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FORENSICS 518

MAC FORENSIC ANALYSIS

518.1

Mac Essentials and the HFS+ File System

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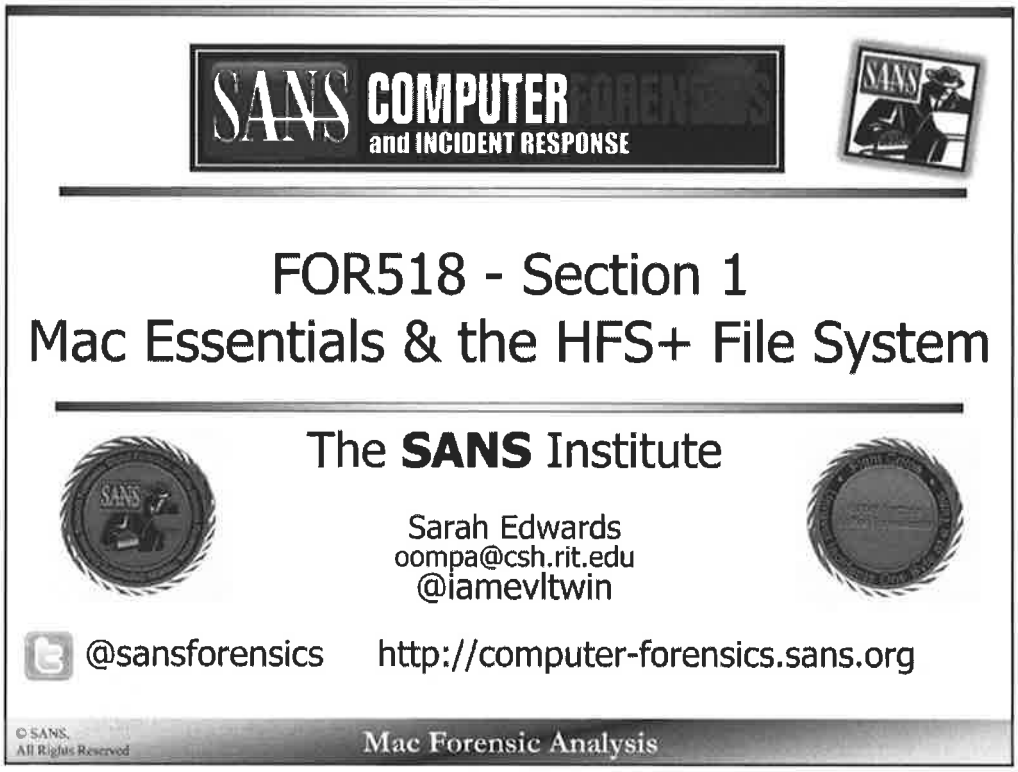

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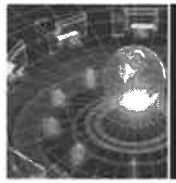

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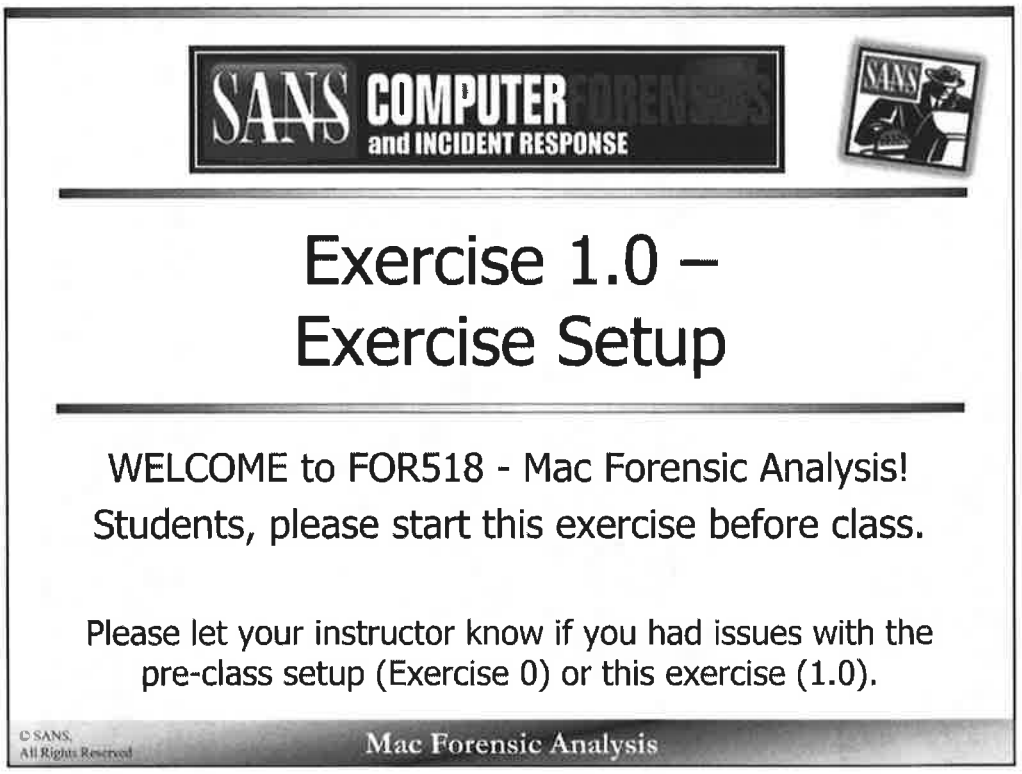

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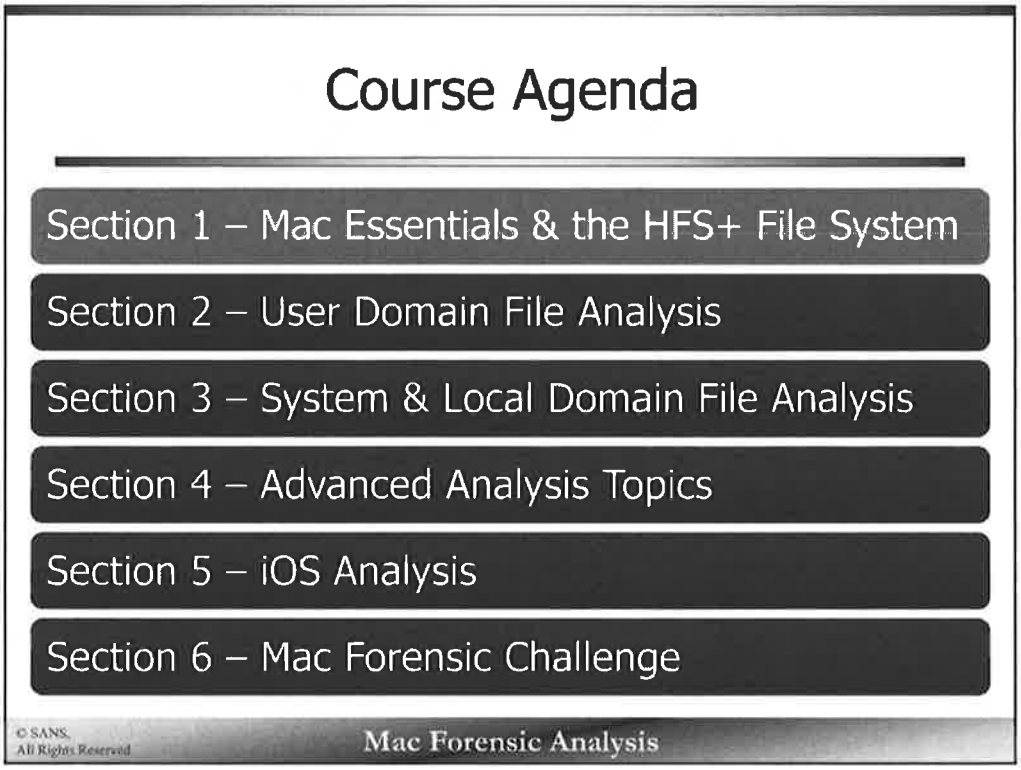

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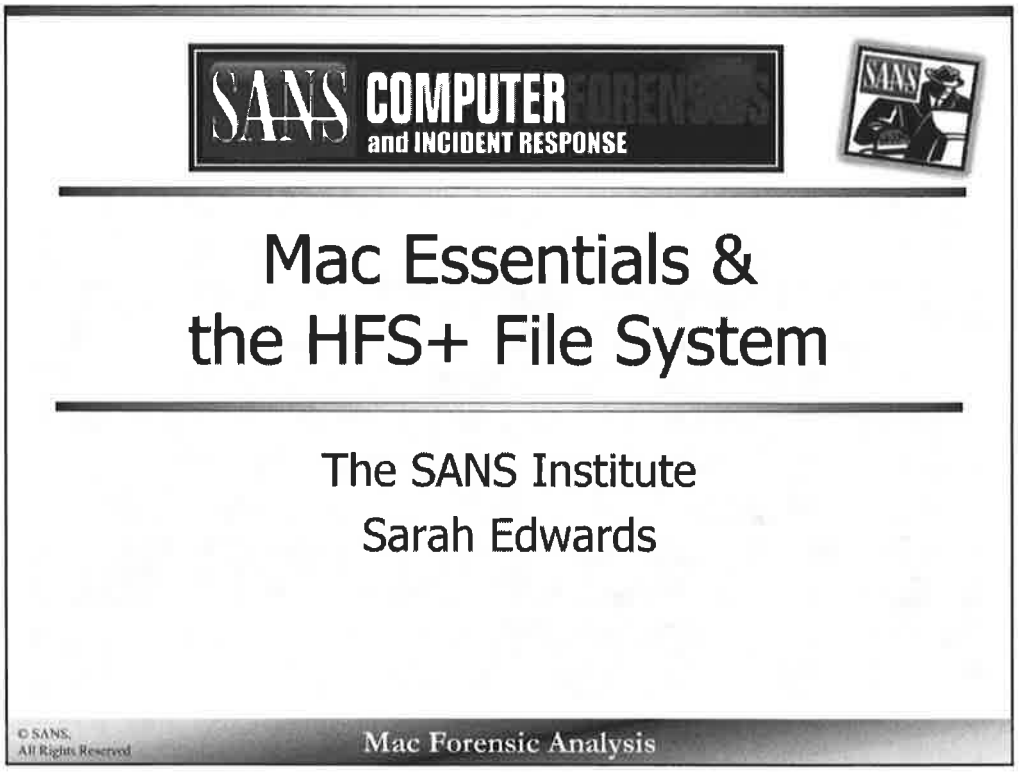

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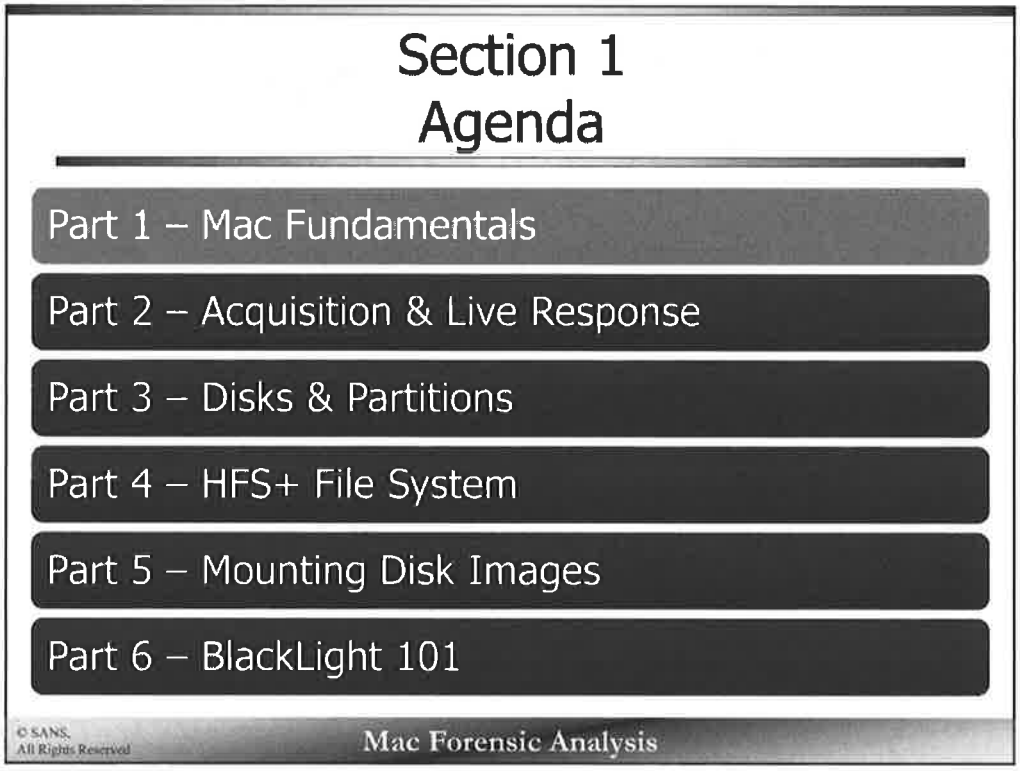

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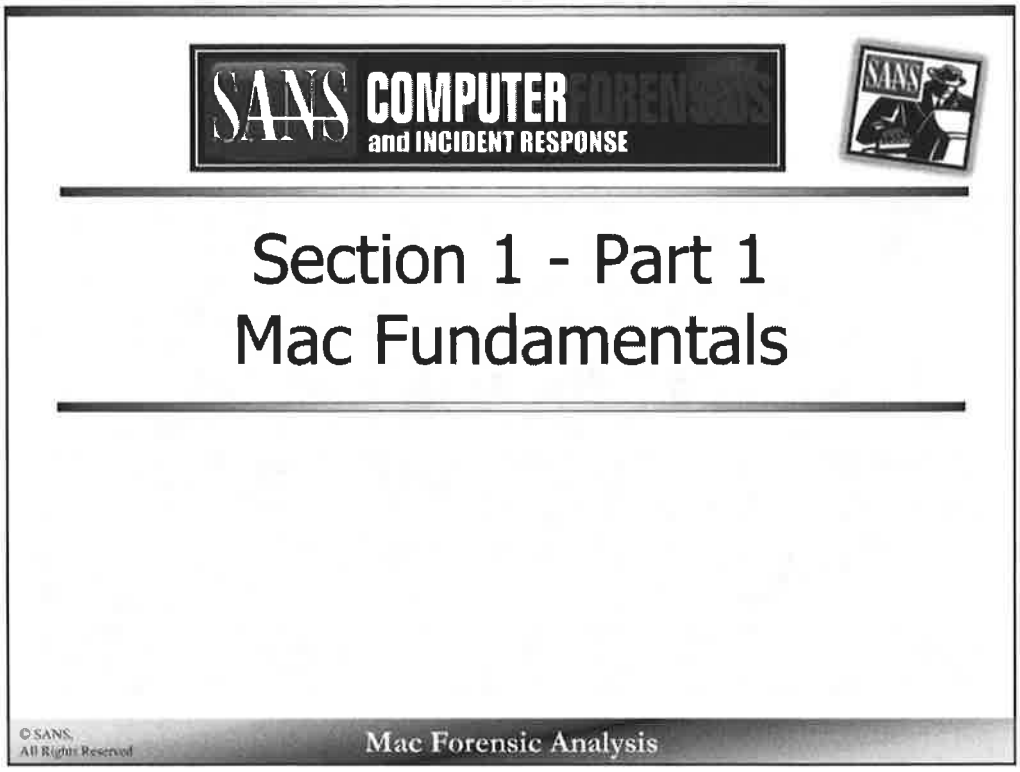

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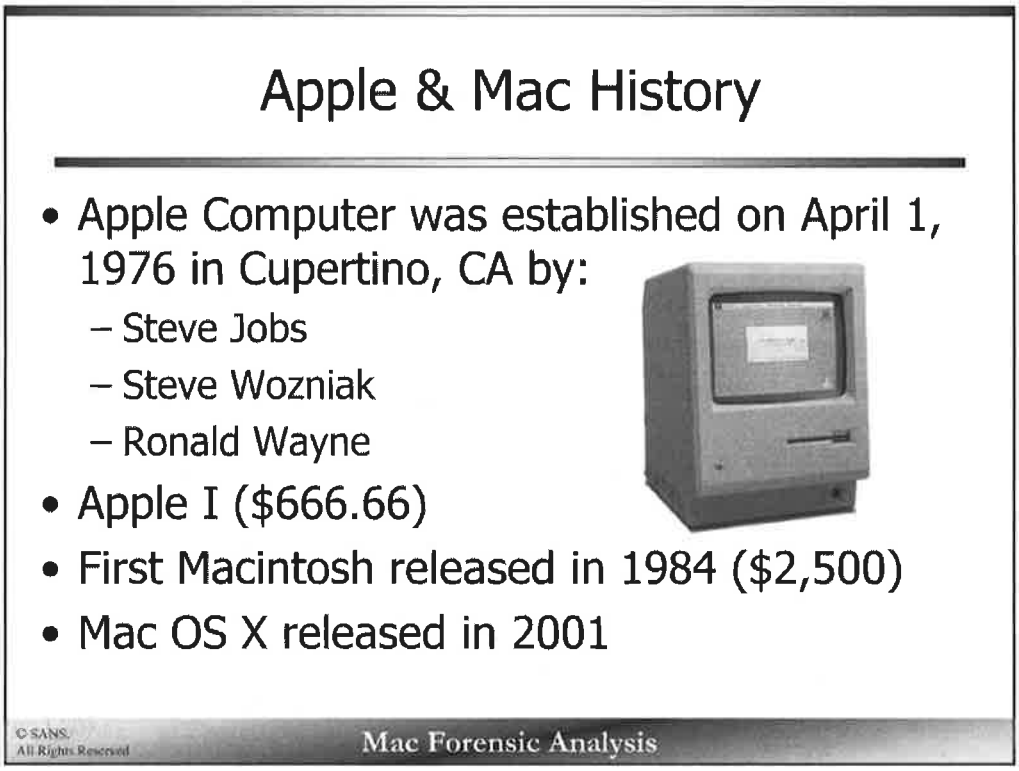
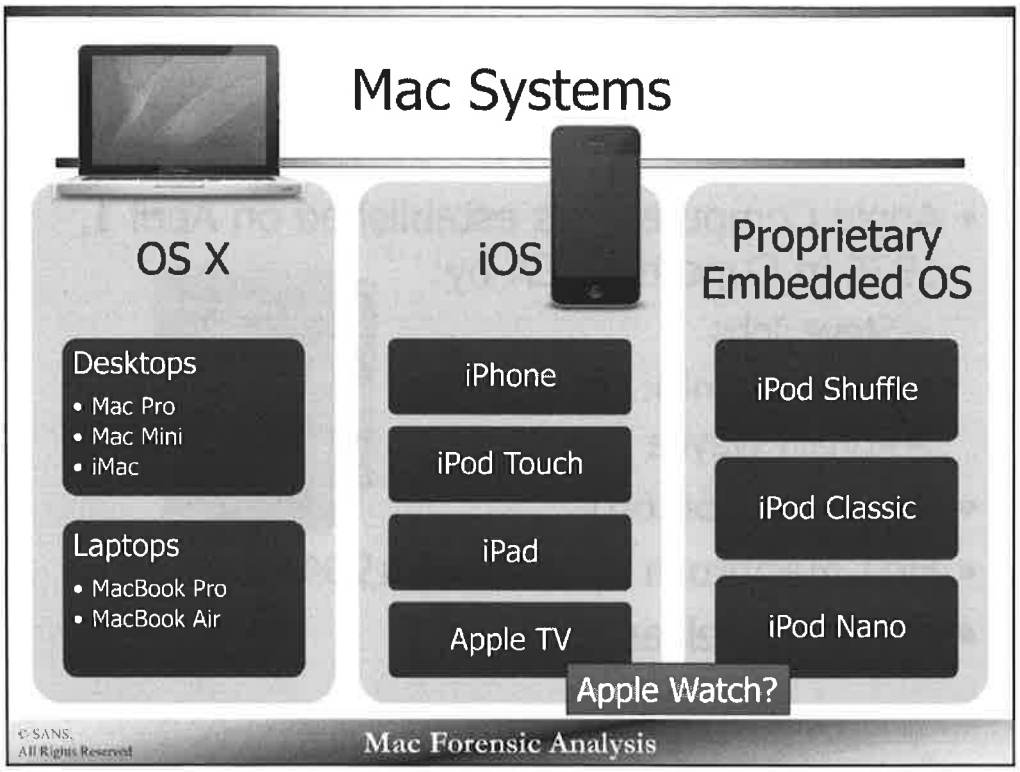


Apple Computer was established on April 1, 1976 (incorporated January 3, 1977) by Steve Jobs, Steve Wozniak and Ronald Wayne.

The first computer they sold was the Apple I for $666.66 in 1976. In 1984 the first Macintosh was introduced to the Super Bowl audience with the famous "1984" commercial. The Macintosh was touted as the first commercially successful personal computer with a graphical user interface. It was also $2,500!

Macintosh computers use the Mac Operating System (Mac OS). The older Macs used the "Classic" Mac OS (System 1-9) while the newer Macs use Mac OS X (Ten). Mac OS X introduced a Unix-based operating system.

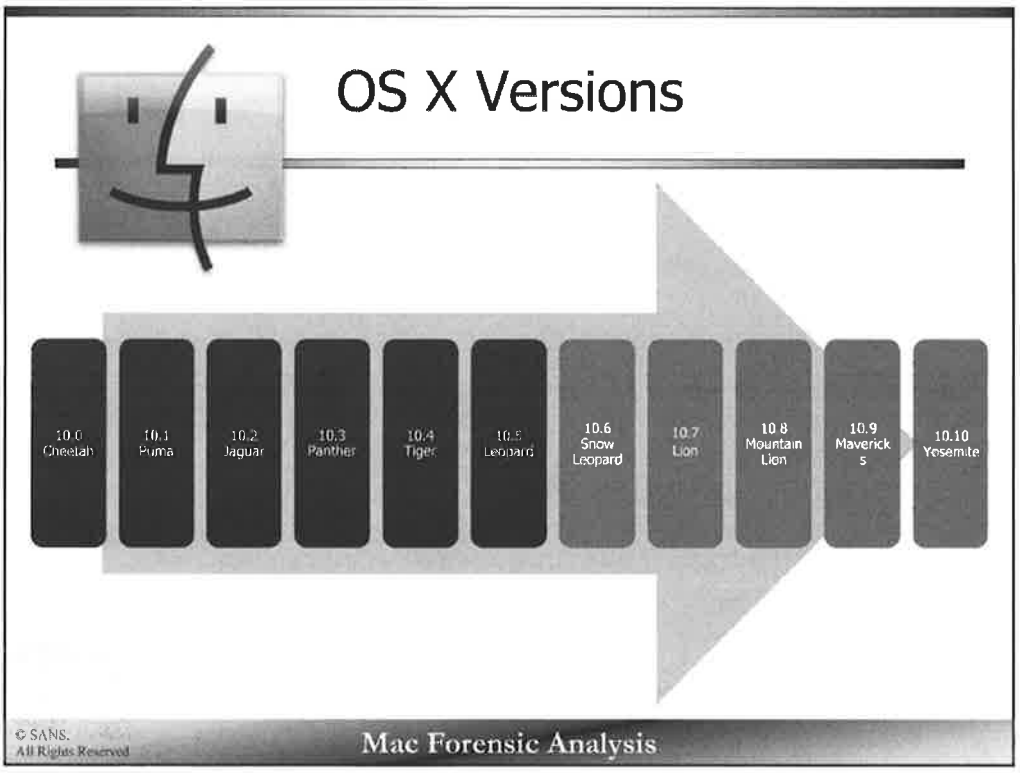


Modern Mac Systems are comprised of three types: OS X, iOS and a proprietary embedded operating system.

OS X is featured on the desktop and laptop product lines.

iOS is featured on mobile devices such as the iPhone, iPad and the Apple TV. iOS is based upon OS X, and could be considered OS X "lite". It has many of the same characteristics and file system intricacies but does not contain all the software and features of OS X.

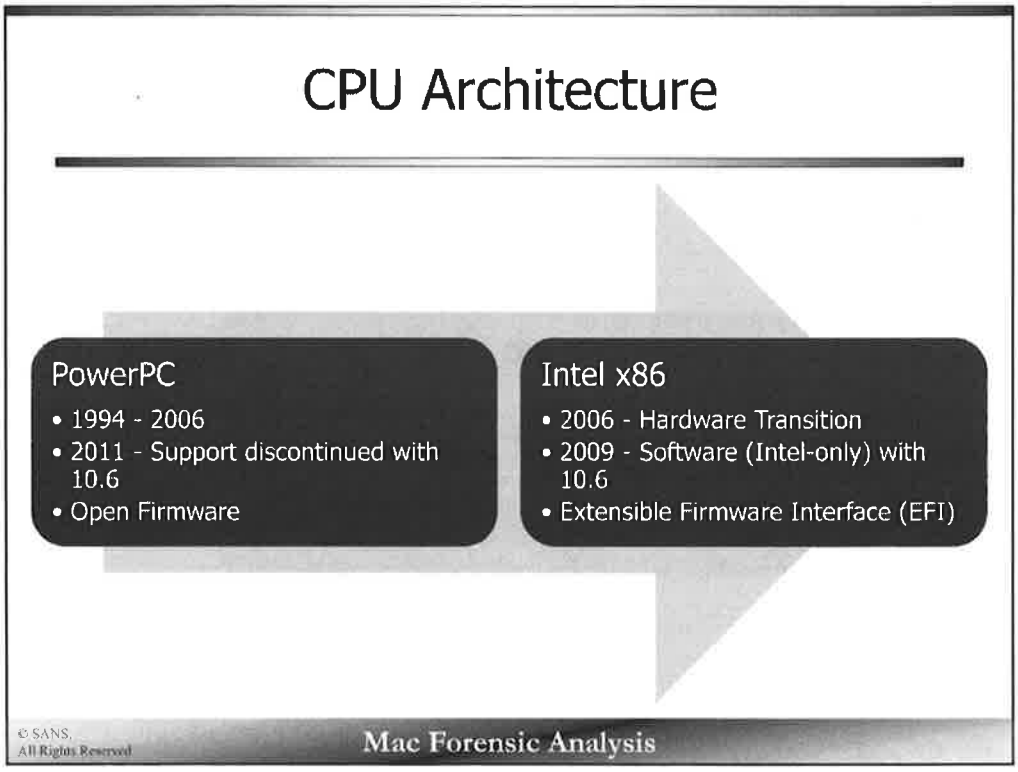
The iPod Shuffle, Nano, and Classic contain a proprietary embedded operating system.



There have been eleven versions of OS X, 10.0 – 10.10. The latest, Yosemite was released in October of 2014.

OS X introduced the Unix-based operating system with an easy-to-use GUI for the casual user.

This class will feature some items since 10.6, unless otherwise noted. Each version of the operating system changes slightly and can differ in various ways. Where appropriate the version of the operating system will be listed, but be aware that changes may vary and testing the various operating systems may help you with specific questions.

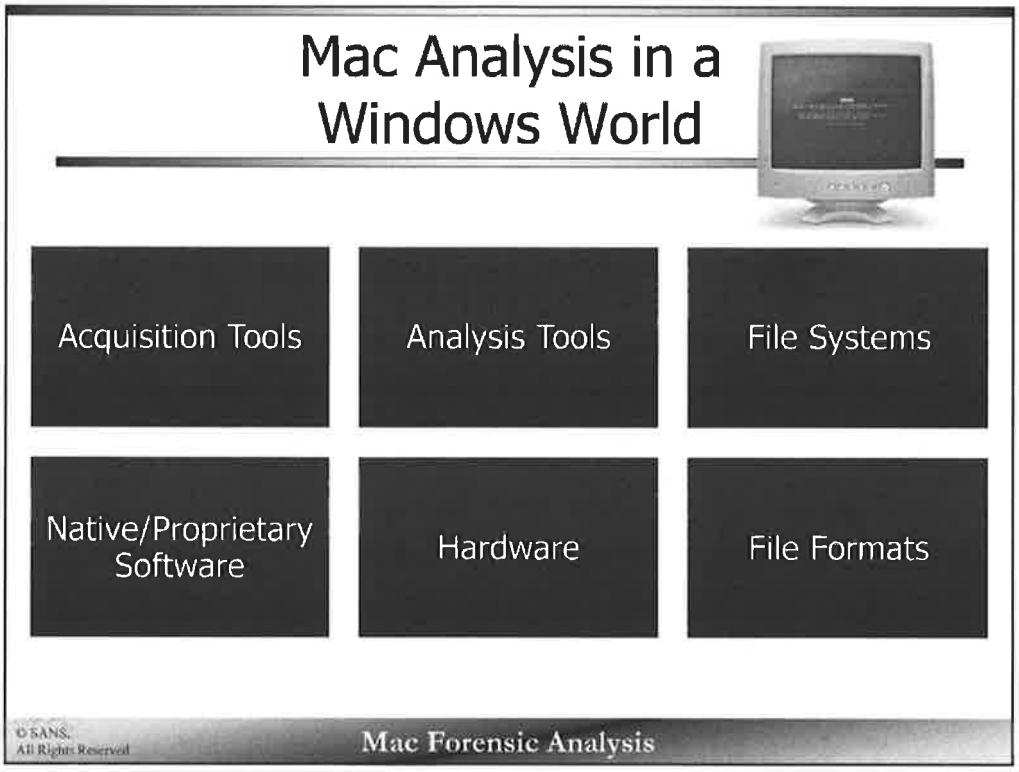


After the introduction of Unix core components to the operating system, Apple Computer made the transition from PowerPC to Intel x86 architecture.

PowerPC (Performance Optimization With Enhanced RISC – Performance Computing) was used from 1994 to 2006. PowerPC was no longer supported with OS X Snow Leopard (10.6). This architecture used the Open Firmware interface, similar to a PC's BIOS. The last version of OS X that was PowerPC-only was OS X Panther (10.3). This interface was accessible using the CMD+Option+O+F.

The Intel x86 transition started in 2006. OS X Tiger (10.4) was the first available OS X version that one could use on x86 architecture. Intel-based Macs use the Extensible Firmware Interface (EFI), also similar to a PCs BIOS.

Open Firmware and EFI interface between the hardware and the operating system to provide drivers and a pre-OS environment. EFI has additional advantages such as the ability to boot from USB, and larger disks.

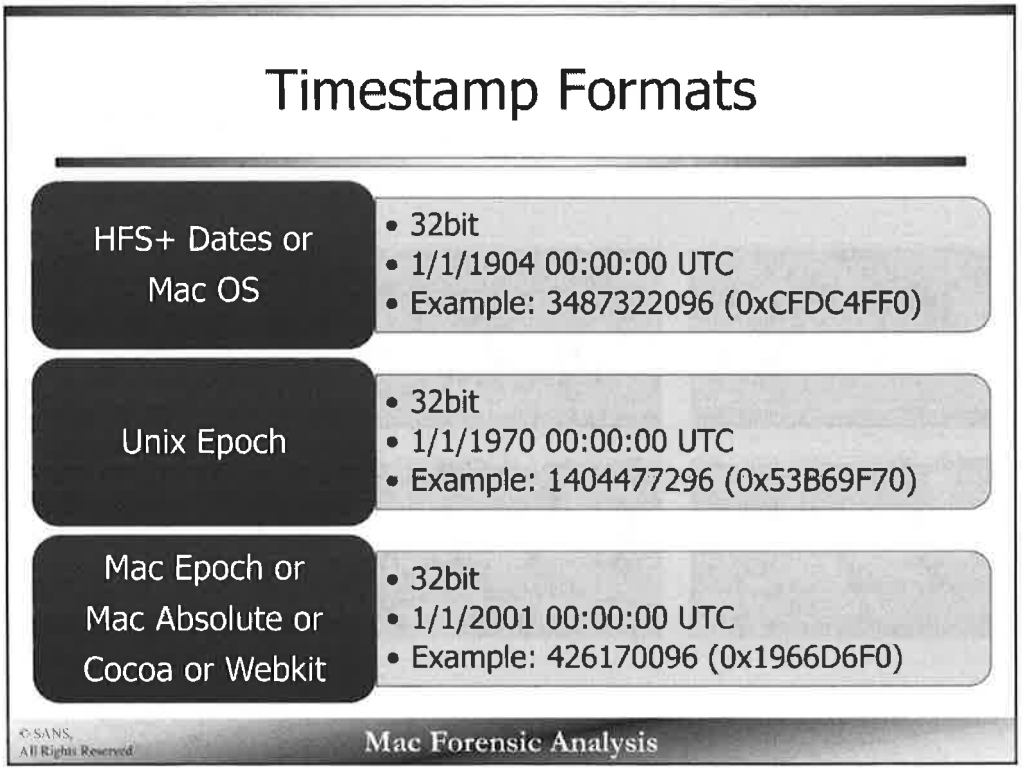


The Windows platform is by far the most popular analysis platform in the digital forensics community.

Many of the tools used for acquisition are the same as those used in acquiring Windows systems. A hard drive is a hard drive. Live acquisitions, however, pose a different challenge, the same techniques can be used but tools specific to Mac OS X will be needed to acquire memory, create an image, and to gather volatile data.

Analysis tools may also be the same as those used for Windows systems (i.e.: Encase, FTK, X-Ways). Many of the most popular forensic analysis tools can be used with varying success depending on their Hierarchical File System Plus (HFS+) file system interpretation and Mac-specific file capabilities. Not all tools understand what a binary property list file is. The Mac OS, as with many operating systems, uses different software and file formats.

The HFS+ file system can bring up certain challenges to forensic tools and analysis techniques. For example, HFS+ cannot be read or written to natively on Windows systems, therefore mounting an HFS+ drive in Windows requires additional software or the use of a Mac.



You will encounter a variety of timestamps on a Mac system. While Unix epoch is relatively well known, the number of seconds from midnight on 1/1/1970, the HFS+ file system uses a different epoch date, midnight on 1/1/1904. Another epoch time, sometimes called Mac Absolute Time starts at midnight on 1/1/2001.

Throughout the class the various timestamps will be highlighted.

Convert timestamps using `date -ur <epochtime>`:

- Mac Epoch – add 978307200
- HFS+ Date – subtract 2082844800

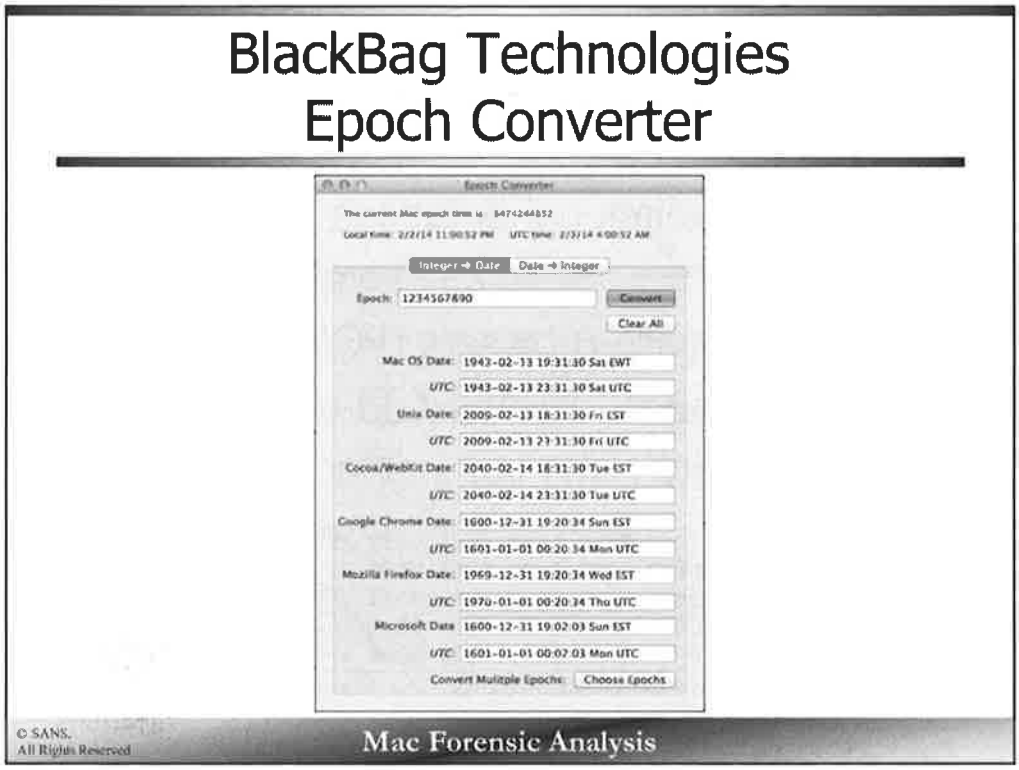
For example:

```
$ date -ur 1234567890
Fri Feb 13 23:31:30 UTC 2009
```

Reference:

Mac Developer Library – NSDate Class Reference

[https://developer.apple.com/library/mac/#documentation/Cocoa/Reference/Foundation/Classes/nsdate_Class/Reference/Reference.html]

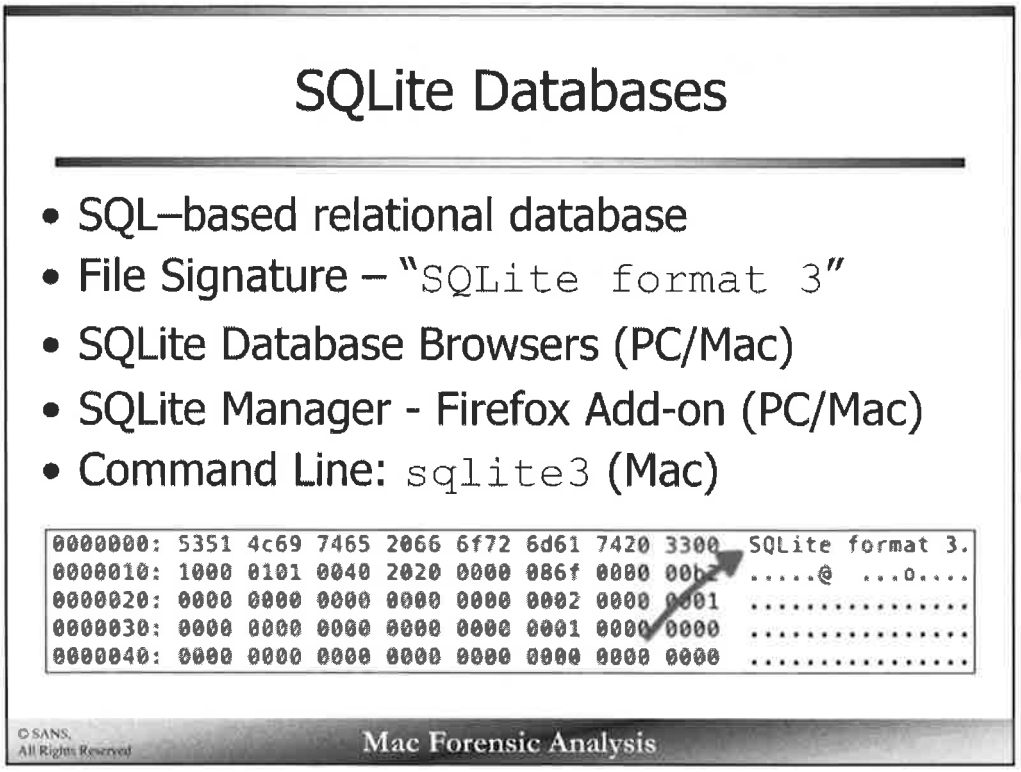


BlackBag Technologies has a wonderful GUI-based timestamp converter. It has the ability to convert from timestamp integer to date and vice versa.

This utility supports many timestamp formats in local system time and UTC:

- Mac OS (HFS+)
- Unix Epoch
- Cocoa/Webkit
- Google Chrome
- Mozilla Firefox
- Microsoft

This application is similar to Dcode by Digital Detective for Windows-based systems.

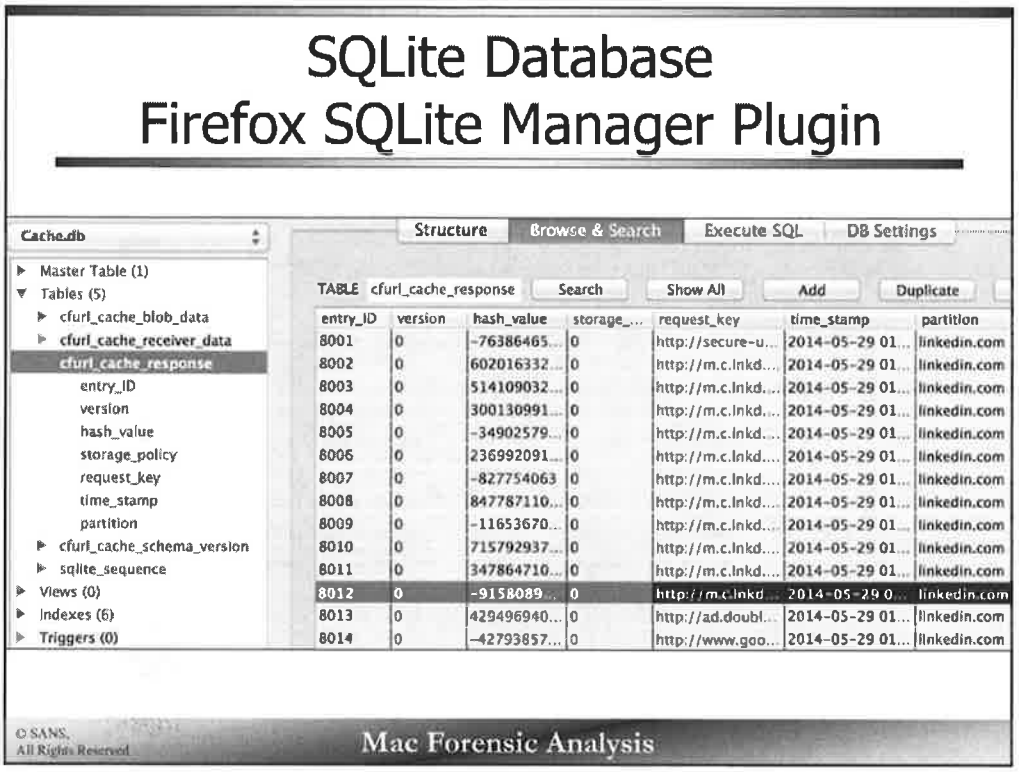


Software on Mac systems use SQLite databases to store various types of information such as settings and Internet histories. SQLite is a SQL-based relational database. These databases can have multiple tables with multiple types of keys and values.

In the screenshot above, the signature used for SQLite databases is "SQLite format 3". An easy way to carve for these files would be to use that signature as a starting point.

SQLite files are non-system specific and can be viewed using different tools for Mac, Windows or Linux systems. You may want to use SQLite Database Browser. This application was recently updated and now handles newer SQLite files that it was not able to do before.

Another utility to use the Firefox Add-On "SQLite Manager". This add-on can be used with any system that Firefox can be installed on. [https://addons.mozilla.org/en-US/firefox/addon/sqlite-manager/]



This is an example of the Safari `Cache.db` SQLite database. The screenshot shown is using the Firefox SQLite Manager Plugin.

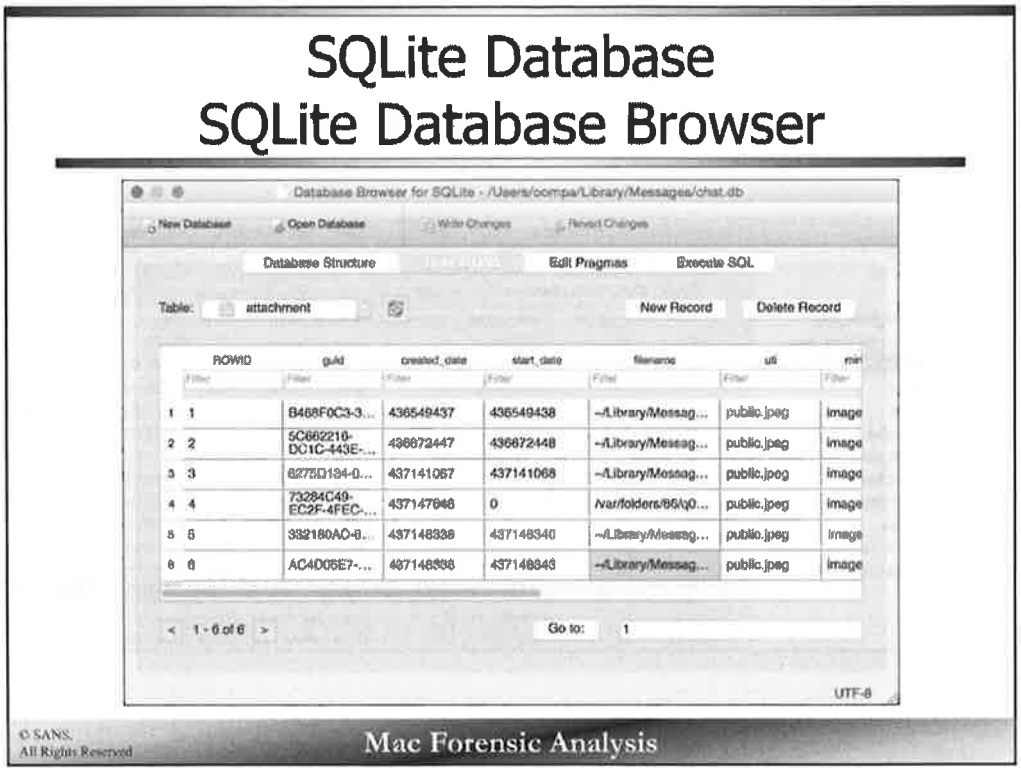
On the left under "Tables" there are five tables shown:

- `cfurl_cache_blob_data`
- `cfurl_cache_receiver_data`
- `cfurl_cache_response`
- `cfurl_cache_schema_version`
- `sqlite_sequence`

Each table is made up of row (or tuples) and columns.

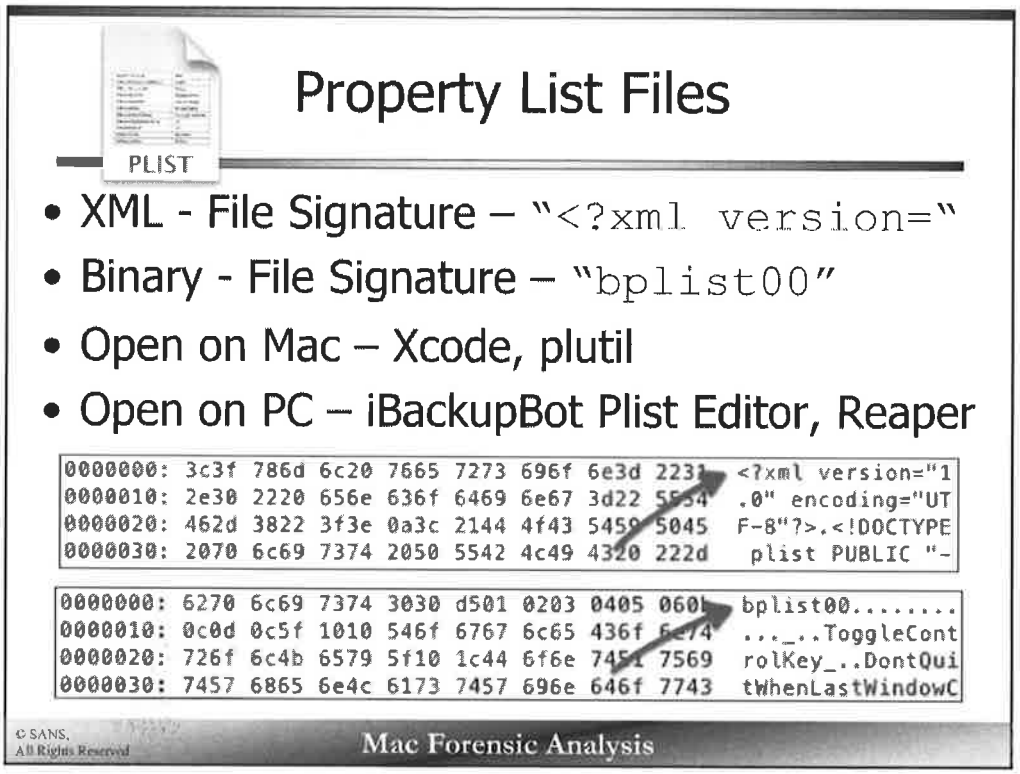
In the example shown, this table has seven columns:

- `entry_ID`
- `version`
- `hash_value`
- `storage_policy`
- `request_key`
- `time_stamp`
- `partition`



This screenshot shows an example of SQLite Database Browser.

This is a standalone application that does not require a browser. Each analyst may have their own favorite SQLite database viewer, please choose what you prefer to use.



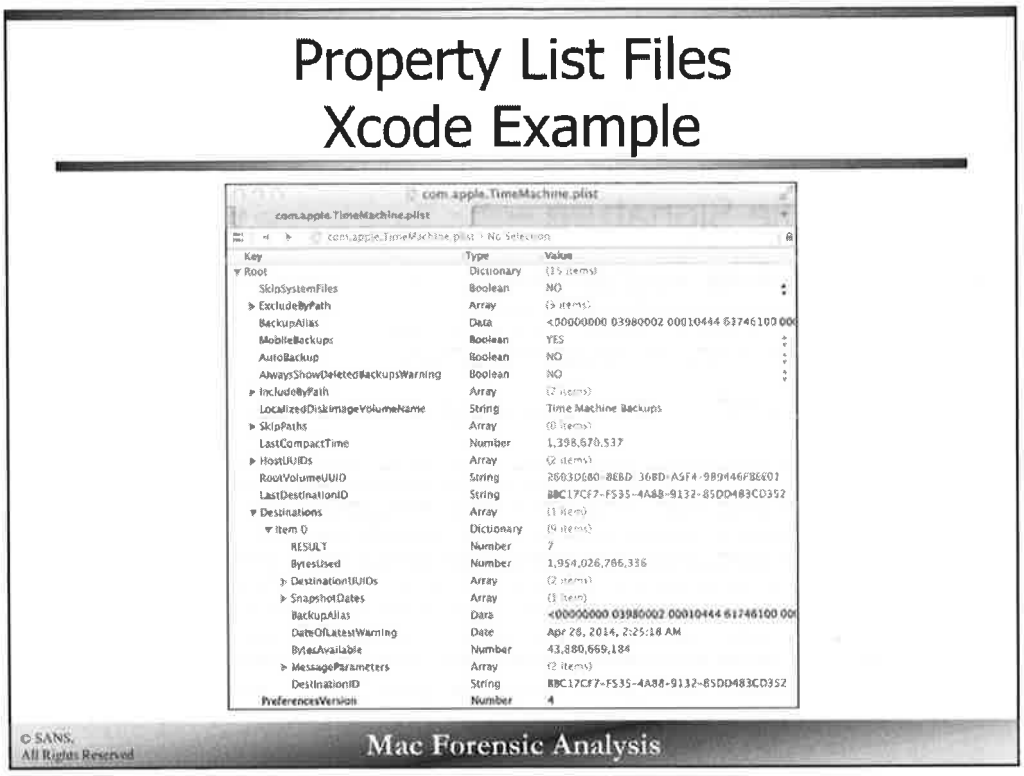
Property list files usually contain configuration data, similar to the Windows registry. These files come in two formats, XML or binary. The older format, XML is human-readable and has the file signature of "`<?xml version=`". The newer binary format is used as it is more efficient on disk space. This format has the file signature "`bplist00`" for binary plist.

These files can be read using the Xcode or by the command-line tool `plutil`.

Xcode is not installed by default on Mac OS X, it can be installed by downloading it from Apple's website or by using the Mac App Store. Older versions of Xcode had a utility named "Property List Editor" that reads property list files without the extraneous bulk of Xcode. Newer versions of Xcode include a property list editor; however, it may take a while to load the whole Xcode programming environment.

A command line tool, `plutil`, can be used to convert property list files into other formats such as binary to XML, or XML to JSON.

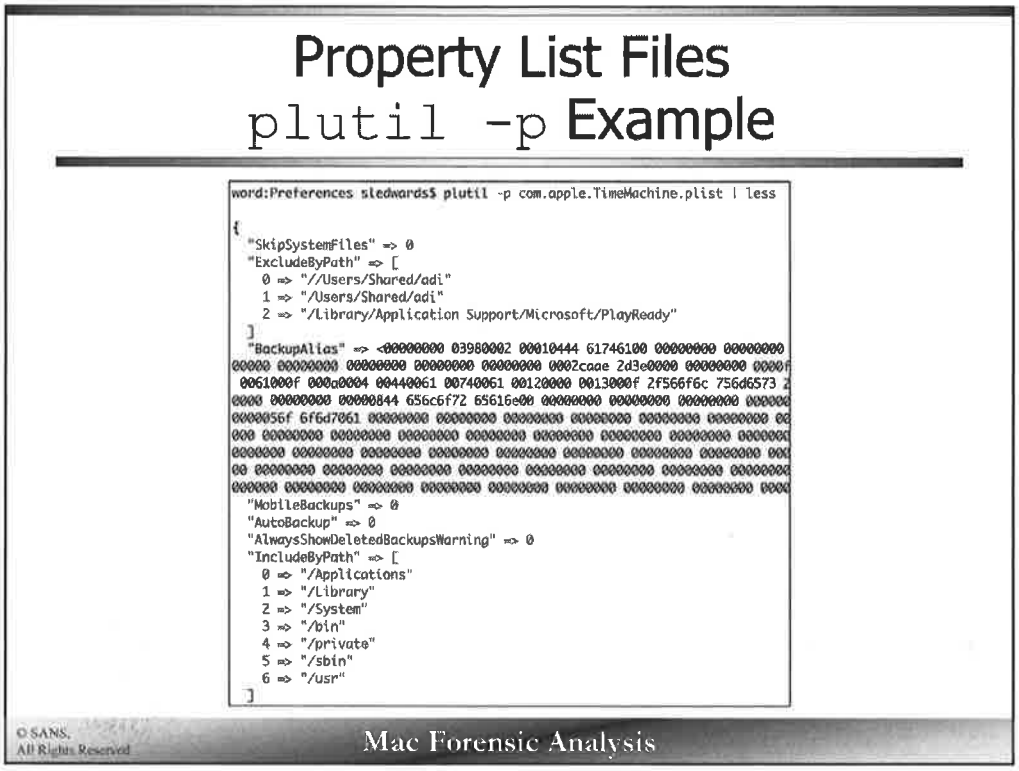
On windows systems, there is one tool that the author has found to parse the property list files, it doesn't work nearly as well as the Mac tools but it works in a pinch. iBackupBot Plist Editor – [http://www.icopybot.com/download.htm] or Reaper (http://insidethecore.com/reaper/reaper.html)



An example of a property list is shown in the screenshot above. This property list is being viewed with the internal Xcode plist viewer.

Each property list contains keys and values. Each value can have different data types such as:

- Boolean - On/Off, Yes/No, 0/1
- Array - Contains additional keys/values
- Data - Binary Data Blob, can be extracted and viewed in a hex editor
    - May contain embedded property lists
- Number
- String
- Date – Dates are shown in local host system time (make sure to check your time zones!)
- Dictionary – Contains additional keys/values (similar to Array)

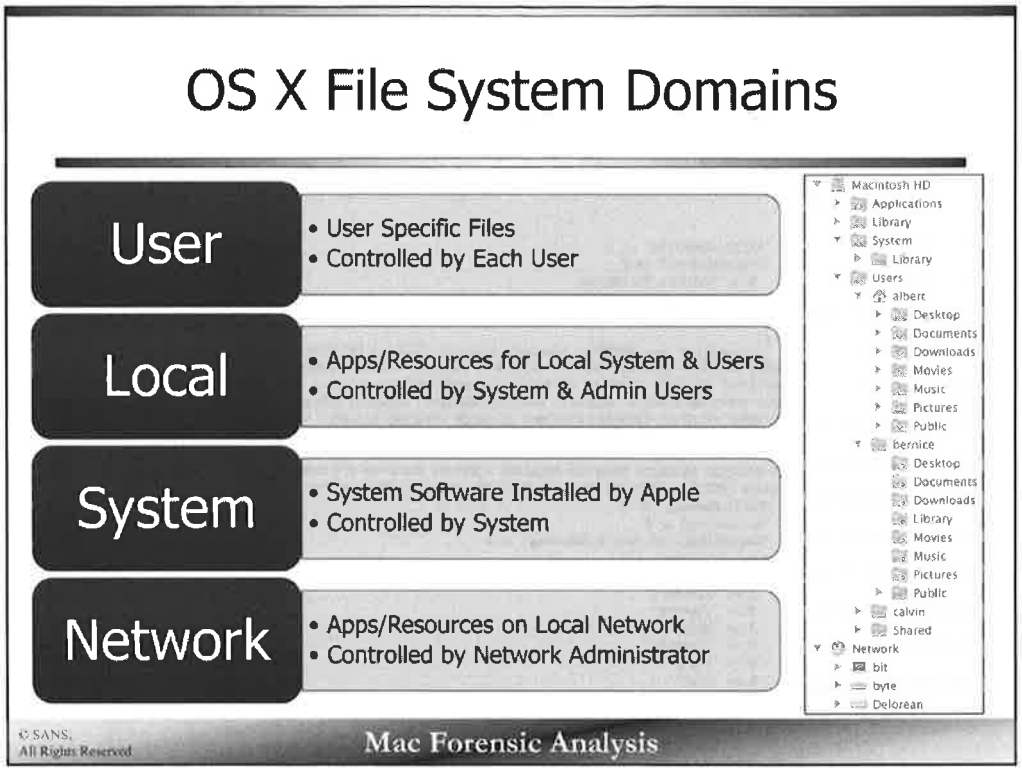


You can also view property lists on the command line using the OS X native tool, `plutil`. Use the `-p` parameter to "print" the property list. The default print view is JSON formatted.

You can also use `plutil` to convert property lists from binary to XML.

Reference:

`plutil` Man Page



The Mac OS X file system is made up of four domains; user, local, system, and network.

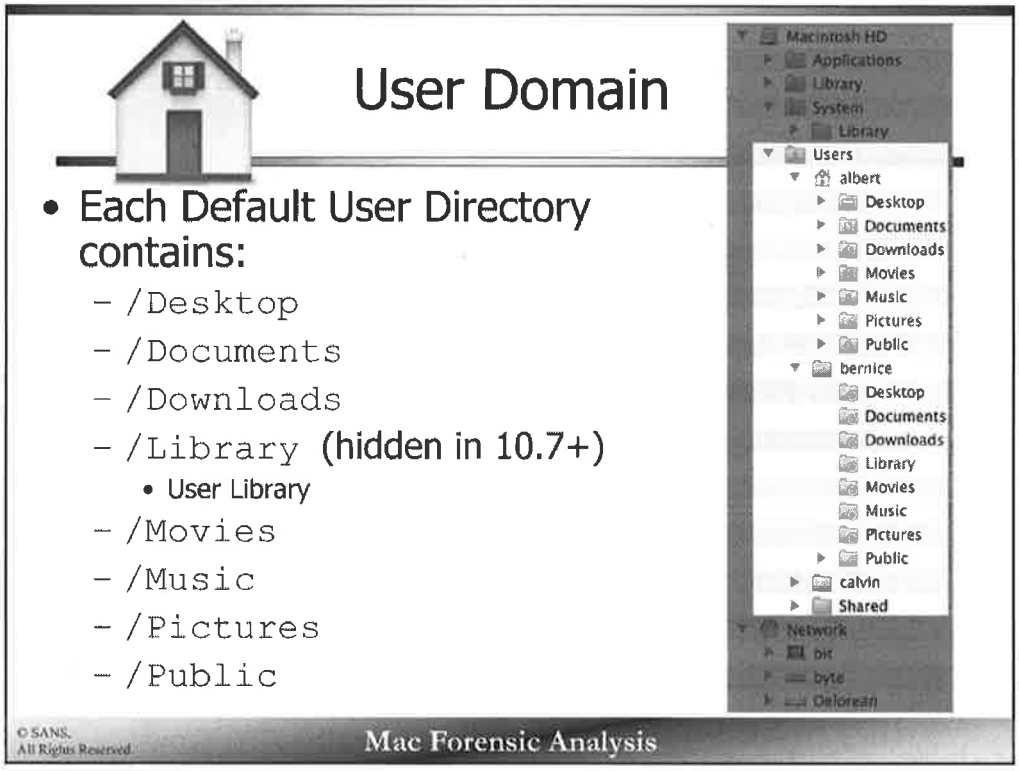
Each domain has a purpose, they may contain user files, system resources, or network data. The domains are used to separate files based on their usage. The breakdown of the domains helps implement access controls so a file is cannot intentionally or unintentionally modified to keep the system secure and functional.

In the following slides, each domain section will be highlighted to show where in the logical file system the files are located.

Reference:

File System Programming Guide – File System Basics

[https://developer.apple.com/library/mac/DOCUMENTATION/FileManagement/Conceptual/FileSystemProgrammingGUide/FileSystemOverview/FileSystemOverview.html]



The User Domain consists of the all the user files. Their documents, pictures, music, etc.

Each user has their own home directory in the `/Users/` folder, marked by a house icon in the screenshot above. If a user is logged on, default permissions will not allow them to view the files in another user's directory noted by the red circle with the line icon.

Most of the directories are self explanatory in terms of information they may contain. The public folder may contain data the user wants to share with other users. The user's Library directory contains app-specific data.

This domain may also contain "Sites" directory if web sharing is enabled; this would contain the user's personal web site.

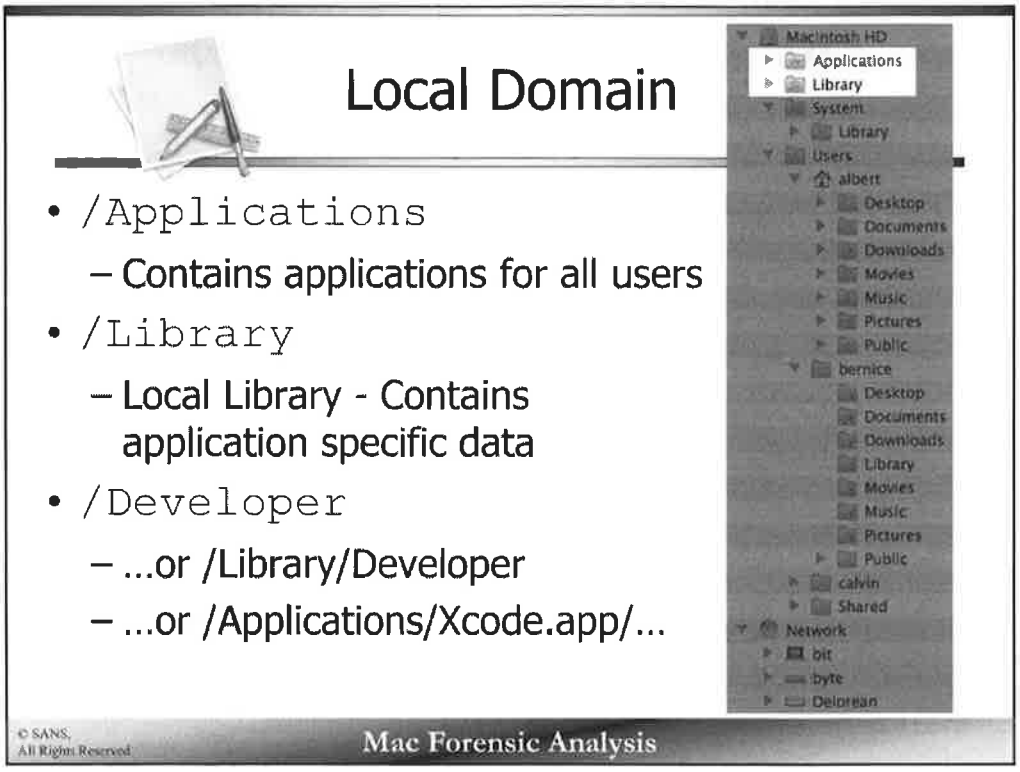
Starting with Mac OS X Lion, the user's `Library` folder was hidden. Some users may prefer to be able to view the files easily. The author finds that it helps forensic research to have the Library directory to be viewable. The command to permanently change this for a specific account is below. It may also be accessed by holding down the "option" key when accessing it via the 'Go' menu in the Finder Toolbar.

```
chflags nohidden /Users/<username>/Library
```

Reference:

File System Programming Guide – File System Basics

[https://developer.apple.com/library/mac/DOCUMENTATION/FileManagement/Conceptual/FileSystemProgrammingGUide/FileSystemOverview/FileSystemOverview.html]



The local domain consists of the applications folder, the (local) Library directory, and if installed, the Developer directory. This domain is used to store the files that may be shared amongst the users, such as applications.

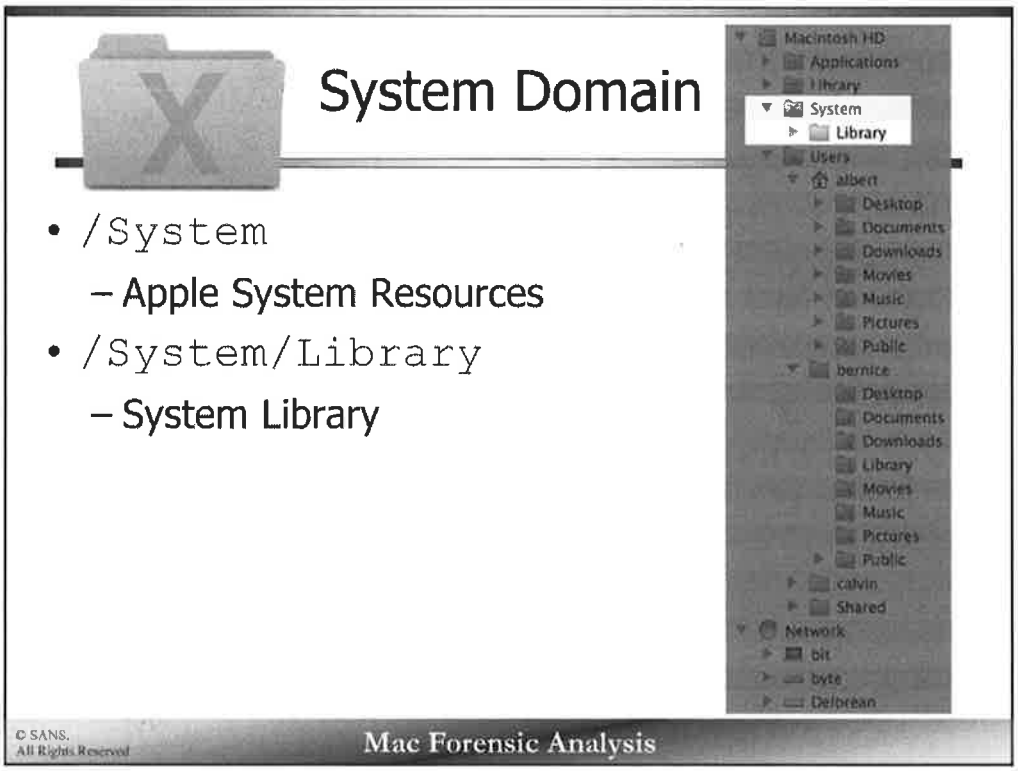
The `/Applications` directory contains the applications available to all users of the system. It is not necessary to run an application from the `/Applications` directory, it may be run from a user directory if needed. Applications from the Mac App Store are installed in the `/Applications` directory.

The `/Developer` directory is created when Xcode is installed. The Developer directory may be located in either the root (/), under `/Library` or embedded in the Xcode.app application in the `/Applications` directory. The Developer folder contains Apple Developer (Mac, iOS,) related data and resources.

Reference:

File System Programming Guide – File System Basics

[https://developer.apple.com/library/mac/DOCUMENTATION/FileManagement/Conceptual/FileSystemProgrammingGUide/FileSystemOverview/FileSystemOverview.html]



The System Domain is used to store Apple specific system software.

The System Domain contains the System `Library` directory which contains files associated with Apple system resources.

The primary files we will be looking at in this domain are system preferences and data files.

You may have noticed a common theme in the directory structure. There are three `Library` directories on Mac OS X, each with its own purpose. It is easy to get confused about which `Library` directory contains what data, this class will discuss the difference between each `Library` directory and the contents located within.

- User Library - `/Users/<username>/Library/`
- Local Library - `/Library/`
- System Library – `/System/Library/`

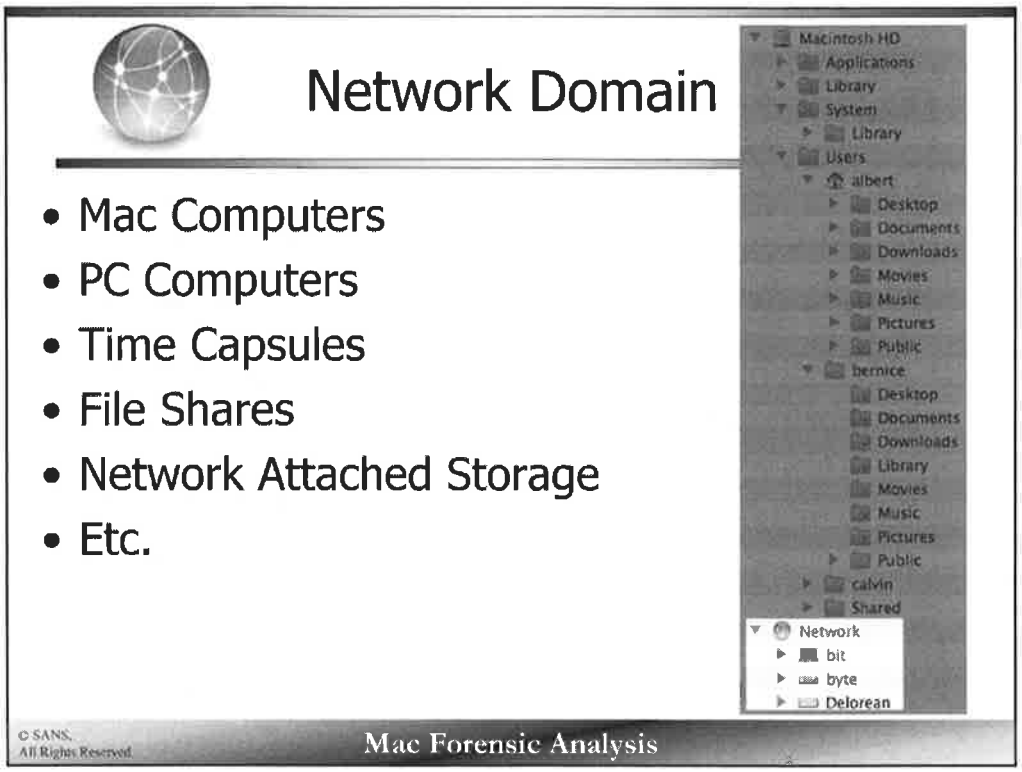
Reference:

File System Programming Guide – File System Basics

[https://developer.apple.com/library/mac/DOCUMENTATION/FileManagement/Conceptual/FileSystemProgrammingGUide/FileSystemOverview/FileSystemOverview.html]

File System Program Guide – OS X Library Directory Details

[https://developer.apple.com/library/mac/DOCUMENTATION/FileManagement/Conceptual/FileSystemProgrammingGUide/MacOSXDirectories/MacOSXDirectories.html#//apple_ref/doc/uid/TP40010672-CH10-SW1]

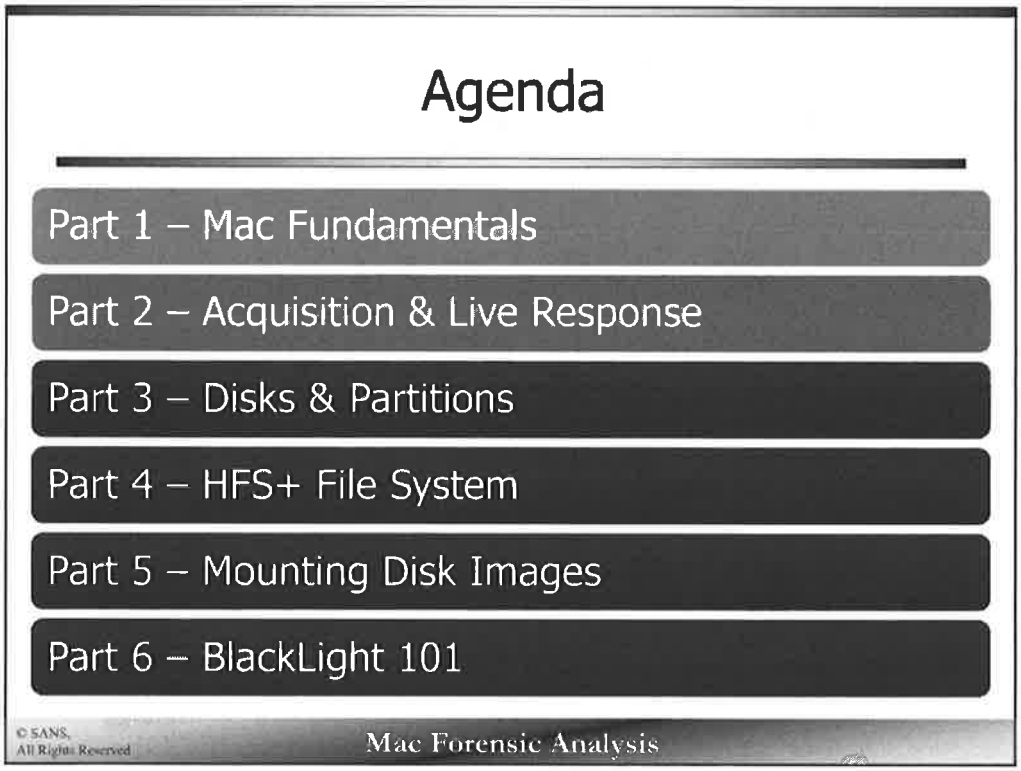


The Network Domain contains the network resources such as network area storage, Time Capsules, and other systems on the network.

Reference:

File System Programming Guide – File System Basics

[https://developer.apple.com/library/mac/DOCUMENTATION/FileManagement/Conceptual/FileSystemProgrammingGUide/FileSystemOverview/FileSystemOverview.html]



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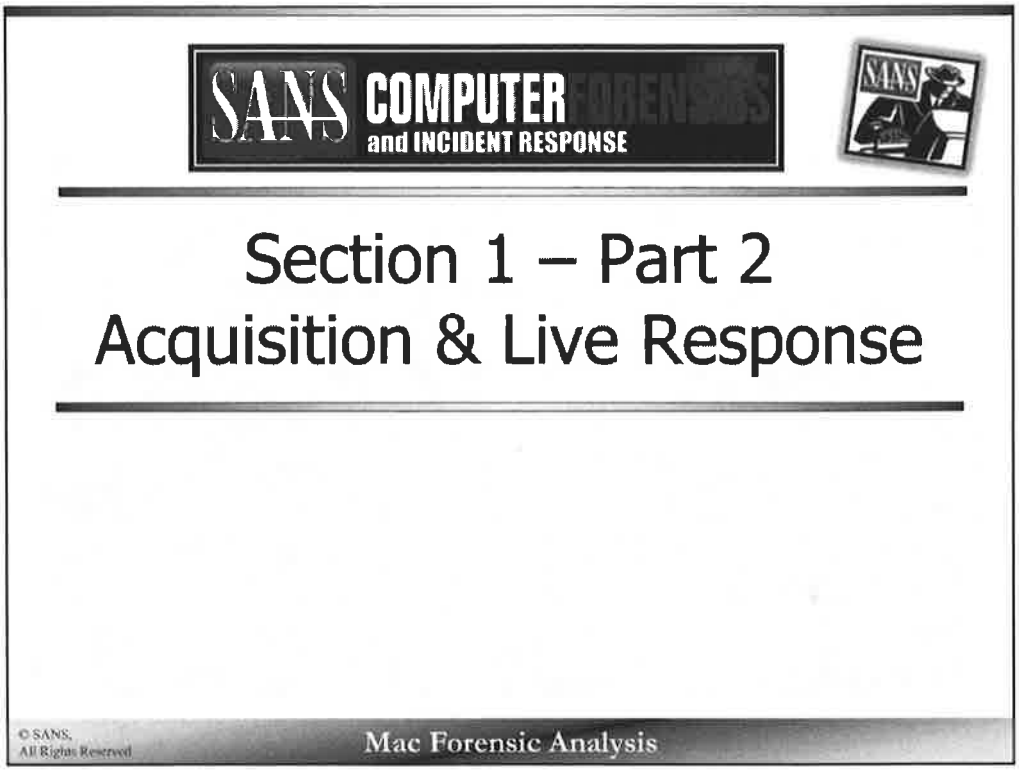

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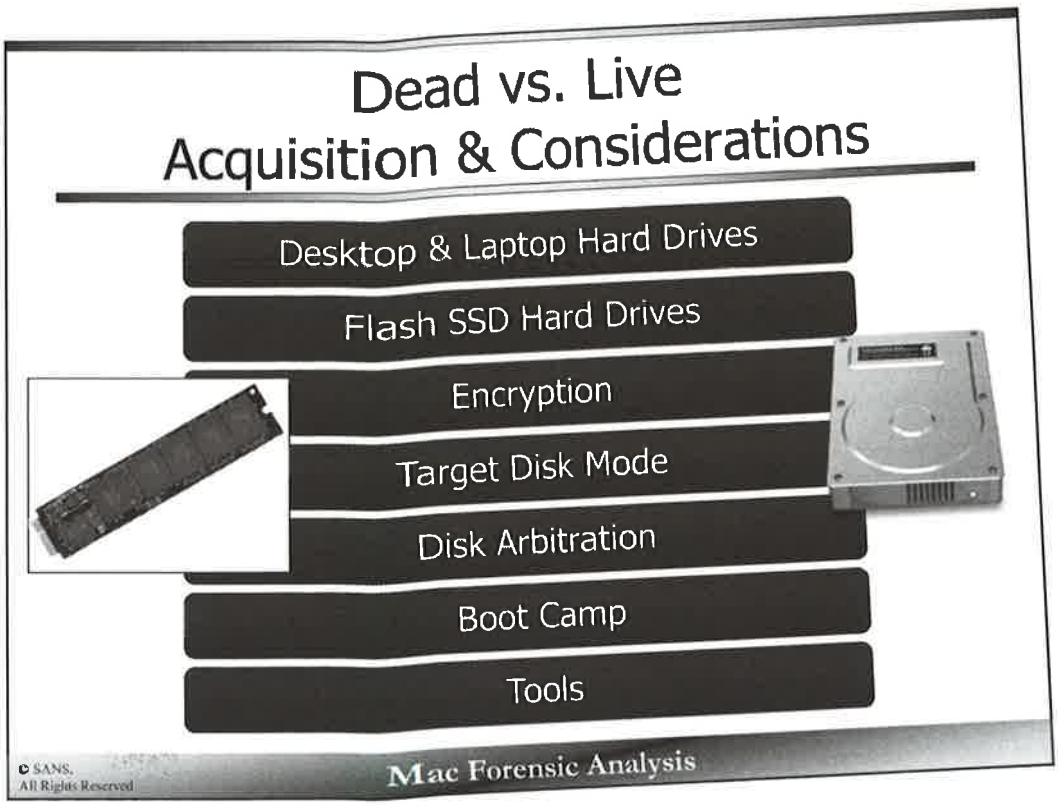


Many of the same tools used for other systems can be used to acquire a Mac. If necessary and physically possible, the hard drives can be removed for acquisition, the author recommends using the website http://www.ifixit.com/ for hard drive removal instructions. Some Macs are known to be harder to extract the hard drive from than others.

The MacBook Air has introduced solid-state/flash hard drives to a wide variety of users. Most models do not use the "regular" 1.8" or 2.5" Solid-state Drive (SSD) hard drive; rather they use a bank of flash chips on a board with a non-standard interface. As of this writing, Old World Computing makes an external enclosure for the MacBook Air SSD drives that will allow use of standard interfaces. Search for "OWC Mercury On-The-Go USB External Enclosure Solution for MacBook Air" (http://eshop.macsales.com/item/OWC/SSDAPOTGU3/)

Encryption can make dead-drive acquisition difficult with Legacy FileVault and FileVault 2 encryption. Legacy FileVault encrypts the user's home directory, while FileVault2 implements full disk encryption. This does not make acquisition impossible, you may image the drive, but you better hope you can get the password! If a system is using FileVault and is up and running – it is best to image unencrypted while you can.

Target Disk Mode (TDM) is used to acquire a Mac hard drive (primary drive only) while still in its original machine. This allows the computer to be seen by an analysis system as an external FireWire/Thunderbolt drive. Some systems, including older MacBook Airs do not have FireWire or Thunderbolt ports, therefore TDM is not possible. When a hard drive has a Boot Camp partition, you will see two volumes – one OS X the other for Windows. If a hard drive has been encrypted using FileVault2, this volume will need to be unlocked. This is described in detail in Section 4. Booting the target system with the "T" key held down can access this mode.

It is worth noting that older systems may have an Open Firmware password may be set, there are a few methods can may be used (with varying levels of success):

- Change the amount of RAM in the system and reboot.
- Press Command+Option+P+R to clear the PRAM.

You may enter the Open Firmware terminal by using Command+Option+O+F key sequence.

On newer systems, if the EFI Firmware password is set you will need to obtain a specific key hash and send to Apple (subpeonas@apple.com). Instructions can be found here: http://www.cnet.com/news/efi-firmware-protection-locks-down-newer-macs/).

Disk arbitration is the process that automatically mounts disks. When acquiring disks using a Mac be aware if Disk Arbitration is enabled or not, you may automatically mount an evidential disk (which makes writes to it). This can be turned on/off using the `launchctl` commands (these commands are not persistent after a reboot):

Enable (Enabled by default):

```
sudo launchctl load
/System/Library/LaunchDaemons/com.apple.diskarbitrationd.plist
```

Disable:

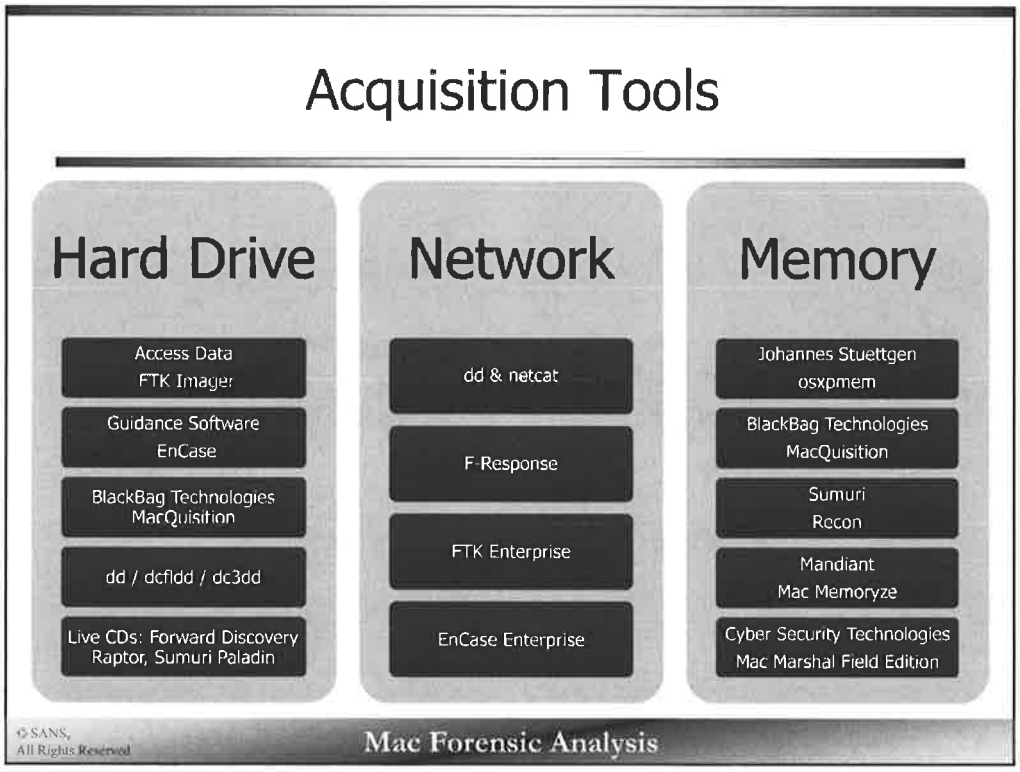
```
sudo launchctl unload
/System/Library/LaunchDaemons/com.apple.diskarbitrationd.plist
```

To determine if disk arbitration is running run the following command to search for the `diskarbitrationd` process (should be under the `root` user context):

```
ps auxw | grep diskarbitrationd
```

Boot Camp is used to create two bootable partitions, one for OS X and one for Windows. While in Target Disk Mode, if the Mac has a Boot Camp partition (a Windows installation on a separate partition) it should be noted that this may be automatically mounted on a Windows acquisition system. It is also possible to triple-boot (Linux!) Mac systems using third-party tools, the most notable is rEFIt (http://refit.sourceforge.net/).

SSD picture from iFixit.com [www.ifixit.com/Teardown/MacBook+Air+11-Inch+Late+2010+Teardown].



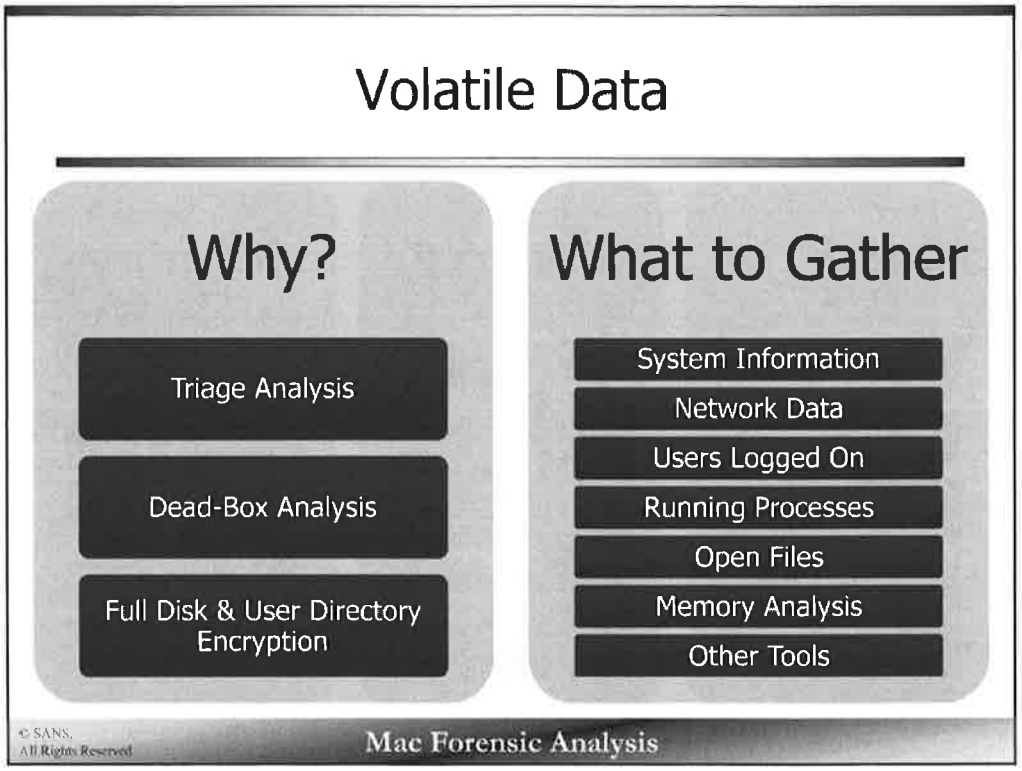
Many of the same acquisition tools can be used on hard drives. Hard drives are hard drives – them same tools you use for Windows-based imaging can be used for Mac systems.

Live acquisition should be used if you need to acquire volatile data or a drive that has implemented encryption. Many of the same tools used for dead-drive acquisition have live response functions as well.

It may be necessary to acquire a system over the network; whether for enterprise or simple distance issues. There are tools that range from a simple over-the-network implementation of `dd` and `netcat` or full-blown enterprise suites.

Memory acquisition may be needed for investigations that are highly dependent on volatile data such as network investigations.

The tools listed are not the only tools available, there are many options at various price points on the market, it is up to you and/or your organization to find the right product for your needs.



Volatile data may be necessary to gather in many types of investigations.

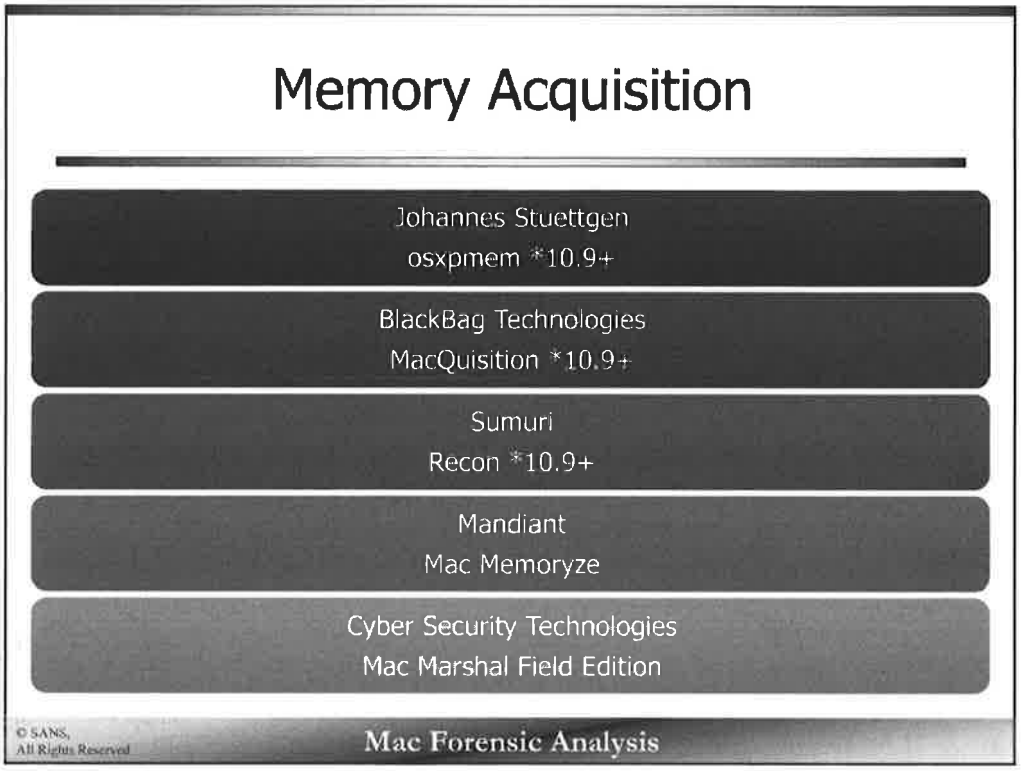
A quick triage may be needed to verify certain data points of a system such as the IP address, a running process, or if a specific file is open.

A dead-box analysis may be incomplete without volatile data, the investigation may need information such as running processes or network data to get a full picture of the system.

If a system is completely inaccessible due to encryption, gathering volatile data may be able to make these types of cases successful. With any luck, a memory image may contain a plaintext password!

Collection of volatile information may help an investigator:

- Decrypt an encrypted volume
- Pin-point a connection to a malicious IP address or a server containing lewd material
- Determine a malicious running process
- Determine what files and documents were open at the time of acquisition
- Determine who was logged onto the system at the time of acquisition

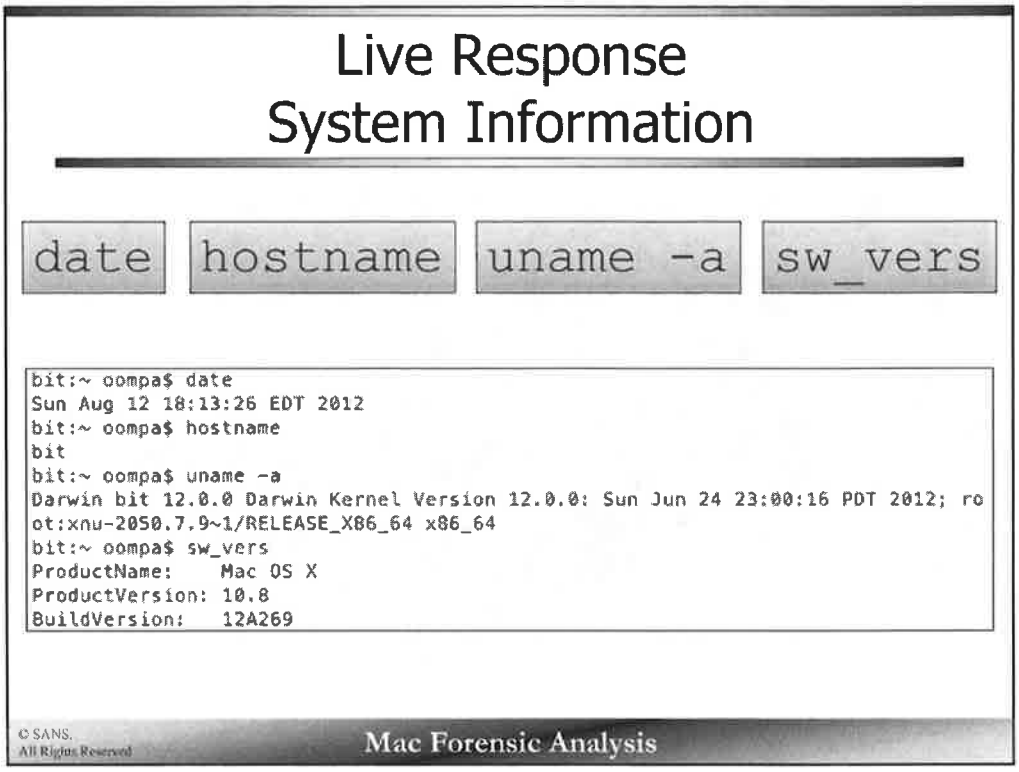


We will go more in-depth into Mac memory acquisition and analysis in Section 4. The tools listed above are some of the recommended tools to acquire Mac memory.

Each tool has their own limitations and benefits, it is up to the user to determine which tool is best for their current situation. For example, MacQuisition and Recon are part of an applications that acquires volatile data, hard drives, and memory. Mac Marshal is a Mac triage/analysis utility that is available for purchase. Mac Memoryze and osxpmem are free and/or open source but do not acquire additional volatile data or hard drive images.

Note: Each tool requires administrative system privileges to run.

*10.9 changes things up a bit, introducing compress memory. As of this writing OSXPMem, MacQuisition, and Recon are the only tools capable of acquiring memory from systems running 10.9+.



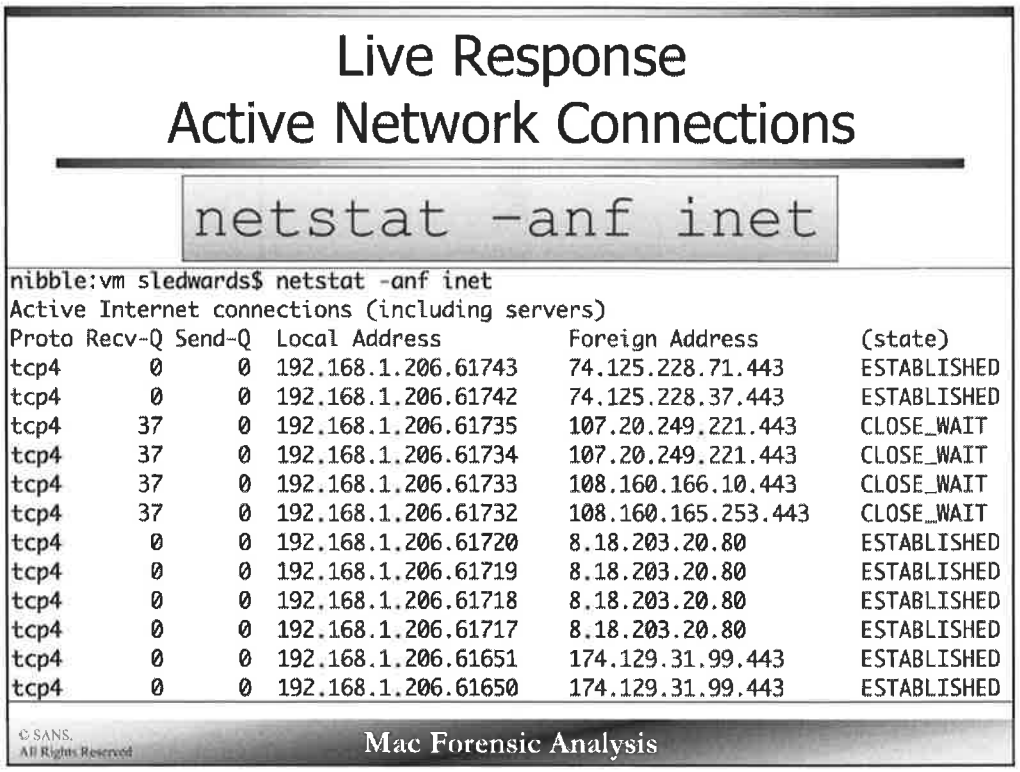
These four commands will give you the basic information about the system.

`date` - The local time of the system.
`hostname` - The hostname of the system.
`uname -a` - Prints the OS name, network node name, system architecture/release/name/version information. (the `-a` parameter displays all the information available for this command)
`sw_vers` – Prints the OS X version and build information.

Many similar commands in other systems do not necessarily work by default on the Mac. The Mac may use a completely different command to perform the same action, or it may just implement different option flags. Getting to know the commands and using man pages will help you understand the command line intricacies of the Mac.

More information about mapping the Darwin Kernel versions can be found here:
http://en.wikipedia.org/wiki/Darwin_(operating_system)

```
bit:~ oompa$ date
Sun Aug 12 18:13:26 EDT 2012
bit:~ oompa$ hostname
bit
bit:~ oompa$ uname -a
Darwin bit 12.0.0 Darwin Kernel Version 12.0.0: Sun Jun 24 23:00:16 PDT 2012; ro
ot:xnu-2050.7.9~1/RELEASE_X86_64 x86_64
bit:~ oompa$ sw_vers
ProductName:    Mac OS X
ProductVersion: 10.8
BuildVersion:   12A269
```



Was the system connected to a lewd server or a malicious IP address? The `netstat -an` command lists active network connections, these can be used to determine what connections the system has.

The `-a` parameter shows the stat of all network sockets.

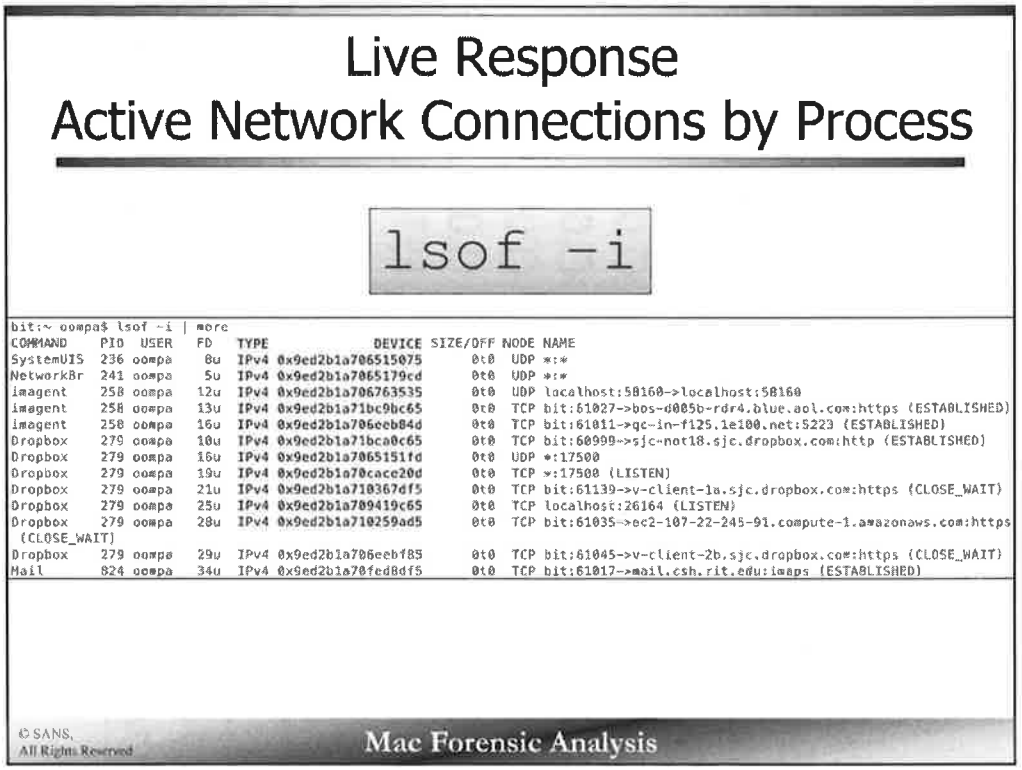
The `-n` parameter shows network addresses as numbers (rather than host and domain names).

The `-f` parameter limits the amount of data shown to only IPv4 and IPv6 network sockets, this does not include UNIX sockets.

The output fields:

- Protocol (TCP or UDP)
- Received Queue (bytes)
- Send Queue (bytes)
- Local IP Address and Port
- Foreign (Remote) IP Address and Port
- State of the Connection

```
nibble:vm sledwards$ netstat -anf inet
Active Internet connections (including servers)
Proto Recv-Q Send-Q  Local Address          Foreign Address        (state)
tcp4       0      0  192.168.1.206.61743    74.125.228.71.443      ESTABLISHED
tcp4       0      0  192.168.1.206.61742    74.125.228.37.443      ESTABLISHED
tcp4      37      0  192.168.1.206.61735    107.20.249.221.443     CLOSE_WAIT
tcp4      37      0  192.168.1.206.61734    107.20.249.221.443     CLOSE_WAIT
tcp4      37      0  192.168.1.206.61733    108.160.166.10.443     CLOSE_WAIT
tcp4      37      0  192.168.1.206.61732    108.160.165.253.443    CLOSE_WAIT
tcp4       0      0  192.168.1.206.61720    8.18.203.20.80         ESTABLISHED
tcp4       0      0  192.168.1.206.61719    8.18.203.20.80         ESTABLISHED
tcp4       0      0  192.168.1.206.61718    8.18.203.20.80         ESTABLISHED
tcp4       0      0  192.168.1.206.61717    8.18.203.20.80         ESTABLISHED
tcp4       0      0  192.168.1.206.61651    174.129.31.99.443      ESTABLISHED
tcp4       0      0  192.168.1.206.61650    174.129.31.99.443      ESTABLISHED
```



The The `lsof -i` command lists Internet and network connections by process. We can see in the screenshot the Dropbox and Mail applications had active connections.

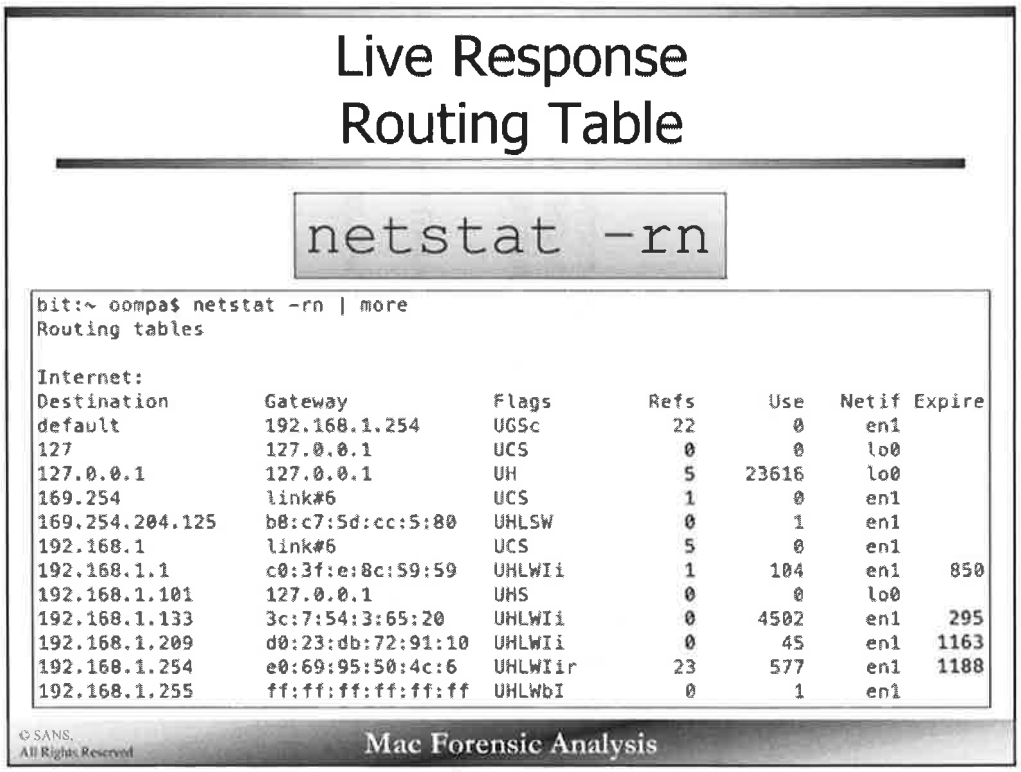
The output fields:

- Process Name
- Process ID
- User Account
- File Descriptor (See man page for details)
- Type (IPv4, IPv6)
- Device (See man page for details)
- Size/Offset (See man page for details)
- Node (TCP or UDP)
- Connection Information & Status (See man page for details)

Other flags that could be of use are the following:

- `-n` – Show IP addresses instead of network names.
- `-P` – Show port numbers versus names.
- `-l` – Show numeric user IDs versus account names.

```
bit:~ oompa$ lsof -i | more
COMMAND    PID  USER   FD   TYPE             DEVICE SIZE/OFF NODE NAME
SystemUIS  236 oompa    8u  IPv4 0x9ed2b1a706515075      0t0  UDP *:*
NetworkBr  241 oompa    5u  IPv4 0x9ed2b1a7065179cd      0t0  UDP *:*
imagent    258 oompa   12u  IPv4 0x9ed2b1a706763535      0t0  UDP localhost:58160->localhost:58160
imagent    258 oompa   13u  IPv4 0x9ed2b1a71bc9bc65      0t0  TCP bit:61027->bos-d005b-rdr4.blue.aol.com:https (ESTABLISHED)
imagent    258 oompa   16u  IPv4 0x9ed2b1a706eeb84d      0t0  TCP bit:61011->qc-in-f125.1e100.net:5223 (ESTABLISHED)
Dropbox    279 oompa   10u  IPv4 0x9ed2b1a71bca0c65      0t0  TCP bit:60999->sjc-not18.sjc.dropbox.com:http (ESTABLISHED)
Dropbox    279 oompa   16u  IPv4 0x9ed2b1a7065151fd      0t0  UDP *:17500
Dropbox    279 oompa   19u  IPv4 0x9ed2b1a70cace20d      0t0  TCP *:17500 (LISTEN)
Dropbox    279 oompa   21u  IPv4 0x9ed2b1a710367df5      0t0  TCP bit:61139->v-client-1a.sjc.dropbox.com:https (CLOSE_WAIT)
Dropbox    279 oompa   25u  IPv4 0x9ed2b1a709419c65      0t0  TCP localhost:26164 (LISTEN)
Dropbox    279 oompa   28u  IPv4 0x9ed2b1a710259ad5      0t0  TCP bit:61035->ec2-107-22-245-91.compute-1.amazonaws.com:https
 (CLOSE_WAIT)
Dropbox    279 oompa   29u  IPv4 0x9ed2b1a706eebf85      0t0  TCP bit:61045->v-client-2b.sjc.dropbox.com:https (CLOSE_WAIT)
Mail       824 oompa   34u  IPv4 0x9ed2b1a70fed8df5      0t0  TCP bit:61017->mail.csh.rit.edu:imaps (ESTABLISHED)
```



Was this system connected to a specific server recently? The `netstat -rn` command prints the routing table. The routing table can be used to determine recent network connections or static routes.

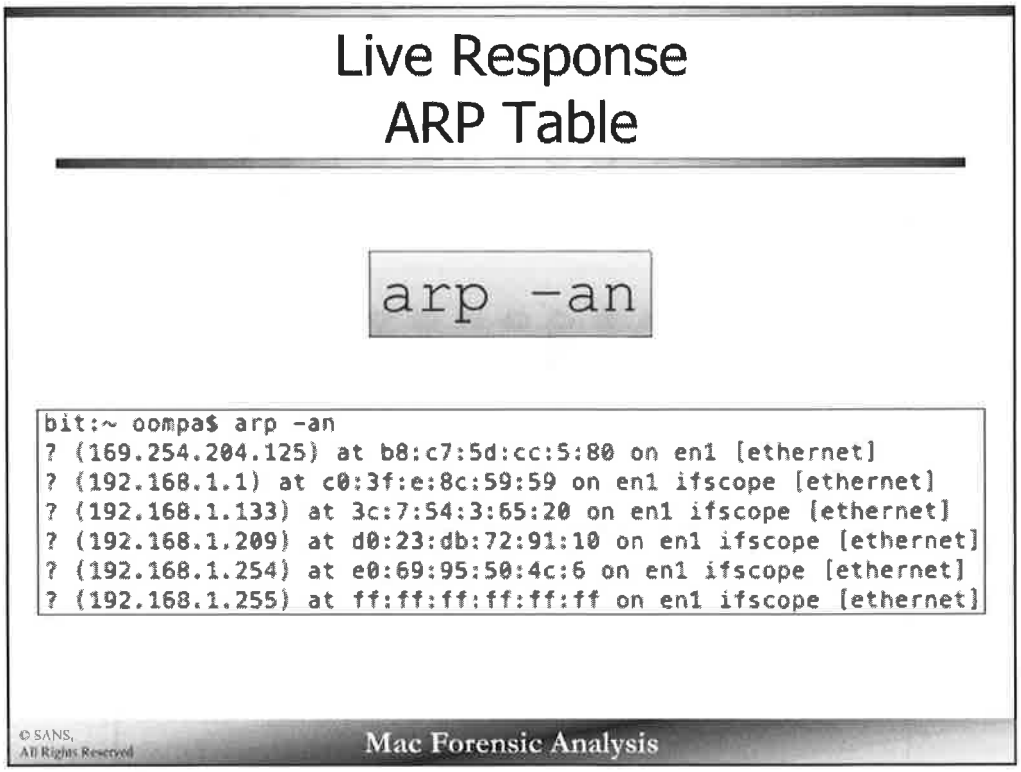
The `-r` parameter shows the routing table.

The `-n` parameter shows network addresses as numbers (rather than host and domain names).

Note: Leading 0's in MAC addresses may not show in output.

```
bit:~ oompa$ netstat -rn | more
Routing tables

Internet:
Destination        Gateway            Flags        Refs      Use   Netif Expire
default            192.168.1.254      UGSc           22        0     en1
127                127.0.0.1          UCS             0        0     lo0
127.0.0.1          127.0.0.1          UH              5    23616     lo0
169.254            link#6             UCS             1        0     en1
169.254.204.125    b8:c7:5d:cc:5:80   UHLSW           0        1     en1
192.168.1          link#6             UCS             5        0     en1
192.168.1.1        c0:3f:e:8c:59:59   UHLWIi          1      104     en1    850
192.168.1.101      127.0.0.1          UHS             0        0     lo0
192.168.1.133      3c:7:54:3:65:20    UHLWIi          0     4502     en1    295
192.168.1.209      d0:23:db:72:91:10  UHLWIi          0       45     en1   1163
192.168.1.254      e0:69:95:50:4c:6   UHLWIir        23      577     en1   1188
192.168.1.255      ff:ff:ff:ff:ff:ff  UHLWbI          0        1     en1
```



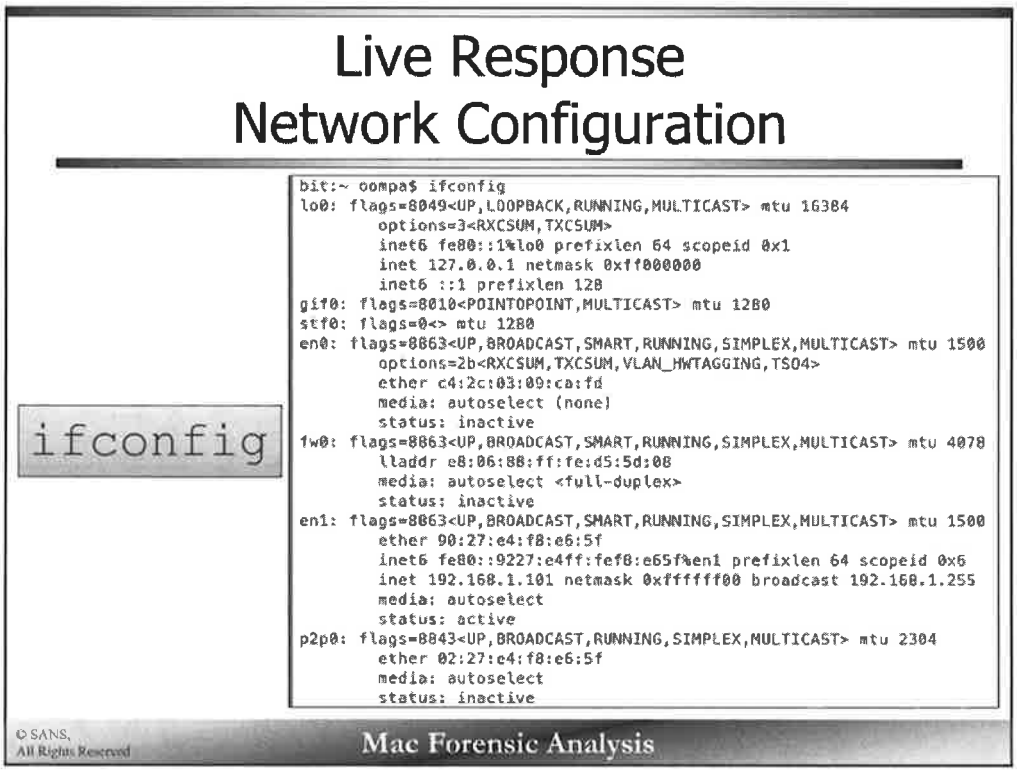
Does the target have a NAS hiding in a closet somewhere?

The `arp -an` command prints the Address Resolution Protocol (ARP) table. ARP table shows the IP address to MAC address resolution used for systems on the local network. They may aid in identifying other systems to pursue.

The `-a` parameter shows the stat of all network sockets.

The `-n` parameter shows network addresses as numbers (rather than host and domain names).

Note: Leading 0's in MAC addresses may not show in output.



The `ifconfig` command prints the network configuration of the system.

In the screenshot we can see this system as multiple network interfaces. The active interface, `en1` has an IP address of `192.168.1.101`. We can also see the various MAC addresses for each interface, this may be helpful if network logs were captured.

Network Interfaces:

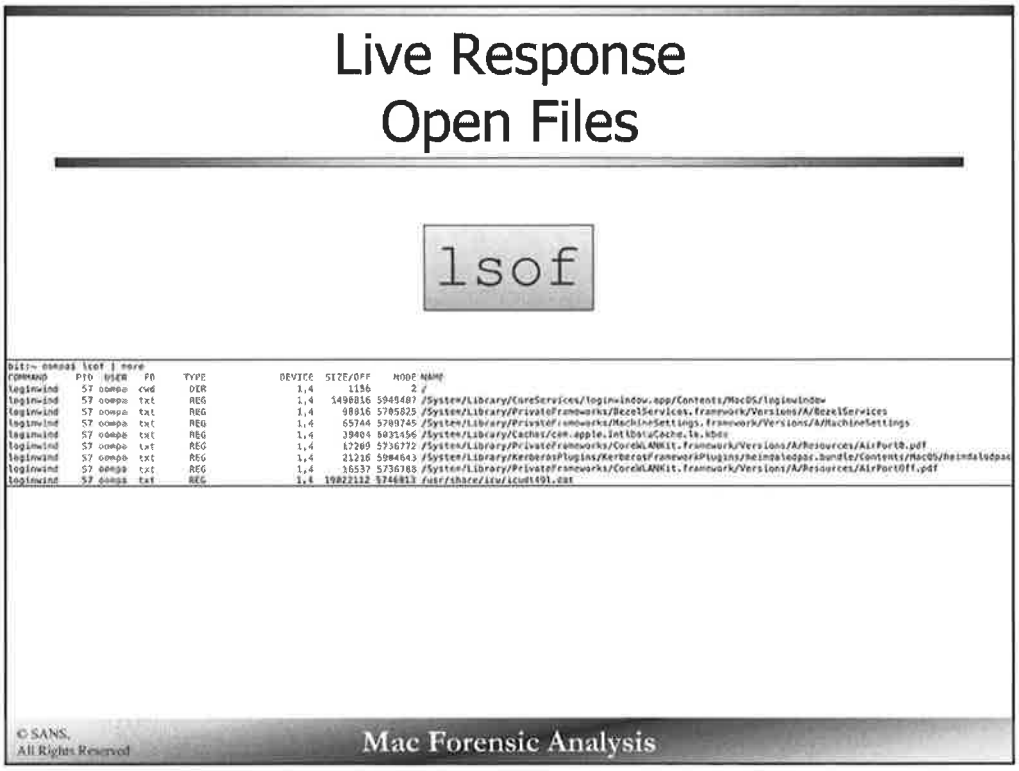
- `lo#` - Loopback
- `gif#` - Generic Tunnel
- `stf#` - IPv6 to IPv4 Tunnel
- `en#` - Ethernet or Wireless – These are likely the most important to an investigator.
- `fw#` - FireWire
- `p2p#` - Point-to-Point

More information about the wireless interface can be done by using the airport command. This utility is located in a directory that is not in the default user's path therefore it should be run as follows. This command can supply the station name, its MAC address, and its authentication status. (i.e., WPA2, WEP).

```
/System/Library/PrivateFrameworks/Apple80211.framework/Versions/Current/Resources/airport -I
```

The `ifconfig -v` command will produce an additional output starting with "`type: *`" that contains the type of connection the interface is implementing (i.e.: Wi-Fi, Ethernet, etc.).

```
bit:~ oompa$ ifconfig
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST> mtu 16384
        options=3<RXCSUM,TXCSUM>
        inet6 fe80::1%lo0 prefixlen 64 scopeid 0x1
        inet 127.0.0.1 netmask 0xff000000
        inet6 ::1 prefixlen 128
gif0: flags=8010<POINTOPOINT,MULTICAST> mtu 1280
stf0: flags=0<> mtu 1280
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        options=2b<RXCSUM,TXCSUM,VLAN_HWTAGGING,TSO4>
        ether c4:2c:03:09:ca:fd
        media: autoselect (none)
        status: inactive
fw0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 4078
        lladdr e8:06:88:ff:fe:d5:5d:08
        media: autoselect <full-duplex>
        status: inactive
en1: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        ether 90:27:e4:f8:e6:5f
        inet6 fe80::9227:e4ff:fef8:e65f%en1 prefixlen 64 scopeid 0x6
        inet 192.168.1.101 netmask 0xffffff00 broadcast 192.168.1.255
        media: autoselect
        status: active
p2p0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 2304
        ether 02:27:e4:f8:e6:5f
        media: autoselect
        status: inactive
```

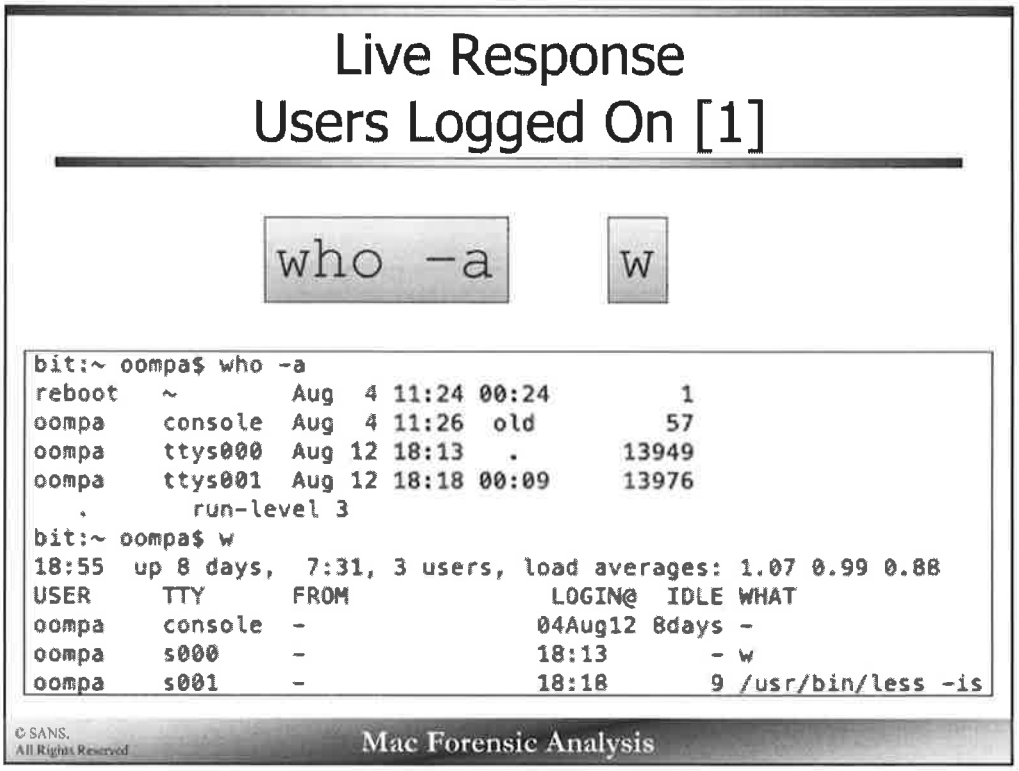


The `lsof` command prints the open files (and network connections) by the process that is using them. We can see what data files and documents the users' processes has open per application.

It includes the process ID, username, and filename.

For example, keyloggers may have an open file handle to the keylog file they are writing keystrokes to. Using the `lsof` command if we are able to identify a rogue keylogger process we may be able to identify the keylog file.

```
bit:~ oompa$ lsof | more
COMMAND     PID  USER   FD   TYPE             DEVICE  SIZE/OFF    NODE NAME
loginwind    57 oompa  cwd    DIR                1,4      1156       2 /
loginwind    57 oompa  txt    REG                1,4   1490816 5949467 /System/Library/CoreServices/loginwindow.app/Contents/MacOS/loginwindow
loginwind    57 oompa  txt    REG                1,4     98816 5705825 /System/Library/PrivateFrameworks/BezelServices.framework/Versions/A/BezelServices
loginwind    57 oompa  txt    REG                1,4     65744 5709745 /System/Library/PrivateFrameworks/MachineSettings.framework/Versions/A/MachineSettings
loginwind    57 oompa  txt    REG                1,4     39404 6031456 /System/Library/Caches/com.apple.IntlDataCache.le.kbdx
loginwind    57 oompa  txt    REG                1,4     17289 5736772 /System/Library/PrivateFrameworks/CoreWLANKit.framework/Versions/A/Resources/AirPort0.pdf
loginwind    57 oompa  txt    REG                1,4     21216 5904643 /System/Library/KerberosPlugins/KerberosFrameworkPlugins/heimdalodpac.bundle/Contents/MacOS/heimdalodpac
loginwind    57 oompa  txt    REG                1,4     16537 5736788 /System/Library/PrivateFrameworks/CoreWLANKit.framework/Versions/A/Resources/AirPortOff.pdf
loginwind    57 oompa  txt    REG                1,4  19022112 5746813 /usr/share/icu/icudt49l.dat
```



The `who -a` command displays the following:

- Time of last system boot
- Logged in users
- Type of Logon
  - `console` - Login via GUI
  - `ttys*` - Login via Terminal
- User Login Time
- User Idle Time
- Associated Process ID

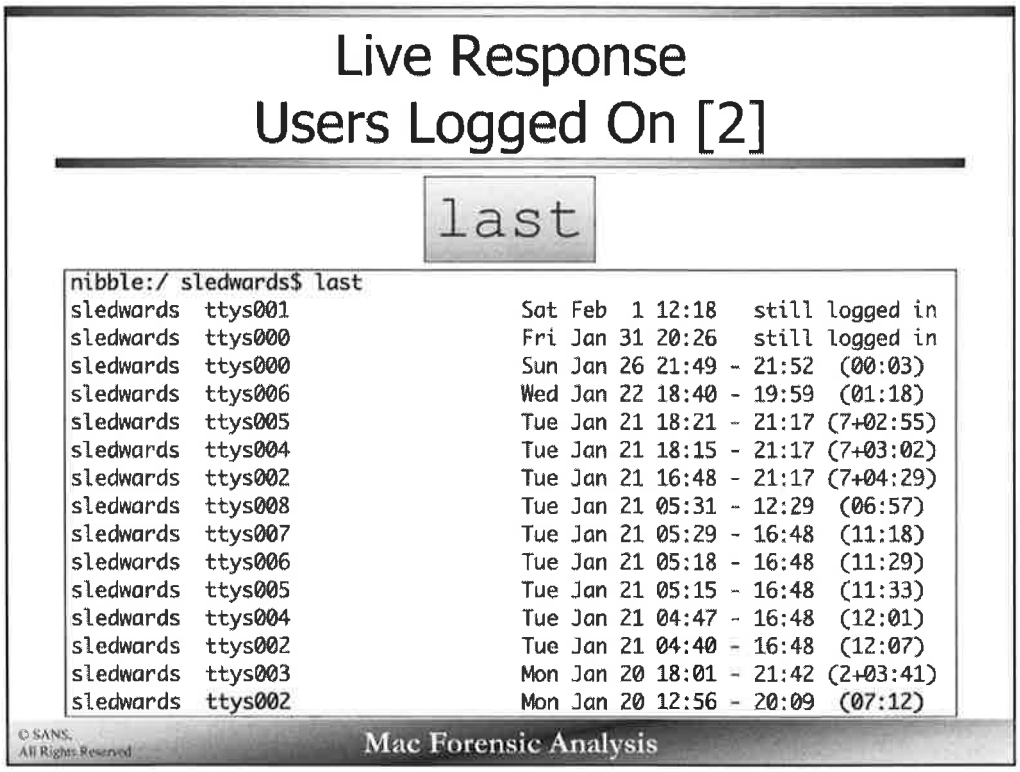
The `w` command has much of the same information as `who -a`, however it also contains:

- Local System Time
- System Uptime
- Number of Users
- Remote Login System Information
- Current Activity of the Logon Process

The '`oompa`' user in the screenshot has one login process open (through the normal login screen) and two Terminal sessions open. Each Terminal session/window is a separate login process.

You may also want to identify the currently logged in user, try these commands:

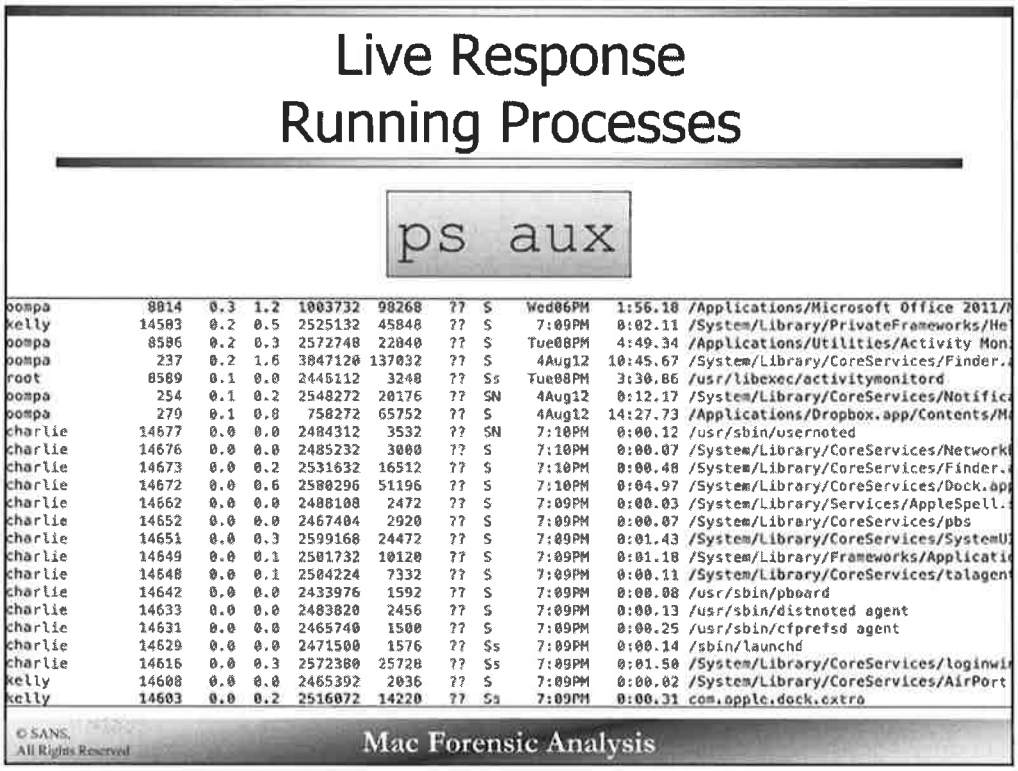
- `who am i` – Show the currently logged in username, console number, and login process timestamp.
- `whoami` – Show the username of currently logged in user.
- `id` – Show the "User Identity" of the current user, including user ID (UID) and group (GID) affiliations.



The `last` command lists the last logins of the system by user, terminal session, date, a hostname (if applicable), and session length.

The timestamp shown gives the duration of the login process. For example, "`7+02:55`" means the user has had this login process open for one week (7 days), 2 hours, and 55 minutes.

The end of the `last` command output contains the timestamp when the "`wtmp`" logging has started. For example, "`wtmp begins Mon Jul 7 10:08 `".



The `ps aux` command outputs the process status. The output contains information such as (see the man page for more detail):

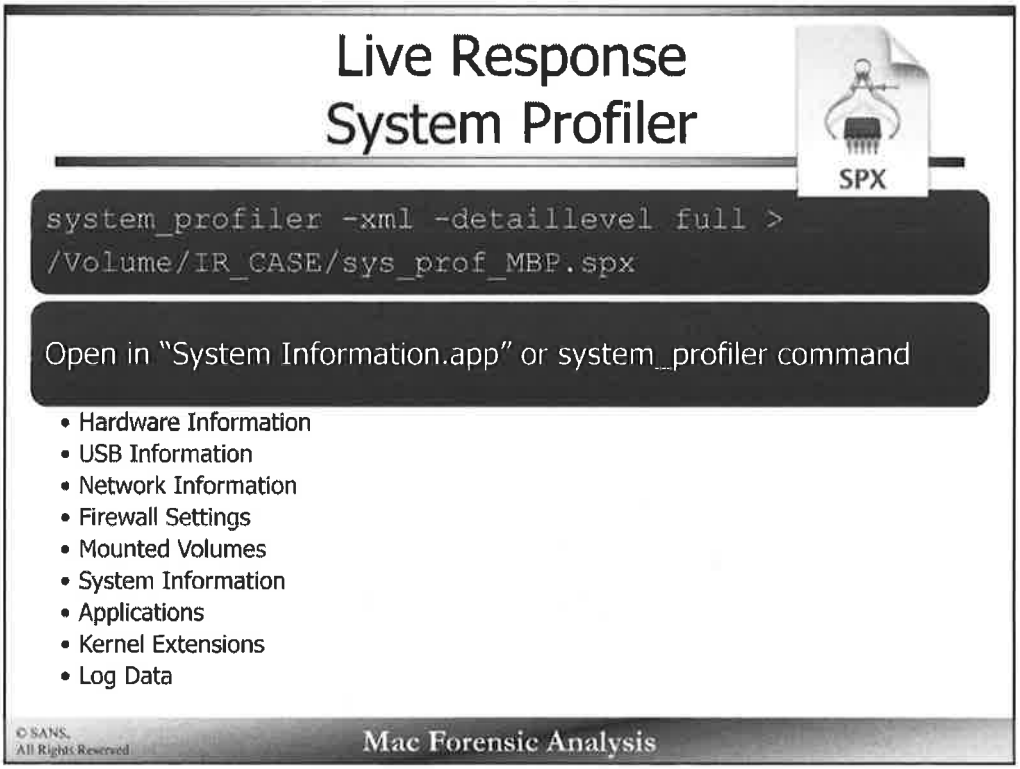
- User Account
- Process ID
- Percentage of CPU and RAM
- Process Start Date and Time
- Issued Command

Note the lack of the '-' in the command. Unlike other systems, putting this dash in the command will be unsuccessful. This is a good example of how OS X commands may different than other UNIX-like systems.

You may want experiment with other command arguments such as the following:

- `-ww` – Use this flag to display all the information, otherwise it defaults to screen width.
- `-ef` – Display more information including parent process IDs.

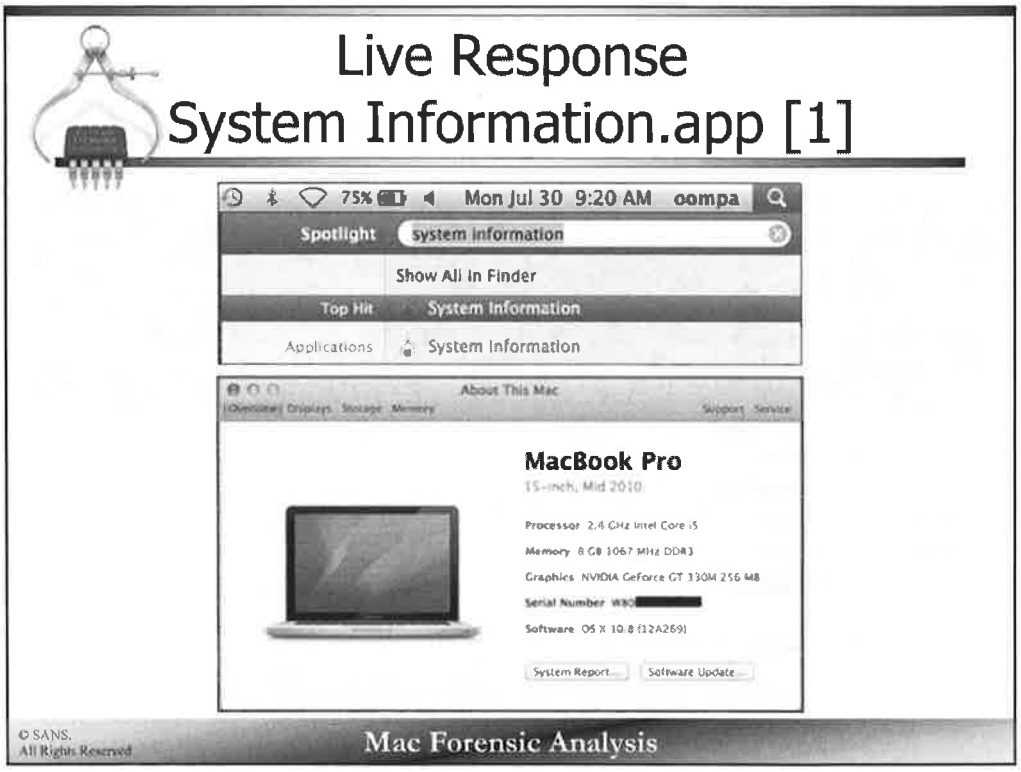
```
oompa      8814   0.3  1.2  1003732  98268  ??  S     Wed06PM   1:56.18 /Applications/Microsoft Office 2011/M
kelly     14583   0.2  0.5  2525132  45848  ??  S      7:09PM   0:02.11 /System/Library/PrivateFrameworks/Hel
oompa      8586   0.2  0.3  2572748  22840  ??  S     Tue08PM   4:49.34 /Applications/Utilities/Activity Moni
oompa       237   0.2  1.6  3847120 137032  ??  S      4Aug12  10:45.67 /System/Library/CoreServices/Finder.a
root       8589   0.1  0.0  2445112   3248  ??  Ss    Tue08PM   3:30.86 /usr/libexec/activitymonitord
oompa       254   0.1  0.2  2548272  20176  ??  SN     4Aug12   0:12.17 /System/Library/CoreServices/Notifica
oompa       279   0.1  0.8   758272  65752  ??  S      4Aug12  14:27.73 /Applications/Dropbox.app/Contents/Ma
charlie   14677   0.0  0.0  2484312   3532  ??  SN     7:10PM   0:00.12 /usr/sbin/usernoted
charlie   14676   0.0  0.0  2485232   3000  ??  S      7:10PM   0:00.07 /System/Library/CoreServices/NetworkB
charlie   14673   0.0  0.2  2531632  16512  ??  S      7:10PM   0:00.48 /System/Library/CoreServices/Finder.a
charlie   14672   0.0  0.6  2580296  51196  ??  S      7:10PM   0:04.97 /System/Library/CoreServices/Dock.app
charlie   14662   0.0  0.0  2488108   2472  ??  S      7:09PM   0:00.03 /System/Library/Services/AppleSpell.s
charlie   14652   0.0  0.0  2467404   2920  ??  S      7:09PM   0:00.07 /System/Library/CoreServices/pbs
charlie   14651   0.0  0.3  2599168  24472  ??  S      7:09PM   0:01.43 /System/Library/CoreServices/SystemUI
charlie   14649   0.0  0.1  2501732  10120  ??  S      7:09PM   0:01.18 /System/Library/Frameworks/Applicatio
charlie   14648   0.0  0.1  2504224   7332  ??  S      7:09PM   0:00.11 /System/Library/CoreServices/talagent
charlie   14642   0.0  0.0  2433976   1592  ??  S      7:09PM   0:00.08 /usr/sbin/pboard
charlie   14633   0.0  0.0  2483820   2456  ??  S      7:09PM   0:00.13 /usr/sbin/distnoted agent
charlie   14631   0.0  0.0  2465740   1500  ??  S      7:09PM   0:00.25 /usr/sbin/cfprefsd agent
charlie   14629   0.0  0.0  2471500   1576  ??  Ss     7:09PM   0:00.14 /sbin/launchd
charlie   14616   0.0  0.3  2572380  25728  ??  Ss     7:09PM   0:01.50 /System/Library/CoreServices/loginwin
kelly     14608   0.0  0.0  2465392   2036  ??  S      7:09PM   0:00.02 /System/Library/CoreServices/AirPort
kelly     14603   0.0  0.2  2516072  14220  ??  Ss     7:09PM   0:00.31 com.apple.dock.extra
```



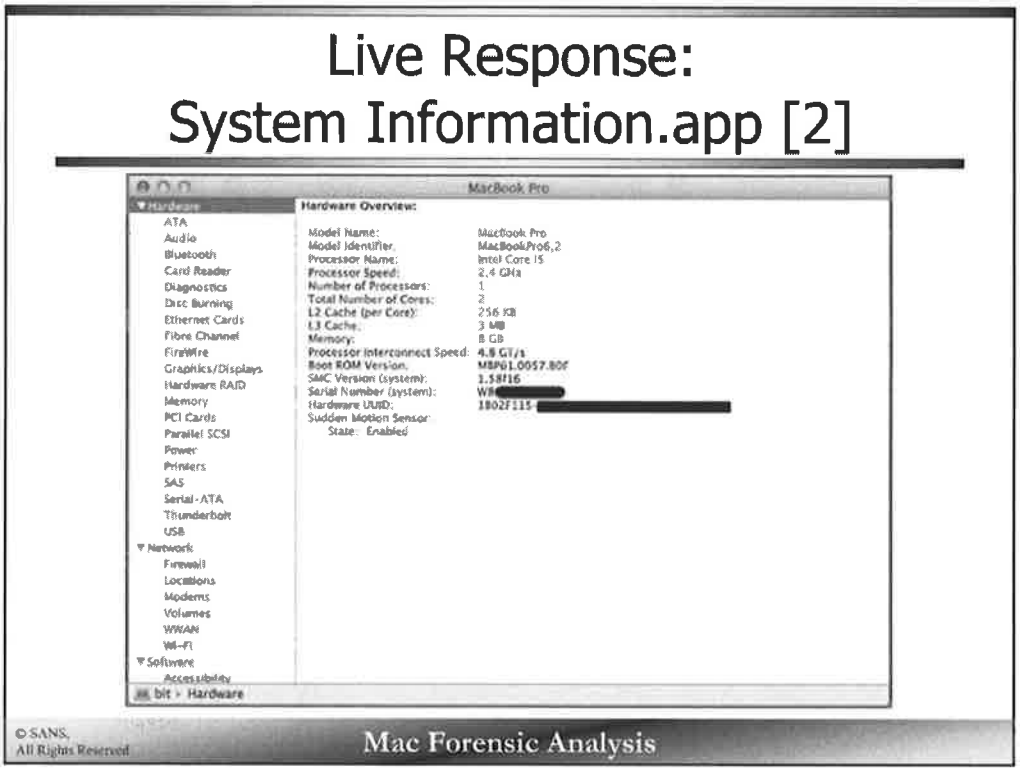
The `system_profiler` command is the command-line version of the System Information application.

The `system_profiler` command has different output formats and detail level options. As long as the output is named with a "`.spx`" file extension, the data can be viewed in the System Information.app. The XML output option can be used with the `System Information.app` located in `/Applications/Utilities/`. The output levels can be set as '`mini`', '`basic`', and '`full`' or by the specific data type that can be accessed by the command:

```
system_profiler -listDataTypes
Available Datatypes:
SPParallelATADataType
SPUniversalAccessDataType
SPApplicationsDataType
SPAudioDataType
SPBluetoothDataType
SPCardReaderDataType
SPComponentDataType
SPDeveloperToolsDataType
SPDiagnosticsDataType
SPDiscBurningDataType
SPEthernetDataType
SPExtensionsDataType
SPFibreChannelDataType
SPFireWireDataType
SPFirewallDataType
SPFontsDataType
SPFrameworksDataType
SPDisplaysDataType
SPHardwareDataType
...
```



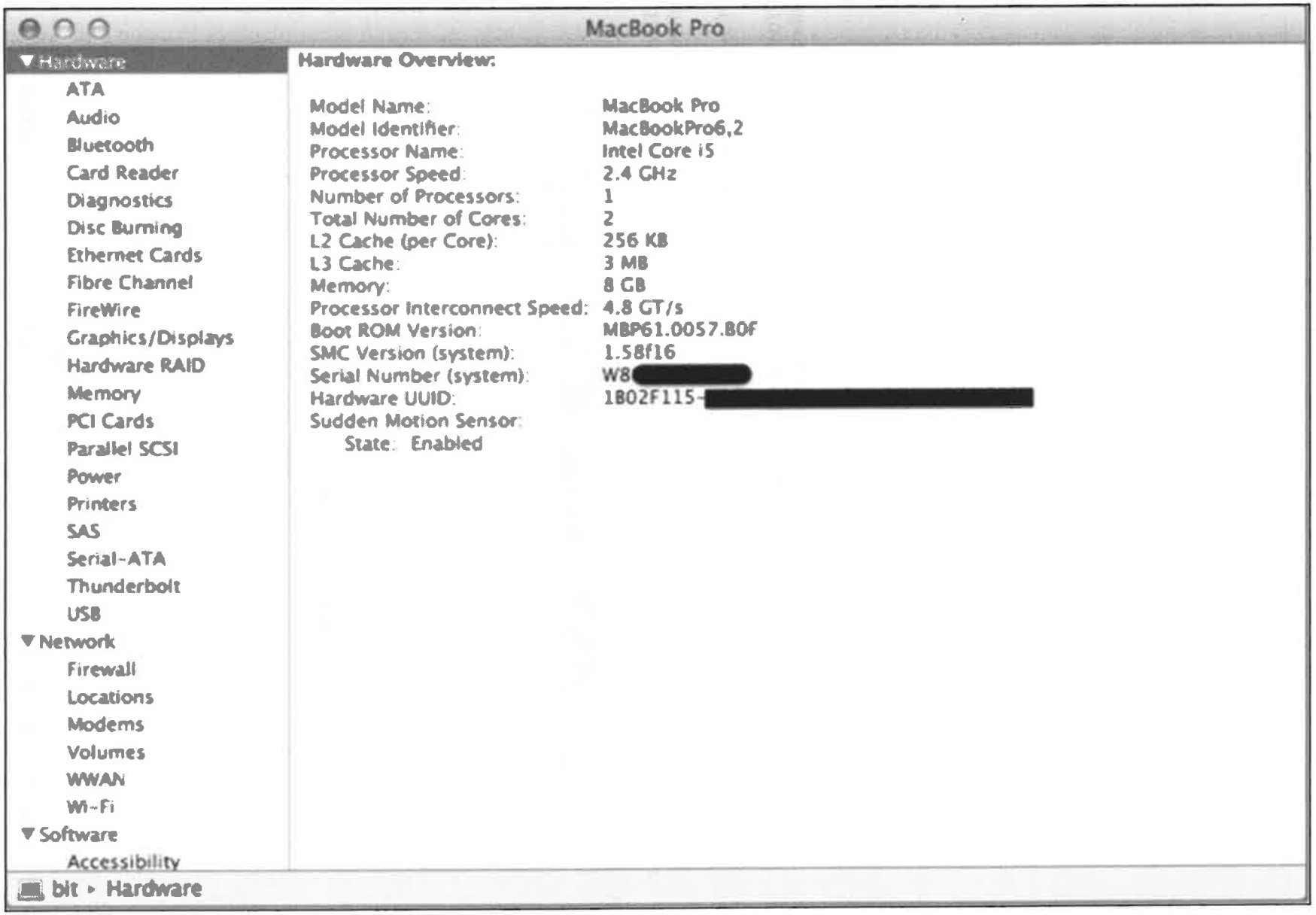
These screen shots show how to access the System Information.app application from the Spotlight menu or from the "About This Mac" menu available by selecting the Apple logo in the top left corner of the screen and selecting "System Report".

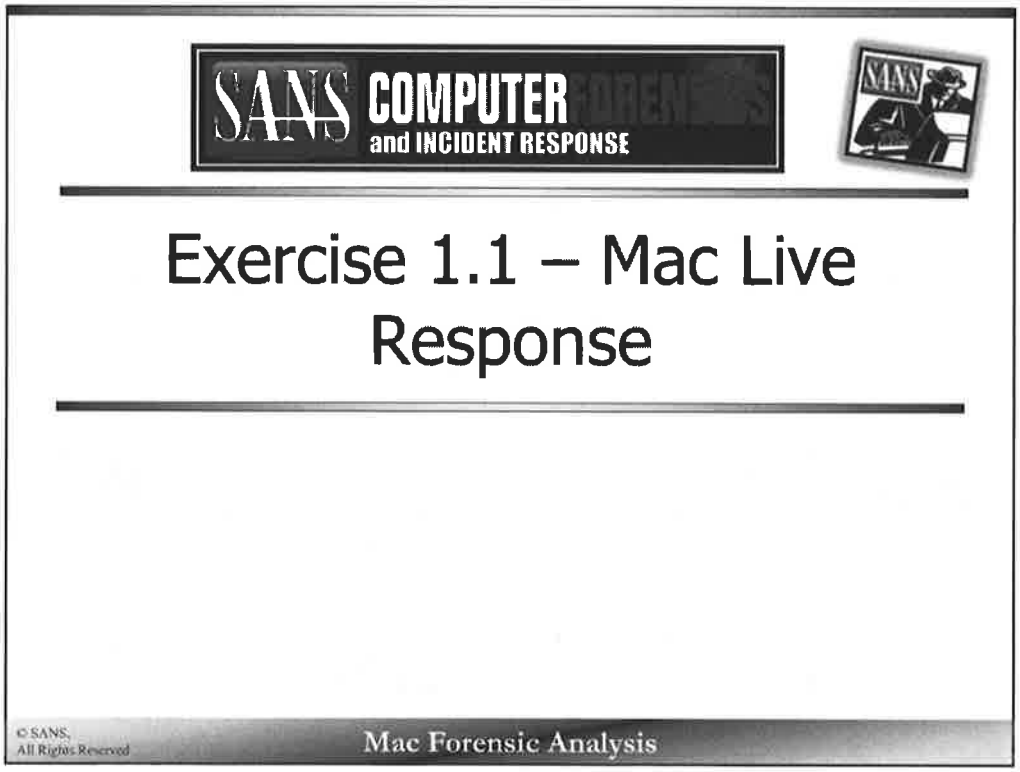


This screen shot shows the types of data available from the `System Information.app` application or from the `system_profiler` command.

This tool is native to OS X.

You may also open the System Information.app application and choose File | Save to save this information directly from the GUI rather than on the command line.


MacBook Pro
Hardware
ATA
Audio
Bluetooth
Card Reader
Diagnostics
Disc Burning
Ethernet Cards
Fibre Channel
FireWire
Graphics/Displays
Hardware RAID
Memory
PCI Cards
Parallel SCSI
Power
Printers
SAS
Serial-ATA
Thunderbolt
USB
Network
Firewall
Locations
Modems
Volumes
WWAN
Wi-Fi
Software
Accessibility
bit ▸ Hardware
Hardware Overview:
Model Name: MacBook Pro
Model Identifier: MacBookPro6,2
Processor Name: Intel Core i5
Processor Speed: 2.4 GHz
Number of Processors: 1
Total Number of Cores: 2
L2 Cache (per Core): 256 KB
L3 Cache: 3 MB
Memory: 8 GB
Processor Interconnect Speed: 4.8 GT/s
Boot ROM Version: MBP61.0057.B0f
SMC Version (system): 1.58f16
Serial Number (system): W8[redacted]
Hardware UUID: 1B02F115-[redacted]
Sudden Motion Sensor:
State: Enabled



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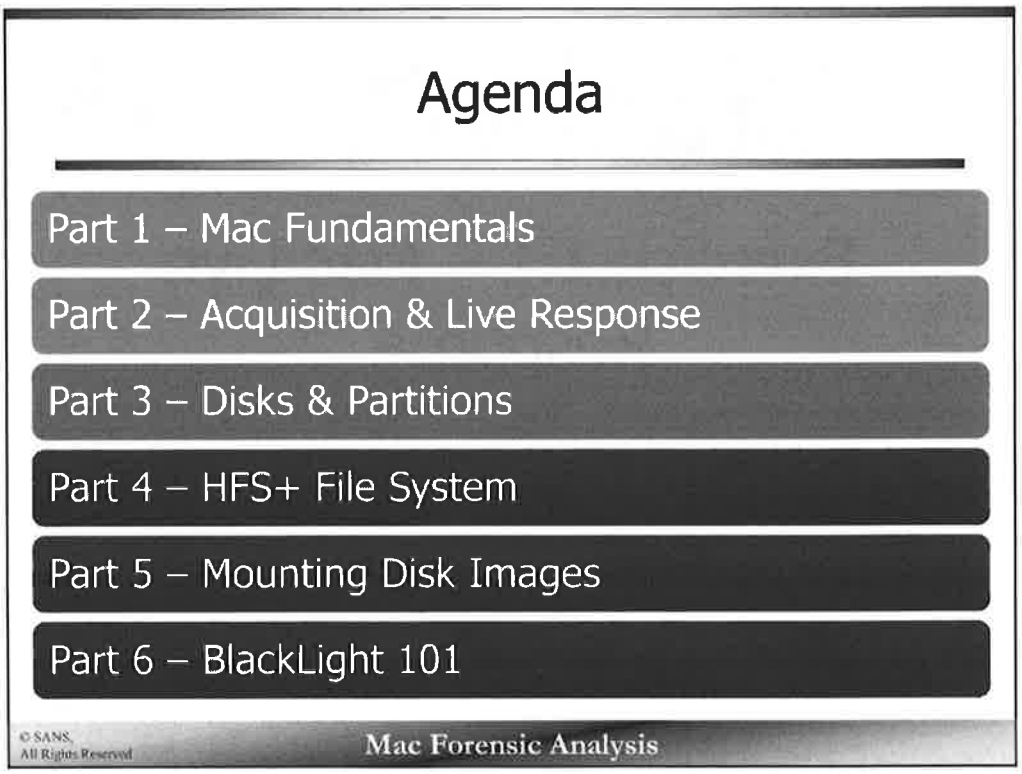

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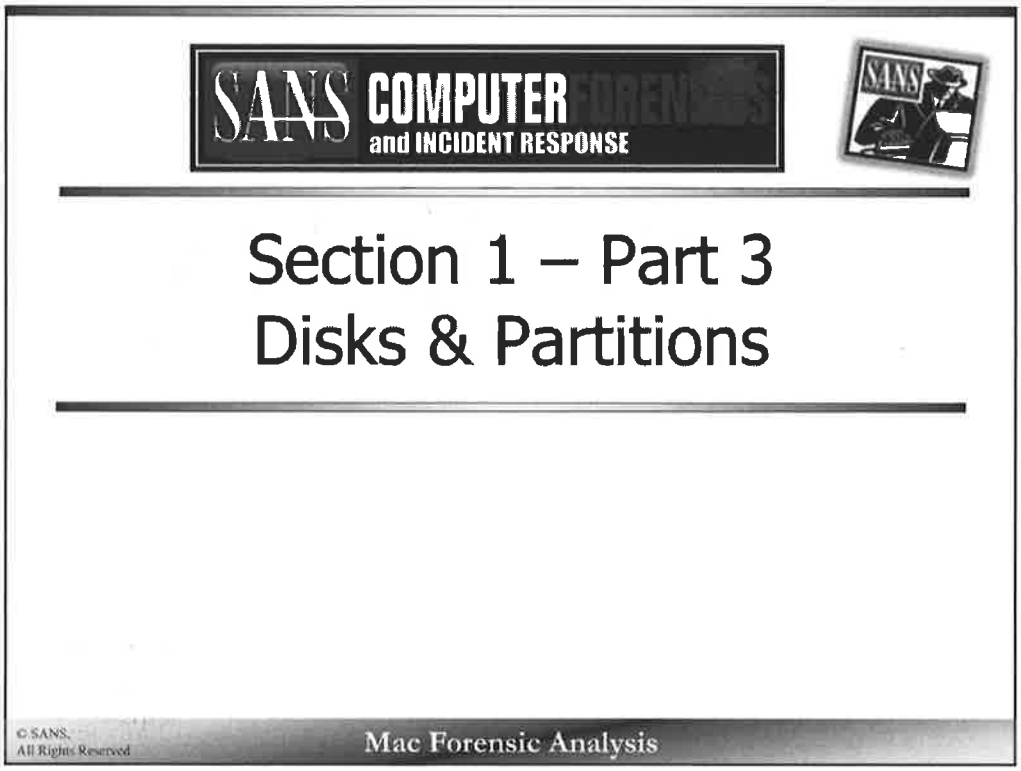

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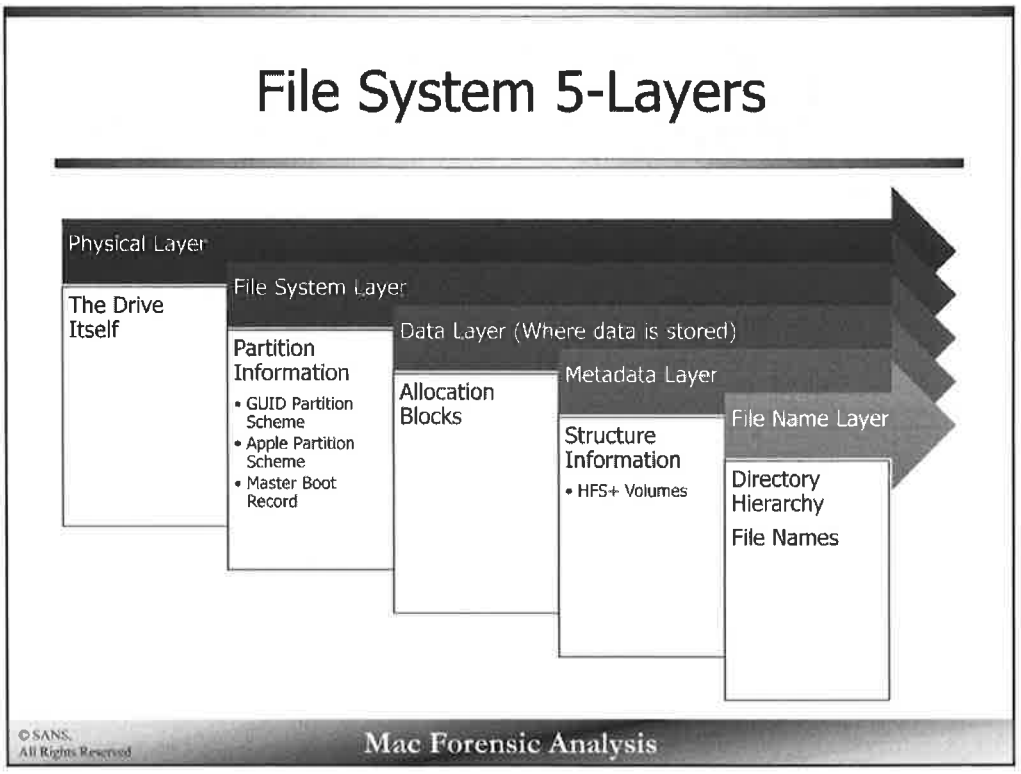


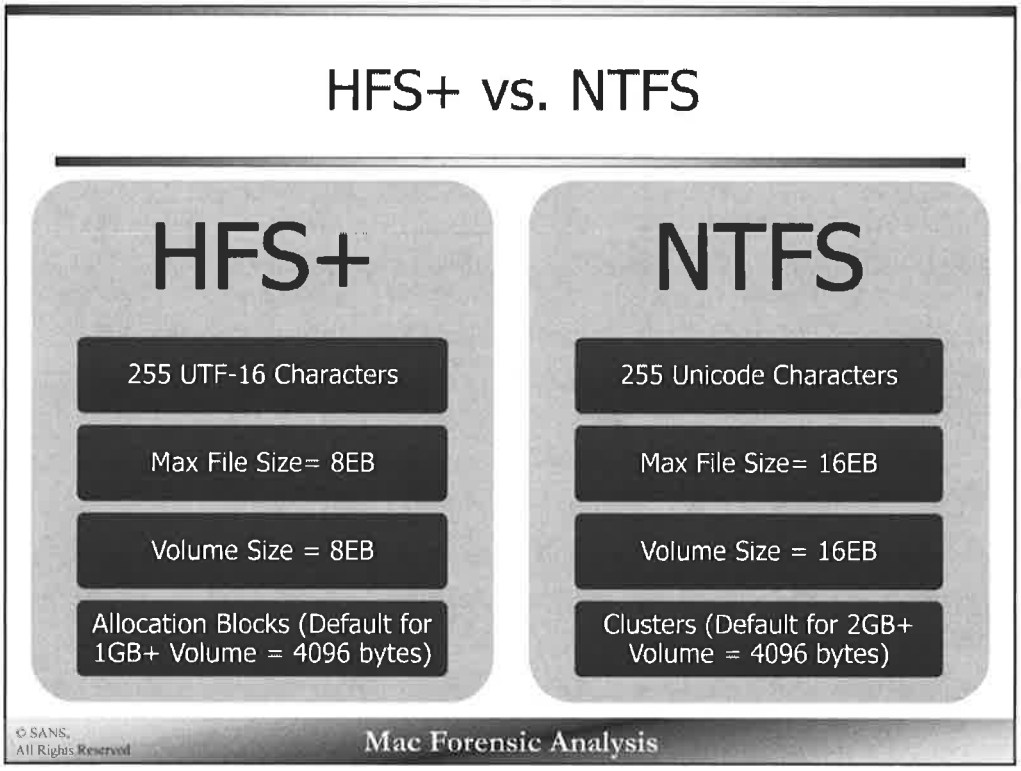
A file system is comprised of five layers; physical, file system, data, metadata, and file name. These will be discussed in this section in detail.

The physical and file system layers contain non-specific file system information such as the hardware and partitioning scheme. These will be discussed first to give a basis for the file system data that is presented on top of these structures.

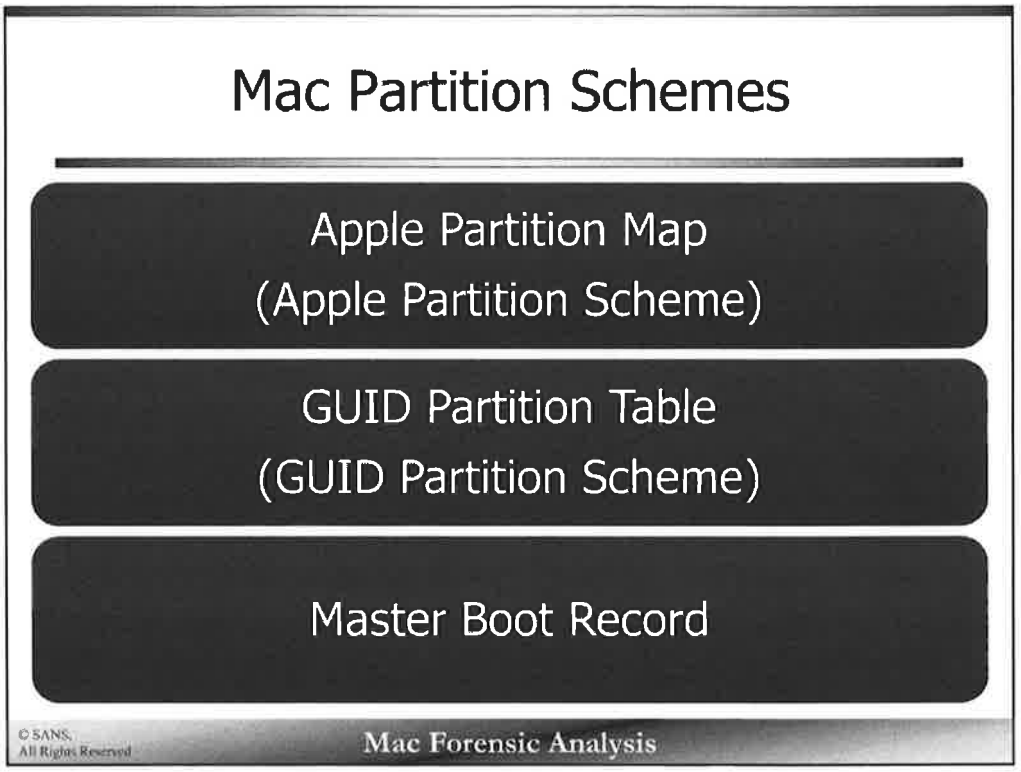
The primary partitioning schemes found on Mac systems are the Globally Unique Identifier (GUID) Partition Scheme, Apple Partition Scheme and the Master Boot Record partitions.

The Allocation blocks used in the Data Layer are analogous to "Clusters" used in NTFS file systems.

The data, metadata, and file name layers contain the majority of the data that is presented and reviewed by forensic analysts. This will be discussed in greater detail in the following section.



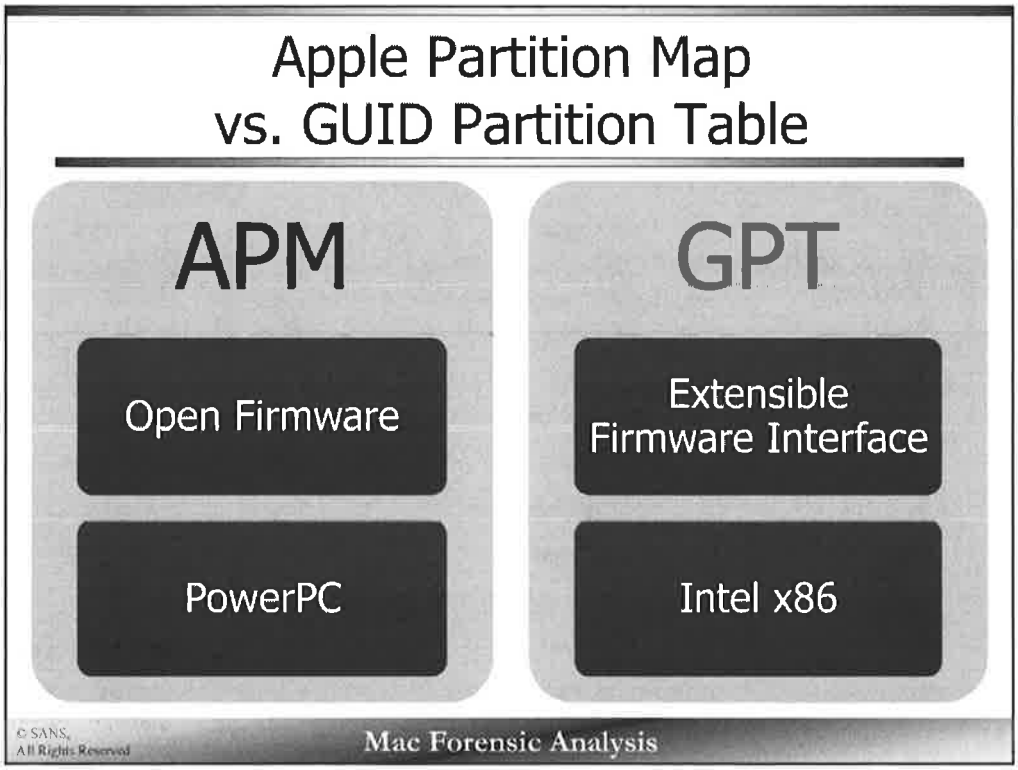
The primary file system used on Mac systems is the Hierarchical File System Plus (HFS+). Compared with New Technology File System (NTFS), it has a smaller maximum file and volume size, but similar in allocation block/cluster size.



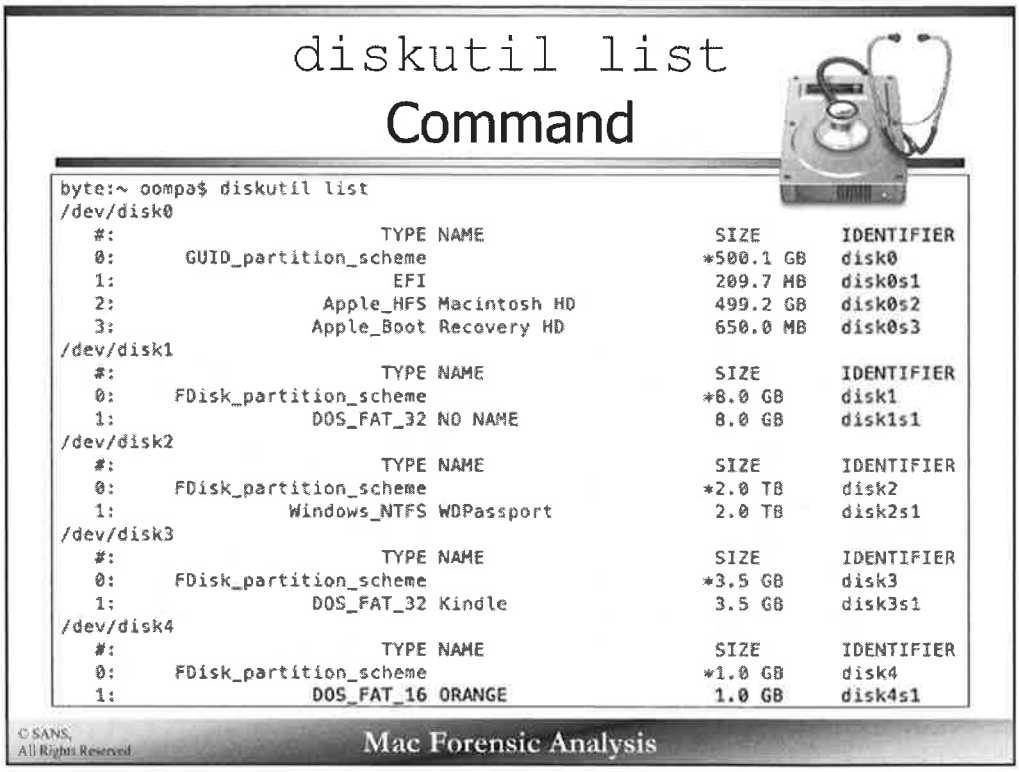
Mac systems primarily use three types of partition schemes for different purposes.

A default installation of Mac OS X will partition the drive using the GUID Partition Scheme, creating an EFI partition and a protective MBR.

Disk image files (`.dmg`), can use the GUID Partition Scheme, the Apple Partition Scheme, a Master Boot Record, or no partition at all depending on what the user wants to do with the disk image.



Mac OS X installations on PowerPC hardware will have a Apple Partition Map and use Open Firmware, while Intel x86 based systems will implement GUID Partition Table with the Extensible Firmware Interface.



To view the disk partitions on the drives associated with a specific Mac you can issue the `diskutil list` command.

The output of the command shown in the screenshot above shows a variety of disk partition types.

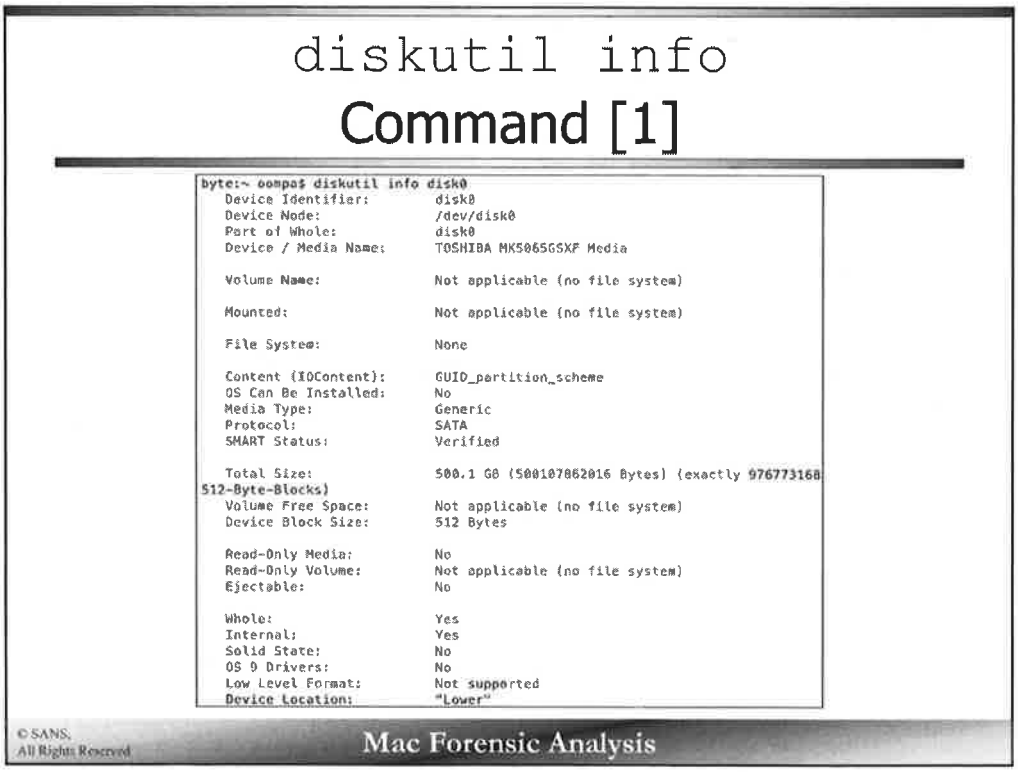
- `/dev/disk0` contains the Mac OS X operating system. This disk uses the GUID Partition Scheme (shown as `GUID_partition_scheme`). Note the EFI partition.
- `/dev/disk1` is an external drive named "`NO NAME`" that uses an Master Boot Record (shown as `FDisk_partition_scheme`) as it is formatted as FAT32.
- `/dev/disk2` is another external drive named "`WDPassport`" that is formatted with NTFS and also uses the MBR.
- `/dev/disk3` is a `Kindle` device that uses the MBR with a FAT32 file system.
- `/dev/disk4` is another external USB named "`ORANGE`" drive that uses the MBR, however it is formatted with FAT16.

The output above also shows the number of partitions each disk contains, with the size and disk identifier.

This disk identifier is formatted in the format `disk#s#` where the first number is the disk number and the second is the partition or "slice". This will be used later to reference a specific partition on a drive.

The same information can be found using the `Disk Utility.app` application located in `/Applications/Utilities/`.

```
byte:~ oompa$ diskutil list
/dev/disk0
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:      GUID_partition_scheme                        *500.1 GB   disk0
   1:                        EFI                         209.7 MB   disk0s1
   2:                  Apple_HFS Macintosh HD            499.2 GB   disk0s2
   3:                 Apple_Boot Recovery HD             650.0 MB   disk0s3
/dev/disk1
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:     FDisk_partition_scheme                        *8.0 GB     disk1
   1:                 DOS_FAT_32 NO NAME                 8.0 GB     disk1s1
/dev/disk2
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:     FDisk_partition_scheme                        *2.0 TB     disk2
   1:               Windows_NTFS WDPassport             2.0 TB     disk2s1
/dev/disk3
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:     FDisk_partition_scheme                        *3.5 GB     disk3
   1:                 DOS_FAT_32 Kindle                  3.5 GB     disk3s1
/dev/disk4
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:     FDisk_partition_scheme                        *1.0 GB     disk4
   1:                 DOS_FAT_16 ORANGE                  1.0 GB     disk4s1
```

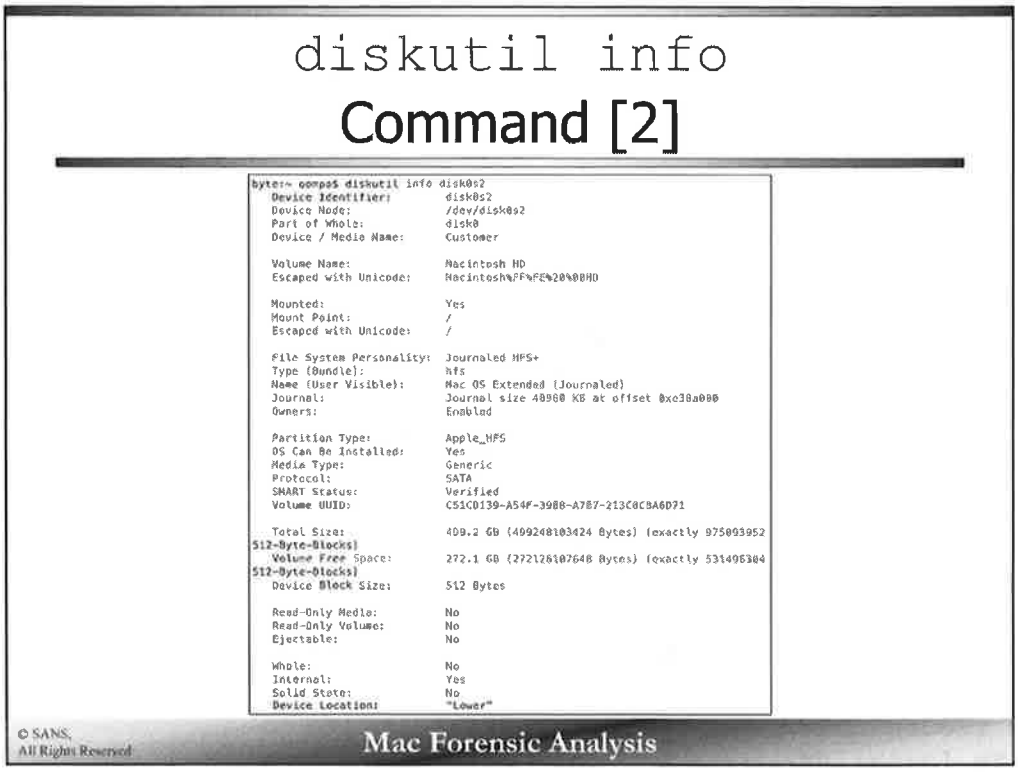


The `diskutil info` command is used on a specific disk or partition to display additional information about the disk or partition.

In the screenshot above `disk0` was used. The output shows various information such as:

- Make/Model of the hardware (Toshiba MK5065GSXF)
- The drive interface (SATA)
- Drive size in bytes and blocks
- Block Size
- Read-Only
- Location, useful for systems with multiple internal disks such as Mac Pro systems.

```
byte:~ oompa$ diskutil info disk0
   Device Identifier:         disk0
   Device Node:               /dev/disk0
   Part of Whole:             disk0
   Device / Media Name:       TOSHIBA MK5065GSXF Media

   Volume Name:               Not applicable (no file system)

   Mounted:                   Not applicable (no file system)

   File System:               None

   Content (IOContent):       GUID_partition_scheme
   OS Can Be Installed:       No
   Media Type:                Generic
   Protocol:                  SATA
   SMART Status:              Verified

   Total Size:                500.1 GB (500107862016 Bytes) (exactly 976773168
512-Byte-Blocks)
   Volume Free Space:         Not applicable (no file system)
   Device Block Size:         512 Bytes

   Read-Only Media:           No
   Read-Only Volume:          Not applicable (no file system)
   Ejectable:                 No

   Whole:                     Yes
   Internal:                  Yes
   Solid State:               No
   OS 9 Drivers:              No
   Low Level Format:          Not supported
   Device Location:           "Lower"
```

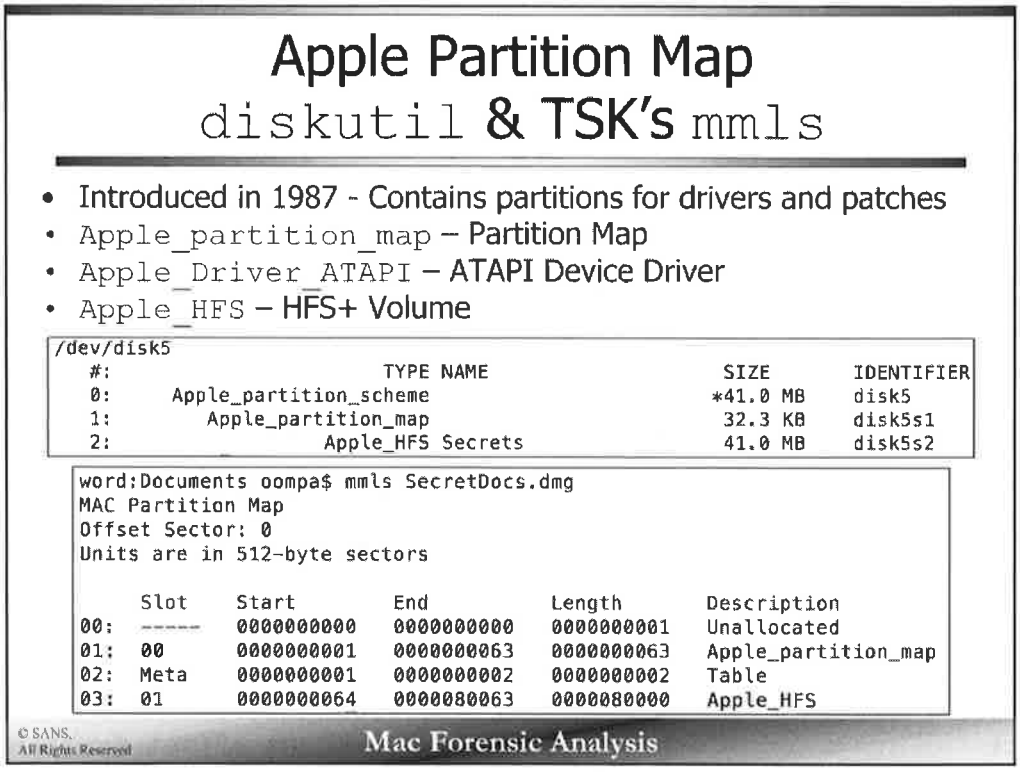


Another example of the `diskutil info` command, used on the partition `disk0s2`.

Additional information is shown about the partition:

- Volume Name (Macintosh HD)
- File System (HFS+, Mac OS Extended)
- Volume Universal Unique Identifier
- Volume Size and Free Space

```
byte:~ oompa$ diskutil info disk0s2
   Device Identifier:         disk0s2
   Device Node:               /dev/disk0s2
   Part of Whole:             disk0
   Device / Media Name:       Customer

   Volume Name:               Macintosh HD
   Escaped with Unicode:      Macintosh%FF%FE%20%00HD

   Mounted:                   Yes
   Mount Point:               /
   Escaped with Unicode:      /

   File System Personality:   Journaled HFS+
   Type (Bundle):             hfs
   Name (User Visible):       Mac OS Extended (Journaled)
   Journal:                   Journal size 40960 KB at offset 0xe38a000
   Owners:                    Enabled

   Partition Type:            Apple_HFS
   OS Can Be Installed:       Yes
   Media Type:                Generic
   Protocol:                  SATA
   SMART Status:              Verified
   Volume UUID:               C51CD139-A54F-3988-A787-213C0CBA6D71

   Total Size:                499.2 GB (499248103424 Bytes) (exactly 975093952
512-Byte-Blocks)
   Volume Free Space:         272.1 GB (272126107648 Bytes) (exactly 531496304
512-Byte-Blocks)
   Device Block Size:         512 Bytes

   Read-Only Media:           No
   Read-Only Volume:          No
   Ejectable:                 No

   Whole:                     No
   Internal:                  Yes
   Solid State:               No
   Device Location:           "Lower"
```



The Apple Partition Map partitioning scheme was introduced in 1987. APM is known to create multiple partitions with various drivers and patches contained in them. This creates partitions with names such as `Apple_Driver_ATAPI` that contains ATAPI drivers or `Apple_FWDriver` that contains FireWire drivers. Many of these partition names have been enumerated on the Wikipedia page for Apple Partition Map.
[http://en.wikipedia.org/wiki/Apple_Partition_Map]

The partition names that you will want to look for should be named `Apple_HFS`. This is the primary partition containing the user and system data. The `Apple_partition_map` partition contains the partition map and is also a partition in and of itself.

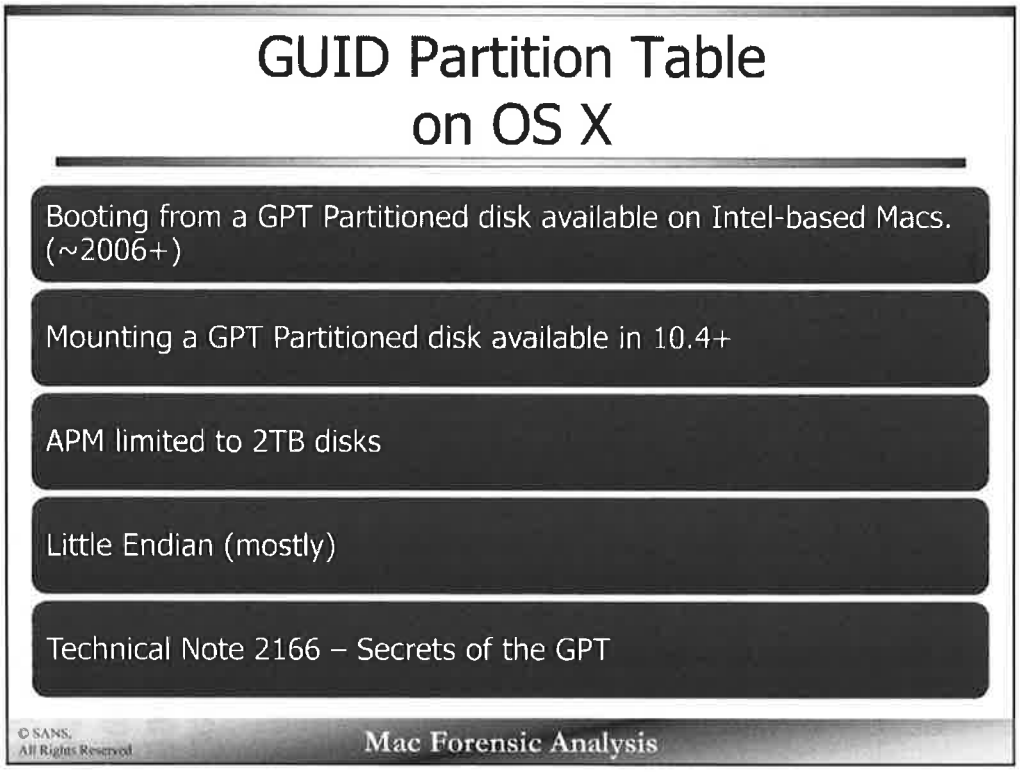
In the screenshot above, the example shown as `disk3` is the partition table located on a Mac OS X installation DVD.

References:
File System Forensic Analysis – Brian Carrier - pp.101-107
Mac OS X Internals - Amit Singh – pp. 1349-1352
TN2166 – Secrets of the GPT
https://developer.apple.com/library/mac/technotes/tn2166/_index.html

```
/dev/disk5
   #:                       TYPE NAME                    SIZE       IDENTIFIER
   0:     Apple_partition_scheme                        *41.0 MB    disk5
   1:        Apple_partition_map                         32.3 KB    disk5s1
   2:                  Apple_HFS Secrets                 41.0 MB    disk5s2
```



```
word:Documents oompa$ mmls SecretDocs.dmg
MAC Partition Map
Offset Sector: 0
Units are in 512-byte sectors

     Slot    Start        End          Length       Description
00:  -----   0000000000   0000000000   0000000001   Unallocated
01:  00      0000000001   0000000063   0000000063   Apple_partition_map
02:  Meta    0000000001   0000000002   0000000002   Table
03:  01      0000000064   0000080063   0000080000   Apple_HFS
```

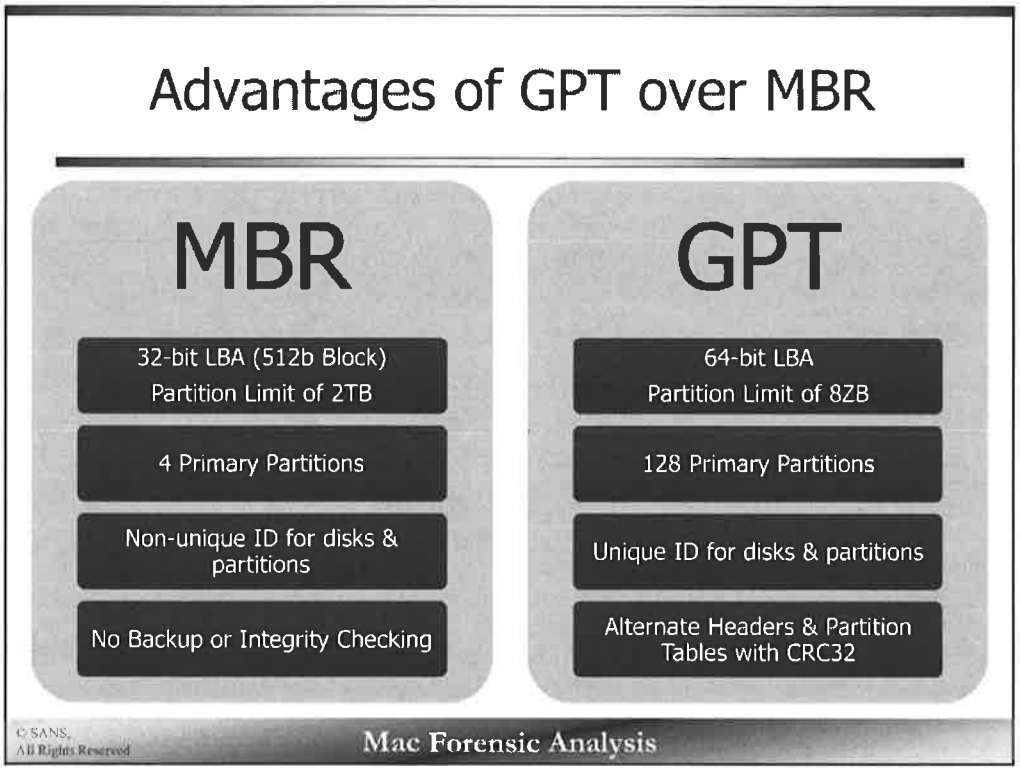


The GUID Partition Table implemented on Intel-based Mac systems started in 2006 with the transition to Intel hardware; however, mounting a GPT partition disk was available in Mac OS X 10.4.

The switch to GPT from APM was due to the limited disk size that APM could not provide for.

Technical Note 2166 provides information pertaining to GPT used on Mac systems.

References:
TN2166 – Secrets of the GPT
https://developer.apple.com/library/mac/technotes/tn2166/_index.html



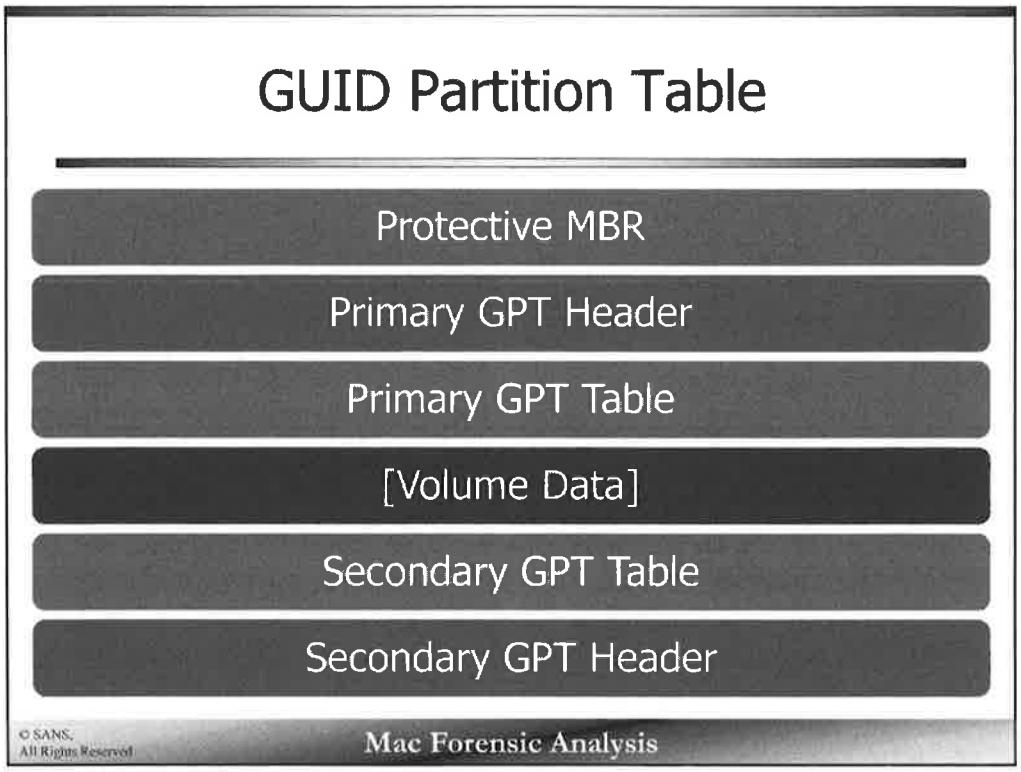
As stated earlier, the switch to GPT to APM was due to limitations such as a limited to a 2TB drive size. The Master Boot Record also had this drive size limit.

There were also limits with the number of partitions. MBR is limited to four primary partitions, while GPT has room for 128 primary partitions.

Other advantages of GPT are the use of unique identification (GUID) for disks and partitions and backups of the GPT header and partition table.

Note:
ZB = Zetta Bytes
LBA = Logical Block Addressing

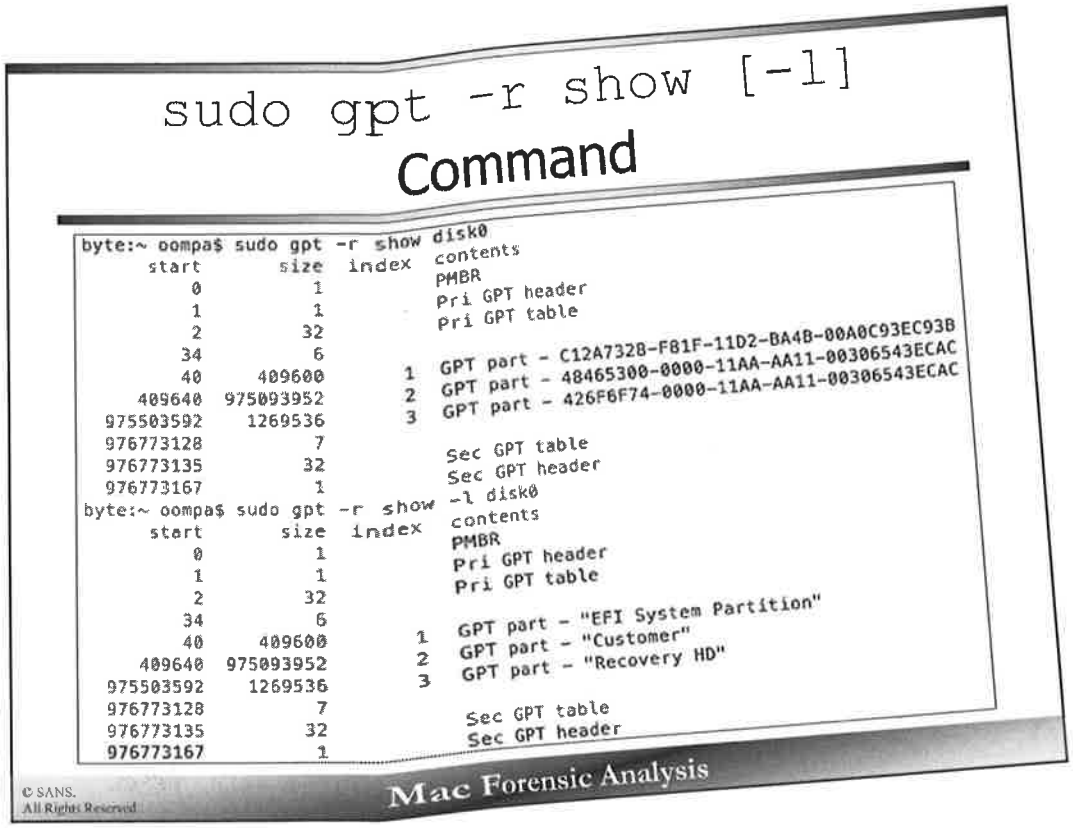
References:
Forensic Analysis of GPT Disks and GUID Partition Tables – Bruce J Nikkel –
http://www.digitalforensics.ch/nikkel09.pdf



A GUID partition table is comprised of five parts:

- Protective Master Boot Record
- Primary GUID Partition Table Header
- Primary GUID Partition Table
- Secondary GUID Partition Table
- Secondary GUID Partition Table Header

The secondary GPT Header and tables are backups of their primary counterparts.



The screenshot above shows the output of the command `'sudo gpt -r show'` and the `'sudo gpt -r show -l'`.

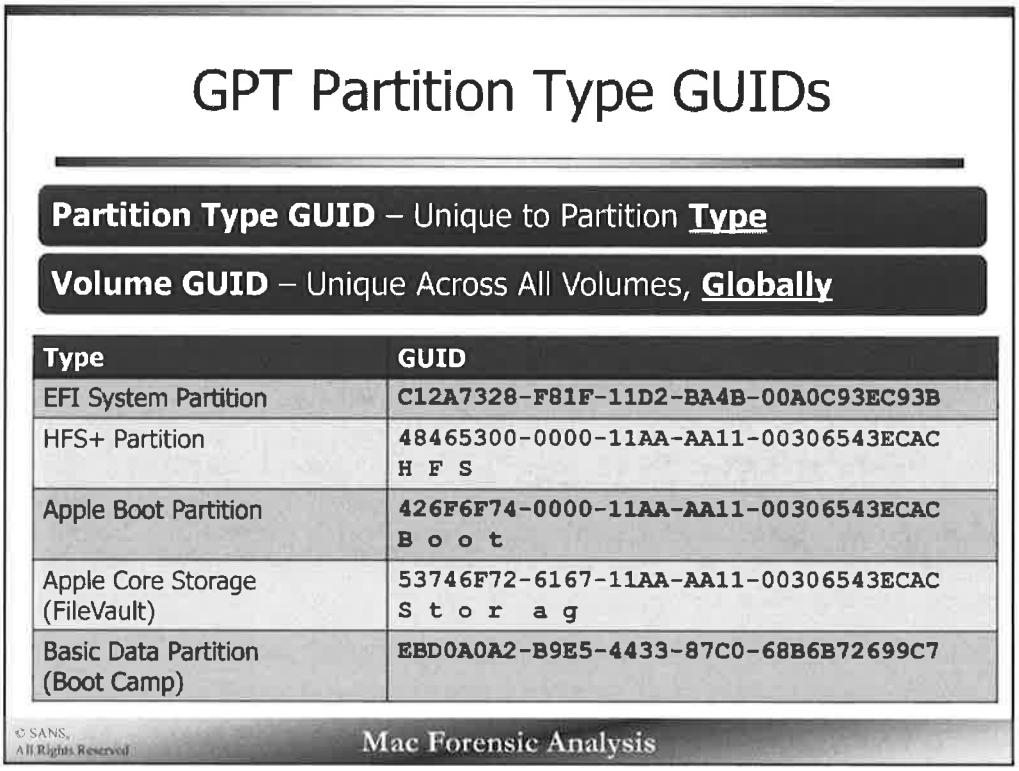
This command is used to print the GUID partition table information for the specified disk. The `'-l'` option can be used to toggle the display of the partition label from the GUID number.

The `-r` argument is used to show the GPT information in a read-only format.

The output of the command contains the starting sector, the size of the partition (in sectors), and the contents. The `PMBR` is the Protective Master Boot Record. Note the primary and secondary GPT header and tables.

Each partition type has an associated GUID that will be the same across all partitions of the same type.

```
byte:~ oompa$ sudo gpt -r show disk0
      start        size  index  contents
          0           1         PMBR
          1           1         Pri GPT header
          2          32         Pri GPT table
         34           6
         40      409600      1  GPT part - C12A7328-F81F-11D2-BA4B-00A0C93EC93B
     409640   975093952      2  GPT part - 48465300-0000-11AA-AA11-00306543ECAC
  975503592     1269536      3  GPT part - 426F6F74-0000-11AA-AA11-00306543ECAC
  976773128           7
  976773135          32         Sec GPT table
  976773167           1         Sec GPT header
byte:~ oompa$ sudo gpt -r show -l disk0
      start        size  index  contents
          0           1         PMBR
          1           1         Pri GPT header
          2          32         Pri GPT table
         34           6
         40      409600      1  GPT part - "EFI System Partition"
     409640   975093952      2  GPT part - "Customer"
  975503592     1269536      3  GPT part - "Recovery HD"
  976773128           7
  976773135          32         Sec GPT table
  976773167           1         Sec GPT header
```



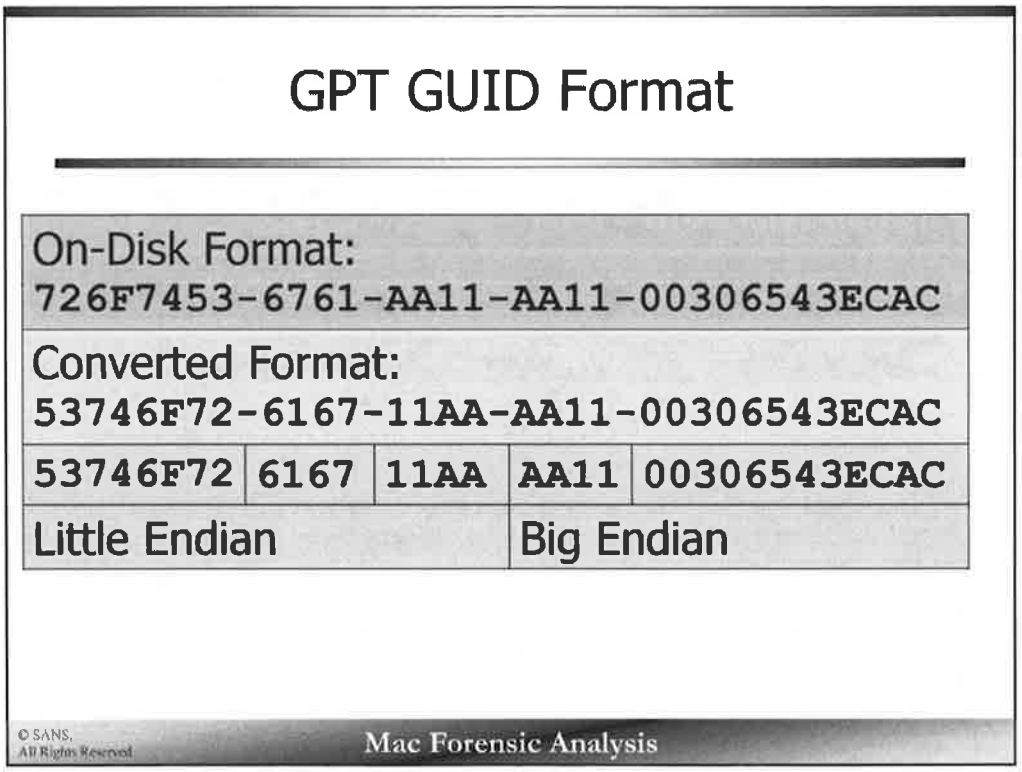
Similar to the MBR, each partition type has its own identifier. GPT uses GUIDs. In the GPT Table example, there were three partitions:

- EFI System Partition - `C12A7328-F81F-11D2-BA4B-00A0C93EC93B` (EFI System Partition)
- Untitled - `48465300-0000-11AA-AA11-00306543ECAC` (HFS+ Partition)
- Recovery HD - `426F6F74-0000-11AA-AA11-00306543ECAC` (Apple Boot Partition)

The Apple created GUIDs contain "hidden" mnemonic type hints.

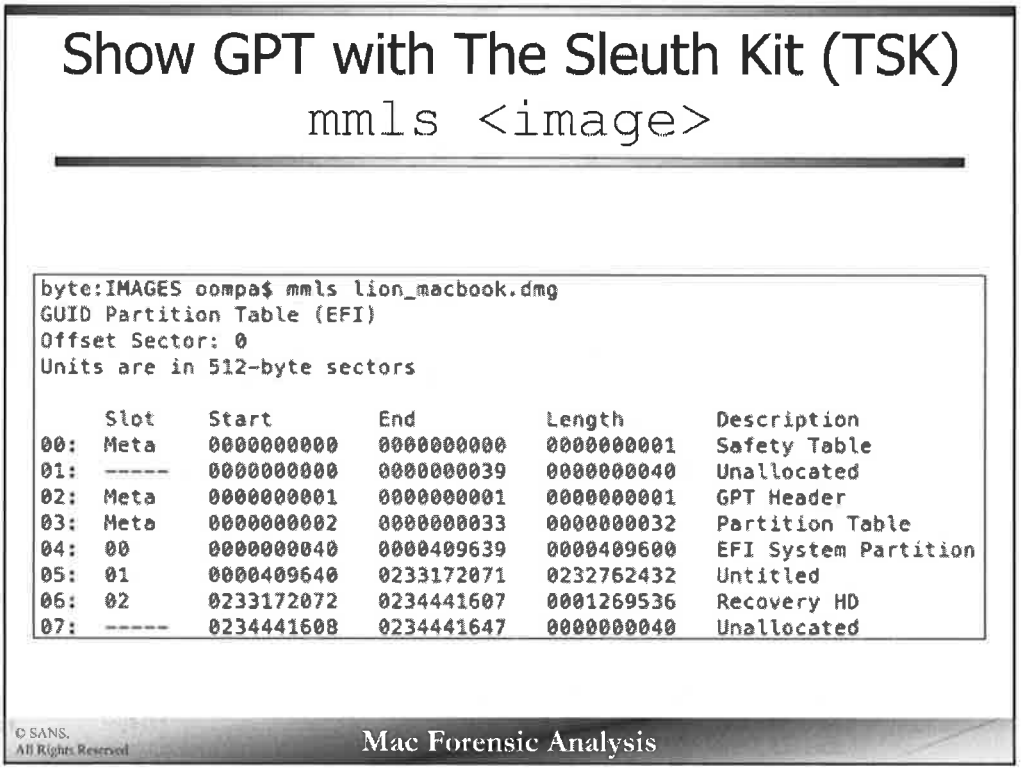
- HFS+ Partition GUIDs contain the string "`HFS`"
- Apple Boot Partition GUIDs contain the string "`Boot`"
- Apple Core Storage Partition GUIDs contain the string "`Storag`"

More GUID partition types can be found on the Wikipedia article for GUID Partition Table [http://en.wikipedia.org/wiki/GUID_Partition_Table]



GPT GUIDs use a combination of little and big endian.

The converted format uses little endian (by byte) for the first three sections of the GUID, while using big endian for the last two.

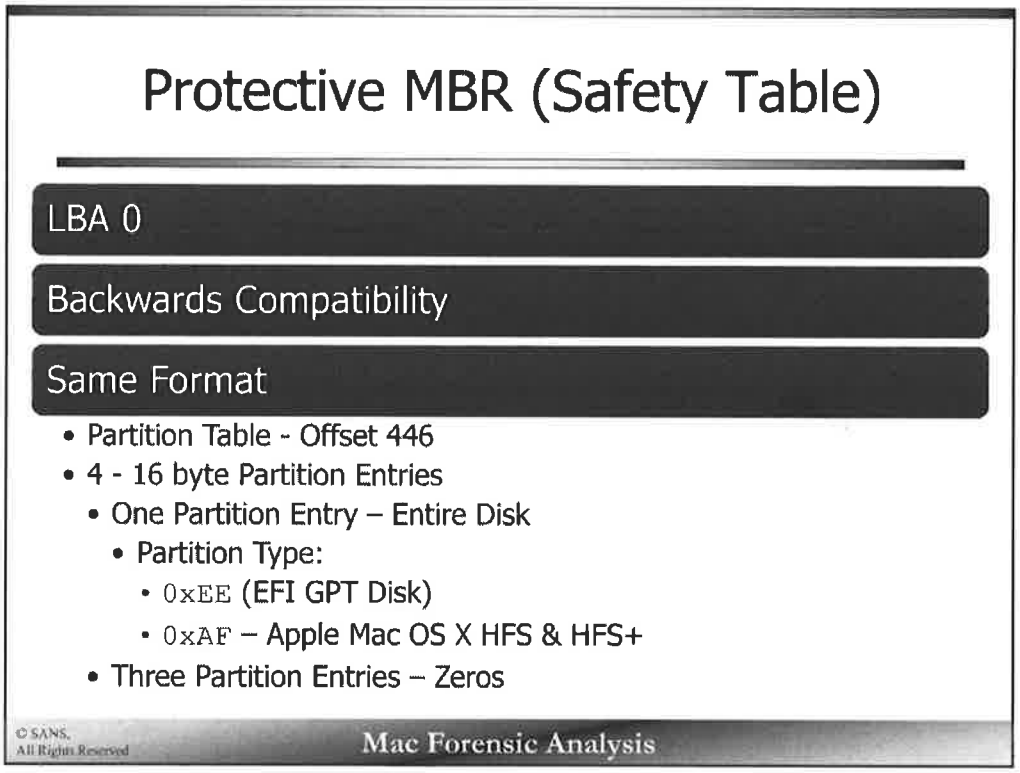


The Sleuth Kit (TSK) can be used to review the GPT partition scheme using the `mmls` command. TSK is a free, open-source tool used to interact with disks, or disk images to provide forensic analysis via the command-line.

In the screenshot above `mmls` is directed at a DMG image of a MacBook with a Mac OS X Lion installation. The Sleuth Kit calls the Protective MBR the Safety Table.

The Sleuth Kit can be downloaded from http://sleuthkit.org/. TSK man pages are located here: http://www.sleuthkit.org/sleuthkit/man/.

```
byte:IMAGES oompa$ mmls lion_macbook.dmg
GUID Partition Table (EFI)
Offset Sector: 0
Units are in 512-byte sectors

     Slot    Start        End          Length       Description
00:  Meta    0000000000   0000000000   0000000001   Safety Table
01:  -----   0000000000   0000000039   0000000040   Unallocated
02:  Meta    0000000001   0000000001   0000000001   GPT Header
03:  Meta    0000000002   0000000033   0000000032   Partition Table
04:  00      0000000040   0000409639   0000409600   EFI System Partition
05:  01      0000409640   0233172071   0232762432   Untitled
06:  02      0233172072   0234441607   0001269536   Recovery HD
07:  -----   0234441608   0234441647   0000000040   Unallocated
```

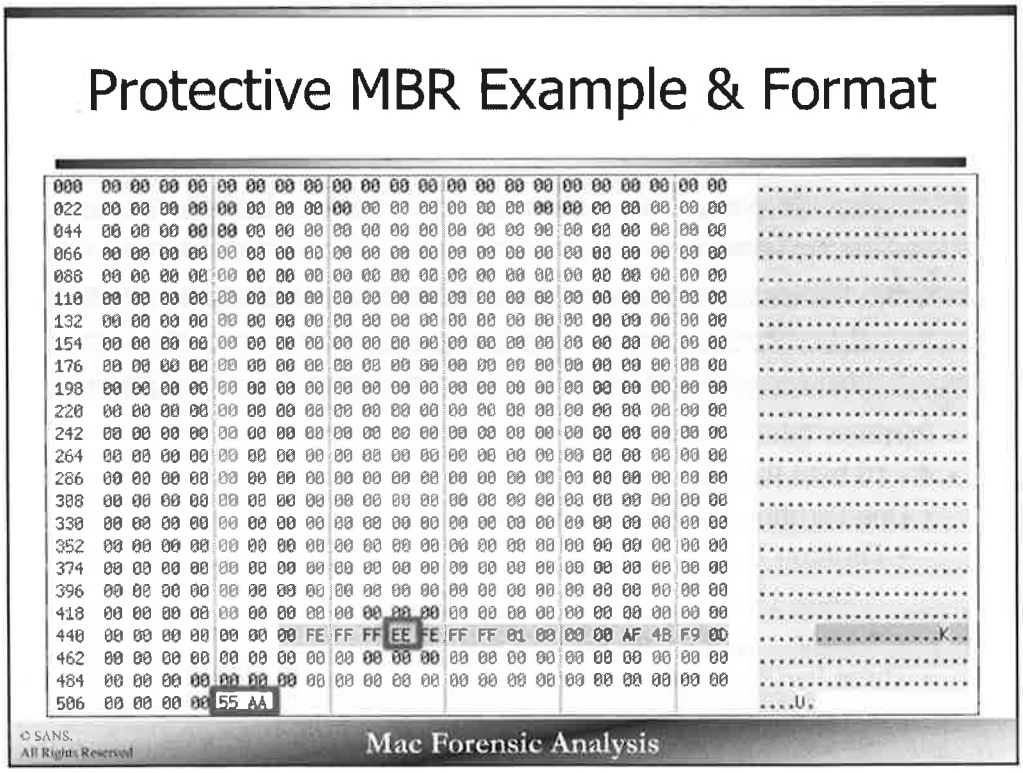


The Protective Master Boot Record, or Safety Table as it may be called, is used for backwards compatibility. If the software does not recognize the GPT format, the Protective MBR may be used to safeguard the GPT data.

This MBR uses the same format as any other MBR with the exception that it only has one partition with the partition type `0xEE` for EFI GPT Disk. The remaining three primary partitions are left blank.

Typical Mac-related Partition Types:

- `0xAF` – Apple Mac OS X HFS & HFS+
- `0xEE` – EFI GPT Disk (EFI Protective MBR)



The format of the highlighted partition entry is shown in the table below. The partition type outlined in the box, `0xEE`, is associated with an EFI GPT Disk partition. The size of the partition is 234,441,647 (`0xAF4BF90D`) in sectors. Note the `0x55AA` signature at the bottom. For more information about the Master Boot Record please review book, File System Forensic Analysis by Brian Carrier.

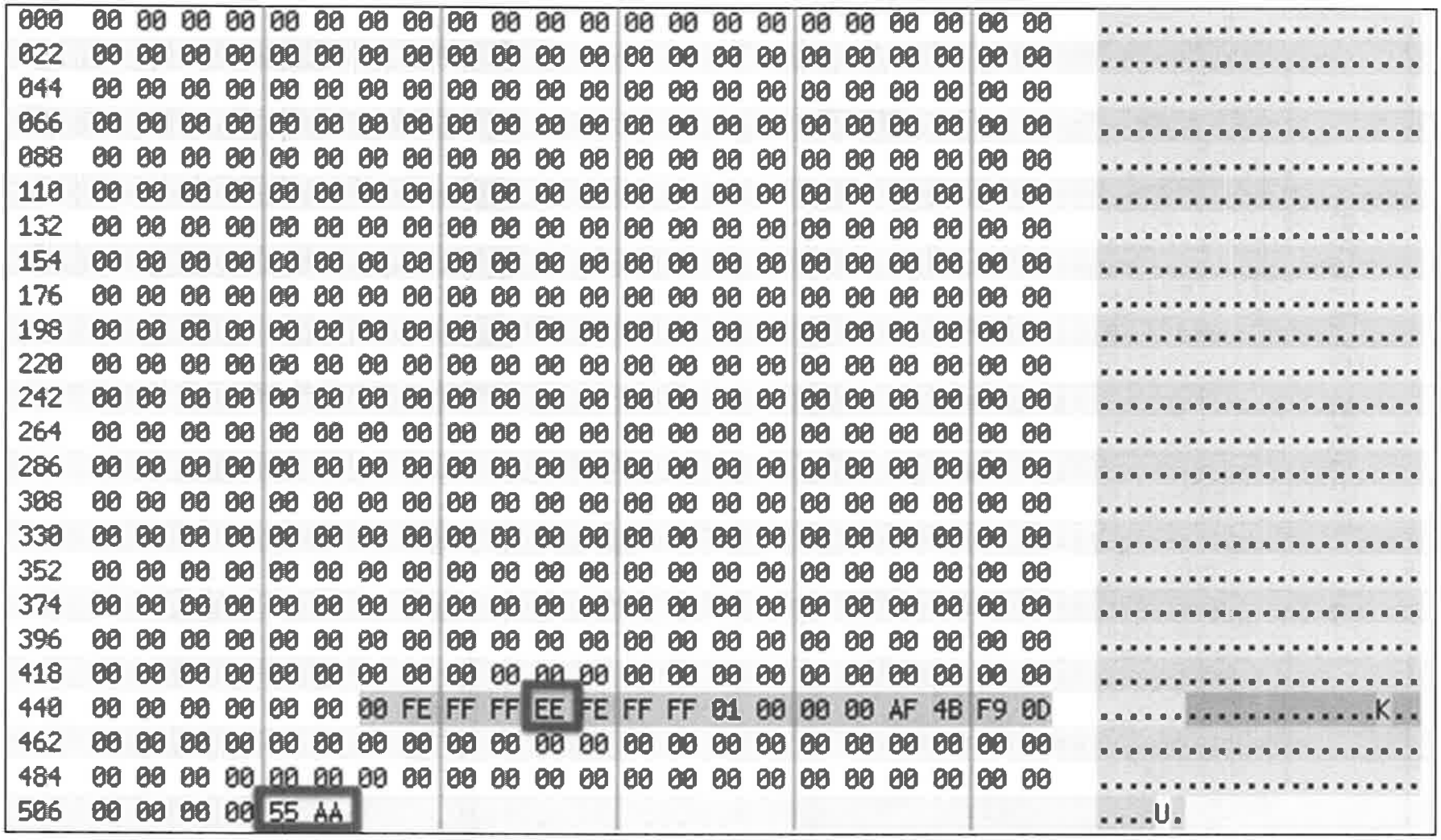
Note: GPT data uses little-endian

CHS = Cylinder-Head-Sectors

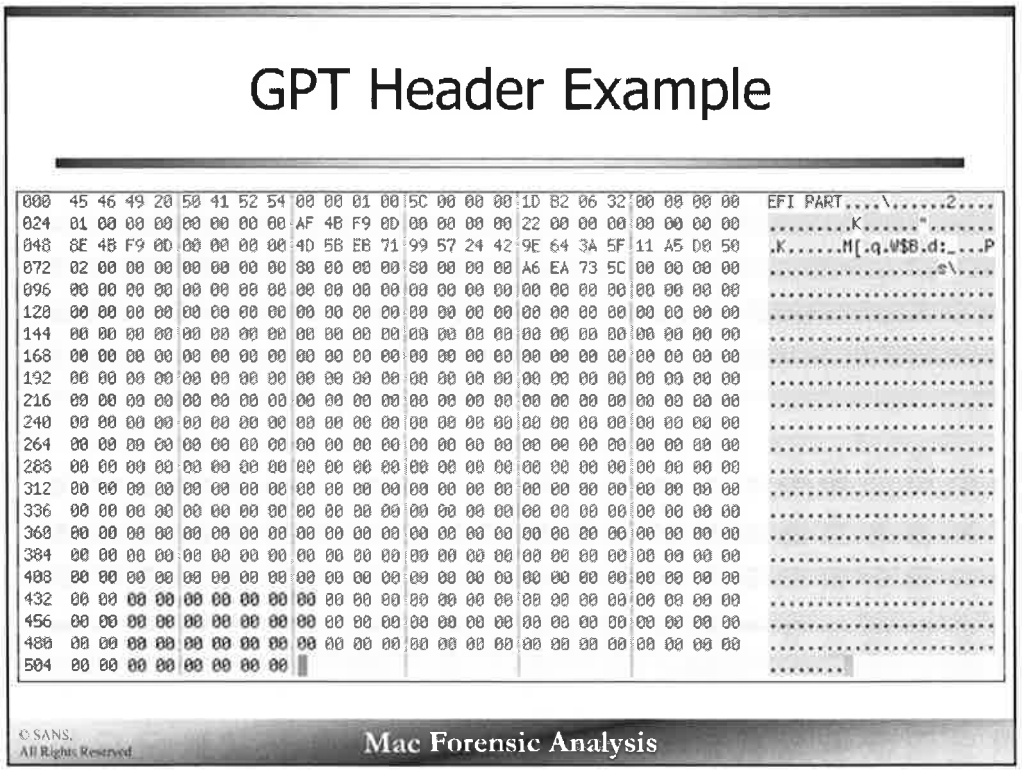
References:

File System Forensic Analysis – Brian Carrier - p.64, Table 5.2

Offset	Byte(s)	Field
446	1	Bootable Flag • 0x00 = non-bootable • 0x80 = bootable
447	3	Starting CHS Address (Little Endian)
450	1	Partition Type
451	3	Ending CHS Address (Little Endian)
454	4	Starting LBA Address (Little Endian)
458	4	Size in Sectors (Little Endian)



000	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
022	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
044	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
066	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
088	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
110	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
132	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
154	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
176	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
198	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
220	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
242	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
264	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
286	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
308	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
330	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
352	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
374	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
396	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
418	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
440	00	00	00	00	00	00	00	FE	FF	FF	EE	FE	FF	FF	01	00	00	00	AF	4B	F9	0D	.....K..
462	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
484	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
506	00	00	00	00	55	AA															....U.



The GPT Header is 512 bytes and contains a human-recognizable signature, "`EFI PART`". Items of interest include:

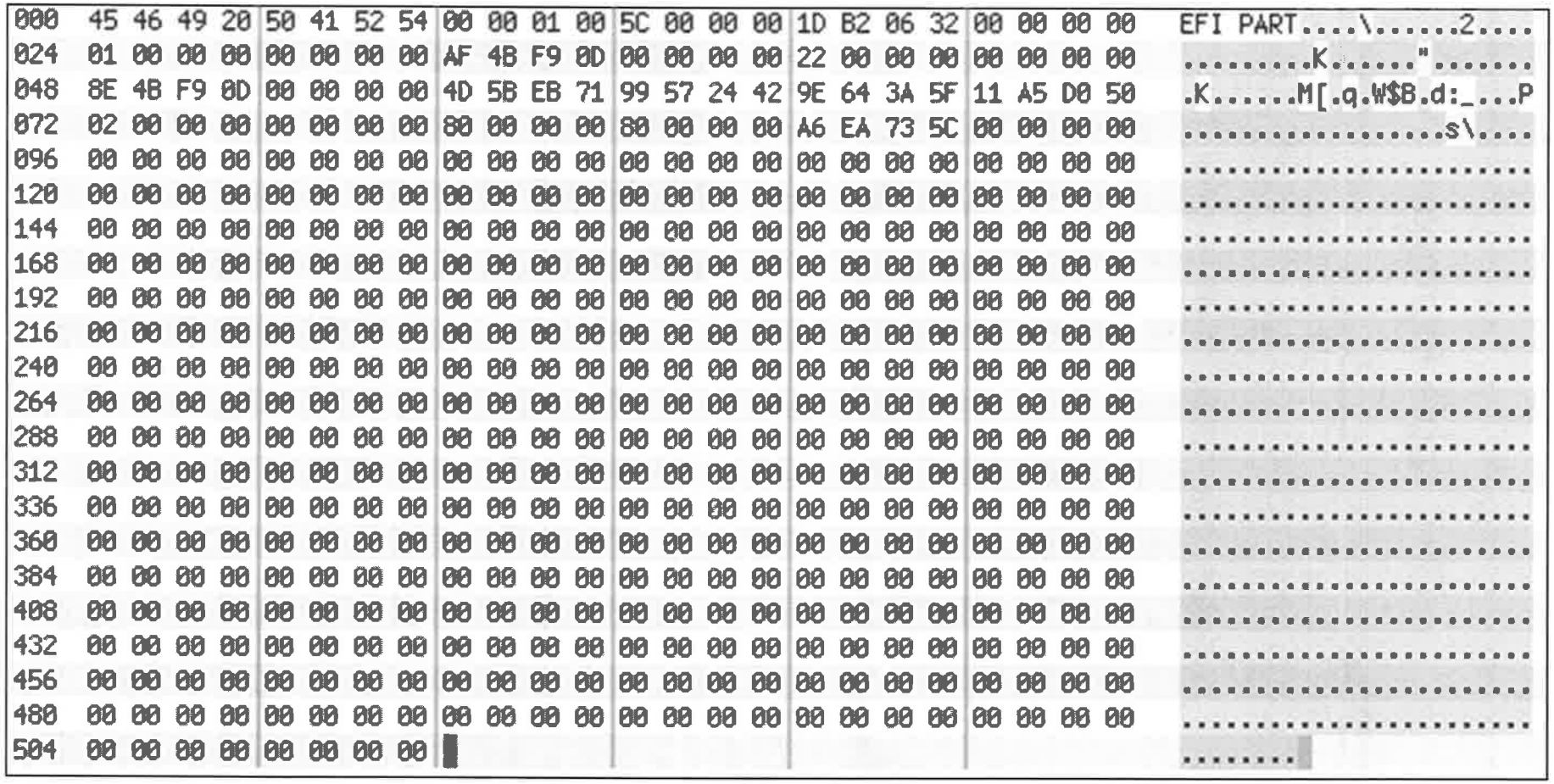
- At offset 24, the LBA (Little Endian) of the GPT Header: 1 (`0x0100000000000000`)
- At offset 32, the LBA (Little Endian) of the alternate GPT header: 234441647 (`0xAF4BF90D`)
- At offset 56, the unique GUID of this disk:
  - `71EB5B4D-5799-4224-9E64-3A5F11A5D050`
- At offset 72, the LBA (Little Endian) of the GUID Partition Table: 2 (`0x0200000000000000`)

Note: GPT data uses little-endian

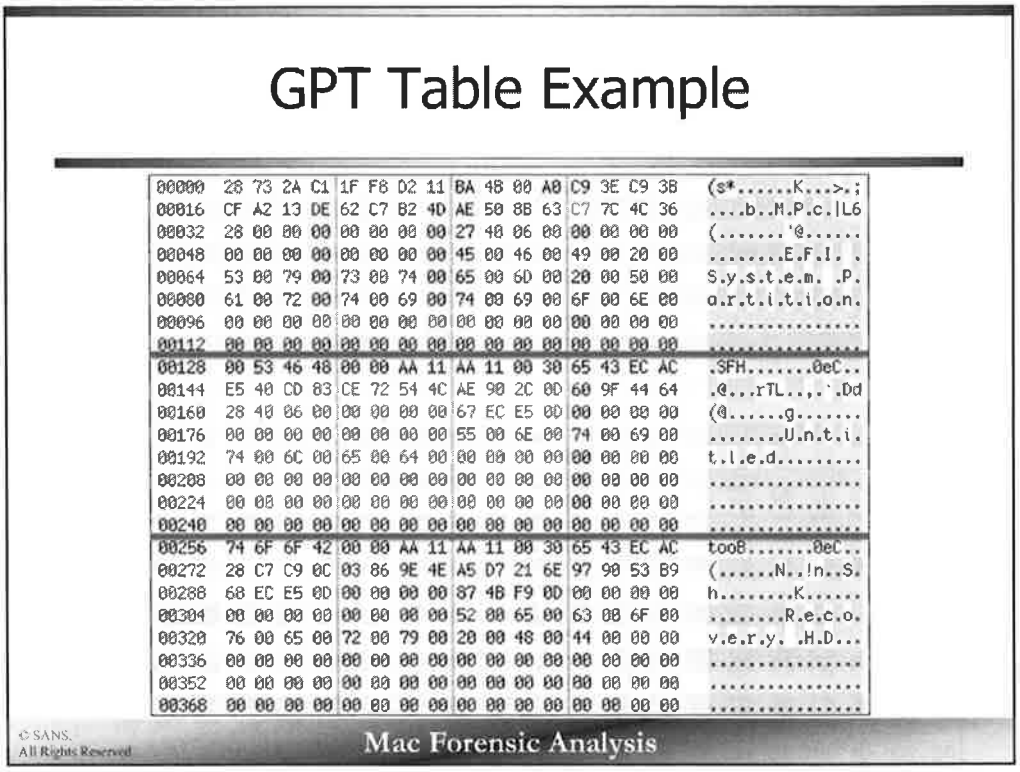
- GUID Endianess - The first three sections are in little-endian while the last two are not.

Reference:
TN2166 – Secrets of the GPT
https://developer.apple.com/library/mac/technotes/tn2166/_index.html
http://www.uefi.org/specs/download/2_3_1_ErrataC.pdf
available though http://www.uefi.org/specs/access
(Registration Required)
Section 5.3.2

Offset	Size (bytes)	Field
0	8	Signature (`EFI PART`)
8	4	Revision (1.0)
12	4	Size of Header (bytes)
16	4	Header CRC32
20	4	Reserved
24	8	LBA of GPT Header
32	8	LBA of Backup GPT Header
40	8	First Usable LBA
48	8	Last Usable LBA
56	16	GUID of Partition
72	8	Starting LBA of GUID Partition Table
80	4	Number of Partition Entries Available
84	4	Size of Partition Entry
88	4	Partition Entry Array CRC32
92	Rest	Reserved



000	45	46	49	20	50	41	52	54	00	00	01	00	5C	00	00	00	1D B2 06 32	00 00 00 00	EFI PART....\.....2....
024	01	00	00	00	00	00	00	00	AF	4B	F9	0D	00	00	00	00	22 00 00 00	00 00 00 00	.........K....."....
048	8E	4B	F9	0D	00	00	00	00	4D	5B	EB	71	99	57	24	42	9E 64 3A 5F	11 A5 D0 50	.K.....M[.q.W$B.d:_...P
072	02	00	00	00	00	00	00	00	80	00	00	00	80	00	00	00	A6 EA 73 5C	00 00 00 00	..............s\....
096	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
120	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
144	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
168	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
192	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
216	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
240	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
264	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
288	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
312	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
336	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
360	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
384	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
408	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
432	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
456	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
480	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00 00 00 00	00 00 00 00	.....
504	00	00	00	00	00	00	00	00											.....



The GPT Table is made up of an array of partition table entries with the format shown in the table below. In the screenshot above, a line splits each partition entry. The **middle** partition table will be analyzed; this partition entry contains the following items:

At offset 128, the **partition type** GUID is:

`48465300-0000-11AA-AA11-00306543ECAC`

`(0x005346480000AA11AA1100306543ECAC)`

This is a unique GUID to this **type** of partition.

At offset 144, the **unique partition** GUID is:

`83CD40E5-72CE-4C54-AE90-2C0D609F4464`

`(0xE540CD83CE72544CAE902C0D609F4464)`

This is a unique GUID only to **this** partition.

Offset	Size (bytes)	Field
0	16	Partition Type GUID
16	16	Unique Partition GUID
32	8	Starting LBA (Little Endian)
40	8	Ending LBA (Little Endian)
48	8	Attributes
56	72	Partition Name
128	Rest	Reserved

At offset 160, the starting LBA is 409640 `(0x2840060000000000)`

At offset 168, the ending LBA is 233172071 `(0x67ECE50D00000000)`

At offset 184, the partition name (in Unicode) is `'Untitled'`.

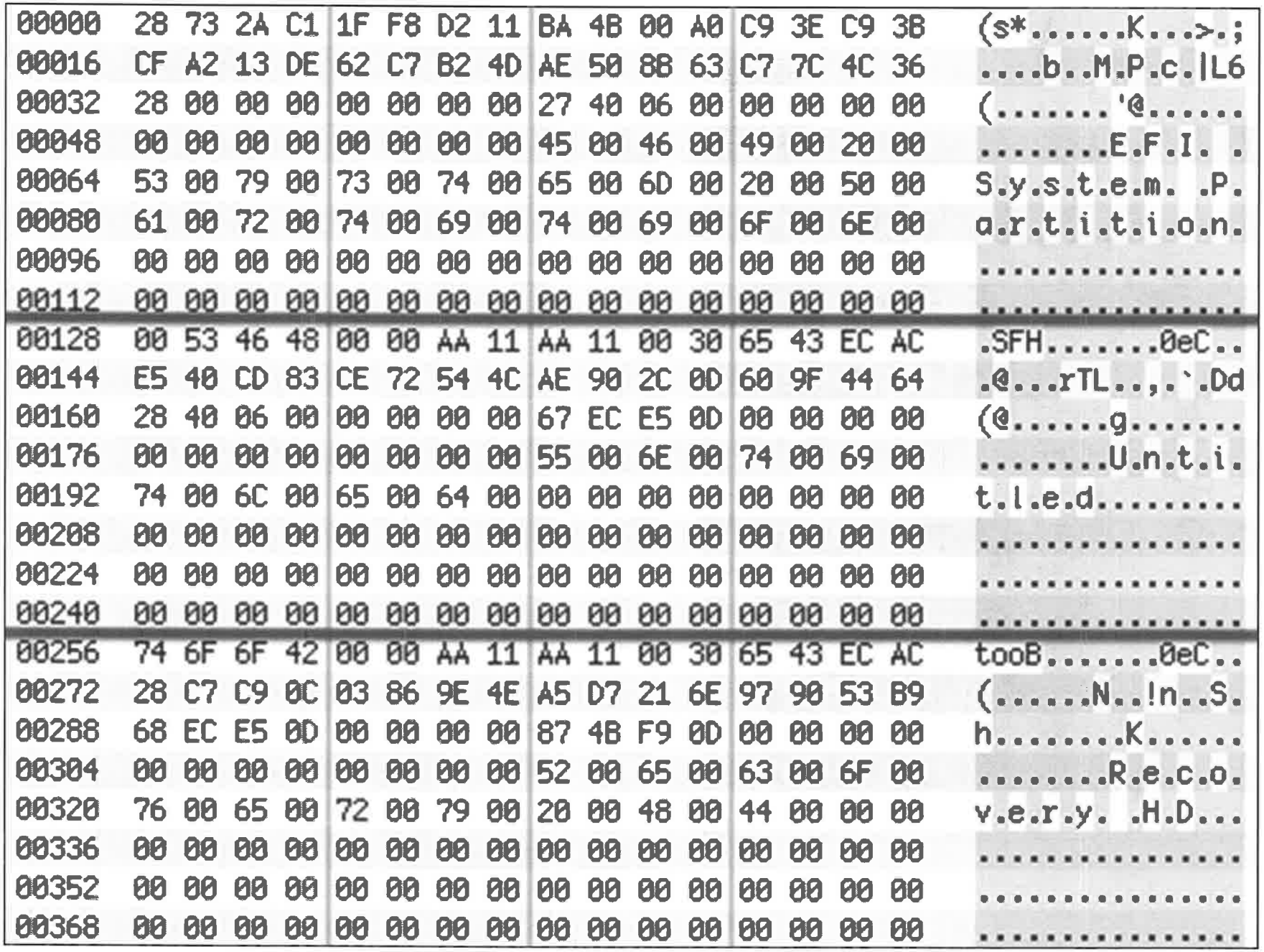
Note: GPT data uses little-endian

- GUID Endianess - The first three sections are in little-endian while the last two are not.

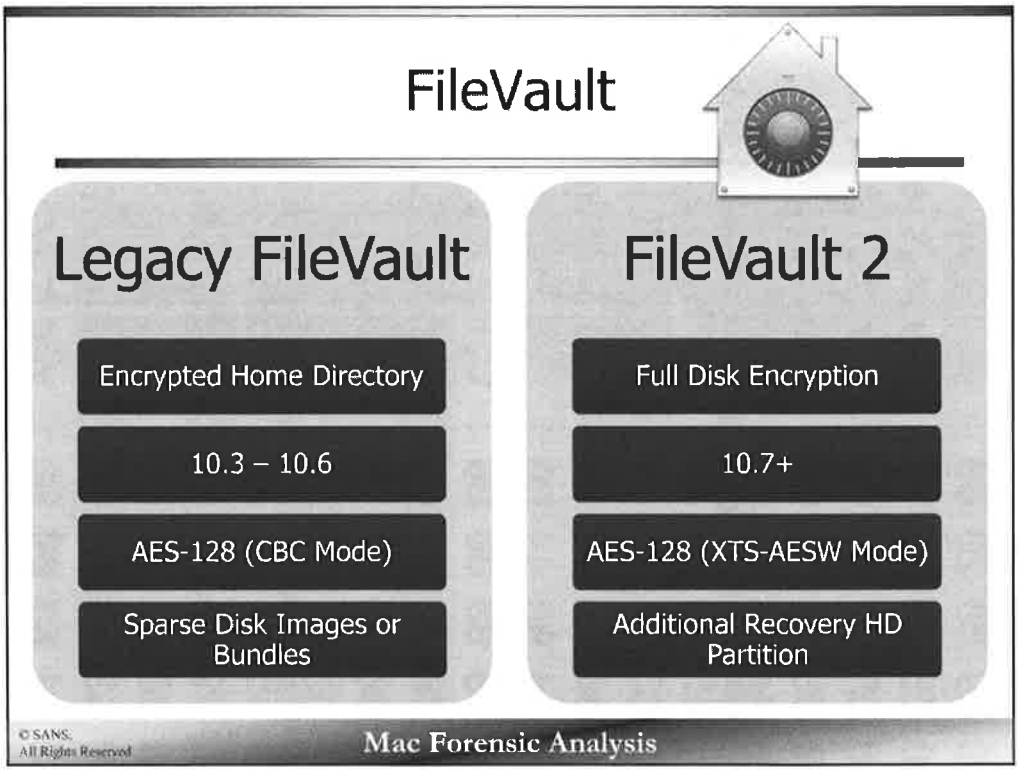
Reference:
TN2166 – Secrets of the GPT

https://developer.apple.com/library/mac/technotes/tn2166/_index.html

http://www.uefi.org/specs/download/2_3_1_ErrataC.pdf available though http://www.uefi.org/specs/access (Registration Required)



```
00000  28 73 2A C1 1F F8 D2 11 BA 4B 00 A0 C9 3E C9 3B   (s*.....K...>.;
00016  CF A2 13 DE 62 C7 B2 4D AE 50 8B 63 C7 7C 4C 36   ....b..M.P.c.|L6
00032  28 00 00 00 00 00 00 00 27 40 06 00 00 00 00 00   (.......'@......
00048  00 00 00 00 00 00 00 00 45 00 46 00 49 00 20 00   ........E.F.I. .
00064  53 00 79 00 73 00 74 00 65 00 6D 00 20 00 50 00   S.y.s.t.e.m. .P.
00080  61 00 72 00 74 00 69 00 74 00 69 00 6F 00 6E 00   a.r.t.i.t.i.o.n.
00096  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
00112  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
00128  00 53 46 48 00 00 AA 11 AA 11 00 30 65 43 EC AC   .SFH.......0eC..
00144  E5 40 CD 83 CE 72 54 4C AE 90 2C 0D 60 9F 44 64   .@...rTL..,.`.Dd
00160  28 40 06 00 00 00 00 00 67 EC E5 0D 00 00 00 00   (@......g.......
00176  00 00 00 00 00 00 00 00 55 00 6E 00 74 00 69 00   ........U.n.t.i.
00192  74 00 6C 00 65 00 64 00 00 00 00 00 00 00 00 00   t.l.e.d.........
00208  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
00224  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
00240  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
00256  74 6F 6F 42 00 00 AA 11 AA 11 00 30 65 43 EC AC   tooB.......0eC..
00272  28 C7 C9 0C 03 86 9E 4E A5 D7 21 6E 97 90 53 B9   (......N..!n..S.
00288  68 EC E5 0D 00 00 00 00 87 4B F9 0D 00 00 00 00   h........K......
00304  00 00 00 00 00 00 00 00 52 00 65 00 63 00 6F 00   ........R.e.c.o.
00320  76 00 65 00 72 00 79 00 20 00 48 00 44 00 00 00   v.e.r.y. .H.D...
00336  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
00352  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
00368  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
```



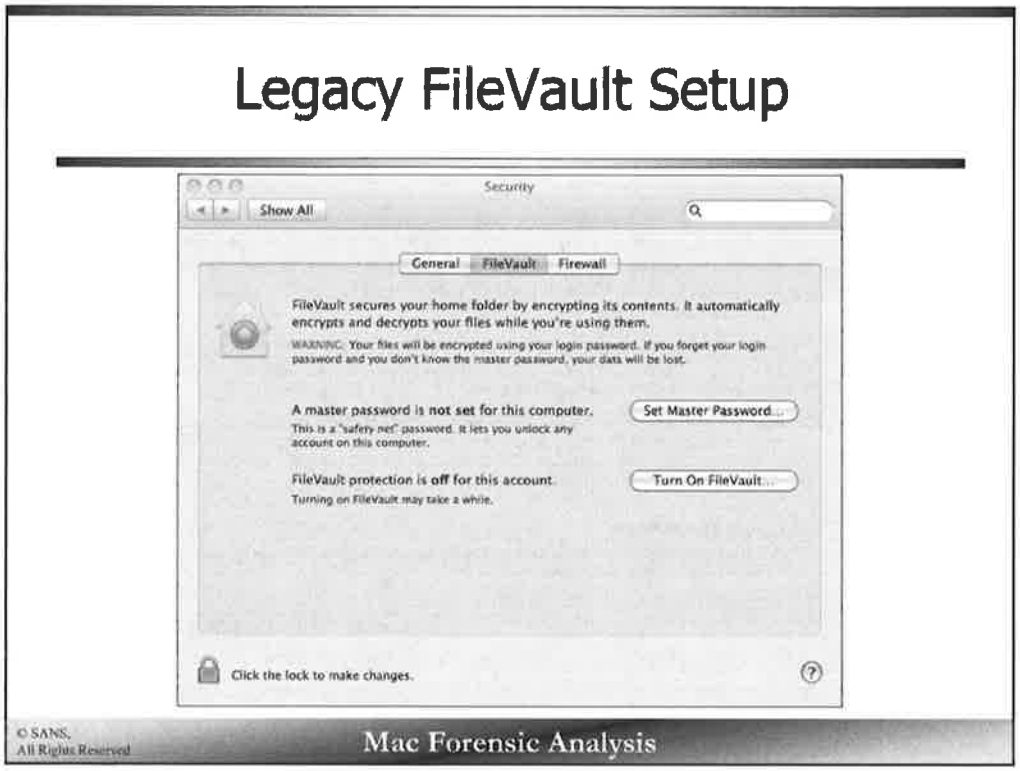
FileVault (now called Legacy FileVault) was introduced in 10.3. FileVault, if implemented, encrypts the home directory of a user. All other user directories and system files remain unencrypted. The encrypted home directory is stored in a sparse disk image, or a sparse bundle.

FileVault 2 was introduced in Mac OS X Lion, and encrypts the whole disk, except for EFI and Recovery partitions.

Reference:

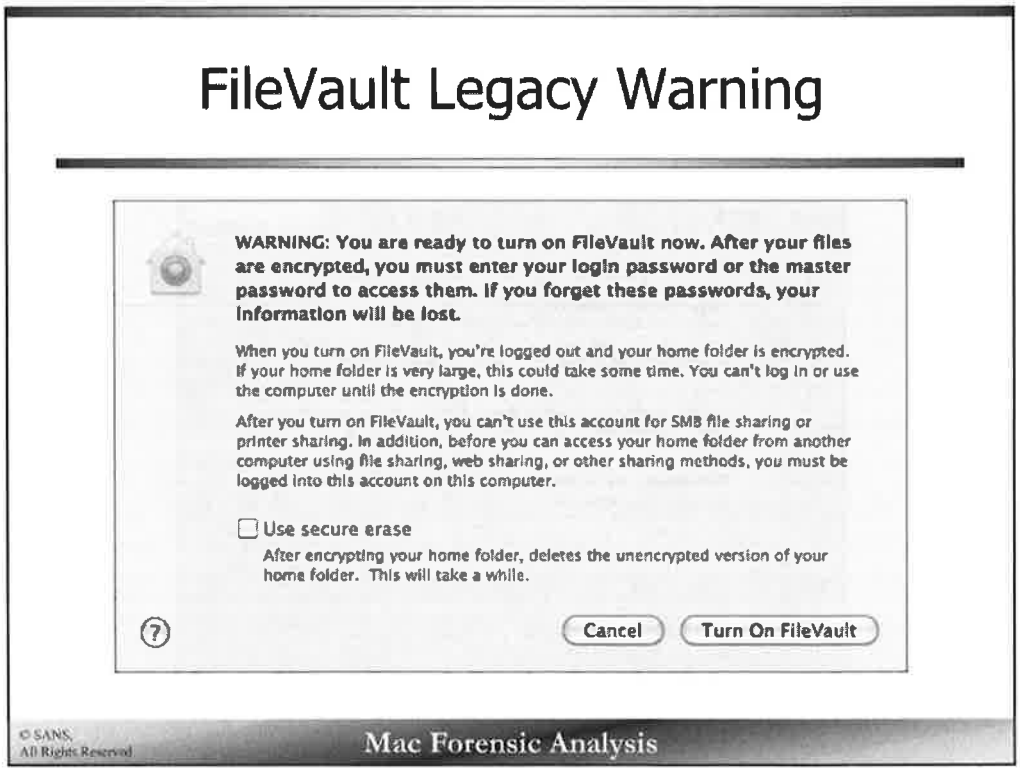
OS X: About FileVault 2

[http://support.apple.com/kb/HT4790]



The screenshot above shows the window a user needs to implement the Legacy FileVault setting.

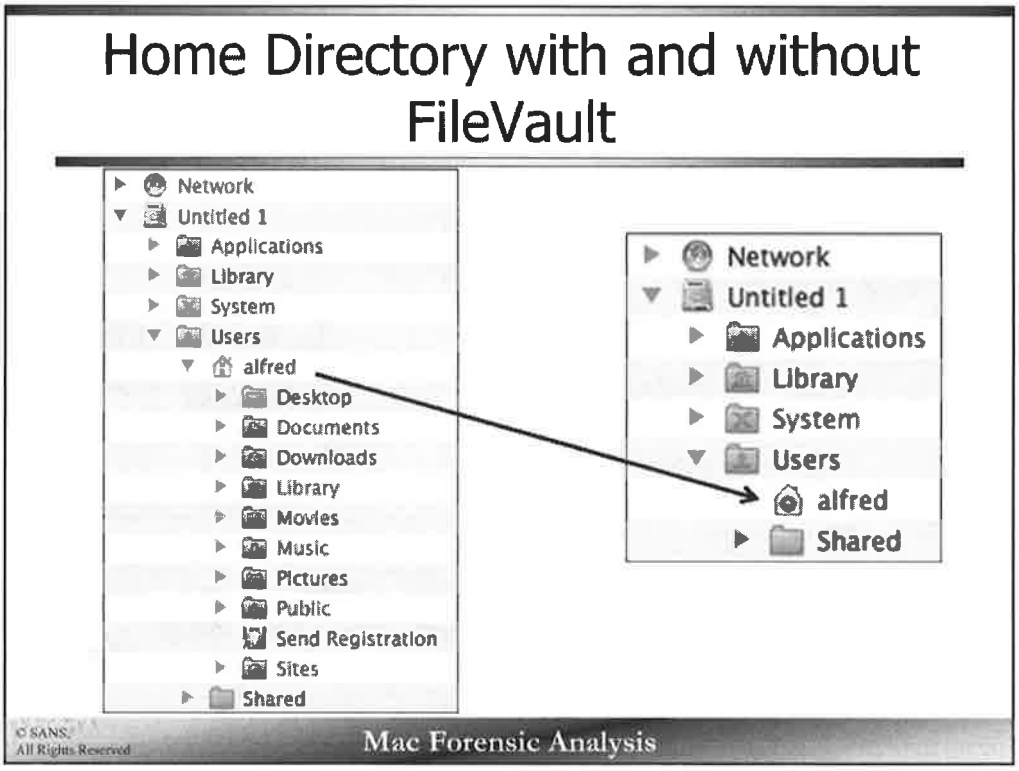
A master password needs to be set before FileVault can be turned on. This master password is used to decrypt any FileVault volume on the system. You may want to ask for the Master Password in the event you are in an enterprise situation.



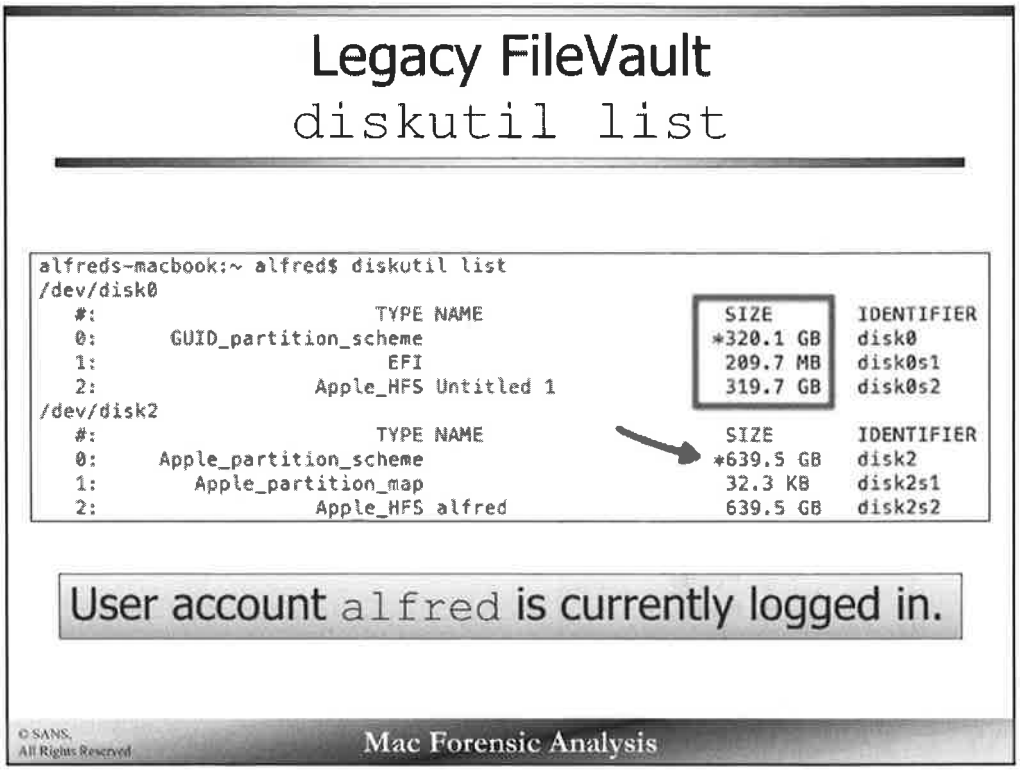
A warning is presented to the user before they are able to turn on FileVault.

A checkbox is enabled for the user to secure erase the disk space after the encryption process takes place.

Note: If the user does not secure erase their home folder, an analyst may be able to carve items from disk free space that would have otherwise been encrypted.

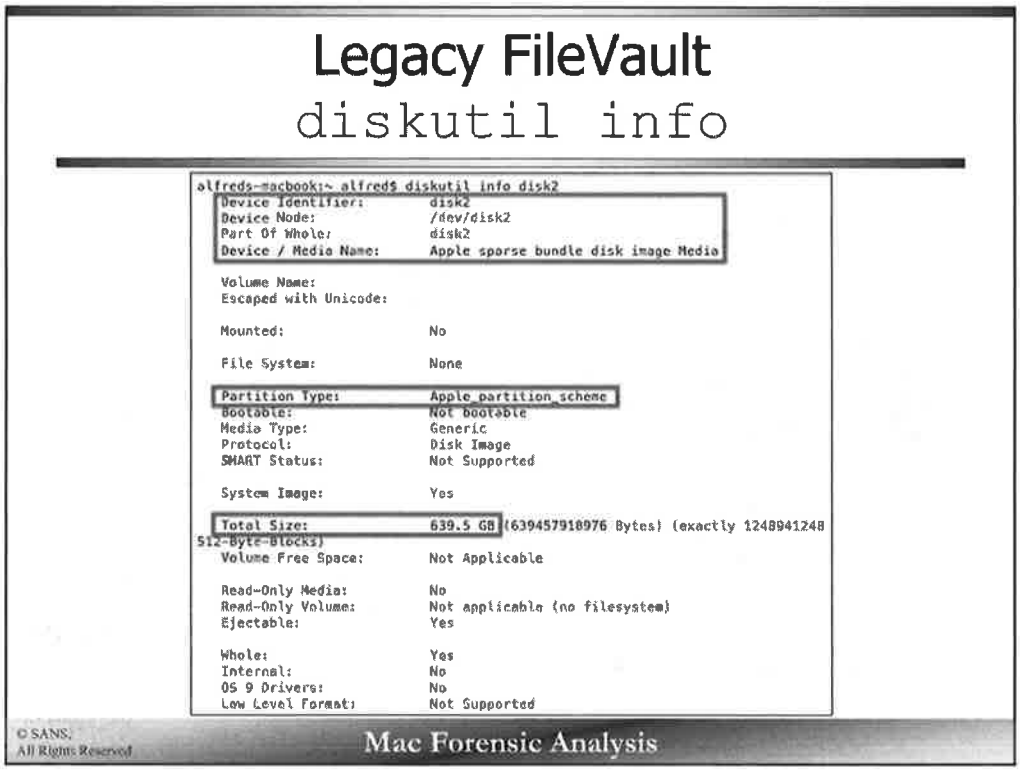


Once a user's home directory is encrypted the house icon changes to a locked house icon, shown in the screenshot above. The folder structure of the user can no longer be seen by other users.

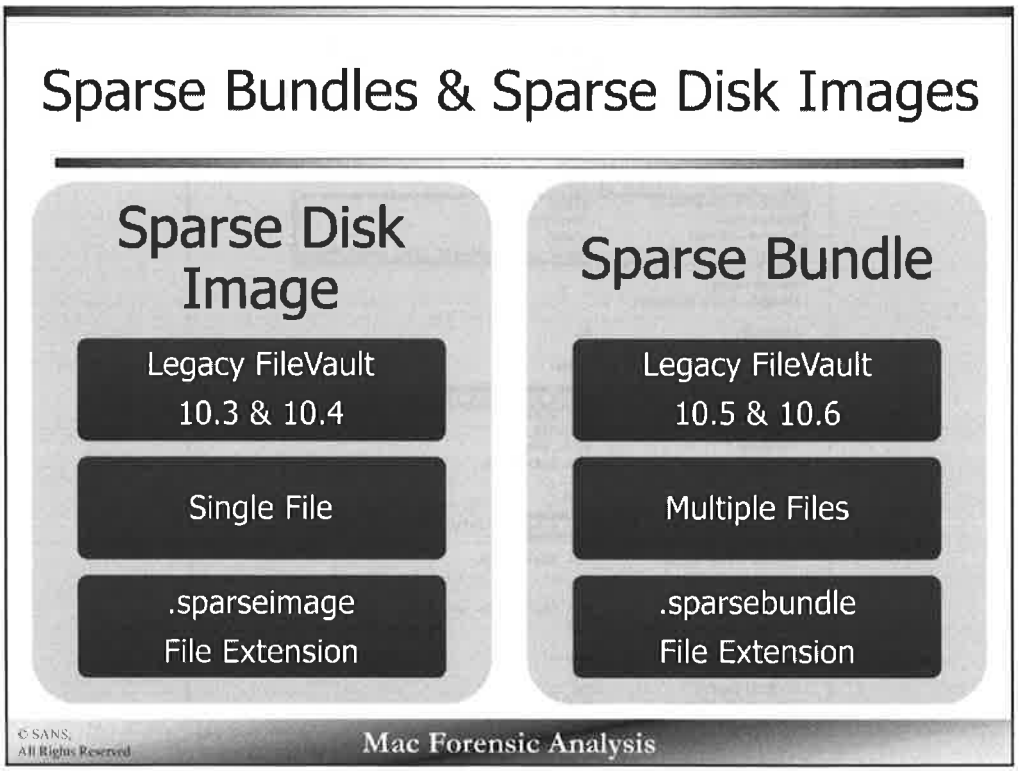


Using the diskutil list command from earlier, we can see how it might look if Legacy FileVault is used on a home directory for the user '`alfred`'.

Alfred's home directory is now on its own `/dev/disk*`. The size of the drive may be much larger than the size of the hard drive in the system. This is due to how the sparse image/bundle file works.



If we look at Alfred's home directory from the previous slide using the `diskutil info` command, we can see that it is contained in a sparse bundle disk image.

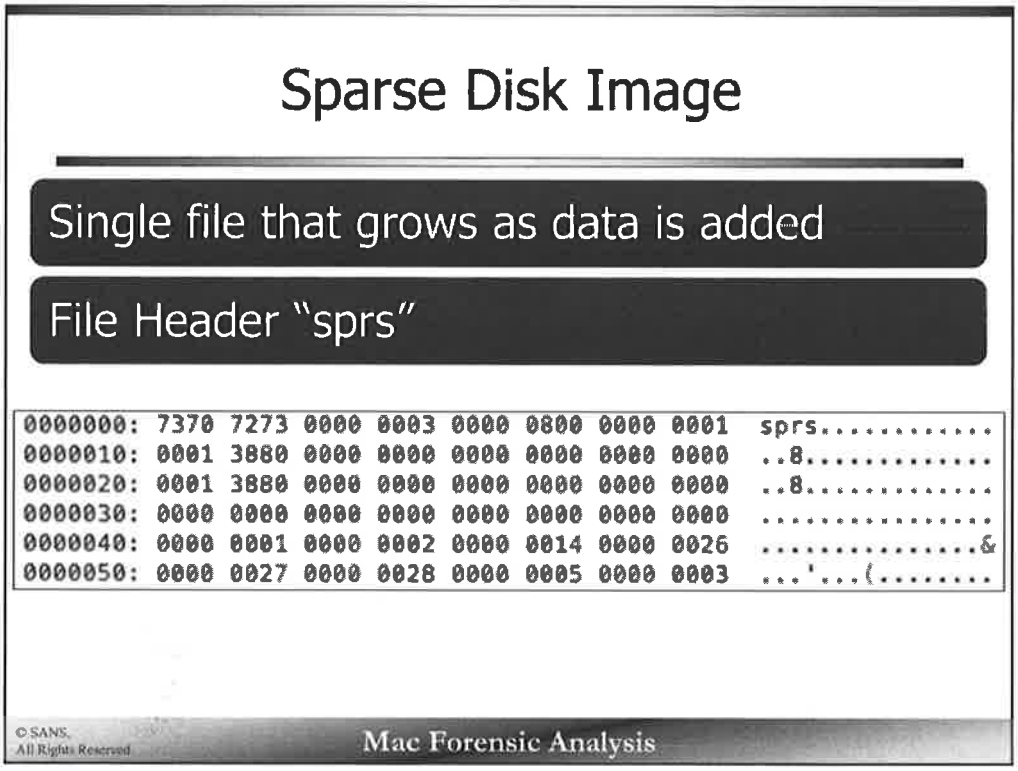


Legacy FileVault implements the Sparse Disk Image and the Sparse Bundle to store encrypted data, these file formats may also be used without the context of FileVault. The Disk Utility.app can be used to create encrypted and unencrypted volumes using these file types.

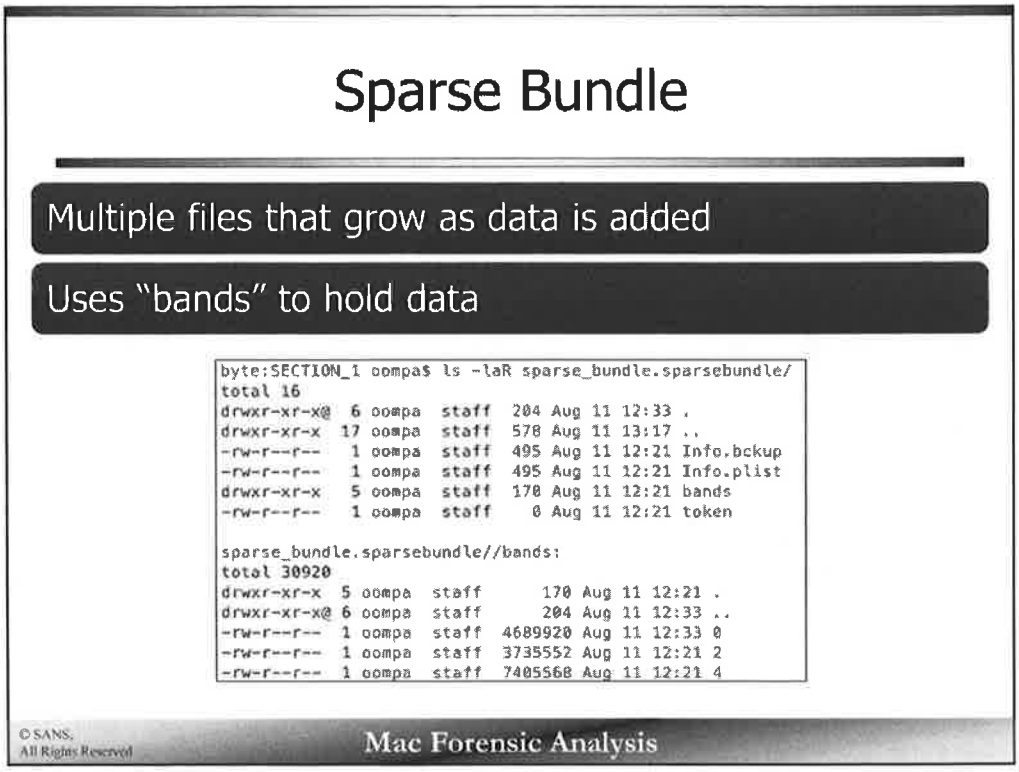
The Sparse Disk Image is a single file with a `.sparseimage` file extension. The Sparse Bundle file is made up of multiple files (in a software bundle) with the file extension `.sparsebundle`.

These files work by increasing the size of the sparse disk or bundle file/s. When these types of volumes are mounted, their "Virtual Volume" size may be much larger than the size of the hard drive the file is located on.

The size of the files will not be reduced if data is removed, but can be fixed after volume is unmounted by using the command `hdiutil compact`. "Virtual volumes" may be larger than the size on which the volume is physically located.



The Sparse Disk Image is made up of one file that grows as data is added. The file has the signature "`sprs`", as shown in the screenshot above.



The Sparse Bundle file is comprised of multiple files that grow as data is added to the volume. These files are called "bands". These "bands" are located in a "Bundle".

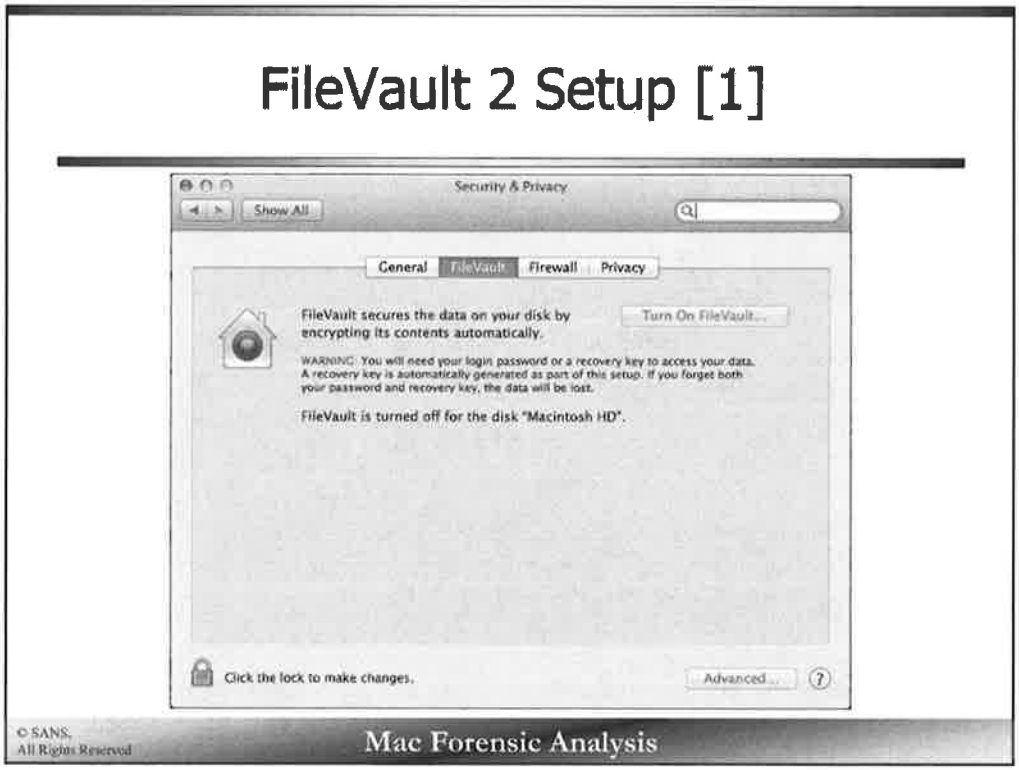
A bundle is a directory that contains files, executable, and/or other resources in one easy to move file. Any application on a Mac system is a "bundle".

Each Sparse Bundle has an `Info.plist` file located within the bundle. This property list file contains the size of the bands, and the original size of the bundle, whether or not it is at capacity. Sizes are in bytes.

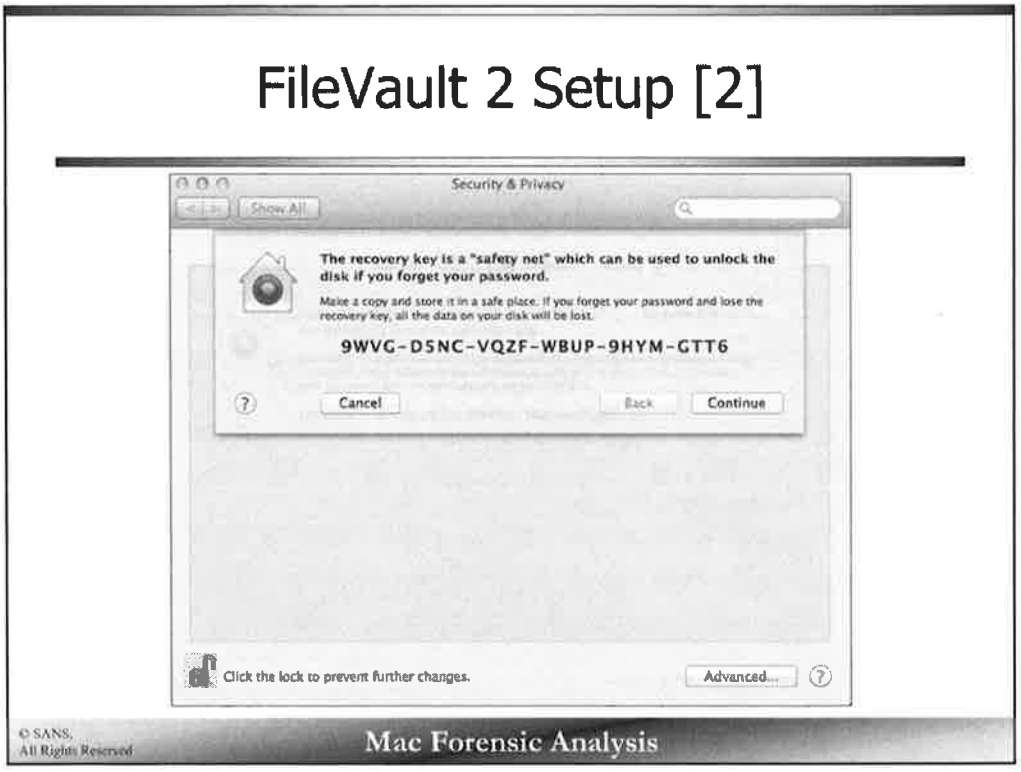
Reference:

Mac Developer Library – Cocoa Core Compentencies

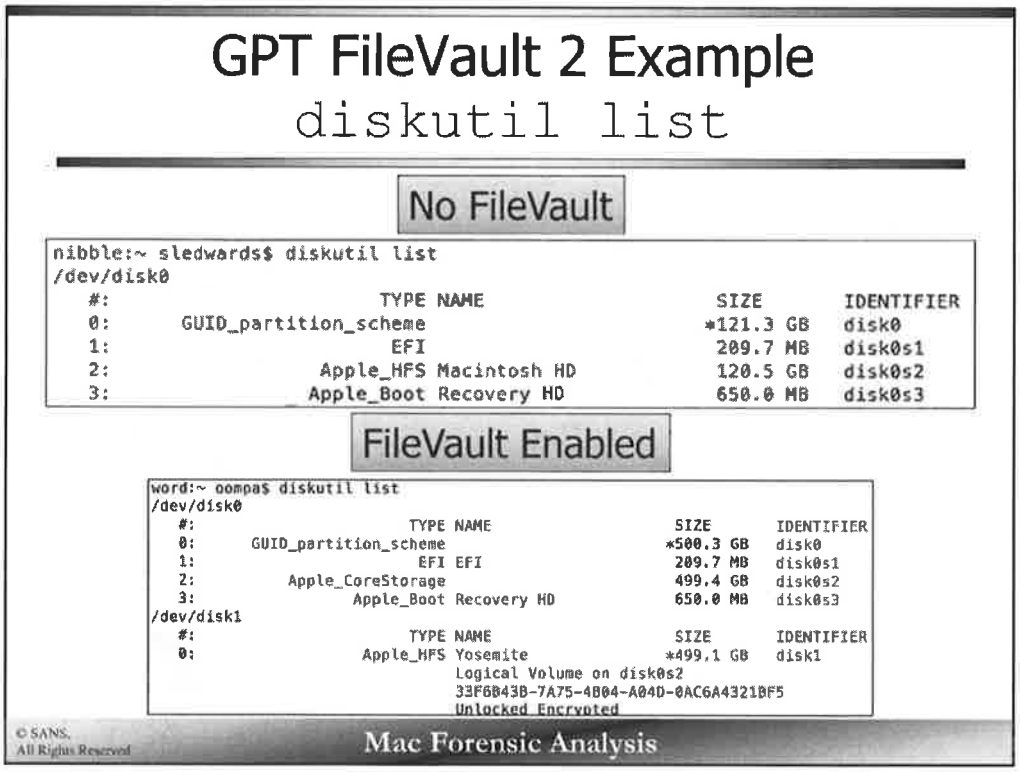
[https://developer.apple.com/library/mac/#documentation/General/Conceptual/DevPedia-CocoaCore/Bundle.html]



FileVault 2 uses a similar setup screen shown above.

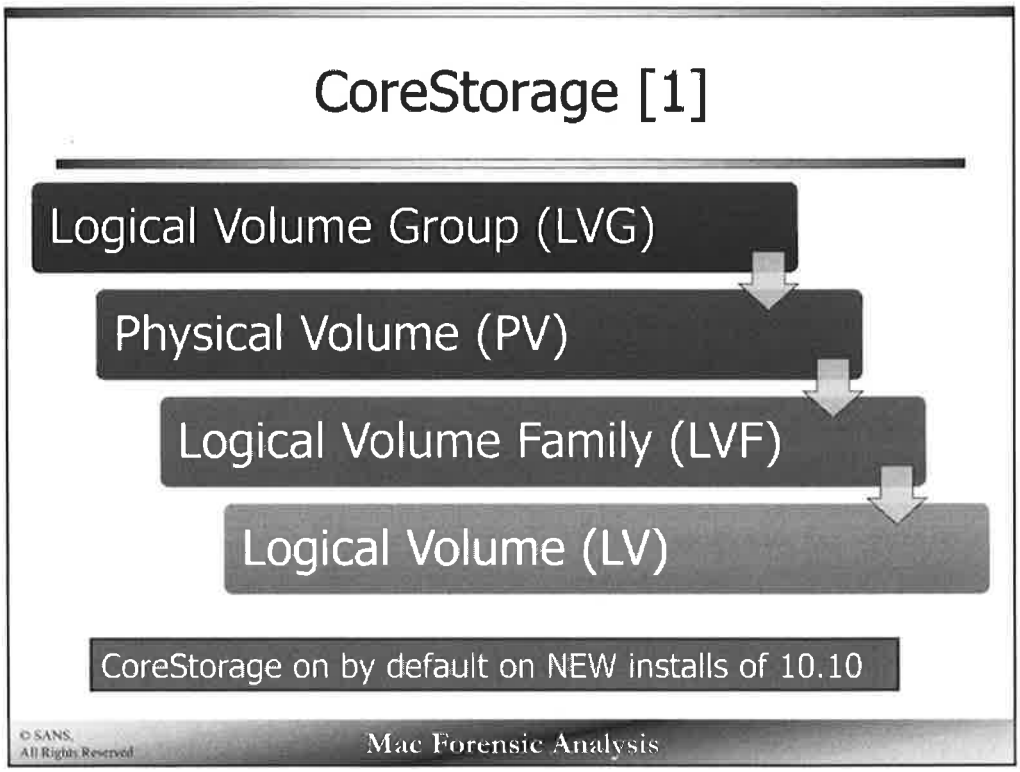


Before the encryption process takes place, the setup will display a recovery key that the user can choose to store with Apple. This recovery key can be used to recover a FileVault 2 encrypted volume.



In the top example, the screenshot shows the output of the `diskutil list` command on a disk that does not have FileVault 2 enabled.

The bottom example shows the same disk with FileVault 2 enabled. Note the addition of the `Apple_CoreStorage` partition and how "`Macintosh HD`" is now on `/dev/disk1`. The Apple CoreStorage partition is the encrypted partition of the FileVault volume on `/dev/disk1`.



CoreStorage is Apple's version of logical volume management – or "virtual volumes". Used with FileVault2 Full Disk Encryption and Fusion Drives.

Logical Volume Group (LVG) – The top level, associated with a specific Physical Volume.

Physical Volume (PV) - The physical disk, or disk image.

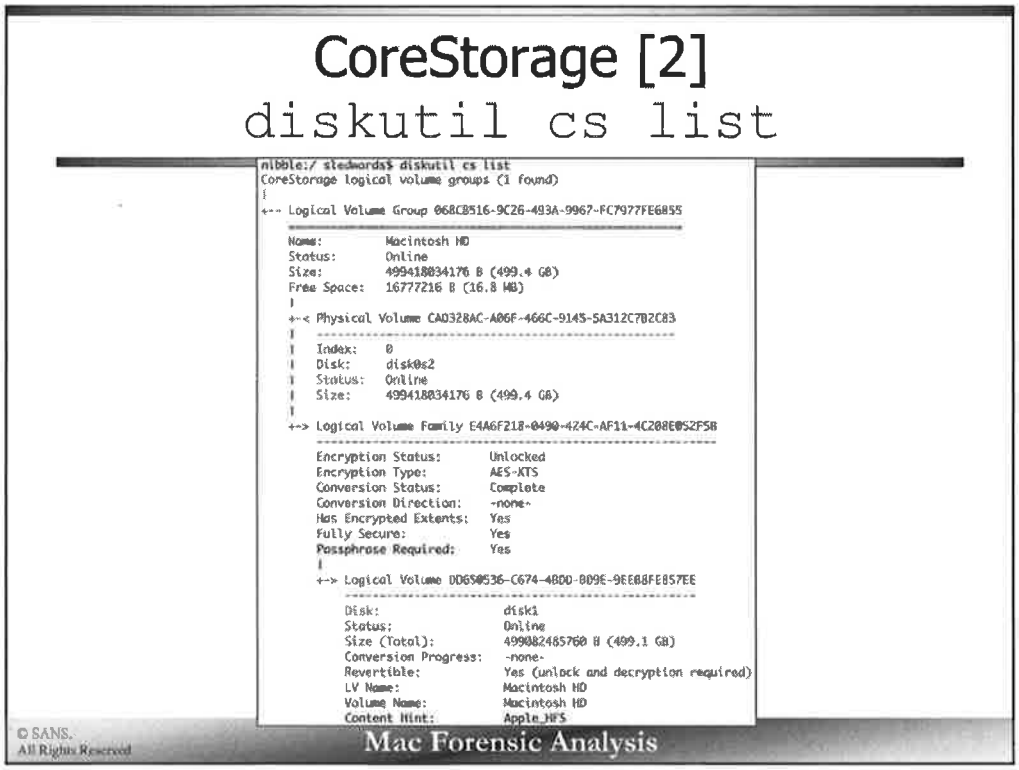
Logical Volume Family (LVF) – Contains one or more Logical Volumes.

Logical Volume (LV) – Where the file system is stored on a `/dev/disk*`.

As of 10.10, CoreStorage is now implemented by default on new installs of 10.10. Upgraded installs will not force CoreStorage to be implemented. This does not necessarily mean the volume is encrypted. CoreStorage can still be used without FileVault2.

References:

`diskutil` manpage



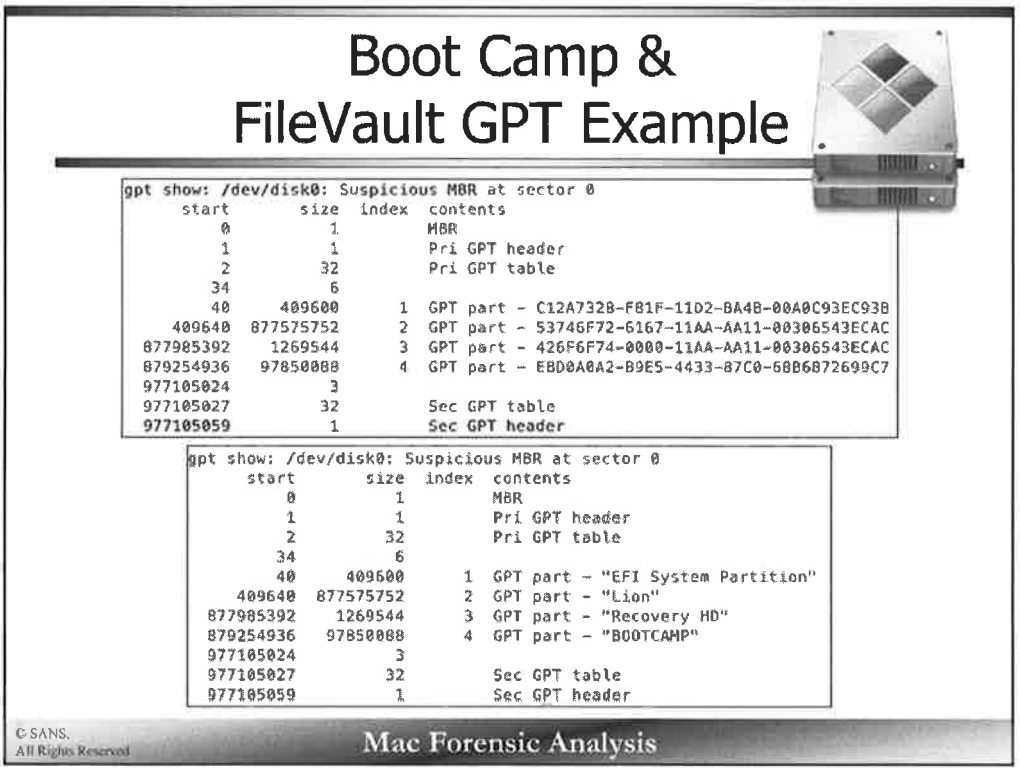
The screenshot shows the output from the `diskutil cs list` command. This command lists all the CoreStorage Logical Volume Groups.

This system has only one LVG for a 499.4GB physical disk. Each part (LVG, PV, LVF, LV) has their own UUID.

We can see from the information found in the LVF section, that this disk is encrypted with AES-XTS (FileVault2).

We can see from the information found in the LV section, this disk is currently unlocked, and could be decrypted if needed. The volume is named "`Macintosh HD`" and is 499.1GB is size.

```
nibble:/ sledwards$ diskutil cs list
CoreStorage logical volume groups (1 found)
|
+-- Logical Volume Group 068CB516-9C26-493A-9967-FC7977FE6855
    =========================================================
    Name:         Macintosh HD
    Status:       Online
    Size:         499418034176 B (499.4 GB)
    Free Space:   16777216 B (16.8 MB)
    |
    +-< Physical Volume CAD328AC-A06F-466C-9145-5A312C7B2C83
    |   ----------------------------------------------------
    |   Index:    0
    |   Disk:     disk0s2
    |   Status:   Online
    |   Size:     499418034176 B (499.4 GB)
    |
    +-> Logical Volume Family E4A6F218-0490-424C-AF11-4C208E052F5B
        ----------------------------------------------------------
        Encryption Status:       Unlocked
        Encryption Type:         AES-XTS
        Conversion Status:       Complete
        Conversion Direction:    -none-
        Has Encrypted Extents:   Yes
        Fully Secure:            Yes
        Passphrase Required:     Yes
        |
        +-> Logical Volume DD650536-C674-4BDD-BD9E-9EEB8FE857EE
            ---------------------------------------------------
            Disk:                  disk1
            Status:                Online
            Size (Total):          499082485760 B (499.1 GB)
            Conversion Progress:   -none-
            Revertible:            Yes (unlock and decryption required)
            LV Name:               Macintosh HD
            Volume Name:           Macintosh HD
            Content Hint:          Apple_HFS
```



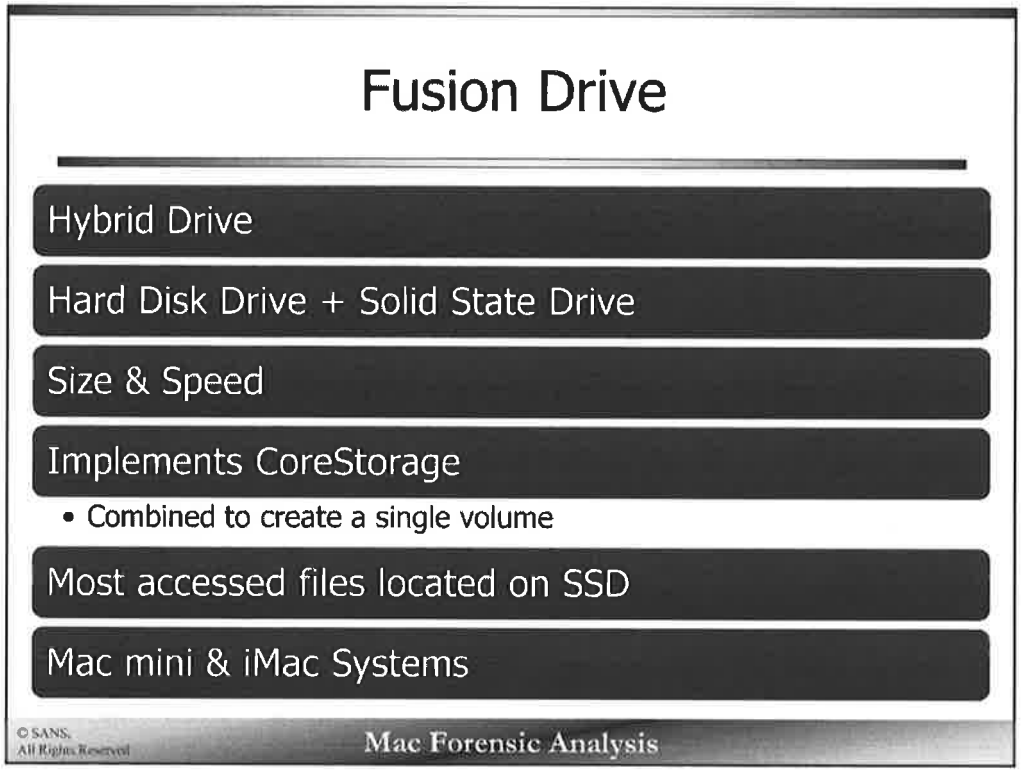
In the screenshots above, there is an example of a Boot Camp partition and a FileVault encrypted partition. This is the same disk with the `'-l'` option of the `gpt` command used in the bottom example.

- Boot Camp Volume GUID: `EBD0A0A2-B9E5-4433-87C0-68B6B72699C7`
- FileVault Volume GUID: `53746F72-6167-11AA-AA11-00306543ECAC`

The "`Suspicious MBR at sector 0`" message shown in the screenshots above validate that it is in fact a boot camped system. When a system is boot camped, meaning it has both an bootable OS X volume and a bootable Windows volume, it writes multiple entries to the MBR making it "suspicious".

```
gpt show: /dev/disk0: Suspicious MBR at sector 0
      start       size  index  contents
          0          1         MBR
          1          1         Pri GPT header
          2         32         Pri GPT table
         34          6
         40     409600      1  GPT part - C12A7328-F81F-11D2-BA4B-00A0C93EC93B
     409640  877575752      2  GPT part - 53746F72-6167-11AA-AA11-00306543ECAC
  877985392    1269544      3  GPT part - 426F6F74-0000-11AA-AA11-00306543ECAC
  879254936   97850088      4  GPT part - EBD0A0A2-B9E5-4433-87C0-68B6B72699C7
  977105024          3
  977105027         32         Sec GPT table
  977105059          1         Sec GPT header
```

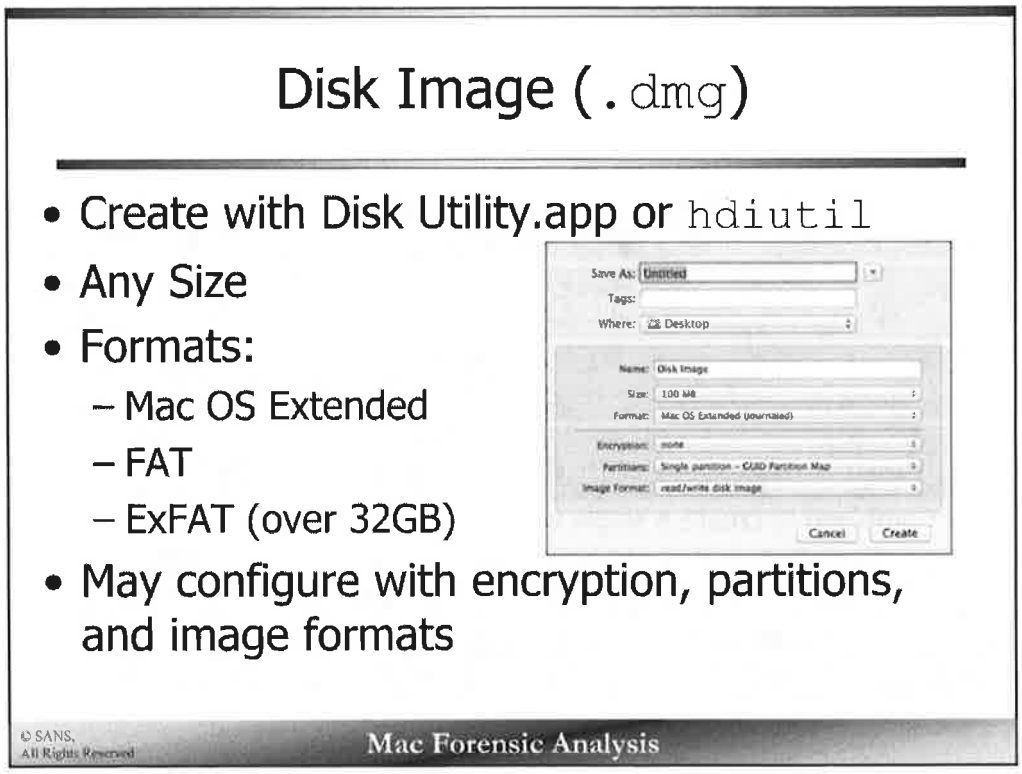
```
gpt show: /dev/disk0: Suspicious MBR at sector 0
      start       size  index  contents
          0          1         MBR
          1          1         Pri GPT header
          2         32         Pri GPT table
         34          6
         40     409600      1  GPT part - "EFI System Partition"
     409640  877575752      2  GPT part - "Lion"
  877985392    1269544      3  GPT part - "Recovery HD"
  879254936   97850088      4  GPT part - "BOOTCAMP"
  977105024          3
  977105027         32         Sec GPT table
  977105059          1         Sec GPT header
```



The Fusion Drive comes with only a few specific systems; late model MacMinis and iMacs.

These drives use a combination of a normal hard disk drive and a solid state drive to get the best of speed and drive size.

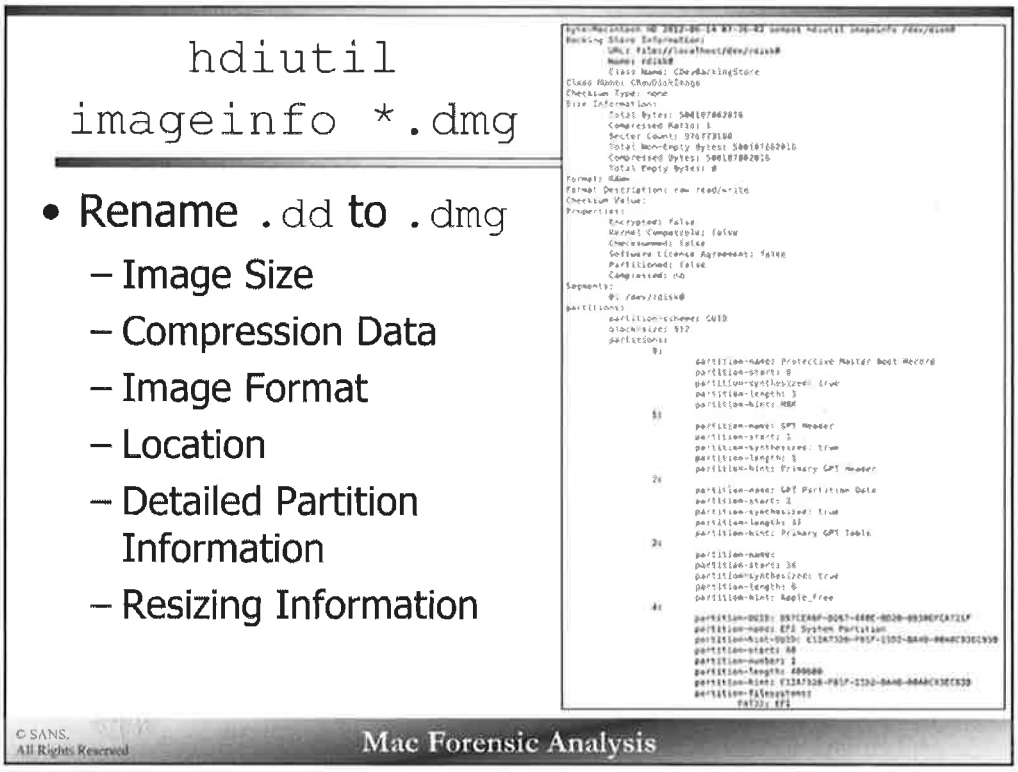
To create a present a single volume to the user, CoreStorage is implemented. The most used files are located on the physical SSD hard drive to speed up file access.



Likely the most well known volume is the DMG file, or Disk Image file. Mac systems use this format for everything from software installation to simple data archives.

Disk Image files can be any size and any format that `hdiutil` or Disk Utility.app can implement; HFS+, FAT or ExFAT.

These volumes can mix and match various types of encryption, partitions and image formats. Please refer to the options listed using the command `hdiutil create -help` or review the options in Disk Utility.app.



The `hdiutil` command is used to interface with disk image files (`*.dmg`) or disk device (`/dev/disk#`).

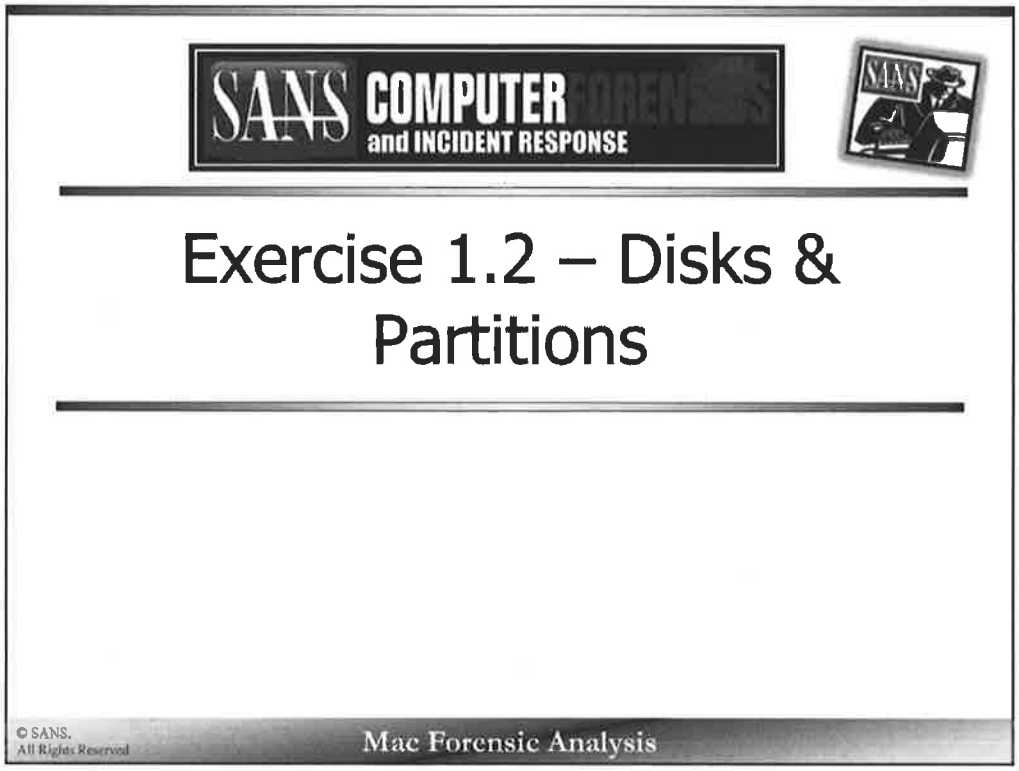
This command must be run with a `*.dmg` file, if you have a raw DD file you can add a `.dmg` extension.

The `imageinfo` parameter is used to display information about the disk image. (Due to the verbose output the screenshot had to be shortened to fit on the slide.)

Information that can be gleaned from an image include:

- Image Size (in bytes)
- Data about the compression, this image was not compressed.
- Image Format – this example is labeled UDRW or RAW Read/Write
  - A list of formats can be viewed in the man page for `hdiutil`
- Image location
- Detailed Partition Information
  - Partition Name
  - Start Block
  - Length (in blocks)
  - Partition Hint – Type of Partition
  - Partition Hint UUID (unique to type of partition)
  - Partition UUID (unique to partition)
  - File System (HFS+, FAT32, etc.)
- Image file resizing information - Can be used to shrink a volume

```
byte:Macintosh HD 2012-06-14 07-36-02 oompa$ hdiutil imageinfo /dev/disk0
Backing Store Information:
        URL: file://localhost/dev/rdisk0
        Name: rdisk0
        Class Name: CDevBackingStore
Class Name: CRawDiskImage
Checksum Type: none
Size Information:
        Total Bytes: 500107862016
        Compressed Ratio: 1
        Sector Count: 976773168
        Total Non-Empty Bytes: 500107862016
        Compressed Bytes: 500107862016
        Total Empty Bytes: 0
Format: RAW*
Format Description: raw read/write
Checksum Value:
Properties:
        Encrypted: false
        Kernel Compatible: false
        Checksummed: false
        Software License Agreement: false
        Partitioned: false
        Compressed: no
Segments:
        0: /dev/rdisk0
partitions:
        partition-scheme: GUID
        block-size: 512
        partitions:
                0:
                        partition-name: Protective Master Boot Record
                        partition-start: 0
                        partition-synthesized: true
                        partition-length: 1
                        partition-hint: MBR
                1:
                        partition-name: GPT Header
                        partition-start: 1
                        partition-synthesized: true
                        partition-length: 1
                        partition-hint: Primary GPT Header
                2:
                        partition-name: GPT Partition Data
                        partition-start: 2
                        partition-synthesized: true
                        partition-length: 32
                        partition-hint: Primary GPT Table
                3:
                        partition-name:
                        partition-start: 34
                        partition-synthesized: true
                        partition-length: 6
                        partition-hint: Apple_Free
                4:
                        partition-UUID: D97CE46F-D267-440E-8D20-8930EFCA721F
                        partition-name: EFI System Partition
                        partition-hint-UUID: C12A7328-F81F-11D2-BA4B-00A0C93EC93B
                        partition-start: 40
                        partition-number: 1
                        partition-length: 409600
                        partition-hint: C12A7328-F81F-11D2-BA4B-00A0C93EC93B
                        partition-filesystems:
                                FAT32: EFI
```



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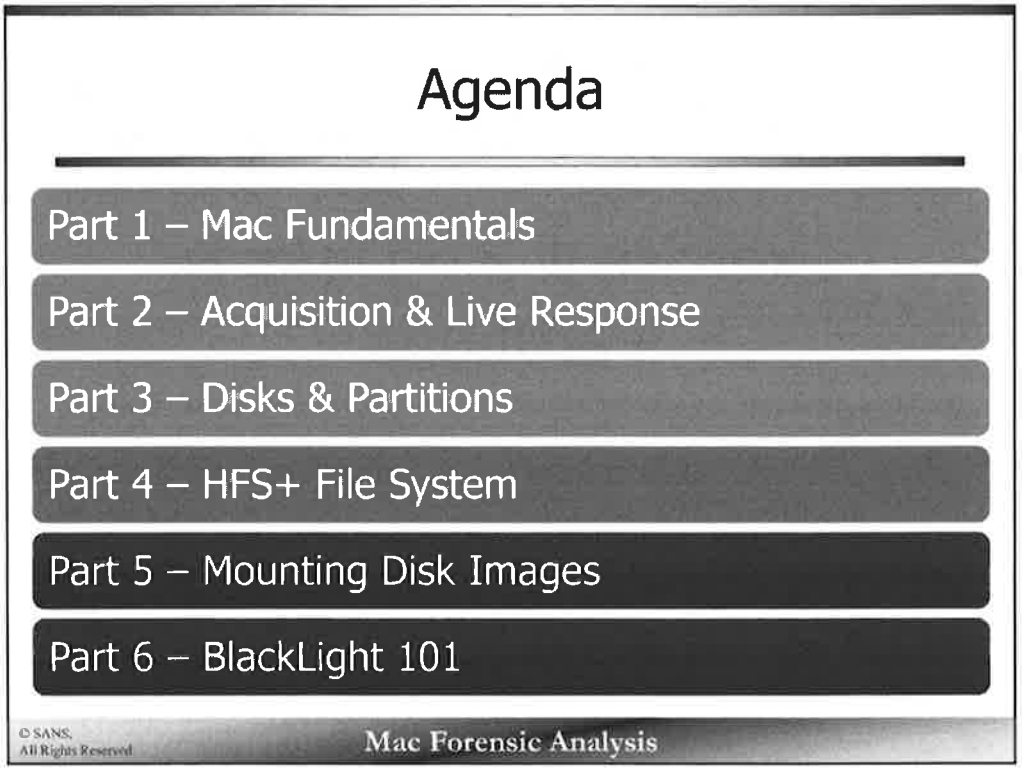

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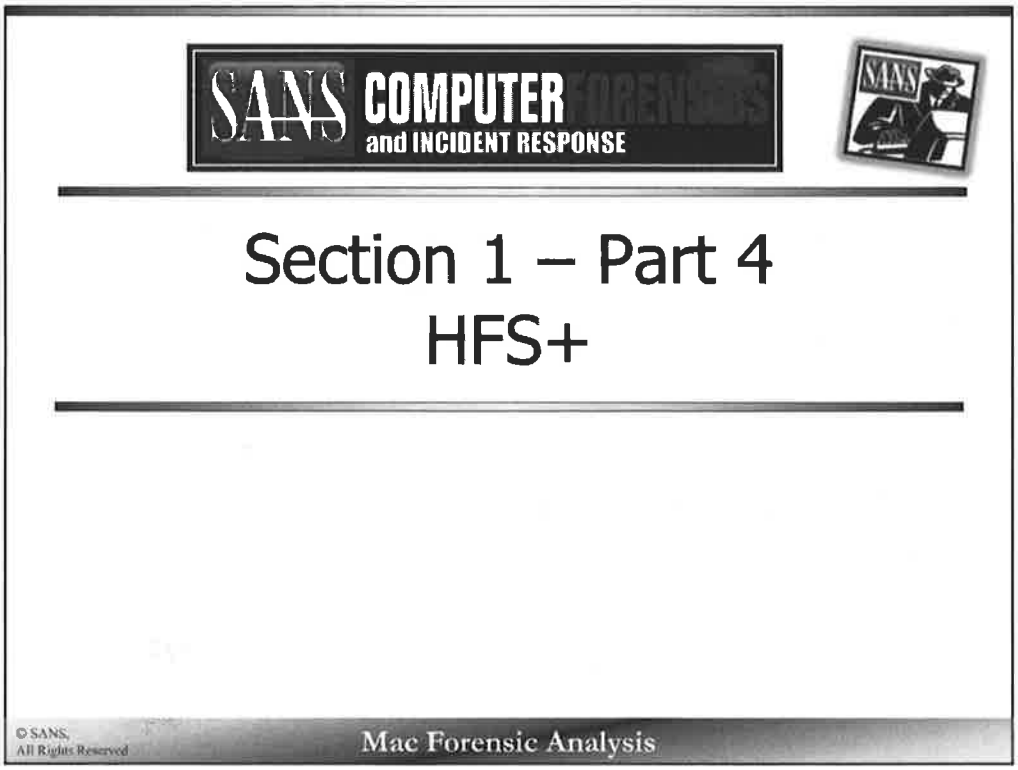

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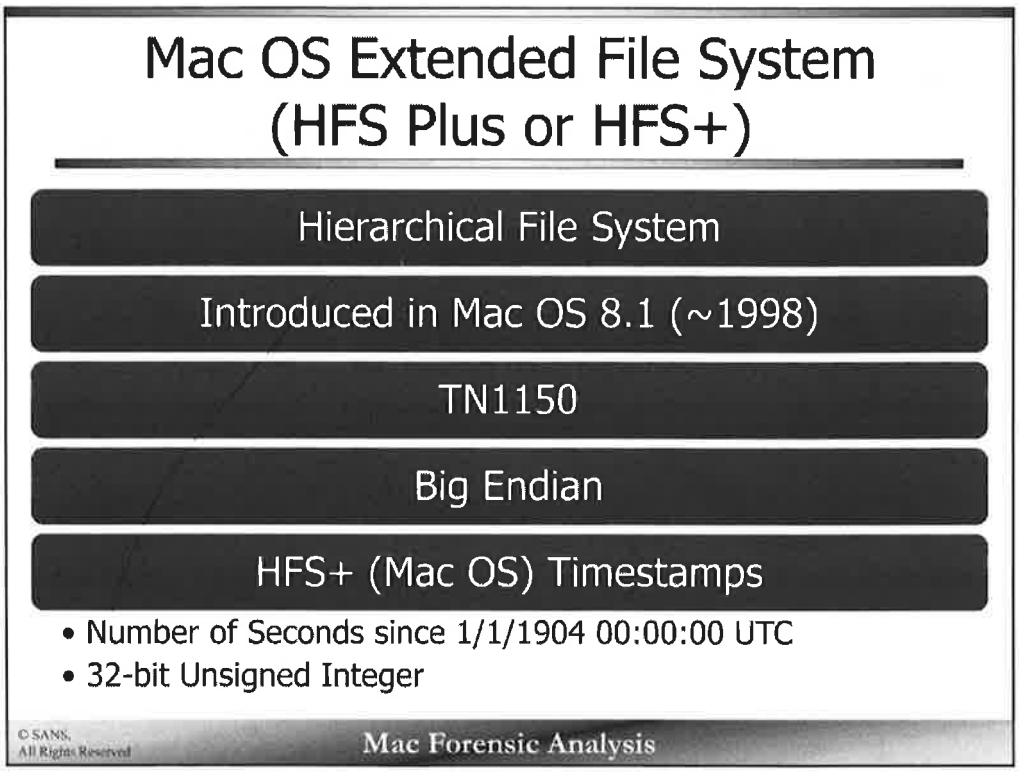

The Mac OS Extended File System is more widely known as Hierarchal File System (HFS+), or HFS Plus. HFS+ was introduced when HFS (Mac OS Standard File System) was limiting the size of the installation media. HFS+ is able to install on larger volumes, have longer filenames, larger file sizes, and more file metadata.

This file system was introduced in Mac OS 8.1, long before Mac OS X.

A very well known Technical Note (at least to nerdy Mac forensicators) is TN1150, the HFS Plus Volume Format. This document explains the technical intricacies of the HFS+ file system and goes into great detail. The document can be found in the Mac Developer Library.
[https://developer.apple.com/legacy/library/technotes/tn/tn1150 or
http://dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html]

Note: HFS+ data uses big-endian

TN1150 will be used as the main reference for the HFS+ file system module of this class.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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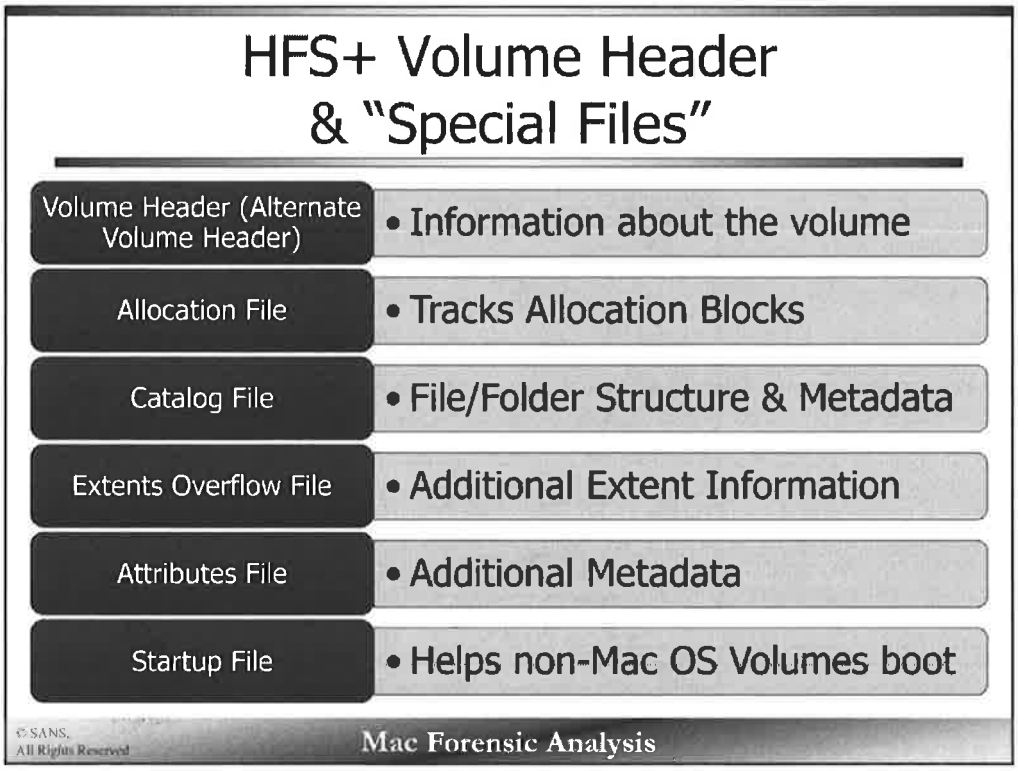

HFS+ is comprised of five "special files" and the HFS+ volume header.

The special files are:

- Allocation File
- Catalog File
- Extents Overflow File
- Attributes File
- Startup File

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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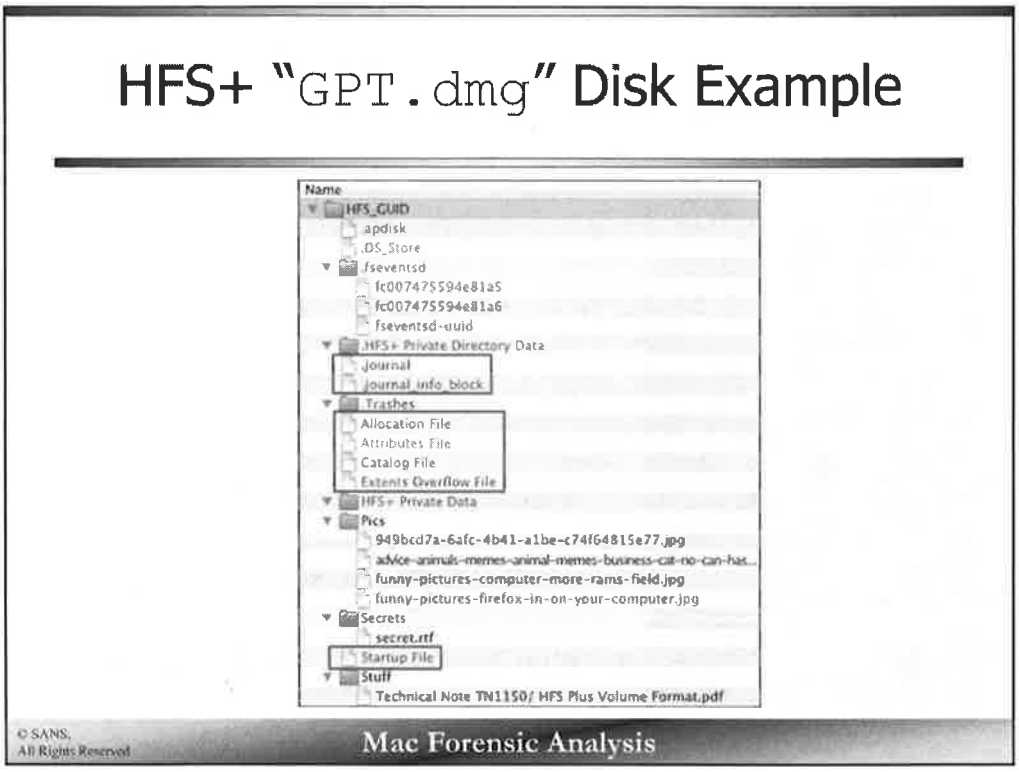


The screenshot shows our example disk image file, `GPT.dmg` that we will use in class.

The GPT.dmg disk was opened in the forensic software Blacklight to show all the files on the disk.

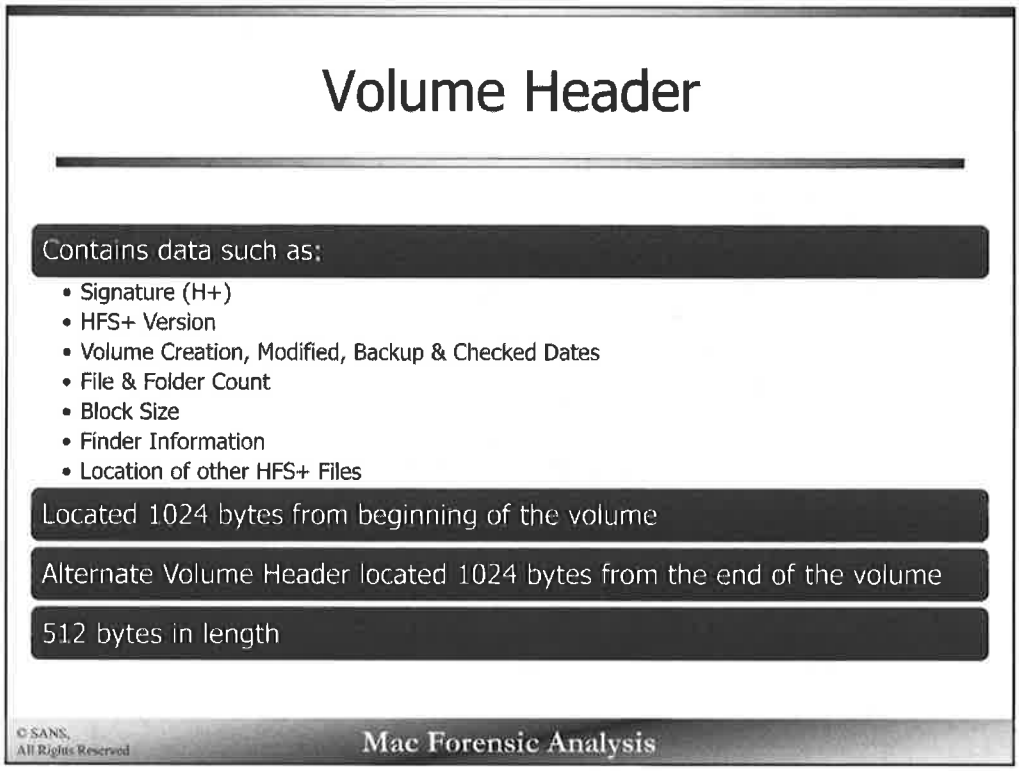
Highlighted in the boxes are the HFS+ Special Files and the Journal files:

- Allocation File
- Attributes File
- Catalog File
- Extents Overflow File
- Startup File
- Journal Files (`.journal` and `.journal_info_block`)

These files are not normally accessible by the user, hence they are greyed out in the screenshot above.

We will be looking at these files in detail in the next few sections.

This disk contains a volume (partition) named "`HFS_GUID`" that contains three user-created directories containing files; `Pics`, `Secrets`, and `Stuff`.



The volume header is located 1024 bytes from the beginning of the volume, while the alternate volume header is located 1024 bytes from the end of the volume. The volume header itself is 512 bytes in size.

The volume header contains information about the volume and the locations of each of the HFS+ "special files".

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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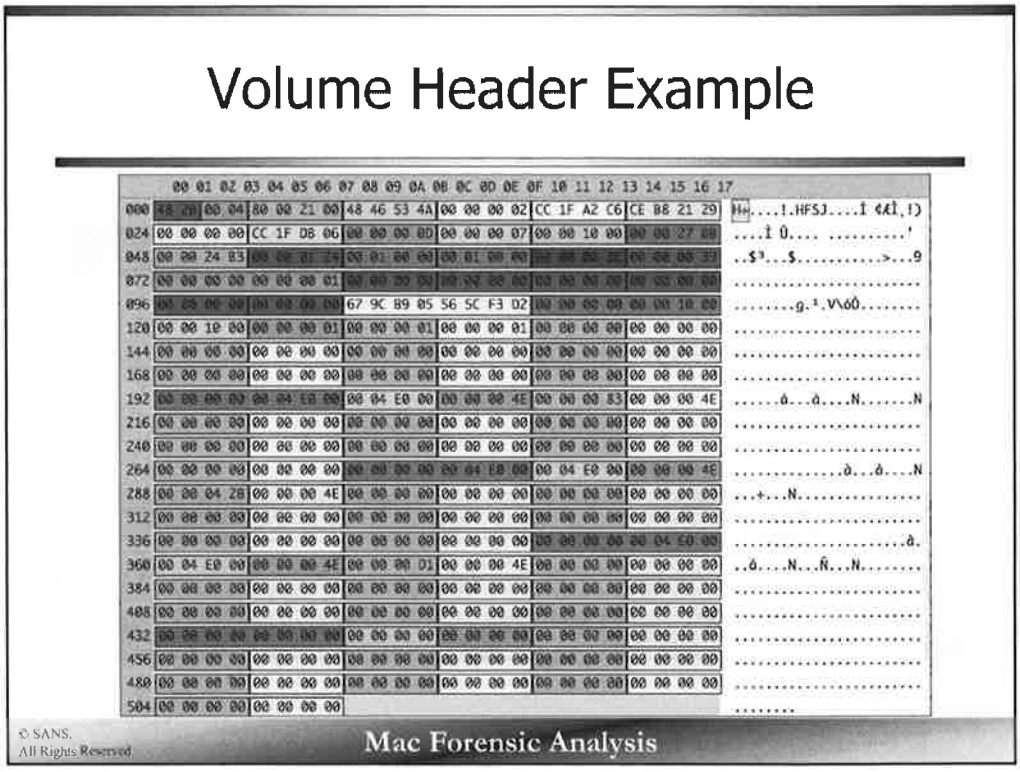

The volume header contains the following notable fields:

- Offset 0 - The signature for the file system, H+ for HFS+. You may also see HX, for HFS+ with case sensitivity, on iOS devices.
- Offset 16 – The volume's creation date. (Stored in local time)
- Offset 20 – Last modification date of the volume. (Stored in GMT)
- Offset 32 – Number of files on the volume.
- Offset 36– Number of folders on the volume.
- Offset 40 – Allocation Block Size (4096 bytes)
- Offset 112 – Location and size of Allocation File.
- Offset 192 – Location and size of Extents Overflow File.
- Offset 272 – Location and size of Catalog File.
- Offset 352 – Location and size of Attributes File.
- Offset 432 – Location and size of Startup File.

Note: HFS+ data uses big-endian

Note: Only the Volume Creation Date stored as local time, all other dates in the volume header are stored as GMT.

This screenshot was created with the Synalyze It! Application.

Offset	Size (in bytes)	Data
0	2	Signature
2	2	Version
4	4	Attributes
8	4	Last Mounted Version
12	4	Journal Info Block
16	4	Create Date
20	4	Modify Date
24	4	Backup Date
28	4	Checked Date
32	4	File Count
36	4	Folder Count
40	4	Block Size
44	4	Total Blocks
48	4	Free Blocks
52	4	Next Allocation
56	4	rsrc Clump Size
60	4	Data Clump Size
64	4	Next Catalog ID
68	4	Write Count
72	8	Encoding Bitmap
80	4	Finder Info Array [0]
84	4	Finder Info Array [1]
88	4	Finder Info Array [2]
92	4	Finder Info Array [3]
96	4	Finder Info Array [4]
100	4	Finder Info Array [5]
104	4	Finder Info Array [6]
108	4	Finder Info Array [7]
112	80	Allocation File Size & Location
192	80	Extents File Size & Location
272	80	Catalog File Size & Location
352	80	Attributes File Size & Location
432	80	Startup File Size & Location

The "size and location" field of each of the HFS+ Special Files have the format shown in the table. Each entry consists of a logical size, a clump size, total number of blocks and an array containing the size and length of each extent of the file. If there are more than eight extents, it will be located in the Extents Overflow File.

Offset	Size (in bytes)	Data
0	8	Logical Size
8	4	Clump Size
12	4	Total Blocks
16	4	Extent 1 – Start Block
20	4	Extent 1 – Block Count
24	4	Extent 2 – Start Block
28	4	Extent 2 – Block Count
32	4	Extent 3 – Start Block
36	4	Extent 3 – Block Count
40	4	Extent 4 – Start Block
44	4	Extent 4 – Block Count
48	4	Extent 5 – Start Block
52	4	Extent 5 – Block Count
56	4	Extent 6 – Start Block
60	4	Extent 6 – Block Count
64	4	Extent 7 – Start Block
68	4	Extent 7 – Block Count
72	4	Extent 8 – Start Block
76	4	Extent 8 – Block Count

HFS+ Dates & Times

The dates and times in HFS+ are unique to HFS. This value represents the number of seconds since 1/1/1904 at midnight or 00:00:00.

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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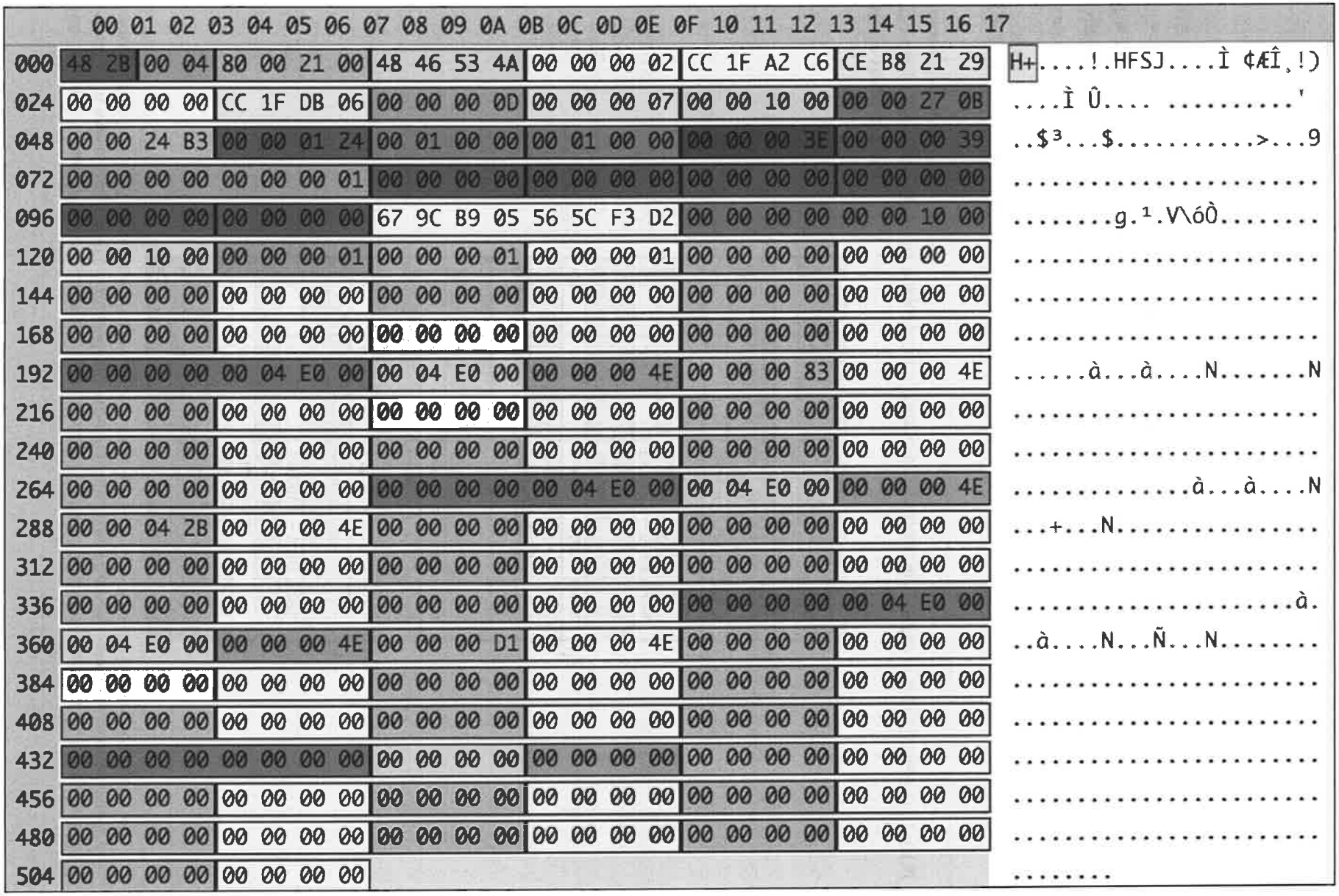
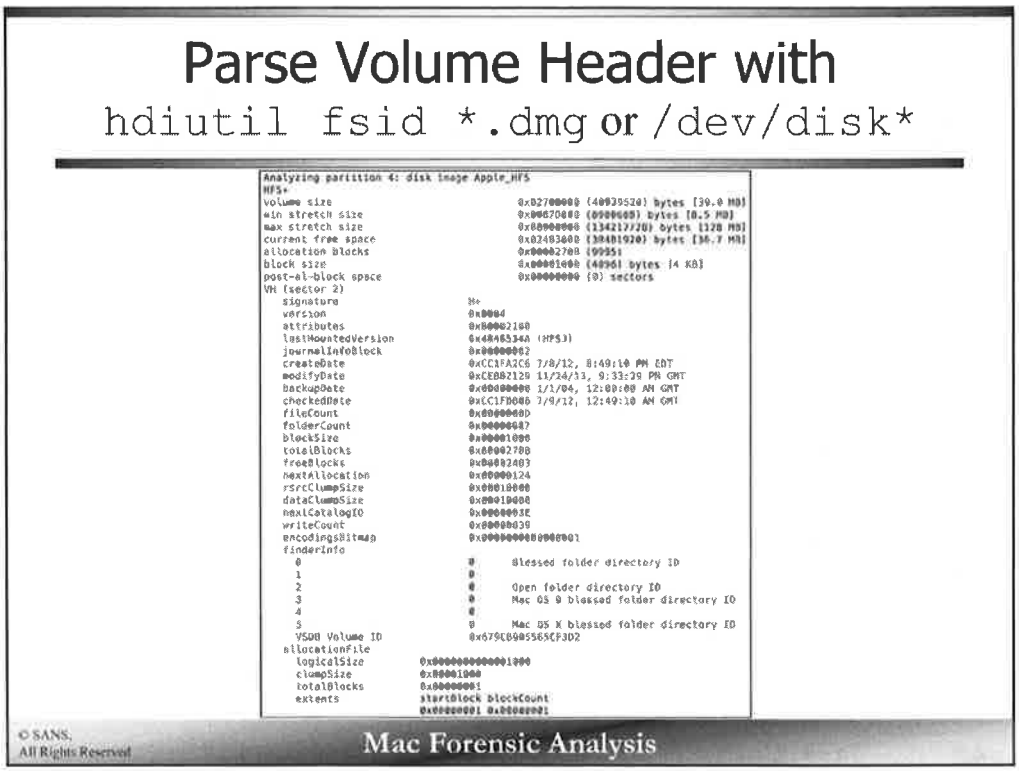


	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	10	11	12	13	14	15	16	17
000	48	2B	00	04	80	00	21	00	48	46	53	4A	00	00	00	02	CC	1F	A2	C6	CE	B8	21	29
024	00	00	00	00	CC	1F	DB	06	00	00	00	0D	00	00	00	07	00	00	10	00	00	00	27	0B
048	00	00	24	B3	00	00	01	24	00	01	00	00	00	01	00	00	00	00	00	3E	00	00	00	39
072	00	00	00	00	00	00	00	01	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
096	00	00	00	00	00	00	00	00	67	9C	B9	05	56	5C	F3	D2	00	00	00	00	00	00	10	00
120	00	00	10	00	00	00	00	01	00	00	00	01	00	00	00	01	00	00	00	00	00	00	00	00
144	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
168	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
192	00	00	00	00	00	04	E0	00	00	04	E0	00	00	00	00	4E	00	00	00	83	00	00	00	4E
216	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
240	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
264	00	00	00	00	00	00	00	00	00	00	00	00	00	04	E0	00	00	04	E0	00	00	00	00	4E
288	00	00	04	2B	00	00	00	4E	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
312	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
336	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	04	E0	00
360	00	04	E0	00	00	00	00	4E	00	00	00	D1	00	00	00	4E	00	00	00	00	00	00	00	00
384	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
408	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
432	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
456	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
480	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
504	00	00	00	00	00	00	00	00																

000	H+....!.HFSJ....Ì ¢ÆÎ¸!)
024	....Ì Û.... .....'
048	..$³...$.....>...9
072	.....
096	........g.¹.V\óÒ.....
120	.....
144	.....
168	.....
192	......à...à....N.....N
216	.....
240	.....
264	.....à...à....N
288	...+...N.....
312	.....
336	.....à.
360	..à....N...Ñ...N.....
384	.....
408	.....
432	.....
456	.....
480	.....
504	.....

Pos...	Off...	Element	Value
0	0	▼HFS+ Volume Header [0]	
0	0	Disk Signature	H+
2	+2	Version	4
4	+4	Attributes	80 00 21 00
8	+8	Last Mounted Version	HFSJ
12	+12	Journal Info Block	2
16	+16	Create Date	3424625350
20	+20	Modify Date	3468173609
24	+24	Backup Date	0
28	+28	Checked Date	3424639750
32	+32	File Count	13
36	+36	Folder Count	7
40	+40	Block Size	4096
44	+44	Total Blocks	9995
48	+48	Free Blocks	9395
52	+52	Next Allocation	292
56	+56	RSRC Clump Size	65536
60	+60	Data Clump Size	65536
64	+64	Next Catalog ID	62
68	+68	Write Count	57
72	+72	Encoding Bitmap	00 00 00 00 00 00 00 01
80	+80	Finder Info Array [0]	0
84	+84	Finder Info Array [1]	0
88	+88	Finder Info Array [2]	0
92	+92	Finder Info Array [3]	0
96	+96	Finder Info Array [4]	0
100	+100	Finder Info Array [5]	0
104	+104	VSDB Volume ID Finder Info Array [6,7]	0x679CB905565CF3D2
112	+112	▶ForkData [0]	
192	+192	▶ForkData [1]	
272	+272	▶ForkData [2]	
352	+352	▶ForkData [3]	
432	+432	▶ForkData [4]	



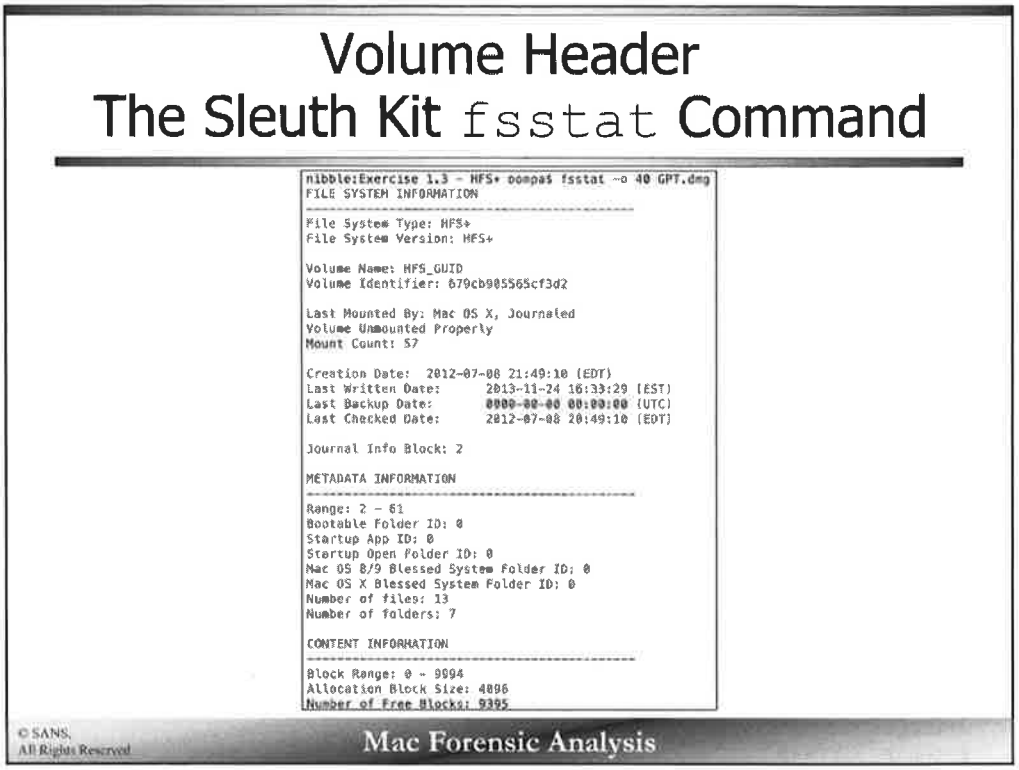
An easy way to view the volume header is to use the `hdiutil fsid` command on a DMG file or on a disk using `/dev/disk*`. This is the volume header information for `GPT.dmg`.

This command must be run with a `*.dmg` file, if you have a raw DD file you can add a `.dmg` extension.

Due to its verbosity, only a section of this output is shown.

Reference:
`hdiutil` Man Page

```
Analyzing partition 4: disk image Apple_HFS
HFS+
volume size                             0x0270B000 (40939520) bytes [39.0 MB]
min stretch size                        0x0087D000 (8900608) bytes [8.5 MB]
max stretch size                        0x08000000 (134217728) bytes [128 MB]
current free space                      0x024B3000 (38481920) bytes [36.7 MB]
allocation blocks                       0x0000270B (9995)
block size                              0x00001000 (4096) bytes [4 KB]
post-al-block space                     0x00000000 (0) sectors
VH (sector 2)
   signature                    H+
   version                      0x0004
   attributes                   0x80002100
   lastMountedVersion           0x4846534A (HFSJ)
   journalInfoBlock             0x00000002
   createDate                   0xCC1FA2C6 7/8/12, 8:49:10 PM EDT
   modifyDate                   0xCEB82129 11/24/13, 9:33:29 PM GMT
   backupDate                   0x00000000 1/1/04, 12:00:00 AM GMT
   checkedDate                  0xCC1FDB06 7/9/12, 12:49:10 AM GMT
   fileCount                    0x0000000D
   folderCount                  0x00000007
   blockSize                    0x00001000
   totalBlocks                  0x0000270B
   freeBlocks                   0x000024B3
   nextAllocation               0x00000124
   rsrcClumpSize                0x00010000
   dataClumpSize                0x00010000
   nextCatalogID                0x0000003E
   writeCount                   0x00000039
   encodingsBitmap              0x0000000000000001
   finderInfo
     0                          0      Blessed folder directory ID
     1                          0
     2                          0      Open folder directory ID
     3                          0      Mac OS 9 blessed folder directory ID
     4                          0
     5                          0      Mac OS X blessed folder directory ID
     VSDB Volume ID             0x679CB905565CF3D2
   allocationFile
     logicalSize          0x0000000000001000
     clumpSize            0x00001000
     totalBlocks          0x00000001
     extents              startBlock blockCount
                          0x00000001 0x00000001
   extentsFile
     logicalSize          0x000000000004E000
     clumpSize            0x0004E000
     totalBlocks          0x0000004E
     extents              startBlock blockCount
                          0x00000083 0x0000004E
   catalogFile
     logicalSize          0x000000000004E000
     clumpSize            0x0004E000
     totalBlocks          0x0000004E
     extents              startBlock blockCount
                          0x0000042B 0x0000004E
   attributesFile
     logicalSize          0x000000000004E000
     clumpSize            0x0004E000
     totalBlocks          0x0000004E
     extents              startBlock blockCount
                          0x000000D1 0x0000004E
   startupFile
     logicalSize          0x0000000000000000
     clumpSize            0x00000000
     totalBlocks          0x00000000
     extents              startBlock blockCount
```



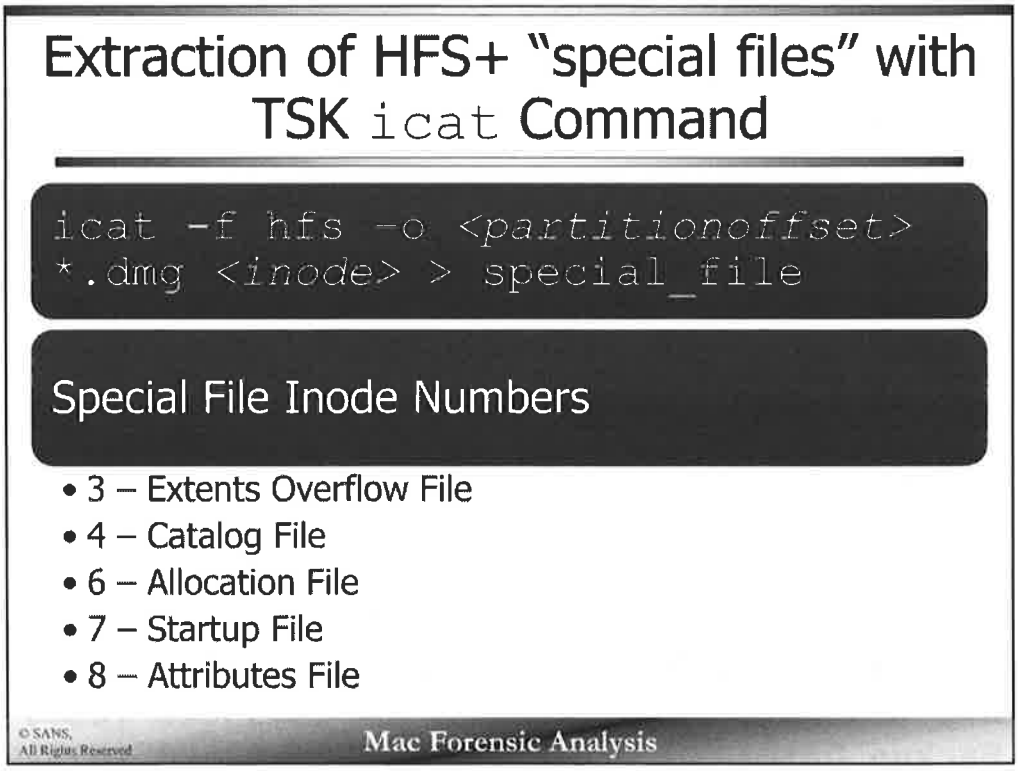
Another way we can view some of the volume header information is to use The Sleuth Kit `fsstat` command. While this does not contain the size and location of the HFS+ special files – it does give us a concise view of the volume including timestamps, volume name, format and file/folder information.

This command can be used on a disk image or on a live system using the raw disk device (`/dev/rdisk#`)

Reference:

`fsstat` Man Page

```
nibble:Exercise 1.3 - HFS+ oompa$ fsstat -o 40 GPT.dmg
FILE SYSTEM INFORMATION
--------------------------------------------
File System Type: HFS+
File System Version: HFS+

Volume Name: HFS_GUID
Volume Identifier: 679cb905565cf3d2

Last Mounted By: Mac OS X, Journaled
Volume Unmounted Properly
Mount Count: 57

Creation Date:  2012-07-08 21:49:10 (EDT)
Last Written Date:      2013-11-24 16:33:29 (EST)
Last Backup Date:       0000-00-00 00:00:00 (UTC)
Last Checked Date:      2012-07-08 20:49:10 (EDT)

Journal Info Block: 2

METADATA INFORMATION
--------------------------------------------
Range: 2 - 61
Bootable Folder ID: 0
Startup App ID: 0
Startup Open Folder ID: 0
Mac OS 8/9 Blessed System Folder ID: 0
Mac OS X Blessed System Folder ID: 0
Number of files: 13
Number of folders: 7

CONTENT INFORMATION
--------------------------------------------
Block Range: 0 - 9994
Allocation Block Size: 4096
Number of Free Blocks: 9395
```

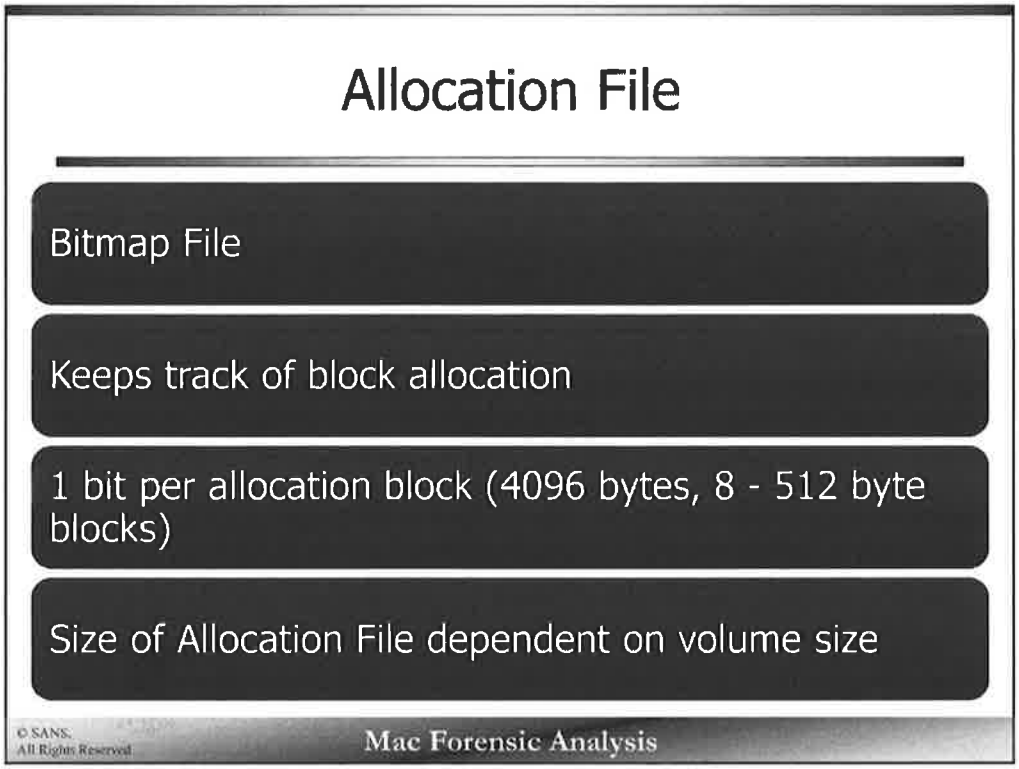


The following slides describe the special files and how they are laid out. Each of these special files has their own "inode" or Catalog Node ID (CNID). Apple has reserved the first 16 CNIDs for special files, some of which are listed above.

Some forensic tools do not allow access to these files as they are "system" files. Each special file can be accessed and extracted by their CNID using the `icat` command from Sleuthkit. Extraction of these files may be useful if you need to do additional analysis on them.

To extract the Allocation File you would use the following command:

```
icat -f hfs -o 409640 lion_macbook.dmg 6 > allocation_file
```



The Allocation File is used to track which blocks on a volume are allocated (or not). The size of this file is dependent of the size of the volume.

The Allocation File uses a bitmap format to store its data. Each 512 byte block is represented by one bit. The file tracks eight blocks at a time, or 4,096 bytes.

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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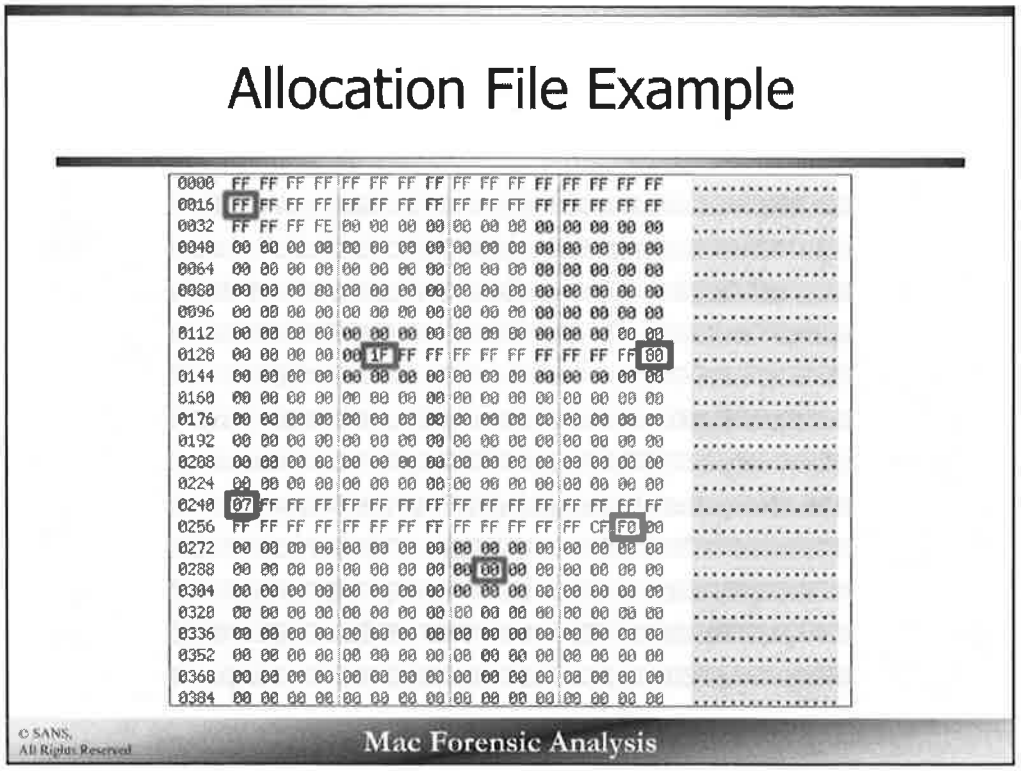
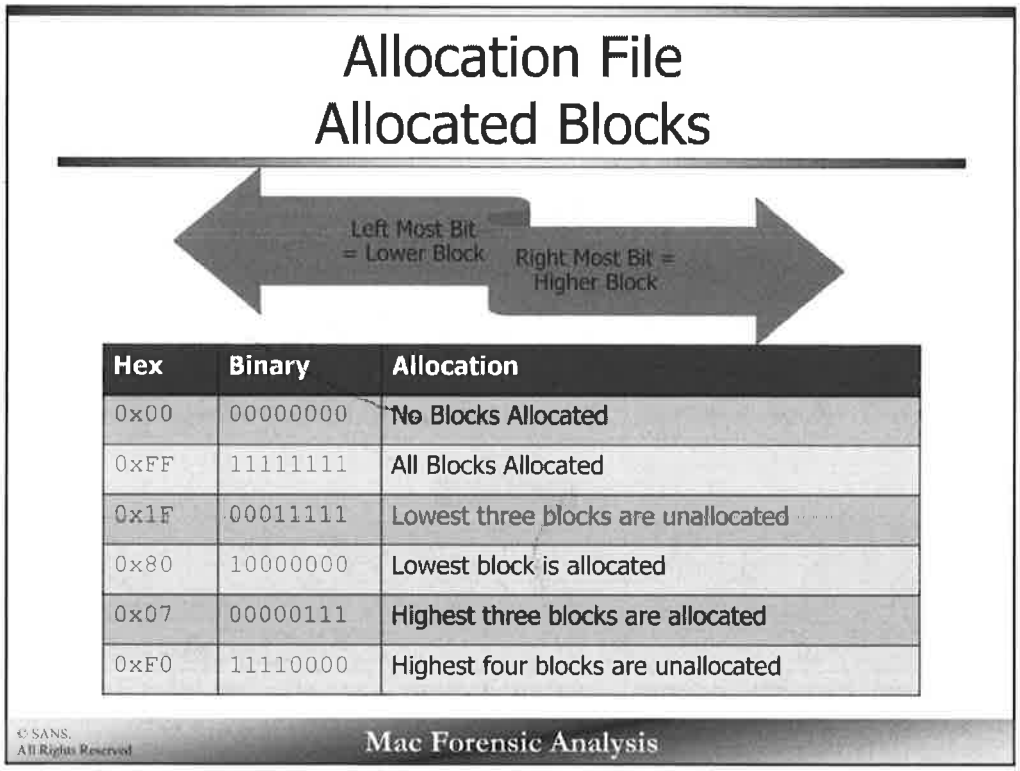


In the Allocation File example above, the highlighted blocks contain the tracking status for the specific eight blocks that are assigned to that byte.



Each byte in the Allocation File is organized as follows:

- The **left most bit** contains the status of the block with the **lowest** number.
- The **right most bit** contains the status of the block with the **highest** number.

In the table above, the examples from the previous screenshot are shown in binary to demonstrate which blocks are allocated and which are not.

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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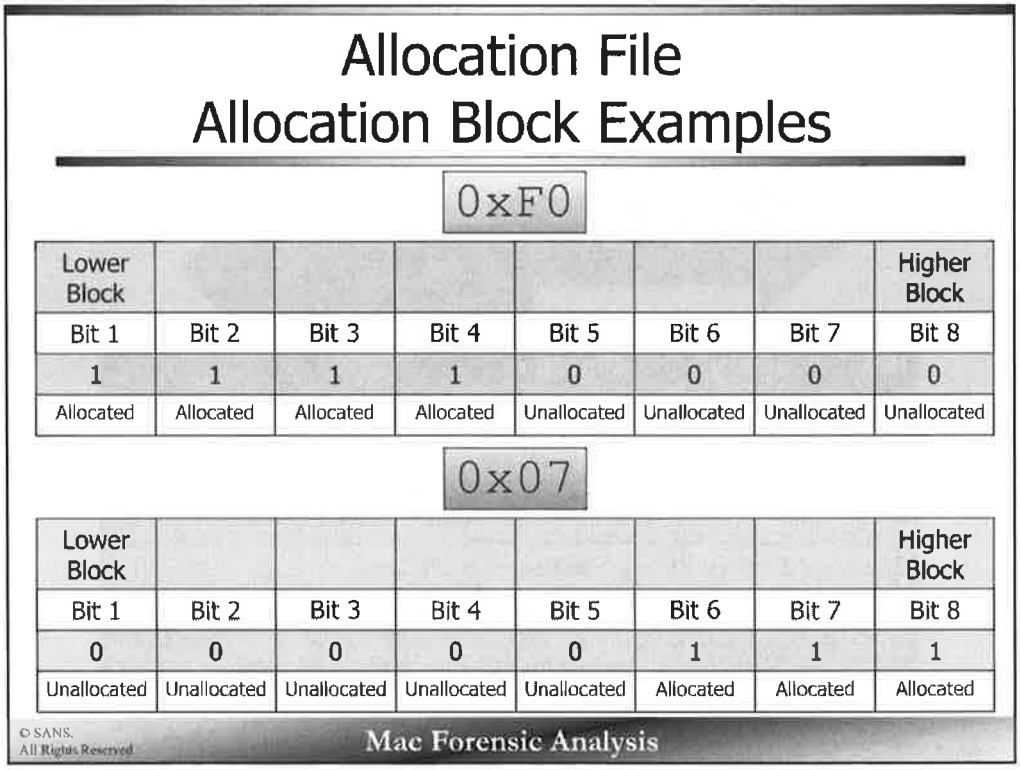

Each byte in the Allocation File is organized as follows:

- The **most** significant bit contains the status of the block with the **lowest** number.
- The **least** significant bit contains the status of the block with the **highest** number.

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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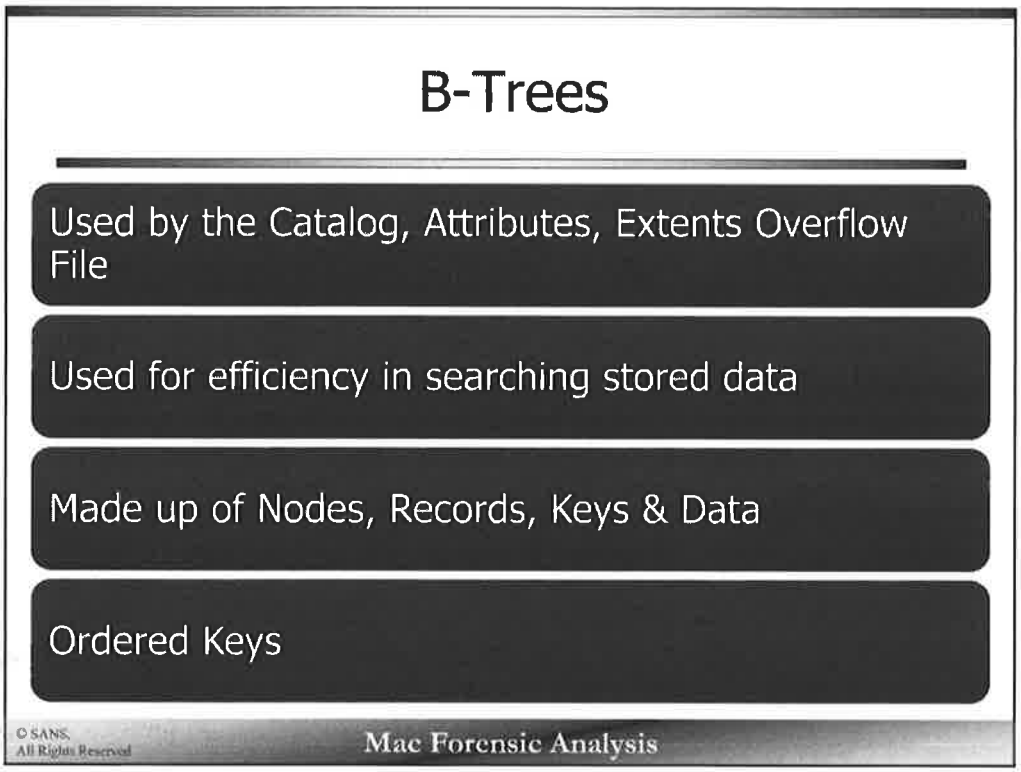

The balanced tree or B-tree structure is used by the three HFS+ special files.

- Catalog File
- Attributes File
- Extents Overflow File

The B-tree structure is used to efficiently search the records in the tree where file system data is stored. A B-tree is made up of nodes, records, keys, and data. The data is ordered by keys.

This B-tree concept is not very easy to understand and takes time and patience to grasp the structure of B-trees and their purpose in the HFS+ file system.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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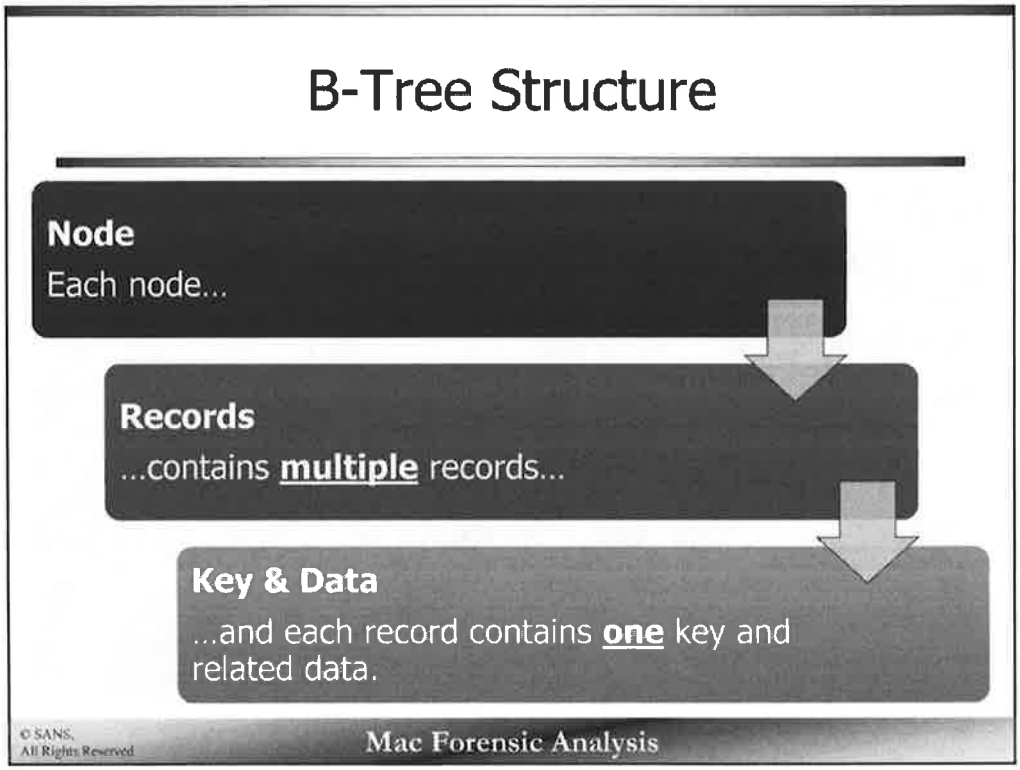

The B-tree structure is made up of nodes, records, keys, and data.

Each **node** may contain *multiple* records.
Each **record** contains only *one* **key and data**.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
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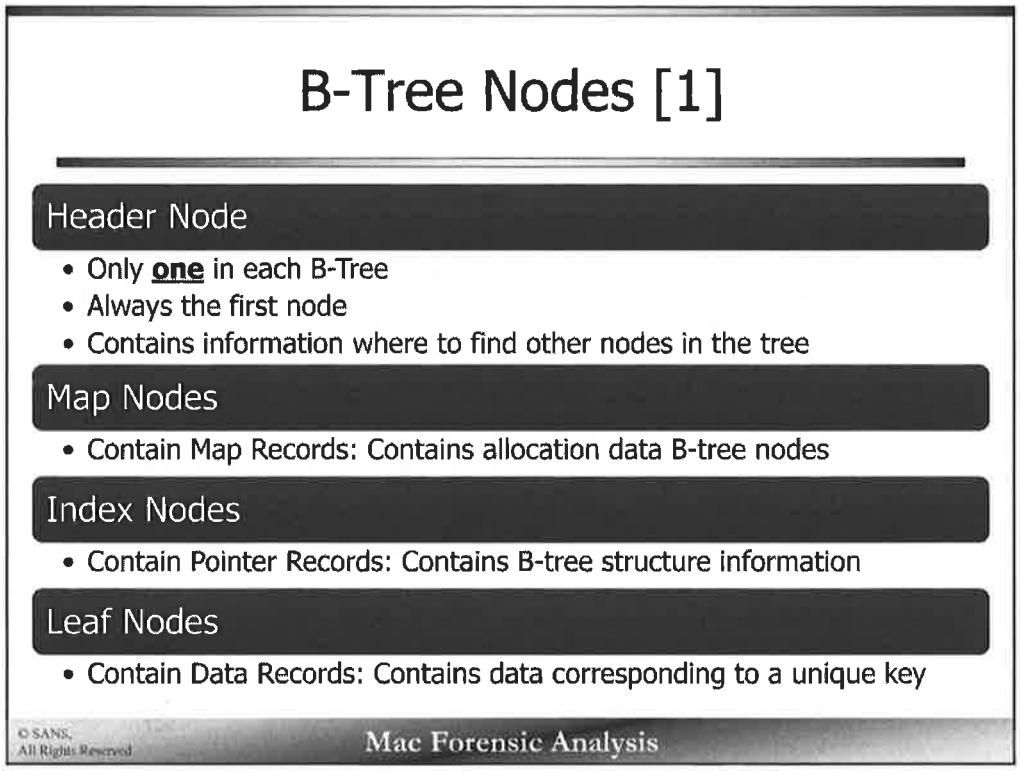
Mac OS X and iOS Internals: To the Apple's Core by Jonathan Levin – Chapter 16



A B-tree uses four types of nodes:

- Header Node
- Map Nodes
- Index Nodes
- Leaf Nodes

There is only one Header Node in each B-tree. There is **only one** Header Node for each of the Catalog, Attributes, and Extents Overflow files. The Header Node is always the first node in the B-tree, it contains information on how to find other nodes in the B-tree.

Map Nodes contain **Map Records**. These records contain allocation data of B-tree nodes.

Index Nodes contain **Pointer Records**. These records contain B-tree structure information.

Leaf Nodes contain **Data Records**. These records contain data corresponding to a unique key.

Each node type has a standard structure that is the same across all nodes.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
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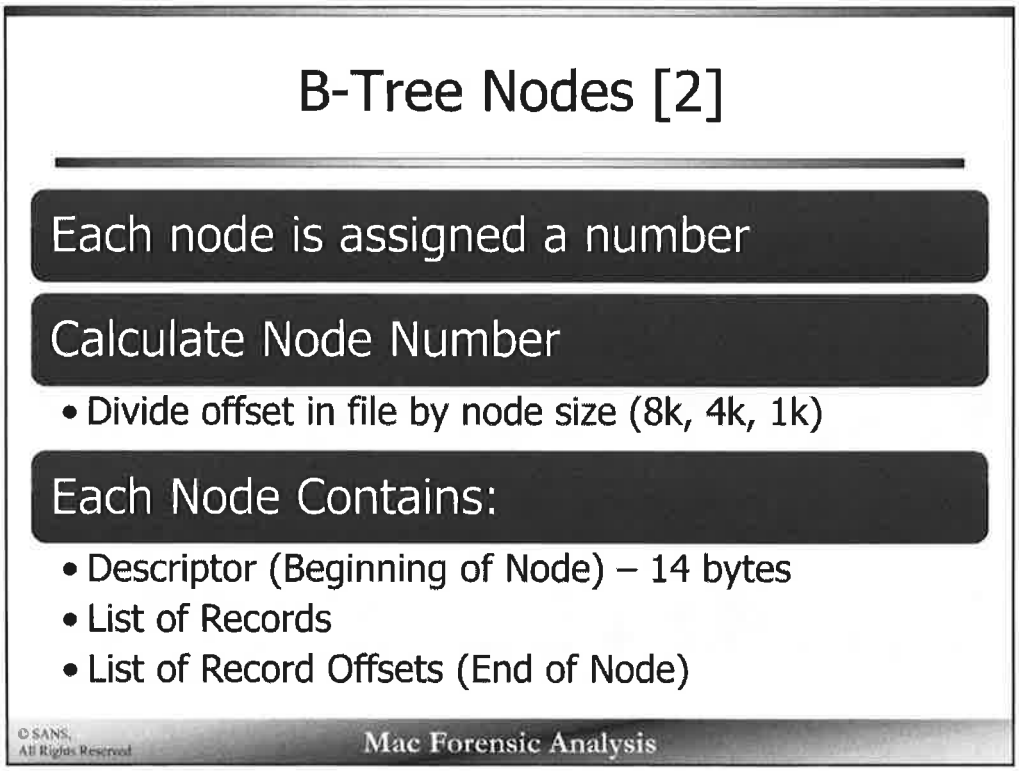

Each B-tree node is assigned a number. This number can be calculated by dividing the offset of the node in the file (from the beginning of the special file) by the node size, found in the Header Node's Header Record.

Default Node Size for Mac OS X:

- Catalog File – 8,192 bytes
- Attributes File – 4,096 bytes
- Extents Overflow File – 1,024 bytes

Each node contains the following pieces:

- Descriptor – starts at the beginning of the node.
- List of Record Offsets – starting from the end of the node.
- List of Records

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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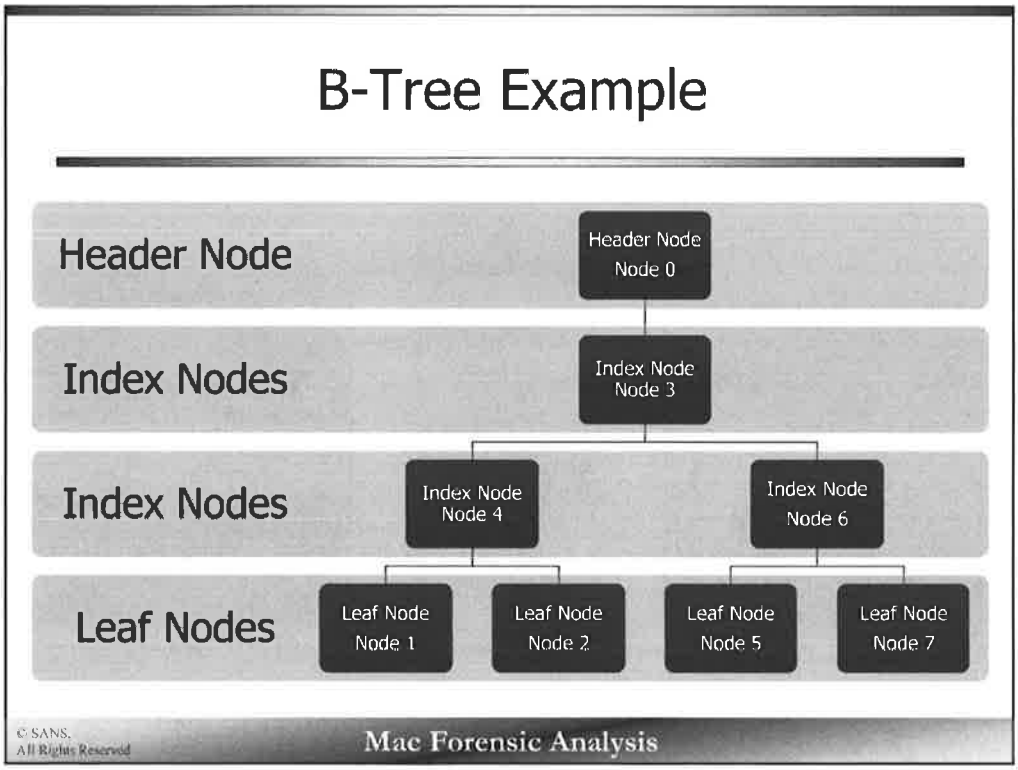
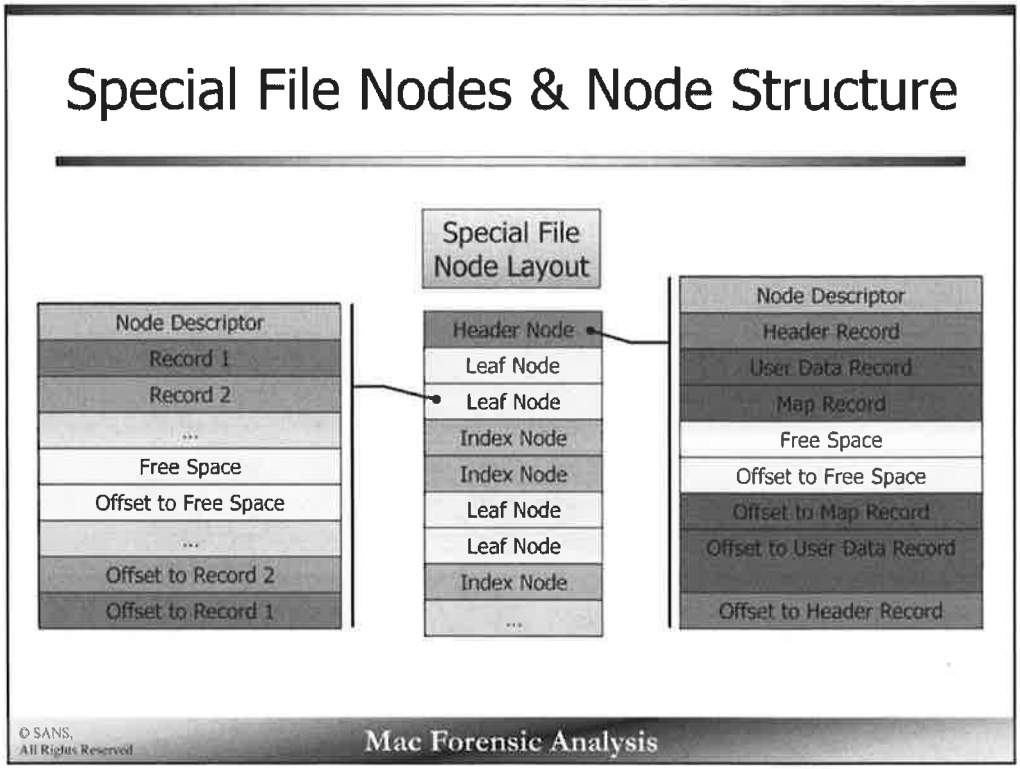


A B-Tree is made up of different nodes, the Header Node at the top is always Node 0.

Index Nodes build the branches of the tree, while Leaf Nodes are the leaves. Leaf Nodes are always at the "bottom" of the tree.



Each special file using a B-Tree (Catalog, Attributes, Extents Overflow) will be comprised of ONE Header Node, and multiple Leaf, Index, (and possibly) Map Nodes. Each node size is determined by data found in the Header Node (Node Size), this may be 4,096 bytes for each node, for example.

Each Header Node is comprised of a Node Descriptor, Header Record, User Data Record, and Map Record.

Other Nodes (Leaf, Index) are comprised of a Node Descriptor, and Keyed Records.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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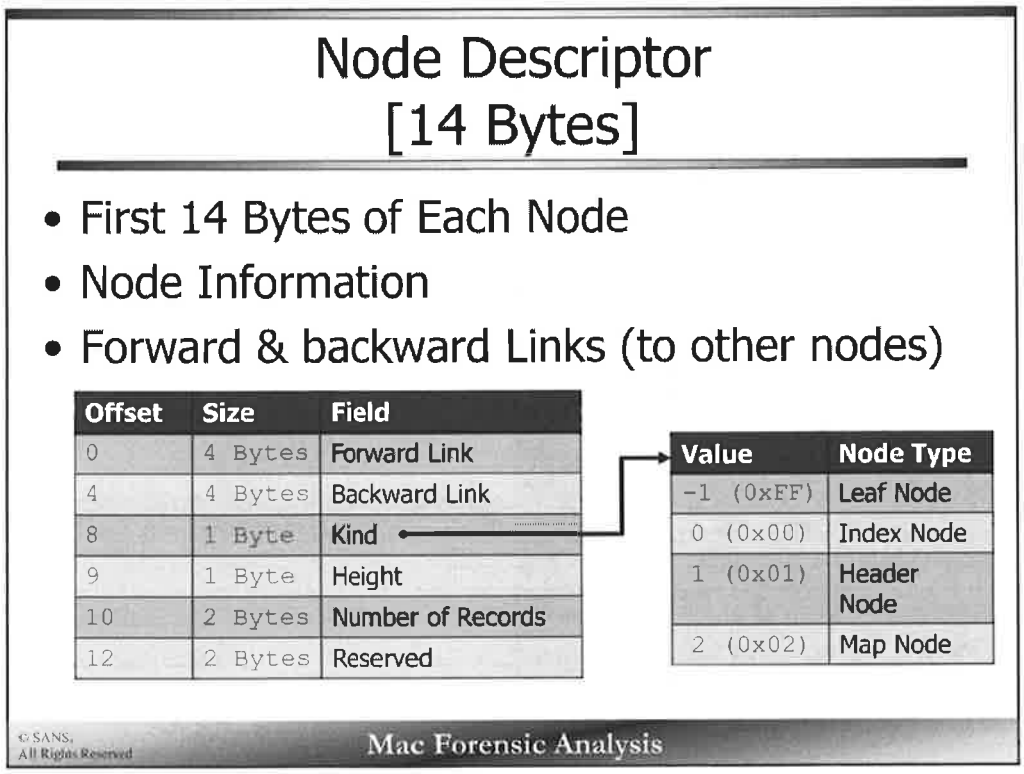

The Node Descriptor part of the Node starts at the beginning of the node.

The Node Descriptor is always 14 bytes in size, and contains node information such as the forward and backward links to other nodes. These links tell the system how to find the nodes. If the forward link is 0, it is the last node. If the backward link is 0, it is the first node in the list.

The Node Descriptor also contains a value describing the `kind` of node it is. This will help determine what type of data is contained in the node.

The `height` field contains the depth in the B-tree of where this node is located. A node at level 0, may be the Header Node or a Map Node. Leaf Nodes will always be at a level 1.

The `Number of Records` field determines the number of records contained in this node.

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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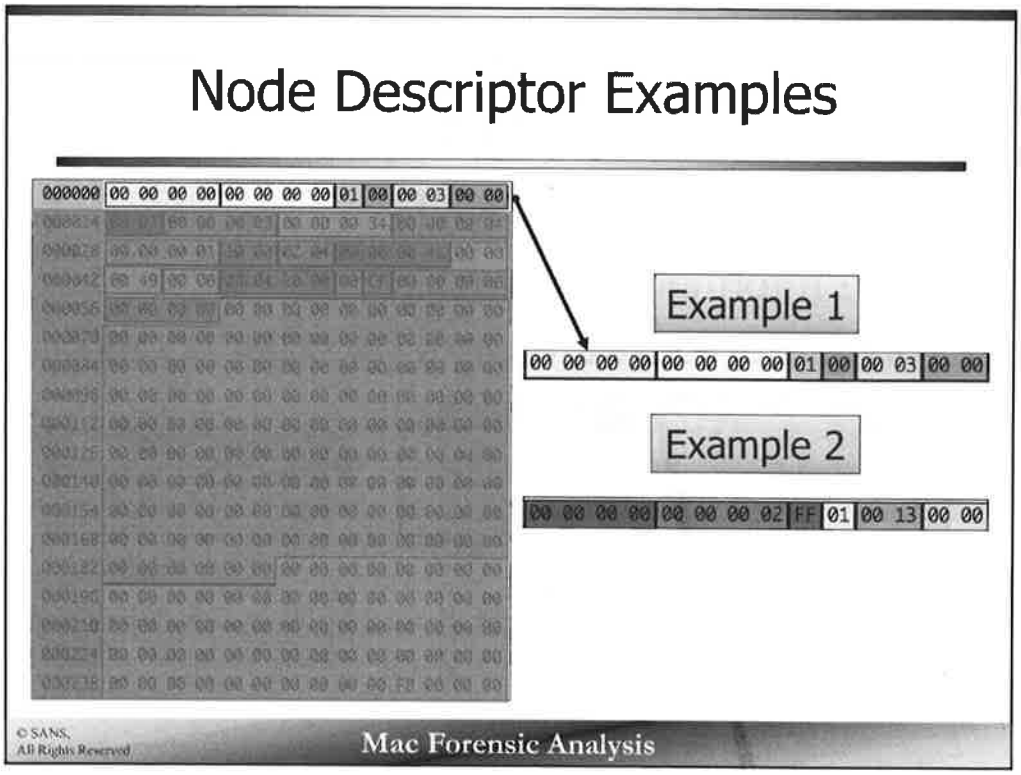

Example 1:

- Forward Link - 0x00000000 = 0
- Backward Link – 0x00000000 = 0
- Kind – 0x01 = 1 (Header Node)
- Height – 0x00 = 0
- Number of Records – 0x0003 = 3 Records
- Reserved – 0x0000

Example 2:

- Forward Link - 0x00000000 = 0
- Backward Link – 0x00000002 = 2
- Kind – 0xff = -1 (Leaf Node)
- Height – 0x01 = 1
- Number of Records – 0x0013 = 19 Records
- Reserved – 0x0000

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
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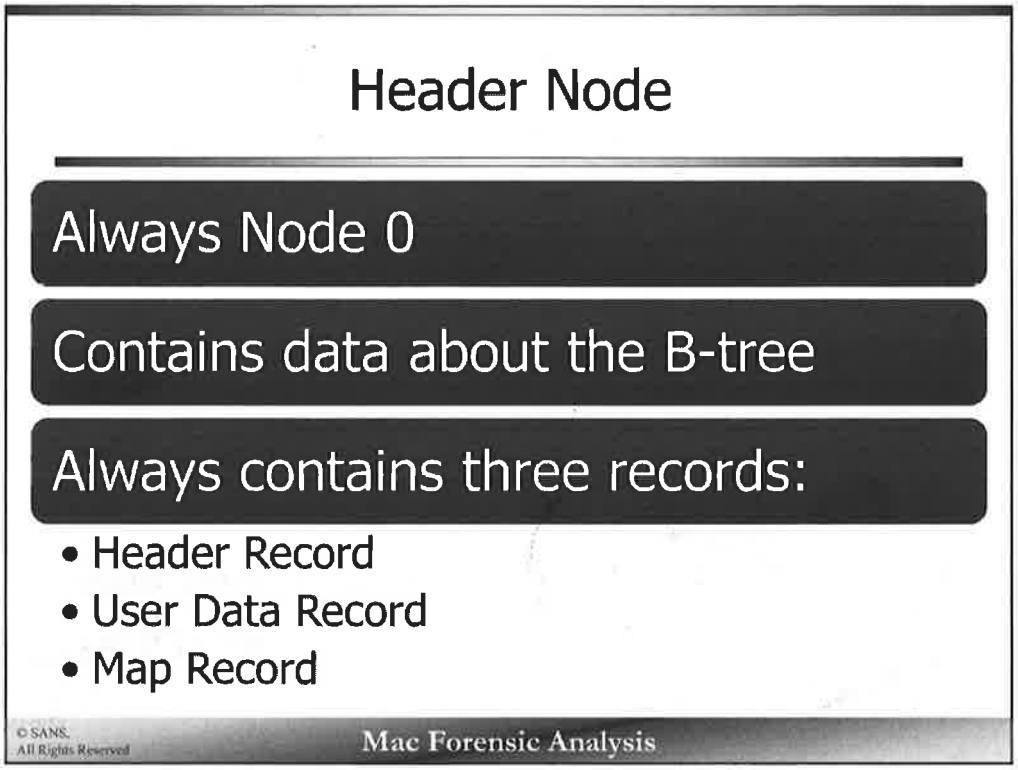
Mac OS X and iOS Internals: To the Apple's Core by Jonathan Levin – Chapter 16



The Header Node is always node 0. It contains information about the specific B-tree.

The Header Node is comprised of three records:

- Header Record
- User Data Record
- Map Record

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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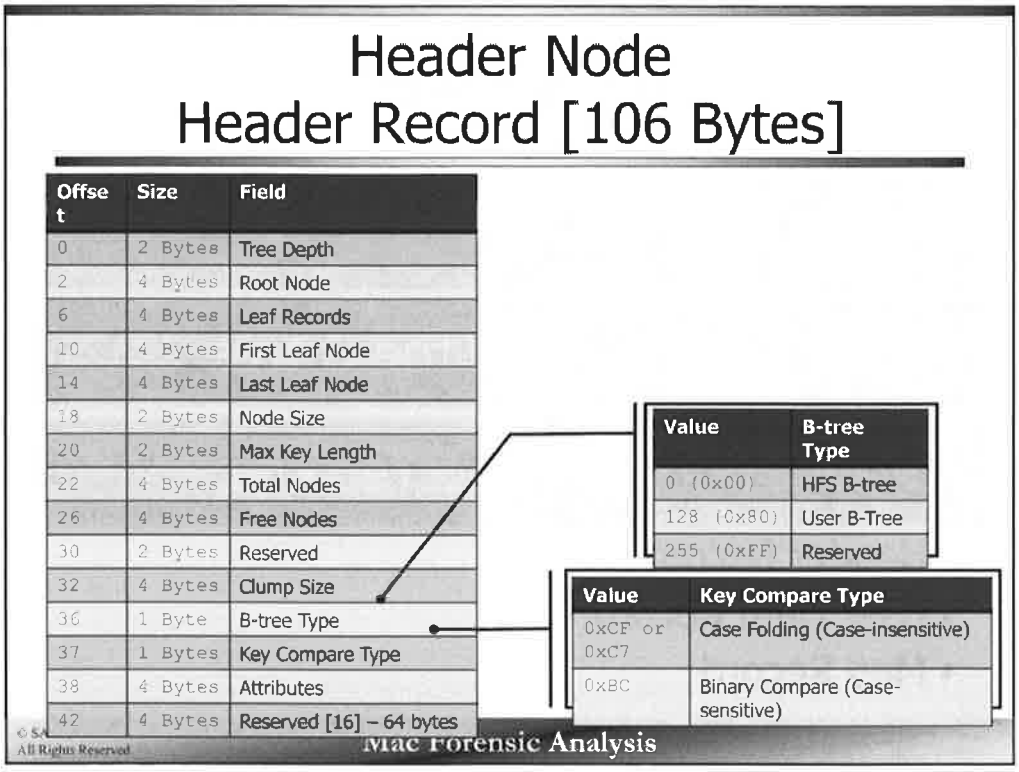

The Header Record in the Header Node is 106 bytes in size.

The Header Record contains data such:

- The number of the root Index Node (Root Node)
- Node numbers for the first and last leaf nodes
- Size of the nodes
- Total number of nodes in the B-tree
- Number of free nodes
- Type of B-tree
- Comparison type for searching keys
- Attributes specific to the B-tree (detailed in TN1150)

The type of B-tree for HFS+ special files will have the value '0'. The comparison type of key searching may have one of three values. The volume may be case-sensitive or case-insensitive.

More detailed information about the record fields can be found in TN1150.

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
Mac OS X Internals: A Systems Approach by Amit Singh – Chapter 12
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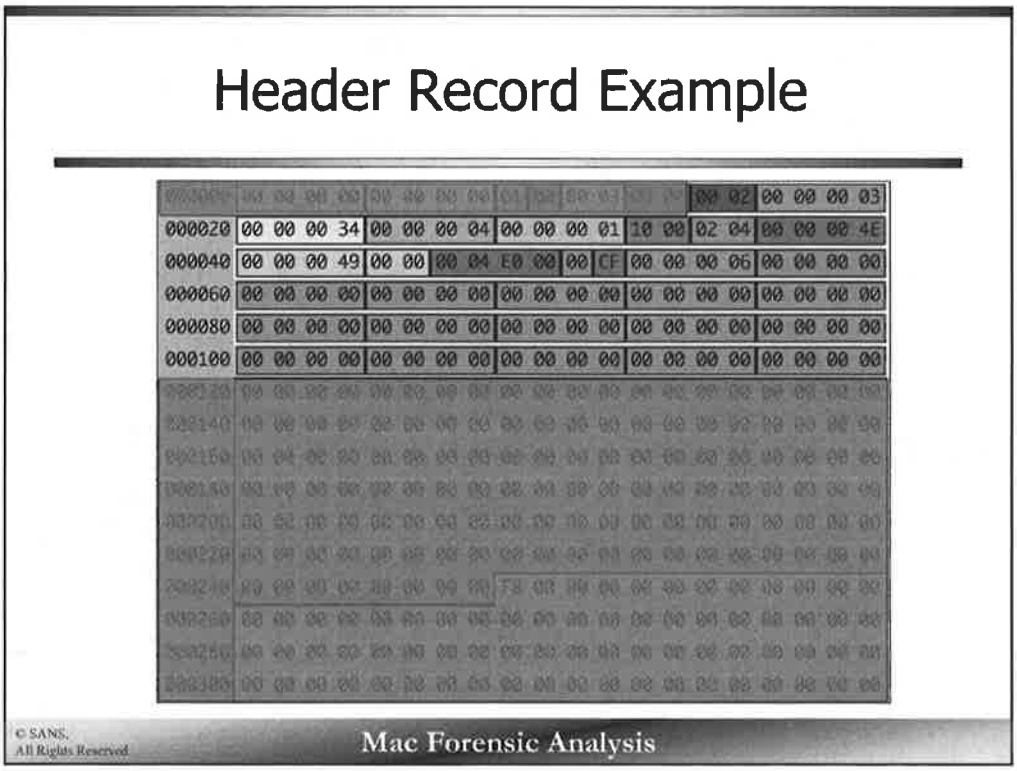


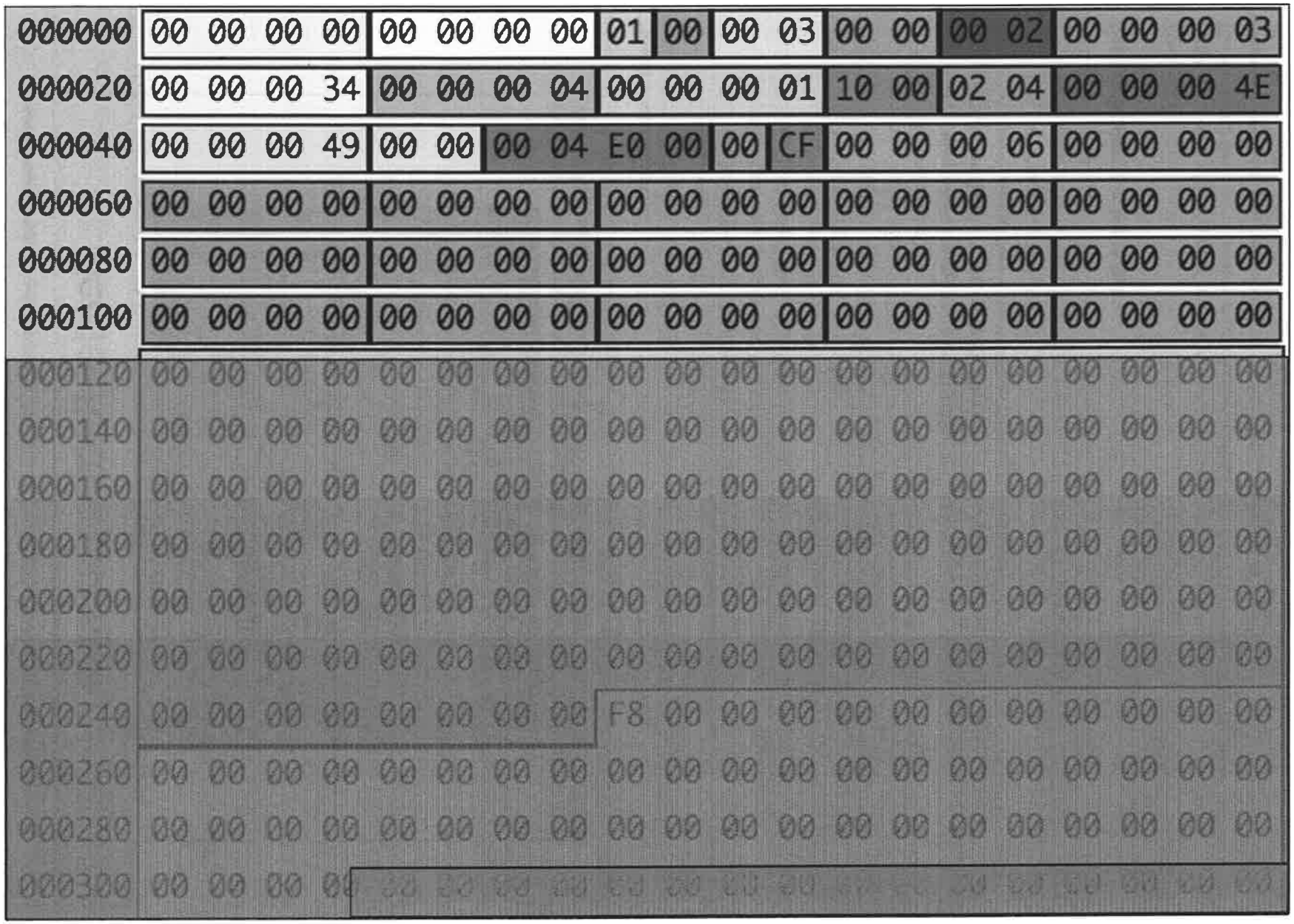
Header Record Example:

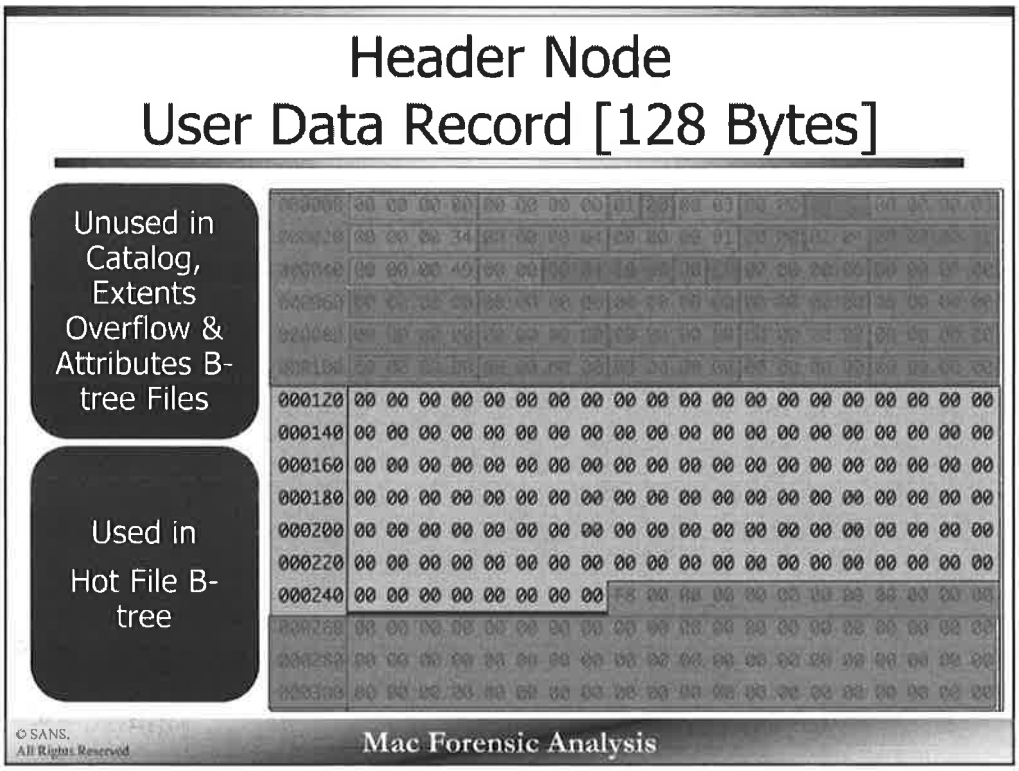
- Tree Depth – `0x0002` = 2
- Root Node – `0x00000003` = 3
- Leaf Records – `0x00000034` = 52
- First Leaf Node – `0x00000004` = 4
- Last Leaf Node – `0x00000001` = 1
- Node Size – `0x1000` = 4096
- Max Key Length – `0x0204` = 516
- Total Nodes – `0x0000004E` = 78
- Free Nodes – `0x00000049` = 73
- Reserved – `0x0000`
- Clump Size – `0x0004E000` = 319488
- B-Tree Type – `0x00` = 0 = HFS B-Tree
- Key Compare Type – `0xCF` = Case Folding (Insensitive)
- Attributes – `0x00000006`
- Reserved – `0x00000000 [Array of 16 for 64 bytes total]`

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
Mac OS X Internals: A Systems Approach by Amit Singh – Chapter 12
Mac OS X and iOS Internals: To the Apple's Core by Jonathan Levin – Chapter 16


000000 00 00 00 00 00 00 00 00 01 00 00 03 00 00 00 02 00 00 00 03
000020 00 00 00 34 00 00 00 04 00 00 00 01 10 00 02 04 00 00 00 4E
000040 00 00 00 49 00 00 00 04 E0 00 00 CF 00 00 00 06 00 00 00 00
000060 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000080 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000100 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000120 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000140 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000160 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000180 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000200 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000220 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000240 00 00 00 00 00 00 00 00 F8 00 00 00 00 00 00 00 00 00 00 00
000260 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000280 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
000300 00 00 00 00



The User Data Record of the Header Node is always 128 bytes in size, however it is unused in the HFS+ special files. It is used in the Hot File B-tree, explained later.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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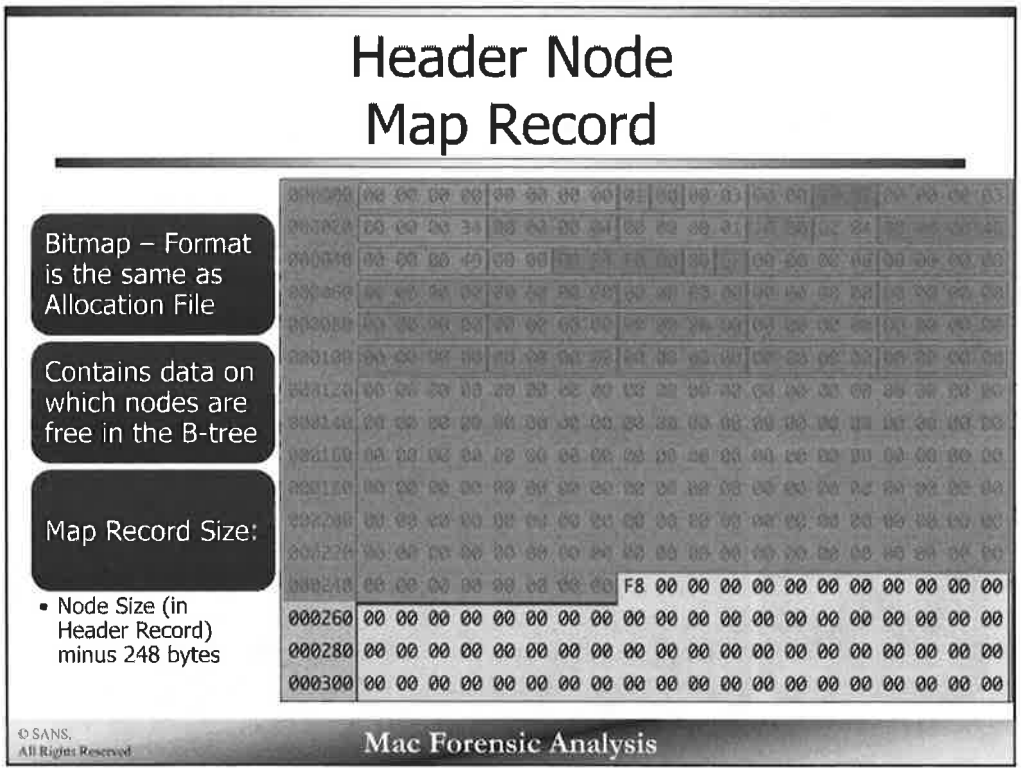

The Map Record of the Header Node has a very similar function to the Allocation File. Recall that the Allocation File uses a bitmap format to determine which blocks on a volume are used and which are free. The Map Record does the same function but for which nodes are allocated and which are free.

The size of the Map Record is always the Node Size (found in the Header Record) minus 248 bytes.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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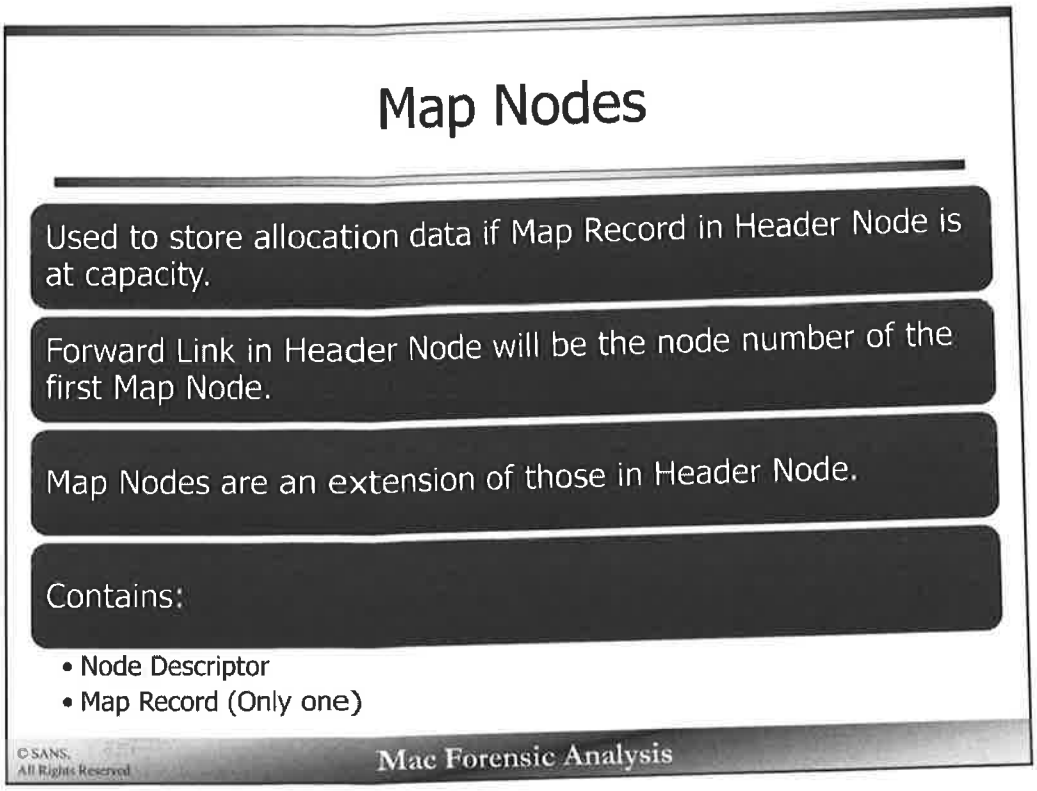

Map Nodes are used when the Header Node is at capacity, meaning there is no more space to store data about the allocation of nodes.

The forward link in the Header Node will point to the node number of the first Map Node. Map Nodes extend the Header Node. There may be multiple Map Nodes.

Map Nodes contain a Node Descriptor and a Map Record, both have been detailed previously.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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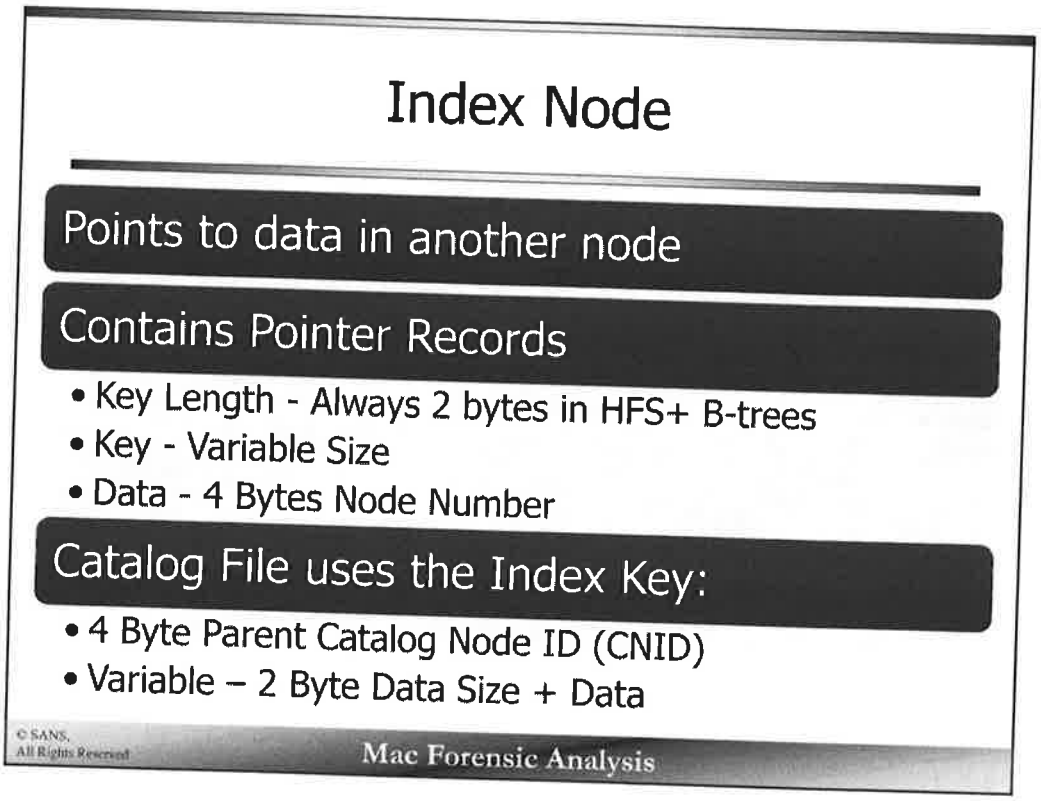

The Index Node contains Pointer Records. These records contain three parts:

- Key Length
- Key (See next table)
- Node Number (4 bytes) – This node will contain the data for the specified file/folder.

Index Node Layout: Size (in bytes)	Field
2	Key Length
Variable	Key (see table below)
4	Node Number

For Example: The Key used in the Catalog File is comprised of the Parent Catalog Node ID (CNID) number and the variable data string (Data size + File/Folder Name)

Index Key for Catalog File: Size (in bytes)	Field
4	Parent CNID
Variable	Data Size [2 bytes] + Data (Empty String 0x0000 in thread records) (+padding byte if key length is odd)

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
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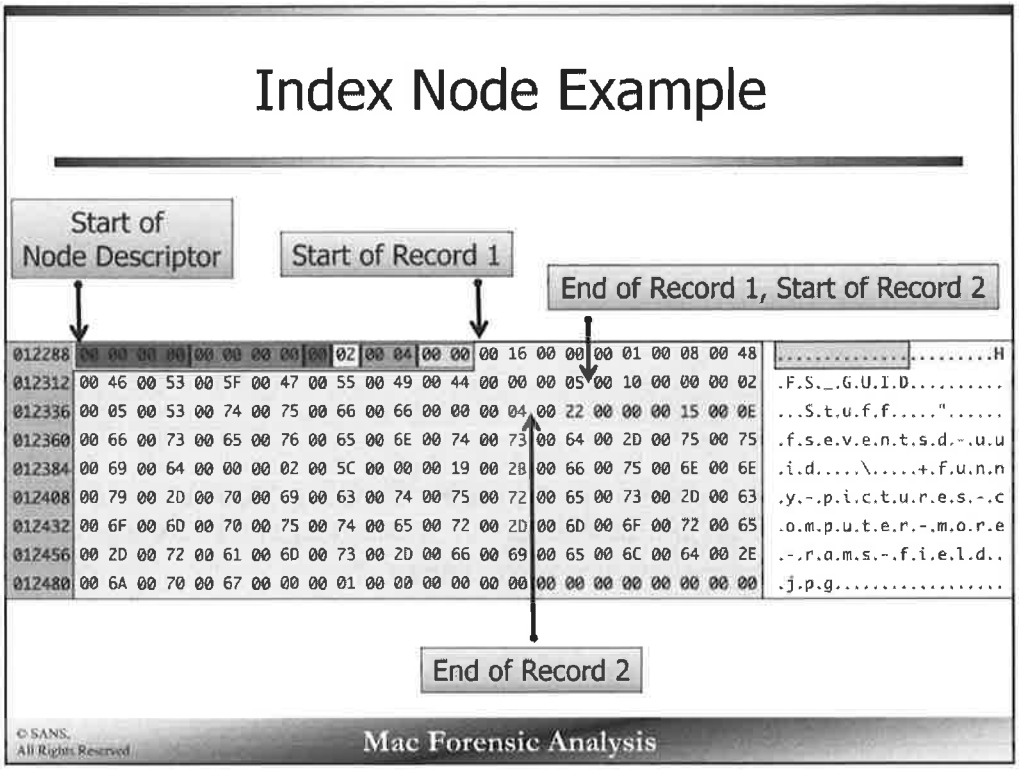

Index Node Layout: Size (in bytes)	Field
2	Key Length
Variable	Key (see table below)
4	Node Number

Index Key for Catalog File: Size (in bytes)	Field
4	Parent CNID
Variable	Data Size [2 bytes] + Data (Empty String 0x0000 in thread records) (+padding byte if key length is odd)

Example 1:

- Forward Link - `0x00000000` = 0
- Backward Link – `0x00000000` = 0
- Kind – `0x00` = 0 (Index Node)
- Height – `0x02` = 2
- Number of Records – `0x0004` = 4 Records (`HFS_GUID`, `Stuff`, `fseventsd-uuid`, `funny-pictures-computer-more-rams-field.jpg`)
- Reserved – `0x0000`

Record 1:

- Key Length – `0x0016` = 22 bytes
- Key –
  - Parent Catalog Node ID (CNID) – `0x00000001` = 1
  - Data:
    - Data Size: `0x0008` = 8 (16 bytes Unicode)
    - Data – `0x004800460053005F0047005500490044` = "`HFS_GUID`"
- Node Number – `0x00000005` = Node 5

Record 2:

- Key Length – `0x0010` – 16 bytes
- Key –
    - Parent Catalog Node ID (CNID) – `0x00000002` = 2
    - Data:
        - Data Size: `0x0005` = 5 (10 bytes Unicode)
        - Data – `0x0053007400750066006600` = "`Stuff`"
- Node Number – `0x00000004` = Node 4

Note: HFS+ data uses big-endian

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
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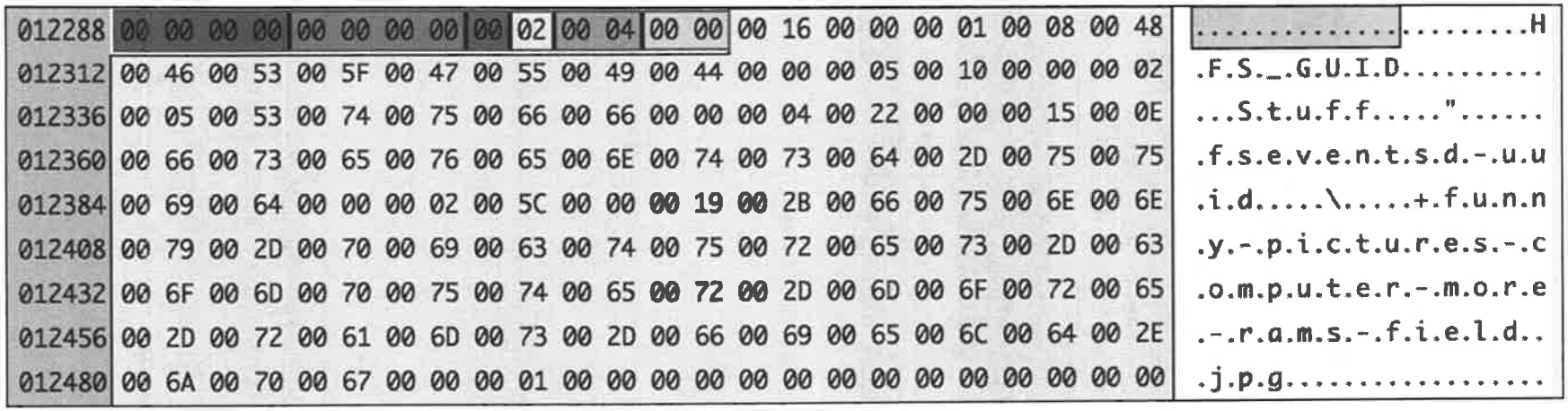
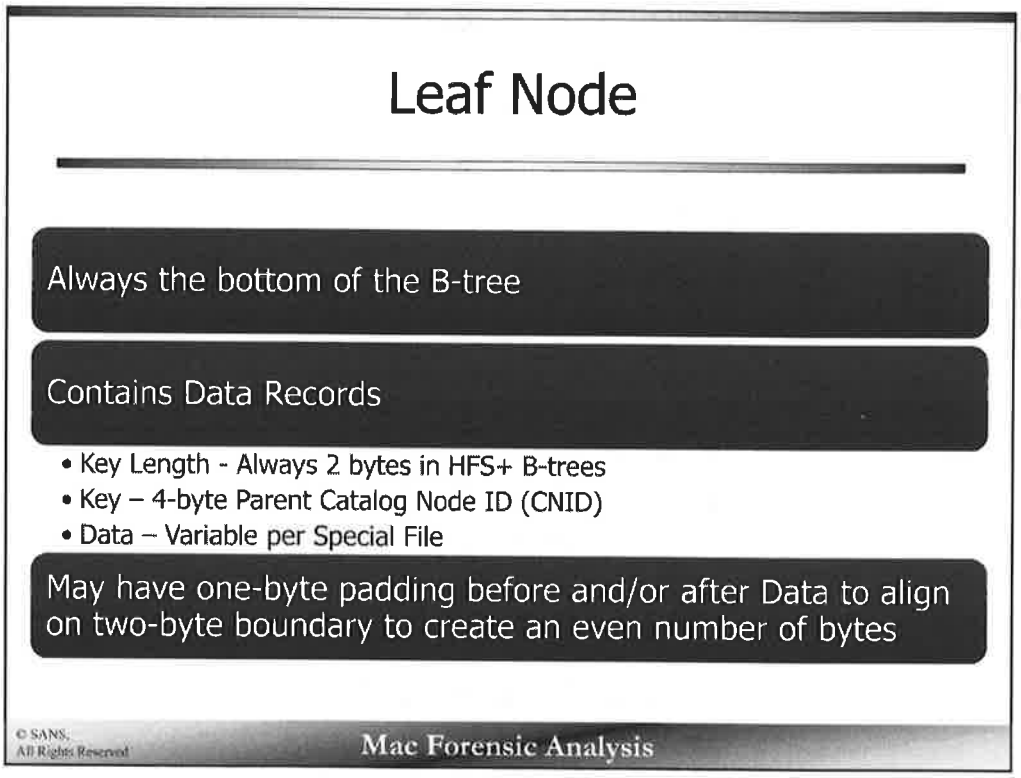


012288	00	00	00	00	00	00	00	00	00	02	00	04	00	00	00	16	00	00	00	01	00	08	00	48
012312	00	46	00	53	00	5F	00	47	00	55	00	49	00	44	00	00	00	05	00	10	00	00	00	02
012336	00	05	00	53	00	74	00	75	00	66	00	66	00	00	00	04	00	22	00	00	00	15	00	0E
012360	00	66	00	73	00	65	00	76	00	65	00	6E	00	74	00	73	00	64	00	2D	00	75	00	75
012384	00	69	00	64	00	00	00	02	00	5C	00	00	**00**	**19**	**00**	2B	00	66	00	75	00	6E	00	6E
012408	00	79	00	2D	00	70	00	69	00	63	00	74	00	75	00	72	00	65	00	73	00	2D	00	63
012432	00	6F	00	6D	00	70	00	75	00	74	00	65	**00**	**72**	**00**	2D	00	6D	00	6F	00	72	00	65
012456	00	2D	00	72	00	61	00	6D	00	73	00	2D	00	66	00	69	00	65	00	6C	00	64	00	2E
012480	00	6A	00	70	00	67	00	00	00	01	00	00	00	00	00	00	00	00	00	00	00	00	00	00

012288	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	H
012312	.	F	.	S	.	_	.	G	.	U	.	I	.	D	.	.	.	.	.	.	.	.	.	.
012336	.	.	.	S	.	t	.	u	.	f	.	f	.	.	.	.	.	"	.	.	.	.	.	.
012360	.	f	.	s	.	e	.	v	.	e	.	n	.	t	.	s	.	d	.	-	.	u	.	u
012384	.	i	.	d	.	.	.	.	.	\	.	.	.	.	.	+	.	f	.	u	.	n	.	n
012408	.	y	.	-	.	p	.	i	.	c	.	t	.	u	.	r	.	e	.	s	.	-	.	c
012432	.	o	.	m	.	p	.	u	.	t	.	e	.	r	.	-	.	m	.	o	.	r	.	e
012456	.	-	.	r	.	a	.	m	.	s	.	-	.	f	.	i	.	e	.	l	.	d	.	.
012480	.	j	.	p	.	g	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.



A Leaf Node contains Data Records. Leaf Nodes are always located at the bottom of the B-tree.

Data Records are comprised of three parts:

- Key Length
- Key
- Data

Leaf Node Layout: Size (in bytes)	Field
2	Key Length
4	Key – Parent CNID
4	HFSUniStr255 (Data Size + Data)

The Data in an HFS+ B-tree will contain one of the following depending on the type of special file.

- Catalog Record
- Extent Record
- Attribute Record

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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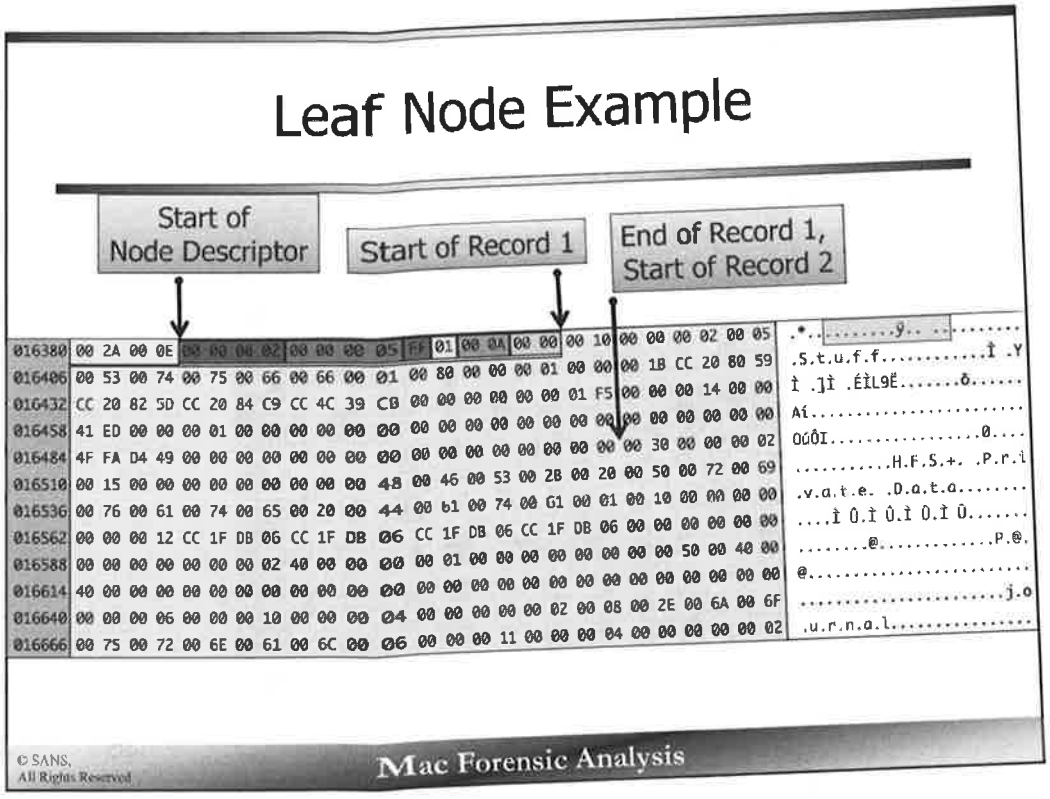


Leaf Node Layout: Size (in bytes)	Field
2	Key Length
4	Key – Parent CNID
4	HFSUniStr255 (Data Size + Data)

Example 1 (Node 4, from previous example):

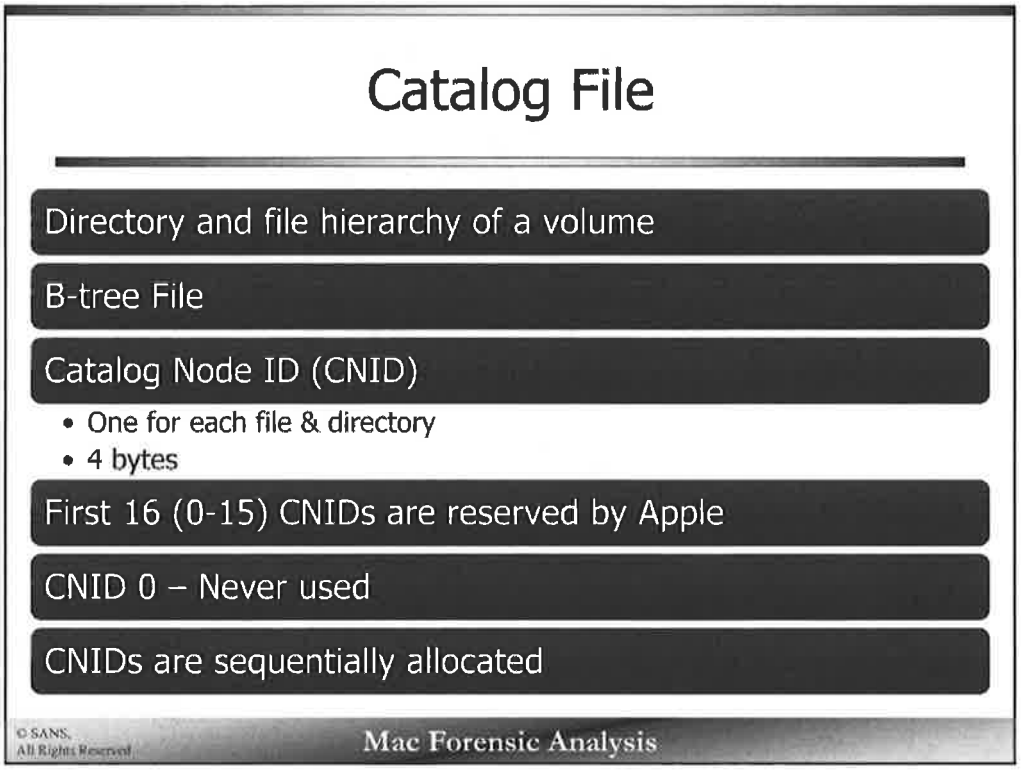
- Forward Link - 0x00000002 = 2
- Backward Link – 0x00000005 = 5
- Kind – 0xFF = 0 (Leaf Node)
- Height – 0x01 = 1
- Number of Records – 0x000A = 10 Records
- Reserved – 0x0000

Record 1:

- Key Length – 0x0010 = 16 bytes
- Key – (Parent Catalog Node ID (CNID)) – 0x00000002 = 2
- Data:
  - Data Size: 0x0005 = 5 (10 bytes Unicode)
  - Data – 0x0053007400750066006600 = "Stuff"
- *...Continue on to Catalog File/Folder Records...*

Note: HFS+ data uses big-endian

016380	00	2A	00	0E	00	00	00	02	00	00	00	05	FF	01	00	0A	00	00	00	10	00	00	00	00	02	00	05	.*.. ..... ÿ.. .. ..
016406	00	53	00	74	00	75	00	66	00	66	00	01	00	80	00	00	00	01	00	00	00	1B	CC	20	80	59		.S.t.u.f.f. ..... Ì . Y
016432	CC	20	82	5D	CC	20	84	C9	CC	4C	39	CB	00	00	00	00	00	00	01	F5	00	00	14	00	00			Ì .]Ì . ÉÌL9Ë ..... õ .....
016458	41	ED	00	00	00	01	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00		Aí .....
016484	4F	FA	D4	49	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	30	00	00	00	02		OúÔI ..... 0 .....
016510	00	15	00	00	00	00	00	00	00	48	00	46	00	53	00	2B	00	20	00	50	00	72	00	69				..... H.F.S.+. .P.r.i
016536	00	76	00	61	00	74	00	65	00	20	00	44	00	61	00	74	00	61	00	01	00	10	00	00	00	00		.v.a.t.e. .D.a.t.a. .....
016562	00	00	00	12	CC	1F	DB	06	CC	1F	DB	06	CC	1F	DB	06	CC	1F	DB	06	00	00	00	00	00	00		...Ì Û.Ì Û.Ì Û.Ì Û.....
016588	00	00	00	00	00	00	00	02	40	00	00	00	01	00	00	00	00	00	00	00	00	50	00	40	00			..... @ ..... P.@.
016614	40	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		@ .....
016640	00	00	00	06	00	00	00	10	00	00	00	04	00	00	00	00	00	02	00	00	08	00	2E	00	6A	00	6F	..... j.o
016666	00	75	00	72	00	6E	00	61	00	6C	00	00	06	00	00	00	11	00	00	00	04	00	00	00	00	00	02	.u.r.n.a.l .....



The Catalog File will contain the bulk of the forensic data we are interested in. This file contains the directory and file hierarchy of a volume in a B-tree structure.

Each file and folder on a volume has a unique Catalog Node ID or CNID. This is a 4-byte value that is sequentially allocated. The first 16 CNIDs are reserved by Apple for specific files. CNID 0 is never used. CNIDs may be reused.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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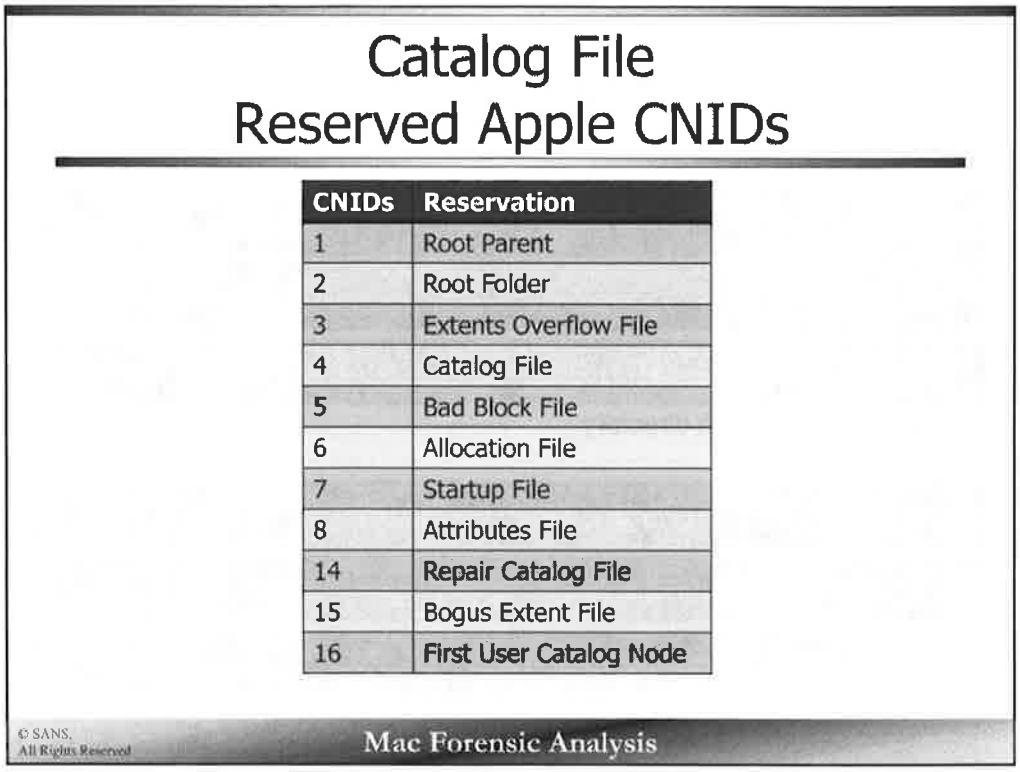

This list contains the reserved Catalog Node IDs for the first 16 CNIDs. The assigned file or folder is standard and can always be referenced by that specific CNID.

CNID 16 is always the first CNID available for user files or directories. CNIDs 9-13 do not appear to be used at this time.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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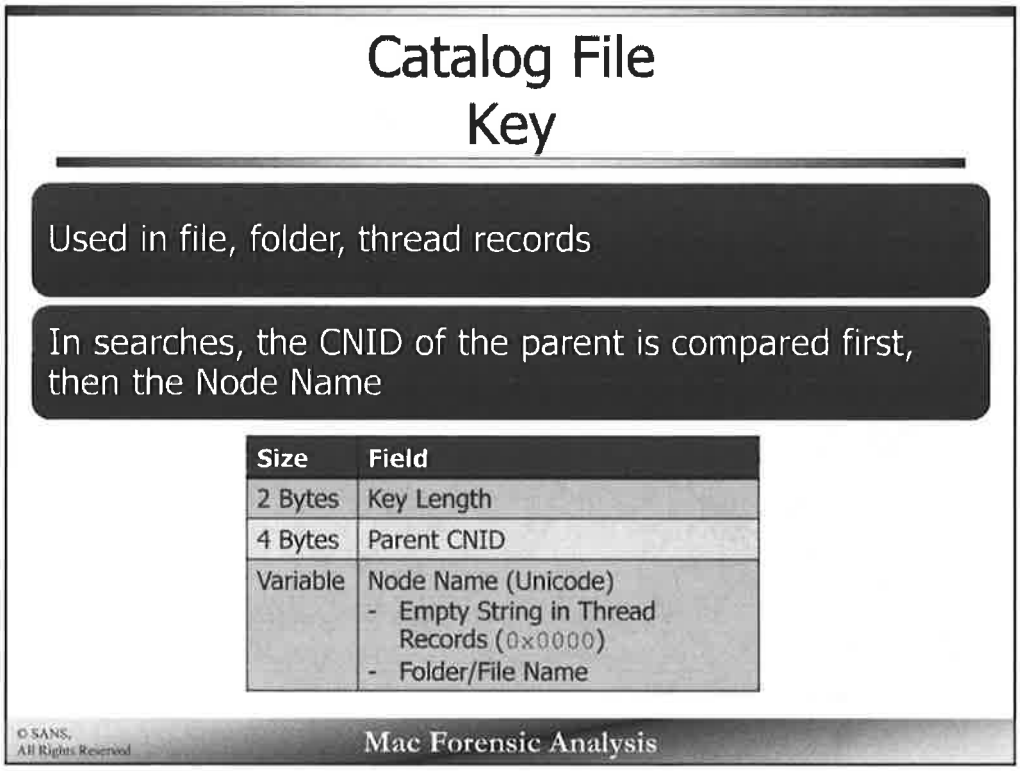

The key used in the Catalog File is used for each file, folder or thread record and has the format shown in the table above.

Searches will compare the CNID of the parent first, then it will compare the Node Name (File or Folder Name) to determine if a file or folder exists.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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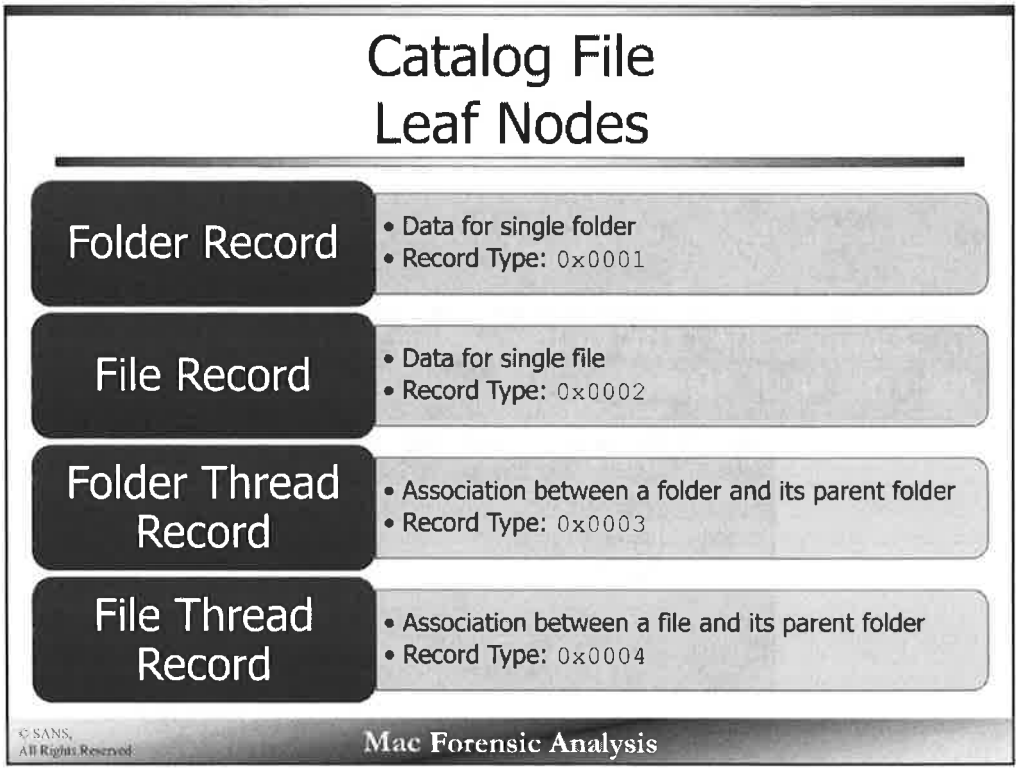

The Catalog File implements four types of Leaf Nodes.

- Folder Record
- File Record
- Folder Thread Record
- File Thread Record

The Folder Record (Type `0x0001`) contains the data for a single folder.

The File Record (Type `0x0002`) contains the data for a single file.

The Folder Thread Record (Type `0x0003`) contains an association between a folder and its parent folder.

The File Thread Record (Type `0x0004`) contains an association between a file and its parent folder.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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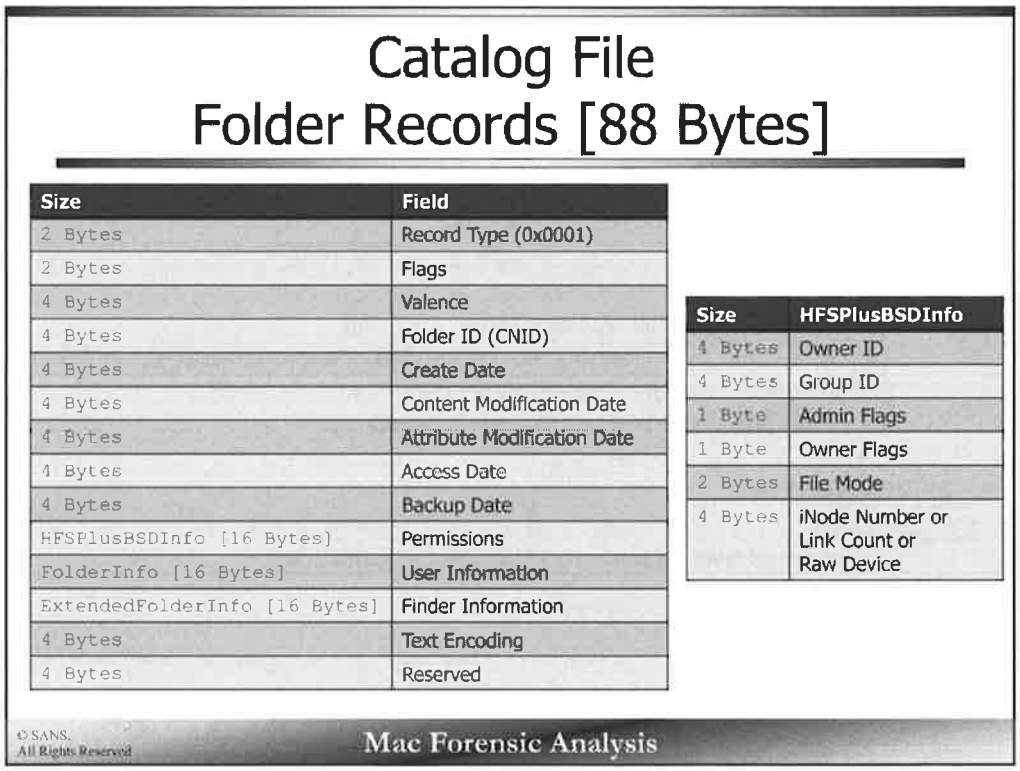

The Folder Records of the Catalog File contain the data shown in the left table above. Each Folder Record will have the value 0x0001 in the `Record Type` field.

The `Valence` field contains the number of files and directories contained in this folder.
The `Folder ID` contains the CNID of this folder.

Each Folder Record contains five dates (HFS+ Timestamp 1/1/1904 00:00:00: in GMT):

- Creation Date – Date and time the folder was created
- Content Modification Date – Date and time the content of the folder was modified
- Attribute Modification Date – Date and time the Catalog Record for this folder was changed
- Access Date – Date and time the contents of the folder were accessed
- Backup Date – Date and time the folder was backed up. Likely unused.

The `User Information and Finder Information` fields contain information specific to the Mac OS Finder such as:

- Location in Finder window
- If the folder has a custom icon or has a colored 'label'
- If the folder is locked or invisible

The table to the right contains the format for HFS+ file system metadata for the folder.

References:
Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
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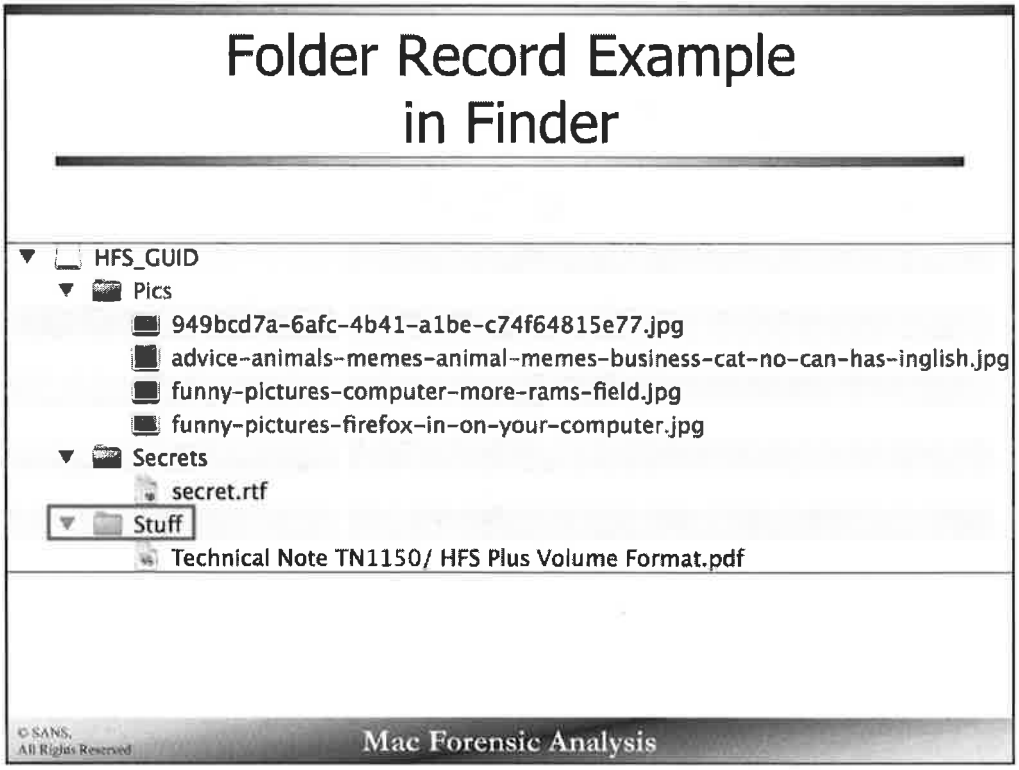
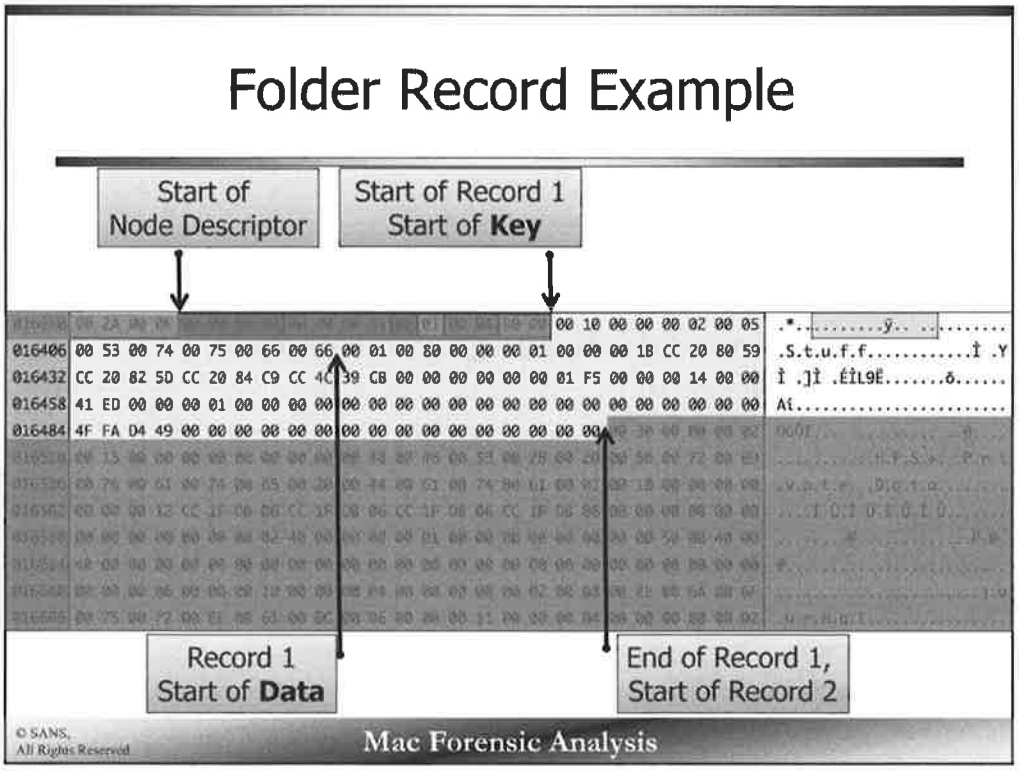


In our `GPT.dmg` example, we are going to be looking at the `Stuff` directory shown in the screenshot above.



Folder Record Example: (**Note: HFS+ data uses big-endian**)

KEY:

- Key Length – `0x0010` = 16 bytes
- Key – (Parent Catalog Node ID (CNID)) – `0x00000002` = 2
- Data:
  - Data Size: `0x0005` = 5 (10 bytes Unicode)
  - Data – `0x00530074007500660066` = "`Stuff`"

DATA:

- Record Type – `0x0001` =1 = Folder Record
- Flags – `0x0080`
- Valence – `0x00000001` – 1 (1 File in this folder)
- Folder ID (CNID) – `0x0000001B` = 27
- Create Date – `0xCC208059` = 3424682073 = 2012-07-09 12:34:33 Mon UTC
- Content Modification Date – `0xCC20825D` = 3424682589 = 2012-07-09 12:43:09 Mon UTC
- Attribute Modification Date – `0xCC2084C9` = 3424683209 = 2012-07-09 12:53:29 Mon UTC
- Access Date – `0xCC4C39CB` = `3427547595 = 2012-08-11 16:33:15 Sat UTC`
- Backup Date – `0x00000000 = Null Timestamp`

...continued on next page...

- Permissions – 0x000001F500000014000041ED00000001
    - Owner ID – 0x000001F5 = 501
    - Group ID – 0x00000014 = 20
    - Admin Flags – 0x00
    - Owner Flags – 0x00
    - File Mode – 0x41ED (See decoding below)
    - Link Count – 0x00000001 = 1
- User Information – 0x00000000000000000000000000000000
- Finder Information – 0x000000004FFAD4490000000000000000
- Text Encoding - 0x00000000
- Reserved – 0x00000000

File Mode Decoding (See tables 15.11-15.13 in File System Forensic Analysis by Brian Carrier):

Example: 0x41ED = 0100000111101101

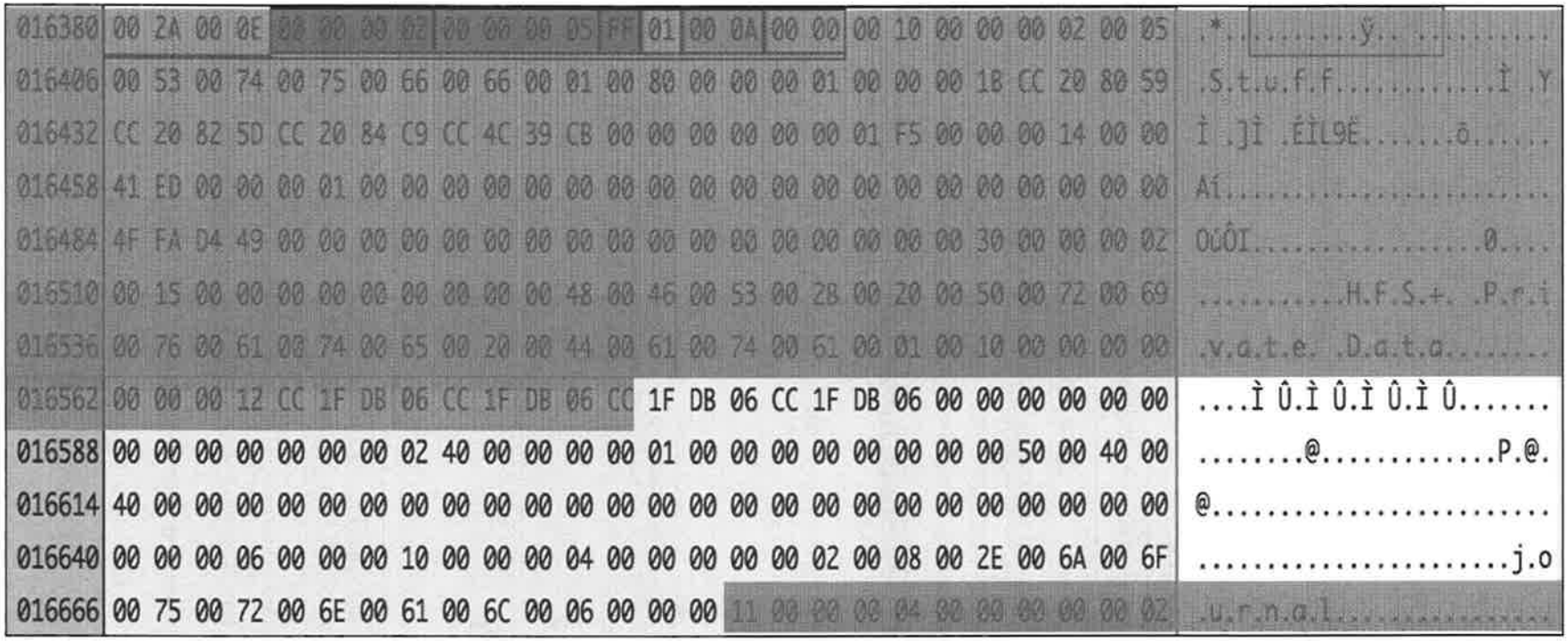
0100 = 4 = Directory

000 = SetUID, SetGID, Sticky bits

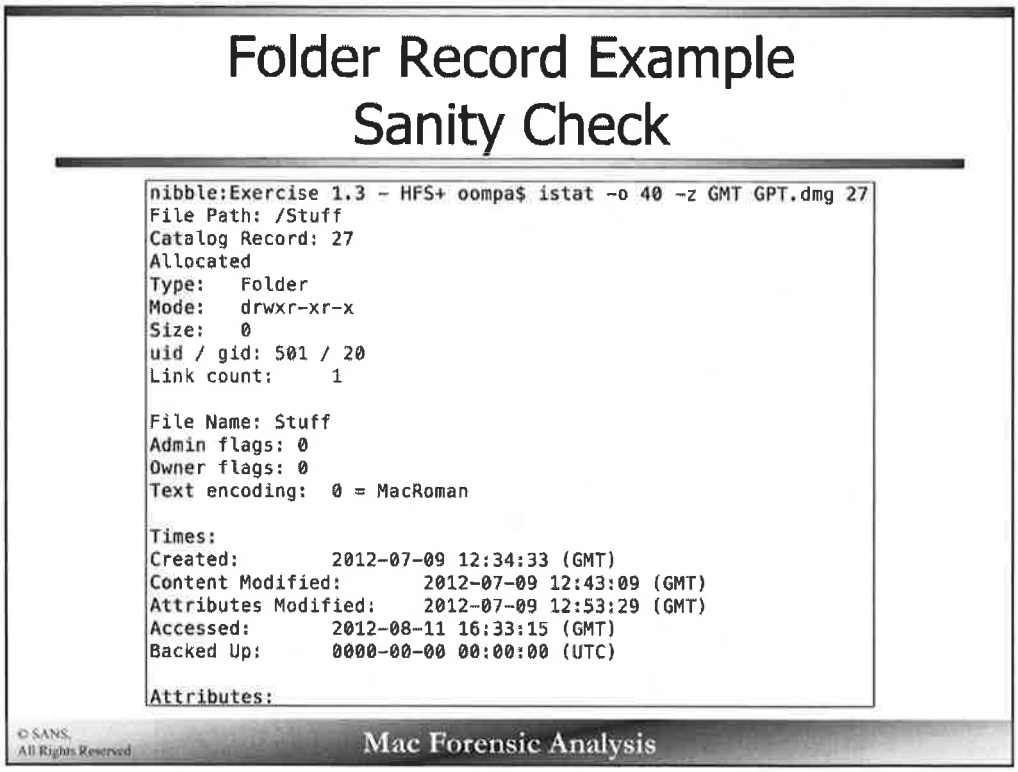
111 = User Permissions = rwx = 7

101 = Group Permissions = r-x = 5

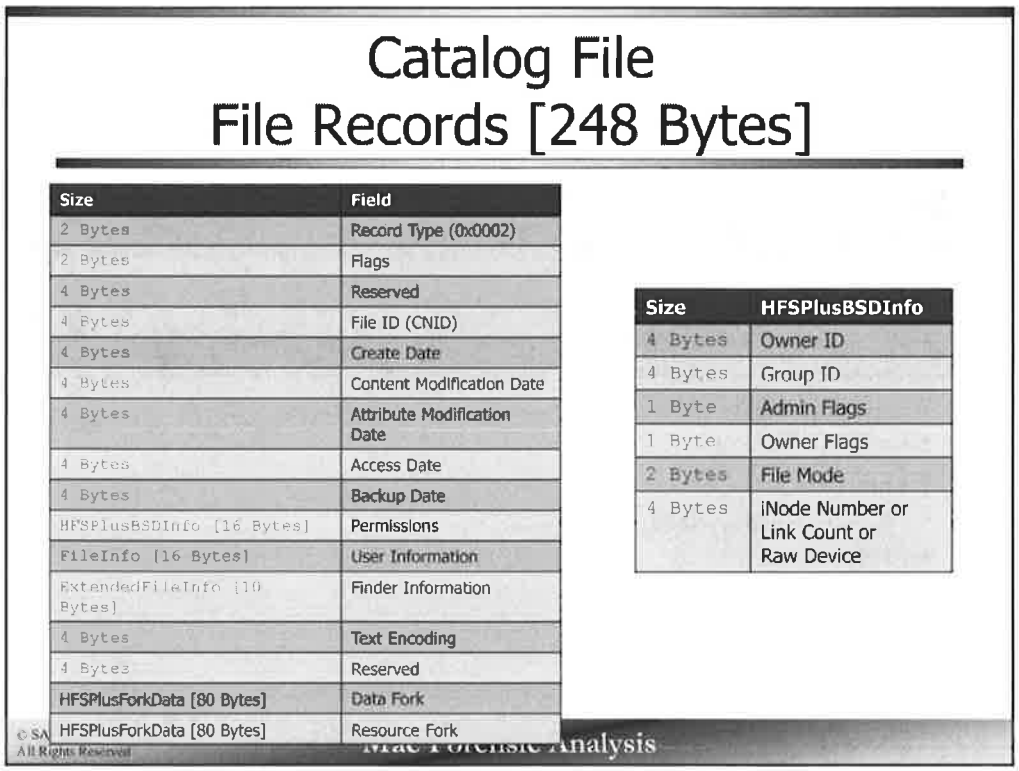
101 = Other Permissions = r-x = 5



016380	00	2A	00	0E	00	00	00	03	00	00	00	05	FF	01	00	0A	00	00	00	10	00	00	00	02	00	05	.*.....ÿ.. .....
016406	00	53	00	74	00	75	00	66	00	66	00	01	00	80	00	00	00	01	00	00	00	18	CC	20	80	59	.S.t.u.f.f.....Ì .Y
016432	CC	20	82	5D	CC	20	84	C9	CC	4C	39	CB	00	00	00	00	00	00	01	F5	00	00	00	14	00	00	Ì .]Ì .ÉÌL9Ë.....õ.....
016458	41	ED	00	00	00	01	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	Aí.....
016484	4F	FA	D4	49	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	30	00	00	00	OúÔI.....0....
016510	00	15	00	00	00	00	00	00	00	00	00	48	00	46	00	53	00	2B	00	20	00	50	00	72	00	69	.....H.F.S.+. .P.r.i
016536	00	76	00	61	00	74	00	65	00	20	00	44	00	61	00	74	00	61	00	01	00	10	00	00	00	00	.v.a.t.e. .D.a.t.a.....
016562	00	00	00	12	CC	1F	DB	06	CC	1F	DB	06	CC	1F	DB	06	CC	1F	DB	06	00	00	00	00	00	00	....Ì Û.Ì Û.Ì Û.Ì Û.....
016588	00	00	00	00	00	00	00	02	40	00	00	00	00	01	00	00	00	00	00	00	00	00	50	00	40	00	........@.....P.@.
016614	40	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	@.....
016640	00	00	00	06	00	00	00	10	00	00	00	04	00	00	00	00	00	02	00	08	00	2E	00	6A	00	6F	.....j.o
016666	00	75	00	72	00	6E	00	61	00	6C	00	06	00	00	00	11	00	00	00	04	00	00	00	00	00	02	.u.r.n.a.l.....



Lets check our results by using the `istat` tool by The Sleuth Kit.



The File Records of the Catalog File contain the data shown in the left table above. Each File Record will have the value `0x0002` in the `Record Type` field. The contents of this record are very similar to the Folder Record.

The `File ID` contains the CNID of this file.

Each Folder Record contains five dates (HFS+ Timestamp 1/1/1904 00:00:00: in GMT):

- Creation Date – Date and time the file was created
- Content Modification Date – Date and time the content of the file was modified
- Attribute Modification Date – Date and time the Catalog Record for this file was changed
- Access Date – Date and time the contents of the file were accessed
- Backup Date – Date and time the file was backed up. Likely unused.

The `User Information and Finder Information` fields contain information specific to the Mac OS Finder such as

- Location in Finder window
- If the file is a Bundle or an Alias
- The file's File Type and Creator codes

The table to the right contains the format for HFS+ `permissions` for the file.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html
The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h
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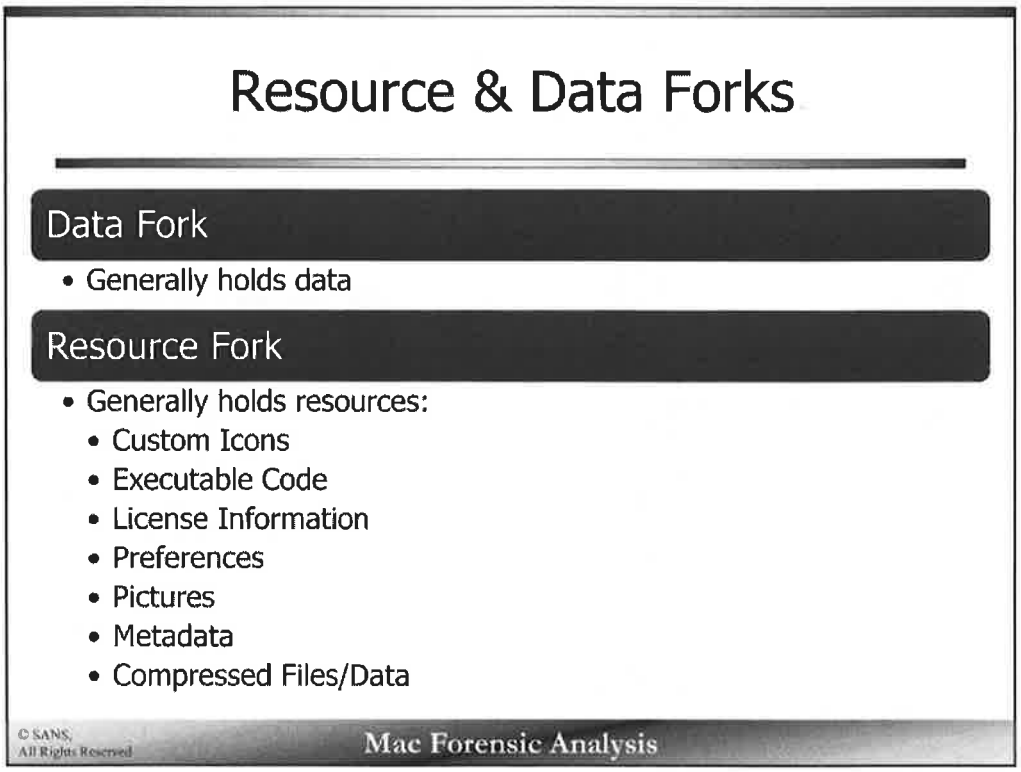

As you may have noticed in the previous slide, the File Record also contains the information about the Data and Resource Forks. This data includes the location and size of each fork.

Mac OS X may use one or both of the forks to contain a file data and metadata.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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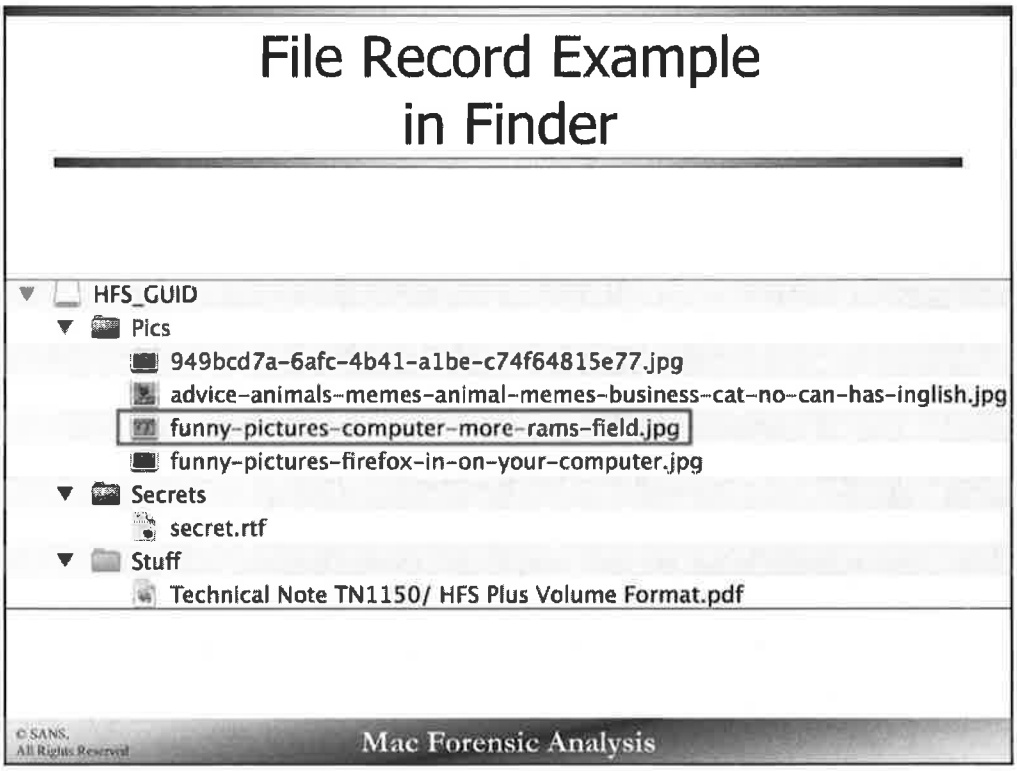
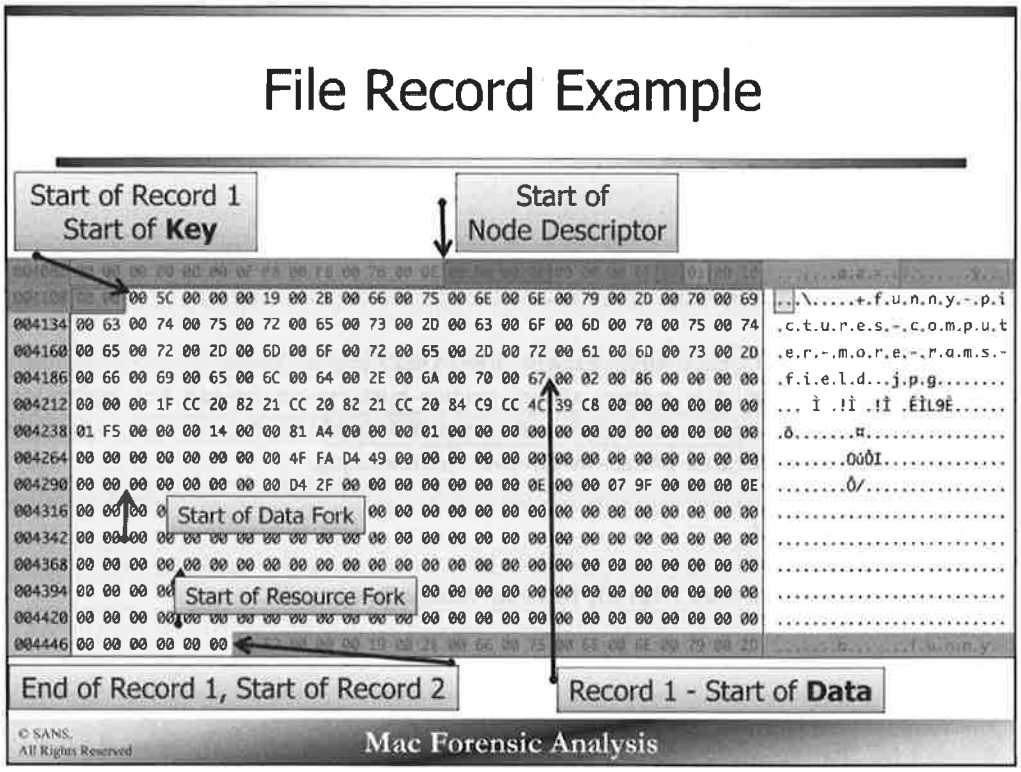


In our `GPT.dmg` example, we are going to be looking at the `funny-pictures-computer-more-rams-field.jpg` file located in the `Pics` directory shown in the screenshot above.



File Record Example: (**Note: HFS+ data uses big-endian**)

KEY:

- Key Length – `0x005C` = 92 bytes
- Key – (Parent Catalog Node ID (CNID)) – `0x00000019` = 25
- Node Name:
  - Node Size - `0x002B` = 43 (86 bytes Unicode)
  - Node Name – `0x00660075006E006E0079002D007000690063007400750072006500730002D0063006F006D00700075007400650072002D006D006F00720065002D00720061006D0073002D006600690065006C0064002E006A00700067` = "funny-pictures-computer-more-rams-field.jpg"

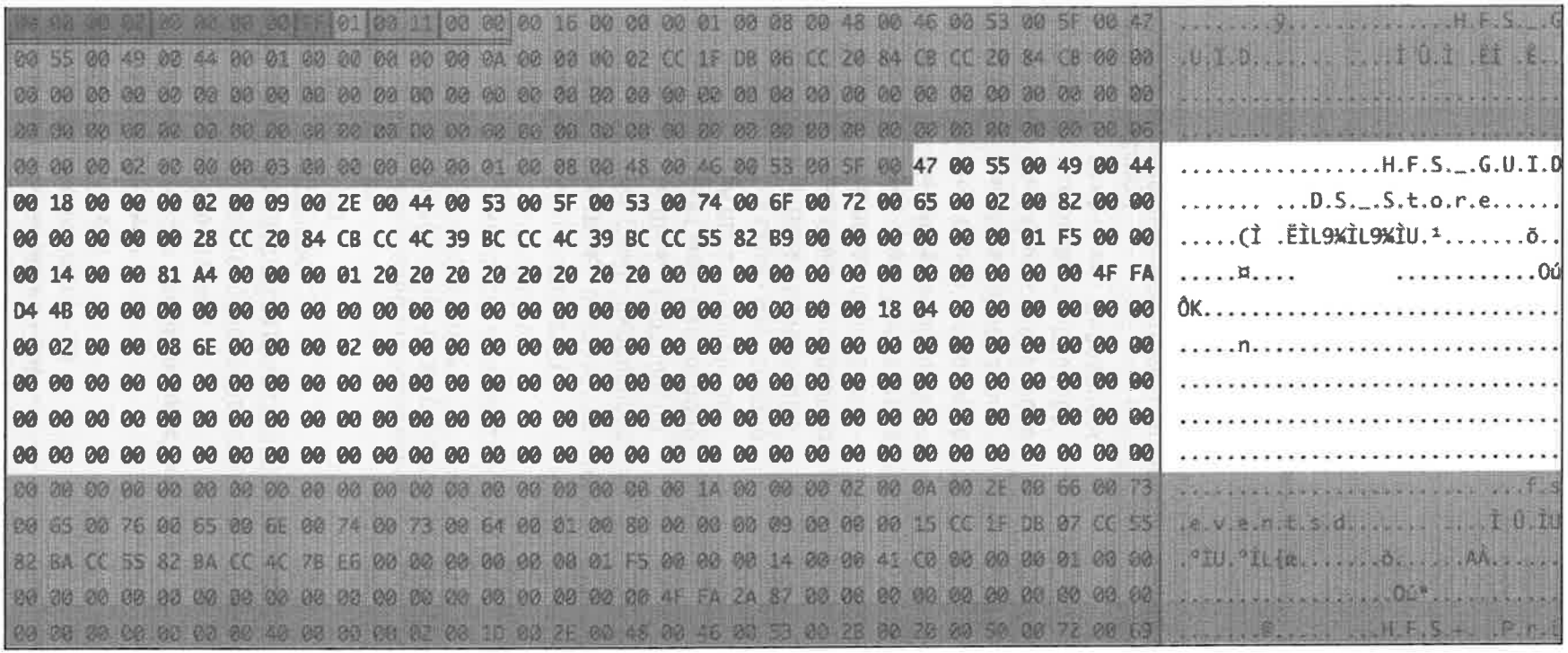
DATA:

- Record Type – `0x0002` = 2 = File Record
- Flags – `0x0086`
- Reserved – `0x00000000`
- File ID (CNID) – `0x0000001F` = 31
- Create Date – `0xCC208221` = 3424682529 = 2012-07-09 12:42:09 Mon UTC
- Content Modification Date – `0xCC208221` = 3424682529 = 2012-07-09 12:42:09 Mon UTC
- Attribute Modification Date – `0xCC2084C9` = 3424683209 = 2012-07-09 12:53:29 Mon UTC
- Access Date – `0xCC4C39C8` = 3427547592 = 2012-08-11 16:33:12 Sat UTC
- Backup Date – `0x00000000 - Null Timestamp`

...continued on next page...

- Permissions – 0x000001F500000014000081A400000001
  - Owner ID – 0x000001F5 = 501
  - Group ID – 0x00000014 = 20
  - Admin Flags – 0x00
  - Owner Flags – 0x00
  - File Mode – 0x81A4 (See decoding below)
  - Link Count – 0x00000001
- User Information – 0x00000000000000000000000000000000
- Finder Information – 0x000000004FFAD4490000000000000000
- Text Encoding - 0x00000000
- Reserved – 0x00000000
- Data Fork -
  0x000000000000D42F00000000000000E0000079F0000000E0000000000000000
  00000000000000000000000000000000000000000000000000000000000000000
  000000000000000000000000000000
  - Logical Size – 0x000000000000D42F = 54319 bytes
  - Clump Size – 0x00000000
  - Total Blocks –0x0000000E = 14
  - Extent 1 – Start Block – 0x0000079F = 1951
  - Extent 1 – Block Count – 0x0000000E = 14
  - Extent 2 – Start Block – 0x00000000
  - Extent 2 – Block Count - 0x00000000
  - Extent 3 – Start Block - 0x00000000
  - Extent 3 – Block Count - 0x00000000
  - Extent 4 – Start Block - 0x00000000
  - Extent 4 – Block Count - 0x00000000
  - Extent 5 – Start Block - 0x00000000
  - Extent 5 – Block Count - 0x00000000
  - Extent 6 – Start Block - 0x00000000
  - Extent 6 – Block Count - 0x00000000
  - Extent 7 – Start Block - 0x00000000
  - Extent 7 – Block Count - 0x00000000
  - Extent 8 – Start Block - 0x00000000
  - Extent 8 – Block Count - 0x00000000
- Resource Fork – (Empty)
  0x00000000000000000000000000000000000000000000000000000000000000000
  00000000000000000000000000000000000000000000000000000000000000000
  000000000000000000000000000000

File Mode Decoding (See tables 15.11-15.13 in File System Forensic Analysis by Brian Carrier):
Example: 0x81A4 = 1000000110100100
1000 = 8 = Regular File
000 = SetUID, SetGID, Sticky bits
110 = User Permissions = rw- = 6
100 = Group Permissions = r-- = 4
100 = Other Permissions = r-- = 4



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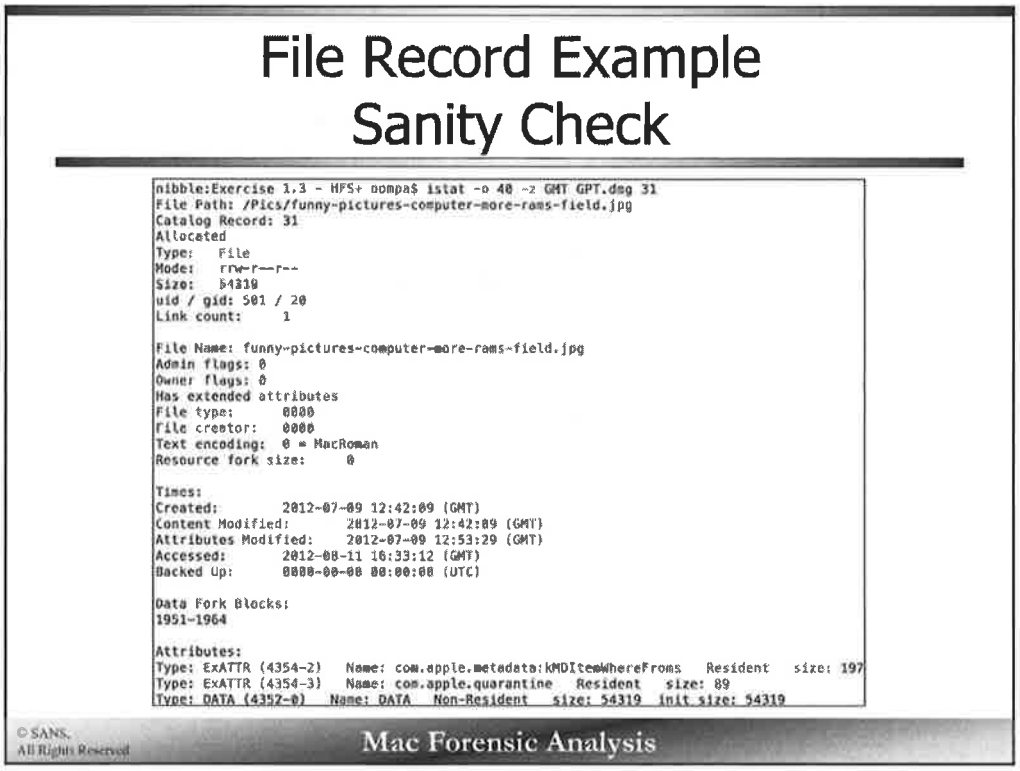
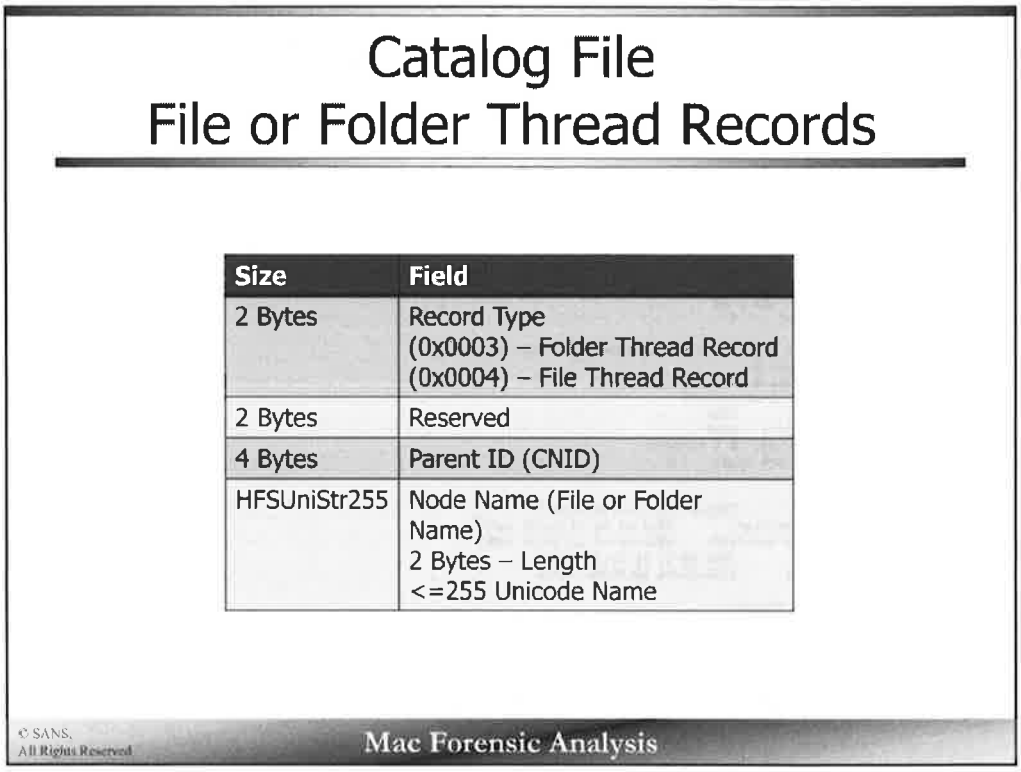


Let's check our results by using the `istat` tool by The Sleuth Kit.



The Folder and File Thread Records in the Catalog File are used to associate a file or folder to the parent folder's CNID. These records can be remembered as using a thread to sew together a file or folder with its parent directory.

Each File or Folder Thread Record contains:

- The record type will be either 0x0003 or 0x0004 for folder or file, respectively.
- The CNID of the file/folder parent directory.
- The Node Name which is the name of the file or folder in Unicode.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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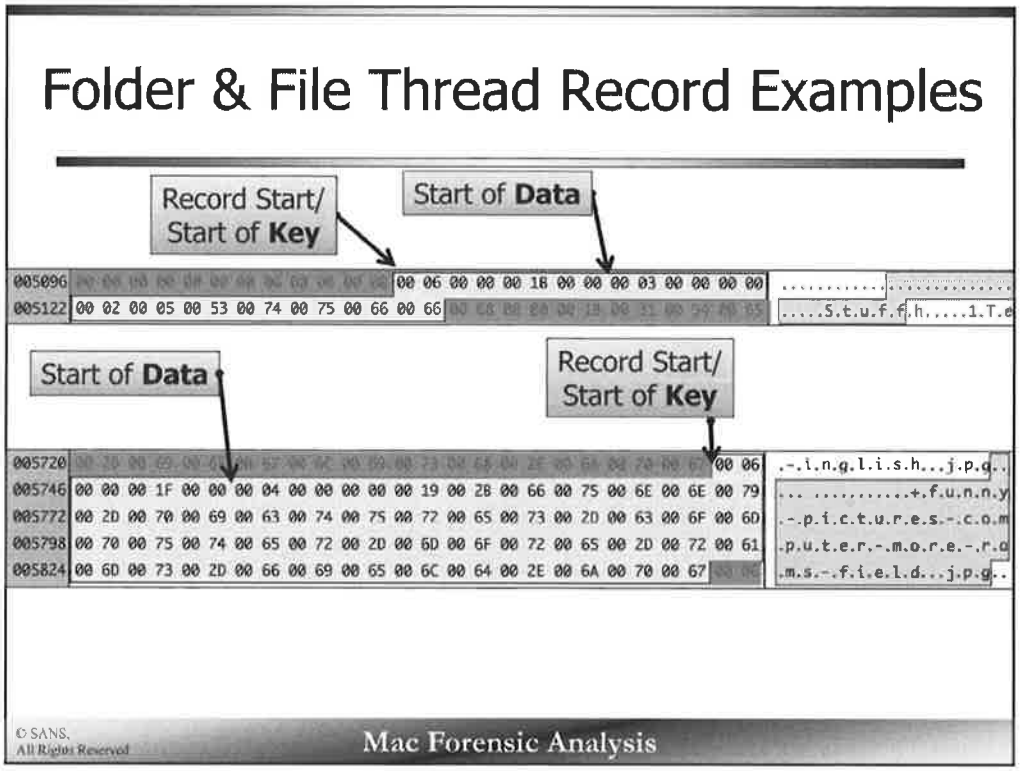


In this example we will be looking at the folder and file examples that we analyzed previously.

Folder Thread Record Example: (**Note: HFS+ data uses big-endian**)

Top Example:

KEY:

- Key Length – `0x0006` = 6 bytes
- Key – (Parent Catalog Node ID (CNID)) – `0x0000001B` = 27
- Data – 0x0000 (Will be "blank" for Thread Records)

DATA:

- Record Type – `0x0003` = 3 = Folder Thread Record
- Reserved – 0x0000
- Parent CNID – `0x00000002` = 2
- Node Name:
  - Node Size – `0x0005` = 5 (10 Unicode bytes)
  - Node Name – "`Stuff`"

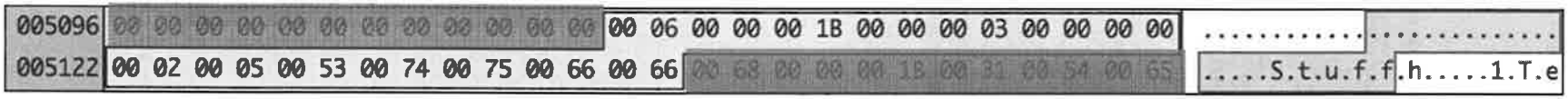
Bottom Example:

KEY:

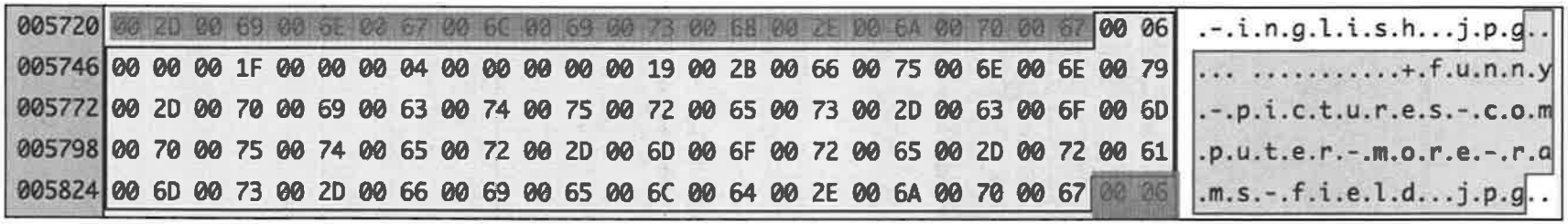
- Key Length – `0x0006` = 6 bytes
- Key – (Parent Catalog Node ID (CNID)) – `0x0000001F` = 31
- Data – 0x0000 (Will be "blank" for Thread Records)

DATA:

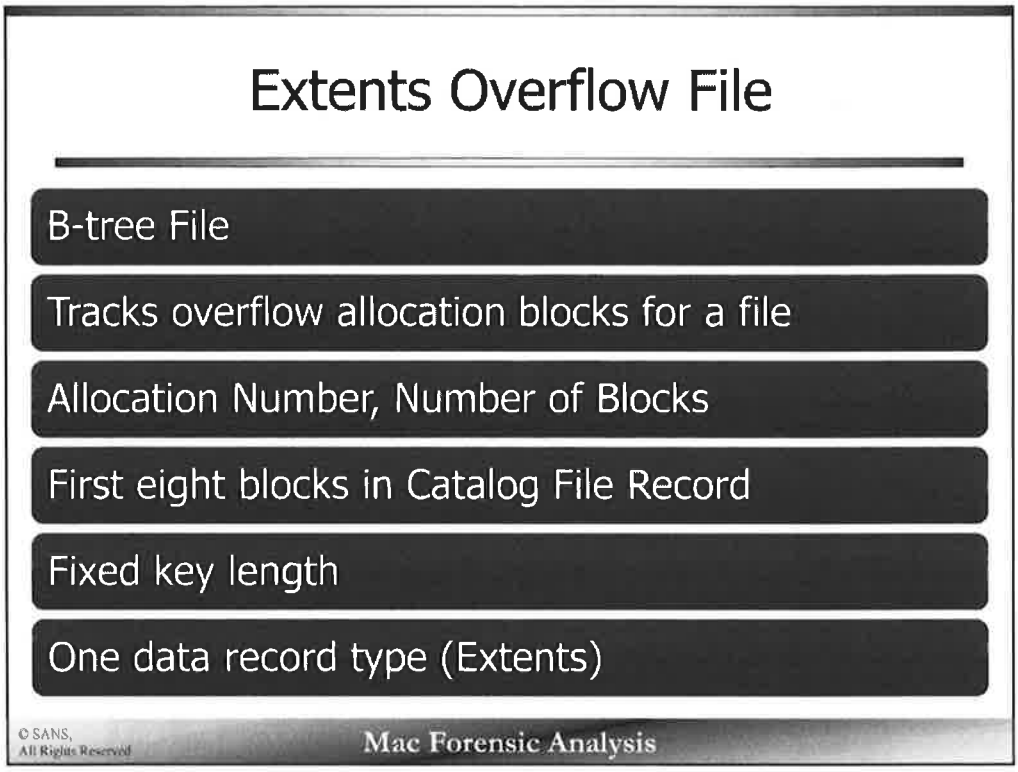
- Record Type – 0x0004 = 3 = File Thread Record
- Reserved – 0x0000
- Parent CNID – 0x00000019 = 25
- Node Name:
    - Node Size – 0x002B = 43 (86 Unicode bytes)
    - Node Name – "funny-pictures-computer-more-rams-field.jpg"



005096	00 00 00 00 00 00 00 00 00 00 00 00 00 06 00 00 00 1B 00 00 00 03 00 00 00 00	.....
005122	00 02 00 05 00 53 00 74 00 75 00 66 00 66 00 68 00 00 00 1B 00 31 00 54 00 65	.....S.t.u.f.f.h.....1.T.e



005720	00 2D 00 69 00 6E 00 67 00 6C 00 69 00 73 00 68 00 2E 00 6A 00 70 00 67 00 06	.-.i.n.g.l.i.s.h...j.p.g..
005746	00 00 00 1F 00 00 00 04 00 00 00 00 00 19 00 2B 00 66 00 75 00 6E 00 6E 00 79	... .+.f.u.n.n.y
005772	00 2D 00 70 00 69 00 63 00 74 00 75 00 72 00 65 00 73 00 2D 00 63 00 6F 00 6D	.-.p.i.c.t.u.r.e.s.-.c.o.m
005798	00 70 00 75 00 74 00 65 00 72 00 2D 00 6D 00 6F 00 72 00 65 00 2D 00 72 00 61	.p.u.t.e.r.-.m.o.r.e.-.r.a
005824	00 6D 00 73 00 2D 00 66 00 69 00 65 00 6C 00 64 00 2E 00 6A 00 70 00 67 00 06	.m.s.-.f.i.e.l.d...j.p.g..



The Extents Overflow File is another B-tree formatted file. This file tracks the overflow allocation extents that could not fit into the Catalog File Records.

The Catalog File holds the location and size of the first eight extents of a file (eight for each fork), all others will be located in the Extents Overflow File.

The Extents Overflow File uses only one Data Record type.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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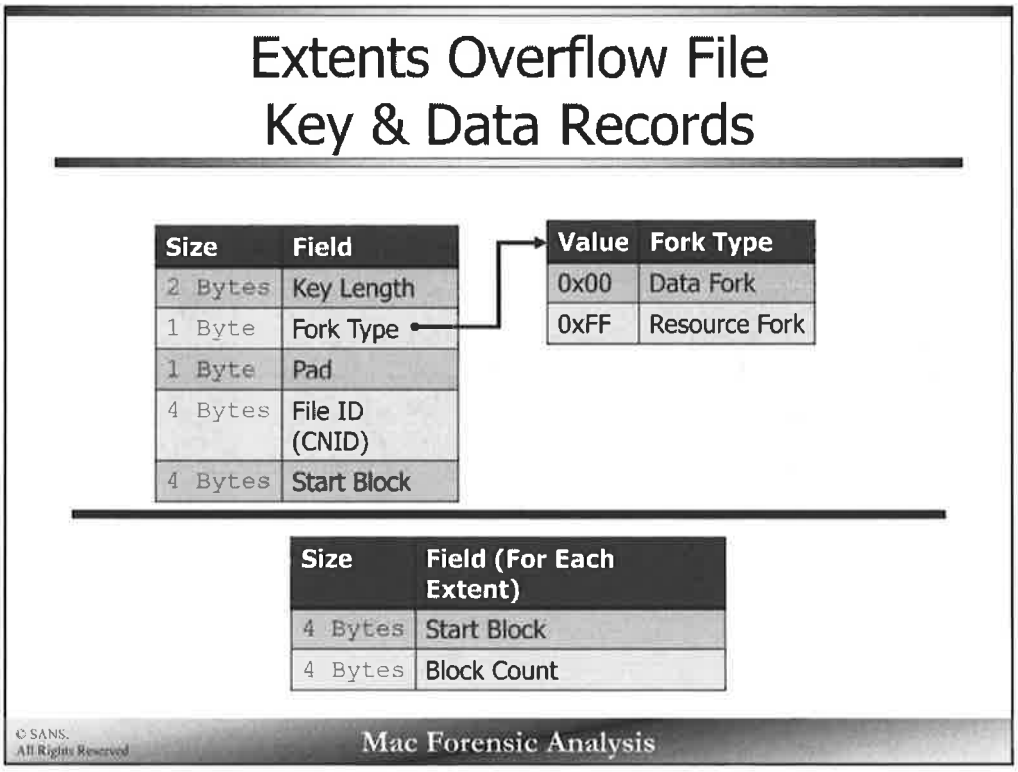

The Key Record for the Extents Overflow File contains:

- Key Length
- Fork Type - 0x00 for Data or 0xFF for Resource
- Padding
- Catalog Node ID
- Start Block – The block in the file where this extent group starts. (The first eight file extents are in the Catalog File.)

The Data Record will contain extent records containing a Start Block and a Block Count. There may be multiple extents, thus multiple Data Records.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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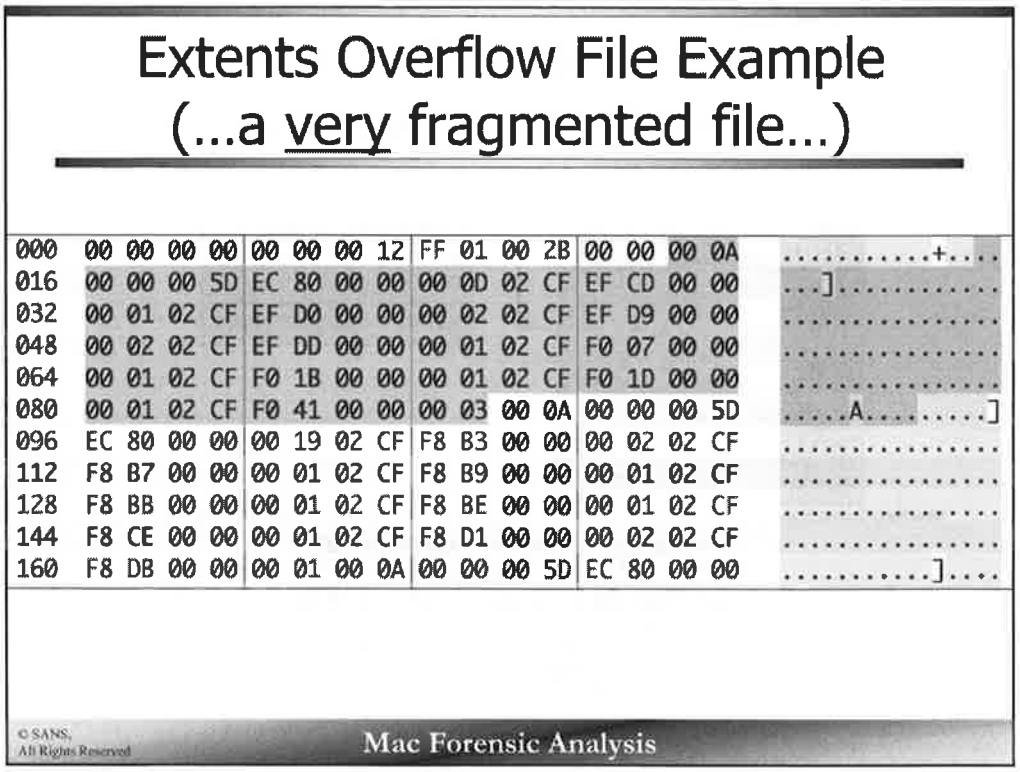


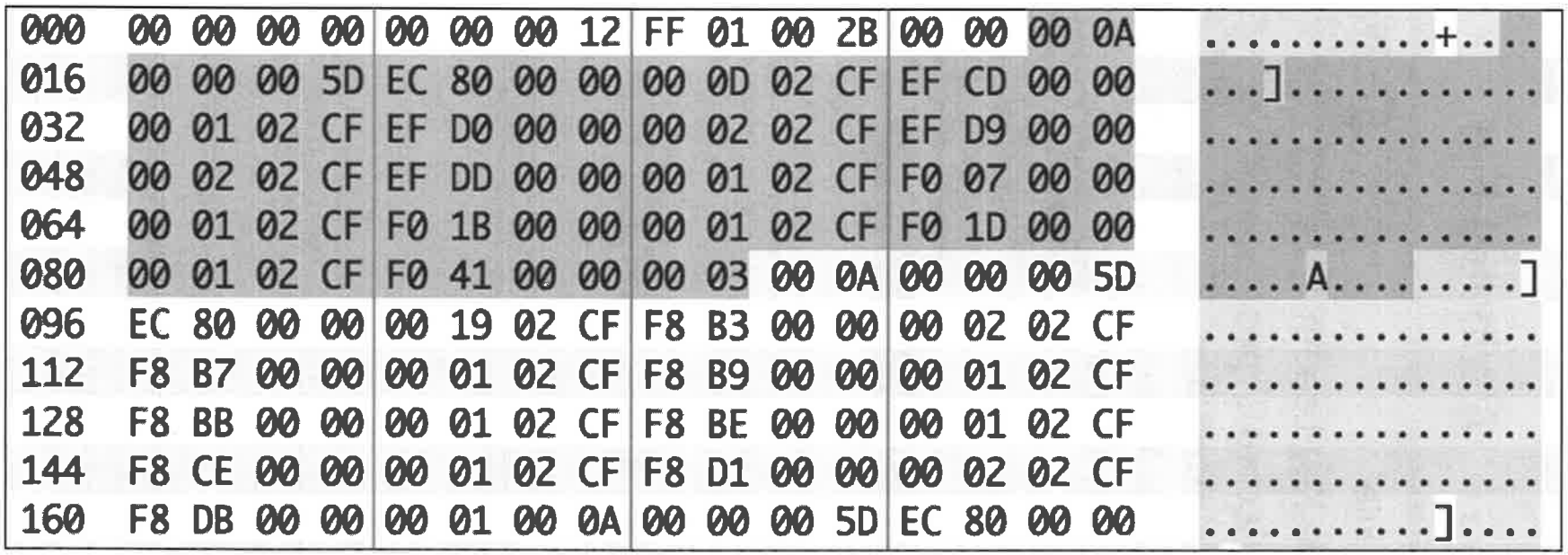
Extents Overflow Example: (**Note: HFS+ data uses big-endian**)
(Remember: The first 14 bytes are Node Descriptor) The first record is the highlighted section.

KEY:

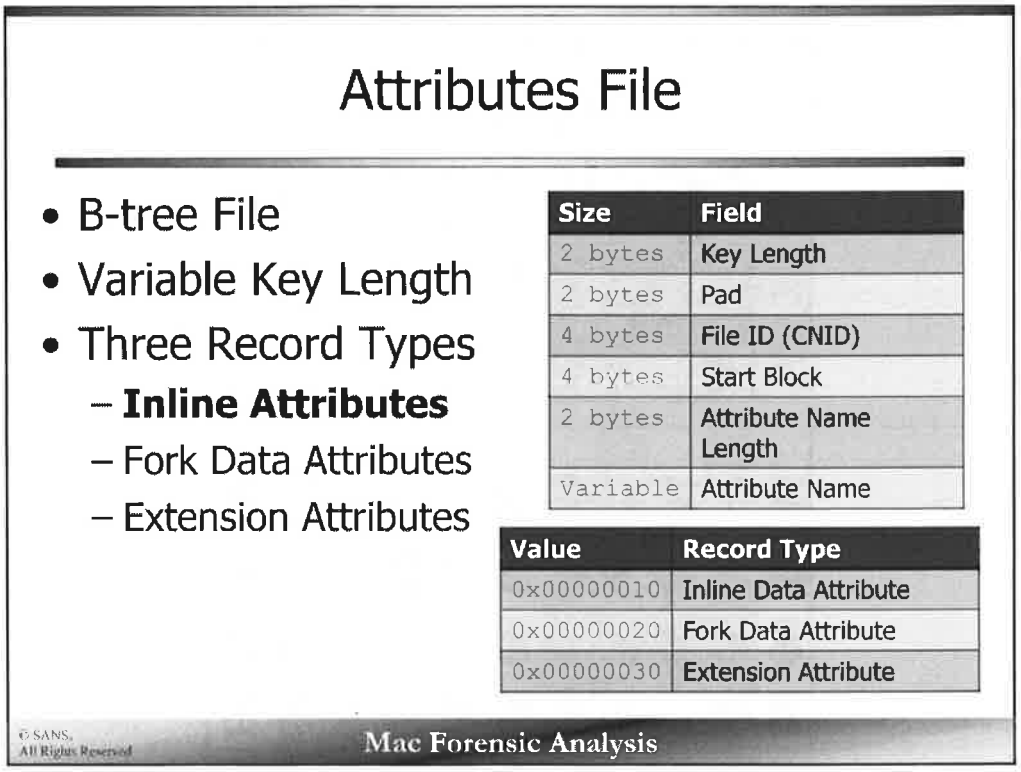
- Key Length – 0x000A = 10 bytes
- Fork Type – 0x00 = Data Fork
- Pad – 0x00
- File ID (CNID) – 0x005DEC80 = 6155392
- Start Block – 0x0000000D = 13 (this block count is 13 blocks after the first eight extents in the File Record)

DATA:

- Extent 1 – Start Block – 0x02CFEFCD = 47181773
- Extent 1 – Block Count – 0x00000001 = 1
- Extent 2 – Start Block – 0x02CFEFD0 = 47181776
- Extent 2 – Block Count - 0x00000002 = 2
- Extent 3 – Start Block – 0x02CFEFD9 = 47181785
- Extent 3 – Block Count – 0x00000002 = 2
- Extent 4 – Start Block – 0x02CFEFDD = 47181789
- Extent 4 – Block Count – 0x00000001 = 1
- Extent 5 – Start Block – 0x02CFF007 = 47181831
- Extent 5 – Block Count – 0x00000001 = 1
- Extent 6 – Start Block – 0x02CFF01B = 47181851
- Extent 6 – Block Count – 0x00000001 = 1
- Extent 7 – Start Block – 0x02CFF01D = 47181853
- Extent 7 – Block Count – 0x00000001 = 1
- Extent 8 – Start Block – 0x02CFF041 = 47181889
- Extent 8 – Block Count – 0x00000003 = 3



000	00	00	00	00	00	00	00	12	FF	01	00	2B	00	00	00	0A
016	00	00	00	5D	EC	80	00	00	00	0D	02	CF	EF	CD	00	00
032	00	01	02	CF	EF	D0	00	00	00	02	02	CF	EF	D9	00	00
048	00	02	02	CF	EF	DD	00	00	00	01	02	CF	F0	07	00	00
064	00	01	02	CF	F0	1B	00	00	00	01	02	CF	F0	1D	00	00
080	00	01	02	CF	F0	41	00	00	00	03	00	0A	00	00	00	5D
096	EC	80	00	00	00	19	02	CF	F8	B3	00	00	00	02	02	CF
112	F8	B7	00	00	00	01	02	CF	F8	B9	00	00	00	01	02	CF
128	F8	BB	00	00	00	01	02	CF	F8	BE	00	00	00	01	02	CF
144	F8	CE	00	00	00	01	02	CF	F8	D1	00	00	00	02	02	CF
160	F8	DB	00	00	00	01	00	0A	00	00	00	5D	EC	80	00	00



The Attributes File is yet another B-tree structured file. To show the age of TN1150, the Attributes File section states "*the structure of the keys in the attribute B-tree has not been finalized and is subject to change*". The layout of the Key for the Attributes files was found in another favorite Mac source, the Mac OS X Internals book by Amit Singh. This book, while published in 2007, still proves to be a helpful (sometimes dated) resource for Mac forensics.

The Key Record for the Attributes File is comprised of the following fields:

- Key Length
- Pad
- File ID (CNID)
- Start Block (unused for Inline Attributes)
- Attribute Name Length
- Attribute Name

This file uses three types of Data Records. While there are three types, recent versions of OS X are using Inline Attributes.

- Inline Data Attributes
- Fork Data Attributes
- Extension Attributes

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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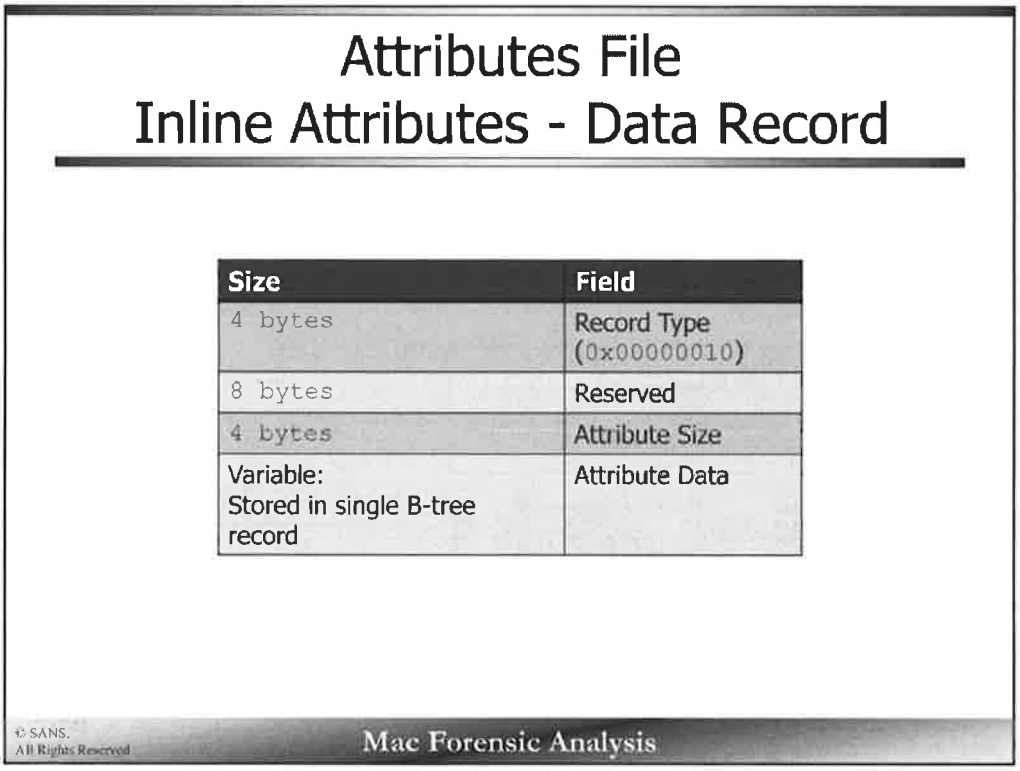

By far the most populous Data Record in the Attributes File is the Inline Attribute Data Record. TN1150, again showing its age, described this data record as "*reserved for future use*".

Discussed later on in the course is Extended Attributes, which is where you will find these type of file metadata. An example of Extended Attributes is the the `com.apple.quarantine` attribute. This attribute contains file quarantine information such as when the file was downloaded, what program was used to download the file, etc.

The Inline Attribute Data Record consists of the following fields:

- Record Type (`0x00000010`)
- Reserved
- Attribute Size
- Attribute Data

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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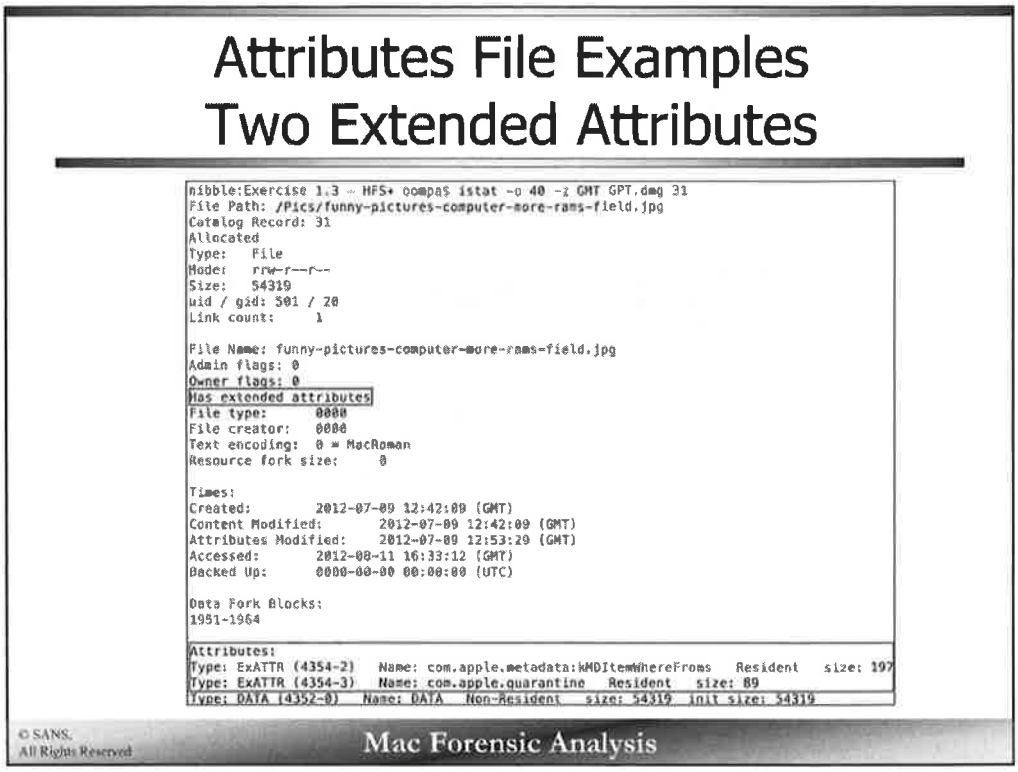
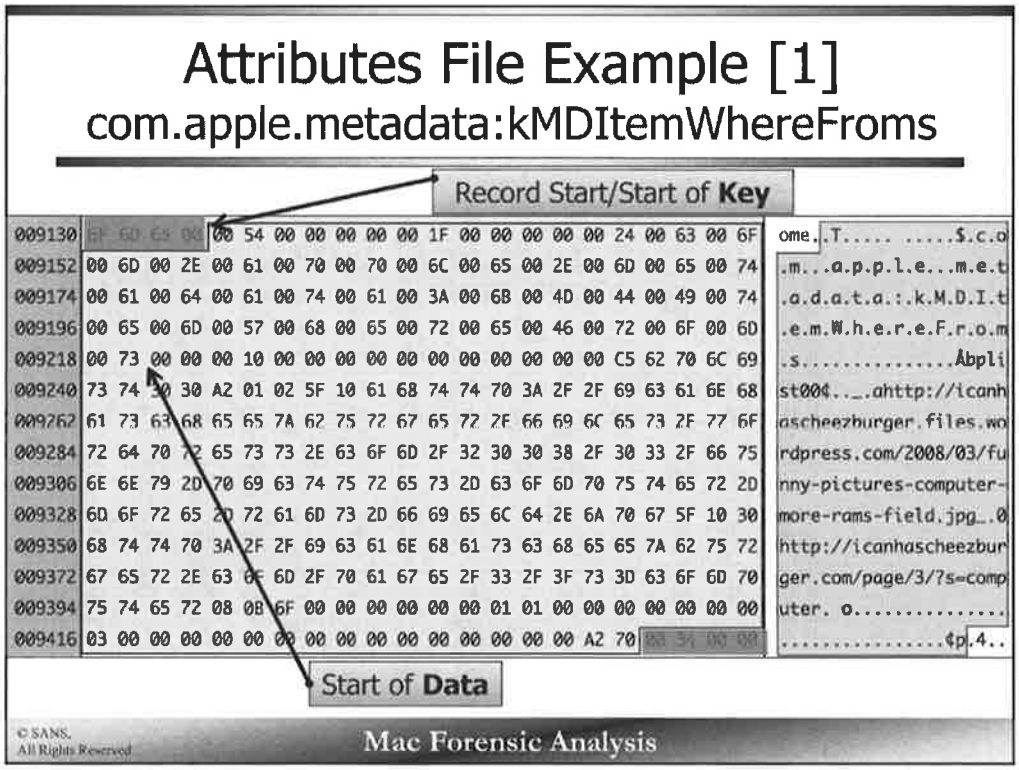


We will be looking at the extended attributes from the `funny-pictures-computer-more-rams-field.jpg` example.

This file has two extended attributes:

- `com.apple.metadata:KMDItemWhereFroms`
- `com.apple.quarantine`



Attribute File Example: (**Note: HFS+ data uses big-endian**)

These extended attributes are from the `funny-pictures-computer-more-rams-field.jpg` example.

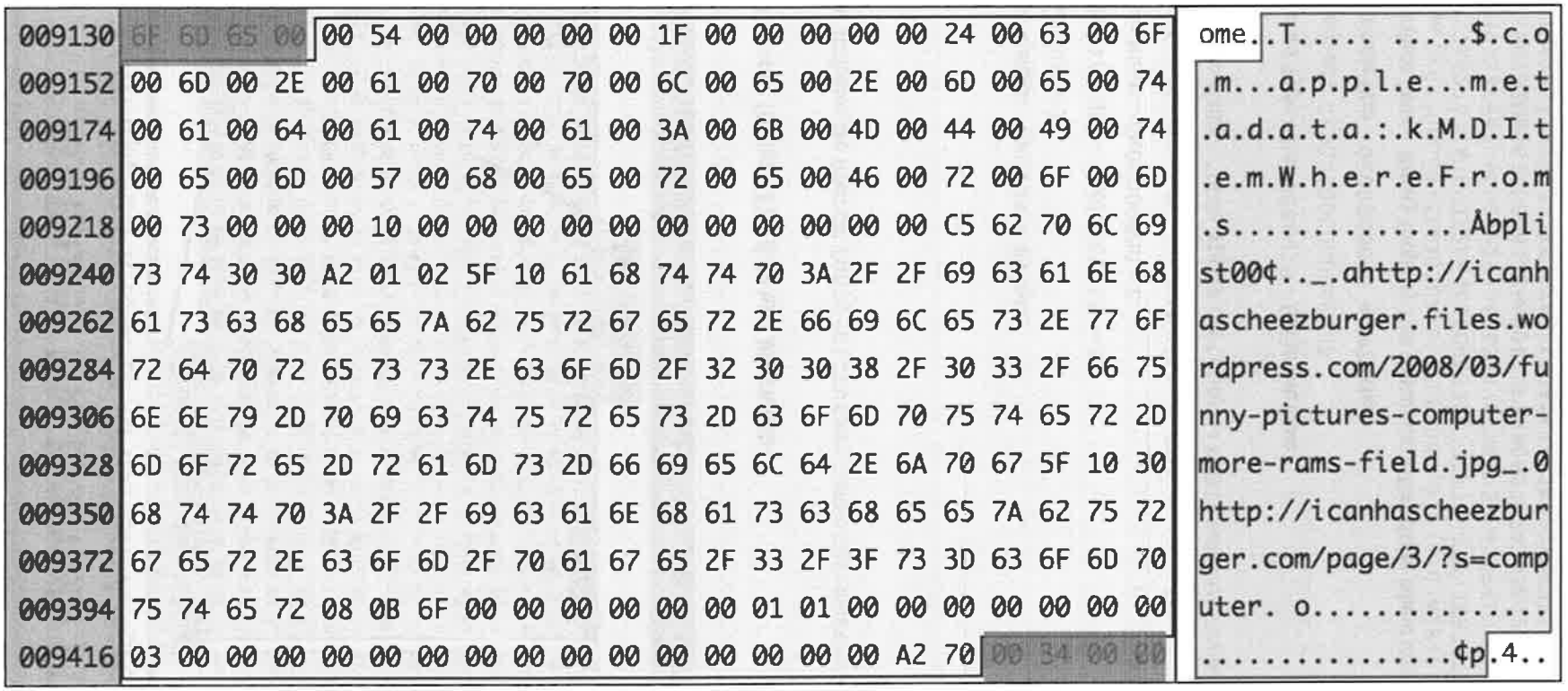
Attribute 1:

KEY:

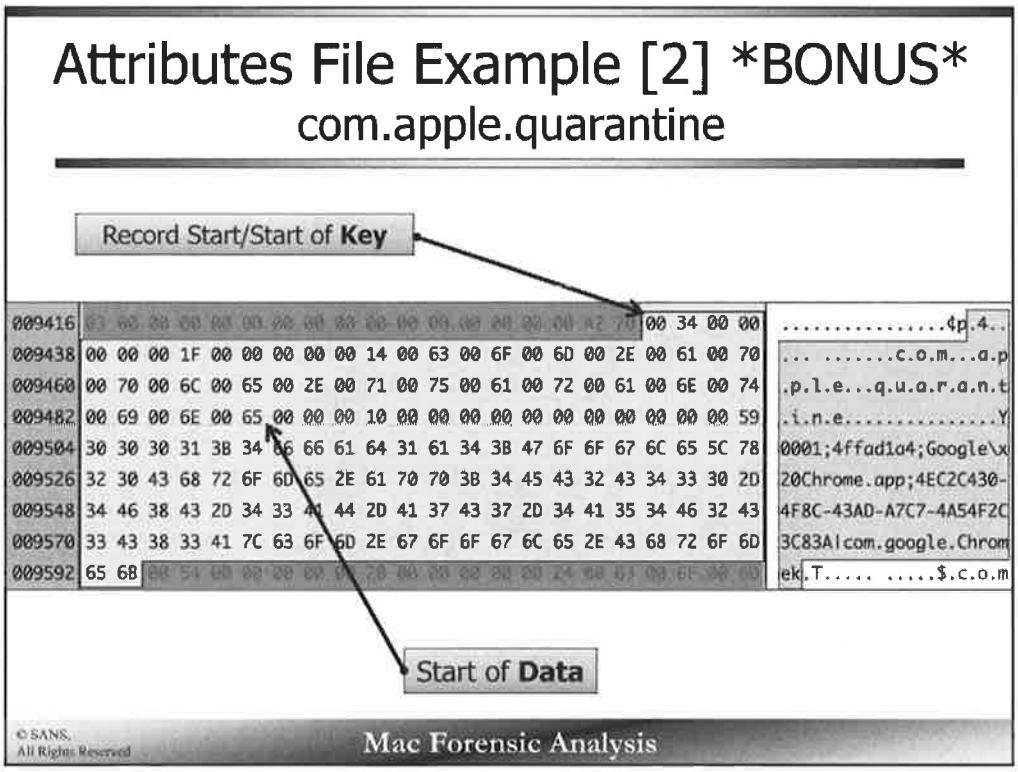
- Key Length – `0x0054` = 84 bytes
- Pad – `0x0000`
- File ID (CNID) – `0x0000001F` = 31
- Start Block – `0x00000000` = 0
- Attribute Name Length – `0x0024` = 36 bytes (72 bytes Unicode)
- Attribute Name – "`com.apple.metadata:kMDItemWhereFroms`"

DATA:

- Record Type – `0x00000010` – Inline Attribute
- Reserved – `0x0000000000000000`
- Attribute Size – `0x000000C5` = 197 bytes
- Attribute Data Binary Property List containing information where this picture was downloaded from.`0x62706C6973743030A201025F1061687474703A2F2F6963616E68617363686865657A6275726765722E66696C65732E776F726470726573732E636F6D2F323030382F30332F66756E6E792D7069637475726573732D636F6D70757465722D6D6F72652D72616D732D6669656C642E6A70675F1030687474703A2F2F6963616E686173636865657A6275726765722E636F6D2F706167652F332F3F733D636F6D7075746572080B6F0000000000000101000000000000000300000000000000000000000000000000A270`



009130	6F	6D	65	00	00	54	00	00	00	00	00	1F	00	00	00	00	00	24	00	63	00	6F	ome.	.T.....	.....	$.c.o
009152	00	6D	00	2E	00	61	00	70	00	70	00	6C	00	65	00	2E	00	6D	00	65	00	74	.m...	a.p.p.	l.e...	m.e.t
009174	00	61	00	64	00	61	00	74	00	61	00	3A	00	6B	00	4D	00	44	00	49	00	74	.a.d.	a.t.a.	:.k.M.	D.I.t
009196	00	65	00	6D	00	57	00	68	00	65	00	72	00	65	00	46	00	72	00	6F	00	6D	.e.m.	W.h.e.	r.e.F.	r.o.m
009218	00	73	00	00	00	10	00	00	00	00	00	00	00	00	00	00	00	C5	62	70	6C	69	.s.....	.....	.....	Åbpli
009240	73	74	30	30	A2	01	02	5F	10	61	68	74	74	70	3A	2F	2F	69	63	61	6E	68	st00¢.	.._.a	http:	//icanh
009262	61	73	63	68	65	65	7A	62	75	72	67	65	72	2E	66	69	6C	65	73	2E	77	6F	ascheezburger.files.wo			
009284	72	64	70	72	65	73	73	2E	63	6F	6D	2F	32	30	30	38	2F	30	33	2F	66	75	rdpress.com/2008/03/fu			
009306	6E	6E	79	2D	70	69	63	74	75	72	65	73	2D	63	6F	6D	70	75	74	65	72	2D	nny-pictures-computer-			
009328	6D	6F	72	65	2D	72	61	6D	73	2D	66	69	65	6C	64	2E	6A	70	67	5F	10	30	more-rams-field.jpg_.0			
009350	68	74	74	70	3A	2F	2F	69	63	61	6E	68	61	73	63	68	65	65	7A	62	75	72	http://	icanhas	cheezbur		
009372	67	65	72	2E	63	6F	6D	2F	70	61	67	65	2F	33	2F	3F	73	3D	63	6F	6D	70	ger.com/page/3/?s=comp			
009394	75	74	65	72	08	0B	6F	00	00	00	00	00	00	01	01	00	00	00	00	00	00	00	uter. o	.....	.....	
009416	03	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	A2	70	00	34	00	00	.....	.....	¢p.4..



Attribute File Example: (**Note: HFS+ data uses big-endian**)

These extended attributes are from the `funny-pictures-computer-more-rams-field.jpg example.`

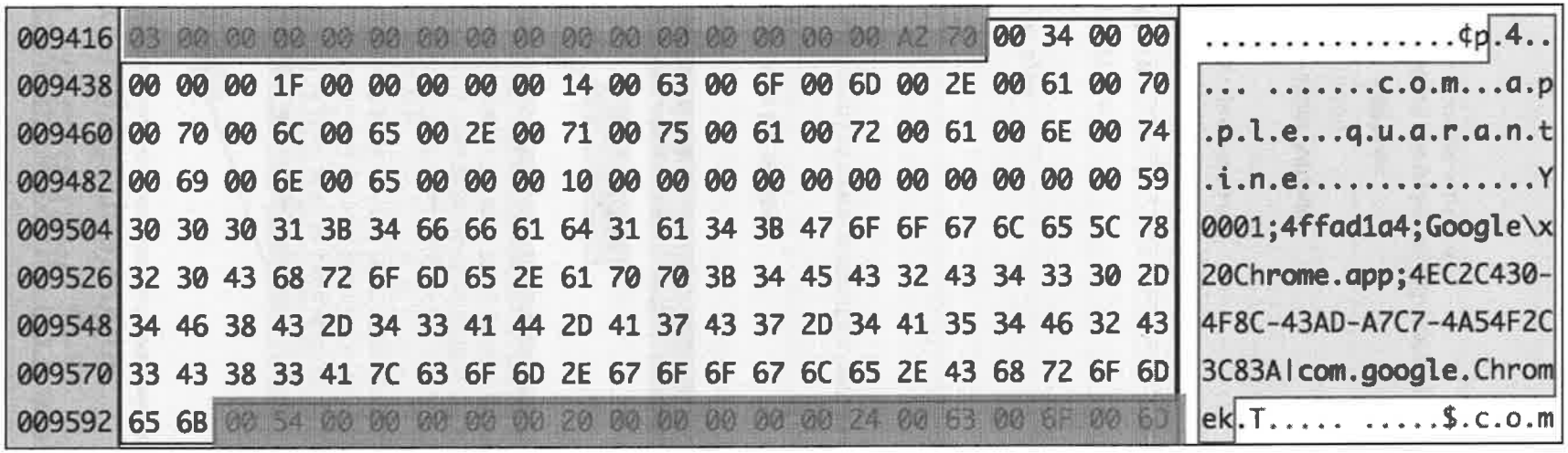
Attribute 2:

KEY:

- Key Length – `0x0034` = 52 bytes
- Pad – `0x0000`
- File ID (CNID) – `0x0000001F` = 31
- Start Block – `0x00000000` = 0
- Attribute Name Length – `0x0014` = 20 bytes (40 bytes Unicode)
- Attribute Name – "`com.apple.quarantine`"

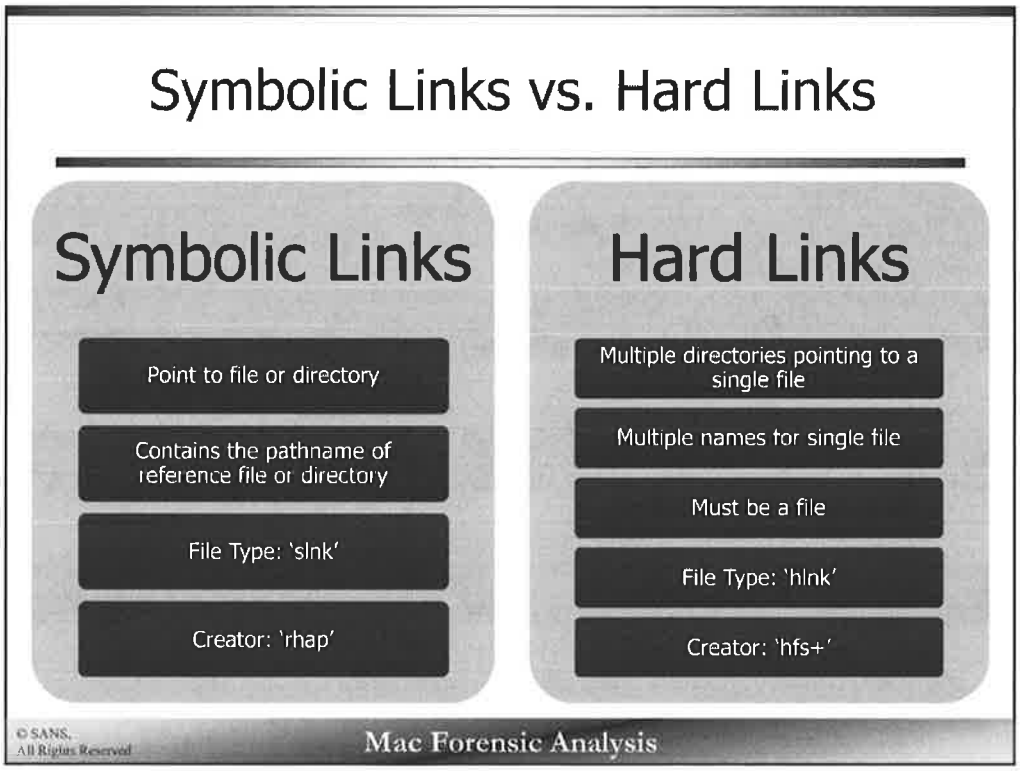
DATA:

- Record Type – `0x00000010` – Inline Attribute
- Reserved – `0x0000000000000000`
- Attribute Size – `0x00000059` = 89 bytes
- Attribute Data – "`0001;4ffad1a4;Google\x20Chrome.app;4EC2C430-4F8C-43AD-A7C7-4A54F2C3C83A|com.google.Chrome`"



009416	03	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	A2	70	00	34	00	00	..... ¢p.4..
009438	00	00	00	1F	00	00	00	00	00	14	00	63	00	6F	00	6D	00	2E	00	61	00	70	... .c.o.m...a.p
009460	00	70	00	6C	00	65	00	2E	00	71	00	75	00	61	00	72	00	61	00	6E	00	74	.p.l.e...q.u.a.r.a.n.t
009482	00	69	00	6E	00	65	00	00	00	10	00	00	00	00	00	00	00	00	00	00	00	59	.i.n.e.....Y
009504	30	30	30	31	3B	34	66	66	61	64	31	61	34	3B	47	6F	6F	67	6C	65	5C	78	0001;4ffad1a4;Google\x
009526	32	30	43	68	72	6F	6D	65	2E	61	70	70	3B	34	45	43	32	43	34	33	30	2D	20Chrome.app;4EC2C430-
009548	34	46	38	43	2D	34	33	41	44	2D	41	37	43	37	2D	34	41	35	34	46	32	43	4F8C-43AD-A7C7-4A54F2C
009570	33	43	38	33	41	7C	63	6F	6D	2E	67	6F	6F	67	6C	65	2E	43	68	72	6F	6D	3C83A|com.google.Chrom
009592	65	6B	00	54	00	00	00	00	00	20	00	00	00	00	00	24	00	63	00	6F	00	6D	ek.T..... .....$.c.o.m

180



Mac OS X uses two types of links, Hard and Symbolic.

Hard links are used to have multiple directories point to a single file, so there can be multiple names for a single file. Hard links can only be used on a file. Hard link files will have a file type of '`hlnk`' and a creator code of '`hfs+`'.

Symbolic Links are used to point to a file or directory and can be used on a file or a directory. Symbolic links have a file type of '`slnk`' and a creator code of '`rhap`'. These are shown in the terminal as follows:

```
lrwxr-xr-x@  1 root  wheel       11 Jul 15 22:20 etc -> private/etc
lrwxr-xr-x@  1 root  wheel       11 Jul 15 22:21 tmp -> private/tmp
lrwxr-xr-x@  1 root  wheel       11 Jul 15 22:21 var -> private/var
```

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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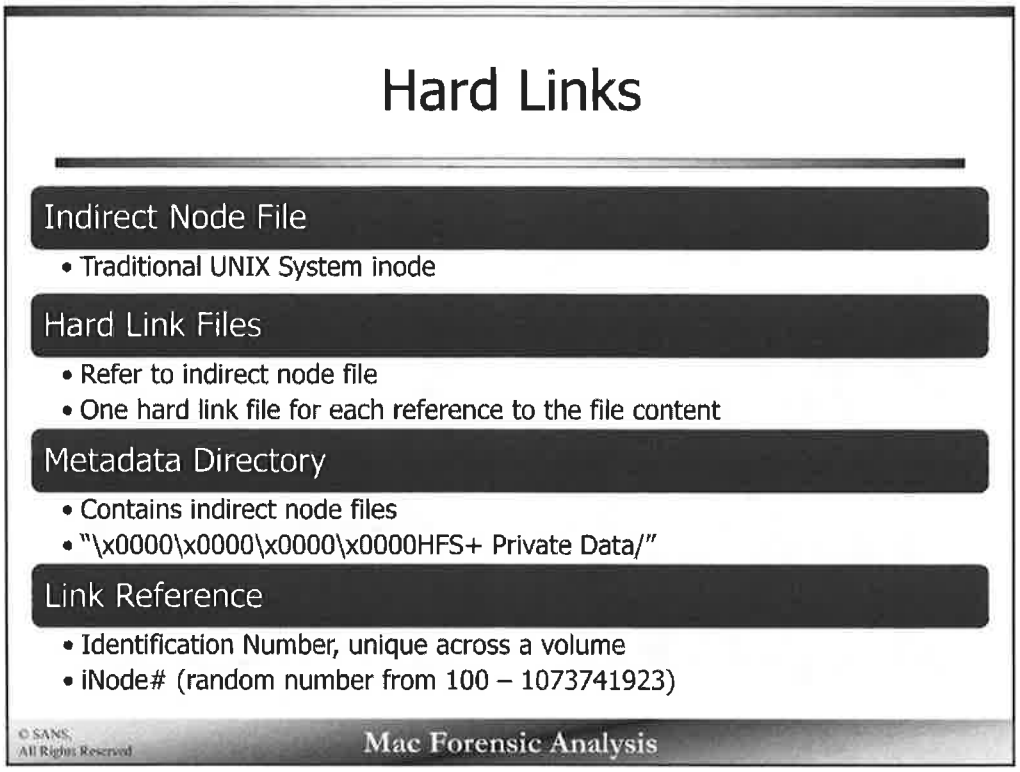

Hard links use an Indirect Node File to store the actual file data of the hard link, making it similar to an inode in a Unix-based system.

Hard Link Files are used to point to an Indirect Node File, one for each directory that references the file content.

You may have noticed the strange directory in the root of the volume called "^^^^HFS+ Private Data/", where the caret is a null. This is the Metadata Directory. This directory contains multiple files with the filename "iNode" and some number. These files are the Indirect Node Files. The number after "iNode" is the link reference number. This number is randomly chosen from 100-1073741923. The link reference number is not the same as the files Catalog Node ID number.

References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

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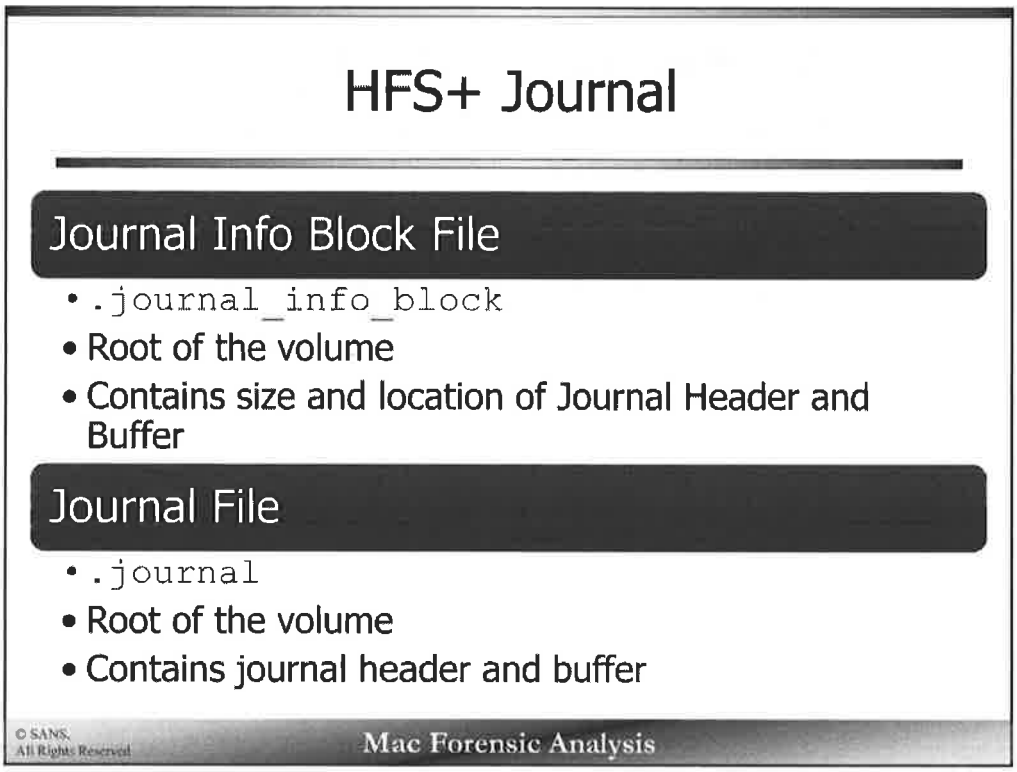


HFS+ can implement the journaling feature, but is not required. Most Mac OS X installations do, by default, install on HFS+ with journaling enabled.

The journal can be used to restore the file system to a safe state if the volume suffered a crash or was otherwise unmounted ungracefully.

The journal consists of two files, both of which are located in the root of the volume and have the hidden file attribute set.

- `.journal_info_block`
- `.journal`

The Journal Info Block file contains the size and location of the journal header and buffer.

The Journal contains the journal header and buffer. The journal header contains transaction information. The journal buffer holds transactions.

The layout and structure of the journal files will not be covered in this class, however it is detailed in TN1150.

G-C Partners has created a journal parser called "Triforce AHJP HFS+ Journal Parse" is available at https://www.gettriforce.com/product/hfs-journal-parser/.

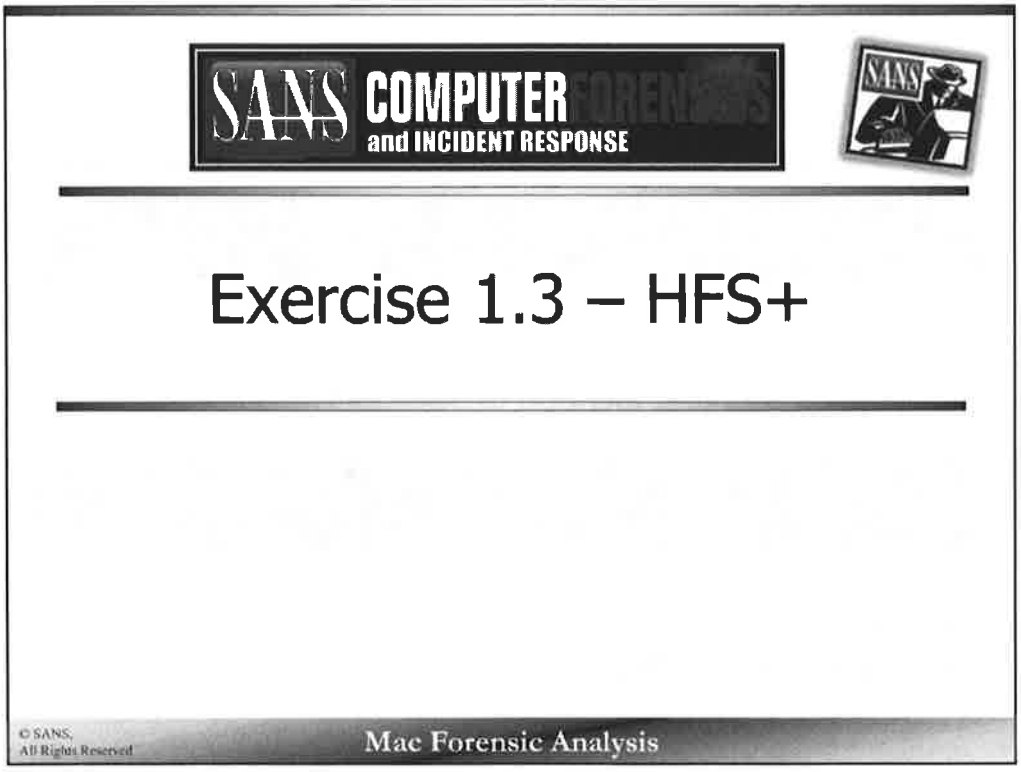
References:

Apple Tech Note 1150 – Available at dubeiko.com/development/FileSystems/HFSPLUS/tn1150.html

The Sleuth Kit Source – Available at github.com/sleuthkit/sleuthkit/blob/master/tsk/fs/tsk_hfs.h

Mac OS X Internals: A Systems Approach by Amit Singh – Chapter 12

Mac OS X and iOS Internals: To the Apple's Core by Jonathan Levin – Chapter 16



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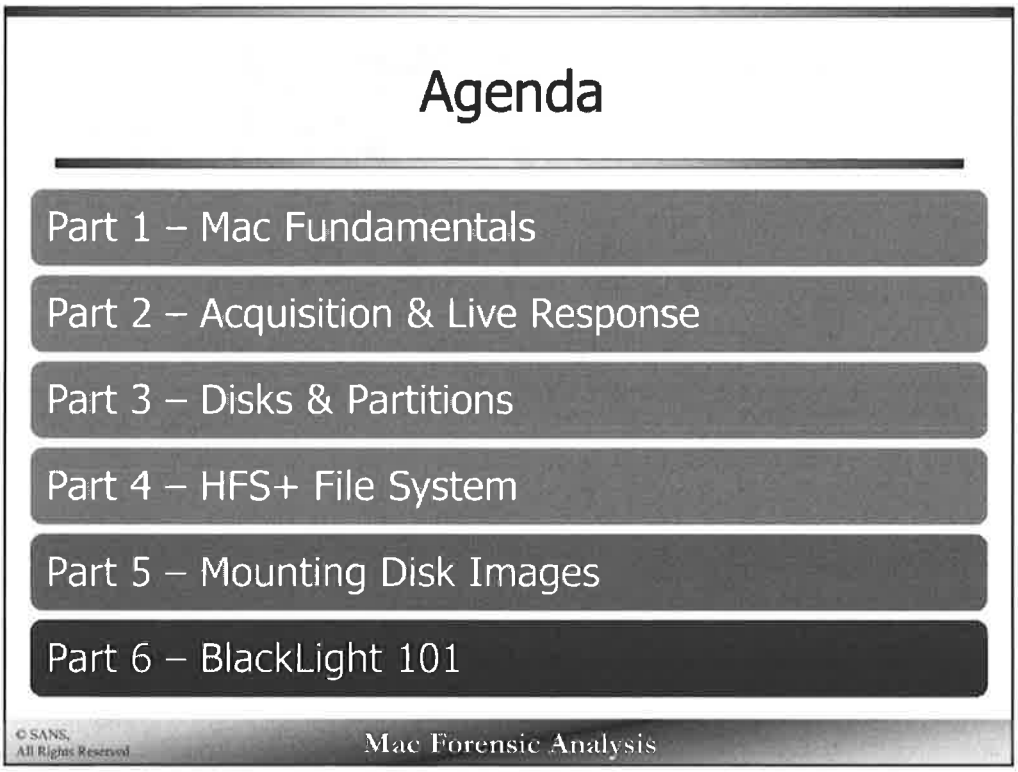

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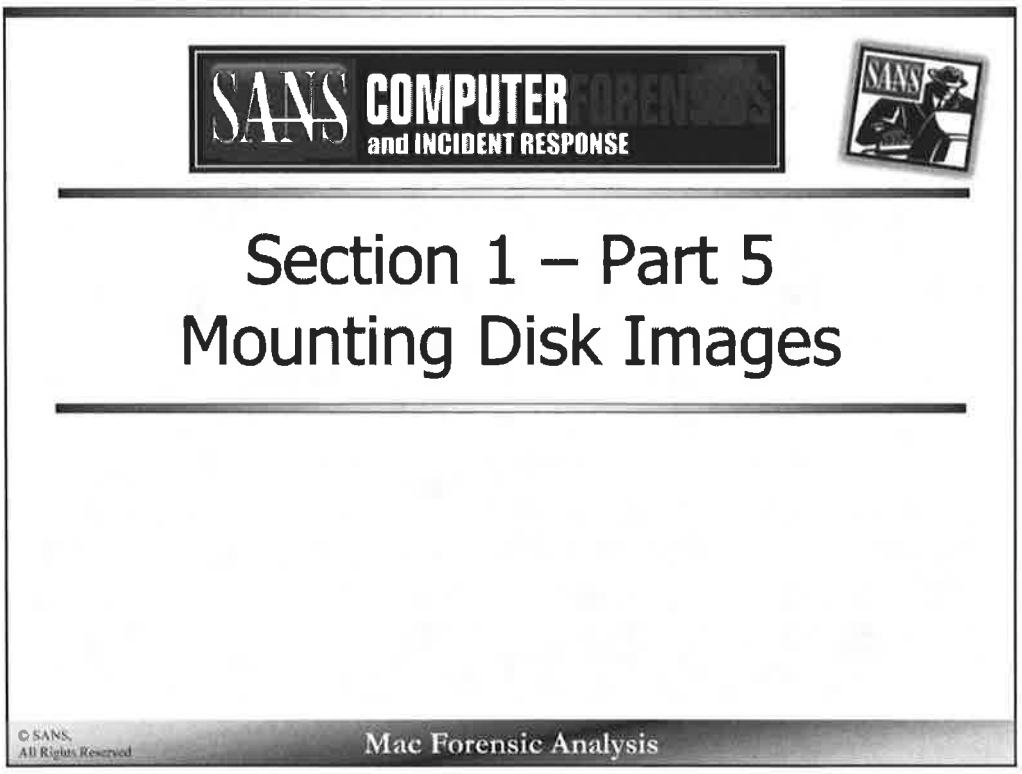

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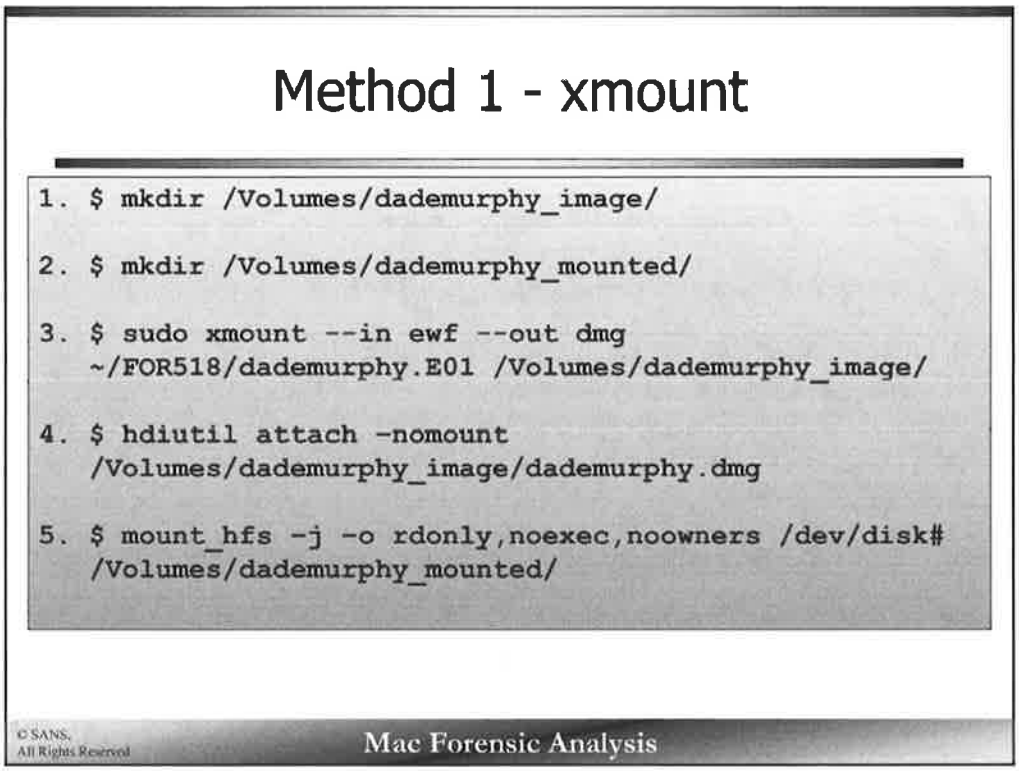
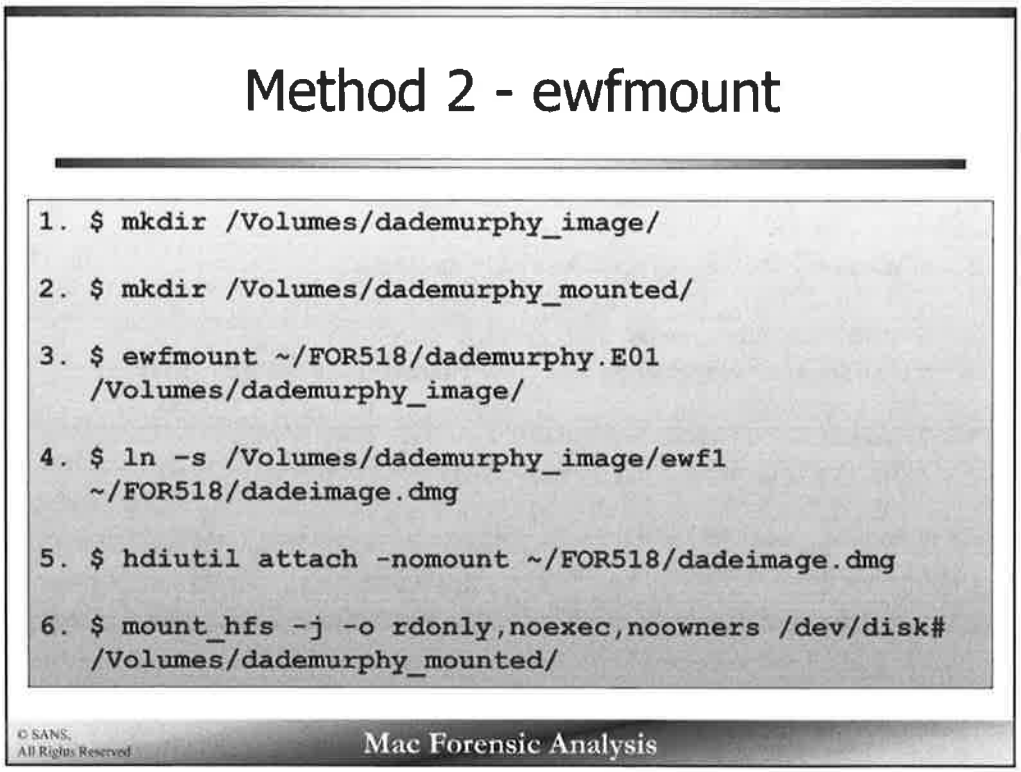


The first method to mount an image file is to use the `xmount` command from www.pinguin.lu/index.php.

1. Use the `mkdir` command to create a mount point for the `xmount` output. In this class the directory name `dademurphy_image` is used because it will just host the image file.
2. Use the `mkdir` command to create a mount point for the mounted drive. The directory `dademurphy_mounted` is used in this class to represent the mounted disk image.
3. Uses `xmount` to mount the `dademurphy.e01` image (where you have your image located, the example shows `~/FOR518`) as a DMG file. This command requires you to use the `sudo` command, thus it will ask you for your administrator password when executed.
    - `--in` – Tells xmount what input file type to expect, our images are in a compressed EWF format.
    - `--out` – Tells xmount what output format you want, we want a DMG file so we can mount it in Finder.
    - `Input File` – Where the image file is located.
    - `Mount Point` – Newly created specifically for this image.
4. Uses the `hdiutil` command with the "`attach`" verb to mount the newly created DMG volume so it is available in Finder and Terminal application. Use the `-nomount` argument to suppress mounting (for now). The output from this command will display a `/dev/disk#`, use the appropriate disk device in the next command.
5. Use the `mount_hfs` command with the following parameters to mount the `/dev/disk#` (from the previous command) to the `/Volumes/dademurphy_mounted/` mount point. This drive will now be available in the Finder or Terminal applications.
    - `-j` – Ignore the journal
    - `-o` – Options:
        - `rdonly` – Mount in read-only mode.
        - `noexec` – Do not allow execution of binaries on mounted system.
        - `noowners` – Ignore ownership on the mounted volume.

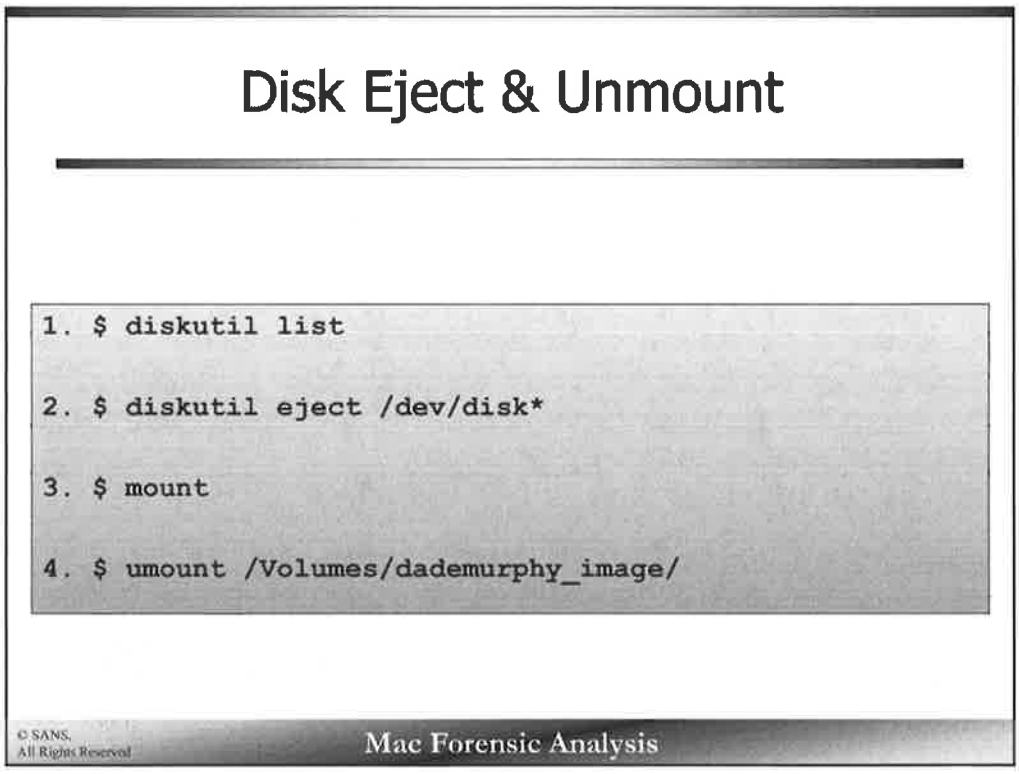
You can access this newly created mounted drive on `/Volumes/dademurphy_mounted/`.



It can never hurt to have more than one way to mount an image. A second way uses the `ewfmount` command from the `libewf` package available at code.google.com/p/libewf/.

1. Use the `mkdir` command to create a mount point for the `ewfmount` output. The directory name `dademurphy_image` is used in the example.
2. Use the `mkdir` command again to create a mount point for the mounted disk image, the example `dademurphy_mounted` in used the example above.
3. Use `ewfmount` to mount the `dademurphy.e01` image to the `/Volumes/dadmurphy_image/` mount point.
4. Use the `ln -s` command to create a symbolic link for the `ewf1` file, name the link `dadeimage.dmg`. (A DMG file is needed for `hdiutil` to recognize the file.)
5. Uses the `hdiutil` command with the "`attach`" verb to mount the newly created DMG volume so it is available in Finder and Terminal application. Use the `-nomount` argument to suppress mounting (for now). The output from this command will display a `/dev/disk#`, use the appropriate disk device in the next command.
6. Use the `mount_hfs` command with the following parameters to mount the `/dev/disk#` (from the previous command) to the `/Volumes/dademurphy_mounted/` mount point. This drive will now be available in the Finder or Terminal applications.
   - `-j` – Ignore the journal
   - `-o` – Options:
     - `rdonly` – Mount in read-only mode.
     - `noexec` – Do not allow execution of binaries on mounted system.
     - `noowners` – Ignore ownership on the mounted volume.

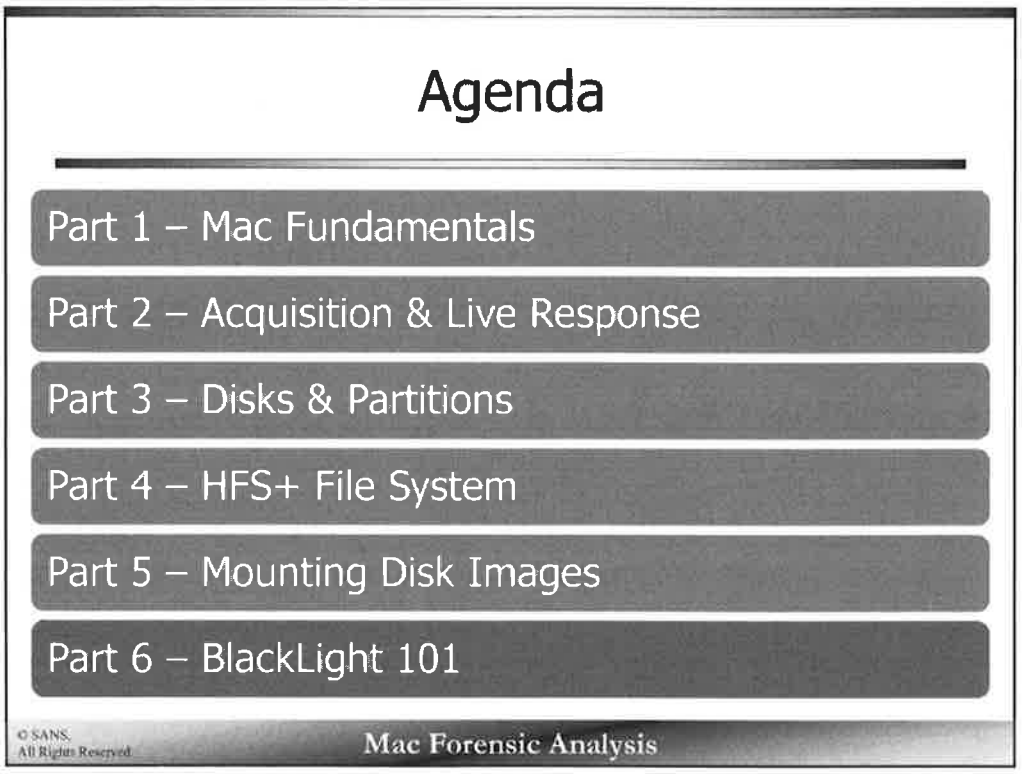
You can access this newly created mounted drive on `/Volumes/dademurphy_mounted/`.



The disk images should stay mounted and available until you reboot or until you eject/unmount them.

When you are finished with the mounted images, you will need to eject and unmount them.

1. Use the `diskutil list` command to view the list of mounted disks. Find the disk that you want to eject.
2. Use the `diskutil eject` command on the disk you would like to eject. (This may also be done by pressing the eject button in the Finder application.)
3. Use the `mount` command to view the list of mounted disks. Find the disk that you want to unmount (likely `/Volumes/dademurphy_image/`, if you following the naming scheme from the examples.)
4. Use the `umount` command with the mount point to unmount the disk. A troublesome disk may have to be unmounted using the `-f` option, to forcibly unmount the disk.



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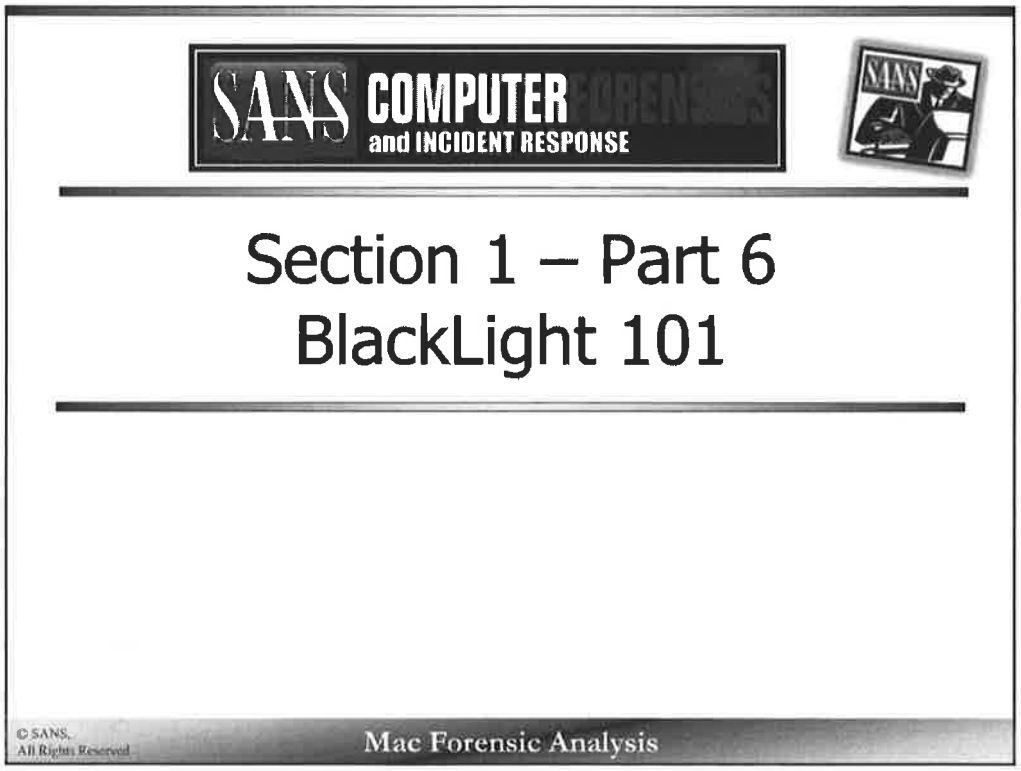

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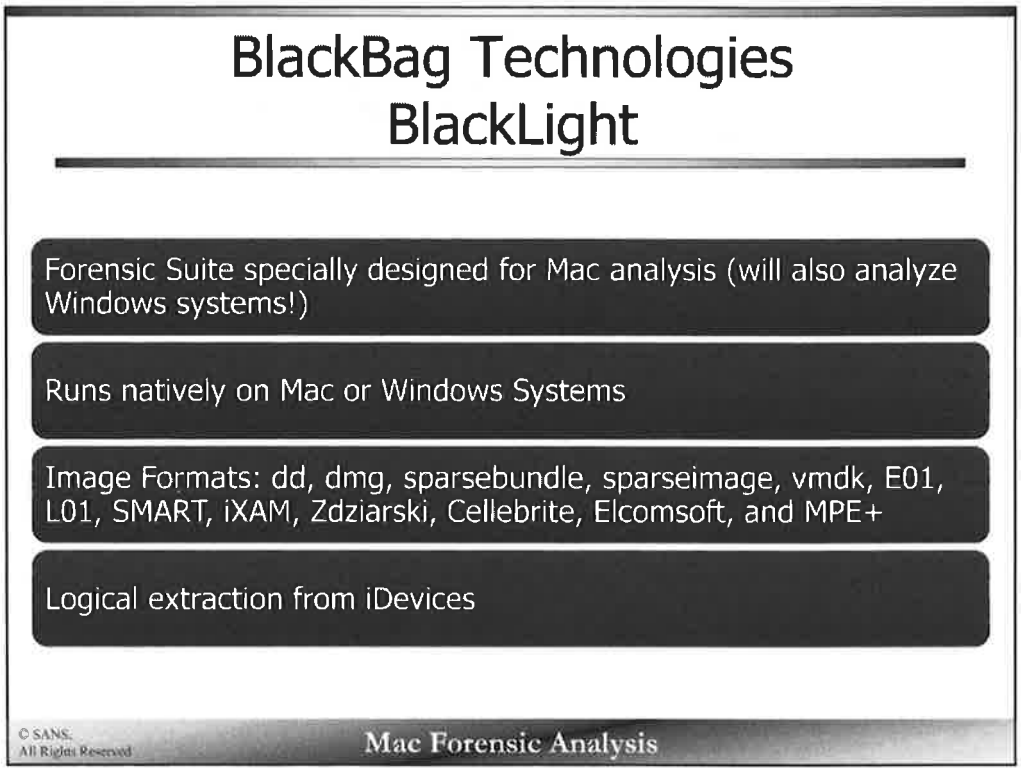


We will be using the BlackLight forensic suite in class for some of the labs; however, it will be available during the whole of the class via the Network License Server running on your instructor's laptop.

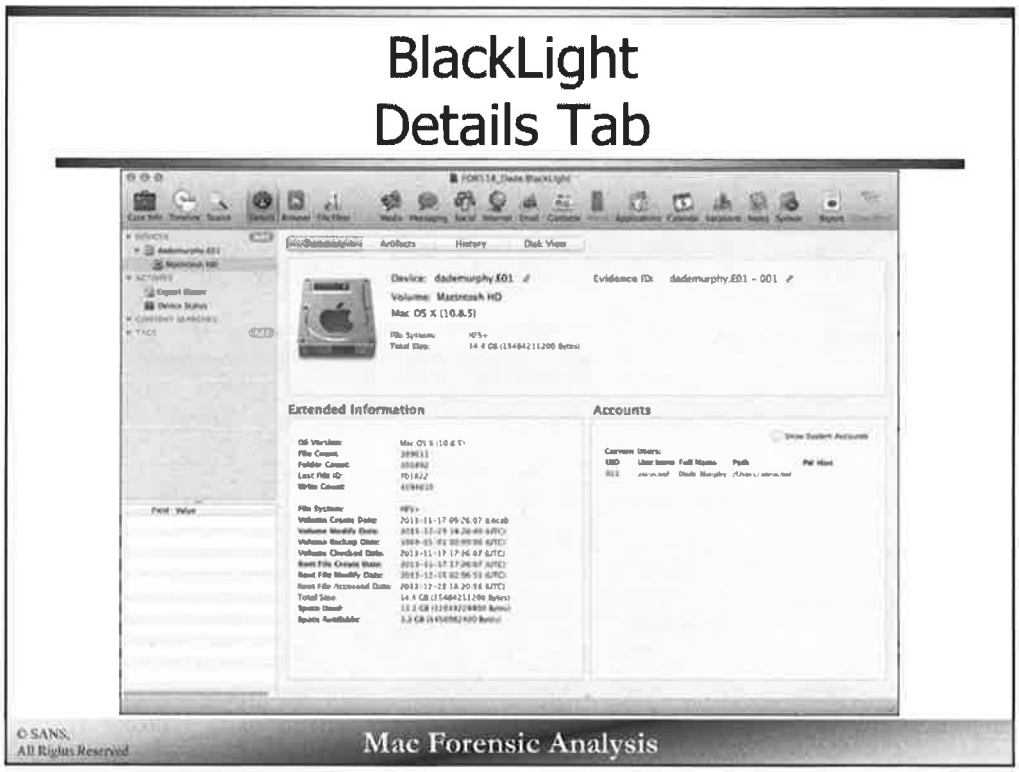
The suite runs natively on both Mac and Windows-based systems (normally with a USB dongle, or a Network License server setup at your agency).

Along with the cross-platform capabilities– the software can also analyze Mac and Windows file systems – this is convenient when a system has been Boot Camped.

Most disk image formats are accepted as well as many from the most popular iDevice acquisition suites.

While BlackLight is not an acquisition tool (MacQuisition is used for acquisition), it is able to acquire a logical extraction from iDevices.

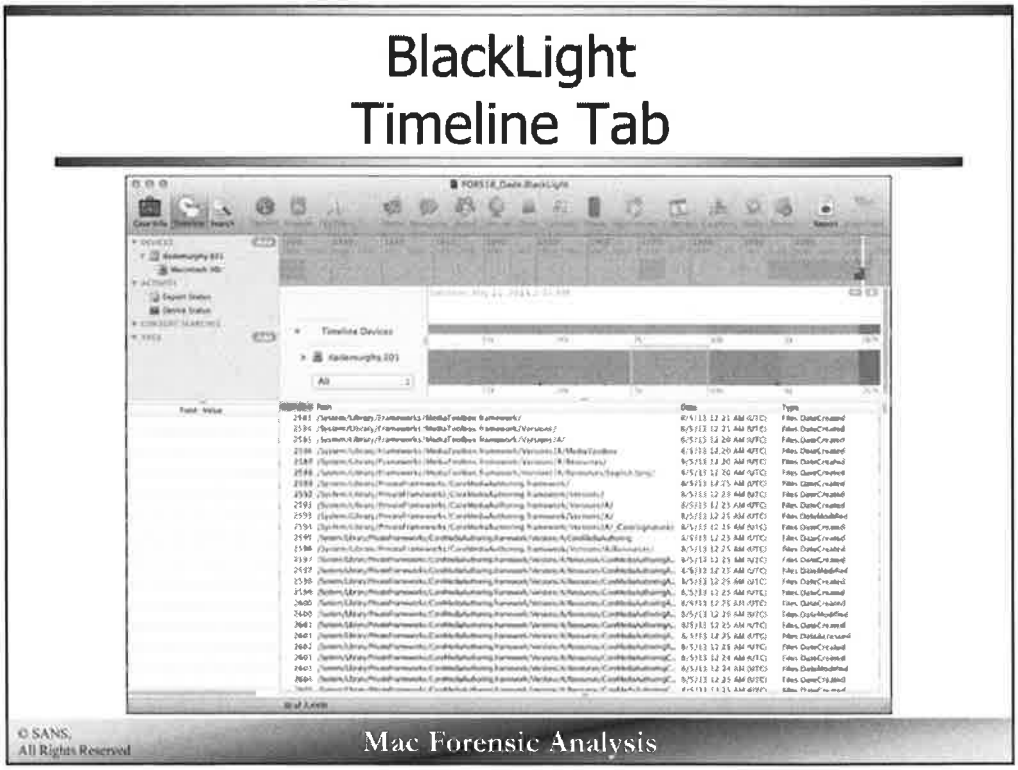
The BlackLight software is available from BlackBag Technologies, blackbagtech.com.



By selecting the `Macintosh HD` drive under the `DEVICES` section, we can view the disk Details tab.

The information in this "`Summary`" window includes file system specifics and user accounts.

You may select and explore the other tabs, "`Artifacts`", "`History`", and "`Disk View`".



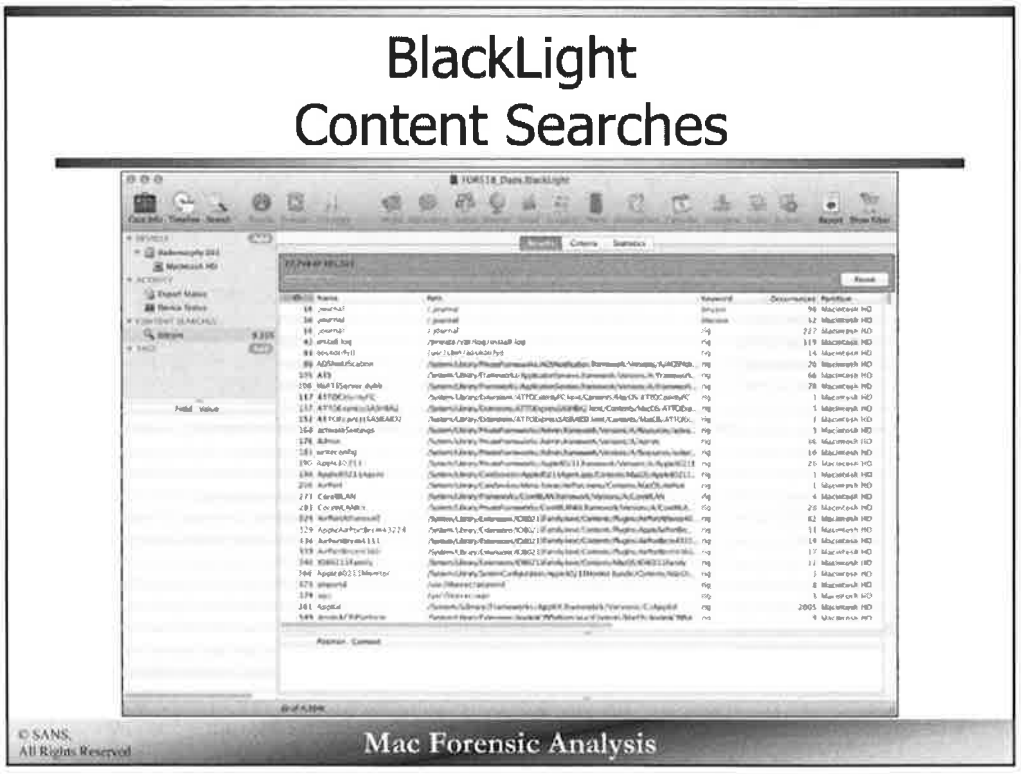
The Timeline tab shows a timeline information for the selected hard drive. This can be zoomed in/out for specific timeline analysis.

The Search tab allows an investigator to perform keyword searches.

Each keyword list has a Name as filled in the `Name` textbox. The keywords may be typed in the `Keywords` pane.

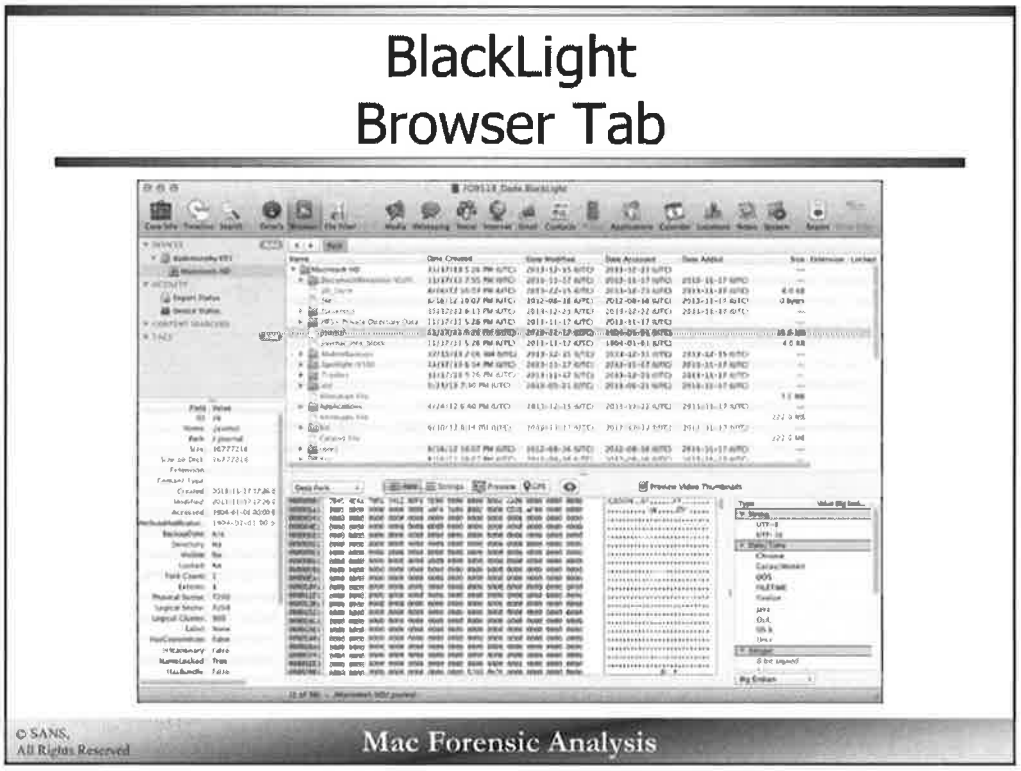
File extensions may be ignored, but typing them into the `Ignore Extensions` pane. Other keyword configurations may be selected in the pane on the right side.

Select "`Start Search`" when ready search.



The Content Searches window will appear once a search has started. This window shows the results from the keyword search, as well as the progression.

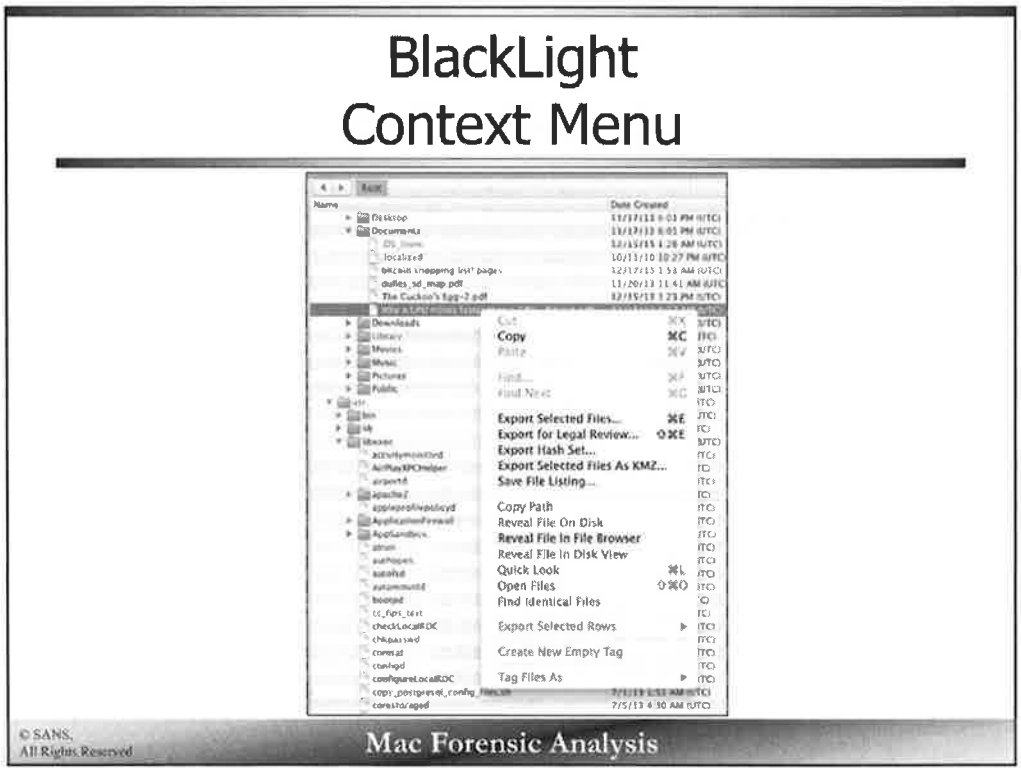
You may select the "`Criteria`" or "`Statistics`" tabs for more information pertaining to this particular keyword search.



The Browser tab shows the file system as an investigator is most likely used to. This view shows the file system in a tree format with hidden files shown in gray and other file metadata including timestamps and file size.

In the lower pane (the bar may have to be moved up from the bottom of the window) shows the file. The views available include Hex, Strings, Preview, and GPS. An analyst may also select the "eye" shaped button to do a "Quick Look" on the file. The Data and Resource fork may also be chosen. In the Hex view the data-type window on the right will be shown for the analyst to select various data types if conversion is needed.

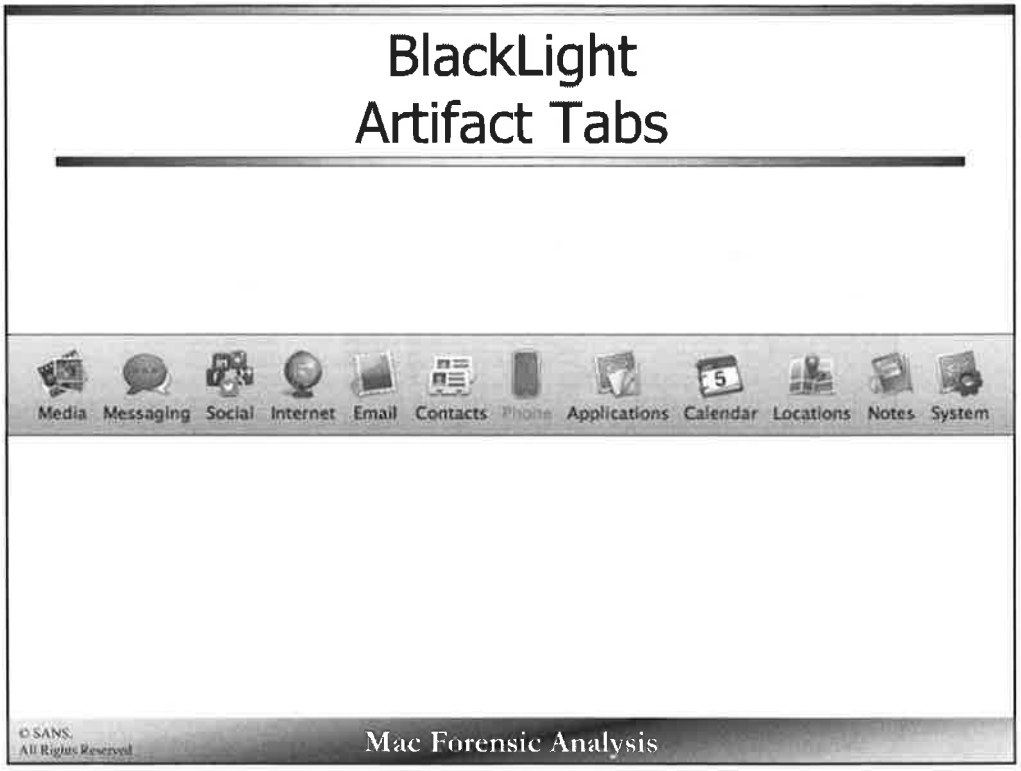
In the lower-left pane the file metadata and extended attributes are shown. Everything from file size, file name, timestamps, Finder data, disk location, to extended attributes are available in this window. Lots of good information may be found here!



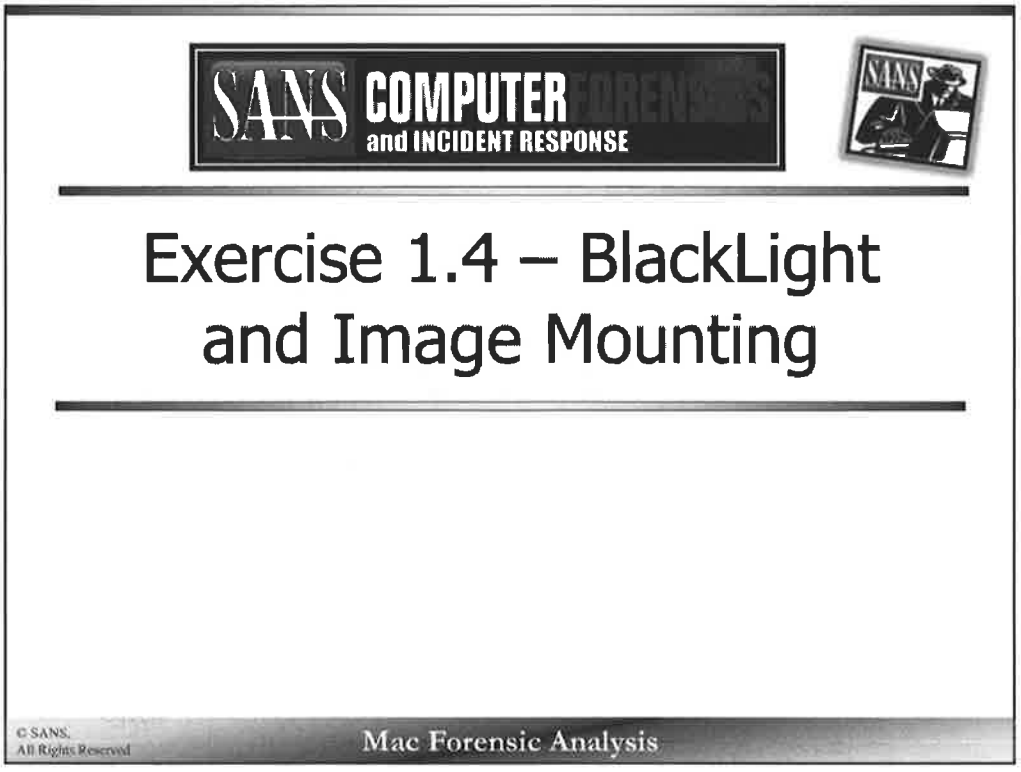
A "right-click" (or two-finger click on a track pad, or control-click) will bring up a context menu as shown above. This menu allows the analyst to perform certain actions such as export information, jump to a file location, or tag a file.

File tagging is similar to bookmarking as seen in other forensic suites. These tags will show up in the left pane under "TAGS".

The File Filter tab allows an investigator to select certain files based on some type of data. Whether it is size, file type, or by creation date. Many different combinations can be played with. The author highly recommend spending some time with this feature. It can help you pinpoint specific files quickly.



BlackLight also does some pre-processing when it comes to various popular artifacts. We will be reviewing some of these more in-depth during the course exercises, but you may start reviewing the contents on your own time.



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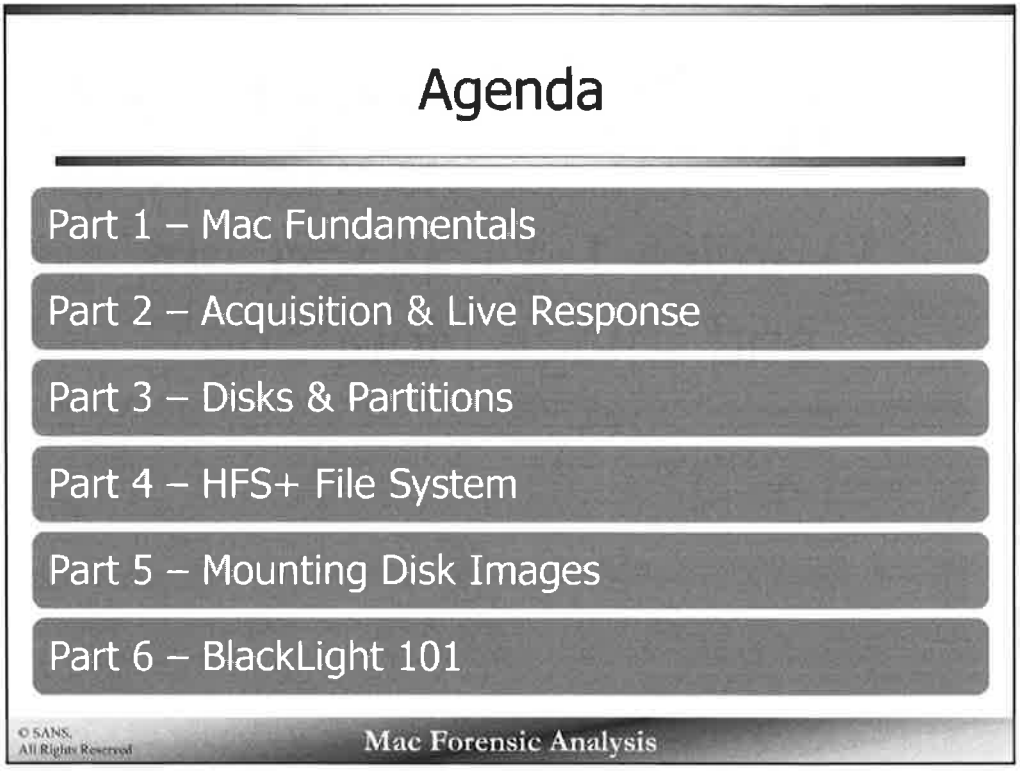

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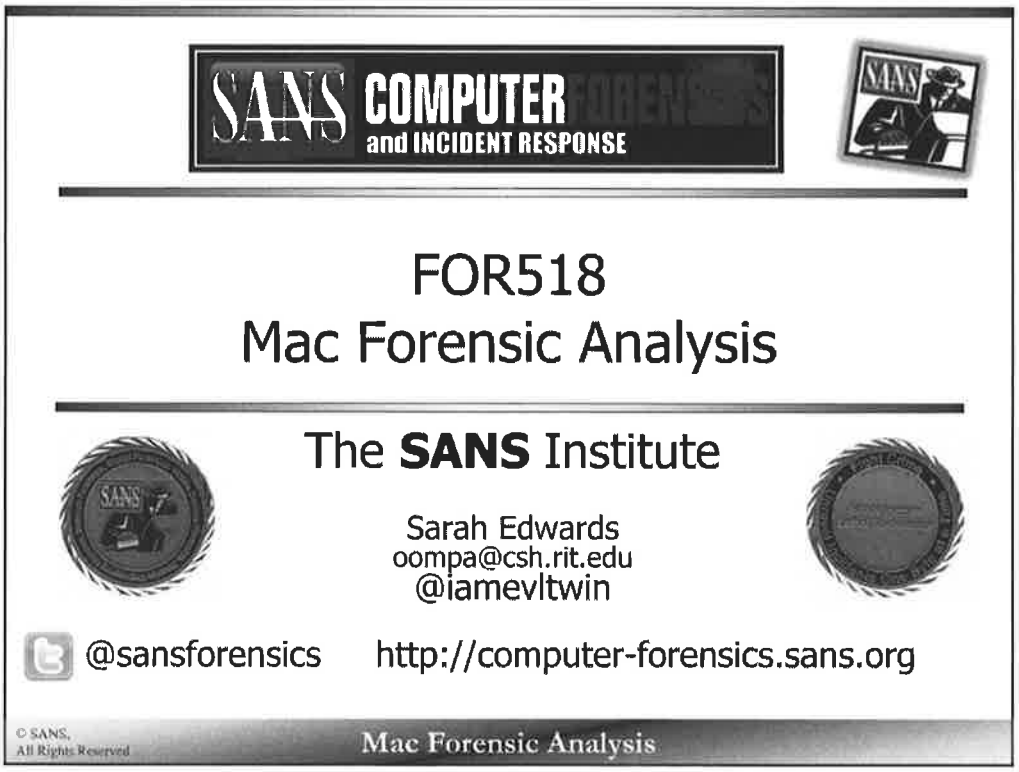

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