digital Forensics XML*, 171.
[116] Simson Garfinkel, "Automating disk forensic processing with SleuthKit, XML and Python," *Systematic Approaches to Digital Forensic Engineering*, 2009. *SADFE'09.* Fourth International IEEE Workshop on, pp. 73-84. (IEEE, 2009).
[117] Garfinkel, *Automating Disk Forensic Processing*, 2.

removal of digital artifacts from an electronic information storage system, regardless of sensitivity. Stripping or overwriting data can fall under this definition.

As Lee and Woods point out, "modern computing devices often contain a significant amount of private and sensitive information."[118] Because disk images are identical copies of a computer's storage media, they also can contain a significant amount of sensitive information. In archival settings, disk images can contain sensitive or personal data that is not appropriate for the collection or should not be immediately disclosed to the public. Patient data, social security numbers, credit card numbers, contact lists, address books, email, and personal files are all examples of data that may need to be removed from a disk image before making it available.

There are two methods to redact information form storage media: 1) overwrite the original disk image data in-place or 2) create a redacted copy of the disk image. Creating a redacted copy of the disk image can be divided further based on when redaction is performed: 1) In advance or 2) upon request. In an Open Archival Information System (OAIS), redacting information in advance would be akin to creating a new Archival Information Package (AIP) whereas creating a redacted disk image on-demand would be analogous to creating a new Dissemination Information Package (DIP)[119]. Both the redaction in-place method and creating a redacted copy method have benefits and drawbacks. Redacting the data in-place ensures that all original target data is permanently destroyed.[120] Because only the original redacted disk image is needed, this method

[118] Christopher A. Lee and Kam Woods, "Automated Redaction of Private and Personal Data in Collections," *Proceedings of The Memory of the World in the Digital Age: Digitization and Preservation.* An international conference on permanent access to digital documentary heritage, (2012).
[119] The Consultative Committee for Space Data Systems, "Reference Model for an Open Archival Information System (OAIS)," Magenta Book, Issue 2 (2002).
[120] Complete destruction of data assumes that standard data sanitization practices are followed.

requires the least amount of storage space for the disk images. Creating a redacted copy preserves the original data at the expense of requiring more storage space. Depending on the amount of data redacted, as much as twice the disk space can be required to store the original and the redacted disk images. The size of the redacted disk image is influenced by the amount of data redacted and the method of redaction. Because the master disk images are not redacted and contain target data, they should be securely stored with limited access.

Some practitioners recommend overwriting with a single byte, while others recommend overwriting the data with random byte sequences.[121] Another method for overwriting the data is to encrypt the original sensitive data and write out the encrypted file. The advantage to encrypting the data in-place instead of overwriting a duplicate disk image is that the redacted data is secure and yet recoverable on the original medium. A secondary benefit to encryption in-place method is the reduction of storage space required to house duplicate redacted disk images.

Because disk images are bit-identical copies of the underlying blocks or clusters of storage on a medium, disk images include all information on the original media, including unwritten space and deleted space. Disk images are created by reading the bits from the storage medium and copying the bits in the same order they were retrieved from the disk to another medium.[122]

Disk images are used in a variety of applications including digital forensics, computer repair, and preservation. One of the first steps that law enforcement takes when logging digital evidence is to create a disk image of the acquired evidence. This is done

[121] Garfinkel, *One Big File is not Enough*, 15.
[122] Kirschenbaum, *Digital Forensics and Born-Digital*, 37.

to preserve the evidence and prevent tampering that could jeopardize a trial. In computer repair, disk images are retrieved from failing media or devices infected with viruses or malware. In preservation contexts, disk images are used to transfer information from the original physical medium to the repository's storage media. There are a variety of reasons why a disk image would be taken of a storage medium, e.g., in cases when the original media is obsolete or failing, to prevent bit rot of the original media, etc.

Related Work

There is surprisingly little research on redacting disk images. Because of this relative dearth of information, this project draws from research from three areas: automating forensic analysis, applying forensic methods to digital curation, and electronic document redaction. Each area offers a unique perspective into disk image redaction.

Automating Forensic Analysis

Commercial forensic toolkits like Access Data's FTK or Guidance Software's EnCase Forensic provide users the ability to process and analyze the contents of forensic disk images.[123,124] EnCase also has the ability to automate forensic processing through its proprietary EnScript scripting language. However, a shortcoming of EnScript is that external programs cannot interface with it.[125] In addition, commercial forensic tools are often cost-prohibitive for use in non-forensic environments like libraries and archives.

[123] "Computer Forensics Software for Digital Investigations," Access Data, accessed November 8, 2013, http://www.accessdata.com/products/digital-forensics/ftk.
[124] "Computer Forensic Software - Encase Forensic," Guidance Software, accessed November 8, 2013, http://www.encase.com/products/Pages/encase-forensic/overview.aspx
[125] Garfinkel, *Automating Disk Forensic Processing*, 2.

Despite a plethora of document redaction tools, there are few tools designed for redacting data from forensic disk images. Joachim Metz's libewf library can export forensically packaged disk images to the RAW format, which can then be edited using third-party software and imported back into the forensically packaged disk image format. Libewf reads and writes EWF disk images.[126] In an email exchange with Metz, he acknowledges that libewf cannot overwrite data in a EWF image.[127] Several open source toolkits include this library to edit EWF files. Similarly, Simson Garfinkel's AFFLIBv3 library allows third party tools to read and write AFF files.[128]

There are a few open source forensic tools that provide access to external programs through application programming interfaces (API). The PyFlag project, originally created by the Australian Federal Police, enabled developers to integrate forensic analysis into the development of new forensic software.[129,130] The SleuthKit (TSK), one of the most popular open source digital forensic tool kits available, includes an API for programmers to access the tools from other programs.[131] However, some developers have found it difficult and cumbersome to interface with the API when creating new forensic applications.[132]

Garfinkel's work with DFXML and fiwalk advanced the body of knowledge around open source forensic analysis and included an easy-to-use API to create new

[126] "Libewf."
[127] Joachim Metz, e-mail message to author, January 3, 2014.
[128] "AFF."
[129] Garfinkel, *In Systematic Approaches,* 75.
[130] "Forensic and Log Analysis GUI," Source Forge, accessed November 12, 2013, http://sourceforge.net/projects/pyflag/.
[131] "The Sleuth Kit (TSK) & Autopsy: Open Source Digital Forensics Tools," last modified April 4, 2014, http://www.sleuthkit.org/.
[132] Garfinkel, *Automating Disk Forensic Processing,* 84.

forensic tools.[133,134] The development of two modules included with fiwalk, imicrosoft_redact.py and iredact.py, are the basis for this project. Imicrosoft_redact.py overwrites crucial components within a disk image of a Windows operation system so the disk image cannot be booted.[135] Iredact.py is an experimental module designed to redact individual files or multiple files with similar characteristics based on user-defined parameters.[136] At the time of this writing, iredact.py has limited functionality, e.g., it can only redact files from RAW disk images based on their file hash signature.

Applying Forensic Methods to Digital Collections

Lee, Woods, Kirschenbaum, and Chassanoff's white paper reviews how forensic methods have been applied in libraries, archives, and museums to improve their digital curation workflows. In addition they detail how collecting institutions can begin using forensic methods, software and equipment.[137] Kirschenbaum, Ovenden, and Redwine's report provides an in-depth review of how digital forensic methods can and are being applied to collecting institution workflows.[138] Most of the forensic tools presented in the report were not packaged together for use in collection institutions. The BitCurator Project, led by Lee and Kirschenbaum, with Kam Woods as the technical lead, organized several open source forensic tools into a self-contained Linux package for use by collection professionals.[139] The package contains a disk imaging tool, a disk image exploration tool,

[133] Garfinkel, *Automating Disk Forensic Processing,* 75.
[134] "Category:Forensics File Formats," Forensics Wiki, last modified July 21, 2012, http://www.forensicswiki.org/wiki/Forensic_file_formats.
[135] Garfinkel, *Digital Forensics XML,* 172.
[136] Garfinkel, *Automating Disk Forensic Processing,* 83.
[137] Christopher A. Lee et al., "From Bitstreams to Heritage: Putting Digital Forensics into Practice in Collecting Institutions," (2013).
[138] Kirschenbaum, *Digital Forensics and Born-Digital*, 16.
[139] "About | BitCurator," BitCurator, last modified April 2, 2014, http://www.bitcurator.net/aboutbc/.

and automated processes to capture digital forensic XML data about the data on the disk image, among other features.

Electronic Document Redaction

Electronic document redaction parallels disk image redaction in that the process of selectively removing subsections of information from an entire document is similar to removing subsections of data from a disk image. Analogous to disk image redaction, electronic document redaction is focused on removing both the directly visible and “hidden” contents from the document.[140] Improper electronic document redaction techniques have led to several high profile cases of sensitive information being inadvertently released.[141]

There are two standard methods for performing analog redactions to physical documents. The first is to black out or cover the text of a document.[142] The second is to physically remove parts or entire pages of a document.[143] After the physical redaction has been made, the document is photocopied and distributed.[144] The methods used in electronic document redaction are similar to those used in analog document redaction. Data within an electronic can be overwritten or can be omitted when copying the data to another document.[145]

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[140] Mads R. Dahl and Eivind O. Simonsen and Christian B. Høyer, "What You See is not What You get in the PDF Document Format," *Health Informatics Journal 17, no. 1 (2011)*: 24-32.
[141] Jembaa Cole, "When Invisible Electronic Ink Leaves Red Faces: Tactical, Legal and Ethical Consequences of the Failure to Remove Metadata," *Shidler JL Com. & Tech. 1* (2005): 8-12.
[142] Daniel P. Lopresti and A. Lawrence Spitz, "Information Leakage Through Document Redaction: Attacks and Countermeasures," *Electronic Imaging 2005*, pp. 183-190, International Society for Optics and Photonics, (2005).
[143] Alexander Barclay, “Redacting Digital Information From Electronic Devices,” *Advances in Digital Forensics III: IFIP International Conference on Digital Forensics*, National Center for Forensic Science, (2007).
[144] Lopresti, *Information Leakage*, 183.
[145] Barclay, *Redacting Digital Information*.

Project Design

The purpose of this project is to analyze the feasibility of automating disk image redaction for use in digital curation environments. My two primary research questions are:

- Can the disk image redaction process be automated?
- Can an automated redaction process remove all target data identified for redaction?

My approach to answer these questions is to identify and then automate, a basic disk image redaction workflow using open-source digital forensic tools.

Development Environment

The BitCurator environment was selected to develop and evaluate the automated redaction workflow because it includes all of the software libraries necessary to automate the redaction processes. The BitCurator virtual machine, a self-contained Linux-based package that runs on a host operating system, was the ideal development environment because it did not require special hardware and could run on a laptop.[146] It includes Python, bulk_extractor, fiwalk, Guymager and several code libraries – libewf, AFFLIB, and The SleuthKit – which were all used to create and evaluate the automated workflow.

Corpus

Disk images from the public Naval Postgraduate School (NPS) Realistic Corpora were used to test and evaluate the effectiveness of the automated redaction workflow.[147] The NPS Realistic Corpora consists of disk images created by a project team that

[146] "BitCurator," last modified April 1, 2014, http://wiki.bitcurator.net/index.php?title=Main_Page.
[147] "Index of /corp/nps/scenarios/2009-m57-patents/usb," Digital Corpora, last modified April 3, 2012, http://digitalcorpora.org/corp/nps/scenarios/2009-m57-patents/usb/.

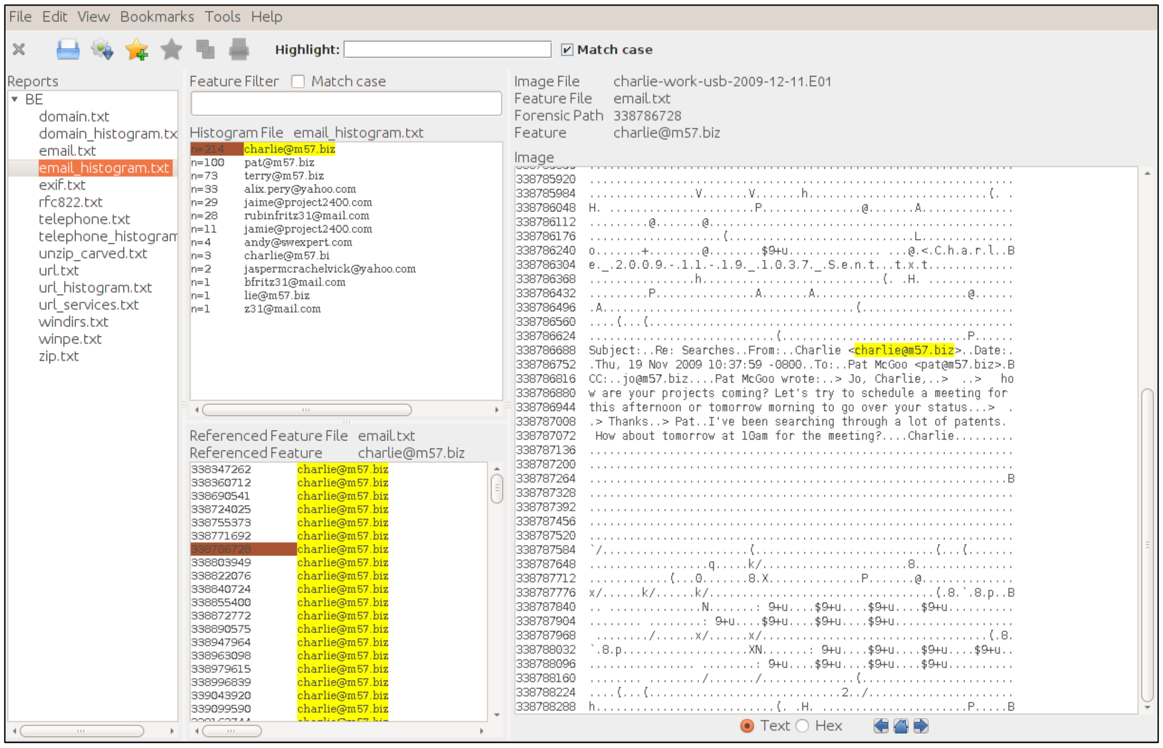
executed user actions and used scripts to mimic actual users.[148] However, the disk images do not contain personally identifiable information from real people. Individual disk images are made available on the digitalcorpora.org website in the EWF disk image format. As noted above, packaged forensic disk image formats are not designed for editing. The easiest method to redact a disk image is to first convert it to the RAW image format so the target data can be overwritten. RAW disk images can be accessed as binary files by most programming languages, which make the actual redaction a trivial task. The redacted RAW disk image is then converted back into the packaged image format. Because each disk image in the corpus had to be expanded into the RAW image format for redaction, the smaller USB Drive images from the M57 Patents scenario were used instead of the much larger Redacted Drive Images.[149] The USB Drive images range in size from 8 megabytes to 217 megabytes in the EWF format. When expanded to RAW, the disk images used in this project occupied a total of 3 gigabytes, which is manageable within the BitCurator virtual machine. The Redacted Drive Images ranged in size from 2.2 gigabytes to 10 gigabytes, which are too large to store and process within a virtual machine hosted on the laptop computer used for this study.

Redaction Workflow

The manual disk image redaction work flow is comprised of three basic steps: 1. Identify data within the disk image to redact, 2. Redact the data from the disk image, 3. Document and save the changes to a file.

[148] "Disk Images," Digital Corpora, last modified June 24, 2013, http://digitalcorpora.org/corpora/disk-images.
[149] The Redacted Drive Images get their name because the Microsoft system files that would allow the disk image to be booted have been removed. The disk images still contain mock data that could be used to test redaction methods.

I targeted specific textual data patterns for redaction within the NPS Corpora disk images. Domains, email addresses, and phone numbers represent common contact information that donors may not want disseminated publicly.[150]



Reports
- BE
  - domain.txt
  - domain_histogram.tx
  - email.txt
  - email_histogram.txt
  - exif.txt
  - rfc822.txt
  - telephone.txt
  - telephone_histogram
  - unzip_carved.txt
  - url.txt
  - url_histogram.txt
  - url_services.txt
  - windirs.txt
  - winpe.txt
  - zip.txt

Feature Filter ☐ Match case

Histogram File email_histogram.txt

```
n=214    charlie@m57.biz
n=100    pat@m57.biz
n=73     terry@m57.biz
n=33     alix.pery@yahoo.com
n=29     jaime@project2400.com
n=28     rubinfritz31@mail.com
n=11     jamie@project2400.com
n=4      andy@swexpert.com
n=3      charlie@m57.bi
n=2      jaspermcrachelvick@yahoo.com
n=1      bfritz31@mail.com
n=1      lie@m57.biz
n=1      z31@mail.com
```

Referenced Feature File email.txt
Referenced Feature charlie@m57.biz

```
338347262     charlie@m57.biz
338360712     charlie@m57.biz
338690541     charlie@m57.biz
338724025     charlie@m57.biz
338755373     charlie@m57.biz
338771692     charlie@m57.biz
338786728     charlie@m57.biz
338803949     charlie@m57.biz
338822076     charlie@m57.biz
338840724     charlie@m57.biz
338855400     charlie@m57.biz
338872772     charlie@m57.biz
338890575     charlie@m57.biz
338947964     charlie@m57.biz
338963098     charlie@m57.biz
338979615     charlie@m57.biz
338996839     charlie@m57.biz
339043920     charlie@m57.biz
339099590     charlie@m57.biz
```

Image File charlie-work-usb-2009-12-11.E01
Feature File email.txt
Forensic Path 338786728
Feature charlie@m57.biz

Image

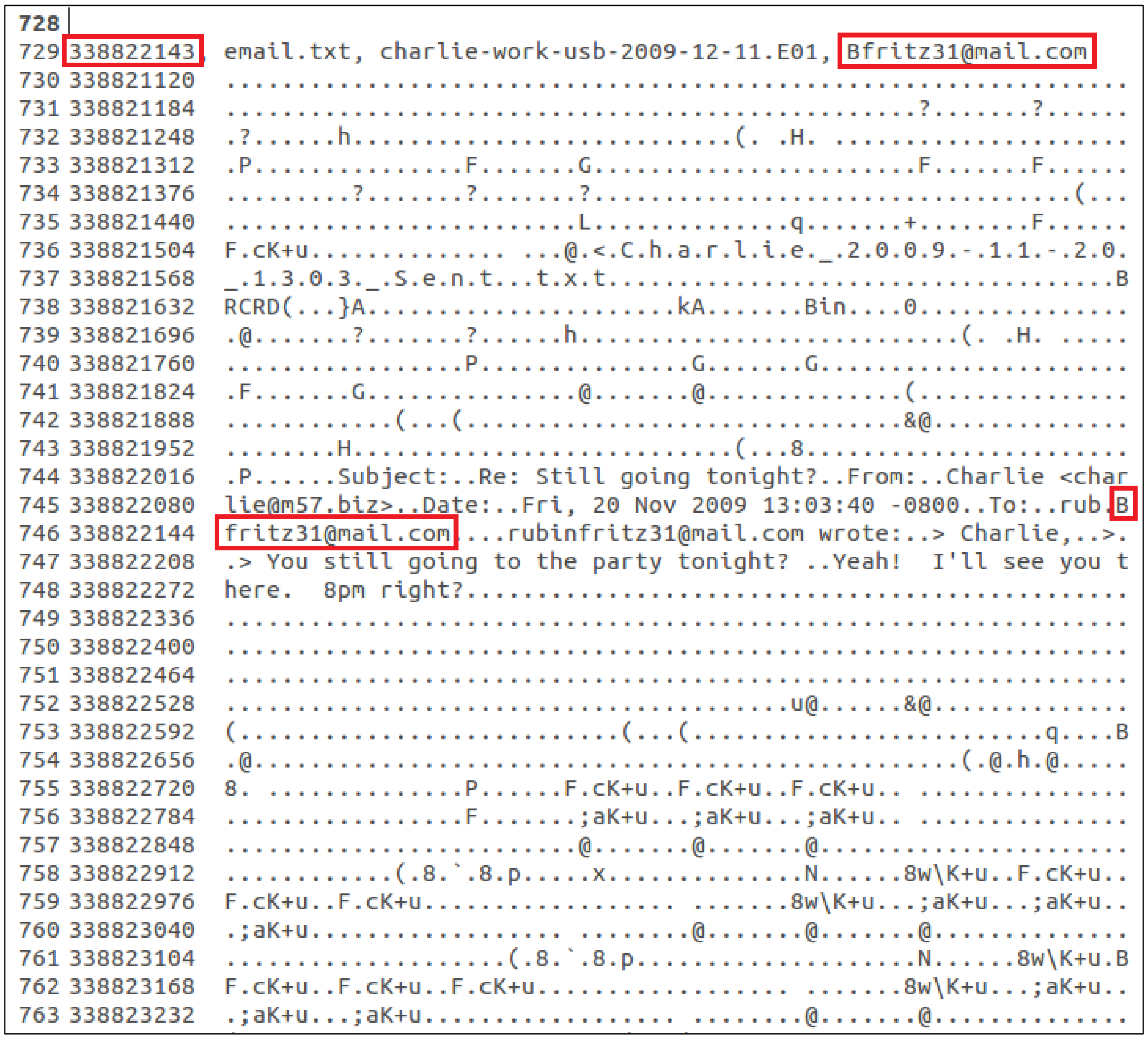
```
338785920  ................................................................
338785984  ...............V.......V......h...........................{. .
338786048  H. ......................P.............@.......A.............
338786112  ........@.......@...............................................
338786176  ......................{...........................L.............
338786240  o.......+........@.......$9+u............. ...@.<.C.h.a.r.l..B
338786304  e._.2.0.0.9.-.1.1.-.1.9._.1.0.3.7._.S.e.n.t...t.x.t............
338786368  ................h...........................{. .H. ............
338786432  .........P...............A.......A......................@......
338786496  .A.......................................{......................
338786560  ....{...{.......................................................
338786624  ...........................{...........................P......
338786688  Subject:..Re: Searches..From:..Charlie <charlie@m57.biz>..Date:.
338786752  .Thu, 19 Nov 2009 10:37:59 -0800..To:..Pat McGoo <pat@m57.biz>.B
338786816  CC:..jo@m57.biz....Pat McGoo wrote:..> Jo, Charlie,..>  ..>   ho
338786880  w are your projects coming? Let's try to schedule a meeting for
338786944  this afternoon or tomorrow morning to go over your status...>  .
338787008  .> Thanks..> Pat..I've been searching through a lot of patents.
338787072   How about tomorrow at 10am for the meeting?....Charlie.........
338787136  ................................................................
338787200  ................................................................
338787264  ...............................................................B
338787328  ................................................................
338787392  ................................................................
338787456  ................................................................
338787520  ................................................................
338787584  `/.......................{...........................{...{.......
338787648  ..................q.....k/......................8..............
338787712  ............{...0.......8.X.............P.......@.............
338787776  x/......k/......k/................................{.8.`.8.p..B
338787840  .. ..............N.......: 9+u....$9+u....$9+u....$9+u..........
338787904  ........ ........: 9+u....$9+u....$9+u....$9+u.................
338787968   ........./......x/......x/................................{.8.
338788032  `.8.p...................XN.......: 9+u....$9+u....$9+u....$9+u..
338788096  ................ ........: 9+u....$9+u....$9+u....$9+u..........
338788160  ........ ......../......./.............{.......................
338788224  ....{...{...............................2../...................
338788288  h...........................{. .H. ....................P.....B
```

Figure 3: **BEViewer. Partial view of an email histogram containing 214 instances of charlie@m57.biz and the context of the selected instance.**

To execute the first process in the workflow, bulk_extractor was selected to query the disk image to identify target data to redact because of its execution speed and easy-to-use BEViewer user interface.[151] Once the target data was identified, it was selected using the bookmark function in bulk_extractor. The bookmark function is used to document interesting features to the forensic examiner or archive professional. It also allows the

[150] Lee, "Automated Redaction of Private," 299.
[151] "Using Bulk Extractor Viewer to Find Potentially Sensitive Information on a Disk Image," BitCurator, last modified March 9, 2014, http://wiki.bitcurator.net/index.php?title=Using_Bulk_Extractor_Viewer_to_Find_Potentially_Sensitive_Information_on_a_Disk_Image.

BEViewer user to export the bookmarked features to a text file. The export file contains the starting offset and length of each bookmarked target data.[152]



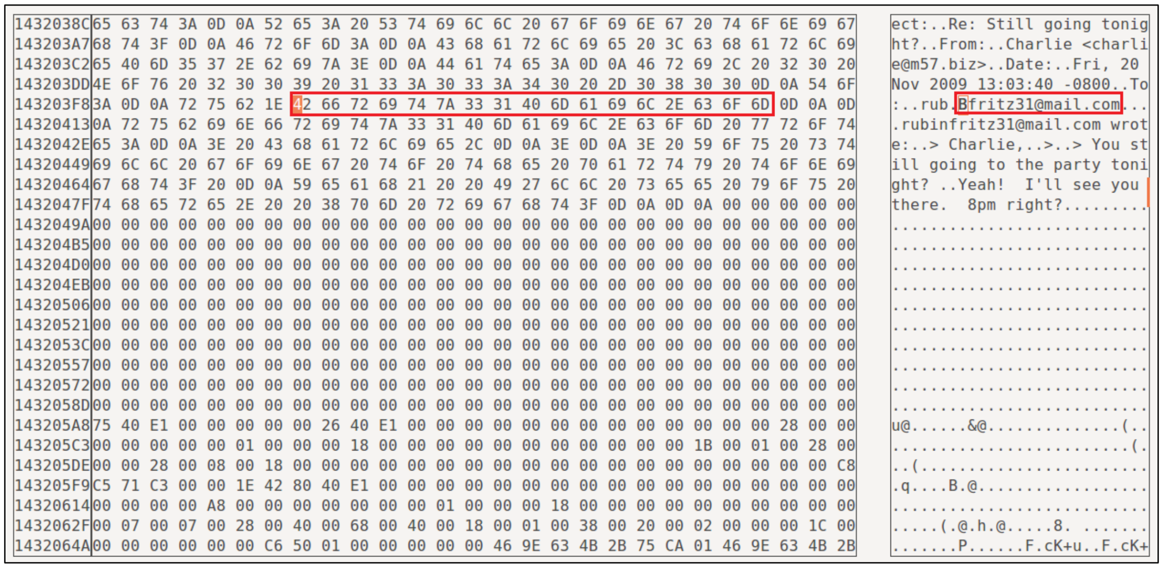
```
338822143, email.txt, charlie-work-usb-2009-12-11.E01, Bfritz31@mail.com
338821120  ................................................................
338821184  .................................................?.......?......
338821248  .?......h...........................(. .H. .....................
338821312  .P...............F.......G.......................F.......F......
338821376  .........?.......?.......?..................................(...
338821440  .........................L..............q.......+........F......
338821504  F.cK+u.............. ...@.<.C.h.a.r.l.i.e._.2.0.0.9.-.1.1.-.2.0.
338821568  _.1.3.0.3._.S.e.n.t...t.x.t....................................B
338821632  RCRD(...}A......................kA.......Bin....0...............
338821696  .@.......?.......?......h...........................(. .H. .....
338821760  .................P...............G.......G......................
338821824  .F.......G...............@.......@..............(...............
338821888  ............(...(...............................&@..............
338821952  ........H...........................(...8.......................
338822016  .P......Subject:..Re: Still going tonight?..From:..Charlie <char
338822080  lie@m57.biz>..Date:..Fri, 20 Nov 2009 13:03:40 -0800..To:..rub.B
338822144  fritz31@mail.com...rubinfritz31@mail.com wrote:..> Charlie,..>.
338822208  .> You still going to the party tonight? ..Yeah!  I'll see you t
338822272  here.  8pm right?...............................................
338822336  ................................................................
338822400  ................................................................
338822464  ................................................................
338822528  ........................................u@......&@..............
338822592  (...........................(...(.........................q....B
338822656  .@..................................................(.@.h.@.....
338822720  8. ..............P......F.cK+u..F.cK+u..F.cK+u.. ...............
338822784  .................F.......;aK+u...;aK+u...;aK+u.. ...............
338822848  .........................@.......@.......@......................
338822912  ............(.8.`.8.p.....x..............N......8w\K+u..F.cK+u..
338822976  F.cK+u..F.cK+u.................. .......8w\K+u...;aK+u...;aK+u..
338823040  .;aK+u................... .......@.......@.......@..............
338823104  ....................(.8.`.8.p....................N......8w\K+u.B
338823168  F.cK+u..F.cK+u..F.cK+u.................. .......8w\K+u...;aK+u..
338823232  .;aK+u...;aK+u.................. ........@.......@..............
```

Figure 4: Partial view of a bulk_extractor bookmark file. Note the boxes drawn around the feature and corresponding offset.

To execute the second process of the workflow, the disk image files were converted to the RAW file format. Because all selected NPS Corpora disk images were in the EWF packaged disk image format and contained forensic metadata like examiner name, evidence number, acquisition date, etc., the forensic metadata had to be retained

[152] "Bulk Extractor Viewer," Forensics Wiki, last modified April 5, 2012, http://www.forensicswiki.org/wiki/Bulk_Extractor_Viewer.

during the redaction process and inserted back into the redacted packaged disk image. The ewfexport and the ewfinfo functions within libewf were used to convert EWF format disk images into RAW disk images and save the forensic metadata.[153] To make parsing the forensic metadata easier, it was exported as DFXML instead of into the default flat text file. The following DFXML objects were used: examiner name, case number, evidence number, description, notes, media size, media type, file format, bytes per sector, sectors per chunk, error granularity, and segment file size. These options were chosen because they are needed to import a RAW disk image into EWF.



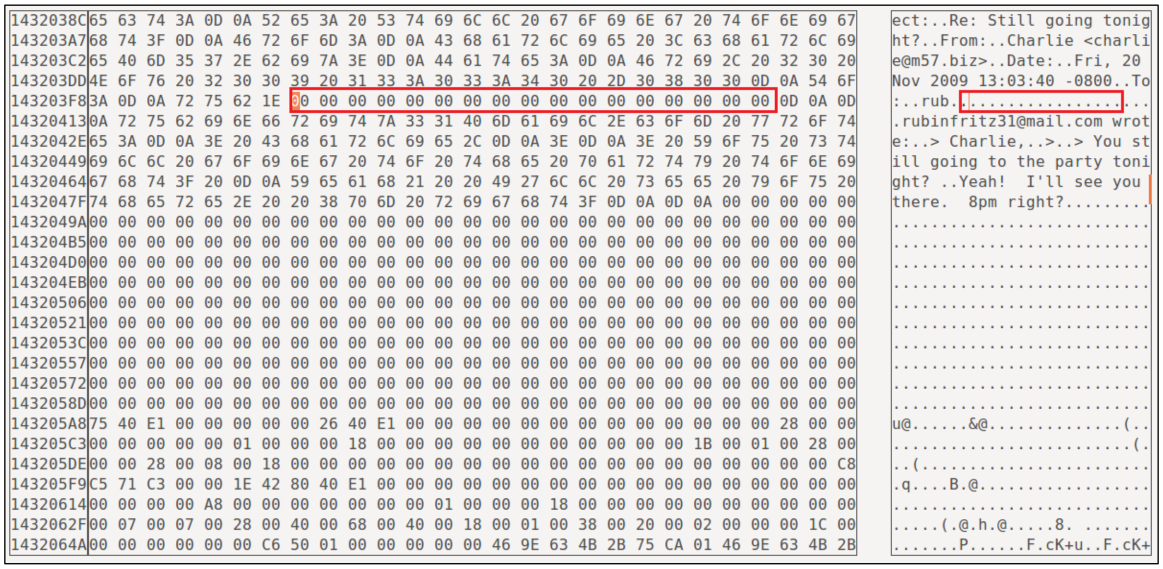
```
1432038C65 63 74 3A 0D 0A 52 65 3A 20 53 74 69 6C 6C 20 67 6F 69 6E 67 20 74 6F 6E 69 67   ect:..Re: Still going tonig
143203A768 74 3F 0D 0A 46 72 6F 6D 3A 0D 0A 43 68 61 72 6C 69 65 20 3C 63 68 61 72 6C 69   ht?..From:..Charlie <charli
143203C265 40 6D 35 37 2E 62 69 7A 3E 0D 0A 44 61 74 65 3A 0D 0A 46 72 69 2C 20 32 30 20   e@m57.biz>..Date:..Fri, 20 
143203DD4E 6F 76 20 32 30 30 39 20 31 33 3A 30 33 3A 34 30 20 2D 30 38 30 30 0D 0A 54 6F   Nov 2009 13:03:40 -0800..To
143203F83A 0D 0A 72 75 62 1E 42 66 72 69 74 7A 33 31 40 6D 61 69 6C 2E 63 6F 6D 0D 0A 0D   :..rub.Bfritz31@mail.com...
143204130A 72 75 62 69 6E 66 72 69 74 7A 33 31 40 6D 61 69 6C 2E 63 6F 6D 20 77 72 6F 74   .rubinfritz31@mail.com wrot
1432042E65 3A 0D 0A 3E 20 43 68 61 72 6C 69 65 2C 0D 0A 3E 0D 0A 3E 20 59 6F 75 20 73 74   e:..> Charlie,..>..> You st
1432044969 6C 6C 20 67 6F 69 6E 67 20 74 6F 20 74 68 65 20 70 61 72 74 79 20 74 6F 6E 69   ill going to the party toni
1432046467 68 74 3F 20 0D 0A 59 65 61 68 21 20 20 49 27 6C 6C 20 73 65 65 20 79 6F 75 20   ght? ..Yeah!  I'll see you 
1432047F74 68 65 72 65 2E 20 20 38 70 6D 20 72 69 67 68 74 3F 0D 0A 0D 0A 00 00 00 00 00   there.  8pm right?.........
1432049A00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
143204B500 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
143204D000 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
143204EB00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
1432050600 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
1432052100 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
1432053C00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
1432055700 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
1432057200 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
1432058D00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
143205A875 40 E1 00 00 00 00 00 26 40 E1 00 00 00 00 00 00 00 00 00 00 00 00 00 28 00 00   u@......&@..............(..
143205C300 00 00 00 00 01 00 00 00 18 00 00 00 00 00 00 00 00 00 00 00 1B 00 01 00 28 00   .........................(.
143205DE00 00 28 00 08 00 18 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 C8   ..(........................
143205F9C5 71 C3 00 00 1E 42 80 40 E1 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   .q....B.@..................
1432061400 00 00 00 A8 00 00 00 00 00 00 00 01 00 00 00 18 00 00 00 00 00 00 00 00 00 00   ...........................
1432062F00 07 00 07 00 28 00 40 00 68 00 40 00 18 00 01 00 38 00 20 00 02 00 00 00 1C 00   .....(.@.h.@.....8. .......
1432064A00 00 00 00 00 00 C6 50 01 00 00 00 00 00 46 9E 63 4B 2B 75 CA 01 46 9E 63 4B 2B   .......P......F.cK+u..F.cK+
```

Figure 5: GHex view before redaction. Note the box drawn around the bytes representing the feature (on left) and the feature in its context (on right).

Once the disk images were converted to the RAW format, the bookmark file was reviewed to determine the disk offsets and the number of bytes to be redacted. GHex, an open-source hex editor, was used to open the RAW disk image, locate the starting offset of the first redaction target, and then overwrite the target data.[154] Overwriting the data

[153] "Libewf and Tooling to Access the Expert Witness Compression Format (EWF)," Google Project Hosting, last modified April 3, 2014, http://code.google.com/p/libewf/.
[154] "Software," BitCurator, last modified April 1, 2014, http://wiki.bitcurator.net/index.php?title=Software.

involved manually locating the starting offset and then changing all hex values from the starting offset to the ending offset. The hex value for each byte within the data string was changed to the NULL ‘x00’ value. After each redaction, a note was added to the end of the DFXML notes object describing the starting offset, the value used to overwrite the data, and the length of the redacted data. This redaction process was manually repeated for all data targeted for redaction. Depending on the number of redaction targets and their length, this activity proved to be the most labor-intensive process in the workflow. Performing this manual process on several offsets is manageable; however, performing this process on hundreds or thousands of offsets in a single disk image is not realistic.



```
1432038C 65 63 74 3A 0D 0A 52 65 3A 20 53 74 69 6C 6C 20 67 6F 69 6E 67 20 74 6F 6E 69 67   ect:..Re: Still going tonig
143203A7 68 74 3F 0D 0A 46 72 6F 6D 3A 0D 0A 43 68 61 72 6C 69 65 20 3C 63 68 61 72 6C 69   ht?..From:..Charlie <charli
143203C2 65 40 6D 35 37 2E 62 69 7A 3E 0D 0A 44 61 74 65 3A 0D 0A 46 72 69 2C 20 32 30 20   e@m57.biz>..Date:..Fri, 20 
143203DD 4E 6F 76 20 32 30 30 39 20 31 33 3A 30 33 3A 34 30 20 2D 30 38 30 30 0D 0A 54 6F   Nov 2009 13:03:40 -0800..To
143203F8 3A 0D 0A 72 75 62 1E 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0D 0A 0D   :..rub.....................
14320413 0A 72 75 62 69 6E 66 72 69 74 7A 33 31 40 6D 61 69 6C 2E 63 6F 6D 20 77 72 6F 74   .rubinfritz31@mail.com wrot
1432042E 65 3A 0D 0A 3E 20 43 68 61 72 6C 69 65 2C 0D 0A 3E 0D 0A 3E 20 59 6F 75 20 73 74   e:..> Charlie,..>..> You st
14320449 69 6C 6C 20 67 6F 69 6E 67 20 74 6F 20 74 68 65 20 70 61 72 74 79 20 74 6F 6E 69   ill going to the party toni
14320464 67 68 74 3F 20 0D 0A 59 65 61 68 21 20 20 49 27 6C 6C 20 73 65 65 20 79 6F 75 20   ght? ..Yeah!  I'll see you 
1432047F 74 68 65 72 65 2E 20 20 38 70 6D 20 72 69 67 68 74 3F 0D 0A 0D 0A 00 00 00 00 00   there.  8pm right?.........
1432049A 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
143204B5 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
143204D0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
143204EB 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
14320506 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
14320521 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
1432053C 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
14320557 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
14320572 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
1432058D 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ...........................
143205A8 75 40 E1 00 00 00 00 00 26 40 E1 00 00 00 00 00 00 00 00 00 00 00 00 00 28 00 00   u@......&@.............(..
143205C3 00 00 00 00 00 01 00 00 00 18 00 00 00 00 00 00 00 00 00 00 00 1B 00 01 00 28 00   .........................(.
143205DE 00 00 28 00 08 00 18 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 C8   ..(........................
143205F9 C5 71 C3 00 00 1E 42 80 40 E1 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   .q....B.@..................
14320614 00 00 00 00 A8 00 00 00 00 00 00 00 01 00 00 00 18 00 00 00 00 00 00 00 00 00 00   ...........................
1432062F 00 07 00 07 00 28 00 40 00 68 00 40 00 18 00 01 00 38 00 20 00 02 00 00 00 1C 00   .....(.@.h.@.....8. .......
1432064A 00 00 00 00 00 00 C6 50 01 00 00 00 00 00 46 9E 63 4B 2B 75 CA 01 46 9E 63 4B 2B   .......P......F.cK+u..F.cK+
```

Figure 6: GHex view after redaction. Note the box drawn around the bytes representing the redacted feature (on left) and the redacted feature in its context (on right).

The third process in the workflow was to convert the redacted RAW disk image back into the original EWF packaged format. The ewfacquire function from libewf was used for this process. The redacted RAW file and forensic metadata stored as DFXML was entered into the ewfacquire function which produced a redacted disk image. The redaction process was confirmed by opening the redacted disk image in bulk_extractor and searching for the original target data. If the data was not found, it was assumed that the workflow was performed correctly. However, if targeted data was found, the workflow was repeated on the redacted disk image.

Automated Redaction

After I established the manual workflow and performed it several times, I developed a Python script to automate the process. The workflow of the script is detailed in Figure 6 below. The Python programming language was chosen to automate the redaction workflow over Java, C, and C++ because of its ease of use and ability to integrate into existing forensic tools, including pyewf and pyflag.[155] If the program were to be written in C or C++, it could potentially execute faster and run in different environments.

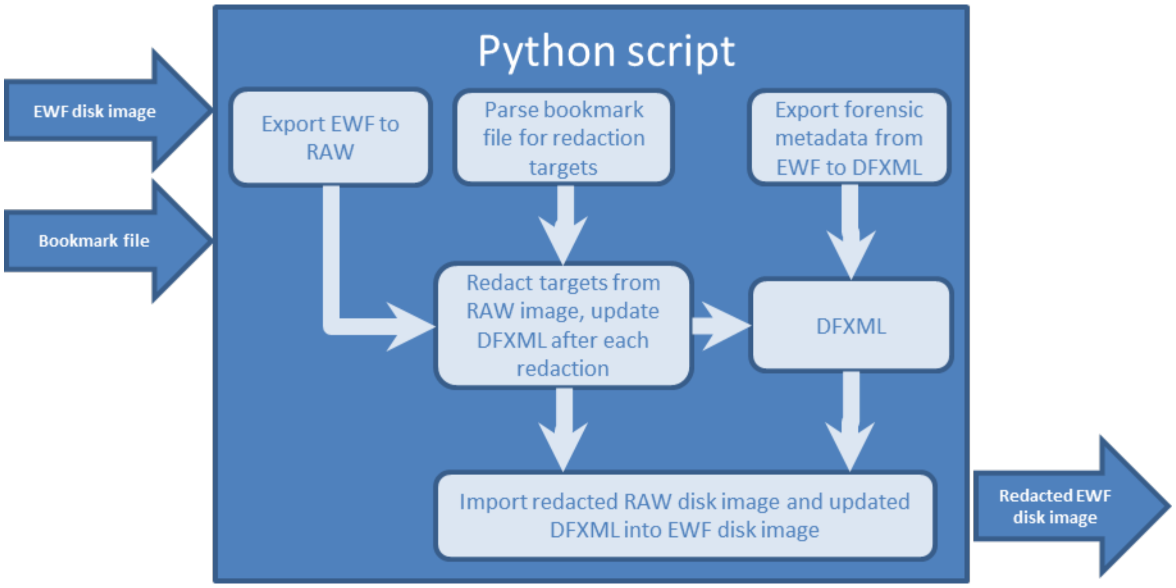
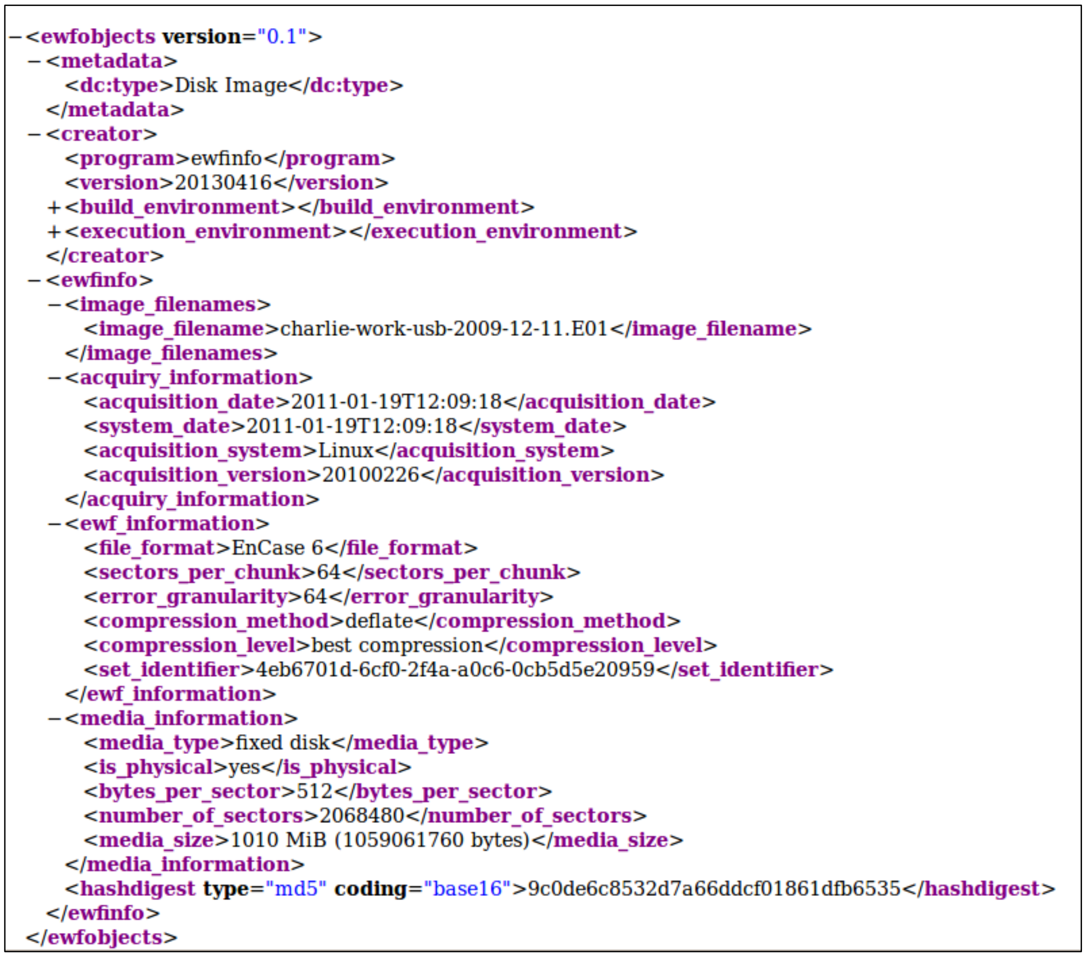

Python script
EWF disk image
Bookmark file
Export EWF to RAW
Parse bookmark file for redaction targets
Export forensic metadata from EWF to DFXML
Redact targets from RAW image, update DFXML after each redaction
DFXML
Import redacted RAW disk image and updated DFXML into EWF disk image
Redacted EWF disk image

Figure 7: Python script workflow.

When the Python script is run from the command line, the user is prompted for the location of the bookmark file created in bulk_extractor, the location of the disk image,

[155] "Pyewf," Libewf, last modified February 27 2014, http://code.google.com/p/libewf/wiki/pyewf.

and the image format, e.g., RAW, EWF, AFF, ISO, etc. If the disk image format is anything but RAW, the appropriate conversion function is called to convert the disk image to the RAW format. If forensic metadata is included in the packaged disk image, it is saved as DFXML in an array within the Python script while the redaction function executes.



```
-<ewfobjects version="0.1">
  -<metadata>
     <dc:type>Disk Image</dc:type>
   </metadata>
  -<creator>
     <program>ewfinfo</program>
     <version>20130416</version>
    +<build_environment></build_environment>
    +<execution_environment></execution_environment>
   </creator>
  -<ewfinfo>
    -<image_filenames>
       <image_filename>charlie-work-usb-2009-12-11.E01</image_filename>
     </image_filenames>
    -<acquiry_information>
       <acquisition_date>2011-01-19T12:09:18</acquisition_date>
       <system_date>2011-01-19T12:09:18</system_date>
       <acquisition_system>Linux</acquisition_system>
       <acquisition_version>20100226</acquisition_version>
     </acquiry_information>
    -<ewf_information>
       <file_format>EnCase 6</file_format>
       <sectors_per_chunk>64</sectors_per_chunk>
       <error_granularity>64</error_granularity>
       <compression_method>deflate</compression_method>
       <compression_level>best compression</compression_level>
       <set_identifier>4eb6701d-6cf0-2f4a-a0c6-0cb5d5e20959</set_identifier>
     </ewf_information>
    -<media_information>
       <media_type>fixed disk</media_type>
       <is_physical>yes</is_physical>
       <bytes_per_sector>512</bytes_per_sector>
       <number_of_sectors>2068480</number_of_sectors>
       <media_size>1010 MiB (1059061760 bytes)</media_size>
     </media_information>
     <hashdigest type="md5" coding="base16">9c0de6c8532d7a66ddcf01861dfb6535</hashdigest>
   </ewfinfo>
 </ewfobjects>
```

Figure 8: Partial view of DFXML from the charlie-work-usb-2009-12-11.E01 disk image.

Once the disk image has been converted to the RAW format, the redaction process begins. The Python script parses the bookmark file created by bulk_extractor and stores the starting offset and length of each target into an array. Based on this information, the ending offset is also calculated and stored in the array. The RAW disk image is opened and the NULL character ‘x00’ is written to each targeted byte offset, beginning with the starting offset through the ending offset of the target data. Each time target data is redacted, the byte offset and length is appended to the notes section of the DFXML. The redaction process is repeated until all targeted byte offsets have been redacted. After all target data has been redacted, the script either converts the RAW disk image back to its original format or saves the redacted RAW image file. When exporting the RAW disk image back to EWF, the stored DFXML is parsed and inserted as command arguments into the ewfacquire function. This allows most of the original forensic metadata to be retained in the redacted EWF disk image. I will discuss metadata that is not retained in this process in the Limitations section below.

To maintain the provenance of the disk image, each transformation performed on the disk image is documented in the notes section of the DFXML when the Python script executes. The Python script can add three different changes: conversion to RAW image, conversion to packaged image, and redaction. All changes start on a new line with a time stamp and are followed by the type of change made. Every time a target offset is redacted, the starting offset and ending offset of the target data, as well as the character used to overwrite the offsets, are documented in the DFXML. It is important to note that only the redacted disk offsets are written into the DFXML and not the actual redacted data itself. After all redactions are complete, the content of the temporary DFXML file is either imported into a forensically packaged image when the RAW disk image is converted back into the packaged image format or saved as a separate XML file in the same directory as the redacted RAW disk image.

Evaluation

Disk Image Name	Pattern	Target	# of Instances	# Redacted Instances	# Remaining Instances	Size of EWF (megabytes))	Size of RAW (megabytes)	Total Execution Time (minutes)
Charlie						9.3	1010	1:53
	Email	andy@swexpert.com	3	2	1			
		jaspermcrachelvick@yahoo.com	1	0	1			
		jamie@project2400.com	7	3	4			
		Bfritz31@mail.com	1	1	0			
		lie@m57.biz	1	1	0			
	Domain	192.168.1.103	1	1	0			
		www.google.com	1	0	1			
		mustang.nps.edu	1	0	1			
		2.0.0.23	1	0	1			
		autos.yahoo.com	2	1	1			
		swexpert.com	3	2	1			
		192.168.1.104	2	0	2			
		205.155.65.103	3	1	2			
		208.97.132.222	4	1	3			
	Phone	831-555-1234	3	1	2			
	URL	http://autos.yahoo.com/2010_ford_shelby_gt500/	2	1	1			
		http://www.w3.org/1999/02/22-rdf-syntax-ns#	4	0	4			
		http://ns.adobe.com/xap/1.0/mm/	4	0	4			
		http://purl.org/dc/elements/1.1/	6	0	6			
		http://www.w3.org/1999/xlink	3	0	3			
Jo-work						118.2	125	0:14
	Domain	gmail.com	10	10	0			
		mail.gmail.com	1	1	0			
	Email	gross.joshua.b@gmail.com	5	5	0			
		hous-daccq-1369054661@craigslist.org	4	4	0			
		amsuich@nps.edu	3	3	0			
Jo-favorites			23	23		227.1	1000	1:11
	Windirs	DSC00003.JPG	1	1	0			
		DSC00004.JPG	1	1	0			
		DSC00005.JPG	1	1	0			
		DSC00006.JPG	1	1	0			
		DSC00007.JPG	1	1	0			
		DSC00008.JPG	1	1	0			
		DSC00009.JPG	2	2	0			
		DSC00010.JPG	1	1	0			
		DSC00011.JPG	1	1	0			
		DSC00012.JPG	1	1	0			
		DSC00013.JPG	2	2	0			
		DSC00014.JPG	2	2	0			
		DSC00015.JPG	2	2	0			
		DSC00016.JPG	2	2	0			
		DSC00017.JPG	2	2	0			
		DSC00018.JPG	2	2	0			
		DSC00019.JPG	2	2	0			
		DSC00020.JPG	2	2	0			
		DSC00021.JPG	2	2	0			
		DSC00022.JPG	2	2	0			
		DSC00023.JPG	2	2	0			
		DSC00024.JPG	2	2	0			

Table 2: Redaction results. Note all remaining instances in the Charlie disk image are located in compressed files, which the Python script cannot process.

The effectiveness of the automated disk image redaction script was evaluated using three disk images from the NPS Corpora that had not been previously examined. Using bulk_extractor, several targets from within each disk image were identified and marked for redaction. The Python script then attempted to redact the targets from each disk image. To measure the efficacy of the Python script, each redacted disk image produced by the Python script was searched for remaining target data. The redacted disk images were opened in bulk_extractor and queried for target data. The presence of target data after the redaction indicated a failure in the redaction process.

The disk images used to evaluate the Python script were "charlie-work-usb-2009-12-11.E01", "jo-work-usb-2009-12-11.E01", and "jo-favorites-usb-2009-12-11.E01."[156] Within these disk images, several bulk_extractor pattern types were selected for redaction: email addresses, domains, Uniform Resource Locators (URL), phone numbers, and Windirs. The number of features from each pattern varied based on the number of features available on each disk image. Several data targets within a given pattern appeared in multiple locations on the disk. To simplify the evaluation, all recurrences of a data target were marked for redaction, including targets in compressed files.

In the first evaluation disk image, charlie-work-usb-2009-12-11.E01, fifty-three instances from four pattern types was marked for redaction. The Python script processed the disk image in one minute and fifty-three seconds. The first one minute and twenty-two seconds was spent converting the disk image from EWF to RAW. The actual redaction of target data took less than one second to complete.[157] The remaining thirty-one seconds was spent converting the RAW image back to EWF. The original EWF image was 9.8 megabytes, but the RAW image expanded to 1,010 megabytes during the redaction process. The EWF image was compressed one hundred and three times smaller than the RAW image file. Of the fifty-three instances, thirteen instances were from five

[156] "Index of /corp/nps/scenarios/2009-m57-patents/usb."
[157] The duration of the redaction was calculated by comparing timestamps for each process in the log file. The smallest unit of measurement in the log timestamps is one second. All logged redacted instances had the same timestamp.

email addresses, eighteen instances were from nine domains, three instances were from one phone number, and nineteen instances were from five URLs. Of the thirteen email instances, seven were successfully redacted. Of the eighteen domain instances, six were successfully redacted. Of the three phone number instances, one was successfully redacted. The initial accuracy of the Python script redacting data targets from the charlie-work-usb-2009-12-11.E01 disk image is 38 percent.

In the second evaluation disk image, jo-work-usb-2009-12-11.E01, twenty-three instances from two pattern types was marked for redaction. The Python script processed the disk image in fourteen seconds. Three seconds was spent converting the disk image from EWF to RAW. The actual redaction of target data took less than one second to complete.[158] The remaining ten seconds was spent converting the RAW image back to EWF. The original EWF image was 118.2 megabytes, but the RAW image expanded to 125 megabytes during the redaction process. The EWF image was barely compressed 1.05 times smaller than the RAW image file. Of the twenty-three instances, twelve instances were from three email addresses and eleven instances were from two domains. All twelve email instances and eleven domain instances were successfully redacted. The initial accuracy of the Python script redacting data targets from the jo-work-usb-2009-12-11.E01 disk image is 100 percent.

In the third evaluation disk image, jo-favorites-usb-2009-12-11.E01, thirty-five instances from the Windirs pattern type was marked for redaction. The Python script processed the disk image in one minute and eleven seconds. The first twenty-three seconds was spent converting the disk image from EWF to RAW. The actual redaction of

[158] The duration of the redaction was calculated by comparing timestamps for each process in the log file. The smallest unit of measurement in the log timestamps is one second. All logged redacted instances had the same timestamp.

target data took less than one second to complete.[159] The remaining forty-seven seconds was spent converting the RAW image back to EWF. The original EWF image was 227.1 megabytes, but the RAW image expanded to 1,000 megabytes during the redaction process. The EWF image was compressed 4.4 times smaller than the RAW image file. All thirty-five Windirs instances were successfully redacted. The initial accuracy of the Python script redacting data targets from the jo-favorites-usb-2009-12-11.E01 disk image is 100 percent.

Limitations

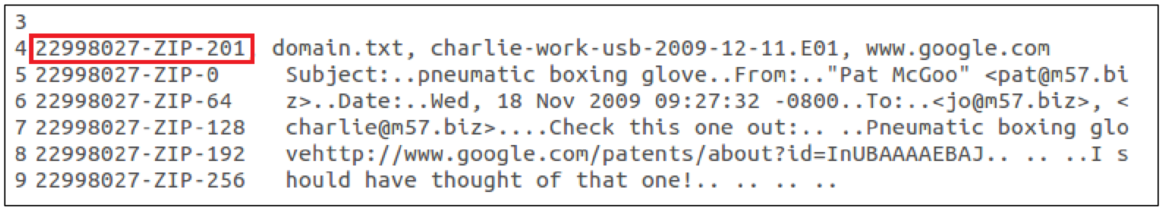
There are several limitations to this project. First, the size of the storage space on the laptop running the BitCurator virtual machine prevented me from testing the redaction script on large disk images, such as those generated from entire workstation hard drives. The laptop hard disk had a capacity of 300 gigabytes; however, only 40 gigabytes were allocated to the BitCurator virtual machine. Of the 40 gigabytes allocated for this project, only 11 gigabytes were available for disk images. The Linux operating system, the software, and libraries in the BitCurator virtual machine occupied 4 gigabytes and the VirtualBox virtual machine environment created periodic backups of the system that used another 25 gigabytes. Because the Python script converts all compressed disk images to RAW during the redaction process, the BitCurator virtual machine would need enough space for the original disk image, the temporary RAW disk image, and the redacted disk image. As a result, only small 2 to 4 gigabyte USB disk images could be redacted.

[159] The duration of the redaction was calculated by comparing timestamps for each process in the log file. The smallest unit of measurement in the log timestamps is one second. All logged redacted instances had the same timestamp.

The second limitation is that only the Expert Witness Format was evaluated in the workflow and subsequent Python script. Time limitations prevented the inclusion of other popular disk image formats like AFF, ISO 9660, DMG, etc.

The third limitation is that the Python script can only redact target offsets that are provided to it. It does not search for target data. The script is only as good as the program feeding it target offsets. In this case, if bulk_extractor did not locate all target data or if the user did not bookmark all target data, the redacted disk image would still contain target data.

The fourth limitation is that target data found within compressed file formats like PDF, ZIP, or DOCX cannot be redacted, despite bulk_extractor identifying the location of the data. The bulk_extractor tool uses special scanners to identify compressed files. Once found, the scanner decompresses the file and re-scans the decompressed data. As shown in Figure 9 below, the location of this data is described using two offsets. The first offset is the starting location of the compressed file on the storage medium. The second offset is the location of the target data within the compressed file. Time limitations prevented the inclusion of a method to expand and redact target data within compressed files, so the Python script ignored targets located in compressed files. As a result, the thirty-eight instances located in compressed files in the charlie-work-usb-2009-12-11.E01 disk image were ignored.



```
22998027-ZIP-201  domain.txt, charlie-work-usb-2009-12-11.E01, www.google.com
22998027-ZIP-0     Subject:..pneumatic boxing glove..From:.."Pat McGoo" <pat@m57.bi
22998027-ZIP-64    z>..Date:..Wed, 18 Nov 2009 09:27:32 -0800..To:..<jo@m57.biz>, <
22998027-ZIP-128   charlie@m57.biz>....Check this one out:.. ..Pneumatic boxing glo
22998027-ZIP-192   vehttp://www.google.com/patents/about?id=InUBAAAAEBAJ.. .. ..I s
22998027-ZIP-256   hould have thought of that one!.. .. .. ..
```

Figure 9: bulk_extractor bookmark file containing entries for targets located in compressed zip files.

The fifth notable limitation is that the python script cannot transfer all of the original forensic metadata from within a packaged disk image to a redacted packaged disk image. When ewfacquire creates a disk image, it uses the current time on the host computer for the acquisition_date and the system_date timestamps. It also assigns a new set_identifier and computes a new hash digest. To preserve this information and maintain the provenance of the disk image, the values from the original disk image are inserted into the notes section of the redacted disk image.

Discussion

The results in Table 2 above show that the Python script was effective at redacting target data in the jo-work-usb-2009-12-11.E01 and jo-favorites-usb-2009-12-11.E01 disk images, but ineffective at redacting all target data in the charlie-work-usb-2009-12-11.E01 disk image. As previously mentioned, all data targets that did not get redacted were located in compressed files within the charlie-work-usb-2009-12-11.E01 disk image.

When I started this project, my primary focus was how to perform the redaction process, that is, the actual overwriting of byte offsets. However, I soon realized that overwriting byte offsets is trivial in most programing languages. In fact the amount of time required to redact all target instances in in each disk image took less than one second to complete. The majority of the execution time was devoted to converting the disk image between the EWF and RAW formats. The more difficult problem was how to preserve the original forensic metadata and record the redactions performed to the disk images. DFXML proved to be a natural solution to this problem because it organized the forensic data in such a way that it could be parsed by the python script, yet was also human readable. Using DFXML for redaction did illuminate a problem with DFXML. There is not a DFXML object for redaction.[160] I relied heavily on the notes section of the DFXML as a catchall for original metadata that could not be preserved in its original context (acquisition_date, system_date, etc.) and to document each redaction performed on the disk image. Depending on the number of redactions performed on a disk image, storing this information in the notes section has the potential to create a large disorganized DFXML file that could become difficult for collection professionals to review. A better method would be to develop a standard redaction object within DFXML that includes attributes and child nodes to better organize this information.

In this project the NULL character was used to overwrite target data because the absence of characters was easy to identify in long strings of text in the GHex editor. Any character could be used, and in fact, a different character should be used in a professional archive environment to make it easy to identify which parts of the disk image have been redacted. If large areas of the image will be redacted, as in the case of a large continuous file or entire directories, a string of characters could be written repeatedly instead of individual characters. Simple strings like "REDACTED_" or even complex strings that include the start offset and end offset, e.g., "REDACTED_STARTING_AT_OFFSET_#########_THROUGH_#########_", could be used.

My intent was to perform the target data redaction on the original disk image format instead of first converting it to RAW and then converting back to the original format. Because packaged formats use file compression, disk space requirements would

[160] The official DFXML Schema can be found on the DFXML Working Group's github page https://github.com/dfxml-working-group/dfxml_schema

be significantly lower if the entire compressed image did not have to be expanded to RAW. Presumably the total execution time could be reduced since the disk image would not be subjected to as much processing. However, because the forensically packaged disk image formats are designed to prevent editing, I did not have time to reverse engineer the EWF format to develop a method to redact target data within the packaged disk image format.

A compromise would be to convert only the parts of the disk containing target data to the RAW format while leaving the rest of the disk in the original format. Once converted to RAW, the target data would be redacted, and then converted back into the original disk image format. For example, EWF disk images are comprised of 32 kilobyte chunks of compressed data.[161] If only the chunks containing target data were converted to RAW, then redacted, and then converted back to the original format, the amount of space required to perform the redaction could be significantly reduced. By processing each chunk sequentially, each temporary copy of the redacted RAW chunk could be deleted before the next chunk is expanded to RAW. The redaction environment would only need to be slightly larger than twice the size of the largest compressed disk image. Once all chunks containing target data have been redacted, a new hash would be computed for the disk image and the changes recorded in the DFXML within the disk image.

I did not test fragmented files or fragmented byte runs; however, the Python script could redact fragmented targets if they were written to the bookmark file as separate offsets with byte lengths. The primary limitation to processing fragmented files or byte runs is the parsing routine that processes the bookmark file.

[161] "Libewf."

Implications

Despite being a proof of concept for performing disk image redaction, this project demonstrates that disk image redaction can indeed be automated. Implementing the Python script in a curatorial workflow, in its current form, would not contribute much and may in fact be a hindrance. However, the project does illuminate several issues that need to be mitigated in future production tools.

Future Work

A limitation of this project was only one packaged image format was tested. Future work on this Python script should include other popular disk image formats like AFF, ISO 9660, DMG (Apple), VMDK (VMware), VDI (Oracle VM VirtualBox), etc. This is by no means a comprehensive list of disk image types. Future work should include disk image formats that suit the needs of preservation professionals at that time. Disk image redaction tools should include support for all common packaged forensic disk image formats.

Another limitation of this project was the lack of support for redacting within compressed files such as PDF, ZIP, the Microsoft DOCX formats, etc. As shown in the “Charlie” disk image above, disk images can contain many different compressed files. Disk image redaction systems should include support for processing compressed files within disk images. A starting place for future work could be the bulk_extractor compressed file scanners. The open-source code for the scanners is available within bulk_extractor and could be modified to work with the Python script.

The current command line interface could be difficult for collection professionals to use. A GUI for the Python script could to be developed or adapted from another program to allow professionals to easily search and for target data and then initiate the redaction by clicking a button within the interface. In addition, the ability to examine and redact individual files and directories in an interface similar to the original operating system would make it easier for preservation professionals to interact with the redaction system.

As more institutions adopt the Preservation Metadata Implementation Strategies (PREMIS) model, future disk image redaction systems should include support for exporting DFXML data into PREMIS records. The offset, length, and byte character used to redact the data that is currently appended to the notes section of the DFXML could be converted into PREMIS records. Of the five PREMIS entity types – intellectual entities, objects, events, agents and rights – the events object would best describe redactions performed to the disk image.[162] Within the PREMIS Event elements, the eventType, eventDateTime, eventDetail, and eventOutcomeInformation entities match to the existing DFXML values.[163] The eventType could be configurable by the user to match the institution's controlled vocabulary. The eventDateTime entity would match to the redacted disk DFXML acquisition_date, the eventDetail would match to each redacted byte offset, and the eventOutcomeInformation would include the byte that was used to redact the data. Additional information about why the redaction was performed could be stored within eventOutcomeDetailNote.

Finally, future disk image redaction systems should be evaluated by preservation professionals and practitioners to determine what additional features and configuration

[162] Sarah Higgins, "Premis Data Dictionary for Preservation Metadata," (2009).
[163] U.S. Library of Congress, *Data Dictionary for Preservation Metadata: PREMIS version 2.2*, (Washington DC, 2012), 130.

options are needed. Like any product, direct feedback from professionals would help to ensure that redaction systems perform as expected.

Conclusion

In this project, I investigated the feasibility of redacting sensitive material from disk images while maintaining the provenance of the disk image using open-source, forensic software. After reviewing fundamental concepts of storage media, file systems, and disk images, I discussed how to perform electronic information redaction. I proposed how to automate a simple manual redaction workflow through a proof-of-concept Python script that effectively redacted target data from packaged forensic disk images. As others advance disk image redaction systems, I make the following recommendations for future work: (i) Include support for the most common disk image formats including AFF, ISO 9660, DMG (Apple), VMDK (VMware), and VDI (Oracle VM VirtualBox). (ii) Develop support for redacting target data from within compressed files such as PDF, ZIP, and the Microsoft DOCX format. (iii) Include support to export descriptive forensic metadata into PREMIS objects. (iv) Finally, seek feedback from preservation professionals on the usefulness and effectiveness of functions within the redaction system.

Bibliography

Barclay, Alexander. Redacting Digital Information from Electronic Devices. Advances in Digital Forensics III : IFIP International Conference on Digital Forensics, National Center for Forensic Science, Orlando, Florida, January 28-January 31, 2007.

BitCurator. “About | BitCurator.” Last modified April 2, 2014. http://www.bitcurator.net/aboutbc/.

BitCurator. “BitCurator.” Last modified April 1, 2014. http://wiki.bitcurator.net/index.php?title=Main_Page.

BitCurator. “Using Bulk Extractor Viewer to Find Potentially Sensitive Information on a Disk Image.” Last modified March 9, 2014. http://wiki.bitcurator.net/index.php?title=Using_Bulk_Extractor_Viewer_to_Find_Potentially_Sensitive_Information_on_a_Disk_Image.

Carrier, Brian. File System Forensic Analysis. Vol. 3. Reading: Addison-Wesley, 2005.

The Consultative Committee for Space Data Systems. “Reference Model for an Open Archival Information System (OAIS).” Magenta Book, Issue 2. 2002.

Digital Corpora. “Index of /corp/nps/scenarios/2009-m57-patents/usb.” Last modified April 3, 2012. http://digitalcorpora.org/corp/nps/scenarios/2009-m57-patents/usb/.

Forensics Wiki. “AFF.” Last modified January 29, 2014. http://www.forensicswiki.org/wiki/AFFLIB.

Forensics Wiki. “ASR Data's Expert Witness Compression Format.” Last modified March 29, 2013.

http://www.forensicswiki.org/wiki/ASR_Data%27s_Expert_Witness_Compression_Format.

Forensics Wiki. “Bulk Extractor Viewer.” Last modified April 5, 2012. http://www.forensicswiki.org/wiki/Bulk_Extractor_Viewer.

Forensics Wiki. “Category: Forensics File Formats.” Last modified July 21, 2012. http://www.forensicswiki.org/wiki/Forensic_file_formats.

Forensics Wiki. “Encase Image File Format.”Last modified July 15, 2013. http://www.forensicswiki.org/wiki/Encase_image_file_format.

Forensics Wiki. “Libewf.” Last modified February 16, 2014. http://www.forensicswiki.org/wiki/Libewf.

Garfinkel, Simson L., and David J. Malan. "One Big File is not Enough: A critical Evaluation of the Dominant Free-Space Sanitization Technique." In Privacy Enhancing Technologies, pp. 135-151. Springer Berlin Heidelberg, 2006.

Garfinkel, Simson L. "Digital Forensics XML and the DFXML Toolset." Digital Investigation 8, no. 3 (2012): 161-174.

Garfinkel, Simson L. "Providing Cryptographic Security and Evidentiary Chain-of-Custody with the Advanced Forensic Format, Library, and Tools," International Journal of Digital Crime and Forensics (IJDCF) 1 (2009): 1-28.

Garfinkel, Simson L. "Digital Media Triage with Bulk Data Analysis and bulk_extractor." Computers & Security 32 (2013): 56-72.

Garfinkel, Simson L. "Automating disk forensic processing with SleuthKit, XML and Python." In Systematic Approaches to Digital Forensic Engineering, 2009. SADFE'09. Fourth International IEEE Workshop on, pp. 73-84. IEEE, 2009.

Gengenbach, Martin J. "“The Way We Do It Here”: Mapping Digital Forensic Workflows in Collecting Institutions." Master’s paper, University of North Carolina, 2012.

HDD-Tool. “NTFS vs FAT, HDD Tool.” Last modified January 25, 2010. http://www.hdd-tool.com/pic/FAT-NTFS.png.

HDD Tool. “What is FAT File System.” Last modified January 20, 2010. http://www.hdd-tool.com/hdd-basic/what-is-fat-file-system.htm.

John, Jeremy Leighton. "Digital Forensics and Preservation." Digital Preservation Coalition (2012).

Kirschenbaum, Matthew, Richard Ovenden, Gabriela Redwine, and Rachel Donahue. "Digital forensics and born-digital content in cultural heritage collections." (2010).

Kirschenbaum, Matthew, Christopher A. Lee, Kam Woods, and Alexandra Chassanoff. "From Bitstreams to Heritage: Putting Digital Forensics into Practice in Collecting Institutions." (2013).

Lee, Christopher A., Kam Woods. "Automated Redaction of Private and Personal Data in Collections," Proceedings of The Memory of the World in the Digital Age: Digitization and Preservation. An International Conference on Permanent Access to Digital Documentary Heritage (2012).

Levendoski, Matthew G. “Solid State Drives and the Forensic Process.” Master’s thesis, Purdue University, 2013.

Google Project Hosting. “Libewf and Tooling to Access the Expert Witness Compression Format (EWF).” Last modified April 3, 2014. http://code.google.com/p/libewf/.

Lopresti, Daniel P., and A. Lawrence Spitz. "Information leakage through document redaction: attacks and countermeasures." In Electronic Imaging 2005, pp. 183-190. International Society for Optics and Photonics, 2005.

Microsoft. “Overview of FAT, HPFS, and NTFS File Systems.” Last modified May 7, 2007. http://support.microsoft.com/kb/100108/EN-US.

Libewf. “Pyewf.” Last modified February 27, 2014. http://code.google.com/p/libewf/wiki/pyewf.

“The Sleuth Kit (TSK) & Autopsy: Open Source Digital Forensics Tools.” Last modified April 4, 2014. http://www.sleuthkit.org/.

Stitch, Malcolm. "Laser Handbook." 1972.

Strickland, Jonathan. "How Cloud Storage Works." HowStuffWorks.com. Last modified April 30, 2008. http://computer.howstuffworks.com/cloud-computing/cloud-storage.htm.

White, Ron, and Downs, Timothy. “How Computers Work.” Que Corp., 2007, 186.

Wikipedia. “Compact Disk.” Accessed February 11, 2014. http://en.wikipedia.org/wiki/Compact_disc.

Wikipedia. "Comparison of File Systems." Accessed February 18, 2014. http://en.wikipedia.org/wiki/Comparison_of_file_systems.

Wikimedia Commons. “ComputerMemoryHierarchy.svg.” Accessed February 11, 2014. http://en.wikipedia.org/wiki/File:ComputerMemoryHierarchy.svg.

Wikimedia Commons. “Ntfs_mft.svg.” Accessed April 13, 2014. http://commons.wikimedia.org/wiki/File:Ntfs_mft.svg.

Wikipedia. “Floppy Disk,” Accessed February 11, 2014. http://en.wikipedia.org/wiki/Floppy_disk.

Wikipedia. “Random-Access Memory.” Accessed February 11, 2014. http://en.wikipedia.org/wiki/Random-access_memory.

Woods, Kam, and Christopher A. Lee. "Acquisition and Processing of Disk Images to Further Archival Goals." In Archiving Conference, vol. 2012, no. 1, pp. 147-152. Society for Imaging Science and Technology, 2012.

Woods, Kam, Christopher A. Lee, and Sunitha Misra. "Automated Analysis and Visualization of Disk Images and File Systems for Preservation." In Archiving Conference, vol. 2013, no. 1, pp. 239-244. Society for Imaging Science and Technology, 2013.

Woods, Kam, Christopher A. Lee, and Simson Garfinkel. "Extending Digital Repository Architectures to Support Disk Image Preservation and Access." In Proceedings of the 11th Annual International ACM/IEEE Joint Conference on Digital Libraries, pp. 57-66. ACM, 2011.

Woods, Kam, Alexandra Chassanoff, and Christopher A. Lee. "Managing and Transforming Digital Forensics Metadata for Digital Collections." Proceedings of the Tenth International Conference on Digital Preservation (iPRES), Lisbon, Portugal, September 2-6, 2013.

Appendix A: Python script code

Updated versions of this code can be found on Github: https://github.com/caseyemerson/redact_disk_images.

```
#
**************************************************************************
******
# This code was written by Casey Emerson on 1/9/14 for his Masters Paper at the
# University of North Carolina School of Information and Library Science.
#
# This script reads a bookmark created by bulk_extractor file that contains one
# or more feature offsets to be redacted. It determines the format of the image
# file and if necessary, converts the image file to RAW for redaction. It then
# overwrites the offsets, and if necessary, converts the image back into the
# original file format.
#
# For proprietary forensic image files, the script also transfers any DFXML from
# the original file into the newly cleansed file. In addition, it appends the
# notes section of the DFXML with the offsets and lengths of the redacted blocks
# of the disk.
#
**************************************************************************
******


"""IMPORTS GO HERE"""

import argparse
import os
from time import localtime, strftime
import re
import subprocess
import xml.etree.ElementTree as ET
import string



"""VARIABLES DEFINED HERE"""

offset = []         # global initialization of this empty list variable
length = []         # global initialization of this empty list variable
feature = []        # global initialization of this empty list variable
flags = {}          # define dictionary (key value pair)
saveFilePath = os.getcwd()     # get the current working directory
```

```
""" FUNCTIONS GO HERE"""

### DFXML PARSING FUNCTION ###
def parseDFXML(ewfDiskImage):
	dfxml = subprocess.check_output(["ewfinfo", ewfDiskImage, "-f", "dfxml"])
	root = ET.fromstring(dfxml)

	log.write('\n\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) +
'Attempting to parse DFXML...')	# update log file

	if root.iter('notes'):	# look for existing notes object
		for acquiry_information in root.iter('acquiry_information'):
			acquiry_information =
ET.SubElement(acquiry_information,'notes') # if notes object doesn't exist, create the
object under acquiry_information
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'The DFXML Notes object already exists')	# update log file
	else:
		for acquiry_information in root.iter('acquiry_information'):
			acquiry_information =
ET.SubElement(acquiry_information,'notes') # if notes object doesn't exist, create the
object under acquiry_information
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'The DFXML Notes object did NOT exist, creating one now...')	#
update log file

	if root.iter('notes'):	# look for existing notes
		for notes in root.iter('notes'):
			#notes.text = 'here is a new note'
			flags['-N'] = notes.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Imported Existing DFXML Notes: ' + str(flags['-N']))	# update log
file

	if root.iter('sectors_per_chunk'):
		for sectors_per_chunk in root.iter('sectors_per_chunk'):
			flags['-b'] = sectors_per_chunk.text
			flags['-p'] = sectors_per_chunk.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Sectors Per Chunk to: ' + sectors_per_chunk.text)	# update log
file
```

```
	if root.iter('media_size'):
		for media_size in root.iter('media_size'):
			size = (re.search('(?<=\()\d+', media_size.text)).group()	# parse
the number between the parens
			flags['-B'] = size
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Media Size to: ' + size)	# update log file

	if root.iter('compression_level'):
		for compression_level in root.iter('compression_level'):
			compression = compression_level.text[:-12]
			flags['-c'] = compression
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Compression Level to: ' + compression)	# update log file

	if root.iter('case_number'):
		for case_number in root.iter('case_number'):
			flags['-C'] = case_number.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Case Number to: ' + case_number.text)	# update log file

	if root.iter('description'):
		for description in root.iter('description'):
			flags['-D'] = description.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Description to: ' + description.text)	# update log file

	if root.iter('examiner_name'):
		for examiner_name in root.iter('examiner_name'):
			flags['-e'] = examiner_name.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Examiner Name to: ' + examiner_name.text)	# update log file

	if root.iter('evidence_number'):
		for evidence_number in root.iter('evidence_number'):
			flags['-E'] = evidence_number.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Evidence Number to: ' + evidence_number.text)	# update log
file

	if root.iter('file_format'):
		for file_format in root.iter('file_format'):
			fformat = file_format.text.replace(" ", "").lower()
			flags['-f'] = fformat
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set File Format to: ' + fformat)	# update log file
```

```
	if root.iter('error_granularity'):
		for error_granularity in root.iter('error_granularity'):
			flags['-g'] = error_granularity.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Error Granularity to: ' + error_granularity.text)  # update log file

	if root.iter('media_type'):
		for media_type in root.iter('media_type'):
			mtype = media_type.text[:-5]
			flags['-m'] = mtype
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Media Type to: ' + mtype)		# update log file

	if root.iter('is_physical'):
		for is_physical in root.iter('is_physical'):
			if is_physical.text == 'yes':
				flags['-M'] = 'physical'
				log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Is Physical to: physical')  # update log file
			else:
				flags['-M'] = 'logical'
				log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Is Physical to: logical')    # update log file

	if root.iter('bytes_per_sector'):
		for bytes_per_sector in root.iter('bytes_per_sector'):
			flags['-P'] = bytes_per_sector.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Bytes per Sector to: ' + bytes_per_sector.text)    # update log file

	if root.iter('segment_file_size'):
		for segment_file_size in root.iter('segment_file_size'):
			flags['-S'] = segment_file_size.text
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ",
localtime())) + 'Set Segment File Size to: ' + segment_file_size.text)		# update log
file
	else:
		flags['-S'] = '100 TiB'
		log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) +
'Set Segment File Size to: 100 TiB')   # update log file

	flags['-r'] = 2   # set the retry number to 2
	log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) + 'Set the
Retry limit to: 2')		# update log file
	flags['-o'] = 0   # set the begining offset to zero
```

```
        log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) + 'Set the
Begining Offset to: 0')# update log file
        flags['-t'] = args.output + '_REDACTED'
        return


### BOOKMARK PARSING FUNCTION ###
def parseBookmarks(BookmarkFile):# open and parse the Bulk_Extractor bookmark file
        log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - processing bookmark file
located at: ", localtime())) + (BookmarkFile) + '\n')  # enter into log
        with open(BookmarkFile, "r") as file:                   # open the bookmark file in
read mode
                for line in file:                       # parse each line of the file
                        if re.match(r'[0-9]+,', line):     # look for the offset (a sequence of
numbers followed by a comma)
                                try:
                                        line = line.split(', ')      # split the line into pieces
using ', ' delimeter
                                        offset.append(line[0]) # append the first part of the
line into the offset list
                                        feature.append((line[3]).rstrip())                  #
append the third part of the line into the feature list
                                        length.append(len((line[3]).rstrip()))              #
calculate the length of the feature and append it into the length list
                                except:
                                        print('Something went wrong matching the offset')
        # if there was a problem, display an error
                                        log.write((strftime("%H:%M:%S %b %d, %Y -
ERROR parsing offset " + offset + " in the bookmark file ", localtime())) + '\n')     # enter
into log

        log.write((strftime("%H:%M:%S %b %d, %Y - Finished parsing the bookmark
file ", localtime())) + '\n')       # enter into log
        return (feature,offset,length)              # return the disk image, list of features, their
offsets and lengths. This is redundant because of the global declaration of these variables


### REDACTION FUNCTION ###
def redact(diskimage,beginOffset,featureLength): # redact the disk image by passing the
image location, offset, and length of target data
        byte ="\x00"                        # hex byte used to overwrite data
        endOffset = int(beginOffset) + int(featureLength)
        #print(diskimage)       # used for debug
        #print(beginOffset)     # used for debug
        #print(featureLength) # used for debug
        #print(endOffset)       # used for debug
```

```
	#print(byte)		# used for debug

	try:
		file = open(diskimage, "r+b")	# open the image in read and binary write
mode
		try:
			for num in range(int(beginOffset),int(endOffset)):
				file.seek(num,0)	# find the location of the offset from
begining
				file.write(byte)	# overwrite the byte
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y -",
localtime())) + ' Successfully redacted offset: ' + beginOffset + ' with \\x00 \n')
			print('Successfully redacted offset ' + beginOffset)
		except:
			log.write('\n' + (strftime("%H:%M:%S %b %d, %Y -",
localtime())) + ' ERROR: REDACTING OFFSET: ' + beginOffset)
			print('ERROR redacting offset ' + beginOffset)
	except:
		print('There was a problem opening the file at ' + diskimage)
		log.write('\n' + (strftime("%H:%M:%S %b %d, %Y -", localtime())) + '
There was a problem opening the image file located: ' + diskimage)
	return		# return



### CONVERT RAW TO EWF ###
def exportEWF(rawDiskImage):
	log.write('\n\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) +
'Atempting to create packaged EWF from RAW image\n')	# update log file
	ewfacquire = ['ewfacquire', rawDiskImage, '-u']	# initialize variable
	[ewfacquire.extend([str(key),str(value)]) for key,value in flags.items()]	#
convert the flags key/value dictionary to a list

	log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) +
'Attempting process: ' + (' '.join(ewfacquire)))	# update log file
	try:
		check = subprocess.check_call(ewfacquire)	# call ewfacquire with the
dfxml arguments
		log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) +
'Successfully created EWF disk image')	# update log file

	except CalledProcessError as e:
		log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) +
'ERROR creating EWF disk image: ' + e)	# update log file

	return
```

```
""" MAIN STARTS HERE"""

parser = argparse.ArgumentParser(description='Redact binary features')     # store all the
information necessary to parse the command line
parser.add_argument('-i','--disk_image', help='This is the location of the disk image to be
redacted', required=True)       # add image file location argument
parser.add_argument('-b','--bookmark_file', help='This is the bookmark file exported
from Bulk_Extractor', required=True)           # add image file location argument
parser.add_argument('-f','--image_format', help='type of image file [EWF] [AFF] [RAW]
[ISO]', required=True)           # add image file location argument
parser.add_argument('-o','--output', help='This is the output location and name (without
extension) to save the redacted disk image', required=True) # add image file location
argument
args = parser.parse_args()       # parse the arguments and store in variable args
print('\nyou entered ' + args.disk_image + ' ' + args.bookmark_file + ' ' +
args.image_format + ' ' + args.output)           # used for debug

try:
        log = open(saveFilePath + '/' + args.output + '.log.txt', 'w')    # open the log file
        #print('\nlog written to ' + saveFilePath + '/log.txt') # used for debug
        log.write('Script started running at ' + (strftime("%H:%M:%S on %a %b %d,
%Y", localtime())) + '\n')    # write the first entry into the log
except:
        print('There was an error creating the log file')


if (args.image_format) == 'EWF':
        print('Converting EWF image to raw...')
        log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) +
'Converting image file from EWF to RAW...')                    # update log file
        subprocess.check_call(['ewfexport', args.disk_image, '-t', args.output, '-f', 'raw', '-
o', '0', '-S', '0', '-u'])      # convert the EWF disk image into RAW using ewfexport
        log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) +
'Successfully converted disk image file to RAW')     # update log file
        parseDFXML(args.disk_image)
        ### save DFXML to temporary file, append notes section with date/time
redaction script was run
"""
if args.image_format == 'AFF':
        print('Converting AFF image to raw...')
        ### convert image to RAW
```

```
if args.image_format == 'ISO':
	print('Converting ISO image to raw...')
	### convert image to RAW
	### save DFXML to temporary file, append notes section with date/time
redaction script was run
"""

bookmarks = parseBookmarks(saveFilePath + '/' + args.bookmark_file)	# parse the
bookmark file, pass it the bookmarks file location

log.write('\nAttempting redaction on RAW disk image located at: ' + saveFilePath + '/' +
args.output + '.raw\n') # enter into log
for i in xrange(len(offset)):
	log.write('\n' + (strftime("%H:%M:%S %b %d, %Y - ", localtime())) + '
Attempting to redact offset: ' + str(bookmarks[1][i]) + ' for ' + str(bookmarks[2][i]) + '
bytes.')
	redact((saveFilePath + '/' + args.output + '.raw'),offset[i],length[i])  # call redact
function, pass the image, offset, and length
	#print(bookmarks[0][i])		# used for debug
### IF original format was RAW, save the DFXML file in the same place as the redacted
RAW file.

exportEWF(args.output + '.raw')

log.write('\nScript stopped running at ' + (strftime("%H:%M:%S on %a %b %d, %Y",
localtime())) + '\n\n')   # write out the last entry in the log
log.close()    # close the log file
```